SHOP THEORY

Sixth Edition

James Anderson
Earl E. Tatro

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About the Authors

JAMES ANDERSON began his long career in the machine trades as an indentured apprentice in London, England. In the years since, he has been involved in almost every phase of machine shop activity. He has taught in the New York City public schools since 1942, most recently as instructor of Instrument Technology at Queens Vocational High School, New York. He is active in the field of machine shop education both in the public schools and in industry, having served as director of machine shop and foreman training for the Kollsman Instrument Corporation, New York, and instructor of machine shop theory for S & S Corrugated Paper Machinery Company, New York. Mr. Anderson was the president of the New York City Machine Shop Teachers Association and chairman of its executive board. He is the coauthor (with Henry D. Burghardt and Aaron Axelrod) of *Machine Tool Operation* (McGraw-Hill) and *Machine Tool Operation, Workbook and Tests* (with Aaron Axelrod).

EARL E TATRO has taught machine shop practice in the New York City school system for many years, most recently at the Alfred E. Smith High School. He has also taught mechanical technology at Bronx Community College. Mr. Tatro served his apprenticeship in the machine trades with the General Electric Company and subsequently worked for more than a decade as an all-around machinist and toolmaker. He has been active in industrial on-the-job training programs, having served as assistant director of training for the Fairchild Camera and Instrument Corporation, New York. Mr. Tatro is a past president of the Machine Shop Teachers Association of New York City and a member of its executive board. He is the author of two machine shop study guides used by the United States Armed Forces Institute, the author of a number of training manuals used widely in the machine trades, and the coauthor of the syllabus for machine shop practice published by the New York City Board of Education.

Preface

Technological advancement in practically every field of endeavor is closely allied with precision machine tools and man's ability to measure and produce parts to accuracies within millionths of an inch. Research and development within the machine tool industry has resulted in more precise machine tools, superior cutting tool materials, and faster methods of production. Yet the search for improved production methods is a continuous and changing process.

The text material for *Shop Theory* originated at the Henry Ford Trade School, Dearborn, Michigan. It was developed by members of the teaching staff who were journeymen mechanics—craftsmen as well as educators. Their material, a collection of instruction sheets, was eventually developed into a book and made available to schools throughout the world. When preparing the previous edition of this textbook, the authors carefully reviewed the many advances that had been made in the machine trades industry. Wherever feasible, chapters were expanded to include the latest developments in the particular areas. Much of the existing material was rewritten in order to bring it into a closer relationship with the most recent trade practices. New chapters were written to meet the changing needs of industry, teachers, and students. Thus, chapters on safety, band machining, grinding machine processes, surface finish, and the fundamentals of numerical control were included in the fifth edition. The book was received with enthusiasm and soon became a standard in its field. It has served the needs of high schools, colleges, vocational and technical schools, technical institutes, industrial apprentice training programs, and the United States Armed Forces schools, as well as students in foreign countries and those who have wished to improve their knowledge of the trade by home study.

In the sixth edition we have again kept in mind the needs of the students and the men in the shop. Developments in industry brought requests for discussions of new and expanded topics that made necessary the writing of new chapters.

The chapter "Careers in Machine Shop" has been added to point out the opportunities that exist in the world of manufacturing for those mastering the skills of the machinist. No longer is the use of intricate precision measuring instruments confined to the laboratory. Metrology, the science of measurement, and the instruments used for the purpose of measuring minute dimensions have been brought into the shop to be used by the men who actually make the product. The machinist who understands the methods and the instruments that will be used to check and inspect his work will make an extra effort and will take greater pride in the quality of his workmanship. Any study of the machine trades must consider and develop an understanding of the metric system. The new chapter "Metric Measurement" provides a clear explanation of the units of measurement and their application to machining.

With the development of new materials has come the need for special processes. "Special Machining Processes," another new chapter, includes developments of well-known processes such as honing and broaching, as well as important developments in lasers, electrochemical and electrolytic grinding, and electric-discharge machining.

The authors are indebted to the numerous leading manufacturers who have provided many of the photographs and drawings used in the book. We take this opportunity to express our appreciation for their cooperation and assistance. Their names appear under the illustrations. The authors wish to express their thanks to the members of the Machine Shop Teachers Association and the many instructors around the world who have used *Shop Theory* and have offered suggestions, corrections, and encouragement. For their expert advice and suggestions, special appreciation is extended to Whitey Wade, Aldrich Div., Ingersoll-Rand Company; Harry Stuber, Ford Instrument Company; W.C. Grindrod and Hans Pauw, Cincinnati Milacron; Joseph E. Kochhan, Brown & Sharpe Manufacturing Company; Fred J. Helgren and Louis F. Sokol, Metric Association, Inc.; F. W. Cooper, Rank Precision Industries, England; James Smith and John Bart, S & S Corrugated Paper Machinery Company; F. H. Clarkson, Jr., L.S. Starrett Company; W. E. Wenger, Cleveland Twist Drill Company; and Robert L. Wilke, professional photographer. This book is dedicated to Mem Anderson, whose culinary skills did much toward sustaining the authors during the preparation of the sixth edition.

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Earl E. Tatro

Contents

SHOP THEORY

chapter 1 careers in machine shop

OPPORTUNITIES IN THE MACHINE TRADES

The tools, the machines, and the skilled workers in the machine trades have played a most important part in every step that man has taken as he has traveled from medieval times to the space age. Everything from the kitchen utensil to the most complicated instrument in a space capsule owes its existence to the skillful use of a machine tool.

Machine tools and their operators are required in the development and manufacture of almost everything used in our present-day lives. Machines are used in the manufacture of newspapers, books, washing machines, automobiles, airplanes, typewriters, telephones, radios, television sets, and many, many more of our everyday conveniences. Machines are used to dig foundations and to build houses, factories, colossal office buildings, and the furnishings within them. All of these machines are made by a special family of machines—*machine tools*. In that family can be found lathes, milling machines, drilling machines, shaping and planing machines, grinding and polishing machines, gear-cutting machines, and many more with specialized purposes.

All of these machine tools are operated by men and women with specialized skills. The one important common skill that these operators must have is an understanding of measurement because precision and accuracy are the most important characteristics of their work. The tools with which they measure their work are graduated to one ten-thousandth (0.0001) of an inch, and the finished machined surfaces must meet a required smoothness measured in millionths of an inch. Such accuracy is necessary not only for the effective functioning of the part within a specific machine, but also if the part is to be interchangeable in any one of thousands of similar machines.

TYPES OF SHOPS

There are many divisions in the machine trades. There are divisions in the grouping of machines, divisions in the skills required of machine operators, and divisions in the types of shops where the work is done. These shops can be divided into three groups: job shops, limited production shops, and mass-production shops.

1. *What is a job shop?*
A job shop is a machine shop that is equipped with machines and workers that can undertake a wide range of machining jobs of limited quantity and usually of a very specialized nature (Fig. 1–1). (In this case, the word "job" refers to the product that has to be made and not to the fact that the worker is employed.) A job shop may be called upon to develop the prototype of an idea thought up by a design engineer or an inventor. It may be employed to make a single piece or a dozen or a hundred pieces in a standard or a special shape. Job shops are often used to repair machinery for manufacturers who do not have a mechanical maintenance department. Speed is frequently an important factor in work of this kind, and overtime work is often necessary to complete a job on schedule.

The machine tools used in a job shop must be adaptable to a wide variety of work; they must also be rugged and reliable.

Fig. 1–1. A typical job shop. (Tris Manufacturing Corp.)

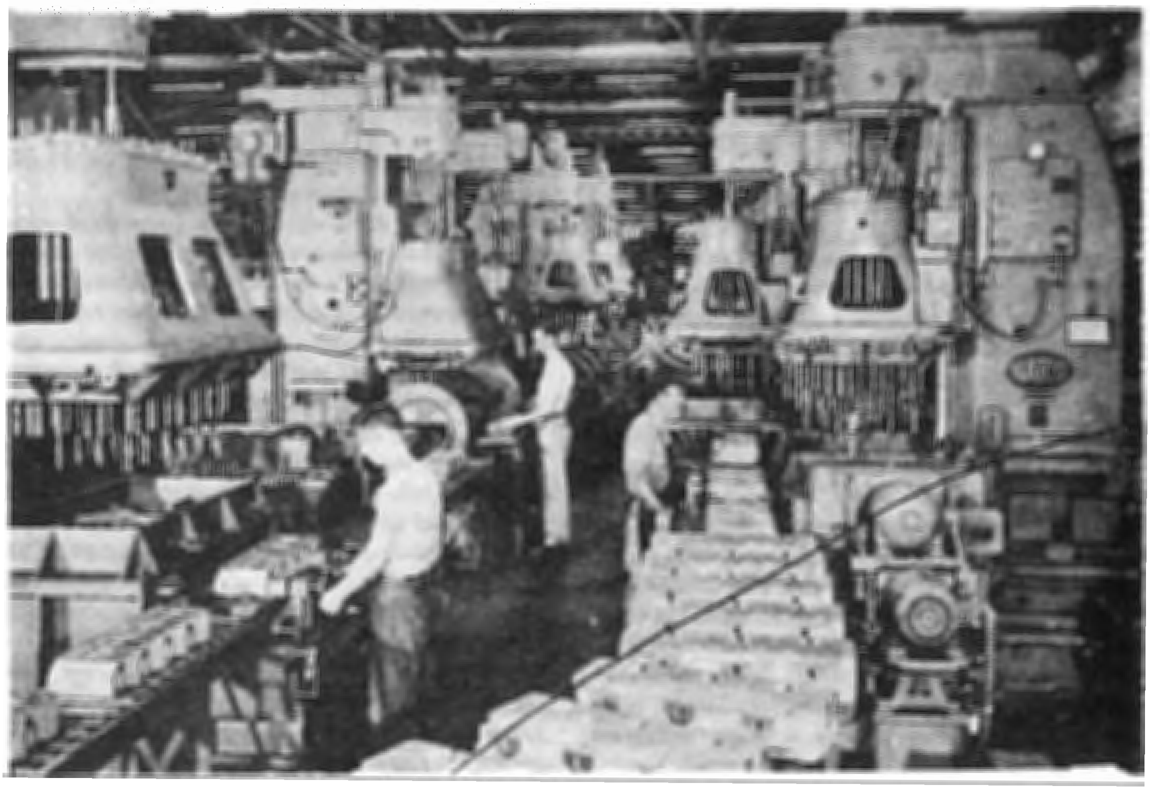
2. *What is a limited production shop?*
A limited production shop falls between a job shop and a mass production shop (Fig. 1–2). It specializes in producing identical parts in limited quantities

Fig. 1–2. An example of a limited production shop. (Warren Pumps Inc. and the Wilking Studio.)

ranging from one hundred to several thousand. Machine tools used in limited production shops are designed to withstand hard wear. They can be easily changed from one setup to another, with each setup able to make many repetitive operations. In recent years, limited production shops, as well as job shops, have been using automatic and numerically controlled machine tools.

3. *What is a mass-production shop?*
This is a shop where parts are manufactured in vast numbers (Fig. 1–3). Automatic and numerically controlled machines are utilized to the fullest extent. Machines are set up to perform several operations with several different cutting tools. Quite often the work is positioned and repositioned by mechanical arms thus enabling one operator to attend to several machines. These shops have their own numerical control systems, programming computers, and tape-making departments.

Fig. 1–3. A mass-production shop. (Caterpillar Tractor Co.)



JOB DESCRIPTIONS

The Apprentice

4. *How does a person become a machine tool operator?*
Most often by completing a training program as an apprentice in a machine shop.

5. *What is an apprentice?*
Apprenticeship is a form of practical on-the-job training given under the direction of skilled mechanics or technicians. A person becomes an apprentice when he agrees to serve a prescribed length of time in order to learn the job or trade offered by an employer. Apprenticeship has passed through many changes since it was recognized by an act of the British Parliament in 1383. In those days, an apprentice lived in his master's home and was fed and clothed by him.

6. *What is an indentured apprentice?*
Indenture was a contract which contained all the

conditions of employment. Typically, the master agreed to teach the apprentice all of the skills of the trade and to pay him specified wages, which were periodically increased. The apprentice promised to work diligently for a specified number of years, preserve his master's secrets, and attend evening school in order to learn mathematics, trade drawing, and trade theory. Worktime lost because of illness and holidays usually had to be made up.

The apprentice's parent or guardian was bound to the agreement as a third and responsible party, and the contract was witnessed by two or three respected members of the community, such as the apprentice's school teacher and minister.

At the completion of his training period, the apprentice received the signed copies of his indenture and an evaluation of his services and skill.

7. *Are all apprentices indentured?*
Indenture as just described is no longer practiced in this country, but in some industries (notably, construction and machine trades), a signed agreement between employer and apprentice is still the custom. A typical agreement is shown in Fig. 1–4.

8. *How does the U.S. Department of Labor define apprentice?*
APPRENTICE—This title is intended to mean a worker not less than 16 years of age engaged under direct journeyman supervision, and according to a prescribed or traditional series of work processes graded to coincide with increasing trade maturity in learning a skilled occupation that requires, during the learning process, several years of reasonably continuous employment prior to the time that the worker may be considered a qualified journeyman. In general, apprenticeship is legally recognized only if recorded in a written contract, indenture, or agreement, in which, in return for services rendered, the employer promises to teach the worker the processes of his trade. The terms of an apprenticeship agreement usually include specific reference to the duration of the apprenticeship period, a progressive scale of wages, and the nature of the processes to be taught. Frequently the agreement also specifies the amount and nature of the related schooling in vocational subjects in which the worker shall engage during his apprenticeship period. When the conditions of the agreement have been satisfactorily completed the apprentice is given a written statement of this fact with an evaluation of his record.

9. *How much time must a machinist apprentice serve?*
A machinist apprentice usually serves from three to five years, depending on the type of work being done in the shop to which he is apprenticed. The longer period is required if the work is particularly painstaking and requires a high degree of accuracy. During his apprenticeship, the young person is instructed in the use of all machines, tools, equipment, and materials used in the shop, and he is expected, in his last apprenticeship year, to use them all with skill and understanding.

10. *Do all machinists learn the trade as apprentices?*
No; many have learned their trade by starting as a machinist's helper, who works at a variety of jobs, advancing to semiskilled jobs, then becoming a single-machine operator, and next operating different machines and taking every opportunity to obtain new experiences. Others learn by taking machine shop and related classes during evening sessions at vocational schools. Extension training programs offered by unions and industry organizations are also popular methods.

These methods take longer than apprenticeship, but often they are the only way available because many who wish to become machinists cannot stay in one place or cannot subsist on an apprentice's small wages.

11. *Is study in a day vocational school a good background for a machinist apprentice?*
The course of study given in a well-equipped vocational school machine shop will enable the student to obtain experience on the basic machines of the trade. Instruction in related theory gives him skills in mathematics, mechanical drawing, physics, elementary metallurgy, and so forth. This will make him more valuable to a prospective employer and provides a good foundation on which to build the knowledge required for a supervisory position. Employers fully realize the value of vocational school training and give credit of a year or more toward the completion of an apprenticeship program.

12. *Is it possible and desirable for a machinist to specialize in one type of industry?*
At the beginning of a young person's career, jobs are usually limited to the type of industry that is found locally. It is desirable to obtain varied experience in all facets of the machine trades. This is best

SOCIAL SECURITY NO.

APPRENTICESHIP AGREEMENT
Between Apprentice and Employer

The employer and apprentice whose signatures appear below agree to these terms of apprenticeship:

The employer agrees to the nondiscriminatory selection and training of apprentices in accordance with the Equal Opportunity Standards stated in Section 30.3 of Title 29, Code of Federal Regulations, Part 30; and in accordance with the terms of the

....
(Name of Apprenticeship Standards)

The apprentice agrees to apply himself diligently and faithfully to learning the trade in accordance with this agreement.

Trade .... Term of apprenticeship .... (Hours or Years)

Probationary period .... Credit for previous experience ....

Term remaining .... Date the apprenticeship begins ....

This agreement may be terminated by mutual consent of the parties, citing cause(s), with notification to the Registration Agency.

....
(Signature of Apprentice)

....
(Address)

....
(Parent or Guardian)

....
(Name of Employer—Company)

....
(Address)

....
(Signature of Authorized Official)

TO BE COMPLETED BY THE APPRENTICE

Date of birth ____________________
Month Day Year

Check: Male _____ Female _____

If you consider yourself a member of one of the ethnic groups listed, please check:

Negro ______ American Indian ______

Oriental _____ Spanish American _____

Approved by .... Joint Apprenticeship Committee

Date..by ....
(Signature of Chairman or Secretary)

Registered by..
(Name of Registration Agency)

Date...by ....
(Signature of Authorized Official)

Fig. 1–4. Apprentice agreement. (National Tool, Die, and Precision Machining Association.)

done at the beginning of one's journeyman career, when family responsibilities are less demanding and confining.

13. *Can the apprentice specialize in one area of the machinist's trade?*
An apprentice can specialize in any one of the several specializations of the machinist's trade.

14. *How is the time of apprenticeship scheduled among the various machines to be learned?*
The following is the apprentice schedule developed and recommended by the National Tool, Die, and Precision Machining Association.

processes	*hours (approximate)*
Tool Crib. To learn the names and types of tools required in the trade.	**200**
Drill Press. Drill grinding, drilling, reaming, counterboring, lapping, tapping, lubrication, speeds, feeds, and safety.	**500**
Shaper. Tool bit grinding, holding work, surface and angle cutting, squaring, speeds, feeds, and safety.	**600**
Milling Machine. General setup, slotting, face milling, vertical and horizontal milling, angle milling, dividing head, lubrication, speeds, feeds, and safety.	**600**
Lathes (Engine and Bench). Use of face plates, straight turning, facing, tapping, threading, setup, lubrication, speeds, feeds, and safety.	**1000**
Grinders. Selection of grinding wheels, mounting wheels, taper, form, and angle grinding, jig grinding, lubrication, speeds, feeds, and safety.	**1400**
Filing Machine. Selection of machine files, die filing, straight and taper filing.	**200**
Contour Cutting. Selection of saws, internal and external cutting, speeds, feeds, and safety.	**100**
Heat Treating. Types and treatments of tool steels, hardening and draw temperatures, carbide brazing, case hardening, annealing, Rockwell testing, and safety.	**100**
Bench Work. Hand filing, micrometer reading, use of gages, layout work, assembling and finishing of tools and dies, and tool and die repair work.	**3000**
Miscellaneous Machines. Machinery repair and such other work as may be considered necessary to complete the experience adequate to attain the skill and versatility required of a journeyman.	**300**

Related Instruction. The apprentice shall take a minimum of 144 hours per year (or 2,000-hour period) of related instruction at an approved school. The time spent in such classes shall not be considered as hours of work unless the apprentice is required to attend classes during his regular working hours. Such classroom instruction should include, but need not be limited to the following subjects: mechanical drawing and shop sketching, elementary physics, science of metals (metallurgy), blueprint reading, shop mathematics, elements of tool and die design, and elementary economics.

15. *How many different job areas are there in the machine trades?*
The following job areas are connected with the machine trades. The descriptions given are based on the *Dictionary of Occupational Titles*, prepared by the U.S. Department of Labor.

Assembler–Fitter. Assembles machine parts according to assembly plans and blueprints (Fig. 1–5). Studies blueprints to determine how the parts go together. Lays out the position of holes to be drilled. Checks the alignment of shafts, bearing, gears, and cams. Chips, scrapes, and files the parts, using hand tools to make sure that the machine's movement, travel, fit, and function are correct. The skills of an all-around machinist are preferred so that the solution of any malfunction can be diagnosed and corrected.

Boring Machine Operator. Sets up and operates a boring machine to bore, drill, mill, or ream metal parts according to specifications, tooling instructions, standard charts, and a knowledge of boring pro-

!1–5. Assemblers at work. (S & S Corrugated Paper Machinery Co.)

Fig. 1–6. Boring machine operator. (S & S Corrugated Paper Machinery Co.)

Fig. 1–7. Jig boring machine operator. (Moore Special Tool Co.)

cedures (Fig. 1–6). Reads blueprints for job description and specifications, hole locations and dimensions, and tooling instructions. Determines holding fixtures, feed rates, cutting speeds, and cutting tools to be used. Lifts workpiece manually or with hoist. Positions and clamps it in fixture on machine table, using wrenches. Secures cutting tool and moves controls. Sets cutting speed and feed rate and depth of cut. Controls feed of tool either manually or by automatic feed. Controls amount and direction of coolant. Verifies conformity of bored workpieces to specifications, using fixed gages, calipers, micrometers and vernier measuring tools. Computes cutting speed, feed rates, and dimensions, using standard charts and shop mathematics.

Jig Boring Machine Setup Operator. Performs operations similar to that of the boring machine operator but with greater accuracy (Fig. 1–7). Sets up and operates machine to drill, bore, and ream holes in metal workpieces such as jigs, fixtures, and dies. Plans sequence of work, lays out reference lines and location of holes according to blueprints and knowledge of shop mathematics. Positions and secures workpiece on table, verifying parallelism of reference line to axis of table motion using dial indicators, edge finders, and similar sensitive instruments.

Fig. 1–8. Broaching machine operator.

Broaching Machine Operator. Sets up and operates one or more internal or external broaching machines to broach cylindrical or flat surfaces of metal workpieces according to specifications, tooling instructions, standard charts, and a knowledge of broaching (Fig. 1–8). Reads blueprints, job order specifications to determine dimensions and tolerances, and tooling instructions such as holding fixtures, cutting speeds and cutting tools (broaches) to be used. Lifts workpiece manually or with hoist and positions and secures it in fixture. Installs broach, or ram, using wrenches. Sets specified depth of cut and ram speed. Verifies that broached workpiece conforms to specifications, using measuring instruments such as fixed gages, calipers, and micrometers. May broach nonmetallic materials such as plastics. May be required to have experience with custom or production work, with particular material or product, or with machine of particular size, type, or trade name. May be designated accordingly.

Drill Press Setup Operator. Sets up and operates drill press to perform such machining operations as drilling, countersinking, counterboring, spot-facing, reaming, boring, and tapping holes in metal workpieces according to specifications, tooling instructions, charts, and a knowledge of drilling procedures (Fig. 1–9). Reads blueprints, job orders, and tooling instructions for required specifications. These include hole position and sizes, feed rates, type of fixture, and cutting speeds and cutting tools to be used. Regulates controls to set cutting speed and feed rates and directs flow of coolant. Positions workpiece either in drill jig or on table. Verifies that machined workpieces conform to specifications using measuring instruments and fixed gages. May measure, mark, scribe, and center punch workpieces to lay out for machining, applying knowledge of shop mathematics, machine drawing, and layout and measuring procedures. Experience with particular product, operation, or size, type, or trade name of machine may be required; may be designated accordingly. May be assigned to operate single- or multiple-spindle, radial, or tape-controlled machines.

Engine Lathe Operator. Sets up and operates engine lathes to perform machining such as turning, facing, boring, and threading on metal or nonmetal workpieces according to specifications, tooling

Fig. 1–9. Drill press operator. (S & S Corrugated Paper Machinery Co.)

instructions, standard charts, and knowledge of machining procedures (Fig. 1–10). Reads blueprints or job order for specifications such as dimensions and tolerances, tooling instructions on holding devices, feed rates, cutting speeds, depth of cut, and cutting tools. Positions and secures tool in holders, using wrenches. Lifts workpiece manually or with hoist and positions and secures by such methods as mounting between centers, inserting in chuck, or clamping to faceplate. Moves controls to set specified rotation speed, feed rate, and depth of cut and to position tool in relation to workpiece. Verifies that machined workpiece conforms to specifications using micrometers, verniers, calipers, and fixed gages. Controls and directs flow of coolant. May compute such data as dimensions, tapers, speeds, and tool settings, using knowledge of metal properties and shop mathematics. May set up tracing attachment that guides cutting tool to follow movement of tracing stylus along template, duplicating template profile on turned workpiece; may be designated "tracing lathe setup operator." May offset position of tailstock to machine tapered surfaces. May mount gears, move levers, and engage threading dial to machine threads, using knowledge of thread cutting. May operate bench grinder to shape and sharpen tools. May be required to have experience with custom or production work or with particular material, product, level of precision, or size, type, or trade name of machine.

Turret Lathe Operator. Sets up and operates turret lathes to perform series of machining operations such as turning, boring, threading, and facing on metal workpieces such as castings, forgings, machine, tool, or die parts according to specifications, tooling instructions, standard charts, and a knowledge of turning procedures (Fig. 1–11). Reads and studies blueprints to visualize machining to be done and plan sequence of operations. Selects method of holding workpiece. Positions and secures workpiece to faceplate or in chuck, collet, or holding fixture. Selects cutting speed, tool feed rate, depth of cut, and cutting tools for each operation according to knowledge of metal properties and shop mathematics. Positions and secures tools in toolholders at each station of the turret and cross-slide tool post and positions tools in relation to workpiece. Moves stops, cams, or levers to control rotation of the workpiece and feeding of the tools. Verifies that machined workpiece conforms to specifications, using measuring instruments such as gages, calipers, and micrometers. May set up fixtures, sharpen tools on bench grinder, direct flow of coolant, and operate tracing attachment to duplicate profile of template

Fig. 1–10. Engine lathe operator. (S & S Corrugated Paper Machinery Co.)

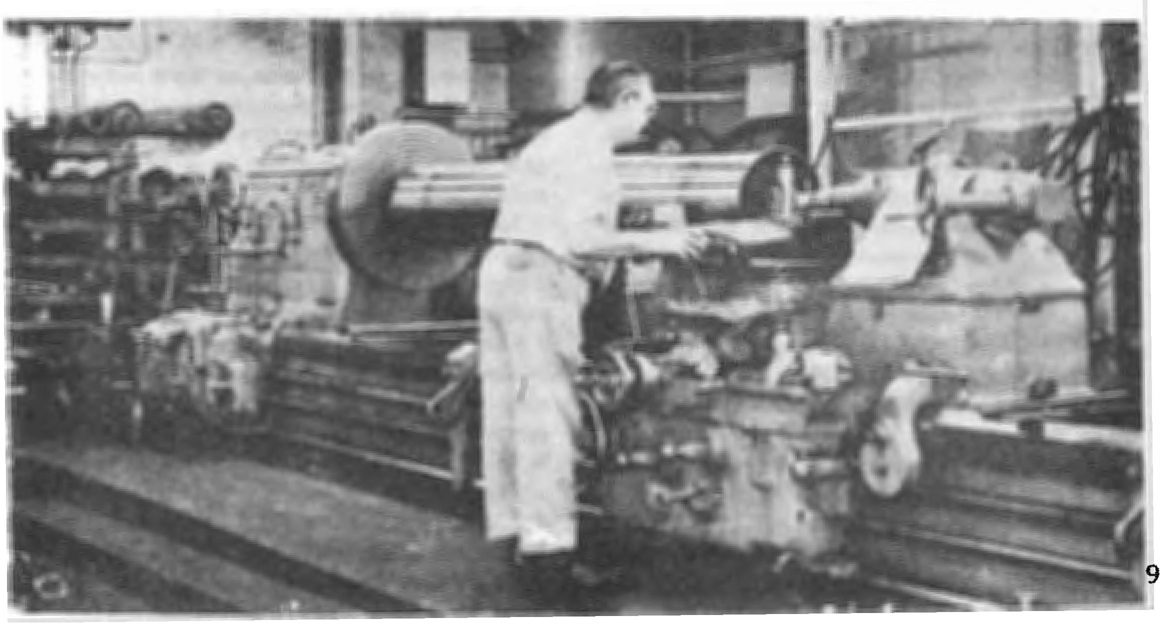


Fig. 1–11. Turret lathe operator. (Warner & Swasey Co.)

Fig. 1–12. Gear-cutting machine operator. (S & S Corrugated Paper Machinery Co.)

or model of workpiece. May be required to have specialized experience with particular material, product, precision level, machining process, or size, type, or trade name of lathe.

Gear-Cutting Machine Setup Operator. Sets up and operates gear-cutting machines such as shapers, hobbers, and generators (Fig. 1–12). Machines spline, rack, or gear teeth on metal blanks, analyzing specifications according to knowledge of gear design, shop mathematics, and gear-machining procedures. Studies blueprints to visualize machining required and plans sequence of operations. Selects machine and method of holding workpiece. Computes machine setting from gear specifications. Positions and secures workpiece to cutting angle, or arbor, in chuck or other holding device. Selects positions and secures cutters on toolhead, in spindle or on arbor. Sets feed rates and rotation speeds of cutters and workpiece in relation to each other by selecting and mounting gears, cams, or templates or by moving levers. Sets cutting speeds, depth of cut, and stroke for reciprocating cutters and positions tool and workpiece in relation to one another. Controls and directs flow of coolant. Verifies that machined gear conforms to specifications, using comparator, gear measuring wires, involute (curve) checker, master gears, optical comparator, and other special gear-inspection equipment. May operate broaching machine to broach internal splines or gears. May work on nonmetallic materials. May be required to have experience with particular gear type, material, or size, type, or trade name of machine such as special gear-cutting machines, special bevel gear generator, straight bevel gear generator, gear hobber, gear-lapping, gear inspector, gear milling, and gear shaper.

Tool Grinder Operator. Sets up and operates variety of grinding machines such as external, internal, and surface grinders, to grind metal workpieces such as machine parts, dies, or tools based on a knowledge of grinding procedures (Fig. 1–13). Studies blueprints or layout on workpiece to visualize grinding to be done and plans sequence of operations. May measure, mark, or scribe workpiece to lay it out for grinding. Selects method of holding workpiece. Lifts workpiece manually or with hoist and positions and secures workpiece in holding device, using wrenches and clamps. Selects feed rates, grinding speeds, depths of cuts, and grinding-

Fig. 1–13. Grinding machine operator.

wheel size, shape, and grade for each operation, applying knowledge of metal properties, abrasives, and shop mathematics. Positions and secures grinding wheel on spindle. Positions and tightens stops to limit travel of workpieces or grinding wheels. Positions wheel and workpiece relative to one another and sets feed, speed, and depth of cut. Directs flow of coolant. Verifies that dimensions of ground workpieces conform to specifications, using measuring instruments such as templates, micrometers, dial indicators, and gage blocks. Works to close tolerances. Positions and secures machine centers, chuck, or grinding spindle at angle to grind tapered surfaces. May dress grinding wheels to complex profiles, using special fixtures and tools. May grind nonmetallic materials such as plastics. May operate tracer attachment to duplicate contours from template or model. May be required to have specialized experience with particular materials, products, or precision levels or with machine of particular size, type, or trade name. Able to operate special grinding machine types such as gear, external, internal, tool, cylindrical, centerless, surface, automatic, production, thread, universal, tool and cutter, and Blanchard grinders.

All-Around Machinist. Carries through to completion the construction and repair of all kinds of tools, metal parts, or machines. Works from blueprints and written specifications. Skillfully uses all machinist's hand tools and measuring instruments. Operates all machine tools including drill presses, band and power saws, lathes, planers, shapers, grinding and milling machines, and specialized machines that have been developed from them (Fig. 1–14). Should be familiar with shop mathematics (including the use of fractions, decimals, powers and roots, and basic algebra), the use of charts and tables, and the planning of work to obtain greatest efficiency and accuracy. Should know the working properties of such metals as brass, cast iron, wrought iron, and various steels and should be able to shape the metals to precise dimensions within the close tolerances prescribed. Lays out work and establishes necessary reference points, center lines, and guidelines. Measures with rule, calipers, micrometers, and verniers and uses a scriber, center punch, surface gage, and dividers to mark metals. Must be able to set up work on all basic machine tools. Selects proper tools for each job and each machine. Grinds and sharpens tools with abrasive wheels and oilstone. May forge blanks from which cutting tools are later ground.

Metal Band Saw Operator. Saws metal sheets and plates, castings, or machine parts to a specified shape and size on a band saw according to blueprints or layout lines (Fig. 1–15). Degree of skill required will depend upon the job. Studies blueprints and judges allowances required for finishing (machining). Uses layout tools to mark limits of saw cut. Adjusts guides to suit variety of saw blades; requires ability to cut, grind, weld, and anneal blades when they are removed and replaced on the saw band carrier wheels. Must be able to utilize various attachments (such as disc and contour cutting attachments) and to mount work on table and in fixtures.

Metal Band Machine Operator. Must have all of the skills of the band saw operator plus the ability to remove the band saw blade and replace it with a band file or an abrasive-coated polishing band. Uses both of these attachments to a high degree of precision. Must be able to use similar machines for electric band sawing and friction sawing.

Milling Machine Setup Operator. Sets up and operates milling machines to mill surfaces on metal workpieces (Fig. 1–16). Positions and secures workpiece in fixture or on machine bed using clamps and

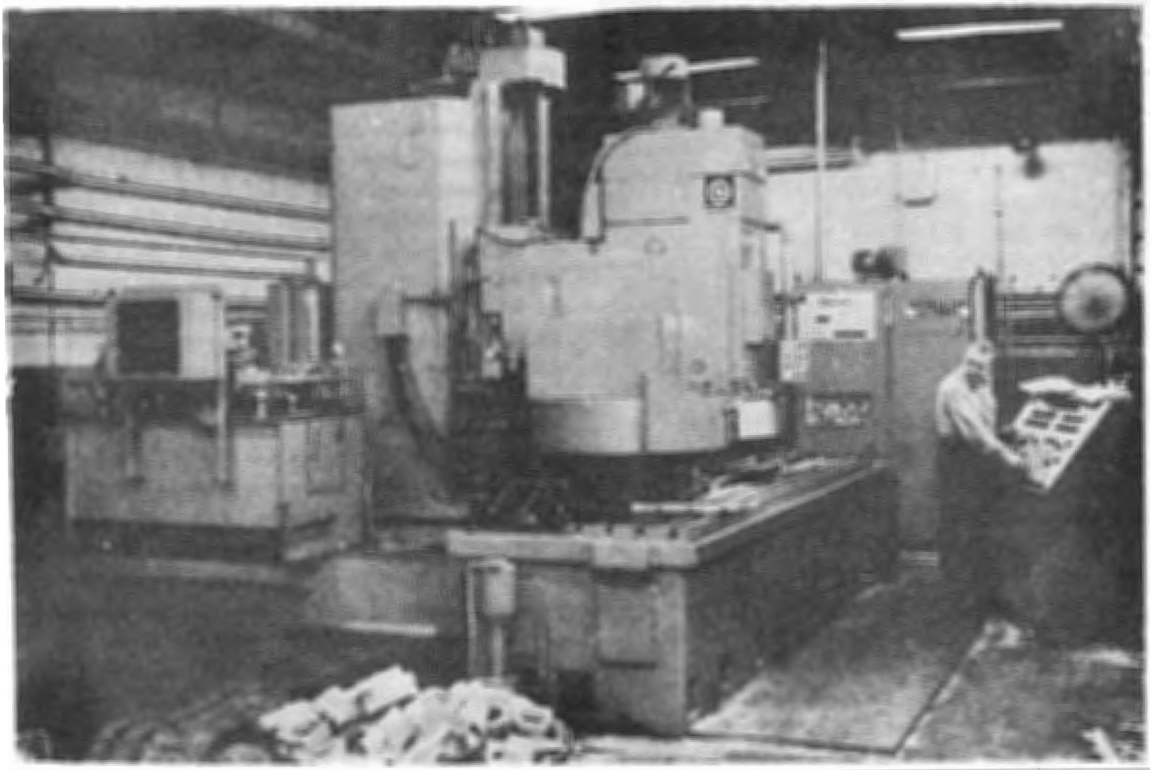
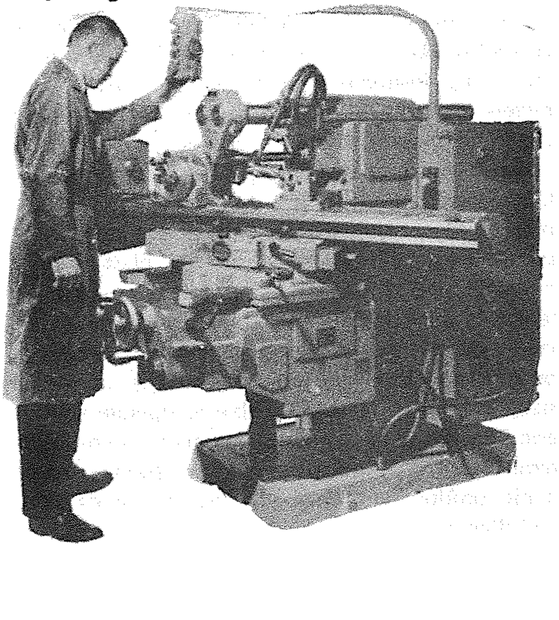


Fig. 1–14. All-around machinist operating machining center. (S & S Corrugated Paper Machinery Co.)

Fig. 1–15. Metal band saw operator. (DoALL Co.)

Fig. 1–16. Milling machine operator. (Brown & Sharpe Mfg. Co.)

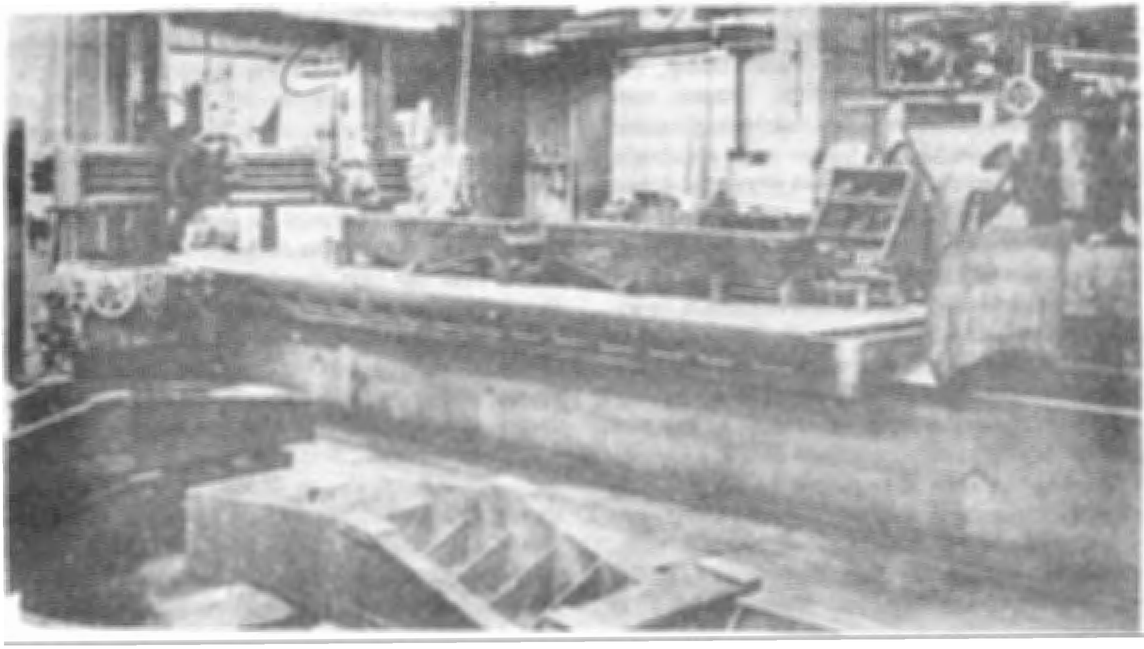


wrenches. Mounts specified cutter in spindle or on arbor. Moves controls to set cutting speed, feed rate, and depth of cut according to tooling instructions. Feeds workpiece to cutter or engages feeding mechanism; changes worn cutters. Verifies dimensions of milled workpieces, using micrometers, verniers, calipers, and fixed gages. Controls and directs flow of coolant over cutting area. May compute dimensions, cutting speeds, or feed rates, using knowledge of metal properties and shop mathematics. May mill plastics or other nonmetallic materials. May compute indexing ratios and set up and operate dividing head to index workpiece for such operations as milling helical cuts. May mount different tool in place of cutter and perform other operations such as drilling and boring. May set up and operate accessories such as tracer attachments or universal head. May be required to have experience with custom or production work or with particular material, product, or precision level or particular size, type, or trade name of machine. May be designated accordingly. Specialized milling machines include gear, production, profiling, and thread-milling machines as well as planer-type milling machines.

Millwright. Installs machinery and equipment according to layout plans, blueprints, and other drawings in an industrial establishment, using hoists, lift trucks, hand tools and power tools. Reads blueprints and schematic drawings to determine work procedures. Dismantles machines, using hammers, wrenches, crowbars, and other hand tools. Moves machinery and equipment, using hoists, dollies, rollers, and lift trucks. Assembles and installs equipment such as shafting, conveyors, and assembly systems, using hand and power tools. Constructs foundations for machines, using building materials such as wood, concrete, and steel. Aligns machines and equipment, using hoists, jacks, hand tools, squares, rules, micrometers, and plumb bobs. Assembles machines; bolts, welds, rivets, or otherwise fastens them to foundations or other structures, using hand and power tools. May operate machine tools in order to machine parts to dimensional specifications. May repair and lubricate machines and equipment.

Planer Setup Operator. Sets up and operates planers to plane and groove large metal workpieces such as castings for metalworking dies and machine ways, analyzing specifications and deciding on tooling according to machine-planing procedures (Fig. 1–17). Studies blueprint or layout on workpieces to visualize planing to be done and plans

Fig. 1–17. Planing machine operator. (S & S Corrugated Paper Machinery Co.)



sequence of operations. Selects method of holding workpieces so that entire surface to be planed will remain parallel to table during planing operation. Lifts workpiece manually or with hoist and positions it on table using shims, parallel blocks, clamps, toe dogs, and poppets. Verifies workpiece positions with gages, rule, square, or other instruments. Selects and mounts cutting tools on rail or side head. Selects and sets cutting speed, length of stroke, and depth of cut according to metal properties and shop mathematics. Sets stops to limit length of stroke and to actuate table-reversing mechanism. Moves controls to position tool in relation to workpiece. Verifies that planed workpiece conforms to specifications within tolerance, using measuring instruments such as surface gage, planer gage, vernier height gage, and micrometer. May operate bench grinder to sharpen tools. Directs flow of coolant. May set up and operate milling attachment instead of rail or side head. May plane nonmetallic materials such as plastics. Specialized experience with product, material, or machine of particular size, type, or trade name may be required; may be designated accordingly.

Shaper Operator. Performs operations on a shaping machine, such as planing or grooving of metal parts including castings, forgings, and steel stock either in rough or simplified form (Fig. 1–18). Selects, sharpens, and installs appropriately shaped cutting tools for each operation; clamps or bolts work on machine table; adjusts and controls operations of machine. Requires precision workmanship and ability to work from blueprints. Fastens work securely to the table; may use machinist's square, scale, and surface gage to place work accurately. Selects ram speed and adjusts belts or gears to obtain that speed; selects and mounts cutting tool. Sets the limits of travel of the ram, the depth of the cut, and the amount of feed.

Instrument Maker. Devises and constructs a variety of prototypes in accordance with sketches, drawings, specifications, and instructions under minimum supervision. Produces parts or instruments in single or limited quantity as required. Uses basic machine tools and performs highly complex bench operations in shaping, forming, assembling, calibrating, and adjusting components and/or complete instruments to extremely close tolerances on delicate parts. Applies knowledge of shop mathematics, tables, and properties of materials. Performs duties as assigned.

Fig. 1–18. Shaping machine operator. (Rockford Machine Tool Co.)

Less experienced instrument makers may carry out these jobs but under general supervision.

Inspector. Develops gaging, setup, and surface plate layout procedures, draws patterns and templates, and inspects a variety of parts and tools to provide inspection devices and fixtures for use in machining or assembly, using blueprints, formulas, trigonometry, and precision measuring instruments (Fig. 1–19). Analyzes inspection problems by comparing part with blueprint or sketches, and devises procedures necessary to measure specified dimensions. Lays out part on surface plate or positions in gaging setup to verify dimensions, using master gages, index heads, Johansson blocks, comparators, verniers, micrometers, and indicators. Develops and draws patterns and templates used to measure curves and angles. Tests surface finish of machined parts, using profilometer. Tests hardness of metal parts. Analyzes defective parts to determine reasons for dimensional variations, such as faulty machining or assembly procedures, setup, tools, or fixtures. Recommends corrective procedures to design, methods, process, or production engineering department. Inspects machining or assembly fixtures, tools, or

Fig. 1–19. Mobile inspector. (DoALL Co.)

gages and suggests replacements or use of new equipment. May approve parts not within specified dimensions or tolerances. May change allowable tolerances specified on blueprint.

ENGINEERING POSITIONS

16. *What opportunities are available to the ambitious, well-trained, and capable machinist?*
Many men in influential positions received their earliest training in a machine shop. Machining parts to a specified size requires careful attention to details. Having to work within close tolerances and to a precise size develops the attitude of a perfectionist. Being able to complete a job in a required and stipulated length of time requires patience, reliability, and a calm unruffled attitude. What better training could there be for a technician or an executive? The following descriptions of professional jobs indicate positions for which a machinist's training provides a desirable foundation.

Industrial Engineering Technician. Studies and records time, motion, methods, and speed involved in performance of maintenance, production, clerical, and other work operations to establish standard production rate and to improve efficiency. Prepares charts, graphs, and diagrams to illustrate work flow, routing, floor layouts, material handling, and machine utilization. Observes workers operating equipment or performing tasks to determine time involved and fatigue rate, using stopwatch, motion-picture camera, electrical recorder, and similar equipment. Recommends revision of methods of operation or material handling, alterations in equipment or layout, or other changes to increase production or improve standards. Aids in planning work assignments in accordance with workers' performance, machine capacity, production schedules, and anticipated delays. Other job titles include methods-study analyst, motion-study analyst, time-study analyst.

Methods Engineer. Plans sequence of operations to be followed in manufacturing product. Examines blueprints, sketches, and specifications of product to be made. Itemizes steps to be followed in the process, using knowledge of material, machine operations, plant layout, and mathematics to select the least expensive and most efficient production methods. Specifies machines and kinds of cutting tools and setups to be used. May be concerned with the writing of technical reports. Other titles include plant layout engineer and production planning engineer.

Time-Study Engineer. Develops work-measurement procedures and directs time-and-motion studies to promote efficient and economical utilization of personnel and facilities. Directs or conducts observation and analysis of personnel and work procedures to determine time-and-motion requirements of job duties. Analyzes work-study data and equipment specifications to establish time and production standards. Applies mathematical analysis to determine validity and reliability of sampling and work-study statistics. Applies principles of industrial engineering and applied psychology to evaluate work-method proposals and to develop recommendations for management affecting work methods, wage rates, and budget decisions. Trains industrial engineering technician in time-and-motion study principles and techniques. Other titles include work-measurement engineer, production engineer, method-and-motion analyst.

Quality-Control Engineer. Performs and oversees activities concerned with development, application, and maintenance of quality standards for processing materials into partially finished or finished products.

Develops and initiates methods and procedures for inspection, testing, and evaluation. Devises sampling procedures, designs forms for recording, evaluating, and reporting quality and reliability data, and writes instructions on use of forms. Establishes programs to evaluate precision and accuracy of production and processing equipment and testing, measurement, and analytical facilities. Develops and implements methods and procedures for disposition of defective material. Devises methods to assess cost and responsibility of such material. Oversees workers engaged in measuring and testing products and tabulating quality and reliability data. Compiles and writes training material and conducts training sessions on quality control activities. May specialize in any of the following areas of quality control engineering: design, process control, product reliability, and research and development. Usually required to have engineering training in a field related to the technology of the product involved.

Foreman. Supervises and coordinates activities of workers engaged in one or more occupations. Studies production schedules and estimates man-hour requirements for completion of job assignment. Interprets company policies to workers and enforces safety regulations. Interprets specifications, blueprints, and job orders to workers and assigns duties. Establishes or adjusts work procedures to meet production schedules, using knowledge of capacities of machines and equipment. Recommends measures to improve production methods, equipment performance, and quality of product, and suggests changes in working conditions and use of equipment to increase efficiency of shop, department, or work crew. Analyzes and resolves work problems or assists workers in resolving work problems. Initiates or suggests plans to motivate workers to achieve work goals. Recommends or initiates personnel actions such as promotions, transfers, discharges, and disciplinary measures. May train new workers. Maintains time and production records. May specify, estimate, requisition, and inspect materials. May confer with other foremen to coordinate activities of individual departments. May confer with workers' representatives to resolve grievances. May set up machines and equipment. When supervising workers engaged chiefly in one occupation or craft, must be adept in such work. When supervising workers engaged in several occupations, must possess general knowledge of the activities involved.

Machine Shop Foreman. Supervises and coordinates activities of workers engaged in machining of metal, applying knowledge of machine shop procedures, machine tool setup and operating techniques and production, or custom machining methods. Performs duties similar to those of a foreman.

Production Superintendent. Coordinates, through subordinate supervisors, all activities of production departments and subdivisions, applying knowledge of plant layout and production capacities of each department. Consults with plant executives and analyzes economic trends, sales forecasts, and marketing and distribution problems to plan and develop production procedures and time-and-cost estimates. Explains company policies and production procedures to subordinate supervisors and directs their activities. Confers with department heads to formulate programs regarding availability of raw materials, maintenance of plant equipment and physical structure, product quality control, related production records, labor and materials costs, and equipment depreciation, to insure that operating costs are maintained at budgeted level. Reports production figures and job completion dates to plant executives. Originates or assesses measures designed to improve production methods, equipment performance, and quality of product. Recommends changes in working conditions and modifications in machines and equipment. Plans surveys and projects manpower requirements. Negotiates with workers' representatives in connection with grievance procedures and reports unsettled grievances to plant executives.

chapter 2 safety in the machine shop

THE SAFE WORKER

An accident in a machine shop can be a messy and painful experience. Most accidents in a machine shop are the result of carelessness. The victim knows at the time that he should not do what he is about to do; he takes a chance. Sometimes he is lucky and gets away with it. Accident statistics prove that he who takes a chance most often loses. The result: pain; loss of time and money; broken tools and equipment; spoiled work. To these could be added the possibility of permanent disfigurement and disablement.

It takes time and experience to develop a skilled machinist. A skilled machinist is seldom involved in accidents. He knows that he cannot take chances with the certainty of the machine's timing, nor with the power of its movement. There are basic rules for the development of safe working habits. The rules must first be understood, then practiced until they become a habit. Each machine has individual hazards to the safety of a careless and thoughtless operator. The careful operator, however, quickly observes each potential danger and sets up a pattern of work habits that will keep him clear of involvement with any dangerous practice.

The skilled machinist dresses safely (Fig. 2–1). He wears nothing that could get caught on the moving job or machine. He is aware of the danger of flying chips and minute particles from abrasive wheels and of the horrible damage that flying particles from drills and cutting tools can do to the human eye. He wears his safety glasses from the time he enters the shop until he leaves it (Fig. 2–2). The skilled machinist handles sharp cutting tools with care. He keeps the floor around his workplace free of oil and short pieces of stock. He stacks the rough castings and the finished workpieces separately and neatly. The stacked material is not permitted to interfere with his movements around the machine, and because of this it is not a hazard to his safety.

When a workpiece or a machine attachment is too cumbersome or too heavy for one man to handle comfortably, the careful worker asks for assistance (Fig. 2–3). Many things the skilled machinist does keep him free from accidents.

The wise student or apprentice is one who observes and profits from the skilled machinist's example. Each workman or student in a machine shop is aware of the dangers that surround him; he

Fig. 2–1. The well-dressed worker.

Fig. 2–2. He wears safety glasses from the time he enters the shop until he leaves it.

Fig. 2–3. Lifting heavy attachments safely.

has been warned of these dangers and has been instructed in the safety rules that apply to his shop activity. This is not sufficient to make a safe worker. Each worker in a machine shop, whether he be a machinist, student, or helper, must develop his own awareness of the importance of avoiding accidents, and his own awareness of the possible hazards to safety that his job involves. He also must develop safe working techniques. He must be alert to possible dangers, and he must be energetic in correcting conditions and habits that could lead to accidents and injury.

GENERAL SHOP SAFETY

1. *What is safe dress for a machinist?*
He should remove his necktie, wristwatch, and jewelry such as identification bracelet and rings. Sleeves are out of danger when they are rolled up. The machinist should wear an apron, shop coat, or coveralls. Apron strings should be tied at the back, and bulging pieces of cotton waste should not be carried in the pocket.

2. *Why is it dangerous for a machine operator to wear a woolen sweater?*
The strands of the wool that go into the making of a sweater are long and unbroken. One strand caught on a revolving dog or job can bring the machine operator much closer to danger. Machine tool spindles, whether on a lathe or a drill press, turn many revolutions in a second, and much damage can be done before the machine is brought to a stop.

3. *What is the objection to wearing canvas shoes in a machine shop?*

The soft material from which the upper part of the canvas shoe is made offers no resistance to a hard object, whether it is falling or stumbled against (Fig. 2–4). The rubber soles are easily penetrable by steel chips and sharp-edged machined surfaces (Fig. 2–5). Strongly made safety shoes having steel toe caps offer good insurance against injuries.

4. *When should gloves be worn in a machine shop?*
Gloves should be worn when the worker is moving sheet metal or large pieces of stock, especially when stock edges are sharp or ragged. Gloves should also be worn when the worker is pouring liquids that are injurious to human skin and whenever it is necessary for him to handle metal chips of any size or shape.

5. *Why should goggles or safety glasses be worn by everybody working in the machine shop?*
Injury to the eye can be caused by flying particles of metal that result when the workpiece resists the cutting tool. These flying pieces of metal do not single out the man behind the cutting tool. Chips can fly in any direction to hit anybody in the shop. Everybody in the shop needs the protection of safety glasses (Fig. 2–6).

6. *Why is it safer to remove a necktie when working on or near machinery?*
A tucked-in tie can slip out of a buttoned shirt. A loose tie can very quickly become caught in a moving machine part; the results are painful (Fig. 2–7).

7. *Can long apron tie-strings create safety hazards?*
When the ends of long or short apron tie-strings become loose, they can be easily caught on the moving parts of any machine (Fig. 2–8).

8. *Is it safer to roll up the sleeves or button them at the wrists?*
Rolled-up sleeves present far less a hazard to safety than buttoned sleeves. A button can unfasten because of a worn buttonhole, or a button may be lost. The sleeve can then easily become caught in a moving job, with serious consequences to the machine operator.

9. *What is the safe way to lift a heavy object?*
Don't attempt to lift a job or machine attachment

Fig. 2–4. Canvas-top shoes offer little protection.

Fig. 2–5. Sharp objects could penetrate soft-soled shoes.

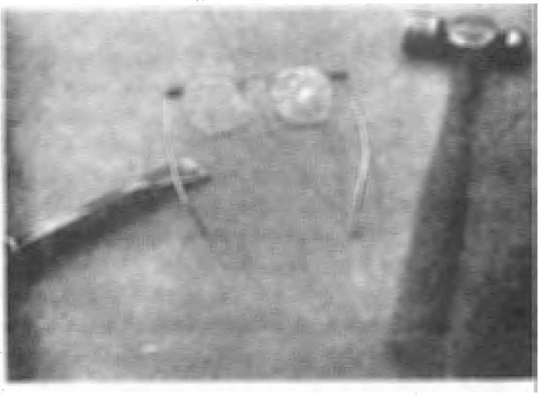
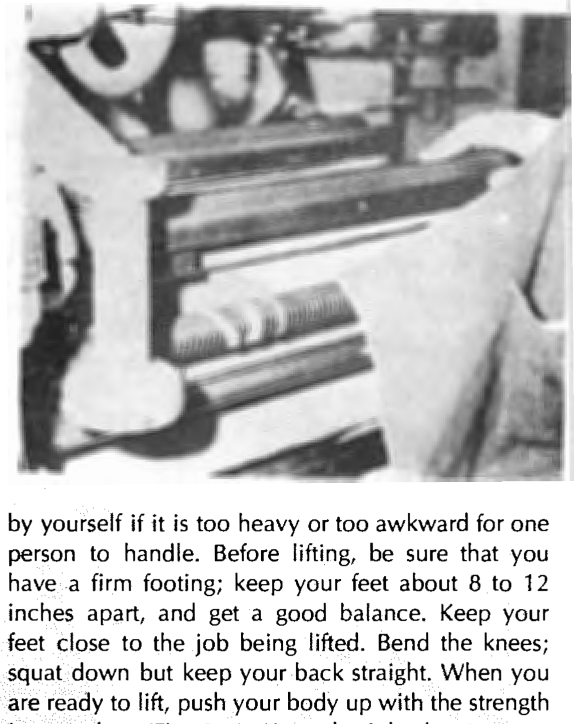


Fig. 2–6. An eye was saved from injury because a worker wore these safety glasses.

Fig. 2-7. A loose tie can quickly become attached to a part of the revolving job.

Fig. 2-8. Apron strings should be tied at the back: dangling strings get caught.



by yourself if it is too heavy or too awkward for one person to handle. Before lifting, be sure that you have a firm footing; keep your feet about 8 to 12 inches apart, and get a good balance. Keep your feet close to the job being lifted. Bend the knees; squat down but keep your back straight. When you are ready to lift, push your body up with the strength in your legs (Fig. 2-9). Keep the job close to your body until you have it in the normal and convenient carrying position. Walk with firm steps; don't twist your body to change your direction, but change the position of your feet. Breathe normally; don't hold your breath. When lifting with another person's help, talk it over first, then move and lift together.

Fig. 2-9. The safe way to lift a heavy object.

10. *How should long steel bar stock be carried i the shop?*
Although it is often easier to carry long pieces (stock on the shoulder (Fig. 2-10) it is not a sa way. We tend to watch where we are going and fo get what happens to the part we are not watchin Stock should be carried vertically so that **all** of can be watched at the same time (Fig. 2-11).

11. *Why is it dangerous to leave pieces of stoc on the floor of the shop?*
Men do not walk through a machine shop wit their eyes looking at the floor; therefore a workma is apt to step on a small piece of stock left on th floor (Fig. 2-12). A fall can cause serious injury. fall that carries the victim into a moving machin can be fatal.

12. *When does grease become a hazard to safety*
When it drips or is dropped on the shop floor. A oil slick under a quick-moving foot may result i a serious accident (Fig. 2-13). Wipe up grease an oil that is dropped on the floor. Clean off the exces grease that is left near bearings and grease cups.

13. *What is meant by good housekeeping in machine shop?*

Fig. 2-10. The UNSAFE way to carry stock.

Fig. 2-11. The SAFE way to carry stock.

Fig. 2-12. Small pieces of stock are hazardous when left on the floor.

Fig. 2-13. Oil on the floor can cause a fall.

The term indicates cleanliness and neatness, a place for everything with everything in its place. The result of good housekeeping: a safe shop.

14. *What are some of the things that contribute to a safe shop?*
Floors, passageways—aisles and space around machines—kept clean and clear of small pieces of metal and machine attachments and accessories. There should be plenty of disposal cans in designated places to receive waste, scrap materials, and floor and machine sweepings. The aisles of passage between machines should be clearly outlined.

There should be a place for each tool and each must be replaced after it has been used (Fig. 2-14).

15. *How should chips be removed from the table or bed of a machine?*
Because metal chips have sharp edges, which cut and penetrate skin, chips should *never* be handled. Machines can be kept clear of chips by periodically sweeping (or brushing) them away (Fig. 2-15).

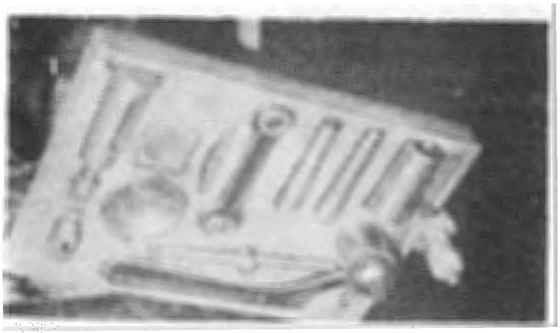


Fig. 2–14. A place for each tool.

Fig. 2–15. Remove chips with a brush.

16. *What must be done before beginning repairs on a machine?*
Remove the fuse that controls the flow of electrical power to the motor of the machine. This should be done before the guards are removed (Fig. 2–16) or any part of the mechanism is touched (Fig. 2–17). Many men who have neglected this safety practice have lost fingers because somebody pressed the starting button.

17. *Why is it dangerous to run a machine from which the guards have been removed?*
Guards removed to repair a machine, or to enable the machinist to make operative changes, should be replaced before the power is turned on. Operating unguarded machines is hazardous not only to the operators, but also to other workers who may come in contact with moving gears and other machine parts. Do not operate a machine until all guards have been replaced.

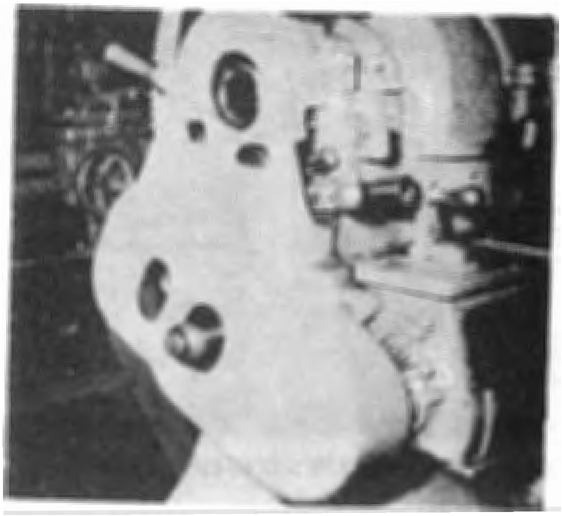
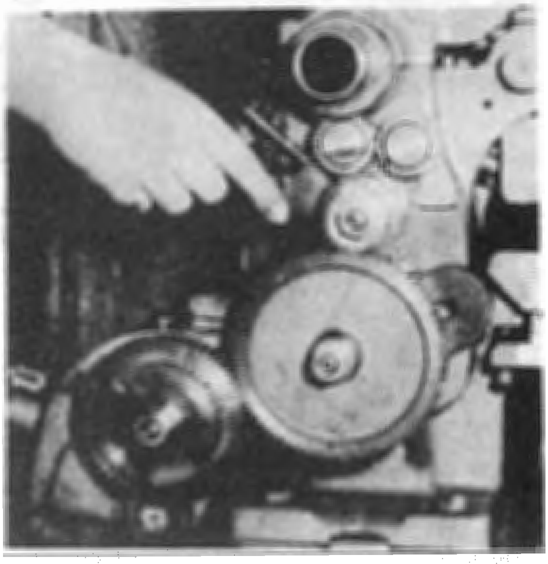


Fig. 2–16. A lathe with the guards in place.

Fig. 2–17. Unguarded gears are dangerous.



SAFETY ON THE BENCH

18. *What causes the greatest number of accidents to bench workers?*
Most accidents to bench workers are caused by thoughtless use of tools, which includes using a tool incorrectly or carelessly. Many accidents result from using a tool to do something for which it was not intended (Fig. 2–18).

Fig. 2–18. A screwdriver should not be used as a chisel.

19. *Many painful accidents are caused by pointed or sharp-edged tools. What can be done to avoid this type of accident?*
Sharp-edged or pointed tools should not be carried in clothing pockets. Arrange the tools on the bench with the sharp ends toward the back of the bench (Fig. 2–19). Lay the tools on a cloth to protect edges. Pick them up carefully. Use the right tool for the job.

20. *What are the rules for the safe use of files?*

A. Be sure that the file has a handle. See that the handle fits securely. Never use a file without a handle.
B. Remove burrs and abrasions from the file handle before using it. They cause blisters.
C. Do not use a file as a hammer. Flying pieces of hardened steel can pierce human skin.
D. Striking a file with a hammer will also cause steel splinters to fly.
E. Using a file as a pry bar is a sure way of breaking it.

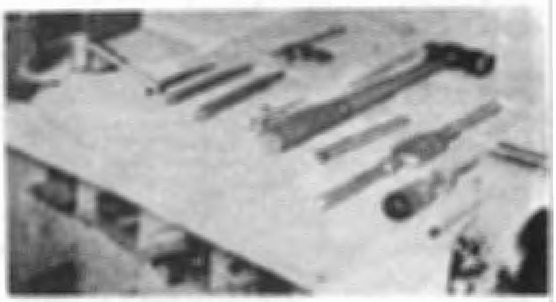


Fig. 2–19. Bench tools arranged for a safe pickup.

Fig. 2–20. Files should be kept separated.

F. Keep files separated from each other (Fig. 2–20) and do not throw files against other files when returning them to the tool drawer.
G. Keep file teeth clear of *pins*. Do not let oil and dirt collect in the gullets of the file. A file that slips over the metal can cause skinned knuckles.

21. *Many workers are hurt because of the misuse of hammers. What rules, if followed, will remove the cause of these accidents?*

A. Always check the fit of the handle in the hammerhead. Make sure that the wedge is in place, and tight.
B. Do not use a hammer with a broken or split handle.
C. Always remove oil, grease, and dirt from the face and the handle of the hammer (Fig. 2–21).
D. Never use the face of the hammer to strike against another hardened tool.

Fig. 2–21. **Remove oil and grease from the face and handle of a hammer before use.**

E. Use the right sized hammer for the job; an 8-oz hammer will not do the work of a 1½-lb hammer.

22. *What rules govern the safe use of wrenches?*

A. Keep wrenches clean; wipe off oil and grease before using the wrench.
B. Stop any machine before using a wrench. Whether it is to tighten, loosen, remove, or adjust, *first stop the machine.*
C. Be sure that the wrench fits the nut snugly. An oversize wrench will slip and round off the corners of the nut.
D. Whenever possible *pull* on the wrench; don't *push.*
E. Stand with proper balance whenever it is necessary to pull hard on a wrench: one leg behind the other (Fig. 2–22).
F. The design of a wrench provides sufficient length for safe leverage. Circumstances arise, however, when extra length must be added. When this happens, take extra safety precautions.
G. Do not hammer on the end of a wrench. This results in springing the jaws of the wrench and raising sharp, dangerous, and unsightly burrs on the end of the wrench.
H. Use an adjustable wrench only when a non-adjustable type is not available. The jaws of an adjustable wrench are not designed to withstand excessive pressure.

HACKSAW SAFETY

23. *Why is it unsafe to use a dull hacksaw blade?*
If a saw does not cut efficiently, it seems practical to apply more pressure. However, this is wrong. More pressure, with poor cutting action, will cause the blade to break.

24. *What is the best procedure to follow if the hacksaw blade breaks before the cut is completed?*
Start the new blade on the opposite side of the job so that it will run into the first cut only when the piece is sawed through. Starting a new blade in the first cut will result in another broken blade.

Fig. 2–22. Pull, do not push, a wrench. Stand with one leg behind the other for proper balance.

25. *How should the hacksaw blade be mounted in the saw frame?*
The teeth of the hacksaw blade should be pointed away from the handle and toward the front of the frame. Tension should be sufficient to prevent the blade from bending, and the blade should be straight, not twisted.

26. *Is there a proper speed for hacksawing?*
The kind of metal being cut and the shape of the job will have much to do with the number of strokes per minute of the hacksaw. The average speed when sawing cold rolled steel that does not spring or chatter should be 50 to 60 strokes per minute, slower when sawing harder and cast metals. The heat of the saw blade will indicate the need to slow down.

27. *Why is it good practice to slow down just before the saw blade completes the cut?*
When the cut is almost completed it is good practice to reduce both speed and pressure because when the saw clears the stock, forward motion will be actually greater. Many knuckles have been skinned and hands cut because this practice was forgotten.

28. *What other rules should be observed for the practice of safety when hacksawing?*
Observe these safe hacksawing practices:

A. Grip the work in the vise so that the saw cut will be near the jaws (Fig. 2–23).
B. Apply pressure only on the forward stroke.
C. Start the saw cut with a light, even, forward stroke, holding the saw frame at an angle. When the cut is established, hold the frame level and saw the full width of the job.
D. Take the longest stroke possible, but do not permit the blade-supporting pins to touch the job.
E. Use a blade having the proper number of teeth per inch to suit the job; fine pitch for thin metal, coarse pitch for thick pieces.

DRILL PRESS SAFETY

29. *What is the most common cause of accidents on a drill press?*
Most drilling accidents are caused by the work not being securely fastened. The job must be securely

Fig. 2-23. The saw cut should be close to the supporting vise jaws.

held, clamped, or bolted down, whatever size hole is being drilled.

30. *Why is it dangerous to drill work held by hand?*
When the fast-moving drill bites into the work, it transfers some of its rotating force to the workpiece. Hands (Fig. 2–24) cannot maintain a secure enough hold to prevent the rotating force from whirling the work away from the operator. The force may be strong enough to send the flying workpiece toward a distant area of the shop, causing injury to an unsuspecting co-worker.

31. *How should work be held for drilling?*
Work should be held in a vise or clamped to the table.

32. *When work to be drilled is held in a vise should the vise be bolted to the table?*
Whenever possible the vise should be bolted to the table (Fig. 2–25) to prevent the rotary force of the drill from dislodging the work and causing personal injury, ruined work, a broken drill, or a combination

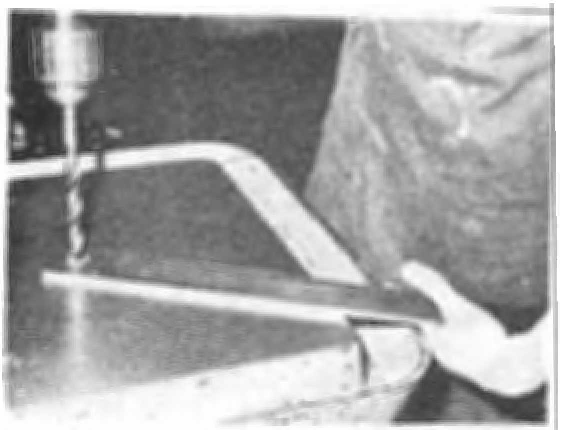


Fig. 2–24. Holding job in hand while drilling is dangerous and may be painful.

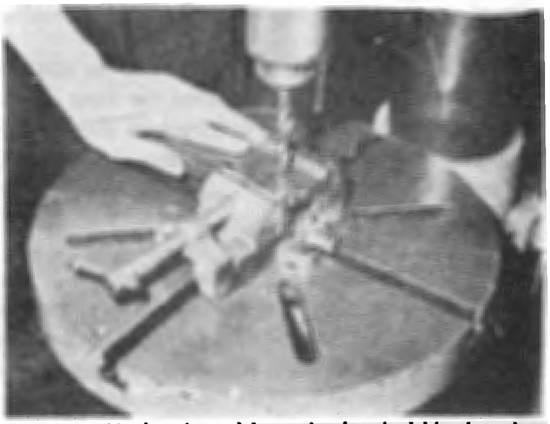


Fig. 2–26. Work gripped in a vise but held by hand is a dangerous practice.

Fig. 2–25. Vise holding the job is bolted to the machine table.

Fig. 2–27. The moving drill can twist the unbolted vise from the operator's hand.

of the three. Never try to hold the work by hand as shown in Fig. 2–26.

33. *How should the vise be set on the machine table when it is not possible to secure it by bolts?* If the vise is held by hand (Fig. 2–27), the force of the moving drill can twist it from the operator's grasp. The vise should be given support by being placed firmly against the column of the machine so that the direction of rotation forces the vise against the column (Fig. 2–28).

34. *Why should the drill press operator keep his hair cut short, or wear a cap?* To prevent stray strands of hair from being caught in the fast-moving belts or the revolving drill spindle (Fig. 2–29).

35. *Why is proper dress so important to the safety of the drill press operator?*

Fig. 2-28. The vise prevented from twisting by the column of the machine.

Fig. 2-29. Long and uncovered hair can easily become entangled with the drill spindle.

Many accidents have been caused by long sleeves, dangling neckties, and untied aprons. It is safer to roll the sleeves above the elbow, remove the necktie, and keep apron strings tightly tied at the back. Do not wear rings or a wristwatch.

36. *How can a dull drill cause an accident?*
A dull drill will not cut, but the inexperienced operator will increase the pressure of the feed, hoping to force the drill into the work. The drill will break, and the flying pieces cause painful injuries.

37. *What is the safest thing to do if the drill digs in and the job is whirled from its fastenings?*
Shut off the power immediately. When all movement has stopped, turn the drill back (reverse) by hand.

38. *Why is it important to make sure that the quick-return lever is firmly locked in place?*
An insecurely locked quick-return lever can fall heavily on the operator's head causing painful injury (Fig. 2–30).

39. *What is the correct tool to use in order to release a taper shank drill from the drilling machine spindle?*
Remove the taper shank drill or taper sleeve with the drill drift. Many injuries are caused when makeshift tools are used. *Do not use drift punches, files, or wedges.* By doing so, the drill, socket, or sleeve may become permanently disfigured. Also, the tang of a file can break and cause injuries.

40. *What are the most important rules for safe operation of the drill press?*
Follow these safe drilling practices:

A. Think about what you are doing. Keep your mind on the job.
B. Dress safely. Remove rings, watches, identification bracelets, and neckties. Roll up sleeves.
C. Fasten the job or vise securely to the table.
D. Remove tools, clamps, wrenches, and so forth from the table before starting the drill.
E. Remove drill drift from spindle or chuck key from the drill chuck immediately after use.
F. When the drill becomes dull, resharpen it or replace it.

G. Grind the drill correctly for the metal it is required to cut.
H. As the drill breaks through the work, relieve the down-feed pressure.
I. Stop the machine before measuring or adjusting the job.
J. Stop the machine before using a brush to remove chips and excess coolant.

41. *What is the safe way of forcing the taper shank drill into the spindle?*
First clean the shank of the drill and the tapered hole in the spindle. Use a cloth, not fingers. After making certain that the tang of the drill is correctly aligned, jam the drill into the spindle. *Never* drive the drill with a hammer because both hammerhead and drill are hardened; the cutting point will be dulled and hard steel splinters may fly.

SAFETY ON THE LATHE

42. *Why should the lathe be stopped before making adjustments to the toolholder?*

Fig. 2–30. The unlocked, quick-acting lever can fall heavily on the operator.

When the tool-post screw is loosened, the wrench may swing into the revolving chuck jaws. The sharp blow would break the tool-post screw, causing it to fly and thus endangering the operator and nearby workers. There is also a danger of the operator's hand being caught between the tool-post wrench and the revolving chuck jaws.

43. *How should the chips from the lathe be prevented from winding around the job?*
A short piece of wood may be used to push the winding chip down into the lathe pan. The chip will break and remain in the pan. Accumulated chips should be swept up into a disposal can (Fig. 2–31). Lathe chips should never be touched by hand (Fig. 2–32).

Fig. 2–31. Pushing the chips away with a short piece of wood will cause them to break off without danger of burns or cuts.

Fig. 2–32. A lathe chip is both hot and sharp and should never be touched by hand.

44. *Why is it considered dangerous to permit a large accumulation of chips in the lathe pan?*
A long chip may begin to wind around the revolving job. Such a chip will carry the chips from the lathe pan with it. Even if the winding chips do not injure the machinist who is operating the lathe, they can spoil the job (Fig. 2–33).

45. *Is it good practice to clean the chips away from the knurling tool while it is in operation?*
Yes. It is bad practice to stop the lathe before the required length of knurl is completed. One pass knurling results in many chips accumulating on the surface of the job; remove them carefully with a brush (Fig. 2–34)—*never with cotton waste or cloth* (Fig. 2–35).

46. *Why is it unsafe to permit the chips to collect when turning magnesium?*

Fig. 2–33. This happens when the chips are allowed to accumulate in the lathe pan.

The slightest spark can ignite magnesium into a fire with tremendous heat. Friction from a rubbing (rather than cutting) tool bit can cause this; therefore, when chips collect around the job, or in the chip pan (Fig. 2–36), there is a greater danger of fire.

Fig. 2–34. Use a brush to remove the chips resulting from a knurling operation.

Fig. 2–35. Do not use cotton waste on a revolving job.

Fig. 2–36. Do not let chips collect arcund the job.

Fig. 2–37. Keep the job and chip pan free from chips by periodic cleanup.

Stop the lathe at short intervals and clean out the chips whenever magnesium is the metal being machined (Fig. 2–37).

47. *How can wearing jewelry create safety hazards for the lathe operator?*
Loose-fitting jewelry, such as an identification bracelet, or an article raised above the skin surface, such as a ring, can easily be caught on a revolving machine part which would drag a hand or arm into the moving machinery, causing serious injury (Fig. 2–38).

48. *Can lifting a lathe chuck onto the spindle cause an accident?*
Yes. Lifting a weight at an unusual angle often causes painful back dislocations (Fig. 2–39).

Fig. 2–38. Wearing jewelry around machinery creates hazards to safety.

Fig. 2–39. Lifting a heavy weight at an unusual angle can cause painful back dislocations.

49. *What is the best means of supporting the chuck when mounting it onto the lathe spindle?*
A wooden board fashioned correctly to clear the ways at the correct height and formed to the shape of the chuck will make mounting the chuck a safe operation (Fig. 2–40).

50. *What point of safety does the machinist stress when he says, "Never let go of the chuck key"?*

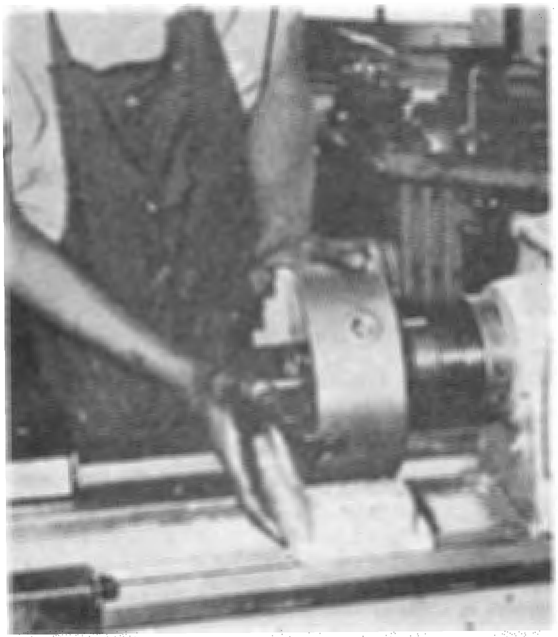


Fig. 2–40. Mounting the chuck with the aid of a specially shaped wooden block.

If the machinist is trying to think three moves ahead, he will not concentrate on the present. He may leave the chuck key in the chuck (Fig. 2–41). Later he may start the lathe without noticing the key in the chuck and serious injury may result (Fig. 2–42).

51. *How can the machinist avoid possible injury from a flying chuck key?*

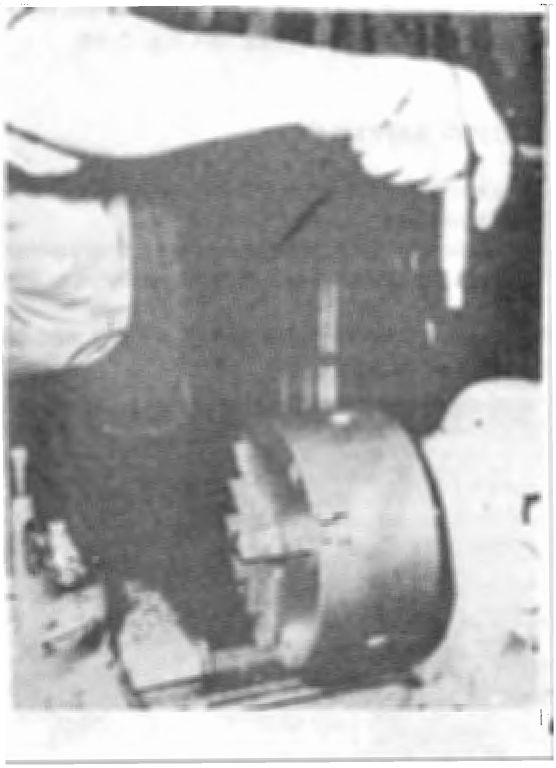
Fig. 2–41. Leaving the chuck key in the chuck leads to trouble.

Fig. 2–42. Starting the lathe without removing the chuck key leads to this.

By following the rule of the old slogan: "Never let go of the chuck key" until it is put in its proper place (Fig. 2–43).

52. *When must care be used in clamping the tool-holder in the tool post?*
When facing or turning work close to the chuck.

Fig. 2–43. Do not allow the chuck key to leave your hand until it is in its proper place.



53. *What procedure should be followed in clamping the toolholder in the tool post when working close to the chuck?*
The tool post should be positioned at the left side of the tool-post slide (Fig. 2–44). If the tool post is clamped at the right side of the slide, the jaws may strike the edge of the compound rest, resulting in chips, sparks, and the possibility of a broken lathe. Most engine lathes show the scars left by careless workers (Fig. 2–45).

54. *Is parting-off a more dangerous operation than any of the other lathe procedures?*
No, there are no dangerous lathe operations provided care is used in the setup and proper trade practices are utilized. Figure 2–46 shows a poor setup, which could result in an accident. Long, slender work will bend from the pressure of the parting tool and spring out from between the centers.

55. *Should the cutting tool be removed before checking a bored hole with a plug gage or with a tapered plug gage if the hole is tapered?*
If the carriage cannot be moved out of the way, the safest way is to remove both tool and toolholder (Fig. 2–47). Many machinists have suffered painful cuts when the plug gage released suddenly and their hands hit the exposed cutting tool (Fig. 2–48).

MILLING SAFETY

56. *Does it save time or is it safer to handle heavy milling machine attachments alone?*
To handle heavy equipment alone is not time saving. To do so increases the possibility of accident to the

Fig. 2–44. Clamp the tool post at the left side of [illegible]

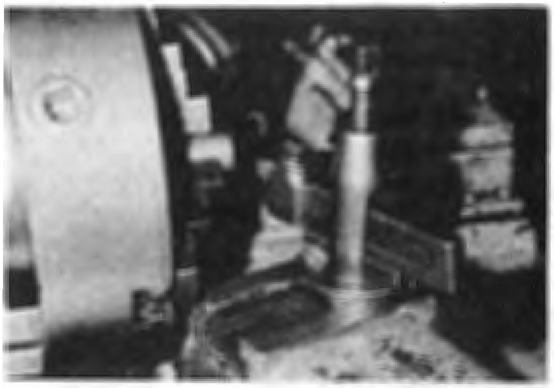


Fig. 2–45. Note the broken corner of the tool-post slide—a result of the tool post having been incorrectly clamped to the right side of the tool-post slide.

Fig 2–46. Parting long, slender work between centers is a dangerous practice.

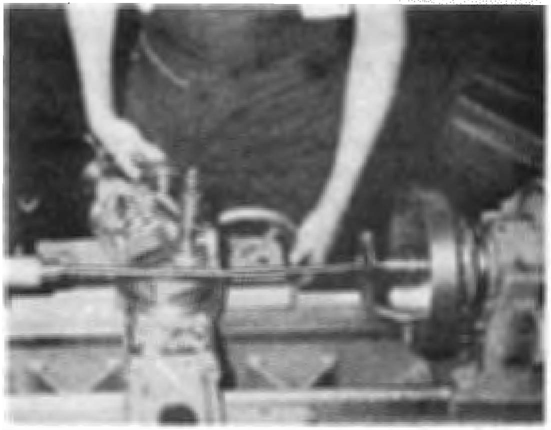


Fig. 2–47. The cutting tool should be removed before checking bored holes with a plug gage.

Fig. 2–48. The exposed tool bit is a danger when using a plug gage (or taper plug gage) to test a bored hole.

Fig. 2–49. Handling heavy equipment alone causes accidents.

workman and damage to the machine equipment (Fig. 2–49). When two people lift a piece of heavy equipment, there is less chance of damaging either the attachment or the finished surfaces of the machine table (Fig. 2–50).

57. *How should milling cutters be handled?*
Milling cutters have sharp cutting edges and should be handled carefully. They should be held in a piece of cloth to prevent injury to the operator and to the cutting edges (Fig. 2–51).

Fig. 2–50. Two people can handle heavy equipment with greater ease and safety.

Fig. 2–51. Handle sharp cutters with care and a cloth.

58. *Why do careful milling machine operators place their tools on a board or piece of cloth?*
Milling cutters have sharp edges that should not be chipped or dulled. Placing these tools on a wooden board protects both the cutting edges of the cutter and the surface of the milling machine table. It also helps the operator to keep his tools together and prevents them from sliding around when the machine vibrates (Fig. 2-52).

Fig. 2-52. A safe practice: placing the tools on a board or cloth.

Fig. 2-53. The arbor is unsupported and the man is strong; the arbor will bend.

59. *What common mistake is often made when tightening the milling cutter on the arbor?*
A common mistake is to attempt to tighten the arbor nut *before* placing the overarm in position (Fig. 2-53).

60. *What will result if this common mistake is made?*
The arbor will be bent and the operator may be injured as the wrench slides off the arbor nut. Always place the overarm bracket in position and clamp it to the overarm before tightening the arbor nut (Fig. 2-54).

61. *Can the arbor nut be tightened by engaging the clutch and using the motor-driven power?*
Power should never be turned on to tighten the arbor nut. Always stop the motor; then engage the clutch, and when the arbor is absolutely stationary, tighten the arbor nut.

62. *Is there a safe side and an unsafe side of a milling machine when the cutter is revolving?*
The milling machine operator should not stand on the side that the cutter is entering the work (Fig. 2-55). The revolving cutter can drag the brush or anything else that gets near enough into the work. The operator should always stand on the going-away side of the cutter (Fig. 2-56).

63. *Why do milling machine safety rules emphasize the importance of keeping away from the cutter?*
There is a tendency for the new operator to get too close to the place where the cutter is removing metal (Fig. 2-57). This makes it possible for the flying chips to cut the operator's face. Also, fumes and spray from the soluble coolant oils may cause infection.

64. *What rules, if followed, will assure the safe operation of a milling machine?*
Observe these safe milling practices:

A. Be sure that you are aware of the function of every operating control. Don't push a button, move a handle, or engage a clutch unless you are sure of the machine action which will occur when you do so.
B. Be sure that everything is secure before turning on the power. Check the cutter, the bolts holding a vise, or any attachments.

Fig. 2–54. The arbor support is now in place and the arbor will not bend.

Fig. 2–55. This operator is standing on the wrong side of the cutter.

Fig. 2–57. The new operator gets too close to the cutter.

Check the job in the vise or chuck for tightness.

C. Check the safe clearance of job, cutter, arbor, overarm brackets, vise, or index head before turning on the power.
D. Check setting of speed and feed before turning on the power.
E. Do not lean on the machine; stand upright.
F. Keep your head out of the direct line of the cutter.
G. Stay on the going-away side of the cutter.
H. Remove chips with a brush.
I. Keep cotton waste and rags away from any part of a milling machine while it is in operation.
J. Stop the machine *before* measuring the job, feeling the surface of the finished cut, tightening a bolt, changing the speed, or reversing the feed.

SHAPER SAFETY

65. *What part of the shaper operator's body is most frequently injured?*
Most accidents happen to the operator's hands. Fingers are caught between the cutting tool and the work. It is dangerous to attempt to remove chips by hand (Fig. 2–58). Wait until the cutting tool is on the return stroke; then brush the chips away (Fig. 2–59).

Fig. 2–56. The operator is now standing on the safe side of the cutter, the going-away side.

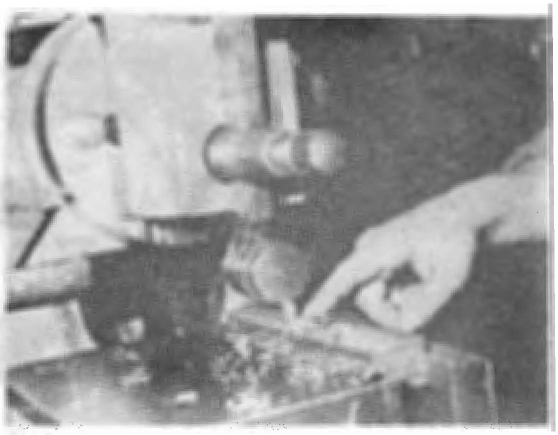


Fig. 2–58. This is the wrong way to remove chips from a shaper tool.

Fig. 2–59. Remove the chips with a brush on the return stroke of the ram.

66. *Why should the operator of the shaping machine wear safety glasses?*
The chips released by the shaper cutting tool seem to fly with extra force. That is why not only the shaper operator, but all those near the shaper should protect their eyes with safety glasses (Fig. 2–60).

67. *Many accidents occur when shaping jobs require the tool slide to be set off from its vertical position. How can an accident be prevented in this circumstance?*
When the tool slide is set off at an angle, some part of the slide may strike the column of the machine (Fig. 2–61). Operate the ram through one complete cycle slowly by hand while closely observing if all parts of the tool slide are clear of the column. In order to do this, the operator should stand at the front of the machine, observing all possible danger spots (Fig. 2–62).

68. *Why should the speed and length of the stroke be checked before starting the machine?*
If the longest stroke is operated at the highest speed, the mechanism of the machine can become damaged. Always check speed and stroke before engaging the clutch.

69. *What should be done directly after the depth of cut is set?*
In order to prevent the tool slide from changing its position because of vibration, tighten the clamping screw. Otherwise, the tool will dig into the work (Fig. 2–63).

Fig. 2–60. Safety glasses should be worn by all those near a shaping machine.

SAFETY ON THE GRINDING MACHINE

70. *Are grinding machines more dangerous than other machines?*
No; all machines are dangerous if used improperly. If the grinding machine operator follows certain rules, accidents will be avoided.

71. *What are the principal safety rules that the grinding machine operator must follow?*
Follow these safe grinding practices:

A. Safety goggles must be worn at all times.

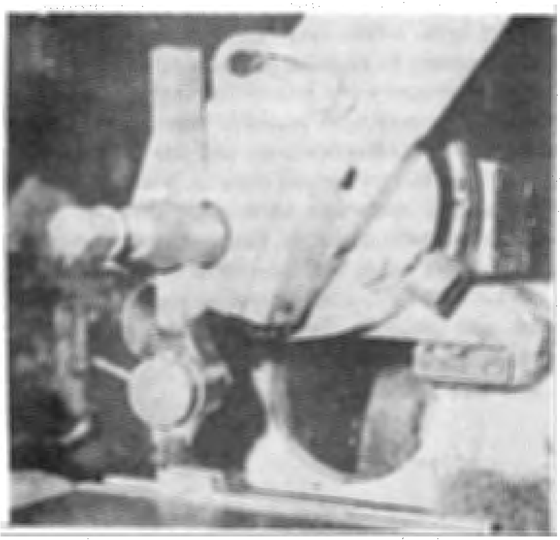
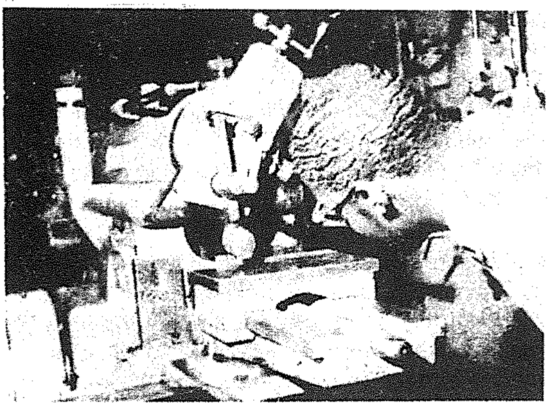


Fig. 2–61. Now that the tool slide has been offset, the clamping screw will not clear the machine column.

Fig. 2–62. Checking for toolhead clearance before starting the machine.



B. Test the soundness of the grinding wheel and inspect it for cracks before mounting it on the machine spindle.
C. Check the wheel bushing and the machine spindle for size identification. The bushing must neither extend beyond the width of the wheel nor bind tightly on the spindle.
D. Wheel blotters must be fitted between the wheel and the flanges. The blotters must be the same diameter as the flanges, never less.

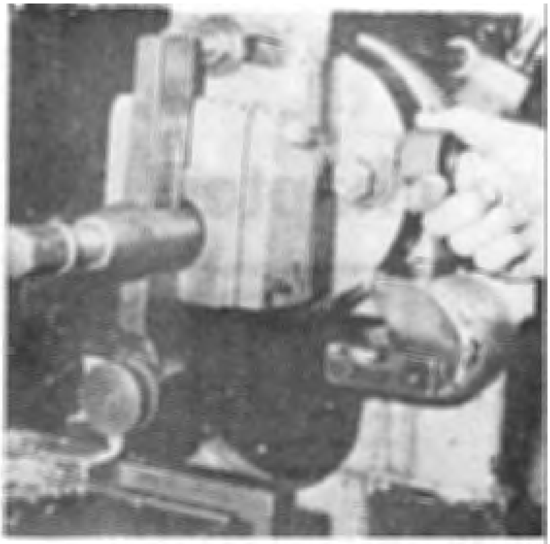


Fig. 2–63. After setting the depth of the cut, clamp the tool slide to prevent movement caused by vibration.

E. Check the operating speed of the machine and compare it with the wheel manufacturer's recommendations.
F. See that all guards and protective hoods are in place and tightly secured before starting the machine. Turn wheel over by hand to check clearance.
G. Check to make sure that the wheel is clear of the work and that the feed is disengaged before starting the machine.
H. Make certain that small work is securely nested and the nest is blocked on two sides.
I. Do not start an unguarded machine. Using unguarded machines can lead to eye injuries or other serious injuries.
J. Before starting *any* grinding wheel stand to one side; allow the wheel to run full speed for one full minute to insure that it is sound.
K. Always feed the work gently and steadily into the revolving grinding wheel.
L. Keep your head out of the line of the sparks.
M. *Never* place your hands near the revolving wheel.
N. Never attempt to remove work, open vise, or shut off magnetic chuck until the wheel clears the job *and has come to a complete stop.*

chapter 3

hand tools for bench work

A machinist must be skilled in the use of the numerous hand tools, which have been designed to make his work easier. In addition to knowing how to use hand tools properly, the machinist must also know the various types of tools available to do a particular job, how to select the best type and size for a given job, and how to care for and store tools when not in use. A skilled craftsman takes great pride in his ability to use tools correctly. Because most of these tools are finely made and expensive the ownership of a good tool kit is a never-ending source of satisfaction and pleasure. This chapter describes and explains many common hand tools used by machinists and tool- and diemakers.

HAMMERS

Hammers were one of man's earliest tools. The types of hammers used by machinists are limited, but they are available in many sizes. Machinist's hammers are classified as hard or soft hammers.

1. *What are hard and soft hammers?*
A hard hammer is one that is made of carbon steel and forged to shape and size. It is heat-treated to make the striking faces hard. A soft hammer (Fig. 3–1) may have the entire head made of a soft metal such as lead, babbitt, copper, or brass. Soft-faced hammers have only their striking surfaces made of plastic, rubber, or rawhide. The faces are either clamped or press fitted on the metal hammerhead (Fig. 3–2).

2. *What are some uses of a hard hammer?*
A hard hammer is used for striking punches, cold chisels, steel letters, and figures. It is also used for forging hot metal, riveting, bending, straightening, peening, stretching, and swaging.

3. *What are some uses of soft hammers?*
Soft hammers are used when striking finished or semifinished workpieces to prevent marring the finished surfaces. For example, soft hammers are commonly used for seating a workpiece in a machine vise or tapping finished work being set up for a machining or layout operation.

4. *Describe the hard hammers most commonly used by machinists and identify their parts. Indicate an important use of each hammer.*

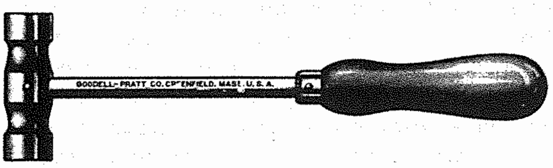
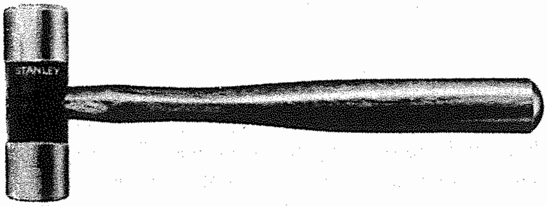


Fig. 3–1. Soft hammer with brass head. (Goodell-Pratt Co.)

Fig. 3–2. Plastic-faced soft hammer. (Stanley Tools.)



The hammers most commonly used by machinists are the ball-peen (Fig. 3–3), the straight-peen (Fig. 3–4), and the cross-peen (Fig. 3–5). The flat face of the ball-peen is used for general work such as striking punches; the rounded (ball) end is used for riveting and peening. The straight-peen, which has a peen-end parallel to the axis of the handle, is used

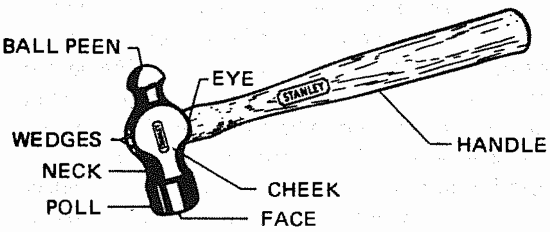
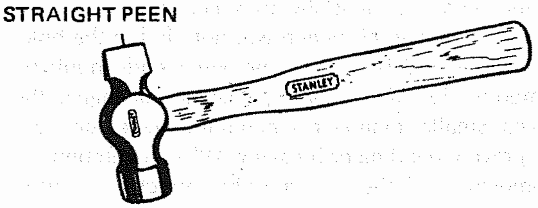


Fig. 3–3. Parts of a ball-peen hammer. (Stanley Tools.)

Fig. 3–4. Straight-peen hammer. (Stanley Tools.)



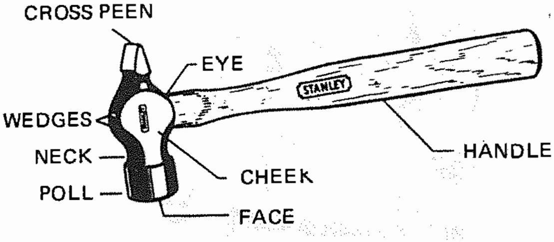


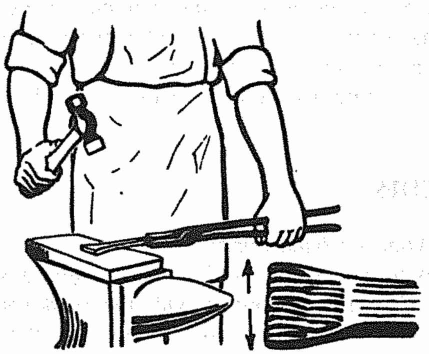
Fig. 3–5. Parts of a cross-peen hammer. (Stanley Tools.)

for stretching and drawing out metal when forging. The cross-peen, which has a peen-end at right angles to the hammer handle, is used for riveting, stretching, and drawing metal (Fig. 3–6).

5. *What is meant by peening, or swaging?* Peening, or swaging, is the stretching or spreading of metal by hammering. Examples of peening include flattening the end of a rivet, spreading babbitt metal to fit tightly in a bearing, and straightening a bar by stretching its short side (Fig. 3–7).

6. *Why should a hammer handle be gripped near the end?* A hammer handle should be gripped near the end so that full leverage may be obtained when swinging the hammer. A solid blow is difficult to deliver when the handle is gripped too close to the head of the hammer (Fig. 3–8). The amount of force with which the hammer strikes depends, in part, on the length of the handle and the weight of the head. To get the most advantage of the handle's length it should be held as far from the head as possible.

Fig. 3–6. Stretching a piece of stock in the direction of its width, using a cross-peen hammer. (Stanley Tools.)



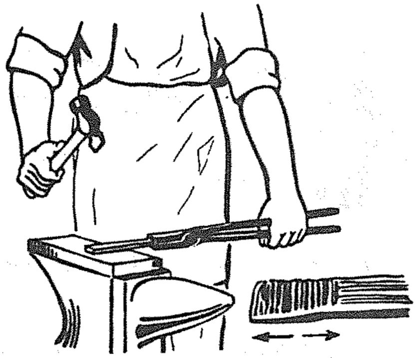
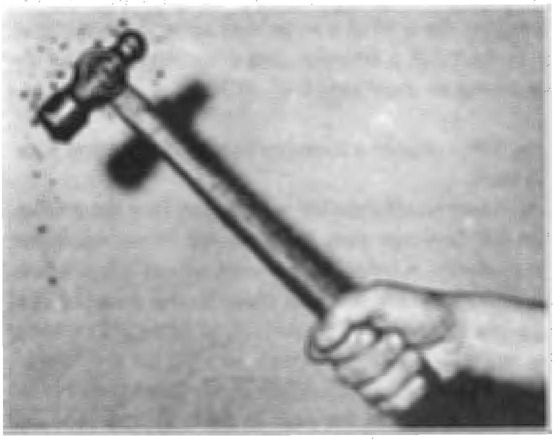


Fig. 3–7. **Stretching a piece of stock in the direction of its length, using a straight-peen hammer. (Stanley Tools.)**

Fig. 3–8. Correct way to hold a hammer.



7. *How is the size of hammers specified?*
The size of a hard hammer is specified by the weight of the head without the handle. Ball-peen hammer sizes range from 2 oz to 3 lb. Sizes of soft-faced hammers are specified by the diameter of the face and the length of the head and range from ⅝-in. diameter to 3-in. diameter. Faces are specified in degrees of hardness from supersoft to extra hard.

PUNCHES

8. *What is a hand punch?*
A hand punch is a tool held by hand against a workpiece. The end in contact with the workpiece is shaped to do a particular job, whereas the other end is flat so that it could be struck easily by a hammer. Punches come in many sizes and shapes to do a variety of jobs. Although most punches are made of hardened and tempered tool steel for greater strength and longer wear, it is sometimes necessary to use punches made of a soft metal such as brass to prevent damage to parts being assembled or disassembled.

9. *Name the different types of punches commonly used by the machinist.*
The punches used most often by the machinist are the drift punch, pin punch, prick punch, center punch, and automatic center punch.

10. *What is a drift punch?*
A drift punch (Fig 3–9) is a long, tapered punch used for loosening straight pins, taper pins, rivets, and other small parts being disassembled. The gradual, uniform taper end provides strength needed to withstand the powerful impact of the punch against the pins or parts being loosened.

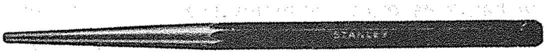


Fig. 3–9. Drift punch. (Stanley Tools.)

11. *How should a drift punch be used?*
The diameter at the small end should be slightly smaller than the diameter of the part to be knocked loose. The punch end should be located squarely on the part and held firmly against the part. The head of the punch should then be struck squarely, using a quick sharp blow with a hard hammer. Once the part has been loosened, the drift punch should not be used because the tapered end will become wedged in the hole. A drive-pin punch should be used to drive the pin through the hole.

12. *What are drive-pin punches and how should they be used?*
Drive-pin punches (Fig. 3–10) are used to set in place or remove straight and taper pins and some types of small parts requiring a drive fit. The diameters of the punch ends are made slightly smaller than the nominal size so that the punch will not bind in the hole. For use on precision parts, the punch ends should be smooth, flat, and square, to avoid damaging the parts. Smaller diameter punches require greater care to prevent bending or breaking. When assembling or removing pins, the work must be correctly supported

as in a V block. To install a taper pin, a punch slightly larger in diameter than the large diameter of the pin is used (Fig. 3–11). To remove a pin, it is better to hit the punch with a quick sharp blow of the hammer than to hit it a number of light taps because this will mushroom the pin, making it difficult to remove (Fig. 3–12).

13. *What is a prick punch?*
A prick punch (Fig. 3–13) is made of hardened tool steel and ground to a slender point having a 30° to 60° included angle (Fig. 3–14). It is used to mark lightly or indent the intersections of layout lines, to locate hole centers, and to provide a small center mark for divider points when laying out circles or spacing dimensions. A lightly made prick-punch mark can be moved to correct an error by tilting the punch and striking it with the hammer.

Fig. 3–10. A set of drive-pin punches. (Lufkin Rule Co.)

14. *What is a center punch?*
A center punch (Fig. 3–15) is similar to a prick punch in appearance except for the point, which is ground to a 90° included angle (Fig. 3–16). The center punch is used to enlarge a prick-punch mark so a drill can be started in the exact location. A center-punch mark is deeper and larger than a prick-punch mark. When used correctly, the point of the center punch is

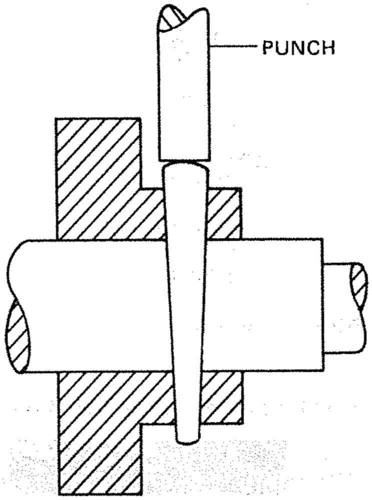


Fig. 3–11. Setting a taper pin, using a drive-pin punch.

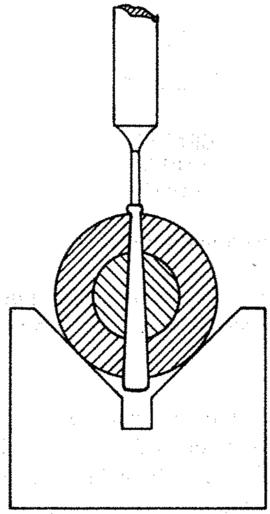


Fig. 3–12. Too much hammering can mushroom the end of a pin.

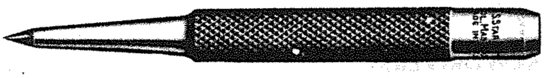


Fig. 3–13. A prick punch. (L. S. Starrett Co.)

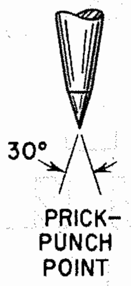
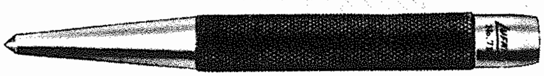


Fig. 3–14. Prick-punch point.

Fig. 3–15. A center punch. (Lufkin Rule Co.)



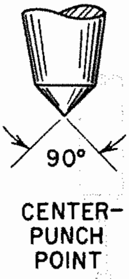


Fig. 3–16. Center-punch point.

placed in the prick-punch mark. The punch, hand held in a vertical position, is struck squarely once with a hammer.

15. *What is an automatic center punch?*
The automatic center punch (Fig. 3–17) makes punch marks of a uniform size without the use of a hammer. The knurled cap may be turned to control the depth of the punch mark. To make a punch mark it is only necessary to locate the punch point and push down. When used with a spacing attachment, this tool can lay out uniformly spaced dimensions rapidly.

SCREWDRIVERS

16. *What is a screwdriver?*
A screwdriver (Fig. 3–18) is a hand tool that is designed to turn screws. The shank is made of steel set into a wooden or plastic handle. The blade is shaped or flattened to fit recesses in the heads of

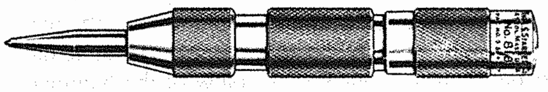


Fig. 3–17. Automatic center punch. (L. S. Starrett Co.)

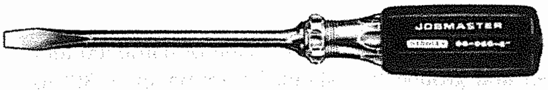


Fig. 3–18. A plain screwdriver. (Stanley Tools.)

screws or bolts. Screwdrivers are made in many sizes. Figure 3–19 shows a set of jewelers' screwdrivers. Figure 3–20 shows the correct way to hold this screwdriver. A stubby screwdriver (Fig. 3–21) helps to start screws where space is limited.

17. *What is a heavy-duty screwdriver?*
A heavy-duty screwdriver (Fig. 3–22) is of average length but is made with a heavy blade and a square shank. The shape of the shank permits the use of a wrench to assist in tightening a screw. Heavy (thick) material is used so that the blade and shank will resist being twisted when a wrench is used.

18. *What is a Phillips screwdriver?*
A Phillips screwdriver (Fig. 3–23) is specially designed to fit the heads of Phillips screws. It differs

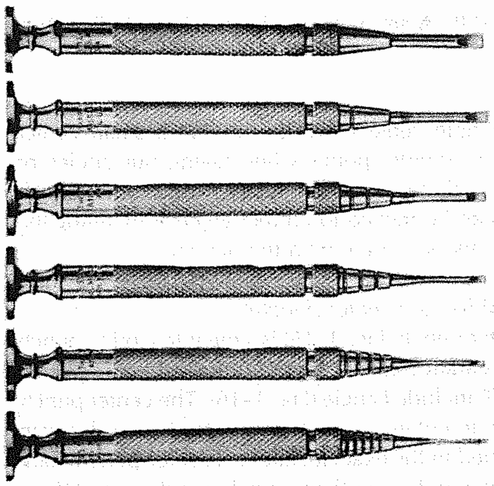


Fig. 3–19. A set of jewelers' screwdrivers. (L. S. Starrett Co.)

Fig. 3-20. Correct way to use a jewelers' screwdriver. (L. S. Starrett Co.)

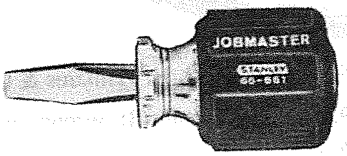


Fig. 3-21. A stubby screwdriver. (Stanley Tools.)

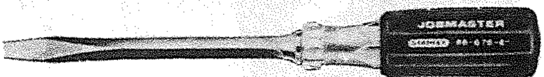


Fig. 3-22. Heavy-duty square-shank screwdriver. (Stanley Tools)

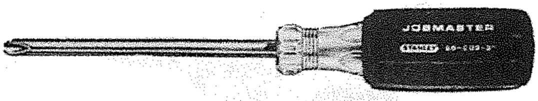


Fig. 3-23. Phillips screwdriver with No. 2 point. (Stanley Tools.)

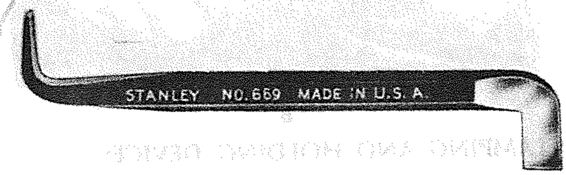


Fig. 3-24. Double-ended offset screwdriver. (Stanley Tools.)

from other screwdrivers in that the end of the blade is fluted instead of flattened. It is made in several sizes. Each size is numbered and relates the diameter of the blade with the point number. For example, a No. 2 point has a ¼-in.-diameter shank.

19. *What is the purpose of a double-ended offset screwdriver?*
A double-ended offset screwdriver (Fig. 3-24) is used for turning screws in awkward places where there is not enough room to use a regular screwdriver.

20. *How should the blade of a worn screwdriver be ground?*
A screwdriver blade should be ground so that the faces will be almost parallel with the sides of the screw slot as in Fig. 3-25. The end of the blade should be made as thick as the slot in the screw will permit. A blade ground to a chisel point has a tendency to slip out of the screw slot and, also, to leave a ragged edge on the slot.

Excessive heat at the time of grinding, indicated by a blue color appearing on the blade, will draw the temper of the steel and cause the blade to become soft. This will result in the end of the blade being bent out of shape when a heavy pressure is applied to tighten a screw.

When reconditioning a screwdriver blade, grind the end of the tip first to square it with the shank. Next, grind the blade to the thickness required by holding it on the grinding wheel, as shown in Fig. 3-25. Usually, the radius of the grinding wheel will produce a satisfactory end on the blade.

PLIERS

21. *What are pliers?*
The word *pliers* is a plural name for a single tool. Pliers are made in many styles and are used to perform as many different operations. Figure 3-26 shows the common slip-joint (or combination) pliers. They are used for holding and gripping small articles in situations where it may be inconvenient or unsafe to use hands. It is not good practice to use pliers in place of a wrench.

22. *What are long-nose pliers?*
Long-nose pliers (Fig. 3-27) are made, as the name implies, with a long tapering nose, or jaws. This tool

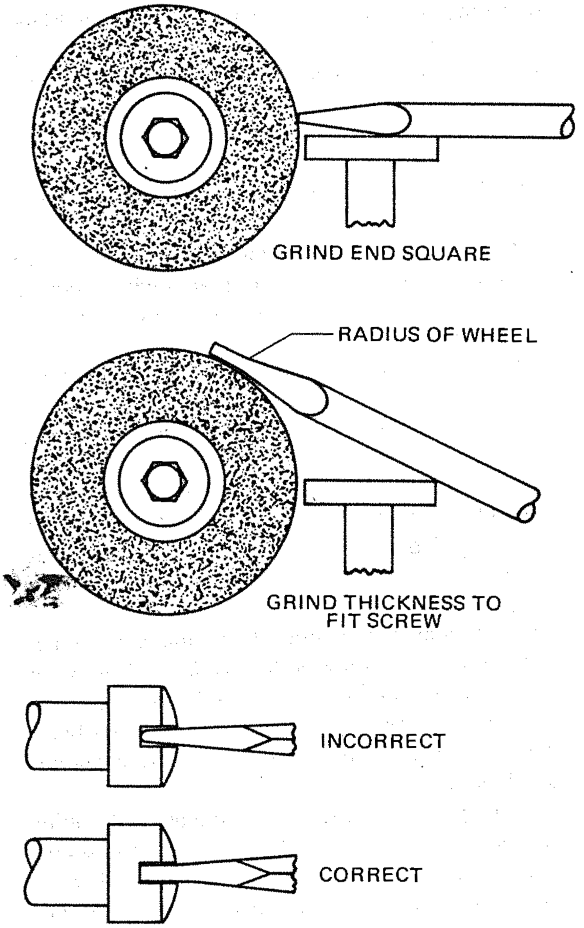
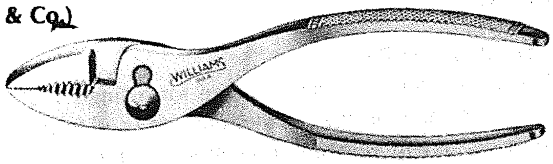


Fig. 3–25. Method of grinding a screwdriver blade to fit a screw slot.

Fig. 3–26. Combination pliers. (J. H. Williams & Co.)



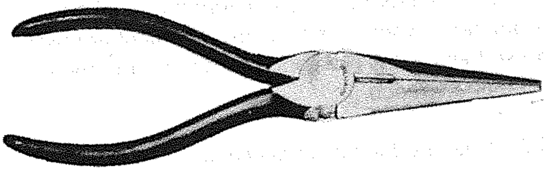


Fig. 3–27. Long-nose pliers. (J. H. Williams & Co.)

can be used for placing and removing small items in narrow spaces. It is also preferred for electrical and radio repair work.

23. *What are diagonals?*
Diagonals (Fig. 3–28) are a special type of pliers used exclusively for cutting and stripping electrical wire. When cutting wire, hold the diagonals as shown in Fig. 3–29A. An operator using diagonals as shown in Fig. 3-29B may be injured. Diagonals should never be used to cut steel wire or rods or in place of snips to cut or notch sheet metal. Such use will destroy the cutting edge and damage the tool's joint.

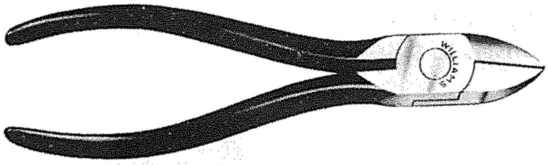


Fig. 3–28. Diagonals. (J. H. Williams & Co.)

Fig. 3–29. (A) Right and (B) wrong way to use diagonals.

CLAMPING AND HOLDING DEVICES

Many devices have been designed to hold work securely while it is being measured or machined.

Some of them are for one specific piece of work; others are of a more general nature. These include many types of clamps and vises.

24. *What is a C clamp?*
A C clamp (Fig. 3–30) is an all-purpose clamp, made in the shape of the letter C. In general use for all kinds of work, it is made in many sizes.

25. *What is a toolmakers' clamp?*
A toolmakers' clamp (Fig. 3–31) consists of two flat steel jaws, which may be adjusted to fit a piece of work by means of a screw passing through the center of each jaw. Another screw in the end of one jaw is used to exert pressure on the other jaw. This pressure tightens the opposite ends of the jaws. It is used by toolmakers for holding small parts both at the bench and at machines. This tool is also known as a *parallel clamp*. Care must be taken to keep the jaws in a parallel position. Otherwise the clamp screws may seem to be tight but will not be holding the work tightly because they are just being tightened one against the other. (Fig. 3–32)

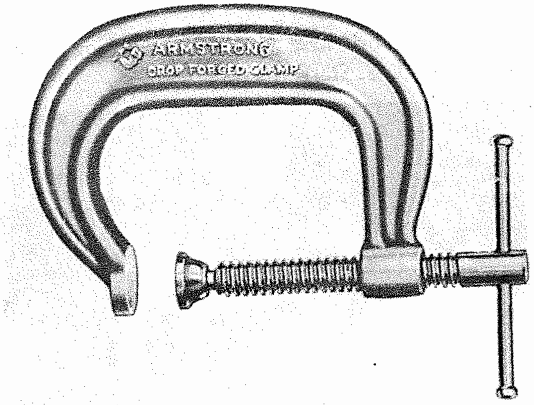


Fig. 3–30. C clamp. (Armstrong Bros. Tool Co.)

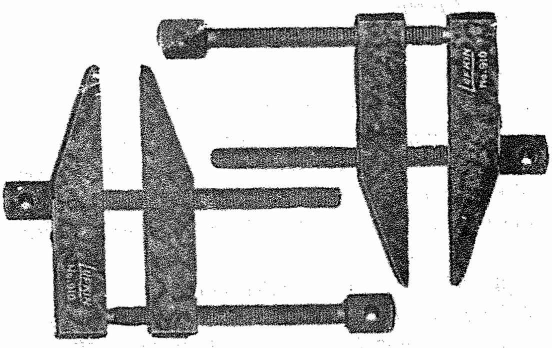


Fig. 3–31. Toolmakers' parallel clamps. (Lufkin Rule Co.)

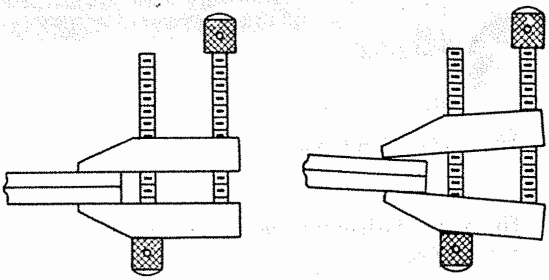


Fig. 3–32. Right and wrong way to use toolmakers' parallel clamps.

26. *What is a toolmakers' hand vise?*
A toolmakers' hand vise (Fig. 3–33) is a small steel vise with two interchangeable blocks. The choice of block to be used depends on the size of the article to be held by the vise. It is used by toolmakers at the bench for small machining operations such as drilling or tapping. Another type of hand vise is shown in Fig. 3–34.

27 *What is a bench vise?*
A bench vise, usually swivel-based as in Fig. 3–35, is the kind most favored for general shop work. It is securely fastened to the bench with bolts. The faces of the jaws are usually lightly serrated and hardened to ensure a firm grip on the work. Finished surfaces should be protected when placed in the vise by using brass or copper jaw caps, as in Fig. 3–36. Tightening the vise by hammering on the handle is poor practice.

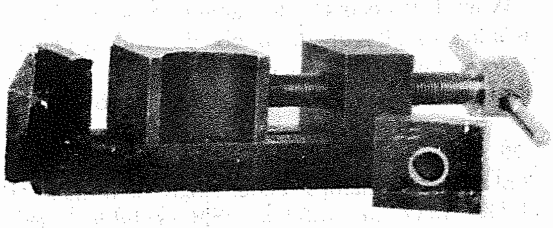


Fig. 3–33. Toolmakers' hand vise. (Brown & Sharpe Mfg. Co.)

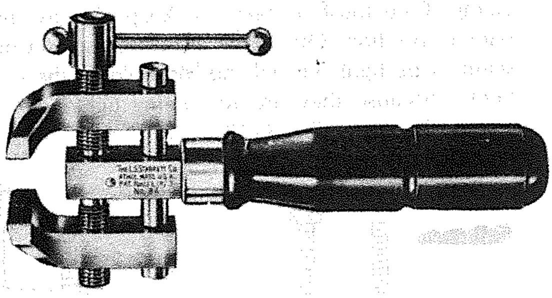
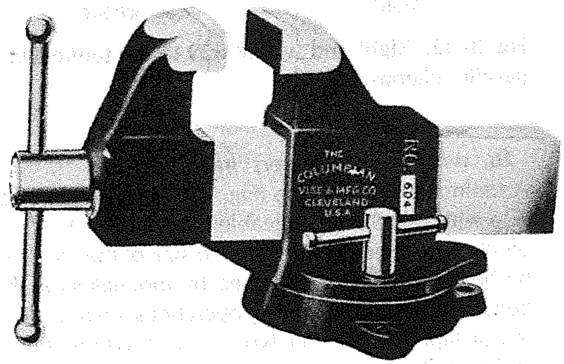


Fig. 3–34. Combination vise. (L. S. Starrett Co.)

Fig. 3–35. Swivel-type bench vise. (Columbian Vise & Mfg. Co.)



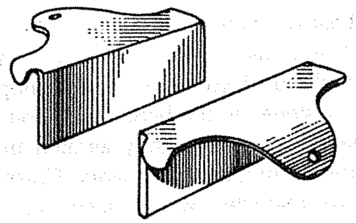


Fig. 3–36. Protective jaw caps for vise. (Columbian Vise & Mfg. Co.)

When it is necessary to hammer a piece of work held in a vise, it is best to support the work by placing a block of wood or metal under it to prevent the work from being driven down through the jaws of the vise.

28. *What are V-blocks with clamps used for?*
V-blocks with clamps, either singly or in pairs, as in Fig. 3–37, are used to hold cylindrical work securely during the laying out of measurements or for machine operations (Fig. 3–38).

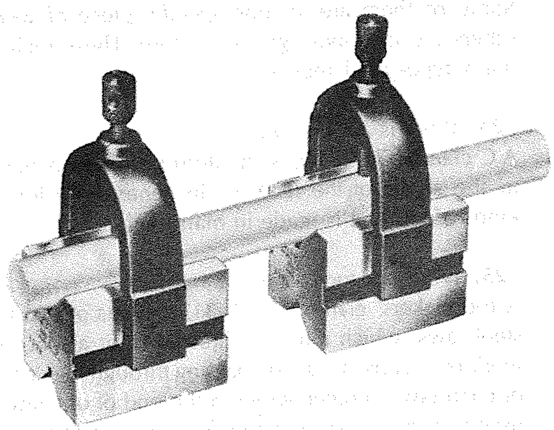
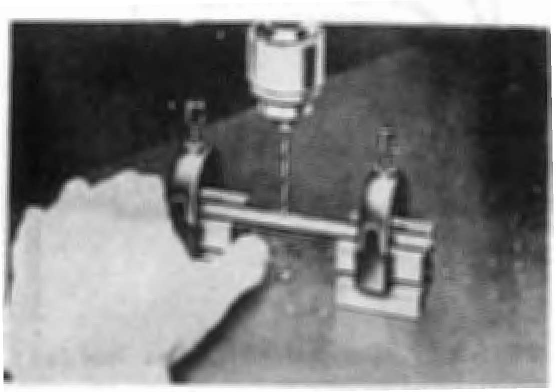


Fig. 3–37. Work held in V-blocks for layout. (L. S. Starrett Co.)

Fig. 3–38. Work held in V-blocks during drilling operation. (L. S. Starrett Co.)



WRENCHES

29. *What is a wrench?*
A wrench is a tool for turning nuts or bolts. It is usually made of steel. There are many kinds of wrenches. They may consist of a slot, socket, pins, or movable jaws for grasping the nut, with the rest of the tool serving as a handle for applying pressure

30. *What is a single-ended wrench?*
A single-ended wrench (Fig. 3–39) is one that is made to fit one size of nut or bolt. This is the most inexpensive type of wrench and is quite efficient in ordinary situations.

31. *What is a double-ended wrench?*
A double-ended wrench (Fig. 3–40) has two openings, one at each end of the handle, to fit two different sizes of nuts or bolt heads.

32. *What is a closed-end wrench?*
A closed-end wrench (Fig. 3–41) is similar to a single-ended wrench, but, because it entirely encloses a nut, there is little danger of the wrench slipping off the nut or of the jaws spreading apart. For these reasons, it is preferred for some jobs. It is also known as a *box wrench*.

33. *What is an adjustable wrench?*
An adjustable wrench (Fig. 3–42) has a movable jaw, which makes it adjustable to various sizes of nuts. A heavy type of adjustable wrench is the monkey wrench shown in Fig. 3–43. When using this type of tool, point the jaws in the direction of the force applied. This will prevent the jaws from springing apart, and the wrench will be less likely to slip off a nut. The movable jaw should be adjusted so that it is tight against a flat surface of the part to be turned. It is not good practice to use a wrench as a hammer. Figure 3–44 shows the right and wrong way to use adjustable wrenches.

Fig. 3–39. Single-ended wrench. (J. H. Williams & Co.)

Fig. 3–40. Double-ended wrench. (J. H. Williams & Co.)

Fig. 3–41. Closed-end, or box, wrench. (Billings & Spencer Co.)

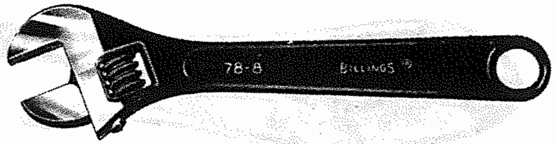
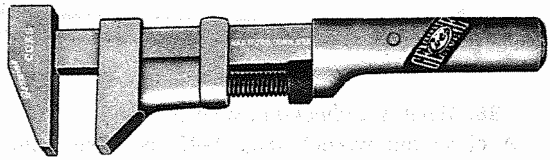


Fig. 3–42. Adjustable wrench. (Billings & Spencer Co.)

Fig. 3–43. Monkey wrench. (Billings & Spencer Co.)



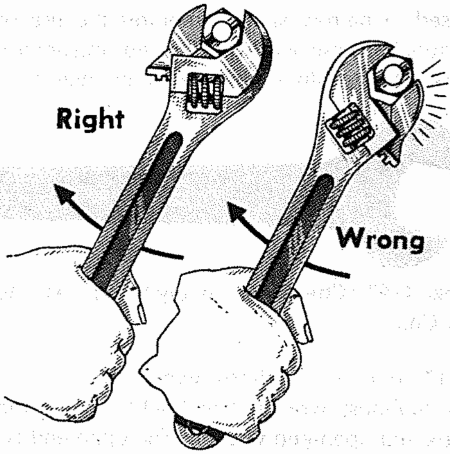


Fig. 3–44. Right and wrong way to use an adjustable wrench.

34. *What is a lever-jaw wrench?*
A lever-jaw wrench (Fig. 3–45) is a combination gripping tool with adjustable jaws, which may be locked in place. It may be used as a wrench, clamp, pliers, or vise.

35. *What is a combination wrench?*
A combination wrench (Fig. 3–46) has two types of openings of the same size. One end has a box type opening with the opposite end designed as an open end. It is a very practical wrench because it can be used in places where the space for movement is limited; if one end will not work conveniently, the other end will.

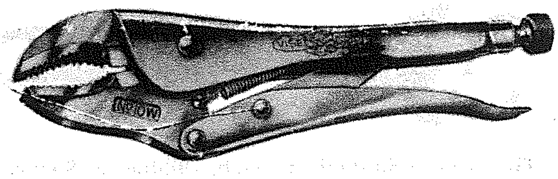
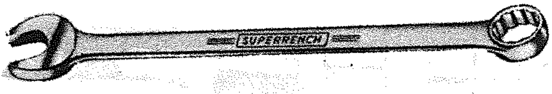


Fig. 3–45. Lever-jaw wrench. (Peterson Mfg. Co.)

Fig. 3–46. Combination wrench. (J. H. Williams & Co.)



36. *What is a check-nut wrench?*
A check-nut wrench (Fig. 3–47) is a thin, single-ended or double-ended wrench used for turning check or jam nuts. The thinness of these nuts, often used in narrow spaces, requires the use of a thin wrench. These wrenches are not intended for hard use. The openings are offset at an angle of 15°.

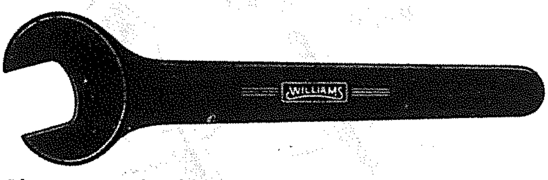


Fig. 3–47. Check-nut wrench. (J. H. Williams & Co.)

37. *What is a tool-post wrench?*
A tool-post wrench (Fig. 3–48) is a combination box and open-end wrench. The open end is straight rather than offset. The square box end is designed to fit tool-post screws and setscrews on lathes and other machine tools. It is ruggedly designed to withstand wear and hard use.

38. *What is a square box wrench?*
A square box wrench (Fig. 3–49) is a single-head closed-end wrench having a rather short handle. It is widely used for square-head setscrews on tool-holders for the lathe and other machine tools. The square opening is made at an angle of 22½° for convenience.

39. *What is a T-handle tap wrench?*
A T-handle tap wrench (sometimes called a *T-tap wrench*) is used to hold and turn small taps up to about ½ in. (Fig. 3–50). It usually has two inserted jaws, which can be adjusted to fit the square end of

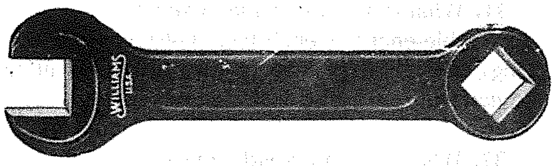


Fig. 3–48. Tool-post wrench. (J. H. Williams & Co.)

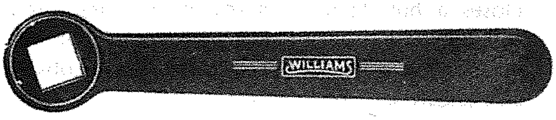


Fig. 3–49. Square box wrench. (J. H. Williams & Co.)

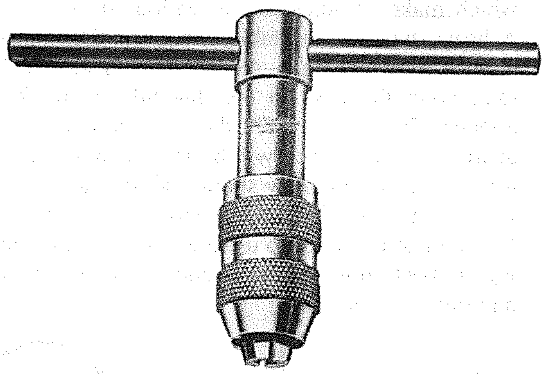


Fig. 3–50. T-handle tap wrench. (L. S. Starrett Co.)

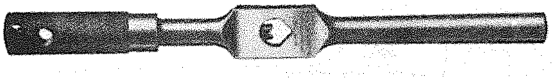
the tap. The chuck when tightened holds the tap securely. This type of wrench is made in several sizes, each size having a capacity for several sizes of taps. This wrench may also be made with a long shank for tapping holes that are difficult to reach. It is also useful for turning small hand reamers. Figure 3–51 shows how it is used for tapping.

40. *What is an adjustable tap wrench?*
An adjustable tap wrench (Fig. 3–52) is a straight type of wrench having a solid V-shaped opening in the center. A sliding member, or adjustable jaw, operated by one of the handles makes it possible to hold taps of various sizes. This type of wrench is made in many sizes to turn taps and reamers of all sizes.

41. *What is a 12-point box wrench?*
A 12-point box wrench (Fig. 3–53) is designed with 12 notches, or points, inside a closed end. The points

Fig. 3–51. Using a T-handle tap wrench. (L. S. Starrett Co.)

Fig. 3–52. Adjustable tap wrench. (L. S. Starrett Co.)



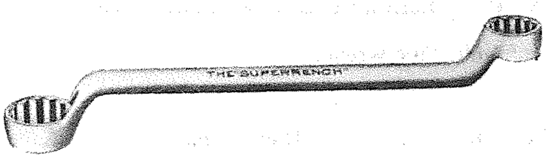


Fig. 3–53. Twelve-point doubled-ended offset box wrench. (J. H. Williams & Co.)

of a nut may be gripped by any one of the notches of the wrench, which permits the turning of a nut where only a short pull of the wrench is possible.

42. *What is a T-socket wrench?*
A T-socket wrench is made in the form of a T, as shown in Fig. 3–54. The hole, or socket, in the end is made in a variety of shapes such as square, hexagonal, or octagonal. It is generally used on jobs where there is insufficient space to permit the use of an ordinary wrench. The handle may be removed from the hexagon-shaped head of the wrench to permit the use of another wrench to turn it when more pressure is required than can be applied with the handle.

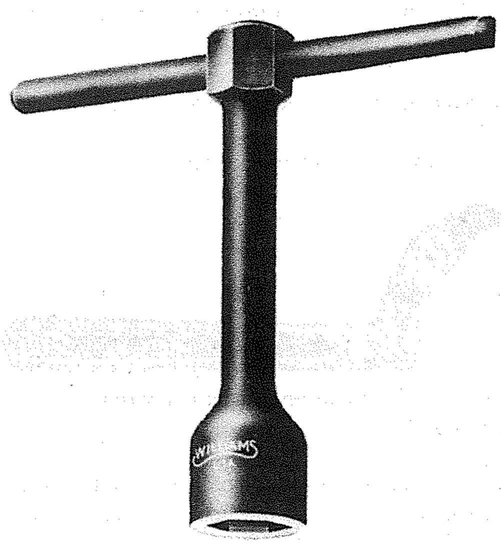


Fig. 3–54. T-socket wrench. (J. H. Williams & Co.)

43. *What is an offset socket wrench?*
An offset socket wrench (Fig. 3–55) is made with the same variety of sockets as a T-socket wrench. It is designed to be used on nuts requiring great leverage or in places where a T-socket wrench cannot be used.

44. *What is a pinhook spanner wrench?*
A pinhook spanner wrench is designed, as shown in Fig. 3–56, to fit around the edge of large round

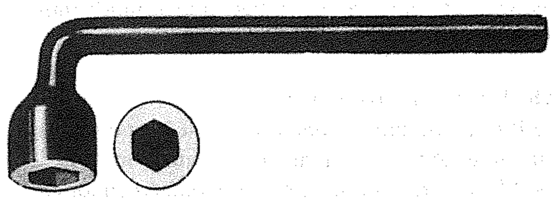


Fig. 3–55. Offset socket wrench. (Billings & Spencer Co.)

Fig. 3–56. Pinhook spanner wrench. (J. H. Williams & Co.)

nuts, which have holes in them to fit the pins of the wrench.

45. *What is an adjustable-hook spanner wrench used for?*
An adjustable-hook spanner wrench (Fig. 3–57) is

Fig. 3–57. Adjustable-hook spanner wrench. (J. H. Williams & Co.)

used on round nuts having notches or slots cut on their periphery to receive the hook at the end of the wrench. Being adjustable, it will fit many sizes of nuts.

46. *What is an adjustable pin-face wrench?*
An adjustable pin-face wrench is designed, as shown in Fig. 3–58, with two arms, each having a pin in one end This tool is used to adjust nuts that are enclosed so that an ordinary wrench cannot be placed around them. A nut in this situation is made with holes around the face to accommodate the pins in the ends of the adjustable legs of the wrench.

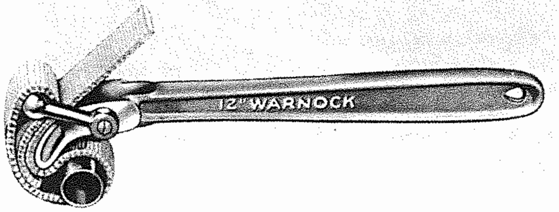
47. *What is a strap wrench?*
A strap wrench (Fig. 3–59) is used for turning cylindrical parts or pipes, removing bezels, or holding or revolving any job on which the surface finish must be preserved.

48 *What is a pipe wrench?*
A Stillson-type pipe wrench (Fig. 3–60) is designed with adjustable jaws that are serrated, making it possible to grip round pipe and other cylindrical parts. The serrated edges tend to cut into the metal being gripped, so care should be used to protect plated or finished surfaces being turned with this kind of wrench.

49. *What is a hex key wrench?*
A hex key wrench, sometimes called an *Allen wrench* (Fig. 3–61), is made of hexagon-shaped stock to fit the holes in the head of setscrews or socket-head screws. They are available in many sizes.

Fig. 3–58. Adjustable pin-face wrench. (J. H. Williams & Co.)

Fig. 3–59. Strap wrench. (Lowell Wrench Co.)



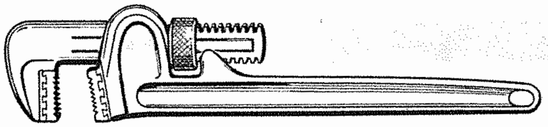
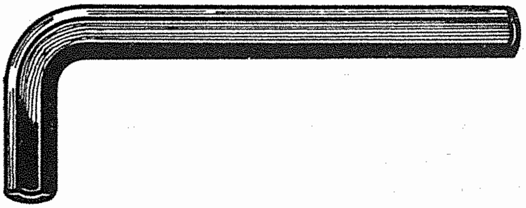


Fig. 3–60. Pipe wrench.

Fig. 3–61. Hex key, or Allen, wrench.



50. *What is a socket wrench and how is it used with a ratchet?*
Socket wrenches are round box type wrenches having two openings. One opening is a square hole into which the various driving attachments used for turning the socket wrench are plugged.

The socket end has an opening with angular notches to fit bolt heads and nuts. This notched opening is made with either 4, 6, 8, or 12 points. The 6- and 12-point sockets are used for hexagon-head bolts and nuts, while the 4- and 8-point sockets are used for square-head bolts and nuts.

A ratchet wrench may be either of the socket type or the open-end type. The handle turns the interchangeable sockets through a ratchet mechanism. This mechanism may be adjusted to operate in the clockwise or the counterclockwise direction so that the ratchet wrench may be used to tighten or loosen nuts or bolts (Fig. 3–62). The sockets may be standard (Fig. 3–63) or extra deep sockets (Fig. 3–64). For hard-to-reach nuts or bolts, extension bar sockets can be used (Fig. 3–65).

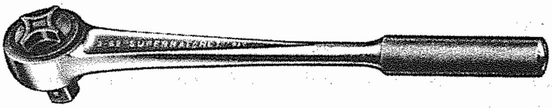
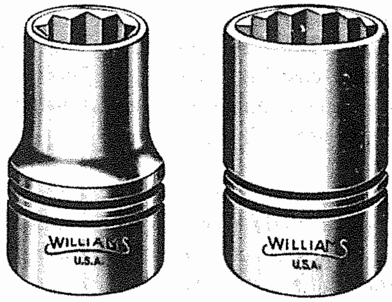


Fig. 3–62. A reversible ratchet. (J. H. Williams & Co.)

Fig. 3–63. Standard, or regular, 8- and 12-point sockets. (J. H. Williams & Co.)



Sockets have a lock-on feature in the form of a small hole on the side of the square hole into which a small spring-loaded ball in the driving attachment fits. When the socket is pushed on the drive attachment and the hole and ball are aligned, the ball is forced into the hole, thus preventing the socket from dropping off.

51. *What is a torque wrench?*
Torque wrenches are used when it is necessary to know the amount of turning or twisting force being applied to a nut. The amount of force is usually indicated on a dial or scale, which is mounted on the wrench handle (Fig. 3–66). On some models the amount of torque required can be preset on the dial,

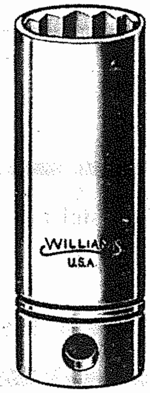


Fig. 3–64. Extra-deep sockets. (J. H. Williams & Co.)

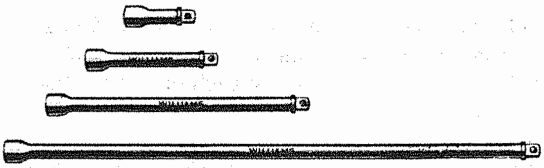


Fig. 3–65. Extension bars. (J. H. Williams & Co.)

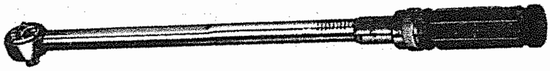


Fig. 3–66. A torque wrench. (J. H. Williams & Co.)

and an indicator will signal when that amount of force is reached.

HACKSAWS AND SAWING

The hacksaw receives a lot of use by the machinist working at a bench, as well as by workers in general. It is a hand tool especially designed for cutting metal. It consists of a metal frame (Fig. 3–67), in the ends of which are metal clips to hold the cutting blade. One clip is threaded on one end for a wing nut, which is used for tightening the blade in the frame. There are many other styles of hacksaws. The frame is adjustable to suit various lengths of blades.

52. *What is a hacksaw blade?*
A hacksaw blade (Fig. 3–68) is a piece of thin steel about 0.027 in. thick, ½ in. wide; it varies in length

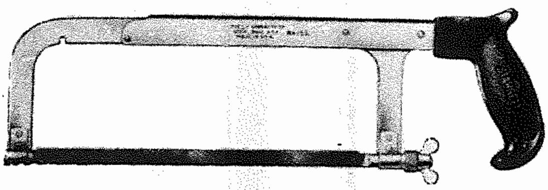


Fig. 3–67. **Adjustable pistol-grip hacksaw. (L. S. Starrett Co.)**

Fig. 3–68. Hacksaw blade. (L. S. Starrett Co.)

from 6 to 12 in. On one edge of the blade are serrations known as *teeth.*

53. *How are hacksaw blades held in the frame?*
Hacksaw blades are made with a hole in each end to fit over pins in the clips at each end of the hacksaw frame.

54. *How is the length of a hacksaw blade determined?*
The length of a blade is the distance from the center of the hole in one end of the blade to the center of the hole in the opposite end.

55. *Do all hacksaw blades have teeth of the same size?*
No. Blades for hacksaws are manufactured with teeth of different sizes ranging from 14 to 32 teeth per inch.

56. *What is meant by the set of a saw?*
The set of a saw means the bending to one side or the other of the teeth of a saw. The standard practice is to bend the teeth alternately; that is, one tooth is turned to the right side, the next one to the left side, and so on, as in Fig. 3–69. The teeth are actually

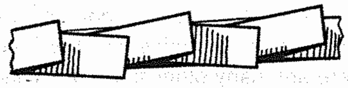


Fig. 3–69. Alternate setting of teeth.

turned very little. Sometimes, in the case of fine-toothed saw blades, the teeth are set alternately in pairs. This is known as *double-alternate* setting.

57. *For what purposes are the teeth of a hacksaw blade set?*
The teeth are set so that the slot made by the saw will be slightly wider than the thickness of the blade. This prevents the blade from binding in the slot, which makes the cutting operation easier for the workman; also, because the friction between blade and work is reduced, the effective life of the blade is increased. The set of the teeth also permits the blade to be guided from left to right to simplify following a layout line.

58. *Of what kinds of steel are hacksaw blades made?*
Hacksaw blades are made of high grades of steel such as tool steel, high-speed steel, or tungsten-alloy steel.

59. *What is meant by an all-hard blade?*
An all-hard blade is one that has been hardened all over.

60. *For what kinds of materials is it desirable to use all-hard blades?*
All-hard saw blades are used for cutting materials such as steel, cast iron, and brass. They are used particularly when cutting solid stock where a straight, even cut is desired.

61. *What is meant by a flexible-back blade?*
A flexible-back blade is one in which only the part where the teeth are cut is hardened, the rest of the blade remaining relatively soft.

62. *For what kinds of material are flexible-back blades preferred?*
Flexible-back blades are preferred for cutting the softer metals such as tin, copper, aluminum, and babbitt, and, in particular, for cutting tubing and various structural shapes with thin cross sections. In the process of cutting such materials, there is a tendency for the blade to be twisted or pulled out of line. The flexible blade will yield under these conditions, whereas an all-hard blade will break.

63. *Is there a particular way of placing a hacksaw blade in a frame?*
Yes. Best results are obtained when the cutting is done on the forward, or pushing, stroke. For this reason, the blade should be placed in the frame so that the teeth point forward.

64. *Can the blade be adjusted in the frame to suit special conditions?*
Yes. The blade may be set in four different positions, so that the teeth may face down, up, left, or right. The clips in the ends of the frame may be turned to four different positions for this purpose. Figure 3-70 shows a blade turned to the right so that a long strip may be conveniently cut from a metal sheet. In all cases, the blade should be drawn tight enough so that it will not bend. A flexible-back blade has a tendency to stretch because of the heat produced by friction. For this reason, it is necessary to increase the tension after the cutting has been started.

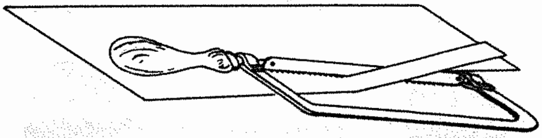
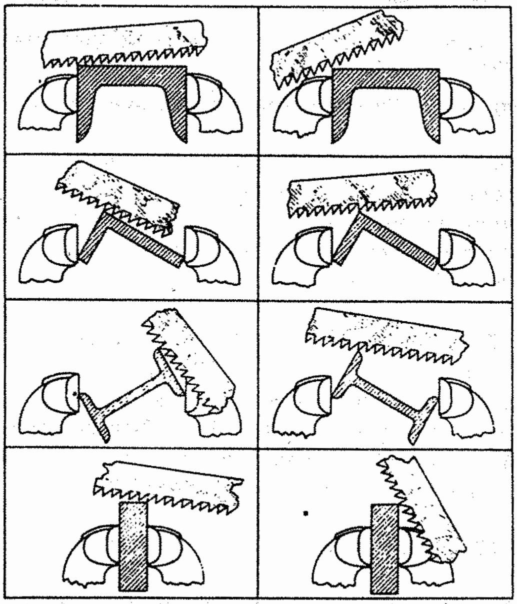


Fig. 3-70. Hacksaw with blade turned at right angles to frame.

Fig. 3-71. Methods of holding work in a vise for sawing.



65. *How should various materials be placed in a vise to obtain the greatest efficiency from the saw blade?*
The workpiece that is to be cut should be placed in a vise so that as much as possible of the surface may be presented to the edge of the blade. Avoid starting to saw on a corner. Corners have a tendency to strip teeth from the blade. The work should be held securely and adjusted so that the cutting will take place close to the end of the vise jaw. This will prevent chattering or vibrating of the work, which is hard on the nerves of the workman and on the teeth of the saw blade. Figure 3-71 shows the correct and incorrect ways of placing material in a vise.

66. *How should thin steel stock be supported while being cut with a hacksaw?*
Clamp thin stock between two pieces of wood or soft steel, and then saw through all three together. Thin stock that is not supported in this manner will bend under the pressure of the saw.

67. *Why are hacksaw blades made with teeth of different sizes?*
It has been found through experience that all materials do not cut equally well with the same size of saw teeth. The greatest efficiency is obtained by using a blade with teeth of the proper size for a given operation. The size of the teeth on a saw blade is referred to as the *pitch* (Fig. 3-72).

68. *On which kind of jobs should a hacksaw blade with 14 teeth per inch be used?*
Use a blade with 14 teeth per inch for sawing machine steel, cold-rolled steel, and structural-steel units having thick sections. The main advantage of the coarse pitch is that it makes the saw free- and fast-cutting, and for that reason is preferred where a smooth cut is not important.

69. *When should a blade with 18 teeth per inch be used?*
Use an 18-pitch blade for sawing any solid stock, including such materials as aluminum, babbitt, cast iron, high-speed steel, tool steel, and so forth. This pitch of blade is recommended for general use where a smooth cut surface is required.

70. *On what kind of jobs should a blade with 24 teeth per inch be used?*
Use a 24-pitch blade for cutting pipe, tin, brass, copper, small structural-steel units, and sheet metal over 18 gage. Although a fire-pitch blade cuts

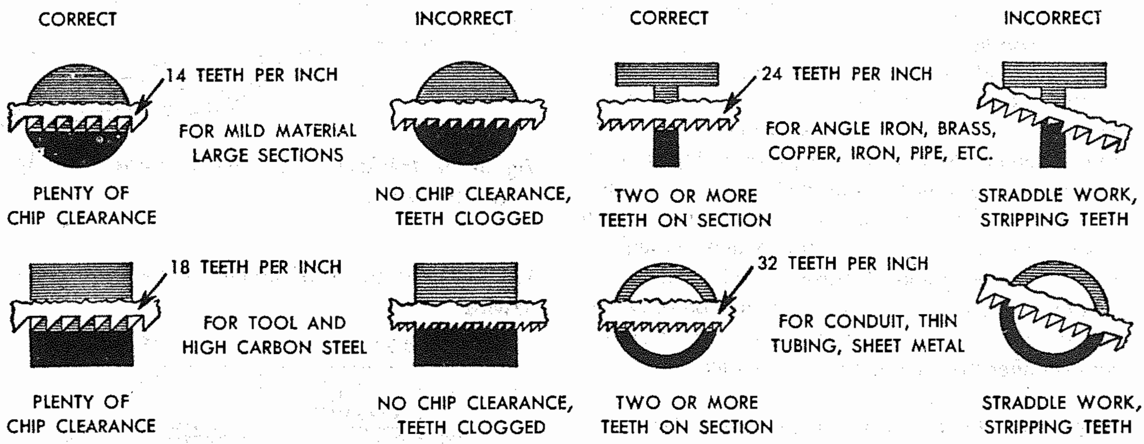


Fig. 3–72. Chart for selecting hacksaw blades of the correct pitch for the job. (L. S. Starrett Co.)

slowly, if a coarser blade is used for such items, the comparatively thin stock will tend to strip the teeth from the saw blade. There is less danger of stripping the teeth when two or more teeth are in contact with the work at all times.

71. *When should a blade with 32 teeth per inch be used?*
Use a 32-pitch blade for cutting small tubing, conduit, and sheet metal less than 18-gage thickness. These very thin materials require a very fine pitch to prevent the stripping of the teeth.

72. *Does a saw blade cut on the return stroke of the saw?*
No. The teeth are designed to cut in one direction only. For this reason, the pressure on the saw should be released during the return stroke, to avoid damage to the teeth.

73. *At what speed should a hacksaw be used?*
Under ordinary conditions, 50 to 60 strokes per minute is satisfactory. About 60 strokes per minute should be the maximum. Hard materials should not be sawed as fast as this, for it will unnecessarily dull the blade. In cutting hard material such as drill rod, for example, it is very effective to saw slowly and to use greater pressure than one would use for ordinary materials.

74. *Describe slotting hacksaw blades.*
Slotting hacksaw blades are similar to other hacksaw blades. They are usually 8 in. long by ½ in. wide, and of four different thicknesses, approximately 0.049, 0.065, 0.083, and 0.109 in. They are very handy when slotting a few screws for a special job that is needed at once. When slotting saw blades are not available, two or more ordinary saw blades may be placed in the frame side by side and used as a substitute.

75. *Why should a new cut be started after replacing a worn blade with a new one?*
The set of the teeth of the old blade will be worn slightly, and so the cut made by it will be narrower than the new blade. The new blade will break if it is forced into the old cut.

76. *Name some common causes for the breaking of hacksaw blades.*
These are common causes of broken blades:

A. Using a coarse-tooth blade on thin material.
B. Drawing the blade too tightly in the frame and then canting (tilting) it over while in the act of sawing.
C. Using too much pressure on the blade.

77. *Give some of the rules to be following in using a hand hacksaw.*
Practice these hacksawing rules:

A. Use a blade with teeth of the correct pitch for the job to be done.
B. Saw as close as possible to the point where the work is clamped, to prevent chattering.
C. Do not cut too fast.

D. Relieve the pressure on the saw on the return stroke.
E. Do not press too hard on the work.
F. Reduce pressure on the forward stroke when the blade is almost through the cut (Fig. 3–73).

Fig. 3–73. The correct way to hold the work and the hacksaw. (L. S. Starrett Co.)

FILES AND FILING

Filing is a method of removing small amounts of material from the surface of a piece of metal or other solid substance. In some respects, the operation compares to smoothing a piece of wood with a chisel or plane. Just as there are many types of chisels and planes to suit many different operations with wood, so there are many types of files designed for specific types of work and for various kinds of metal.

78. *What is a file?*
A file is a hardened-steel cutting tool having parallel rows of cutting edges, or teeth, on its surfaces. On the two wide surfaces, the rows are usually diagonal to the edge. One end of the file is shaped to fit into a wooden handle.

79. *What are the names of the various parts of a file?*
The principal parts of a file are shown in Fig. 3–74. They are the tang, heel, face, edge, and tip.

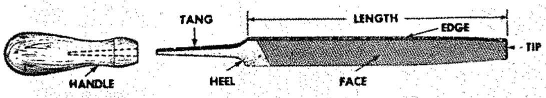


Fig. 3–74. Parts of a file.

80. *How is the length of a file measured?*
The length of a file is the distance from the heel to the tip (Fig 3–74).

81. *What is meant by the safe edge of a file?*
The safe edge of a file is the one on which no teeth have been cut. This edge keeps one side of a piece of work safe while an adjacent surface is being filed.

82. *Are files the same width from tip to heel?*
With one exception, no. Files normally taper in width from the heel to the tip. The exception is known as a *blunt file*.

83. *What are some of the different shapes of files?*
Cross sections of some of the most commonly used files, and their names, are shown in Fig. 3–75.

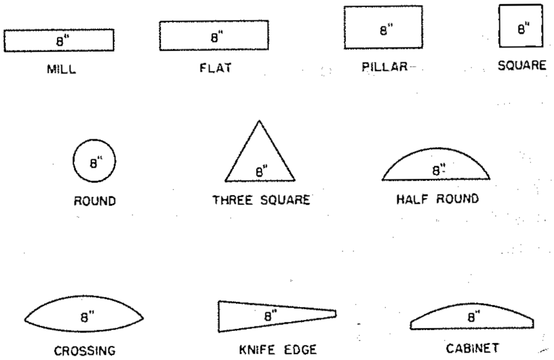


Fig. 3–75. Cross sections of file shapes. (Nicholson File Co.)

84. *How are files classified?*
They are divided into two classes: single-cut and double-cut.

85. *What are some of the characteristics of the two classes of files?*
Single-cut files have rows of teeth running in one direction across their wide surfaces, as in Fig. 3–76. Double-cut files have rows of teeth the same as single-cut files and, in addition, have a second row

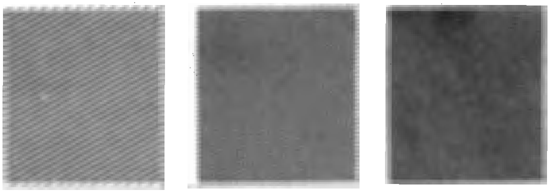


Fig. 3–76. Teeth of typical single-cut files. (Nicholson File Co.)

of teeth cut diagonally to the first row, as in Fig. 3–77. Single-cut files do not remove stock as fast as double-cut files, but the surface finish produced by the use of single-cut files is smoother.

86. *Do all single-cut files have fine teeth, and all double-cut files, coarse teeth?*
No. Both classes of files are made in similar grades, or pitch, such as dead-smooth, smooth, second-cut, bastard, coarse, rough. The degree of roughness on small files is indicated by numbers from 00 to 6, with 00 being the roughest.

87. *Is the pitch of file teeth the same for all sizes of files?*
No. The smaller the file, the finer the pitch. Figure 3–78 illustrates the difference in pitch of a 6-in. second-cut file and a 16-in. second-cut file.

88. *Describe the use of a mill file.*
The mill file (Fig. 3–79), which is single-cut, is used mostly in smooth and second-cut grades. It derives its name from the fact that it was first used for filing mill saws. It is also used for work on a lathe, for draw filing, and for finishing various compositions of brass and bronze. This type of file produces a fine finish. It is available in lengths of from 6 to 16 in.

89. *Describe the use of a flat file.*
Most flat files (Fig. 3–80) are double-cut and are preferred in bastard and second-cut grades. They are used by machinists, machinery builders, ship and engine builders, repairmen, and toolmakers, when a fast-cutting file is needed. This type of file produces a comparatively rough finish. It is usually available in lengths of from 6 to 18 in.

90. *Describe the pillar file.*
The pillar file (Fig. 3–81) is similar to the flat file, except that it is narrower; one or both edges are safe

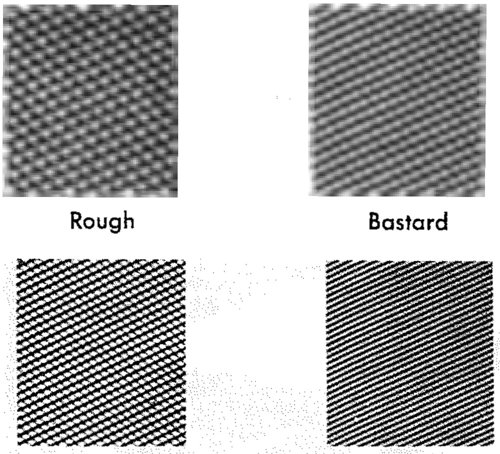
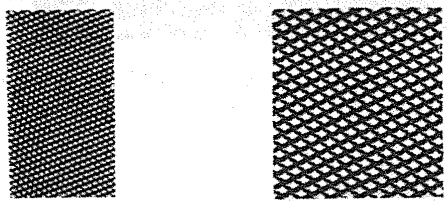


Fig. 3–77. Teeth of typical double-cut files. (Nicholson File Co.)

Fig. 3–78. The pitch of a 6-in. and a 16-in. second-cut file. (Nicholson File Co.)



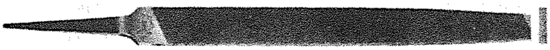


Fig. 3–79. Mill file. (Nicholson File Co.)

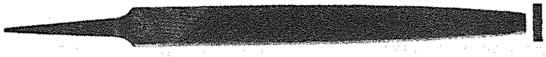


Fig. 3–80. Flat file. (Nicholson File Co.)

Fig. 3–81. Pillar file. (Nicholson File Co.)

edges. The pillar file is used for filing slots and keyways and for filing against shoulders. It is available in lengths of from 6 to 16 in.

91. *Describe the square file.*
The square file has a cross section that is square and

has double-cut teeth on all four sides (Fig. 3–82). It is used for filing small square or rectangular holes, for finishing the bottoms of narrow slots, and so forth. The grade commonly used is bastard, 4 to 16 in. in length.


Fig. 3–82. Square file. (Nicholson File Co.)

92. *Describe the round file.*
The round file (Fig. 3–83) has a circular cross section. It is generally tapered. The small sizes are often called *rattail* files. It is used for enlarging round holes, for rounding irregular holes, and for finishing fillets. The grade commonly used is bastard, 4 to 16 in. in length.


Fig. 3–83. Round file. (Nicholson File Co.)

93. *Describe the three-square file.*
The three-square file shown in Fig. 3–84, commonly called the *three-cornered file*, is triangular in section, with angles of 60°. It tapers to the point, the corners are left sharp. It is double-cut on all three sides and single-cut on the edges. It is generally used for filing internal angles that are less than 90°, for clearing out square corners and for filing taps, cutters, and so forth. The bastard and second-cut grades are preferred. It is available in 4 to 16 in. lengths. Three-cornered files are also used for sharpening saws, either by hand or held in a machine, as in Fig. 3–85.

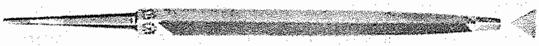


Fig. 3–84. Three-square file. (Nicholson File Co.)

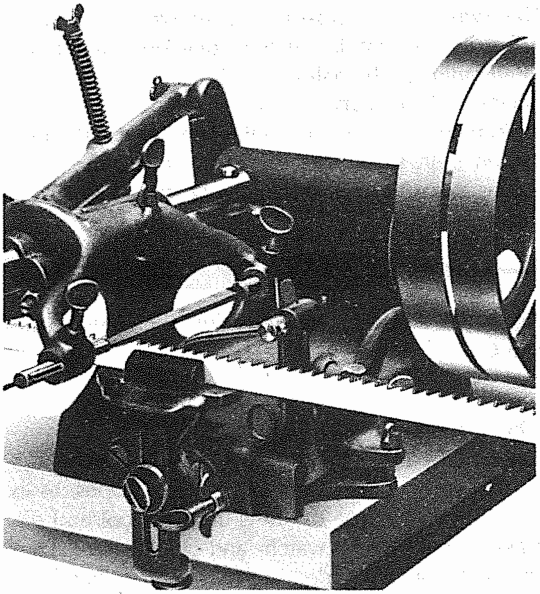


Fig. 3–85. Three-square file used in saw-sharpening machine. (Henry Disston & Sons, Inc.)

94. *Describe a half-round file.*
The half-round file (Fig. 3–86), so named because one half is flat, the other half rounded, is a double-cut file that is used when filing concave surfaces. The bastard grade is used mostly, in lengths of from 6 to 16 in.


Fig. 3–86. Half-round file (Nicholson File Co.)

95. *Describe a knife file.*
The knife file shown in Fig. 3–87 is made knife-shaped, the included angle of the sharp edge being approximately 10°. This file tapers to the point in width and thickness, and is double-cut on both flat sides, and single-cut on both edges. It is used for finishing the sharp corners of many kinds of slots and grooves. The grade preferred is bastard, in lengths of from 6 to 12 in.

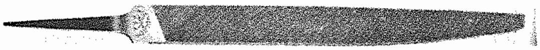


Fig. 3–87. Knife file. (Nicholson File Co.)

96. *Describe a warding file.*
A warding file (Fig. 3–88) is rectangular in section, but tapers to a narrow point in the width. It is used mostly by locksmiths for filing notches in keys and locks. It is made double-cut and is available in sizes of from 4 to 12 in. in length. The 4-in. file is only $^3/_{64}$ in. thick.

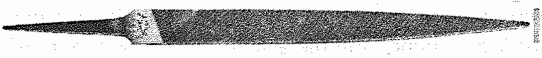


Fig. 3–88. Warding file. (Nicholson File Co.)

97. *What are Swiss pattern files?*
Swiss pattern files are similar to ordinary files but are made to more exacting measurements. The points of Swiss pattern files are smaller, and the tapered files have longer tapers. They are also made in much finer cuts. They are primarily finishing tools, used for removing burrs left over from previous finishing operations; truing up narrow grooves, notches, and keyways; rounding out slots and cleaning out corners; smoothing small parts; doing the final finishing on all sorts of delicate and intricate pieces. The grades vary from 00, the coarsest, to 6, the finest.

98. *Describe a Swiss pattern crossing file.*
The Swiss pattern crossing file shown in Fig. 3–89 has a double circular section, one side having the same radius as the half-round file and the other side having a flatter curve, or larger radius. It tapers to the point in both width and thickness and is double-cut on both sides. These files are available in all grades from 00 to 6, in lengths of from 3 to 10 in.

Fig. 3–89. Swiss pattern crossing file. (Nicholson File Co.)

99. *What are needle files?*
Needle files are members of the Swiss pattern family. They usually come in sets of assorted shapes, as in Fig. 3–90. This type of file is used by tool and die makers, and also by watch- and clockmakers. One end of the file is knurled so that a separate handle is not needed. These files are available in grade 0, 2, 4, and 6 and in lengths of 4, 5½, and 6¼ in.

100. *Why are files made with convex surfaces?*
Files are generally made with convex surfaces; that is, they are thicker in the middle than at the ends (Fig. 3–91). This is done to prevent all the teeth from cutting at the same time because that would require too much pressure on a file and make it hard to control. A flat surface could not be obtained if the face of the file were straight because there is a tendency to rock the file. The convex surface helps to overcome the results of rocking.

The convexity of files also serves another purpose. The pressure applied to a file to make it bite into the work also bends the file a little, and if the file in its natural state were perfectly flat, it would be concave

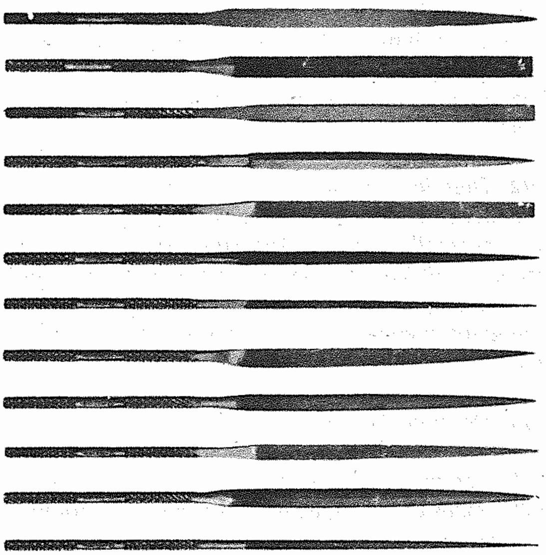


Fig. 3–90. Swiss pattern needle files. (Nicholson File Co.)

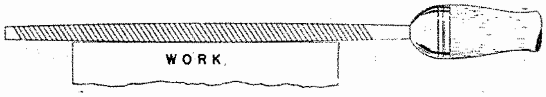


Fig. 3–91. The face of a file is slightly convex along its length.

during the cutting operation. This would prevent the production of a flat surface because the file would cut away more at the edges of the work than in the center and thus leave a convex surface.

101. *What is the proper way to hold a file?*
Grasp the handle in the right hand so that it rests against the palm of the hand, with the thumb placed on top. Place the left hand at the end of the file and let the fingers curl under it (Fig. 3–92).

102. *What should be the position of the body when filing?*
It is important to have the body in the correct position because the muscles must move freely. The left foot should point forward and the right foot brought up close enough to the left to give the necessary balance. When filing, the body should lean forward on the beginning of the forward stroke and then return to the original position at the finish of the stroke. The

Fig. 3–92. The correct way to hold a file when cross-filing. (Nicholson File Co.)

file must be held straight, or the surface will not be flat. The strokes should not be too fast because this will ruin the file and the work. Enough pressure should be applied to make the file cut evenly.

103. *Should the file be lifted from the work on the return stroke? Explain.*
No, but the downward pressure should be released during the return stroke in order to avoid dulling the file by wearing away the back of the teeth. This would destroy the cutting edges. This procedure does not hold true in the filing of soft metals such as lead or aluminum. The file should be drawn back along those metals on the return stroke; this helps clean the teeth.

104. *When does a file cut best?*
A file cuts best after it has cut about 2,500 strokes, or after it has removed about 1 cu in. of material because, at that time, most of the cutting edges will be in contact with the work. It must be remembered, however, that after continued use, the worn-down edges will continue to cut less and less until the life of the file is gone.

105. *What is meant by draw filing?*
Draw filing is the operation of pushing and pulling a file sidewise across the work. For this purpose, the file should be held firmly in both hands so that only a few inches of the file in the center are actually used. Files are normally made to cut on a longitudinal forward stroke, so a file with a short-angle cut ought not to be used for draw filing because of the possibility of scratching or scoring the work, instead of shaving or shearing off the metal smoothly. When it is properly done, draw filing produces a surface with a finer finish than is usually obtained with straight filing. However, the main objective in draw filing is to obtain a perfectly smooth, level surface. A single-cut mill file is preferred for the finishing operation (Fig. 3–93).

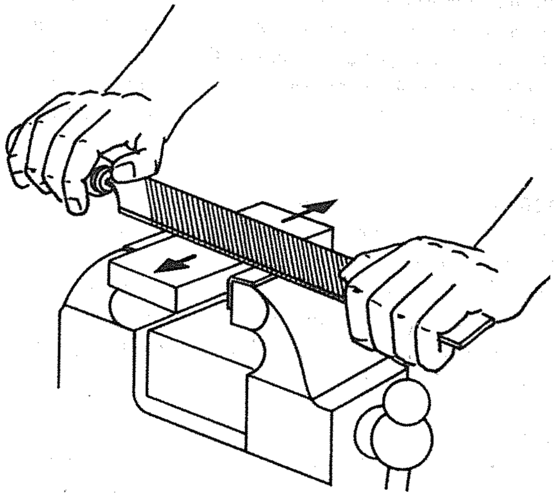
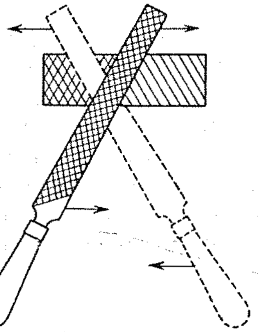


Fig. 3–93. Draw filing.

Fig. 3–94. Crossing the stroke.



106. *What is meant by crossing the stroke?*
Crossing the stroke means changing the angle at which one is holding a file by about 45°. This will show the high spots and also tend to keep the work flat (Fig. 3–94).

107. *What kind of file should be used to remove stock rapidly?*
A large double-cut bastard, or double-cut coarse-tooth, file should be used to remove stock rapidly.

108. *What kind of file should be used for finishing work?*
For ordinary finishing work, a 10-in. single-cut smooth file is preferred.

109. *What precaution should be taken before filing cast iron?*
Before attempting to file cast iron, you must remove the scale from the surface of the casting. This can be done by chipping, scraping with the edge of a file, tumbling, sand-blasting, or pickling. A good pickling solution is 4 to 10 parts of water to 1 part of sulfuric acid.

110. *What is meant by pinning a file?*
When filing soft metals, narrow surfaces, or corners, small particles of the material being filed tend to become clogged in the gullets between the teeth of the file. This is called *pinning* a file. Pinning reduces the efficiency of the file and causes scratches on the surface of the work.

111. *What is the cause of pinning?*
The main cause of pinning is the application of too much pressure on the file, especially when using smooth files. It is helpful when using a new file to allow the rough edges and burrs to become worn slightly before taking heavy cuts. Rubbing chalk on a file will also help prevent pinning.

112. *How may a pinned file be cleaned?*
A file may be cleaned with a file brush (Fig. 3–95). One side of the brush has fine wires, which are used to loosen the embedded material. The other side has bristles, which are used to finish the job. In the handle of the file brush is a piece of metal, called a *scorer,* which is used to remove pinnings that cannot be loosened by the wires. Brush in the direction of the file teeth.

113. *Is it acceptable practice to use a file without a handle?*
No. Never use a file without a handle. This is a safety rule. Make sure that the handle is firmly attached to the file. A good type of file handle is the Lutz design shown in Fig. 3–96.

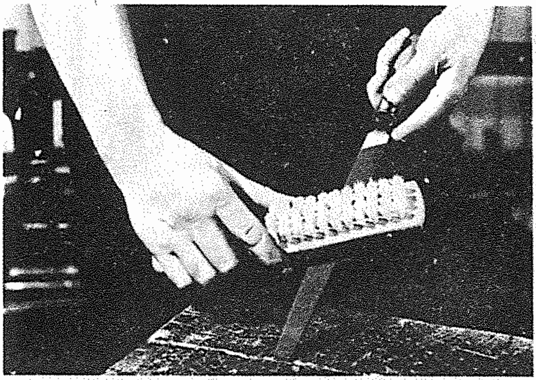
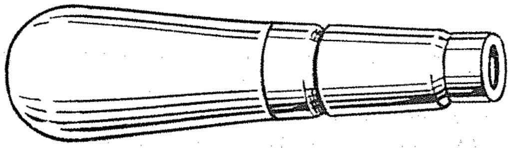


Fig. 3–95. Correct way to use a file card for cleaning a file. (Nicholson File Co.)

Fig. 3–96. Lutz type of file handle. (Lutz File & Tool Co.)



114. *Mention two precautions that should not be overlooked when filing.*

Follow these precautions when filing:

A. Do not rub the hand over the work that is being filed. The grease and perspiration of the hand produce a glazed surface, and the sharp edge of the work may cut the hand.
B. Always make sure that finished surfaces are protected by placing soft material between the work and the vise.

115. *How are files designated, and what information is required when ordering files?*
A file is designated by its length, shape, and grade. When ordering files, the quantity desired should be specified first, as

12 6-in. half-round, second-cut files
6 12-in. flat, bastard files

116. *What is a filing machine?*
A filing machine is a device for holding a file and moving it with a vertical reciprocating action. The

work is placed on the table and pressed against the moving file (see Fig. 3–97). The table may be adjusted to a required angle. When adjusting the table, use the same amount of force in setting the protractor against the file to obtain the proper angle as will be used when forcing the work against the file.

117. *Are special files used with a filing machine?* Yes. Files with straight shanks, as in Fig. 3–98, are used in a filing machine. In placing a file in the machine, the roller guide must be adjusted to give the proper amount of friction against the file.

CHISELS AND CHIPPING

One of the earliest methods of shaping a piece of wood, stone, or metal was to chip away the unwanted material with a hammer and chisel. This practice is still common today for jobs done at the workbench and when it is not practical to do the work on a machine. In this section, we shall be concerned with the chipping of metal.

On any work of this nature, there is always the danger that flying particles of metal may injure the

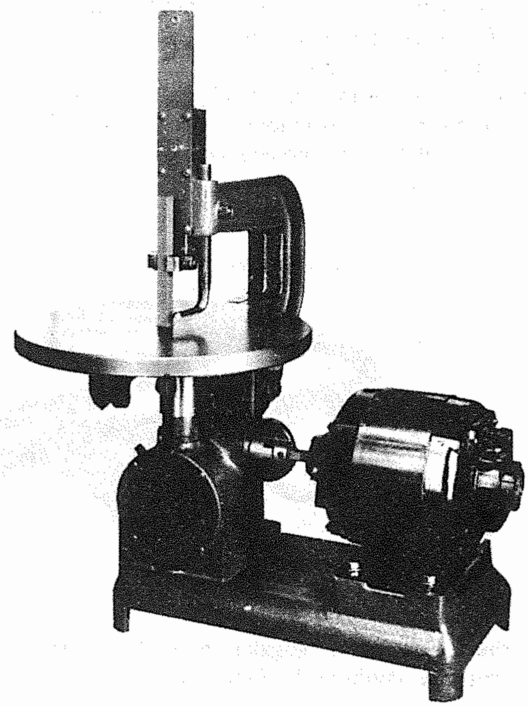
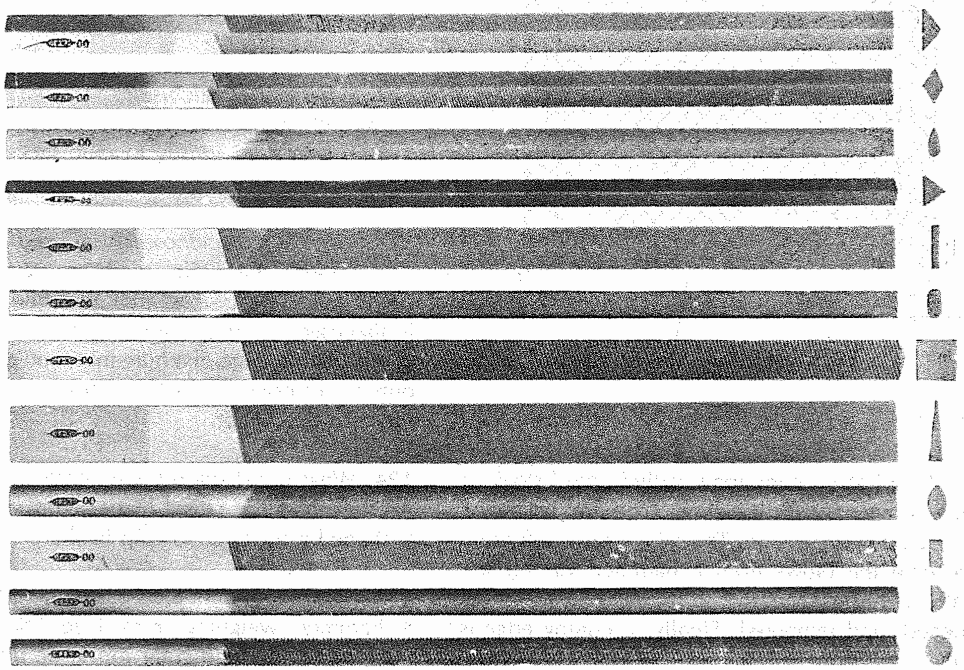


Fig. 3–97. Filing machine. (Oliver Instrument Co.)

Fig. 3–98. Files used in filing machines. (Nicholson File Co.)

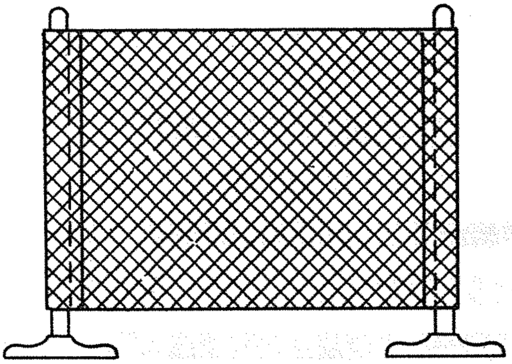


eyes of the workman who is doing the chipping and of other persons who may be nearby.

To do a job safely is the most important rule in any shop. For this reason, goggles must be worn by the person who is chipping, and a guard placed to protect those who are near or passing by (Figs. 3-99 and 3-100).

Fig. 3-99. Safety goggles must be worn when chipping. (Willson Products Co.)

Fig. 3-100. Chipping guard.



118. *What is a chisel?*
A chisel is a tool made from hexagon- or octagon-shaped tool steel, commonly called *chisel steel*, of a size convenient for handling. One end is shaped for the cutting operation. The other end is left blunt to receive the blows from a hammer. Chisels are usually forged to the required shape, then annealed, hardened, and tempered. Finally, a cutting edge is ground.

119. *For what purpose are chisels annealed, hardened, and tempered?*
Annealing relieves the internal strains of the metal, which develop during the forging operation and thus makes a chisel tough and strong. The hardening of the metal makes it possible for a chisel to maintain a sharp cutting edge. Tempering reduces the brittleness of the metal so that the cutting edge of the chisel is less liable to be fractured. All these processes—annealing, hardening, and tempering—are known as *heat treatments*.

120. *Is a chisel hardened all over?*
No. Only the cutting end, and usually for a distance of 1 in. from the end. It is better for the opposite end to remain relatively soft, to avoid its being chipped by the blows of the hammer.

121. *What is a flat cold chisel?*
A flat cold chisel (Fig. 3-101) is the most common type of chisel. It is used to chip flat surfaces and to cut thin sheet metal. It is called a *cold chisel* because it is used to cut metals that have not been heated in a furnace.

Fig. 3-101. Flat cold chisel. (Stanley Tools.)

122. *What is a cape chisel?*
A cape chisel is a narrow chisel shaped as in Fig. 3-102. It is used mostly to chip grooves and keyways.

123. *What is a roundnose chisel used for?*
A roundnose chisel (Fig. 3-103) is used to rough out small concave surfaces such as a filleted corner. It is also used on drill-press work to cut a small groove in the sloping edge of a hole that is off center, for the purpose of drawing the drill back to place, concentric with the layout.

124. *What is a diamond-point chisel used for?*
A diamond-point chisel (Fig. 3-104) is used to cut V-shaped grooves or to chip in sharp corners.

125. *Describe the method of chipping by hand.*
A hammer, weighing from 1 to 1¾ lb, a chisel selected for the particular job to be done, goggles,

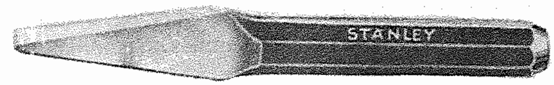


Fig. 3–102. Cape chisel. (Stanley Tools.)

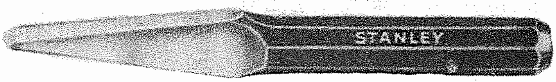


Fig. 3–103. Roundnose chisel. (Stanley Tools.)

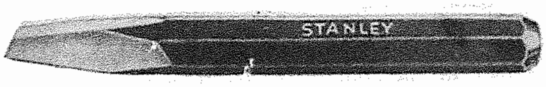


Fig. 3–104. Diamond-point chisel. (Stanley Tools.)

and safety guard are the essential tools. The hammer should be held at the extreme end, grasped by the thumb, second, and third fingers, with the first and fourth fingers closed loosely around the handle. It may thus be swung more steadily and more freely, without tiring the hand as much as when the handle is grasped rigidly by all four fingers.

The chisel should be held with the head of the chisel about 1 in. above the thumb and first finger and gripped firmly with the second and third fingers. The first finger and thumb should be slack because the muscles are then relaxed, and the fingers and hand are less likely to be injured if struck with the hammer. The edge of the chisel should be held on the point where the cut is desired, at an angle that will cause the cutting edge to follow the desired finished surface (Fig. 3–105). After each blow of the hammer, the chisel must be reset to the proper position for the next cut.

126. *To what size angle should the cutting edge of a flat cold chisel be ground?*
The correct cutting angle depends upon the hardness of the material to be cut. An angle of 70° is suitable for iron and steel. For soft metals, the angle should be less (Fig. 3–106). The use of a chisel with a cutting angle of 90° or larger will tend to remove stock by pushing it off instead of cutting it off (Fig. 3–107).

127. *What is the correct procedure in sharpening a cold chisel?*
A cold chisel should be held at the required angle and moved back and forth across the face of the grinding wheel to insure an even surface. The pressure of the chisel against the wheel must be enough to prevent chattering—that is, vibrating or bouncing of the chisel against the wheel. It is also necessary to avoid pressing so hard that the edge of the chisel becomes overheated, which draws the temper of the steel and makes the cutting edge soft. Curving the cutting edge of the chisel as shown in Fig. 3–108 results in a better cutting action.

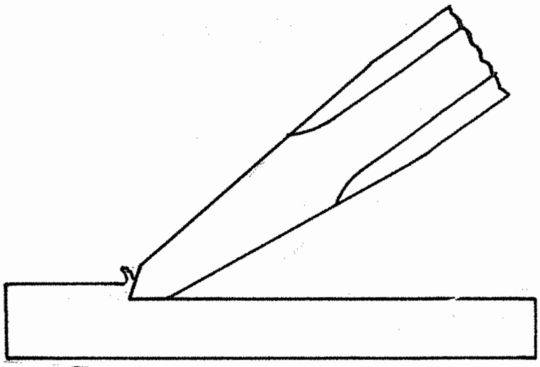


Fig. 3–105. Chisel held at correct angle.

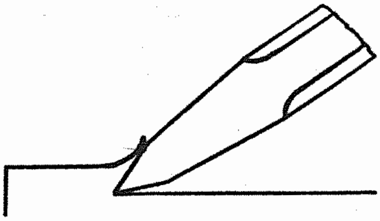


Fig. 3–106. Cutting-edge angle can be smaller for soft metals than for iron and steel.

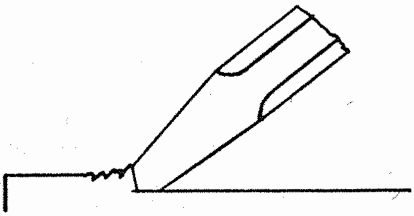


Fig. 3–107. Cutting-edge angle is too large.

128. *When chipping, should the cutting edge or the head of a chisel be watched?*
For accurate cutting, watch the cutting edge of the chisel. The ability to hit the head of the chisel without watching it is soon acquired.

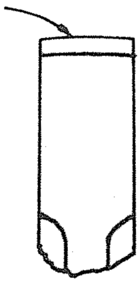


Fig. 3–108. Cutting edge slightly rounded to give better cutting action.

129. *What is meant by "mushroom head" on a chisel?*
A mushroom head on a chisel is a head that has been hammered until the end spreads out to resemble a mushroom (Fig. 3–109). A mushroom head should always be ground off and the cutting edge sharpened before using the chisel.

130. *Why are mushroom-head chisels dangerous?*
The mushroomed part of the head of the chisel may break off when struck by a hammer, and the flying particles of steel may injure someone. The ragged edge may also injure the hand of the person holding the chisel.

131. *Describe the safety precautions and good practices to be observed when chipping.*
Figure 3–110 shows a machinist chipping a piece of work that is held in a vise at the workbench. Several items of safety and good shop practice are indicated by numbers. (1) Always wear goggles. (2) Roll up sleeves. (3) Be sure chisel has no mushroom head. (4) Hold the chisel correctly. (5) Hold the hammer at the end of the handle. (6) Be sure the workpiece is securely held in the vise.

SOLDERING

Soldering is an ancient art, which did not change much during the period when other great technological improvements were taking place. Today, however, craftsmen, technicians, and even hobbyists are familiar with the techniques and skills of soldering. With improved soldering tools and newer methods, soldering is a common method of joining many kinds of metals whether on a job-to-job or mass-production basis. In the canning industries, cans are soldered in large quantities on automatically controlled machinery.

132. *What is soldering?*
Soldering is the process of joining two metals together by a third, soft metal, called *solder,* which is applied in the molten state.

133. *What is solder?*
Solder is an alloy of metals that melt at low temperatures.

134. *What kinds of solder are commonly used?*
Two kinds are commonly used. One is a soft solder, an alloy of tin and lead. A common proportion is three parts of tin and two parts of lead. Small amounts of bismuth and cadmium are frequently added to lower the melting point.

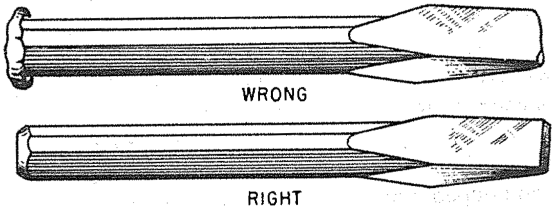


Fig. 3–109. Keep chisels in good condition.

Fig. 3–110. The correct way to do a chipping job.

Another kind is hard solder, sometimes called *spelter,* an alloy of copper and zinc. A common proportion is four parts of copper and one part of zinc.

135. *Why does solder contain lead?*
Lead is used because it has a low melting point, 620.6°F, and because it is inexpensive. It also does not corrode metals with which it comes in contact.

136. *What is one of the most important operations in soldering?*
One of the most important operations, and one that is often overlooked, is cleaning the surface to be soldered.

137. *What is a flux, and why is it used?*
Flux is a cleanser used to remove and prevent the oxidation of the metals, allowing the solder to flow freely and to unite more firmly with the surfaces to be joined.

138. *Why cannot two pieces of metal be soldered together successfully without the aid of a flux after their surfaces have been cleaned?*
A cleaned metal surface tarnishes immediately upon exposure to the air. A thin coating of oxide is formed when the oxygen in the air combines with the metal. Solder will not unite with a metal that has a coating of oxide. A flux is used to remove the oxide the instant the solder comes in contact with the metal.

139. *What is the most commonly used flux in the machine shop?*
Prepared soldering paste is the most commonly used flux in the machine shop.

140. *On what kind of metals is chloride of zinc used as a flux?*
Chloride of zinc is used as a flux on steel, cast iron, brass, zinc, nickel, monel metal, stainless steel, lead, and galvanized iron.

141. *What kind of flux is used for soldering copper and brass?*
Zinc chloride or a commercially prepared soldering flux is used for soldering copper and brass.

142. *What kind of flux is used for soldering lead?*
Rosin, tallow, or zinc chloride may be used as a flux for soldering lead.

143. *What kind of flux is used for soldering sheet tin?*
Beeswax, rosin, or any of the commercially prepared fats, pastes, or liquid fluxes are considered good. Zinc chloride may be used by diluting it with 50 percent alcohol.

144. *What kind of flux should be used for soldering wrought iron or steel?*
Zinc chloride is the best flux to use for soldering wrought iron or steel.

145. *What kind of flux is best to use for soldering commutator wires and electrical connections?*
An alcoholic solution of rosin is considered best for the soldering of commutator wires and electrical connections. Do not use an acid flux because this will cause a corrosive action, which may destroy the wires or the connection.

146. *What is the purpose of a soldering iron?*
A soldering iron is used to melt the solder and to heat the metals that are about to be joined together.

147. *What is a plain soldering iron?*
A plain soldering iron (Fig. 3–111), also called a *soldering copper,* consists of a round-, hexagon-, or octagon-shaped copper tip mounted on a steel rod of suitable length with a handle attached. The copper tip is shaped to an angle on four sides to form a pyramid shape, but not necessarily to a sharp point.

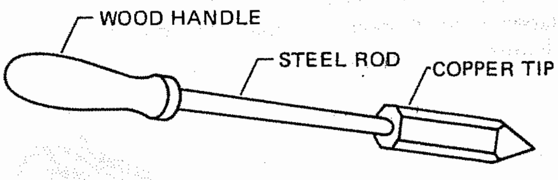


Fig. 3–111. A plain soldering iron.

148. *How is a plain nonelectric soldering iron heated?*
The copper tip is usually heated in a small gas furnace. For outside work, a blowtorch or a propane torch may be used (Fig. 3–112). A propane torch may also be used to apply heat and melt solder directly to the workpiece, as for sweating copper fittings. Various tips, which fit on the torch, are available for soldering, or to give flames of different widths as required for the job.

Fig. 3–112. A propane torch can be used for soldering. (Bernzomatic Corp.)

149. *What is an electric soldering iron?*
An electric soldering iron (Fig. 3–113) transmits heat to the copper tip through a heating element in the heating head. Electric irons are rated according to the number of watts consumed when used at the voltage specified on the iron. Power consumption for the commonly used soldering irons varies from 25 watts for the smaller tips to 550 watts for the larger tips. There are many shapes and sizes of copper tips. A tapered needle-point tip may be only 1/16 in. in diameter (Fig. 3–114), whereas tips for larger work

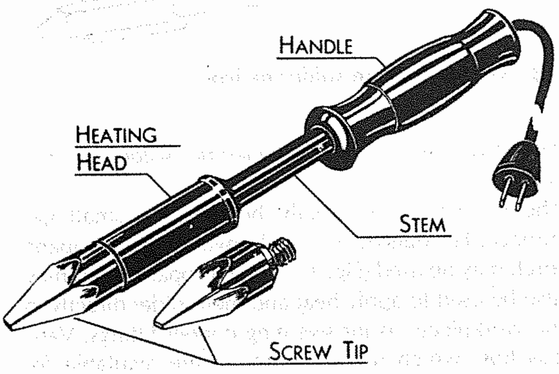


Fig. 3–113. Parts of an electric soldering iron. (Stanley Tools)

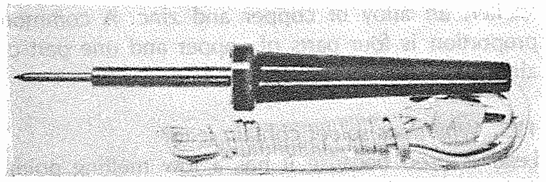


Fig. 3–114. Electric soldering iron with small tip. (Weller Electric Corp.)

may be 1⅛ in. in diameter. Figure 3–115 shows how a large iron is used to solder a seam.

150. *What is a soldering gun?*
A soldering gun (Fig. 3–116) is an electric soldering tool that has a pistol-grip design and is operated by a trigger. When the trigger is pulled, the heat and a spotlight comes on instantly. A dual heat arrangement gives low and high soldering temperatures, which can be controlled by the trigger positions. Various types of tips are available (Fig. 3–117), which can be installed or changed easily and quickly.

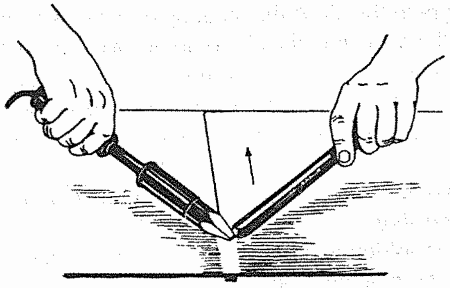


Fig. 3–115. A large electric soldering iron being used to solder a seam. (Stanley Tools.)

151. *How is a soldering iron prepared for use?*
In order to have solder cling to the iron, the tip must be *tinned* (Fig. 3–118). To do this, first use a file to clean the copper back to the end of the beveled top, and then heat the copper a little more than is necessary to melt the solder. Rub the clean, heated copper with sal ammoniac and then apply the solder. To have a good clean point, rub over the soldered point with a rag immediately after it has been tinned. A soldering iron should not be overheated (red hot is too hot) because this will remove the solder from the point, which will have to be tinned again.

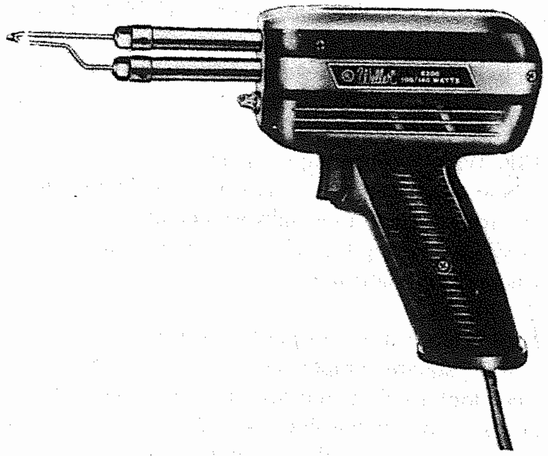


Fig. 3-116. A soldering gun. (Weller Electric Corp.)

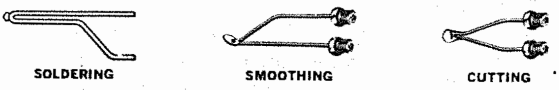


Fig. 3-117. Three types of tips for a soldering gun. (Weller Electric Corp.)

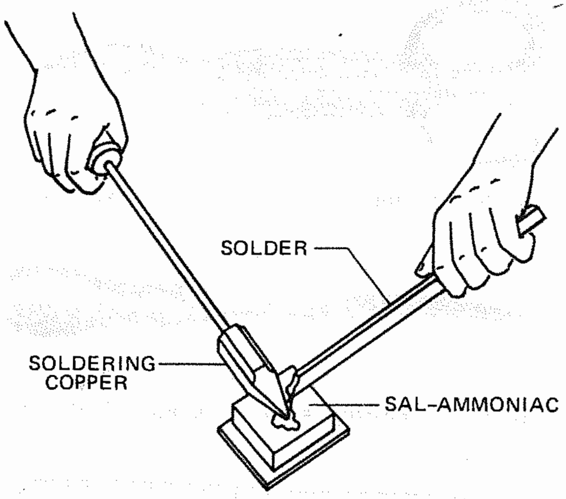


Fig. 3-118. Tinning a soldering iron using sal ammoniac.

152. *How should the surface of a piece of metal be prepared for soldering?*
The surface of the metal must be cleaned. Use a file, scraper, acid cleaner, wirebrush, or abrasive cloth.

153. *What is meant by sweating parts together?*
Sweating parts together is done by first tinning the two surfaces to be joined. After flux is applied to both surfaces, they are clamped together and heated. When cool, the two parts will be soldered to each other. Split bushings are sometimes sweated together in this manner so that they may be machined as one unit. After machining, they may be separated by applying heat and pulling them apart.

154. *What is the difference between soldering and brazing?*
The difference lies in the kind of solder used and the amount of heat applied to the work. Hard solder, mentioned in question 134, requires the use of a blowtorch to melt it and also to heat the parts that are to be brazed together. Borax is often used as a flux for brazing. A brazed joint is much stronger than a soldered joint.

155. *What can be done to prevent solder from running away from the surfaces to be joined?*
For both soldering and brazing, clay is commonly used to surround the area to be joined if the solder will otherwise run away from the surface to be soldered.

156. *What is the correct design of the tip of the soldering iron, and how should it be applied to the work?*
The point of a soldering iron should be rather stubby so that the heat will be retained at the point as long as possible. An included angle of 45° is suitable for medium and large irons. The iron at *A* in Fig. 3-119 is being correctly applied to the work so that the heat can be transmitted as rapidly as possible. The iron at *B* is shaped correctly, but it is being applied improperly to pass the heat to the work. The iron shown at C is too pointed, and the heat at the point is soon lost.

Because solder will not flow upward, an attempt to solder the underside of a job by the method shown at *D* is not successful: The solder will flow away from the joint. However, the following method can be used. Clean only one pointed side of the soldering iron, heat it, tin it, and then apply it to the work, as at *E*. Solder can be applied in this way because it will cling only to the clean side of the iron. Be sure that the other sides are left dirty so that the solder will not run off.

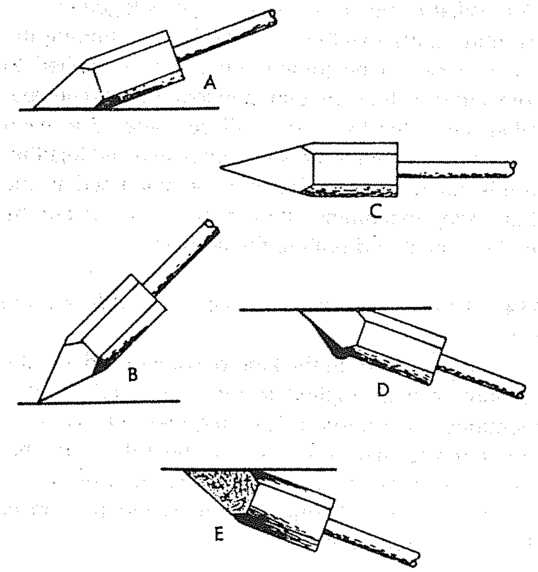


Fig. 3–119. Methods of applying a soldering iron.

Whatever the type of soldering iron selected, it must have adequate capacity for the work it is to do. A perfectly soldered connection can be obtained only when the surfaces to be joined have absorbed enough heat to melt the solder. For example, it is almost impossible to solder a large article with a small soldering iron because the large article will absorb all the heat from the small iron and the part to be soldered will not be heated sufficiently to make a good fusion. A large iron should be used on large jobs because it will carry more heat to the part being soldered. A small iron should be used for small or intricate jobs.

OTHER SMALL TOOLS

157. *What are tinner's snips?*
Tinner's snips (Fig. 3–120), also called *tin snips*, are a common cutting tool used for cutting thin sheets of metal, plastic, fiber, and so forth. They are used not only by tinsmiths, but by all bench workers as a utility tool. They are made in many sizes.

Precision machines do an excellent job in producing surfaces that are accurate in measurement and smooth in finish. However, some operations such as the fitting of bearing surfaces are better done by skillful handwork. Scrapers are used for this work.

158. *What is a bearing scraper?*
A bearing scraper (Fig. 3–121) is a slender tool made of hardened steel especially shaped and curved. It is used for scraping the surface of cylindrical bearings when fitting shafts into them.

159. *What is a three-square scraper?*
A three-square scraper (Fig. 3–122) is a hardened-steel tool used to remove burrs or sharp internal edges from soft bushings and similar parts. An old three-square file makes a good scraper when correctly ground.

160. *What is a flat scraper used for?*
A flat scraper (Fig. 3–123) is used to scrape the high spots off a flat bearing surface that must be perfectly matched to another flat surface. This hand operation requires much skill.

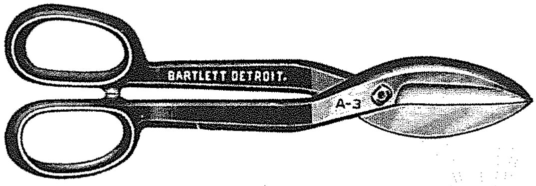


Fig. 3–120. Tinner's snips. (Bertlett Mfg. Co.)

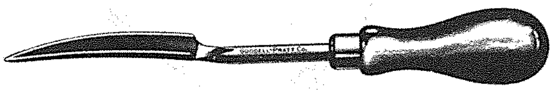


Fig. 3–121. Bearing scraper. (Goodell-Pratt Co.)

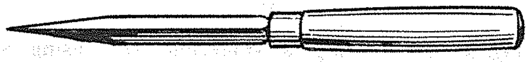


Fig. 3–122. Three-square scraper.

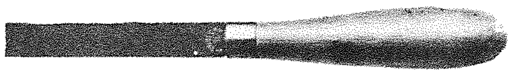


Fig. 3–123. Flat scraper. (Nicholson File Co.)

Fig. 3–124. Machinists' and toolmakers' tool chest. (H. Gerstner & Sons.)

Tools being used while the workman is working on a machine or at a bench should be kept within easy reach of the operator and placed so they will not fall on the floor. Tools ought not to be placed on the finished parts of a machine.

Every mechanic should have a toolbox of his own where he may keep his tools when he is not using them. There should be a place for every tool, and each tool should be kept in its place. A popular style of tool chest is shown in Fig. 3–124.

The condition in which a mechanic keeps the various tools he uses can affect his efficiency as well as the judgment that others pass upon him in the performance of his daily work. A workman is frequently judged by the way in which he handles his tools.

All tools should be wiped clean before they are placed in the toolbox, and, if they are not to be used again for some time, they should be oiled to prevent rusting.

chapter 4 basic measuring and layout tools

INTRODUCTION

One of the most important steps in the manufacture of any product is accurate measurement. The progress of mankind through the ages has been directly connected with the development of better ways to measure.

A wide range of measuring tools and devices have been designed, which makes it possible for the skilled craftsman to measure and lay out workpieces to extremely high accuracy. In the aerospace industries, for example, certain instrument parts may be dimensioned with tolerances specified in millionths of an inch. Other industries may allow lower accuracy, requiring measurements in thousandths, ten-thousandths, or even sixty-fourths of an inch. The degree of accuracy usually depends upon the type of product being manufactured and the manner in which it must function. It would be costly and inefficient to require extremely fine measurements when a part could function satisfactorily at a lesser degree of accuracy.

Machinists and toolmakers use many tools for measuring and laying out work. Some are quite simple and inexpensive, others are more intricate and expensive (Fig. 4–1). Most are used for linear, or straight-line, measurement. This chapter discusses the basic tools for measuring and layout.

1. *Why is a knowledge of fractions and decimals necessary when using measuring tools?*
Before a student can read a rule or any of the precision measuring tools efficiently, he must be thoroughly familiar with common fractions and decimal fractions. Toolmakers and other skilled workers are often called upon to change decimal numbers to common fractions and common fractions to decimals in making measurements and in reading and checking blueprints and sketches.

To change a fraction to a decimal, it is convenient to use a decimal-equivalent chart, but if a chart is not available, the method is to divide the numerator of the fraction by the denominator. For example, in changing $3/16$ to a decimal, divide 3 by 16, which equals 0.1875.

Precision measuring tools such as micrometers and vernier tools are read in thousandths and ever in fractional parts of a thousandth of an inch. For example, $1/8$ (0.125) is read as "one hundred and twenty-five thousandths," while $1/16$ (0.0625) is read as "sixty-two and one-half thousandths"; $1/32$

Fig. 4-1. A toolmaker's work bench for measuring, laying out, and inspecting workpieces.

(0.03125) is read as "thirty-one and one-quarter thousandths"; and so forth. It will be noted that these readings give the full decimal values for the corresponding common fractions. However, because the precision tools commonly used in the shop cannot be read closer than one-tenth of one-thousandth, it is customary for a mechanic to use only those figures up to and including the fourth decimal place. For example, the complete decimal value of 1/64 is 0.015625, which in the shop is commonly read as "fifteen and six-tenths thousanths," being the whole number of thousandths while six is six-tenths of one-thousandth, or a fractional part of a thousandth.

Figure 4–2 contains the decimal equivalents of the fractions most frequently used in the shop. They should be memorized.

The most common measuring tool is a steel rule. There are many varieties. In the shop, rules are often improperly referred to as *scales*. Use of the term *steel rule* is proper and recommended strongly.

2. *What are steel rules?*

Steel rules are measuring tools that depend largely on the user's ability to read and line up the subdivisions marked on the rule. They are not intended for accuracy in terms of thousandths of an inch.

fraction	*64*	*32*	*16*	*8*	*4*	*decimal*
1/64	1					0.015625
1/32	2	1				0.03125
1/16	4	2	1			0.0625
3/32	6	3				0.09375
1/8	8	4	2	1		0.1250
3/16	12	6	3			0.1875
1/4	16	8	4	2	1	0.2500
5/16	20	10	5			0.3125
3/8	24	12	6	3		0.3750
7/16	28	14	7			0.4375
1/2	32	16	8	4	2	0.5000
9/16	36	18	9			0.5625
5/8	40	20	10	5		0.6250
11/16	44	22	11			0.6875
3/4	48	24	12	6	3	0.7500
13/16	52	26	13			0.8125
7/8	56	28	14	7		0.8750
15/16	60	30	15			0.9375

Fig. 4–2. Decimal equivalents of fractions most frequently used in the shop.

With practice over a period of time, an able machinist can measure within three to five thousandths of an inch.

Steel rules are one of the most widely used measuring tools for such work as laying out, checking stock sizes, and setting dividers and calipers. Lines, called *graduations*, which are inscribed on the face of the rule, subdivide the inches into fractional or decimal parts of an inch (Fig. 4–3). Several types of steel rules are generally available to suit the preferences of individual machinists.

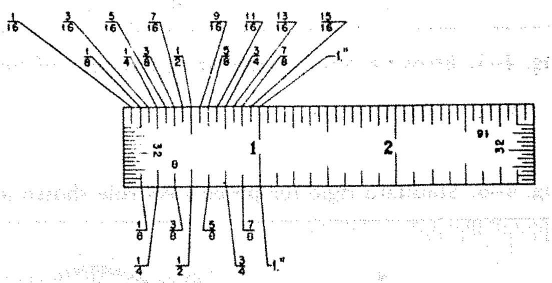


Fig. 4–3. Graduated lines on a steel rule subdivide the inch into its common fractional parts.

3. *Why is it sometimes better to make measurements from an inscribed line rather than from the end of a rule?*
When a steel rule is new, the ends are square and accurate. After considerable use, the ends become worn and even rounded, and it is good practice to make measurements from the 1-in. line or from some other major graduation such as the ½-in. or ¾-in. line, as shown in Fig. 4–4.

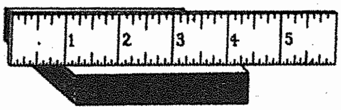


Fig. 4–4. Taking a measurement from the 1-in. graduation.

4. *Are all rules graduated with the same divisions of an inch?*
No. Some rules have four sets of graduations, one on each edge. Many combinations are available. Manufacturers have standard combinations, which are identified by a number from 1 to 12, as shown in Fig. 4–5. Number 4 is the most popular, with eighths and sixteenths on one side, and thirty-seconds and sixty-fourths on the other side.

5. *Describe a standard steel rule.*
The most common steel rule used in a toolroom (Fig. 4–6) is made of tempered steel about 3/64 in. thick, ¾ in. wide, and 6 in. long, with No. 4 graduations. The same style may be obtained in lengths from 1 to 144 in. and in a choice of graduations. The graduations sometimes inscribed on the end of the rule are handy for measuring a narrow space. (See Fig. 4–3.)

When reading a rule, it is sometimes convenient to read either way from some large dimension line. For instance, in measuring 47/64 in., it is easier to find ¾ (48/64) and subtract 1/64 from it than to count the divisions from the end of the rule.

6. *What is a flexible steel rule?*
A flexible steel rule (Fig. 4–7) is made of tempered spring steel about 1/64 in. thick, ½ in. wide, and 6 in. long. It is available in many graduations, Nos. 3 and 4 being most popular. It is also available in other lengths. This type of rule is for general use and for measuring curved work.

7. *What is a narrow rule?*
A narrow rule (Fig. 4–8) is made of tempered steel about 3/64 in. thick, 3/16 in. wide, and 4 to 12 in. long.

number of graduation	*first corner*	*second corner*	*third corner*	*fourth corner*
1	10, 20, 50, 100	12, 24, 48	14, 28	16, 32, 64
2	8	10, 20, 50, 100	12, 24, 48	16, 32, 64
3	10	50	32	64
4	8	16	32	64
7	16	32	64	100
10	32	64		
11	64	100		
12	50	100		

Fig. 4–5. Brown & Sharpe standard graduation of rules. (Brown & Sharpe Mfg. Co.)

Fig. 4–6. Standard rigid tempered-steel rule shown actual size. (Brown & Sharpe Mfg. Co.)

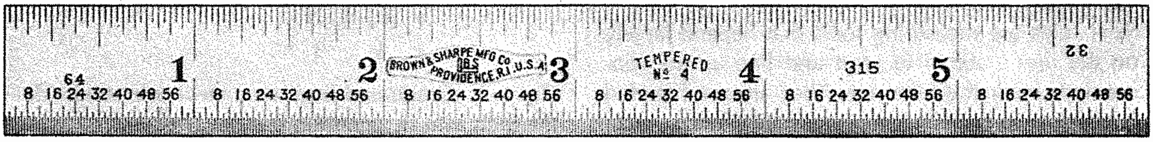


Fig. 4–7. Thin flexible steel rule.

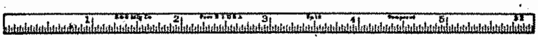


Fig. 4–8. Narrow steel rule. (L. S. Starrett Co.)

It has graduation combinations Nos. 10 or 11 and is useful for measuring in small openings and spaces.

8. *What is a hook rule?*
A hook rule, as shown in Fig. 4–9, has a hook attached to one end, which makes it easy to take measurements from an inside edge when it is not convenient to see the end of the rule. Hook rules are made in many sizes. A narrow hook rule is made for measuring in holes as small as ⅜ in. in diameter (Fig. 4–10). A hook rule may also be used for measuring outside dimensions (Fig. 4–11).

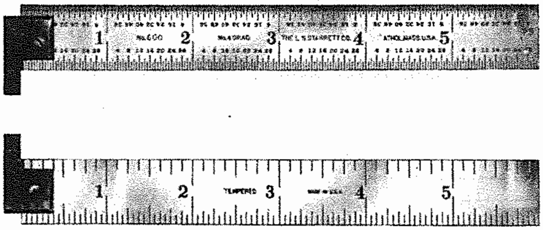


Fig. 4–9. Hook rule. (L. S. Starrett Co.)

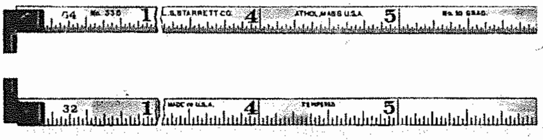


Fig. 4–10. Narrow hook rule. (L. S. Starrett Co.)

9. *What is a shrink rule?*
A shrink rule (Fig. 4–12) is a tempered-steel rule similar in size and appearance to a standard rule. It has No. 4 graduations. It differs from other rules in that the inch markings on the face are slightly longer than actual inches. It is used by patternmakers. Patterns for castings are deliberately made larger than the required castings to allow for the shrinkage of the molten metal as it cools to a solid. If the shrink rule is used, the pattern will automatically be made larger than the actual size of the final casting. Because the amount of shrinkage is not the same for all metals, shrink rules are made from 1/10 to 7/16 in. per ft oversize.

10. *What is a short rule?*
A short rule is usually one of a set of small rules made for measuring in small spaces where it is inconvenient to use any other rule (Fig. 4–13). The set of rules consists of a ¼, ⅜, ½, ¾, and 1 in. rule,

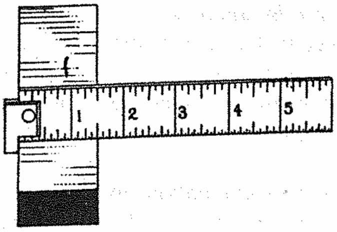


Fig. 4–11. Measuring with a hook rule.

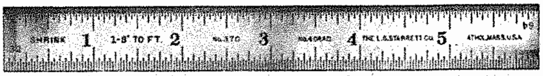


Fig. 4–12. Shrink rule. (L. S. Starrett Co.)

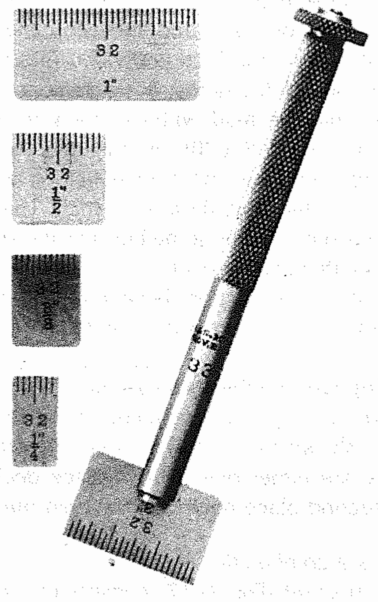


Fig. 4–13. Set of short rules with holder. (Brown & Sharpe Mfg. Co.)

together with a holder. The rule may be held at any angle. It is secured by turning the knurled nut at the end of the holder.

11. *What is a slide caliper rule?*
A slide caliper rule (Fig. 4–14) is made with a narrow rule that slides inside a groove in the side of a wider rule. It may be used to make internal and external measurements. It is provided with a screw that will lock the slide in place as required. The narrow nibs at the end of the jaws will enter a hole as small as ⅛-in. diameter.

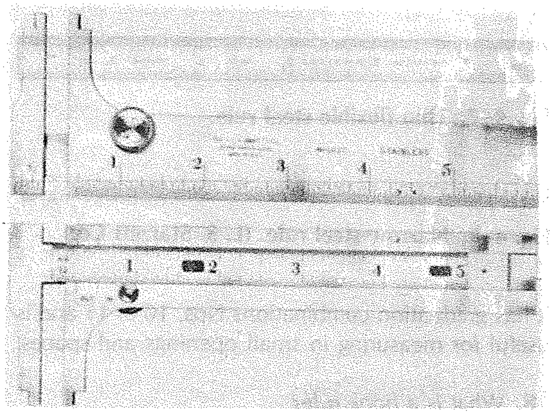


Fig. 4–14. Slide caliper rule. (L. S. Starrett Co.)

12. *What is a rule depth gage?*
A rule depth gage (Fig. 4–15) consists of a steel head that has a slot to receive a narrow rule. The rule is held in position by a knurled nut. It is designed to measure the depth of small holes and slots.

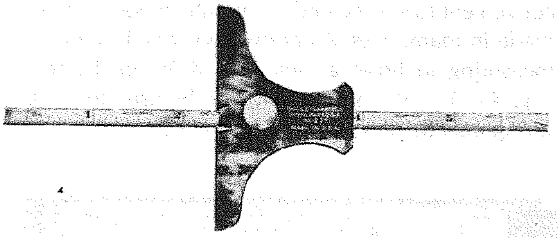


Fig. 4–15. Rule depth gage. (L. S. Starrett Co.)

13. *Why are some graduations in common fractions of an inch and others in decimal fractions of an inch?*
Many U.S. manufacturers design their products using common fractions for measurements of parts of an inch. For ordinary measurements, the rule is satisfactory, most mechanics being able to measure accurately as close as 1/64 in. When greater accuracy is required, dimensions are specified as decimal figures. Such dimensions are usually given to the third or fourth decimal place, as 0.375 or 0.5625.

Some manufacturers have adopted the decimal system for both ordinary and precision measurements. In this case, the inch is divided into tenths, hundredths, and thousandths. Measurements made with a rule may be read with accuracy to within twenty thousandths (0.020) of an inch. For this reason, graduations are made in tenths of an inch (0.100) and in fiftieths (0.020) of an inch. The decimal system is preferred by some because it is simple. There is also little chance of error, as sometimes happens when common fractions have to be changed to decimal fractions for measuring with a precision instrument.

A drawing with dimensions specified in the decimal system and a rule graduated in tenths and fiftieths are shown in Fig. 4–16. Note that ordinary dimensions are either one- or two-place decimals, and that second-place decimals are even numbers.

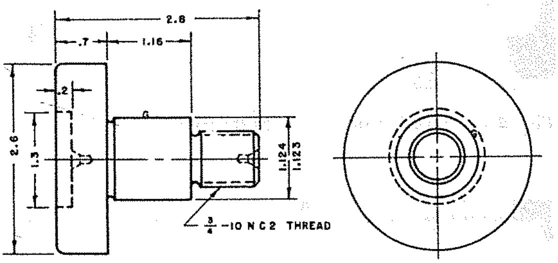


Fig. 4–16. (Top) Drawing with decimal dimensions. (Bottom) Steel rule graduated in tenths and fiftieths of an inch. (Brown & Sharpe Mfg. Co.)

14. *What is a combination set?*
A combination set (Fig. 4–17) consists of a rule, a square, a center head, and a protractor. The rule is made of tempered steel with a groove cut the length of one side along which the other parts may slide. Each part is provided with a knurled nut for locking it into position. The rule has No. 4 or 7 graduations and is available in lengths of from 9 to 24 in. This tool may be used as a rule, a square, a depth gage,

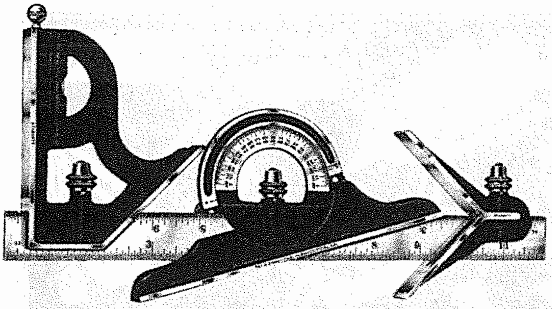


Fig. 4-17. Combination set showing square, protractor, and center heads. (L. S. Starrett Co.)

or a protractor. It is also used for marking miters and for locating the center on circular stock.

15. *What is a bevel protractor?*
A bevel protractor (Fig. 4-18) is a tool for measuring angles within one degree. It consists of a steel rule, a blade, and a protractor head. The protractor head has a revolving turret graduated to read from 0° to 180°

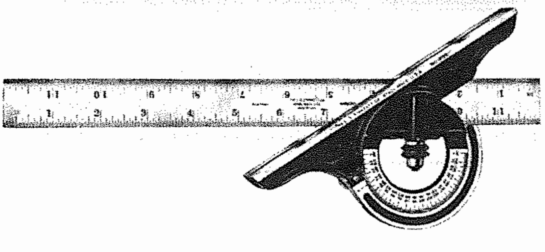


Fig. 4-18. Bevel protractor. (L. S. Starrett Co.)

in opposite directions. The head may be a reversible type with shoulders on both sides of the blade or a nonreversible type with a single shoulder. Most bevel protractors contain a spirit level, which is useful when measuring angles in relation to a horizontal or vertical plane. A plain steel protractor (Fig. 4-19)

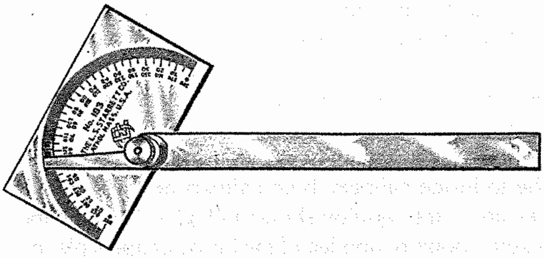


Fig. 4-19. Plain steel protractor. (L. S. Starrett Co.)

may be more convenient to use for laying out and checking angles on some types of work.

16. *What are universal and combination bevels?*
Universal and combination bevels (Fig. 4-20A and B) are useful tools for checking and transferring angles that would be difficult to measure with an ordinary protractor. The bevel may be set to the desired angle using a protractor, or it may be set to the workpiece, then checked against the protractor setting to determine accuracy. A combination bevel serves the same purpose as the universal bevel but has a wider range of applications (Fig. 4-21).

17. *What are some of the uses of outside calipers?*
Outside calipers (Fig. 4-22) are used to measure outside diameters. A rule may be used to measure the diameter of the end of a bar, but it is not practical to measure diameters in between the ends, as in the

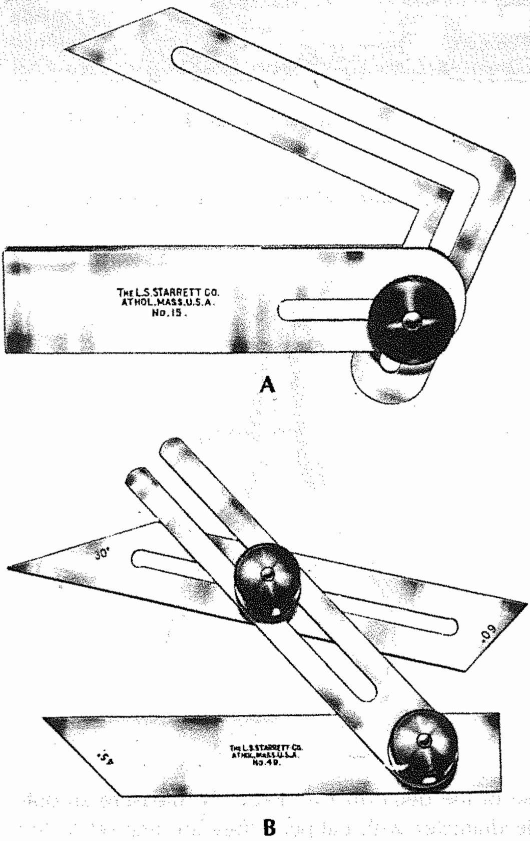


Fig. 4-20. (A) Universal and (B) combination bevels. (L. S. Starrett Co.)

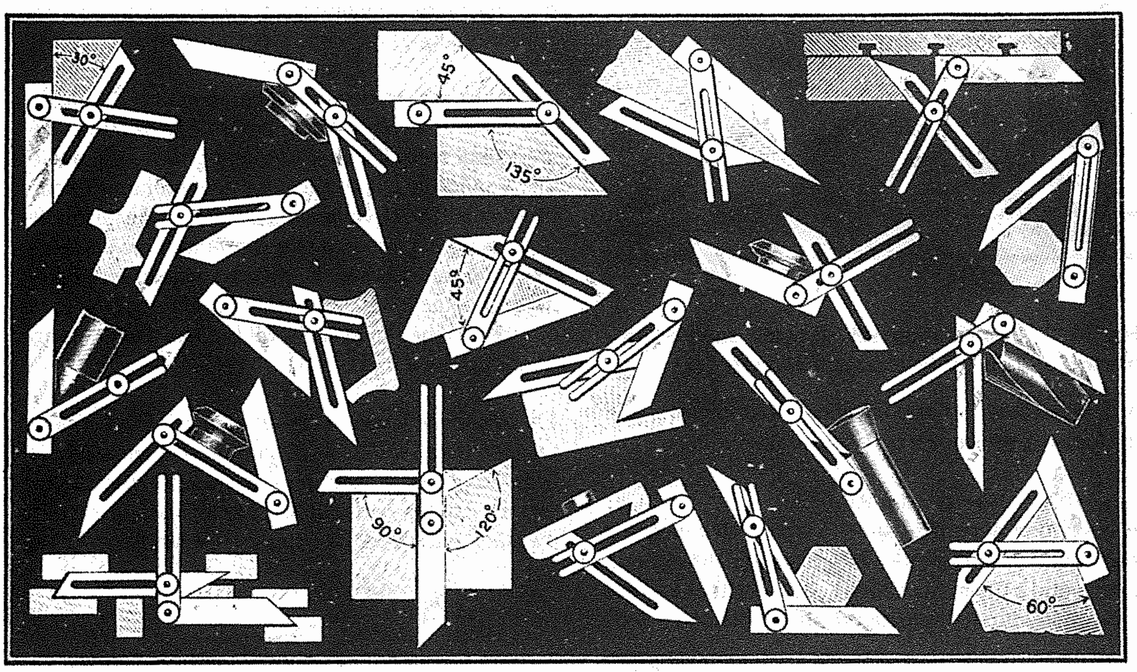
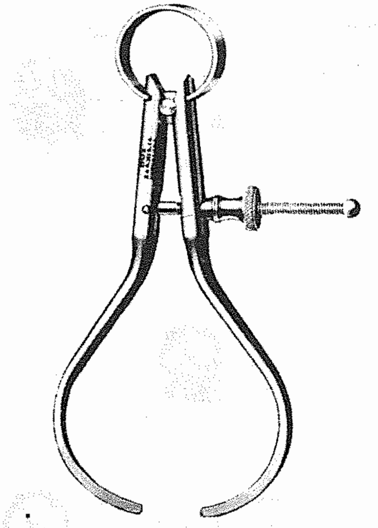


Fig. 4–21. Applications of bevels. (L. S. Starrett Co.)

Fig. 4–22. Outside calipers. (Brown & Sharpe Mfg. Co.)



case of the detail in Fig. 4–23. To measure an outside diameter with calipers, they are first set to the approximate diameter of the stock. Then the calipers are held at right angles to the center line of the work, as in Fig. 4–24, and moved back and forth across the center line, while they are being adjusted, until the points bear lightly on the work. This is called "getting the feel." When the tool has been adjusted properly, the diameter may be read from a rule, as shown in Fig. 4–25.

18. *What are some of the uses of inside calipers?*
Inside calipers (Fig. 4–26) are used to measure inside diameters, widths of slots, and the like. To measure the diameter of a hole, open the calipers to the approximate size, then hold one leg of the calipers against the wall of the hole and turn the adjusting screw until the other leg just touches the opposite side. The calipers should be moved back and forth, as in Fig. 4–27, to feel the proper contact. The size of the opening is then read from a rule, as in Fig. 4–28, or from a micrometer, as in Fig. 4–29.

19. *Describe the transferring of a measurement from outside to inside calipers.*
When a measurement has to be transferred from outside to inside calipers, both calipers are held so that they are in the position shown in Fig. 4–30. With the extreme point of one leg of the inside calipers placed on the extreme point of one leg of the outside calipers, adjust the inside calipers until the two extreme points touch lightly. Care must be taken not to force

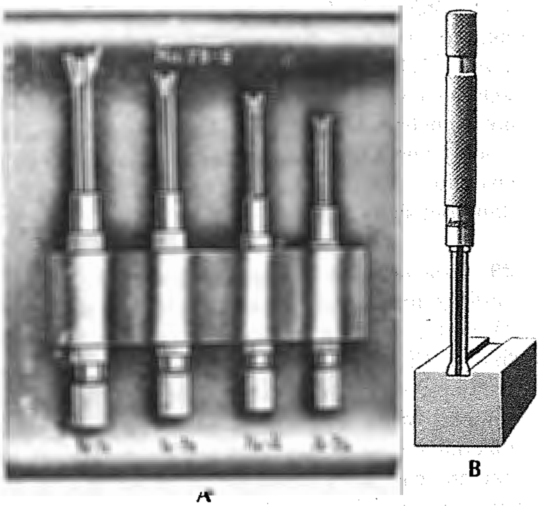


Fig. 4–34. (A) Set of small-hole gages. (B) Application of small-hole gage. (Lufkin Rule Co.)

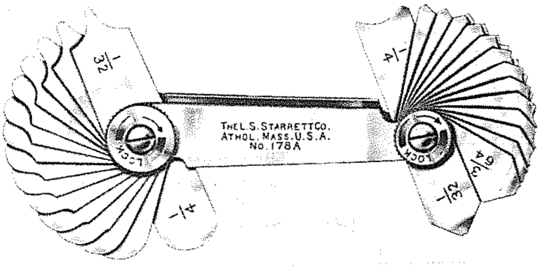


Fig. 4–35. Radius, or fillet, gage. (L. S. Starrett Co.)

A thickness gage (Fig. 4–36) is actually a set of gages consisting of thin strips of metal of various thicknesses from 0.0015 in. up to 0.200 in. thick. Combinations of thickness sizes or leaves may be mounted in a steel case or holder. The individual leaves are marked with the thickness size. Such a gage is widely used for measuring and checking bearing clearances; adjusting tappets, spark plug gaps, jig and fixture parts; and for many other purposes where a specified clearance must be maintained. Accuracy in using these gages requires a sense of feel.

24. *What is a screw-pitch gage?*
A screw-pitch gage (Fig. 4–37) is a gage for quickly determining the pitch, or number of threads per inch, on a threaded part or in a tapped hole. Such a gage consists of a number of leaves mounted in a case or holder. Each leaf has a specified number

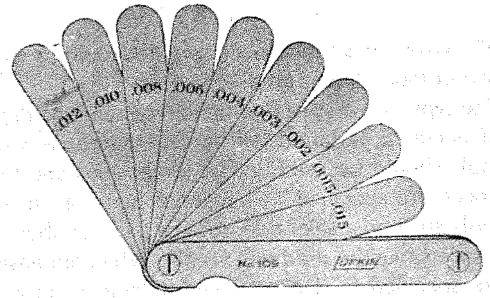


Fig. 4–36. Thickness gage. (Lufkin Rule Co.)

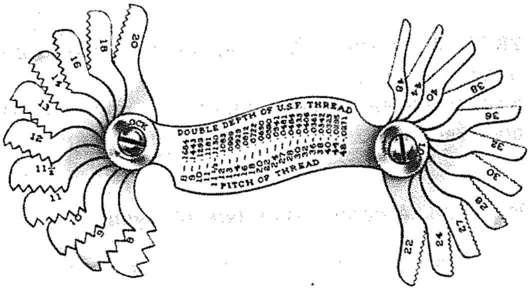


Fig. 4–37. Screw-pitch gage. (Lufkin Rule Co.)

of teeth, which corresponds to a definite pitch and form of thread. The number of threads per inch and the double-depth of the thread is usually marked on each leaf. To check the pitch, it is only necessary to match the teeth in the gage with the threaded part.

25. *What is meant by laying out work?*
Laying out work means accurately inscribing clean, sharp lines on the blank workpiece to show center lines, shape, or form of the finished workpiece, locations of centers for holes, circles for hole sizes, angles, arcs or curves, and slots. Dimensions for the lines to be inscribed on the metal are taken from the blueprint or sketch of the part to be made.

26. *What are some of the tools used for laying out work?*
Several tools are designed especially for marking lines, and many general-purpose tools are used for both layout and inspection of work. Some of the more commonly used tools for marking lines are scribers, dividers, trammels, surface gages, and height gages. Other general-purpose tools used in the layout process are surface plates, angle plates, squares, protractors, steel rules, clamps, prick

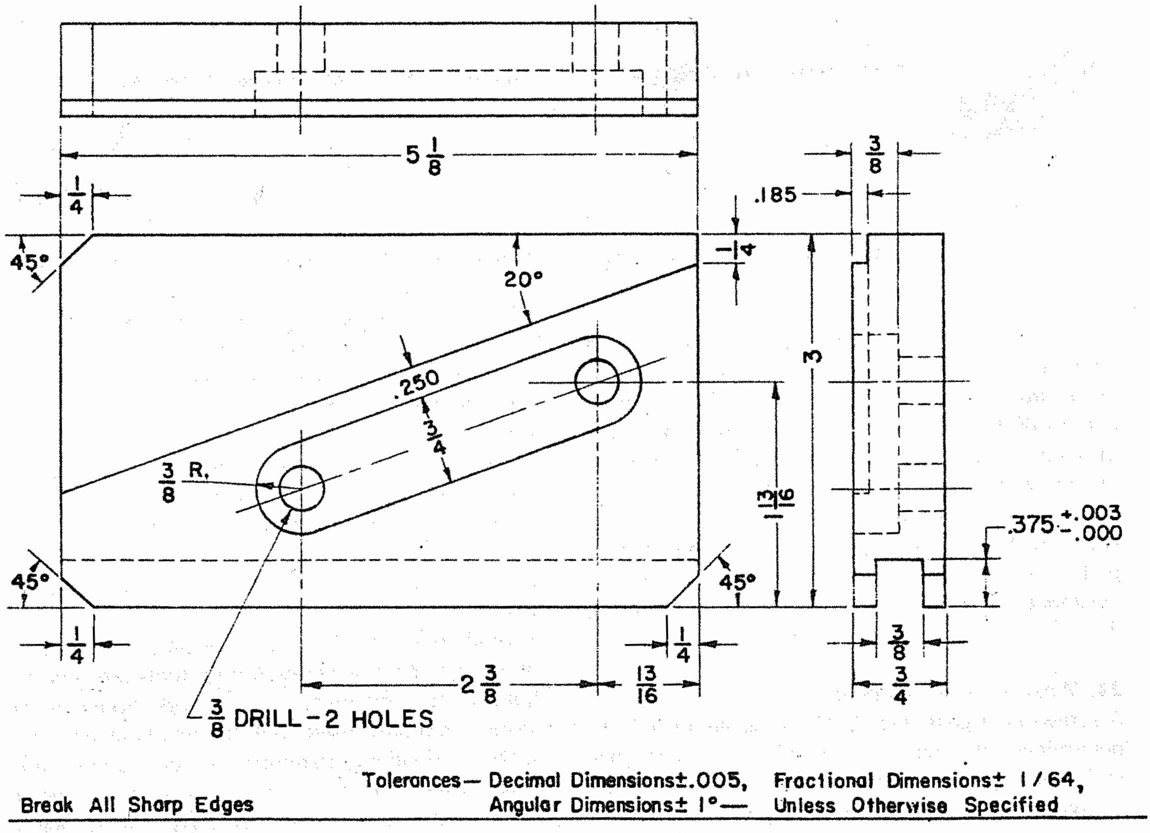
punches, small hammers, V blocks, and straightedges.

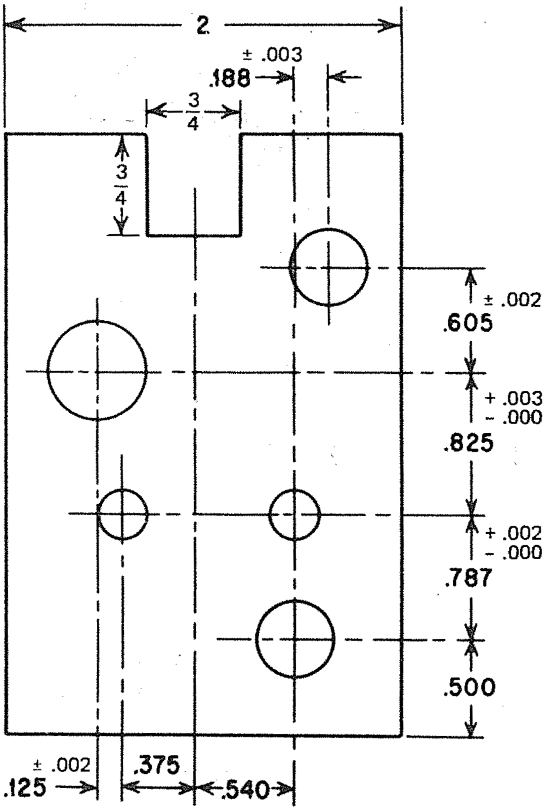
27. *What judgment is necessary to determine which layout tools should be used?*
The type of workpiece to be laid out and the degree of accuracy required will largely determine which tools should be used. When dimensions and tolerances are specified in fractional parts of an inch, tools such as a steel rule, surface gage, scriber, and dividers may be used (Fig. 4–38). When dimensions are specified in decimals, with tolerances of a few thousandths of an inch, precision tools such as a vernier height gage, gage blocks, and vernier protractor are required (Fig. 4–39).

28. *How are small, flat or square metal pieces prepared for layout?*
First, the metal piece is squared to correct length and width. Burrs are removed and sharp edges broken with a smooth file. The surface is cleaned with abrasive cloth to remove oil or grease. Parts for jigs, fixtures, and dies are often surface-ground to give a smooth, flat surface. The metal is colored with a layout dye (Fig. 4–40). Parts for tools and dies are sometimes heated to a steel-blue color, which is more permanent and does not rub off as easily as layout dye. Coloring the work makes the layout lines stand out sharp and clear.

29. *To what extent are castings laid out?*
Castings may require laying out before machining takes place or after a surface or two has been machined (Fig. 4–41). When small castings are to be machined in quantities, it is often necessary to lay out one of the castings to make certain enough material has been provided for machining. Holes that are cast are sometimes off-center due to the core moving during the pouring of the molten metal. Because more metal may have to be removed

Fig. 4–38. A nonprecision type of layout.





TOLERANCES ± .005 UNLESS OTHERWISE SPECIFIED.

Fig. 4–39. A precision layout job.

Fig. 4–40. Coloring the workpiece before layout. (L. S. Starrett Co.)

Fig. 4–41. Laying out a casting.

from one side than the other, the true center of the hole must be located. A piece of soft wood on which the center will be laid out is used to bridge the cast hole. A check is then made to see that there is enough metal to permit the boring of a true, clean hole.

30. *What is a surface plate?*
A surface plate (Fig. 4–42) is a very important and expensive piece of equipment used for laying out

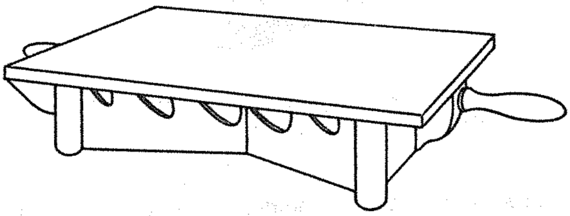


Fig. 4–42. Cast iron surface plate.

and inspecting workpieces. The importance of a surface plate is that it provides a true, smooth, plane surface from which accurate measurements may be made. These plates are made of either cast iron or granite. Cast iron plates are machined very smooth and handscraped to provide a true flat surface. Granite plates are lapped to a fine finish and a degree of accuracy measured in millionths of an inch. Some granite is almost as hard as a diamond. It cannot rust, corrode, or stain; it is resistant to temperature changes; it is nonmagnetic; and it retains its original accuracy much longer than cast iron plates. When worn, it can be restored to the original accuracy.

Rough work and tools such as files should never be placed on a precision surface plate. Finished workpieces and accessories must be carefully cleaned to remove grit, dirt, and chips before being placed on the surface plate. When not in use, the plate is usually protected by a wood cover.

31. *What are angle plates?*
Angle plates are precision tools made of cast iron, tool steel, or granite (Fig. 4–43). They are widely used as a fixture for holding work to be laid out, machined, or inspected. The faces are at right angles and may have threaded holes, slots, and fitted clamps for holding workpieces. Toolmaker's clamps and C clamps are also used to hold the work. Angle plates are generally used on surface plates and machine tool tables. Cast iron plates (Fig. 4–44) are surface-ground and hand scraped to a high degree of accuracy. Hardened tool-steel angle plates (Fig. 4–45) are surface-ground very accurately and may be lapped for accuracy and finish.

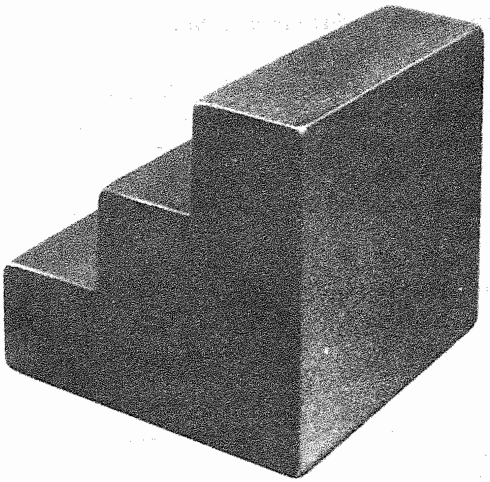


Fig. 4–43. A granite angle plate. (Brown & Sharpe Mfg. Co.)

32. *What is a scriber?*
A scriber is a sharp, pointed steel tool used to scribe lines on metal being laid out. Figure 4–46 shows three styles of scribers in common use. The scriber point is usually made from carbon tool steel, hardened and tempered, then honed on an oilstone to a needle point so it will produce a fine sharp line. Scribers having tungsten carbide points are also available (Fig. 4–47).

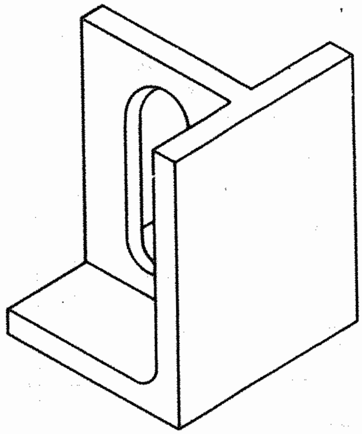


Fig. 4–44. Cast iron angle plate.

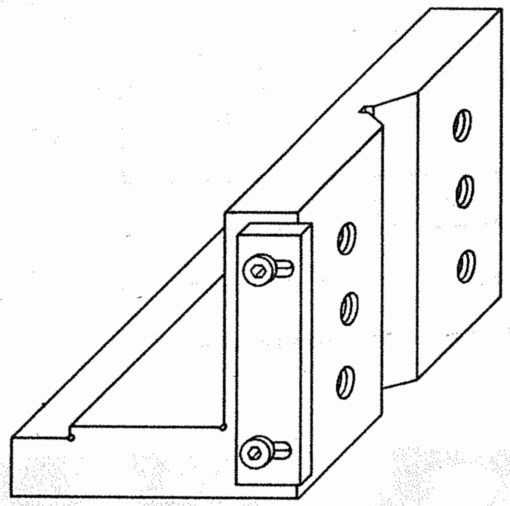


Fig. 4–45. Hardened steel angle plate.

33. *How should a scriber be used?*
Because the point of a scriber is very thin, sharp, and hard, especially those made of tool steel, it may break easily if too much pressure is applied. The

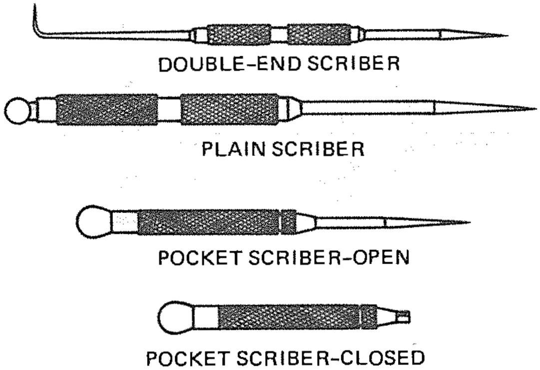


Fig. 4–46. Typical scribers.

Fig. 4–47. Carbide-point pocket scriber. (Lufkin Rule Co.)

amount of pressure used should be just enough to make a clear, clean line. When scribing a line, the scriber should be moved over the work only once. Scribing over the first line two or three times usually produces an unsatisfactory line or lines and is called *shoddy workmanship*. When scribing a line using a steel rule, the scriber should be tilted at a slight angle away from the rule so the point will be against the bottom edge of the rule. The scriber must also be tilted in the direction it is being drawn over the workpiece (Fig. 4–48).

34. *What is a divider?*
A divider (Fig. 4–49) consists of a pair of steel legs adjusted by a screw and nut and held together by a

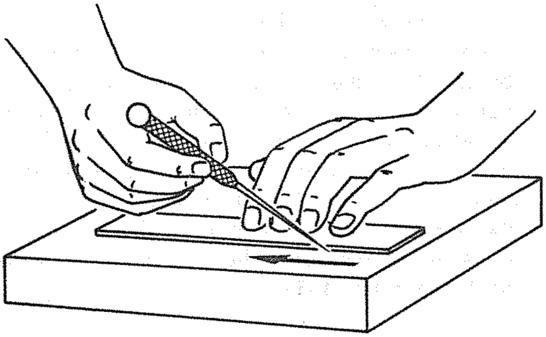


Fig. 4–48. Correct way to scribe a line using a rule as a guide.

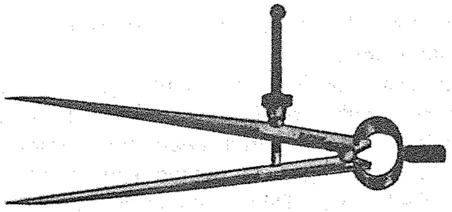


Fig. 4–49. Spring divider. (L. S. Starrett Co.)

circular spring at one end, in which is inserted a handle. It is available in sizes from 2 to 8 in. The size is the length of the legs from the pivot to the point.

35. *For what purposes are dividers used?*
Dividers are used for measuring the distance between points, for transferring a measurement directly from a rule, and for scribing circles and arcs on metal (Fig. 4–50).

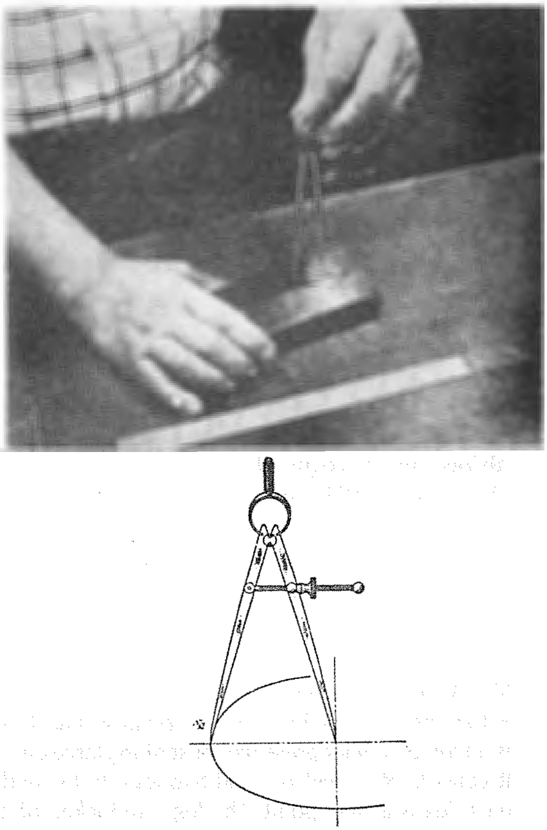
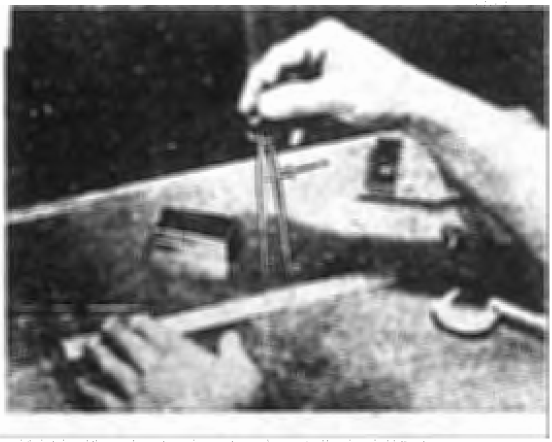


Fig. 4–50. Scribing a circle with dividers. (Lufkin Rule Co.)

36. *Describe the procedure for scribing a circle with dividers.*
The center of the circle should first be located and marked with a prick punch. Adjust the legs of the divider to the required measurement (radius of the circle), as in Fig. 4–51. Set the point of one leg in the pricked center. Then, holding the handle between forefinger and thumb, scribe short arcs on opposite sides of the center. Measure the distance between arcs. If the distance is not equal to the required diameter, make the necessary adjustment of the divider before scribing the complete circle.



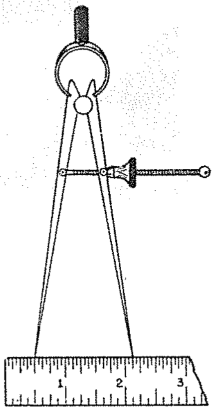


Fig. 4–51. Adjusting a divider to a required dimension. (Lufkin Rule Co.)

37. *What is a trammel?*
A trammel, also called a *beam compass* (Fig. 4–52), is a type of divider preferred for scribing large circles. It consists of a steel bar and two legs. In the end of each leg is a steel point. The legs are locked on the bar by tightening a knurled nut on the top of the leg. One of the legs has an adjusting screw attached to it. In setting the trammel to a required dimension, one leg is secured to one end of the bar; the other leg, with the adjusting screw, is moved from the first leg to approximately the correct distance. The adjusting screw is tightened to the bar, but the leg is not. By turning the adjusting screw, the loose leg is then adjusted for an accurate measurement, after which it, also, is locked on the bar. A V-shaped or a ball-shaped point may be used in one leg so that circles may be scribed from a hole. The bars are available in lengths of from 6 to 20 in.

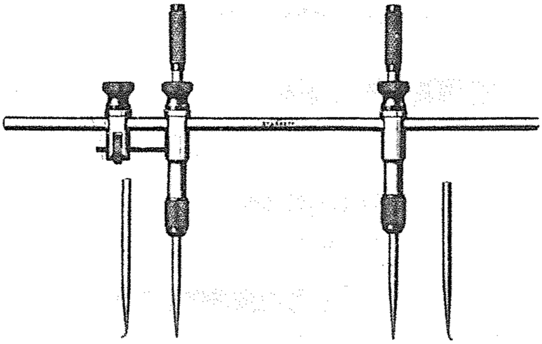


Fig. 4–52. A trammel. (L. S. Starrett Co.)

38. *What is a hermaphrodite caliper?*
A hermaphrodite caliper has two legs, which work on a hinge joint (Fig. 4–53). One leg is similar to a leg of a divider and the other is similar in shape to a leg of an inside caliper. Hermaphrodite calipers may be used to scribe arcs, or as a marking gage in layout work. To set hermaphrodite calipers to a rule, adjust the scriber leg until it is slightly shorter than the curved leg. Then, with the curved leg set on the end of a rule, adjust the scriber leg to a point opposite the required line on the rule, as illustrated in Fig. 4–54. A line parallel to the edge would be scribed as shown in Fig. 4–55.

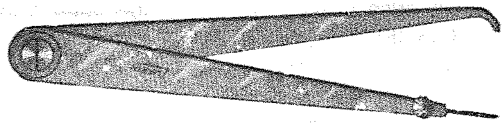


Fig. 4–53. Hermaphrodite caliper. (Lufkin Rule Co.)

39. *What is a surface gage?*
A surface gage (Fig. 4–56) is a tool consisting of a steel base with a rotating clamp, which holds a

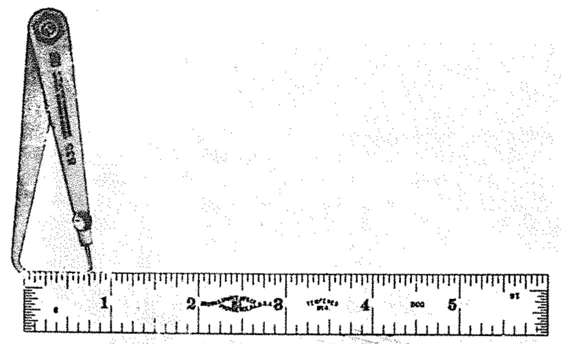


Fig. 4–54. **Adjusting a hermaphrodite caliper to size with a rule. (Brown & Sharpe Mfg. Co.)**

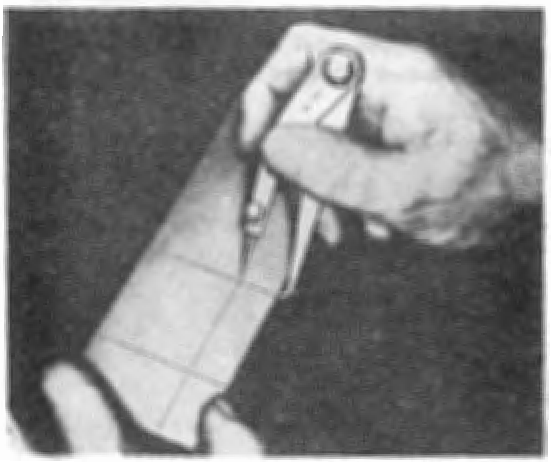


Fig. 4–55. Scribing a parallel line with a hermaphrodite caliper. (L. S. Starrett Co.)

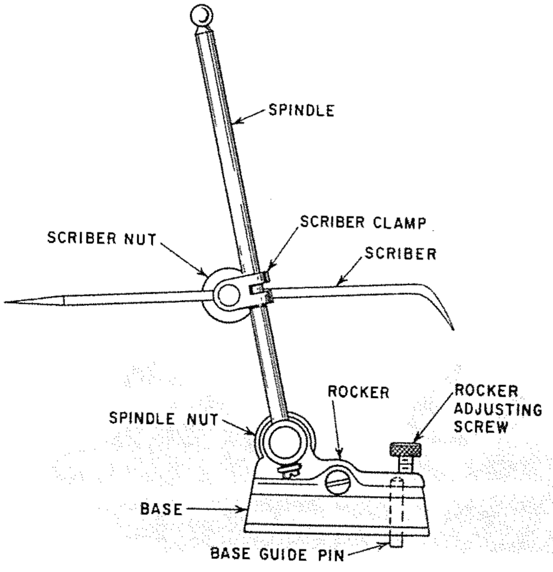


Fig. 4–56. Parts of a surface gage.

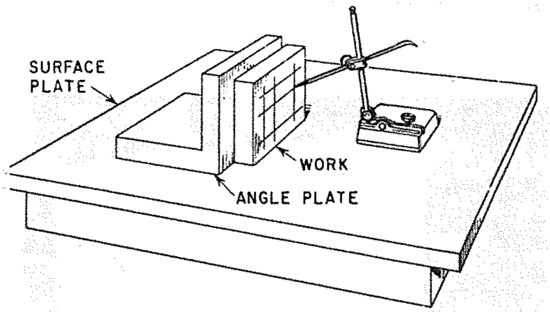


Fig. 4–57. Laying out parallel lines with a surface gage.

steel spindle. On the spindle is clamped a scriber. The base has a V-shaped groove, which makes it convenient for use on cylindrical work. A linear guide is provided by two gage pins, which may be pushed down through the base. The spindle may be rotated to any required position, even below the flat surface of the base. A rocker-adjusting screw is used so that the spindle may be adjusted to the exact dimension required.

40. *What are some of the uses of a surface gage?*
A surface gage is used for scribing lines on layout work (Fig. 4–57) and for checking parallel surfaces. Preferred ways for setting the scriber to a definite dimension are shown. The combination square in Fig. 4–58 and the rule holder in Fig. 4–59 are used in preference to a rule alone because either may be held securely without wobbling. Set the square or rule holder on the layout table, being sure that the rule is resting on the table and is clamped securely to the head of the square or rule holder. Then set the spindle of the gage at a convenient angle, place the scriber on the spindle at the approximate height desired, and, finally, adjust the point of the scriber to the exact measurement by means of the adjusting screw on the base of the gage. Two of the many ways of using a surface gage are shown in Figs. 4–60 and 4–61.

41. *What is a universal precision gage?*
A universal precision gage (Fig. 4–62) is an adjustable type of gage originally used for setting cutting

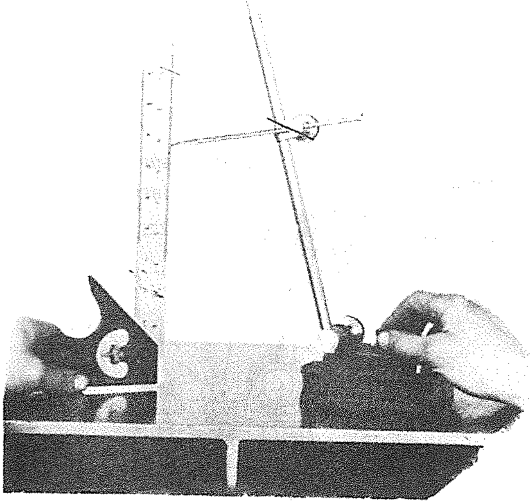


Fig. 4–58. Setting a surface gage using a combination square. (Brown & Sharpe Mfg. Co.)

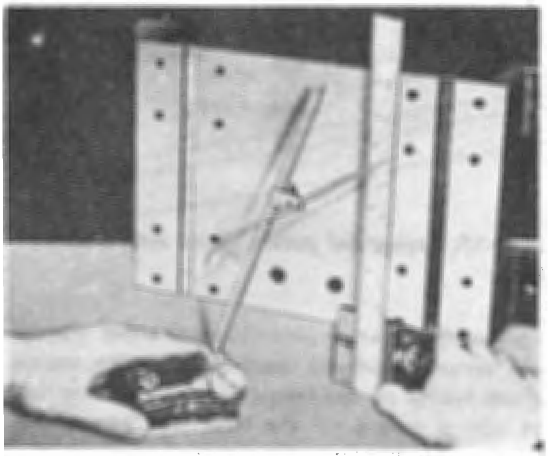


Fig. 4–59. Setting a surface gage to a rule held in a rule holder. (L. S. Starrett Co.)

Fig. 4–60. Checking work on a planer with a surface gage. (Brown & Sharpe Mfg. Co.)

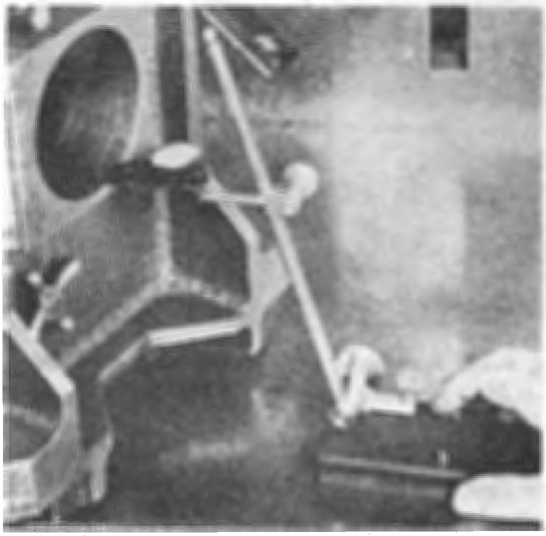


Fig. 4–61. Checking the location of a hole with a dial indicator on a surface gage. (Brown & Sharpe Mfg. Co.)

tools on shapers and planers. However, it has many other applications, such as use in measuring slots and openings, transferring indicator readings, and scribing layout lines and as a height gage. Figure 4–63 shows a universal precision gage with the scriber attachment in use.

42. *What is a steel straightedge?*
A steel straightedge (Fig. 4–64) is a rather thin flat strip of hardened steel, which has been ground parallel and flat and finely finished to a high degree of accuracy. It is used by both draftsmen and skilled craftsmen for drawing straight lines and inspecting surfaces for straightness and flatness.

43. *What is meant by squaring a workpiece?*
Squaring work is the operation of making and checking work surfaces that must be perpendicular, or at

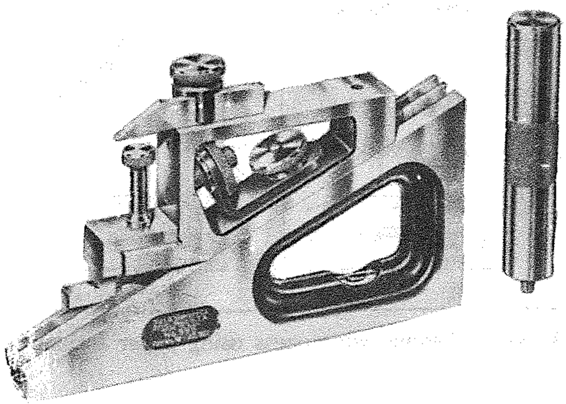


Fig. 4–62. Universal precision gage. (L. S. Starrett Co.)

Fig. 4–63. Scribing a line with a universal precision gage. (L. S. Starrett Co.)

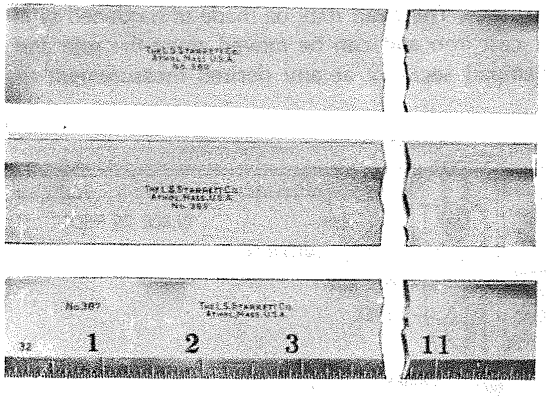


Fig. 4–64. Types of small straightedges. (L. S. Starrett Co.)

right angles (90°), to each other. This may be done by filing or machining. Squaring work is one of the major operations a machinist or toolmaker must perform on many jobs. There are a variety of squares designed to handle any job down to the tiniest part. For larger work there are squares up to 36 in. long.

Checking or testing for squareness is an important part of the squaring operation. This requires knowledge of the methods to be used and certain skills in using a square. The selection of the correct type and size of square, the preparation of the workpiece, and the correct way to hold and apply the square are all important. The following simple rules and illustrations explain how small workpieces may be checked for squareness.

A. Clean the work and remove all burrs and rough edges with a file before using a square (Fig. 4–65).

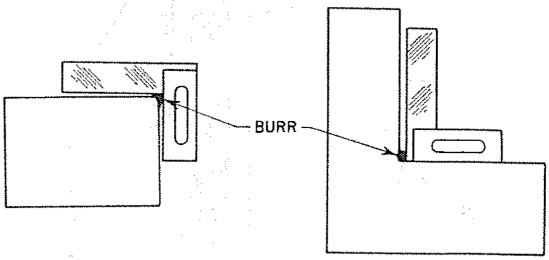


Fig. 4–65. Burrs cause errors when squaring work.

B. Wipe the blade and beam of the square to remove all dirt, chips, and oil.
C. Face the source of light so it will aid in detecting errors. You can judge the squareness by the line of light visible between the blade and work.
D. If you are right-handed, hold the work in your left hand and grasp the beam of the square with the right hand. Place the inside of the beam against the work so it is seated in full contact with the side and a small space is left between the blade and top surface of the work, as shown in Fig. 4–66.
E. Lower the blade by sliding the square downward until the blade touches the top surface very lightly, as shown in Fig. 4–67.
F. If the angle is not square, light will be seen at one end or the other (Fig. 4–68).

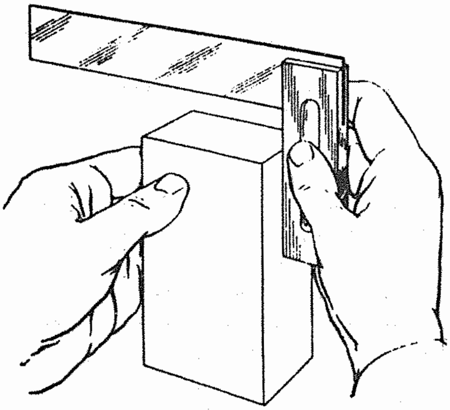


Fig. 4–66. Placing a square on a workpiece.

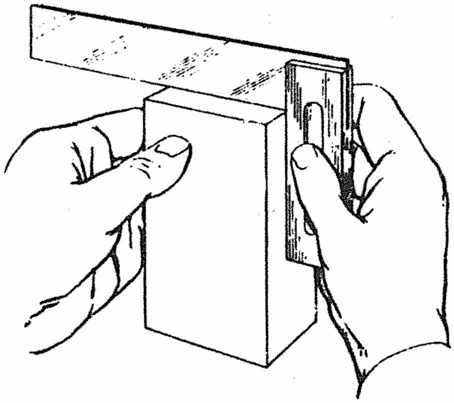


Fig. 4–67. Position for checking squareness.

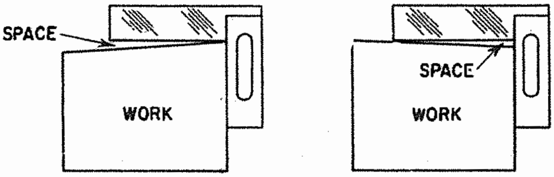


Fig. 4–68. Space at either end of blade indicates unsquared surfaces.

G. When testing inside surfaces, hold the beam down firmly and move it toward the surface to be tested. Tissue paper or cellophane may be used as a feeler at the top and bottom to tell if the blade is making contact, as shown in Fig. 4–69. To detect small errors, the paper strip should be rather narrow at the end

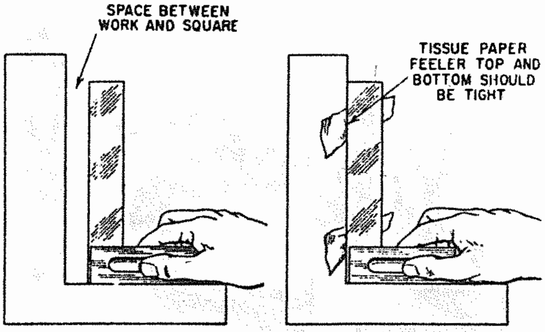


Fig. 4–69. Testing squareness using paper feelers.

placed between blade and work. When the paper feeler is tight when tested at the bottom, and tight when moved to the top, the work is square within the thickness of the paper feeler. The same procedure may be used by placing the work and square on a surface plate (see Fig. 4–78).

44. *Name the types of squares commonly used for layout, setup, and inspection of work*
The types of squares commonly used for layout, setup, and inspection of workpieces are combination square, try square, double square, diemaker's square, and hardened steel square.

45. *Describe a combination square.*
A combination square is a widely used tool for laying out, squaring, and checking work. It consists of a square head and a steel rule. The parts are shown in Fig. 4–70. It differs from other squares because it has a 45° miter face in addition to the 90° face. The head may be made of hardened steel or cast iron and can be moved along the rule and clamped securely at any desired measurement or

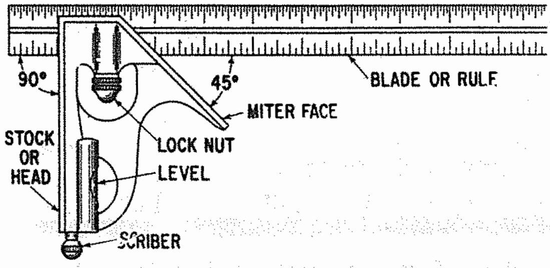


Fig. 4–70. Parts of a combination square.

position. The head is made in various sizes for rule lengths from 4 to 24 in. Figure 4-71 shows a number of applications of this type of square. Although these squares are made accurately, they have moving parts, which eventually wear: where extreme accuracy is required for squaring, setting up precision work, and inspection, a hardened steel square is recommended.

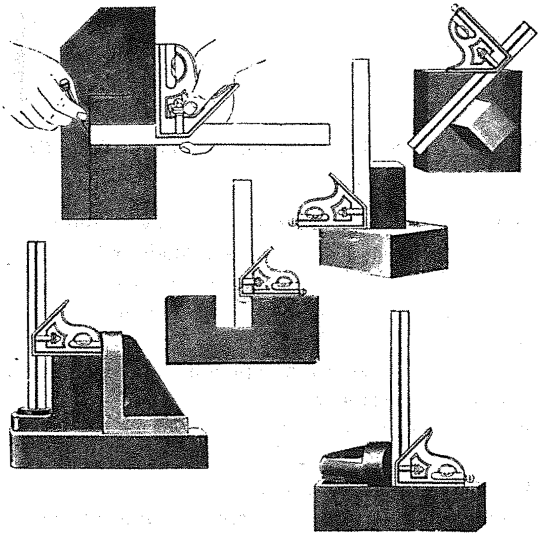


Fig. 4-71. Various ways of using a combination square.

46. *What is a try square?*
A try square (Fig. 4-72) is a small, light square that has a hardened steel blade without graduations. The blade is firmly held onto the beam by means of a special clamp screw. It is used for checking the squareness of many types of small work when extreme accuracy is not required.

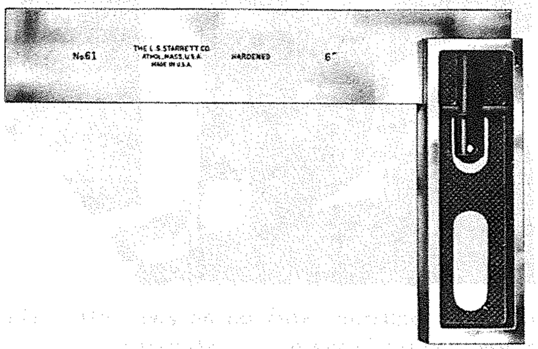


Fig. 4-72. Try square. (L. S. Starrett Co.)

47. *What is a double square?*
A double square (Fig. 4-73) consists of a beam having parallel sides and a sliding steel rule. Additional blades having angular ends provide a means of checking drill points and countersink angles. It is a useful square for general layout and testing of workpieces (Fig. 4-74).

48. *What is a diemaker's square?*
A diemaker's square (Fig. 4-75) is a small precision double square having a sliding graduated blade. Additional blades, which can be adjusted to specified angles, make it possible to measure clearance angles in dies and other types of tool work. Figure 4-76 shows the construction of this square.

49. *What is a hardened steel square?*
A hardened steel square (Fig. 4-77) is a precision

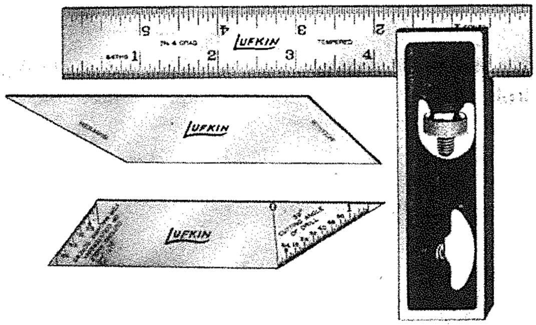


Fig. 4-73. Double square with angle blades. (Lufkin Rule Co.)

Fig. 4-74. Using a double square for laying out. (Lufkin Rule Co.)

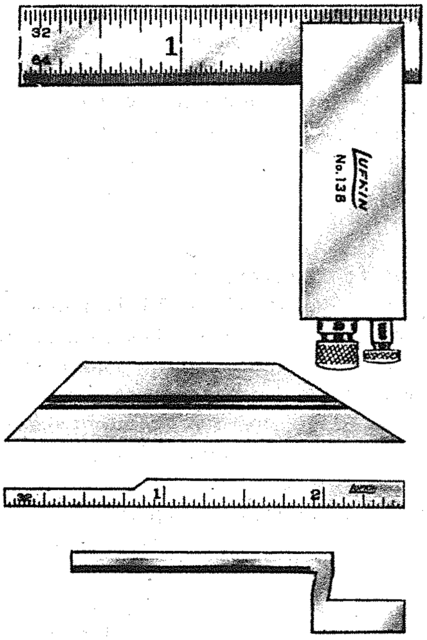


Fig. 4–75. Diemakers' square with blades. (Lufkin Rule Co.)

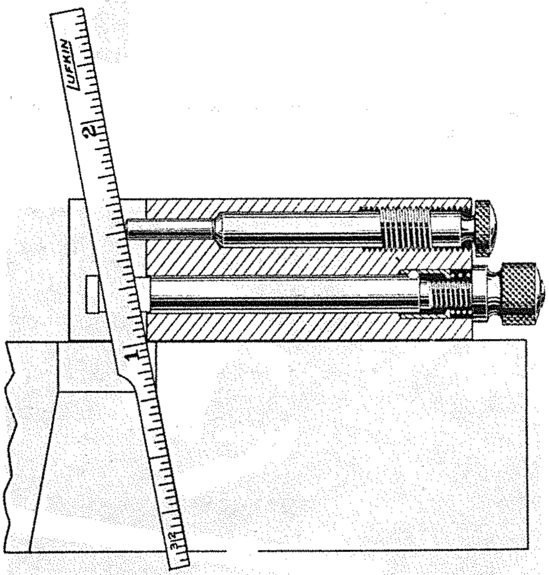


Fig. 4–76. Construction of diemakers' square. (Lufkin Rule Co.)

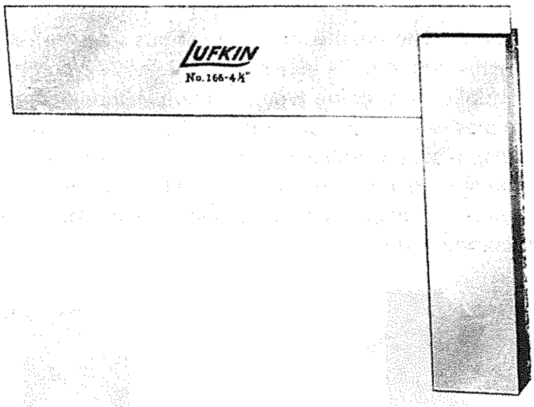


Fig. 4–77. Precision steel square. (Lufkin Rule Co.)

square used when extreme accuracy is required. Both the beam and the blade are made of hardened tool steel and ground and lapped to a fine degree of accuracy. Its use should be limited to the setup and inspection of finished precision workpieces. It is a type of precision tool that requires careful handling to preserve its accuracy. Figure 4–78 shows one of the many uses of this precision square.

50. *What is a center square?*
A center square (Fig. 4–79) consists of a 90° angular head, which fits on a steel rule. It can be clamped at any position along the rule. The edge of the rule bisects the right angle of the head. It is used to locate the centers of round workpieces. While the

Fig. 4–78. Squaring work on an angle plate with a precision steel square. (L. S. Starrett Co.)

Fig. 4–79. Application of a center square.

angular head is held tight against the circumference of the stock, two lines are scribed about 90° apart along the rule. The intersection of these two lines is the center of the circle (Fig. 4–80).

51. *What steps are necessary to complete a layout after the centerlines have been scribed?*
Because layout jobs vary greatly in shape, size, and accuracy the following recommendations are basic for general layout work of a nonprecision type.

After centerlines are scribed, they should be carefully checked for accuracy against the blueprint specifications. The intersecting lines for hole locations and radii should be carefully prick punched. Where accuracy is essential, locating the point of the punch at the exact intersection of the scribed lines is most important. This can be done by placing the sharp punch point in one of the scribed lines near the intersection, then carefully sliding it toward the intersecting line until you "feel" it as it meets the cross line. Hold the punch vertically and tap it very lightly with a small ball-peen hammer or use an automatic center punch (Fig. 4–81). The accuracy of the punch mark may be checked by using an eye loupe, which is a jeweler's magnifying glass. A toolmaker's hammer with a built-in magnifying glass (Fig. 4–82) makes it possible to locate the punch and strike it without removing the eyes from the work. A lightly made prick-punch mark error can be corrected by tilting the punch in the correct direction and tapping it with the hammer. When a number of equally spaced holes are to be made, an automatic center punch with a spacing attachment is a convenient tool to use (Fig. 4–83). Complete the layout by using dividers to scribe the hole sizes, circular

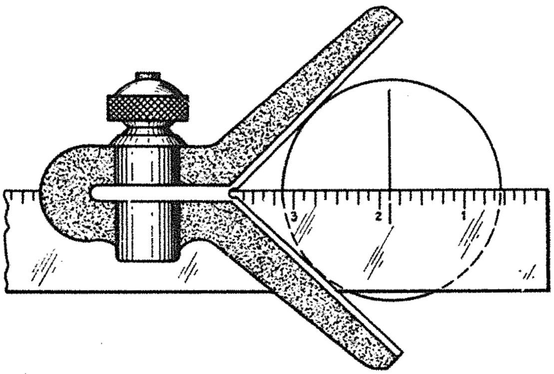


Fig. 4–80. A center square used for locating the center of round work.

Fig. 4–81. Prick punching a layout with an automatic center punch. (L. S. Starrett Co.)

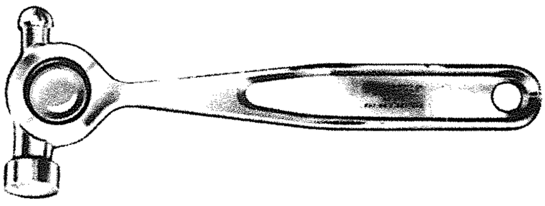


Fig. 4–82. A toolmaker's layout hammer with built-in magnifying glass. (L. S. Starrett Co.)

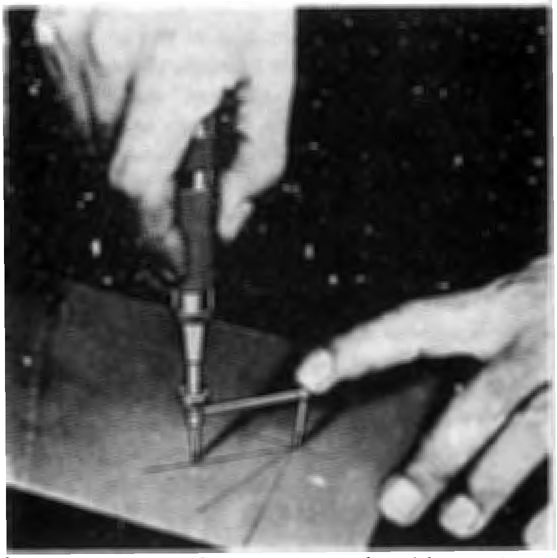


Fig. 4–83. Automatic center punch with spacing attachment. (L. S. Starrett Co.)

parts, and arcs, and, where necessary, scribe connecting straight lines using a steel rule or straightedge as a guide. Where holes are to be drilled, the prick-punch marks must be center punched. A center-punch mark is deeper and at a different angle from the prick-punch mark, and this helps the drill to start in the correct location.

Figure 4–84 shows the centerlines and angular lines that should be scribed first for the layout of the workpiece shown in Fig. 4–38. Figure 4–85 shows the next step of scribing the hole circles, the curved ends of the slot, and the connecting straight lines.

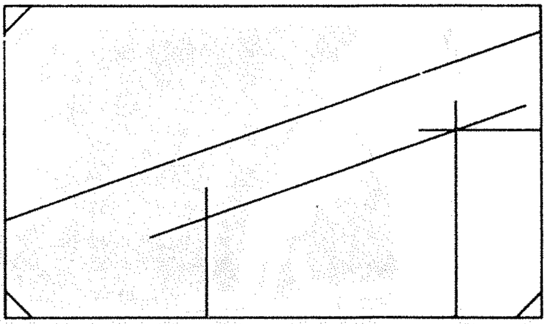


Fig. 4–84. Step 1. Layout centerlines and angular lines.

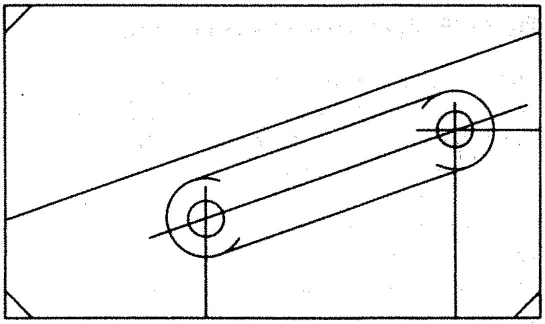


Fig. 4–85. Step 2. Layout hole circles, arcs, and connecting lines.

chapter 5 metrology

Metrology is the science of measurement. Judging by the history of mankind, every advance has been made possible by refinements in measurement of one kind or another. From the earliest civilizations evidence confirms man's dependence on measurement.

Over 4,000 years ago, the Egyptians built giant pyramids, which give ample evidence of their skill in measurement as well as geometric construction. The Egyptians used a master standard of length, the "royal cubit," to check the accuracy of cubit-measuring sticks, which were used "on the job."

At that time, units of measure were based on parts of the human body. The cubit, the length of a man's forearm; the digit, the width of a man's finger; the foot, the palm, the great span, the little span—all were units of measurement used by ancient civilizations.

The Romans retained some of these units in their measuring systems and added units equivalent to our foot, mile, and acre.

Our system of measurement dates back to medieval times, when the yard was proclaimed by king's edict to be the distance from the point of his royal nose along his outstretched arm to the tip of his thumb. The length of three dry grains of barley placed end to end equaled one inch, and by measuring the combined length of the left feet of 16 men (as they left church on a Sunday morning) and dividing by 16, the length of the foot was established.

As man's ingenuity devised new implements for farming and fighting, he also found it necessary to invent new methods of manufacture and with them more accurate systems of measurement. When the demand for an item created a need for increased production, new methods of manufacture had to be devised. Mass production developed interchangeable manufacture, and the need for more accurate means of measurement became evident.

In 1798, when he began manufacturing muskets for the United States Army, Eli Whitney devised the use of fixtures and gages made to conform to standards of measurement. This enabled the production of interchangeable parts.

As new machines were invented, new methods of production, which required more accurate standards of measurement, were developed. The permissible variation in the size of a machined part underwent continuous change. Tolerances of sixty-fourths of an inch were no longer adequate; they were reduced to thousandths, then to ten-thousandths of an inch.

Now that we are in the age of airplanes that fly faster than the speed of sound, capsules that take men to the moon, and satellites that travel to outer space, instruments must be used that measure in the millionths of an inch.

Metrology may well be the most important science in the manufacturing industry!

1. *Does the study of metrology require a knowledge of mathematics?*
Although many instruments used for fine measurements can be operated and read by an operator with little knowledge of mathematics, a complete understanding of metrology requires a good background in mathematics.

2. *What areas of mathematics should be studied?*
The student should have a complete working familiarity with arithmetic, geometry, and trigonometry.

3. *What branch of mathematics is most often used in metrology?*
Trigonometry is most often used in metrology.

4. *Which trigonometric functions are most useful?*
Sine, cosine, and tangent. These are used in solving problems based on the right-angle triangle.

5. *Are metrology problems based only on right-angle triangles?*
No. Trigonometry can be used to solve problems involving other than right triangles.

6. *What shortcuts are available for solving trigonometry problems?*
Values of the sine, cosine, and other trigonometric functions have been computed for all angles and are readily available in printed form. These are known as trigonometrical tables. Approximate solutions to trigonometric problems may be calculated on slide rules having trigonometric scales (S, ST, T).

7. *What other subjects can be useful to the study of metrology?*
The fundamentals of physics or physical science can prove very helpful, particularly the branches that deal with applied mechanics, laws of motion, elasticity, tension, compression, bending, torsion, shearing, and moment of inertia. Because many measuring instruments utilize lens systems, a study of basic optics also would be useful.

8. *Why is an understanding of heat and temperature important in the study of metrology?*
Temperature becomes a very important factor when exceedingly fine measurements are involved. Metals commonly used in engineering undergo significant changes in size when variations in temperature take place. The handling of laboratory equipment, the parts being measured, and the heat radiation from the technician's body can all cause measurable size changes, which must be taken into account.

9. *Is a standard temperature used in metrology?*
The internationally recognized standard temperature for engineering measurements is 68 degrees Fahrenheit (20 degrees Celsius). The temperature is thermostatically controlled in metrology laboratories, and all gages are made to be correct at 68° F (20° C).

10. *Is there an agency through which standards of measurement can be checked and regulated?*
The National Bureau of Standards (NBS), which is part of the U.S. Department of Commerce, has custody of the standards of physical measurement. The Bureau checks, tests, and calibrates measuring instruments with their standards. The Bureau assists industry in maintaining accuracy in measurement by testing and checking with the approved measuring standards. The American National Standards Institute (ANSI), a private standards organization whose members include trade and technical associations, industrial corporations, and interested individuals, approves and publishes standards in a great many areas; it is also the U.S. member of the International Organization for Standardization (ISO).

11. *Why are standards in measurement so important?*
The requirements of present-day industry have made standardization of measurement essential. Machine and instrument parts are manufactured in shops far from the assembly line. Each part is expected to fit into its prepared niche and function efficiently. Interchangeable manufacture makes accuracy in measurement essential. In addition, the operation of many products must be coordinated with the physical laws that control their behavior. Space travel, for example, depends on the operation of motors, timers, and electronic devices, which are manufactured according to the most exacting specifications. To be effective, however, the established standards of measurement must be based on certain natural physical properties of materials.

2. *How is such accuracy obtained?*
y having a system of measurement that is both eliable and repeatable. Also by having instruments hat can maintain repeatability of extremely precise neasurements. Terms that define the basic concepts f measurement are also necessary.

3. *What are some of the important terms that contribute to the understanding of precise measurement?*
Many terms are used to describe measurement. Among these are basic size, limits, tolerance, clearance, and allowance.

4. *How are these terms defined and used?*
The key terms in measurement are defined as follows:

Basic size. The theoretical absolute perfect dimension, without any consideration of limits or tolerances.

Limits. The maximum and minimum allowable dimensions, above and below the basic size.

Tolerance. The permissible variation in the size of a part; shows the permissible variation above and below the basic size. For example, in the dimension:

$$1.500^{+.000}_{-.003}$$

the tolerance is given by the figures +.000 and −.003. This is a bilateral tolerance. Tolerance given in one direction only, either plus or minus, is unilateral.

Clearance. The difference in size between mating parts where the outside dimension of the shaft is smaller than the internal dimension of the hole.

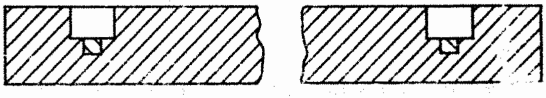
Allowance. The intentional difference in the dimensions of mating parts, or the minimum clearance that can be allowed between mating parts. It provides for different classes of fits.

15. *How many classes of fits are recognized by the American National Standards Institute?*
The eight classes of fits recognized by ANSI are as follows:

Class 1. Loose fit; large allowance
Class 2. Free fit; liberal allowance
Class 3. Medium fit; medium allowance
Class 4. Snug fit; zero allowance
Class 5. Wringing fit; zero to negative allowance
Class 6. Tight fit; slight negative allowance
Class 7. Medium force fit; negative allowance
Class 8. Heavy force and shrink fit; considerable negative allowance.

16. *What is an end standard?*
A measuring device; a block or bar of hardened steel, where the basic dimension is that between two parallel plane surface ends. The ends are ground and lapped parallel and flat to a millionth-of-an-inch accuracy.

17. *What is a line standard?*
A measuring device; a bronze bar that could be 38 in. long and 1 in. square. Two gold plugs, 0.100 in. in diameter, are inserted and the faces polished. A fine line is scribed in the center of each plug, and the distance between the two lines is exactly one yard, one meter, or whatever distance the line standard represents (Fig. 5–1). Standards, whether end or line, are made and used in a temperature-controlled laboratory.



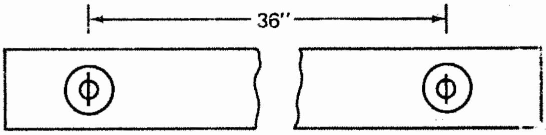


Fig. 5–1. A line standard of one yard.

18. *Are all measuring tools considered to be a part of metrology?*
Yes, but in this section we are considering only precision measuring tools and instruments.

19. *Is the rule considered to be a precision measuring tool?*
No. The rule and the many measuring tools associated with it are used in the shop for measurements where a small variation in the size would not spoil the work. The term commonly used for such dimensions is *scale dimension*. Scale dimensions are usi

ally permitted to vary from the required size ten thousandths (0.010) of an inch either way and still pass inspection. Skilled mechanics are able to measure within such limits with a rule. However, a good percentage of measurements made by toolmakers are for *precision dimensions*. This term is used for dimensions where the amount of error permitted is less than 0.010 of an inch and may be as little as one ten-thousandth (0.0001) of an inch.

20. *What are some of the requirements of a precision measuring instrument?*
A precision measuring instrument should conform to the following requirements:

1. It must be able to measure externally and internally to within one ten-thousandth (0.0001) of an inch.
2. It must be of such design as to be used directly on the work, to eliminate the possibility of error in transferring accurate measurements.
3. It must give the same result, any number of times, in the hands of different mechanics.
4. It must be self-checking, so that error due to wear, accident, or abuse may be readily discovered.
5. The materials from which it is made must be seasoned and stabilized, to reduce to a minimum errors in accuracy due to the changes that take place normally in metals.
6. It must have an established reputation for accuracy that is accepted by the manufacturer and the customer.

MICROMETERS

Special instruments have been invented and designed so that precision dimensions may be accurately measured. The most common precision instrument is the micrometer caliper. It was invented by Jean Palmer, a Frenchman, in 1848. It was introduced in the United States in 1867, when J. R. Brown and L. Sharpe returned from a visit to the Paris Exposition with a Palmer micrometer caliper (Fig. 5–2). From this instrument they developed the predecessor of the modern micrometer, which was offered to the public in 1877 (Fig. 5–3). In 1885, the same men introduced a new model (Fig. 5–4), which is almost identical with those in use today. Compared with the rule, the micrometer is a newcomer in the field of measurement. The regular micrometer, usually referred to in the shop as a *mike*, is used for measuring outside dimensions. It is available in many sizes. There are several other types of micrometers, but all follow the same fundamental principle.

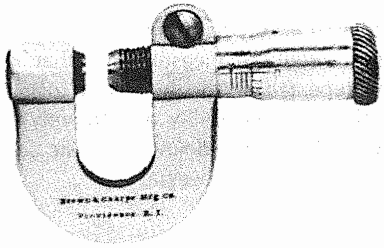


Fig. 5–2. Palmer micrometer of 1867. (Brown & Sharpe Mfg. Co.)

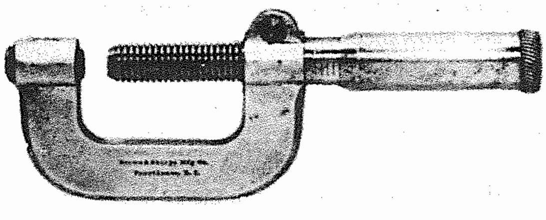


Fig. 5–3. Micrometer caliper of 1877. (Brown & Sharpe Mfg. Co.)

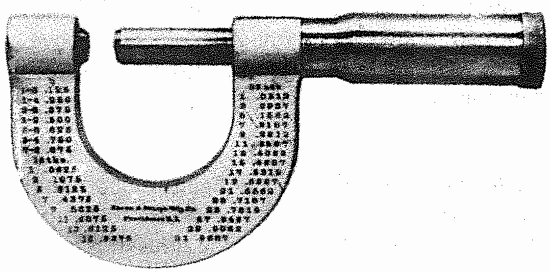


Fig. 5–4. Micrometer caliper of 1885. (Brown & Sharpe Mfg. Co.)

21. *What are the five principal parts of a micrometer?*
The five principal parts are the frame, anvil, spindle, sleeve, and thimble (Fig. 5–5).

22. *What are the graduations of a micrometer?*
The graduations on the sleeve of the micrometer are twenty-five thousandths (0.025) of an inch apart.

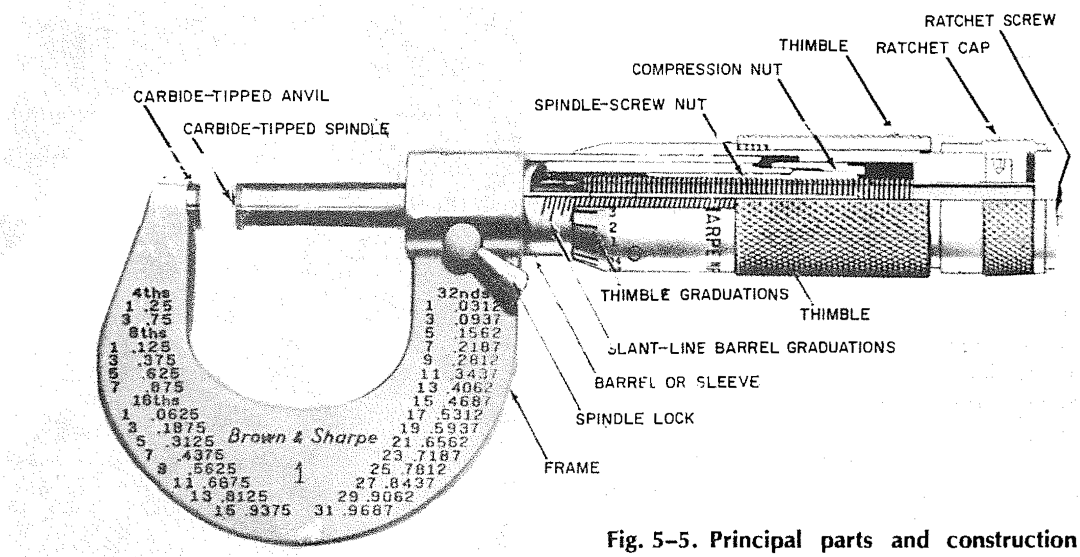
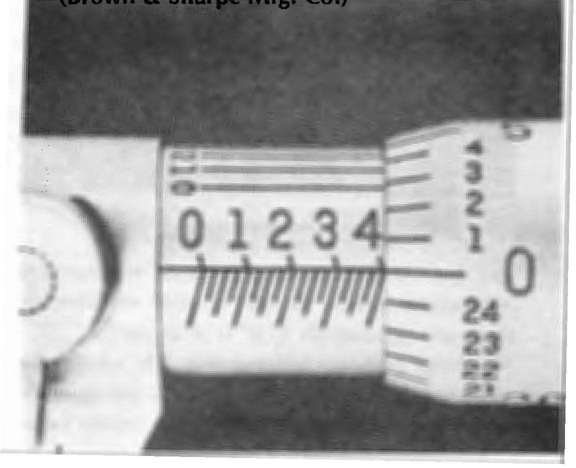


Fig. 5-5. Principal parts and construction of a modern micrometer caliper. (Brown & Sharpe Mfg. Co.)

Every fourth division on the sleeve is marked with a number from 0 to 10, thus identifying each one-tenth of an inch, or a hundred thousandths (0.100). Each of the numbers is read as if two zeros were added to each one, as the 0.400 shown in Fig. 5–6.

The graduations on the thimble represent divisions of one thousandth (0.001) of an inch. This is determined as follows: The edge of the thimble coincides with the zero on the sleeve when the micrometer is closed. Each time the thimble is turned one revolution, it moves along the sleeve one graduation, or 0.025 in. The circular edge of the thimble has 25 equal divisions etched on it, so when the thimble is revolved just enough to equal one of the divisions, it has moved along the sleeve one twenty-fifth (1/25) of twenty-five thousandths, which is one thousandth (0.001) of an inch. In some micrometers only every fifth division is numbered.

Fig. 5–6. Micrometer slant-line sleeve graduations. (Brown & Sharpe Mfg. Co.)



23. *Why does the thimble of a micrometer move along the sleeve exactly twenty-five thousandths (0.025) of an inch for each complete revolution of the thimble?*
The inside of the micrometer is threaded so that each time the thimble is turned, it moves along the sleeve in the same manner as a nut on a bolt. These threads are made 40 to the inch, so when the thimble is revolved one complete revolution, it moves along the sleeve one-fortieth (1/40) of an inch, which equals the decimal fraction of twenty-five thousandths (0.025) of an inch.

24. *How are the graduations read on a micrometer?*
The graduations exposed on the sleeve are read first, the numbers as hundreds, to which is added 25 for each of the remaining whole divisions, plus the actual number of divisions on the thimble which have passed the revolution line. The reading in Fig. 5–7 is 200 plus 25 plus 16, a total of 241

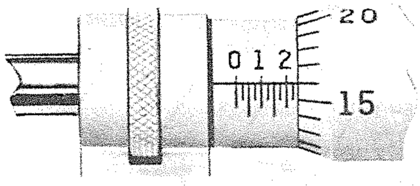


Fig. 5–7. The micrometer shows a reading of 0.241 in. (Brown & Sharpe Mfg. Co.)

thousandths of an inch. In Fig. 5–8, the division on the sleeve past the figure 2 is not a complete division, so the reading is 200 on the sleeve plus 24 on the thimble, a total of 224 thousandths of an inch. In practice, after the micrometer has been adjusted to fit the work to be measured, the size may be read while it is still on the work, or it may be removed, care being taken to avoid moving the thimble.

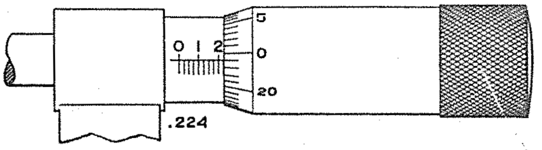


Fig. 5–8. This micrometer reads 0.224 in. (Brown & Sharpe Mfg. Co.)

25. *How is a micrometer held and adjusted to measure a piece of work?*
The work may be held in one hand and the micrometer in the other, as in Fig. 5–9. If the work is supported, as on the lathe in Fig. 5–10, it may be more convenient to use both hands. The thimble should be turned gently until the spindle and the anvil of the micrometer just touch the work. One should be able to feel the contact on both sides. Do not force the spindle against the work to grip it, as with a clamp. It is a common practice to revolve the micrometer back and forth a little on the work to make sure that a correct measurement is made.

26. *What is a ratchet stop on a micrometer?*
A ratchet stop (see Fig. 5–5) is a device that prevents the use of too much pressure when adjusting a micrometer on a part to be measured. The ratchet prevents further turning of the thimble, after the correct amount of pressure has been applied to the spindle to give an accurate measurement.

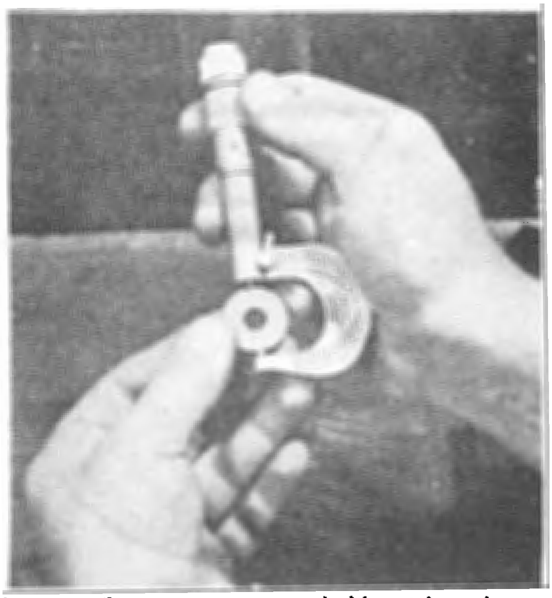
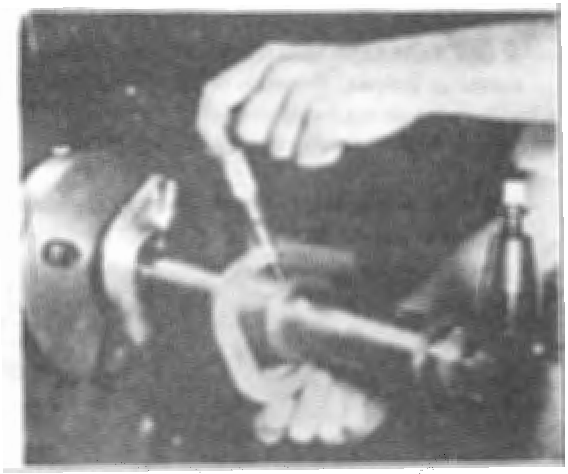


Fig. 5–9. The correct way to hold a 1-in. micrometer when measuring small work. (Lufkin Rule Co.)

Fig. 5–10. Measuring work at the lathe using a large micrometer. (Brown & Sharpe Mfg. Co.)



27. *Can dimensions be accurately measured with a micrometer when the permissible variation is less than one thousandth (0.001) of an inch?*
Yes. With ordinary micrometers it is possible to estimate one-half of one-thousandth (0.0005) of an inch when the revolution line on the sleeve comes in

between two division lines on the thimble. For accurate measurements of less than one thousandth of an inch (0.001), a micrometer with a vernier scale on the sleeve should be used (Fig. 5–11).

28. *Describe the vernier scale of a micrometer.*
The vernier scale of a micrometer consists of 11 graduations (10 equal divisions) etched on the sleeve of the micrometer, numbered 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 0. The 10 divisions equal in space 9 divisions of the thimble, which represent nine thousandths of an inch (0.009). Each division on the vernier scale represents nine ten-thousandths of an inch (0.0009). The difference between one of the divisions on the thimble and one of those on the vernier scale is 0.0001, or one ten-thousandth of an inch.

29. *Explain how the vernier-scale graduations of a micrometer are read.*
When the first and last lines on the vernier scale coincide with the lines on the thimble, as at A and B in Fig. 5–12, it indicates that the reading made in the ordinary way is accurate; in this case, it is 0.250. If one of the other lines on the vernier scale coincides with one of the lines on the thimble, as at C in Fig. 5–12, then the number of the vernier line indicates how many ten-thousandths of an inch should be added to the original reading. In this case, line 7 is the one that coincides with one of the lines on the thimble, so seven ten-thousandths (0.0007) should be added, making the correct reading 0.2507 of an inch.

30. *What are some of the reasons why measurements made with a micrometer are not accurate?*
The most common reason is failure to make sure that the work to be measured and the faces of the anvil and spindle of the micrometer are clean. Another reason is that the micrometer being used may need adjustment due to wear or careless handling. A third reason is lack of care on the part of the workman in reading the graduations.

31. *What is an inside micrometer?*
An inside micrometer (Fig. 5–13) is designed with the same graduations as an outside micrometer and is adjusted by revolving the thimble in the same way. It is used for taking internal measurements where greater accuracy is required than can be obtained

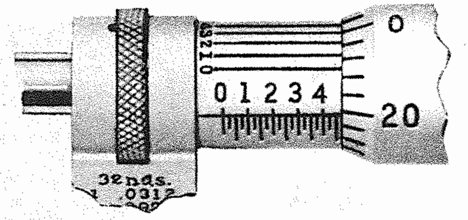


Fig. 5–11. Vernier scale on the sleeve of a micrometer. (Brown & Sharpe Mfg. Co.)

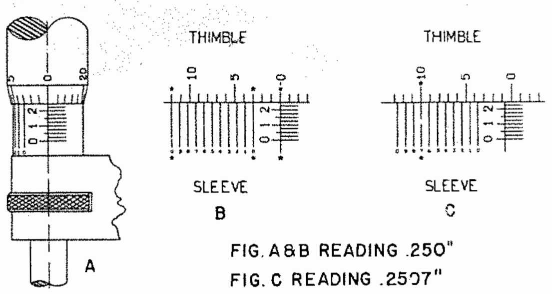


Fig. 5–12. Reading the vernier scale of a micrometer. (L. S. Starrett Co.)

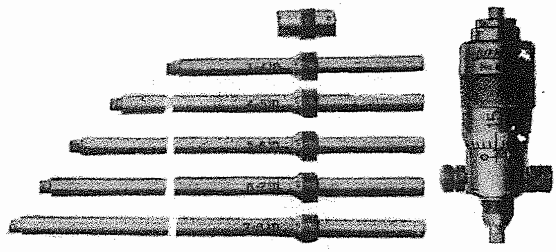


Fig. 5–13. Inside micrometer. (Lufkin Rule Co.)

with inside calipers or telescoping gages. It is available in many sizes. Figure 5–14 shows an inside micrometer in use. Figure 5–15 shows an inside micrometer caliper.

32. *What is a tube micrometer?*
A tube micrometer (Fig. 5–16) is specially designed to measure the thickness of the material of piping, tubing, and similar shapes.

33. *What is a screw-thread micrometer?*
A screw-thread micrometer (Fig. 5–17) is similar to an outside micrometer except that the spindle is

Fig. 5–14. Measuring a bored hole with an inside micrometer. (South Bend Lathe Works.)

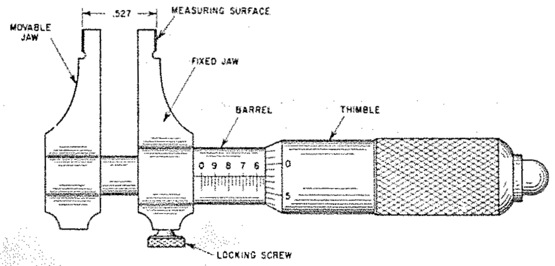


Fig. 5–15. Inside micrometer caliper.

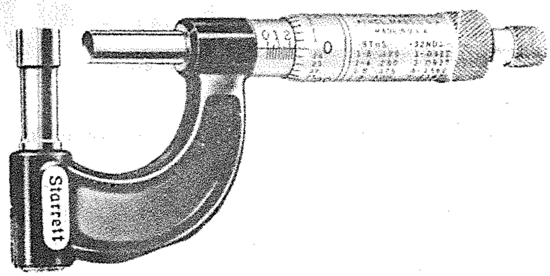


Fig. 5–16. Tube micrometer. (L. S. Starrett Co.)

pointed to fit between 60° V threads, and the anvil is shaped to fit over a 60° V thread. It is used to measure the pitch diameter of a thread. Screw-thread micrometers are available in many sizes depending on the pitch of the thread to be measured.

34. *What is a depth micrometer?*
A depth micrometer (Fig. 5–18) is designed to measure accurately the depth of grooves, recesses, and holes. The graduations are read in the same manner as a regular micrometer.

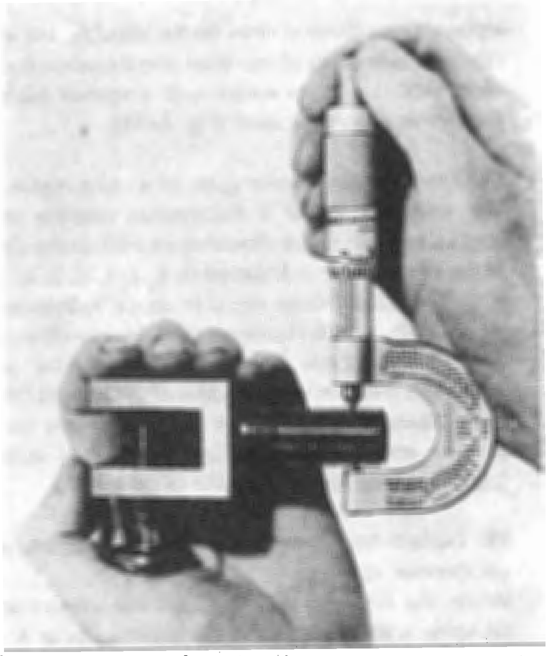
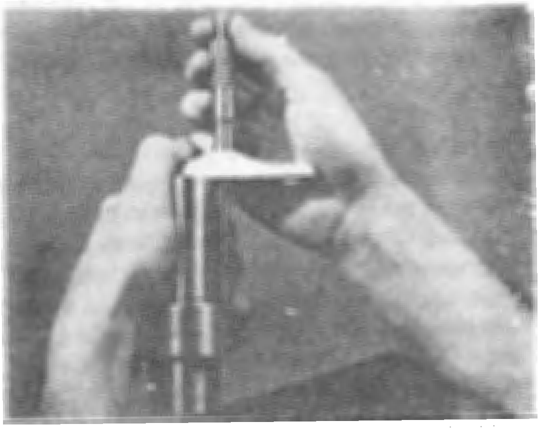


Fig. 5–17. Screw-thread micrometer. (Brown & Sharpe Mfg. Co.)

Fig. 5–18. Depth micrometer or micrometer depth gage. (Brown & Sharpe Mfg. Co.)



35. *What is an indicating micrometer?*
An indicating micrometer (Fig. 5–19) combines the

precision of the dial indicator, for uniform contact pressure, with the accuracy of the micrometer screw for measuring. The graduations on the sleeve and thimble are the same as on a regular micrometer. The indicator dial registers divisions of one ten-thousandth (0.0001) of an inch. In measuring with this type of micrometer, the size is noted on the sleeve in thousandths of an inch, and then the number of ten-thousandths shown on the dial by the indicator finger is added.

The indicating micrometer may also be used as a comparator. For this purpose, the spindle may be clamped in position to a required dimension by tightening the ring nut on the spindle. When it is to be used in this way, the two large hands of the indicator are adjusted on each side of zero, to indicate the amount of variation permitted above or below the required dimension. If the indicating finger is moved outside of the two hands, then the part being measured is too large or too small, depending upon which direction the finger moved. When measuring a number of parts of the same size, it is not necessary to turn the spindle or to force the part between the anvil and spindle. Instead, the anvil may be retracted by pressing a button, as in Fig. 5–20. This saves wear on the ends of the anvil and spindle.

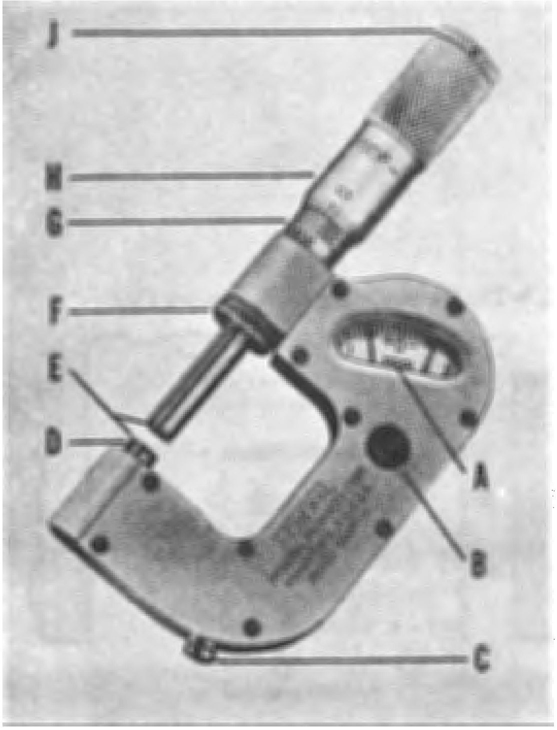


Fig. 5–19. Indicating micrometer. (Federal Products Corp.)
A. Indicating dial.
B. Tolerance hand-setting screws.
C. Retracting button.
D. Retractable anvil.
E. Tungsten carbide lapped spindle and anvil faces.
F. Spindle lock-nut.
G. Barrel and zero graduation.
H. Thimble.
J. Thimble-locking cap.

Fig. 5–20. The indicating micrometer may be used as a comparator. (Federal Products Corp.)

VERNIERS

In 1631, a Frenchman named Pierre Vernier invented a method of making accurate measurements by dividing lined graduations into smaller divisions. This method has been adapted for use with other measuring instruments, which add the name Vernier to identify their more accurate measuring capacity—for example, the vernier micrometer.

36. *Explain the principle of the vernier scale used on a rule.*
A vernier scale for a rule consists of a slide that fits over the rule. A distance on the slide of six-hundred thousandths (0.600) of an inch is graduated into 25 equal parts so that each division measures twenty-four thousandths (0.024) of an inch (Fig. 5–21). The

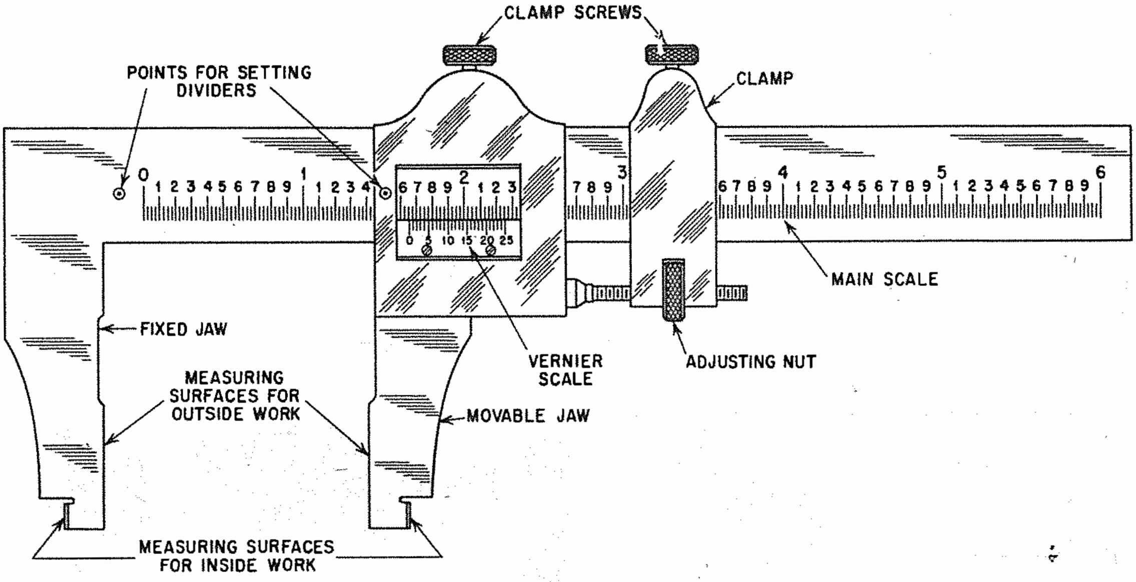


Fig. 5–21. The parts of a vernier caliper.

Fig. 5–22. A zero reading on the vernier scale.

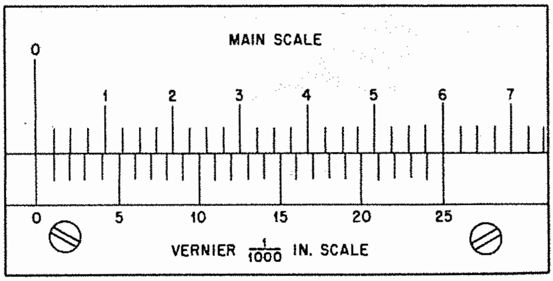
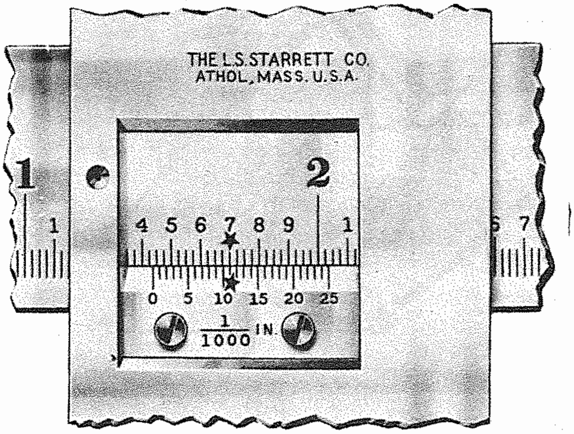


Fig. 5–23. Vernier scale. (L. S. Starrett Co.)



graduations on the rule itself are twenty-five thousandths (0.025) of an inch, so in a distance of 0.600 there are 24 divisions on the rule. The difference in the size of the divisions on the rule and those on the vernier scale is one thousandth (0.001) of an inch (Fig. 5–22).

37. *How are measurements read on a vernier rule?* The zero mark on the vernier scale indicates the measurement to be read on the rule. In Fig. 5–23, this is seen to be 1.425 in. and a little more. The exact amount over 1.425 is found by examining the division lines of the vernier scale to see which one exactly coincides with one of the lines on the rule. In this case, it is line 11, so the full measurement is 1.425 plus 0.011, which equals 1.436 in.

38. *The lines of a vernier scale are very fine and close together, so it is not easy to see which lines coincide. What precautions should be taken to insure an accurate reading?*
Clean the vernier scale and the rule. Face the light with the vernier scale held in a horizontal position and tipped slightly, in order to look directly down the lines on the vernier plate. To make reading easier, it is a common practice to use a magnifying glass (Fig. 5–24).

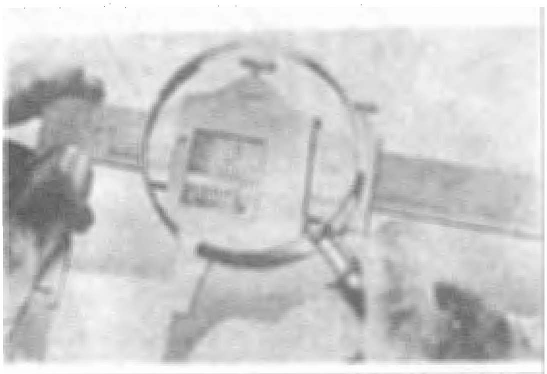


Fig. 5–24. A magnifying glass aids in reading a vernier scale. (Brown & Sharpe Mfg. Co.)

39. *What is a vernier height gage?*
A vernier height gage (Fig. 5–25) consists of an upright steel bar fastened to a steel base. On the bar is a movable jaw with a vernier scale. A clamp on the bar is connected to the movable jaw by a screw. This screw is used to adjust the vernier scale to a required position.

40. *Are both sides of the vernier height gage graduated in the same manner?*
The size of the graduations is the same on both sides of the bar, but one side is for inside measurements with the graduations reading from zero. The other side of the bar has graduations for outside measurements which start at 1 in. For this reason, care should be taken to read the vernier from the correct side for the work being done. Some makes of vernier height gages are graduated only on one side.

41. *What are some of the uses of a vernier height gage?*
Many attachments may be used with a height gage. Figure 5–25 shows a flat scriber clamped to the movable jaw. This is standard equipment. The scriber is used for layout work, as in Fig. 5–26. An offset scriber (Fig. 5–27) is used when it is required to take measurements from the surface upon which the gage is standing to a lower plane, as in Fig. 5–28. A rod may be attached, as in Fig. 5–29, so that the height gage may be used as a depth gage. For measuring between two points where extreme accuracy is required, an indicator may be attached to the movable jaw. Figure 5–30 shows how the location of a

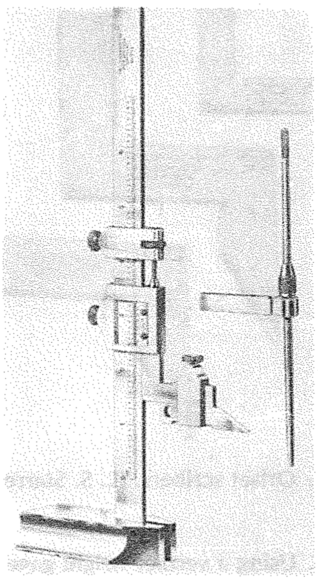


Fig. 5–25. Vernier height gage with depth attachment. (L. S. Starrett Co.)

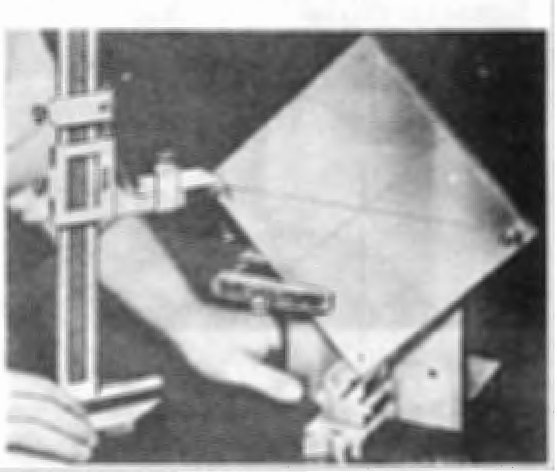


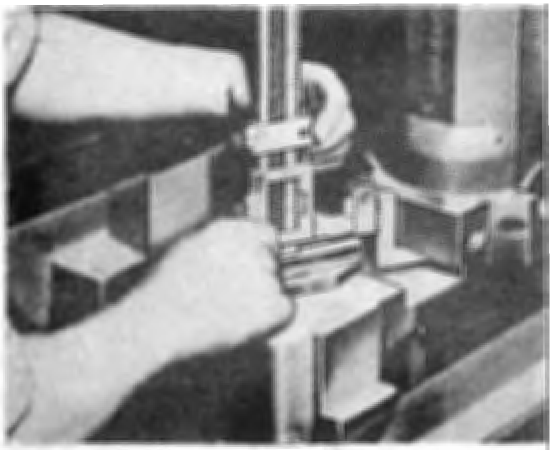
Fig. 5–26. Using a vernier height gage with scriber for layout work. (L. S. Starrett Co.)

hole may be determined accurately with the aid of an indicator attached to a height gage.

42. *What is a vernier caliper?*
A vernier caliper (Fig. 5–31) is a tool for checking inside and outside measurements. Usually, both

Fig 5–27. Offset scribers. (L. S. Starrett Co.)

Fig. 5–28. Using a vernier height gage with an offset scriber. (L. S. Starrett Co.)



sides of the bar are graduated. The jaws are hardened, ground, and lapped parallel with each other. With the jaws in contact, the vernier plate is set at zero on one side and at a point equal to the thickness of the measuring points or jaws on the other side. This is done to make it possible to check either outside or inside measurements without making any calculations. Points are provided on the bar and slide so that dividers may be set to transfer distances from the vernier caliper to a piece of work. Figure 5–32 shows outside measurements being taken with a vernier caliper. Figure 5–33 shows

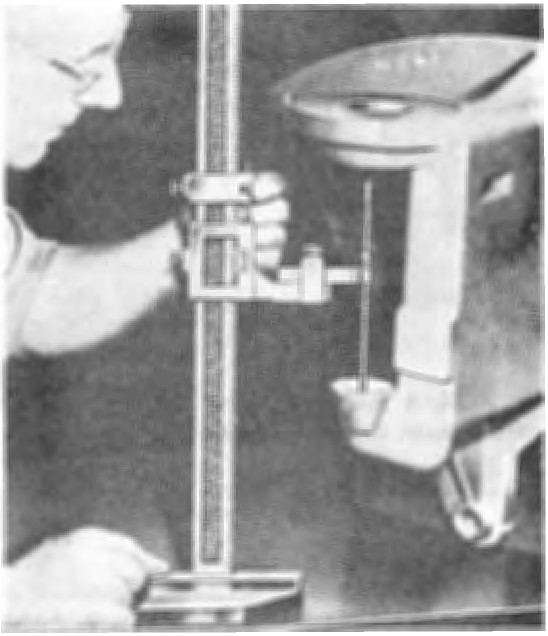
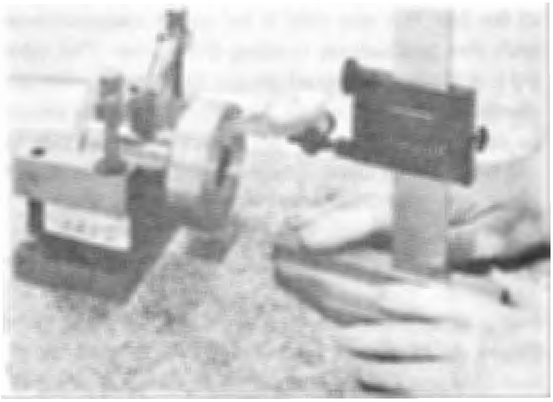


Fig. 5–29. Using a vernier height gage as a depth gage. (L. S. Starrett Co.)

Fig. 5–30. Using a vernier height gage with a dial indicator to check hole locations. (Federal Products Corp.)



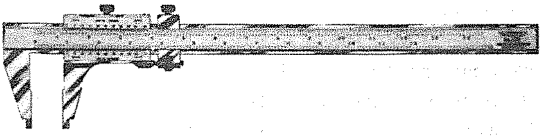


Fig. 5–31. Vernier caliper. (L. S. Starrett Co.)

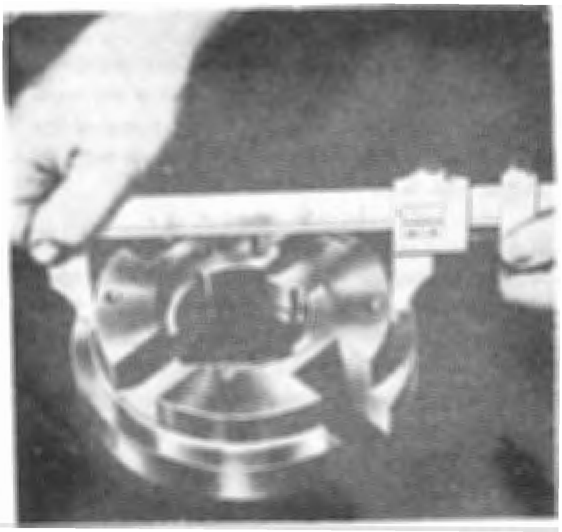


Fig. 5–32. Measuring outside diameter with a vernier caliper. (L. S. Starrett Co.)

Fig. 5–33. Measuring inside diameter with a vernier caliper. (L. S. Starrett Co.)

internal diameters being measured with the vernier caliper.

43. *What is a gear-tooth vernier?*
A gear-tooth vernier (Fig. 5–34) is an instrument with two vernier scales, for measuring the size of gear teeth. The thickness of the gear tooth is measured at a point where the pitch circle of the gear crosses the tooth. The vertical bar of the gear-tooth vernier is adjusted so that the jaws of the vernier will be at the pitch circle of the gear when the vernier rests on the tooth. The horizontal bar is then adjusted to measure the thickness of the gear tooth. These two measurements are known respectively as *corrected addendum* and *chordal thickness*. The graduations on the two bars of the vernier are twenty thousandths of an inch apart instead of twenty-five thousandths as on a height gage. This must be remembered when counting the divisions on the bar.

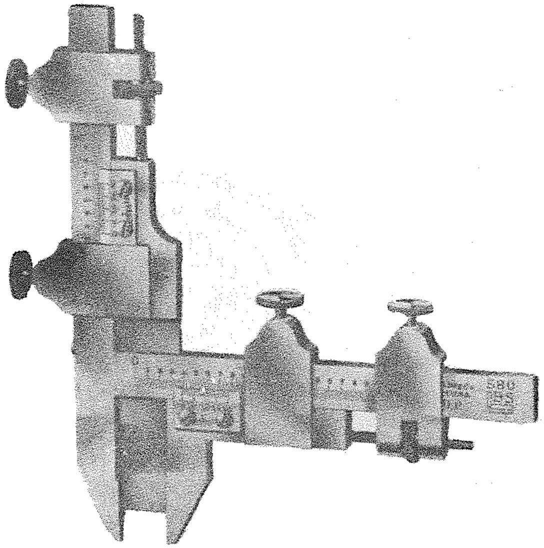


Fig. 5–34. Gear-tooth vernier. (Brown & Sharpe Mfg. Co.)

44. *What is a vernier bevel protractor?*
The vernier bevel protractor (Fig. 5–35) is an instrument having a dial graduated in degrees and a sliding blade which is usually about $\frac{1}{16}$ in. thick. One side of the tool is flat, permitting it to be laid level upon the work. The disk of the bevel protractor is graduated in degrees throughout the entire circle. The vernier is graduated so that 12 divisions on the vernier occupy the same space as 23° on the disk. Each of the 12 divisions of the vernier is equal to one-twelfth of 23° (1,380′), which amounts to 115′. Each 2° on the protractor is equal to 120′. The difference between 2° on the protractor and 1 division on the vernier equals 5′ (Fig. 5–36).

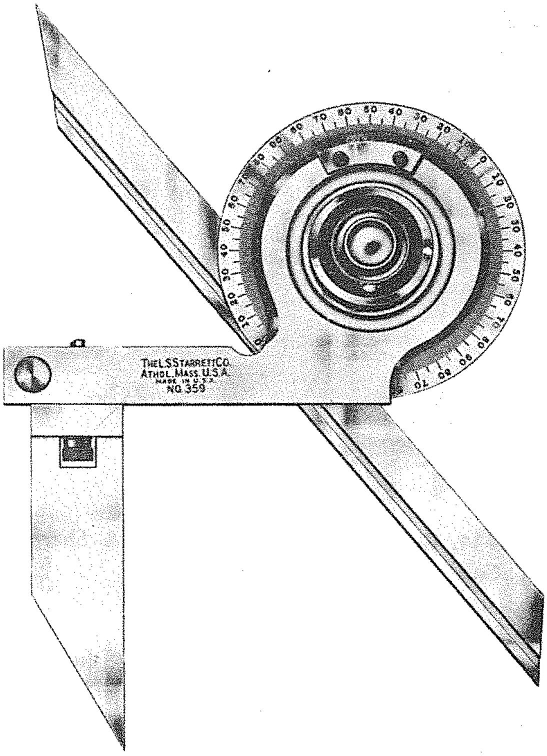
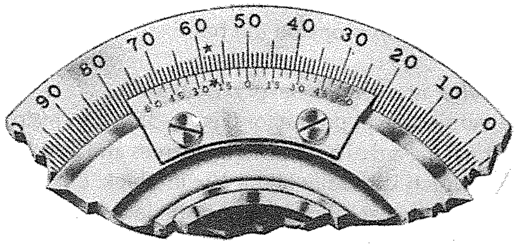


Fig. 5–35. Vernier bevel protractor. (L. S. Starrett Co.)

Fig. 5–36. Reading the size of an angle on a vernier bevel protractor. (L. S. Starrett Co.)



45. *How are measurements read on a vernier bevel protractor?*

The vernier scale of the bevel protractor is double, so that readings may be taken from the left or from the right. In Fig. 5–36, a reading is to be made from the zero on the right side of the protractor. The zero on the vernier indicates the number of degrees, in this case 50, then continuing in the same direction from the point, it may be seen that the division lines of the protractor and those of the vernier coincide on the 20 line of the vernier. The full size of the angle being measured is therefore 50° 20 ′. Some of the ways in which a vernier bevel protractor is used are shown in Figs. 5–37 to 5–39.

46. *What is a vernier depth gage?*

A vernier depth gage (Fig. 5–40) is a precision measuring tool consisting of a hardened steel head equipped with a vernier scale. A narrow, graduated, steel rule slides through the head for making measurements in thousandths of an inch. A vernier depth gage is read the same as a vernier caliper or height gage. It is widely used in tool, die, and inspection work.

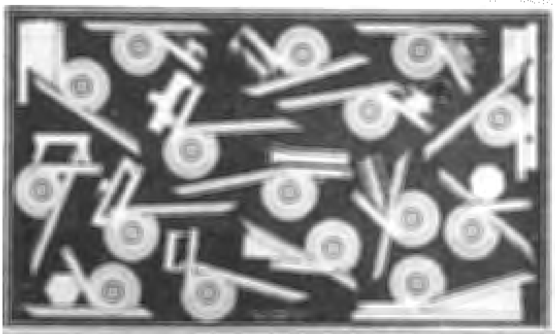
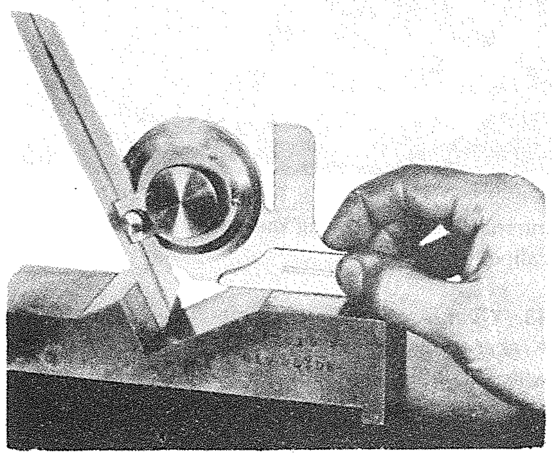


Fig. 5–37. Some applications of the vernier bevel protractor. (L. S. Starrett Co.)

Fig. 5–38. Using a vernier bevel protractor to measure the angle of a slide. (Brown & Sharpe Mfg. Co.)



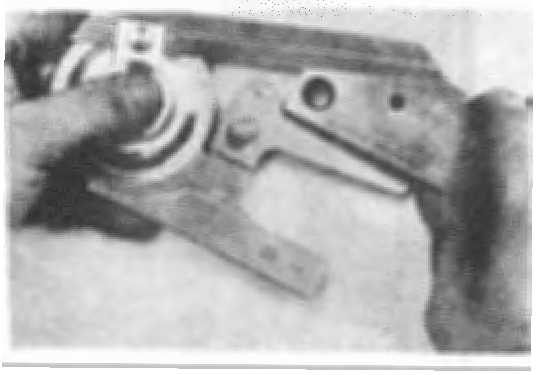


Fig. 5-39. Measuring the angle of a die section using a bevel protractor with an acute angle attachment. (Brown & Sharpe Mfg. Co.)

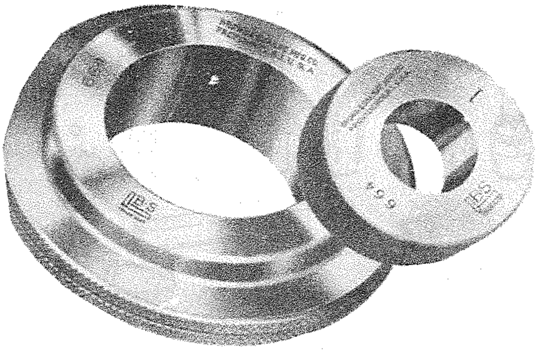
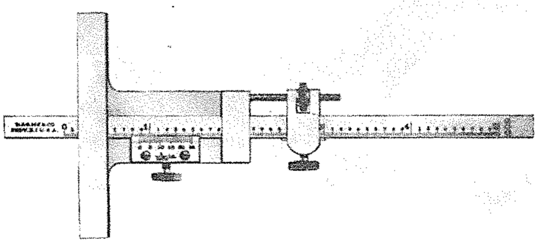


Fig. 5-41. Ring gages. (Brown & Sharpe Mfg. Co.)

Fig. 5-40. Vernier depth gage. (Brown & Sharpe Mfg. Co.)



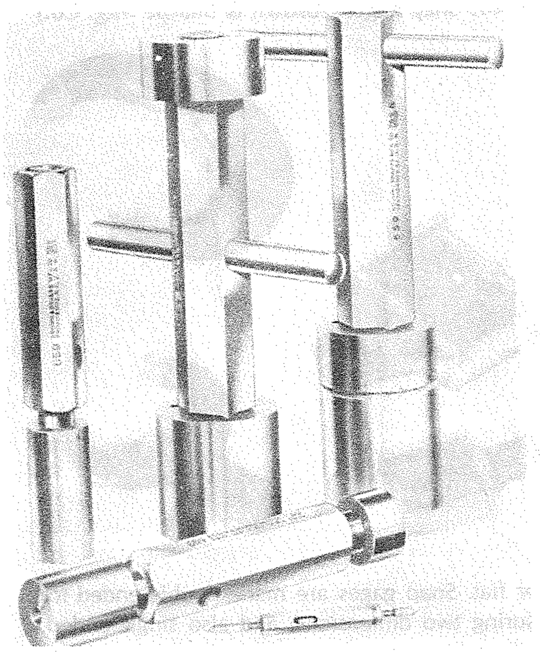


Fig. 5-42. Plug gages. (Brown & Sharpe Mfg. Co.)

GAGES

47. *What are some of the common types of gages?*
The most common types of gages include the ring gage, plug gage, snap gage, caliper gage, receiving gage, master gage, indicating gage, thickness gage, and radius gage.

48. *What is a ring gage?*
A ring gage (Fig. 5-41) is one that is cylindrical in shape with a hole that is of the exact size specified for the part to be measured. In use, a ring gage should fit over the part being checked without the use of force and without any noticeable side movement. The surface being measured may be cylindrical or conical in shape.

49. *What is a plug gage?*
A plug gage (Fig. 5-42) is used to test the accuracy of holes. It should engage the hole to be checked without using pressure and should be able to stand up in the hole without falling through, just able to slowly slide through. The shape of the plug (Fig. 5-43) may be conical, as gages A and C; square, as gage D; hexagon, as gage H; or one of the several others shown.

50. *What is a snap gage?*
A snap gage (Fig. 5-44) is made with openings to fit over a part to be checked. The part may be cylindri-

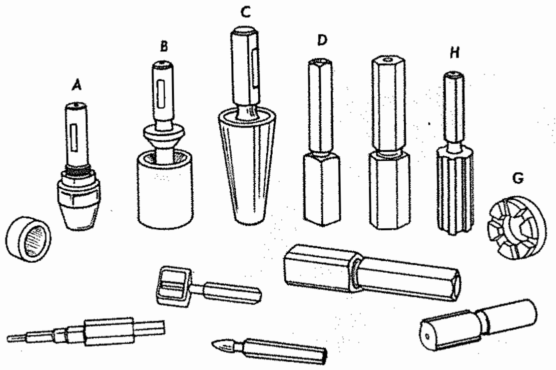
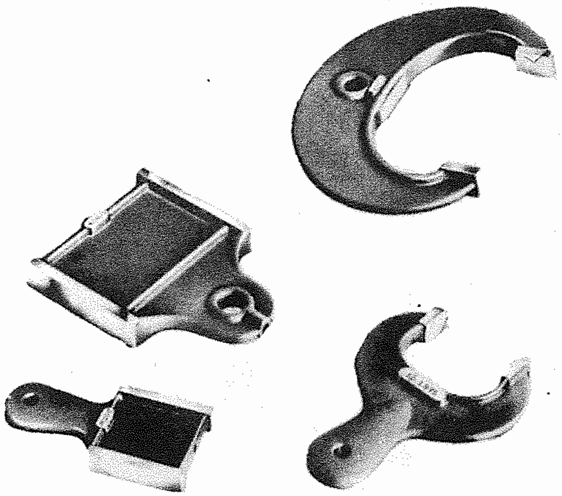


Fig. 5–43. Various shapes of plug gages. (Brown & Sharpe Mfg. Co.)

Fig. 5–44. Snap gages. (Brown & Sharpe Mfg. Co.)



cal or flat. Snap gages are made double-ended for measuring two dimensions, and also single-ended. An adjustable type of snap gage is shown in Fig. 5–45. They are made in many sizes, with openings ranging from ¼ to 12 in. The lower anvils of the gage may be adjusted as much as ¼ in. to a required dimension. Gages with two anvils are sometimes referred to as go and not-go gages. When this is the case, the inner anvil is raised slightly higher than the front one. For example, to measure a shaft with a dimension of 1.500 and a 0.003 limit more or less would call for the inside opening to be 1.498 and the outside opening to be 1.503. In order to pass inspection, the shaft should go through the outer

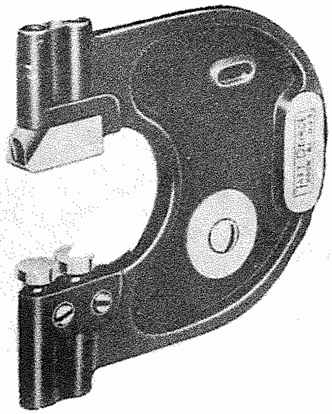
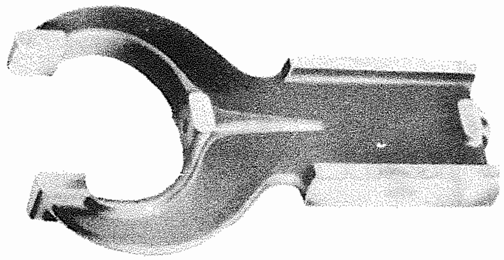


Fig. 5–45. Adjustable snap gage. (Brown & Sharpe Mfg. Co.)

Fig. 5–46. Caliper gage. (Brown & Sharpe Mfg. Co.)



setting of the gage, but should not go through the inner setting.

51. *What is a caliper gage?*
A caliper gage (Fig. 5–46) is similar to a snap gage but is designed to measure an internal dimension with one end and an external dimension with the other end.

52. *What is a receiving gage?*
A receiving gage is one whose inside measuring surfaces are designed to check a specific article for shape and size. An example of this type of gage is shown at G in Fig. 5–43.

53. *What is a taper test gage?*
A taper test gage is a device consisting of a base upon which are located two hardened steel plates, which may be readily adjusted to a special or standard taper. It may then be used to test other tapers.

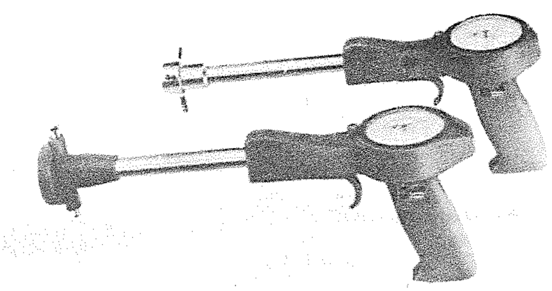
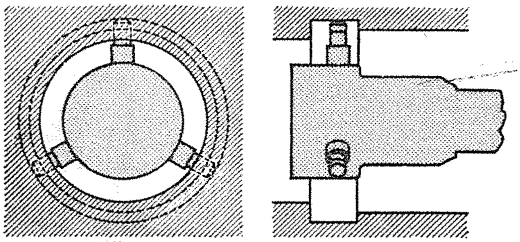


Fig. 5–53. Hole gage with retracting contacts (Federal Products Corp.)

Fig. 5–54. Sketch shows how contacts can be contracted to allow them to pass through small openings and then allowed to expand to contact the larger diameter of the recess. (Federal Products Corp.)



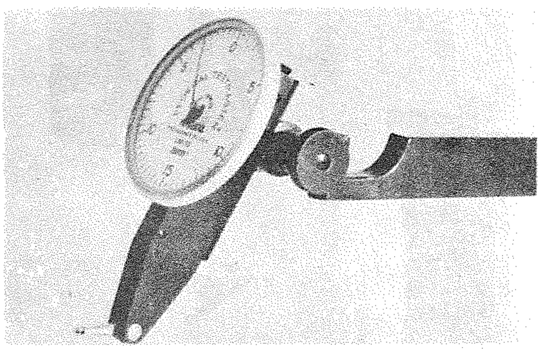
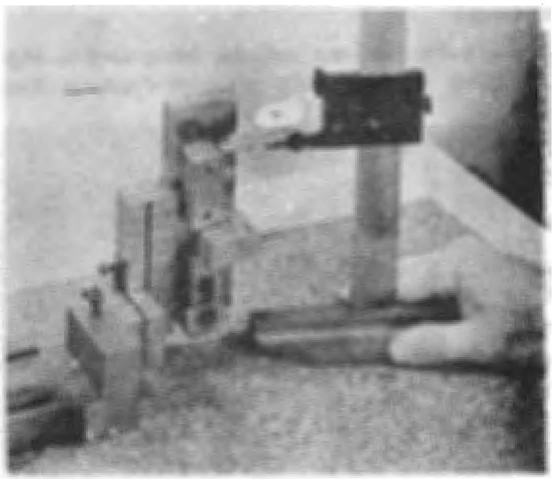


Fig. 5–55. Universal test indicator. (Federal Products Corp.)

of the work, may be readily adjusted with the fingers to suit the job. The movement of the index point is shown on the dial. The graduations on the dial are 0.001 in. on one model and 0.0001 in. on another model. The head of the indicator may be adjusted to many different positions by means of the universal

Fig. 5–56. Dial test indicator used on surface gage for checking a dimension. (Federal Products Corp.)

Fig. 5–57. Dial test indicator used on a height gage to check a dimension. (Federal Products Corp.)



clamp, which holds it to the rectangular shank. It may be attached to a surface gage, as in Fig. 5–56, or to a height gage, as in Fig. 5–57. It may also be attached to the tool post for adjusting or testing work in a lathe, or it may be clamped to the spindle of a mill (Figs. 5–58 and 5–59).

60. *What is an indicating inside-caliper gage?*
A type of inside caliper with an indicating gage is shown in Fig. 5–60. The graduations on the dial face are 0.010 in. with a measuring capacity of from 1 to 3 in. Because of the large size of graduations and range, this gage does not measure as accurately as other types of indicating hole gages but is suitable where a speedy check is desirable.

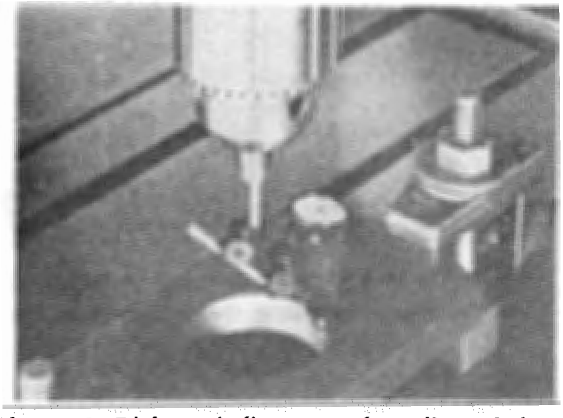
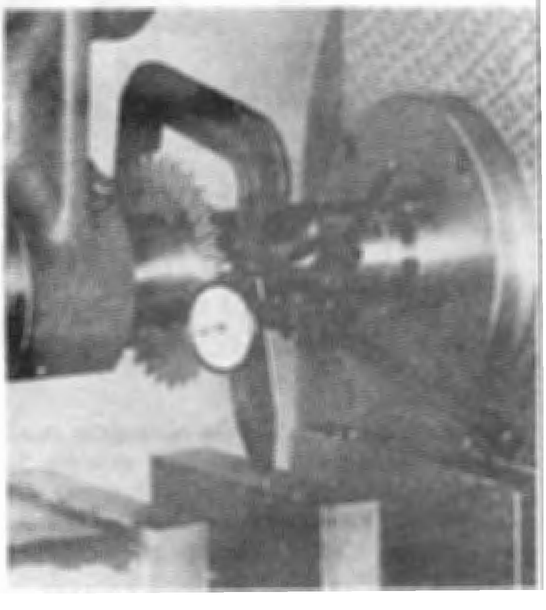


Fig. 5–58. Dial test indicator used to align a hole on a vertical milling machine. (Federal Products Corp.)

Fig. 5–59. Dial test indicator being used to align a milling machine vise. (Federal Products Corp.)



61. *What is an indicating snap gage?*
An indicating snap gage (Fig. 5–61) is similar in design to an ordinary snap gage but has the advantage of indicating on the dial the exact variation from the required dimension of the work. The adjustable lower anvil permits the gage to be set with a wide measuring range. The regular models are available in five sizes with a total measuring range of from 0 to 6 in. The indicating gage dial may be

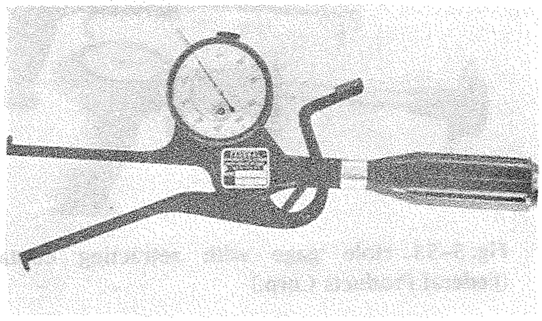


Fig. 5–60. Inside caliper gage. (Federal Products Corp.)

Fig. 5–61. Indicating snap gage. (Federal Products Corp.)

adjusted to any position to suit the convenience of the user. The gage may also be set in a bench stand, as in Fig. 5–62.

Other types of indicating snap gages are the single-purpose gage shown in Fig. 5–63, and an adjustable gage with a retracting anvil, in Fig. 5–64. The latter

Fig. 5-62. **Indicating snap gage attached to a bench stand. (Federal Products Corp.)**

Fig. 5-63. **Single-purpose indicating snap gage. (Federal Products Corp.)**

Fig. 5-64. **Adjustable indicating snap gage with retractable anvil. (Federal Products Corp.)**

type is desirable for measuring highly polished surfaces because it does not mar the finish. Figure 5-65 shows an adjustable backstop that helps to locate the work correctly on the anvil of the gage.

62. *What is an indicating thickness gage?*
Another type of thickness gage (Fig. 5-66) is of the indicating variety. These convenient gages are designed to inspect the thickness of paper, plastic, sheet metal, leather, and so forth, with great accuracy. The graduations on the dial are in 0.001 in. with a measuring range of from 0 to 0.500 in. Another model is available with graduations of 0.0001 in. with a range of 0.100 in. A gage of this type is being used to measure the diameter of round metal in Fig. 5-67.

The indicating outside caliper gage (Fig. 5-68) is also a type of thickness gage. The graduations on the dial are usually 0.010 or $^1/_{64}$ in. The convenience and speed of measuring encourages the measurement of work that might otherwise go unchecked. The jaws are sometimes designed to suit the shape of a particular piece of work.

63. *What is an indicating depth gage?*
An indicating depth gage (Fig. 5-69) is a gage for accurately measuring the depth of holes, slots, and

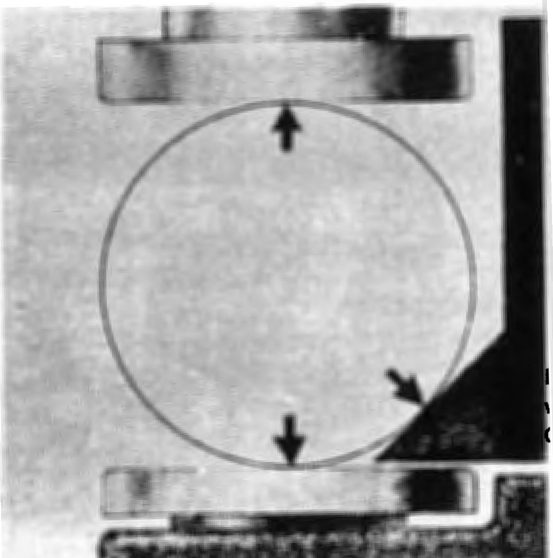


Fig. 5-65. Adjustable backstop for locating work on the anvil of the gage. (Federal Products Corp.)

Fig. 5-66. Indicating thickness gage. (Federal Products Corp.)

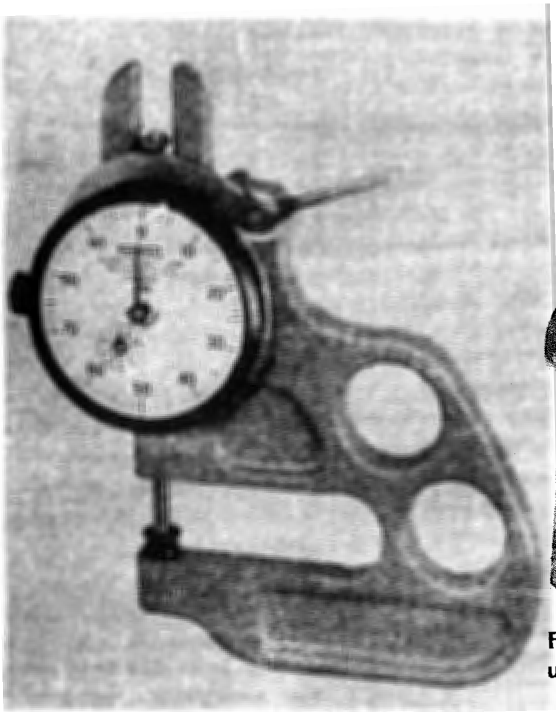
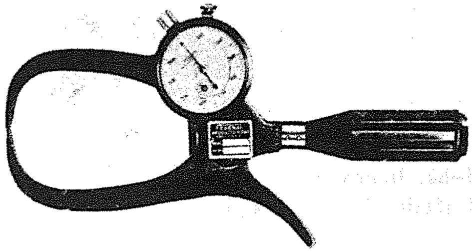


Fig. 5-67. Measuring the diameter of a workpiece with an indicating thickness gage. (Federal Products Corp.)

Fig. 5-68. Indicating outside caliper gage. (Federal Products Corp.)



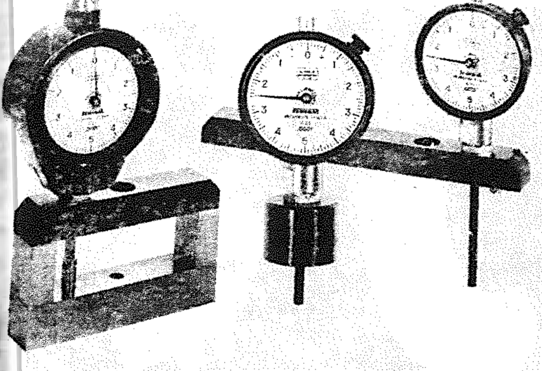


Fig. 5-69. Indicating depth gages. (Federal Products Corp.)

other recesses in a positive and convenient manner. The graduations on the dial are in 0.001 in. with a total measuring range of from 0 to 3 in. Figure 5-70 shows a gage of this type being used to measure the depth of a recess.

64. *What is an amplifying comparator gage?*
An amplifying comparator gage (Fig. 5-71) is an instrument that amplifies the variation in the size of two similar parts 10 times. In using it, a gage of the required size is placed under the indicating point, and the dial of the indicator is set at zero. The gage is then removed and the part to be checked is placed under the point. Any deviation shown on the indicator dial indicates 10 times the amount of error between the gage and the work.

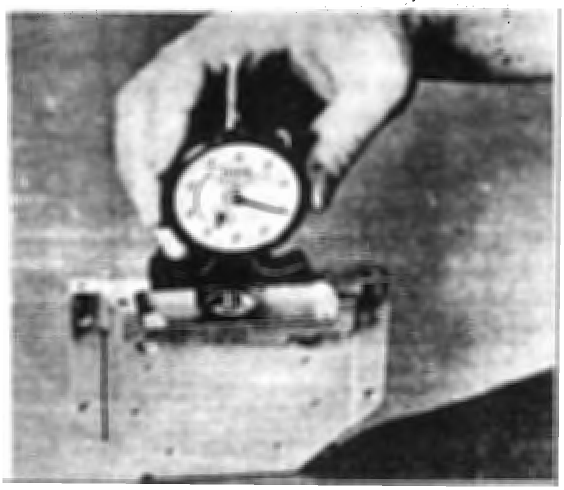


Fig. 5-70. Measuring the depth of a recess with an indicating depth gage. (Federal Products Corp.)

GAGE BLOCKS

65. *What type of gage is considered a universal standard of measurement?*
Johansson-type gage blocks are the standard of precision measurement for the world. They measure accurately in millionths of an inch, an accomplishment considered impossible before their introduction.

66. *What are precision gage blocks?*
Precision gage blocks of the Johansson type (Fig. 5-72) are rectangular pieces of tool steel, approximately 3/8 in. by 1 3/8 in. The blocks are hardened, ground, stabilized, and finished to an accuracy within a few-millionths part of an inch from the specified size. Gage blocks are sized according to their thickness.

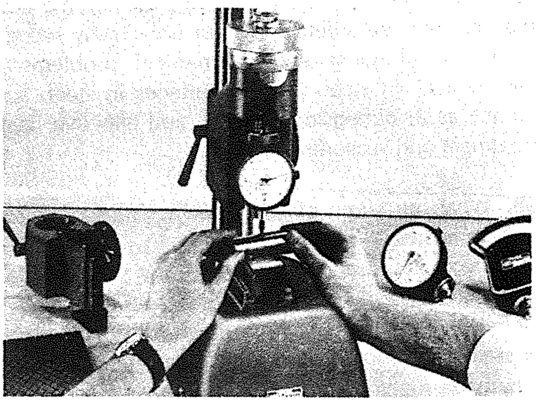
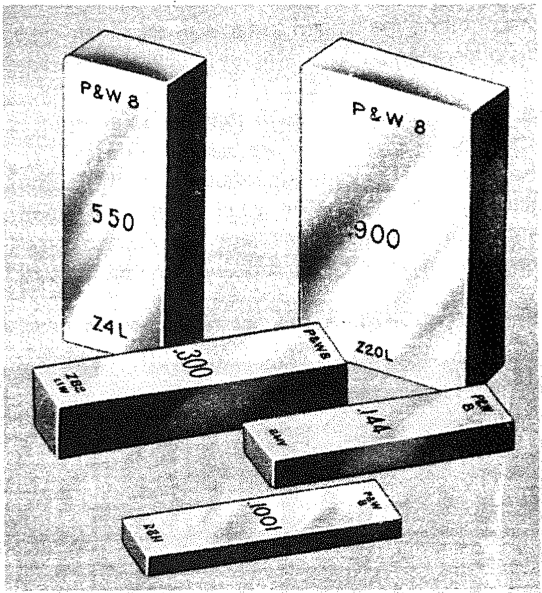


Fig. 5-71. Amplifying comparator gage. (Federal Products Corp.)

Fig. 5-72. Precision gage blocks. (Pratt & Whitney Co.)



67. *What problems in industry have been solved by the use of precision gage blocks?*

Precision gage blocks embody in their commercial manufacture the solution of four universally recognized metallurgical and mechanical problems—flat surfaces in steel, parallel surfaces in steel, accuracy as to dimension in steel, and effective heat treatment and seasoning of steel.

68. *What are some of the characteristics of a flat surface in steel?*
Making a flat surface in steel is one of the most remarkable achievements in mechanics. A flat surface with an extremely high finish, having the appearance of burnished silver, is produced by the Johansson method; it approaches nearer the perfect plane than any other surface produced by the hand of man. These flat-lapped surfaces, when thoroughly cleaned and slid one on the other with a slight inward pressure, will take hold as though magnetized. They have been known to sustain a weight of 200 lb on a direct pull, although the contacting surfaces are less than ½ sq in. Scientists have offered atmospheric pressure, molecular attraction, and a minute film of oil on the lapped surfaces as explanations of this phenomenon.

69. *How can it be shown that the steel surfaces in Johansson gage blocks are parallel surfaces?*
The degree of parallelism attained in the manufacture of the Johansson gage blocks is demonstrated by the fact that any block in a given combination may be turned end for end, at will, without affecting the parallelism of the two extreme surfaces of the combination.

70. *Can parallel surfaces in steel be combined with accurate measurement?*
The making of one steel surface parallel with another is good, but to make one surface a predetermined parallel distance from another surface with an accuracy in millionths of an inch is a more remarkable achievement. This accomplishment is proven by the way in which an equivalent combination of precision gage blocks checks against one solid block.

71. *What is an important process in making gage blocks?*
An important operation in making gage blocks is the seasoning of the metal. This must be done so that the internal stresses and strains within the metal are relieved. The molecules of the steel may be said to be at rest, and because of this, the usual warping or growing is checked.

72. *What is a set of gage blocks?*
A full set of gage blocks (Fig. 5–73) consists of 81 blocks that have surfaces flat and parallel within 0.000008 in. In addition to the regular blocks, many accessories have been designed to be used with them. A group of accessories is shown in Fig. 5–74, including a foot block, straightedge, scriber, trammel points, adjustable holder, and jaws of various sizes.

Fig. 5–73. A full set of Johansson precision gage blocks. (Brown & Sharpe Mfg. Co.)

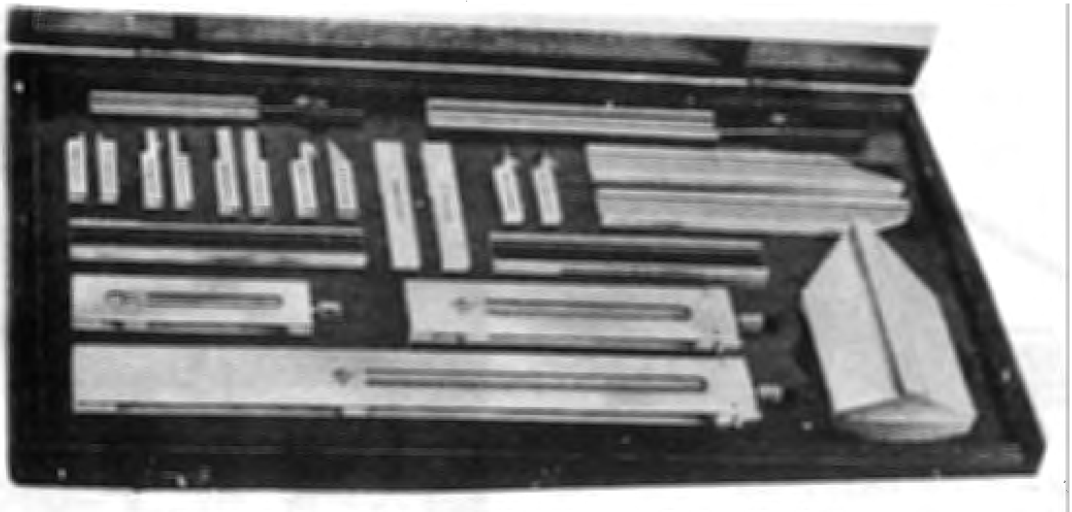


Fig. 5-74. Gage-block accessories. (Brown & Sharpe Mfg. Co.)

Another style of precision gage block is the Hoke type; a complete set is shown in the first three rows of Fig. 5-75. These blocks are approximately 0.950 in. square and vary in thickness. The hole through the center of each block permits the use of internal tie rods, by means of which rapid, compact assembling of various attachments is possible without the use of clamps. Many of these attachments are shown in the back of the box of gage blocks in Fig. 5-75.

Some types of gage blocks have holes near the ends; they may be joined together by an eccentric clamp after the ends have been wrung together, as in Fig. 5-76. Examples of blocks joined together by eccentric clamps are shown in Figs. 5-77 and 5-78.

Precision gage blocks and an Electrolimit height gage are being used in Fig. 5-79 to check the location of a hole in a master railroad gage.

Fig. 5-75. A set of Hoke gage blocks and accessories. (Pratt & Whitney Co.)

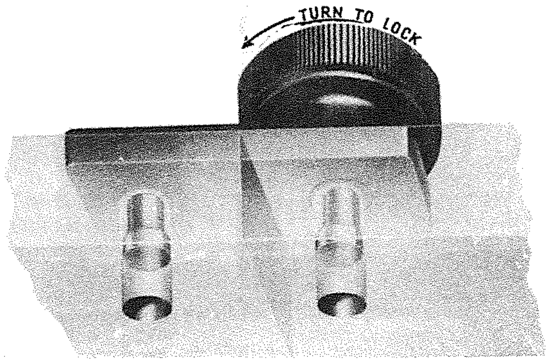


Fig. 5-76. Gage blocks held together with eccentric clamps. (Webber Gage Co.)

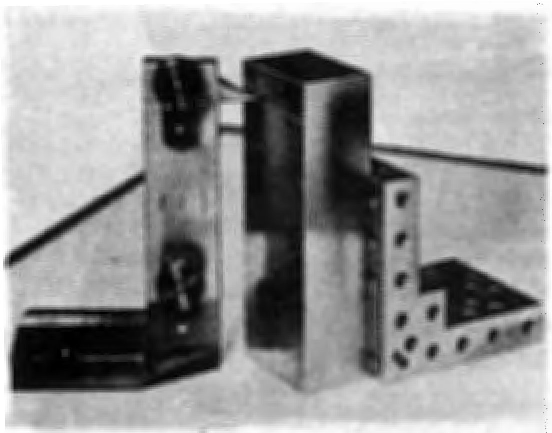


Fig. 5-77. Gage blocks combined to form a precision surface gage. (Webber Gage Co.)

Fig. 5-79. Checking the location of a hole with gage blocks and an Electrolimit height gage. (Pratt & Whitney Co.)

Fig. 5-78. A combination of gage blocks provides a height gage accurate to millionths of an inch. (Webber Gage Co.)

73. *Most styles of precision gage blocks are made in four series. What units are contained in the first series of gage blocks?*

The first series (Fig. 5-80) consists of nine blocks, ranging in size from 0.1001 to 0.1009 in. by steps of 0.0001 in.

74. *What units are contained in the second series of gage blocks?*

The second series (Fig. 5-80) consists of 49 blocks, ranging in size from 0.101 to 0.149 in. by steps of 0.001 in.

75. *What units are contained in the third series of gage blocks?*

The third series (Fig. 5-80) consists of 19 blocks, ranging in size from 0.050 to 0.950 in. by steps of 0.050 in.

76. *What units are contained in the fourth series of gage blocks?*

The fourth series (Fig. 5-80) consists of four blocks measuring 1, 2, 3, and 4 in.

series	no. of blocks	increments (inch)	sizes
1	**9**	**0.0001**	**0.1001, 0.1002, 0.1003, 0.1004, 0.1005, 0.1006, 0.1007, 0.1008, 0.1009**
2	**49**	**0.001**	**0.101, 0.102, 0.103, 0.104, 0.105, 0.106, 0.107, 0.108, 0.109, 0.110, 0.111, 0.112, 0.113, 0.114, 0.115, 0.116, 0.117, 0.118, 0.119, 0.120, 0.121, 0.122, 0.123, 0.124, 0.125, 0.126, 0.127, 0.128, 0.129, 0.130, 0.131, 0.132, 0.133, 0.134, 0.135, 0.136, 0.137, 0.138, 0.139, 0.140, 0.141, 0.142, 0.143, 0.144, 0.145, 0.146, 0.147, 0.148, 0.149**
3	**19**	**0.050**	**0.050, 0.100, 0.150, 0.200, 0.250, 0.300, 0.350, 0.400, 0.450, 0.500, 0.550, 0.600, 0.650, 0.700, 0.750, 0.800, 0.850, 0.900, 0.950**
4	**4**	**1.000**	**1.000, 2.000, 3.000, 4.000**

Fig. 5–80. Precision gage-block series.

77. *How are the blocks usually combined?*
The blocks of the third series may be combined with those of the fourth series to give any multiple of 0.050 between 0.050 and 10 in. The second series may be used to obtain dimensions varying by thousandths of an inch, and the first series to obtain dimensions varying by steps of ten-thousandths of an inch.

78. *Are all gage blocks of the same quality?*
No. Precision gage blocks are made in three qualities designated as B quality, A quality, and AA quality. At a temperature of 68°F, the blocks have the following accuracy:

Working set (B quality) = 0.000008 in.
Inspection set (A quality) = 0.000004 in.
Laboratory set (AA quality) = 0.000002 in.

79. *How does the accuracy of precision gage blocks compare with (1) a human hair, (2) precision tool work, and (3) light waves?*
A human hair is approximately three thousandths (0.003) of an inch thick. The most accurate work in the mechanical field is that of toolmakers, who work to an accuracy of one ten-thousandth of an inch, which is 30 times finer than a human hair. Light waves are approximately sixteen millionths of an inch long, which is 250 times finer than a human hair and 6¼ times finer than the accuracy used by a toolmaker. Compared with the accuracy of AA quality gage blocks (0.000002 in.), these are relatively large amounts. The accuracy of the blocks is 1,500 times finer than a human hair; 50 times finer than a toolmaker's work; and 8 times finer than the length of a light wave.

80. *What is the procedure for building a definite size of gage with gage blocks?*
The following steps are suggested:

A. Become acquainted with the size of the blocks in the set.
B. Begin with the right-hand figure of the specified size.
C. Continue working from the right to the left.
D. Build the combination with the fewest possible number of blocks.

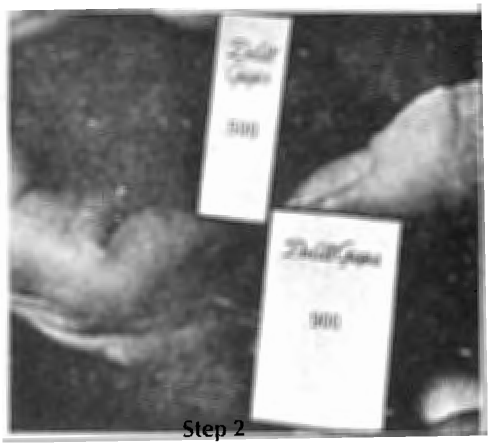
The following example shows some of the possible combinations for one particular size:

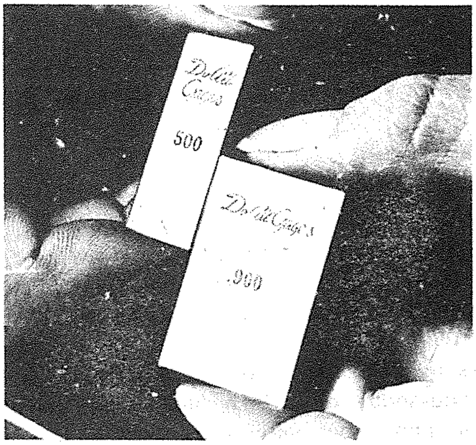
		0.1008	0.1006	0.1007
	0.1009	0.1003	0.1005	0.1004
0.1001	0.1002	0.139	0.138	0.141
0.149	0.147	0.132	0.133	0.130
0.123	0.124	0.100	0.500	0.600
0.900	0.800	0.700	0.300	0.200
1.2721	1.2721	1.2721	1.2721	1.2721

To join one block to another, proceed as follows:

A. Select from the set the first two blocks of the combination.
B. Wipe each of the contacting surfaces of the blocks on the palm of the hand, on the wrist, or on a piece of chamois, and then place the contacting surfaces together.
C. With a slight inward pressure, slide one block on the other. If the contacting surfaces are clean, they will cling together as though they were magnetized.
D. Continue in this manner until the required combination is completed (Fig. 5–81).

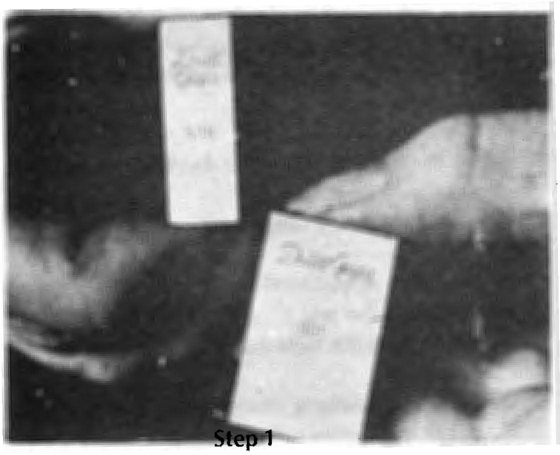
81. *What is a gage block comparator?*
A gage block comparator (Fig. 5–82) is an electronic instrument designed for calibrating working and master gage blocks to an accuracy within several millionths of an inch.

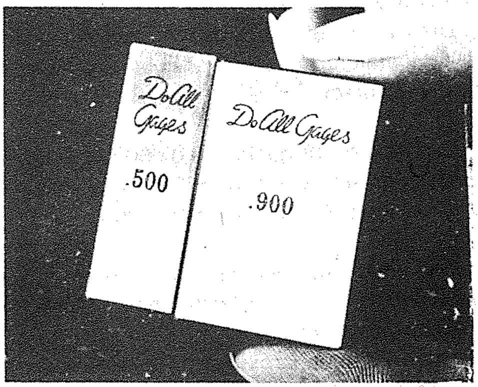

Step 2



Step 3

Fig. 5–81. Steps in assembling precision gage blocks. (DoAll Co.)


Step 1



Step 4

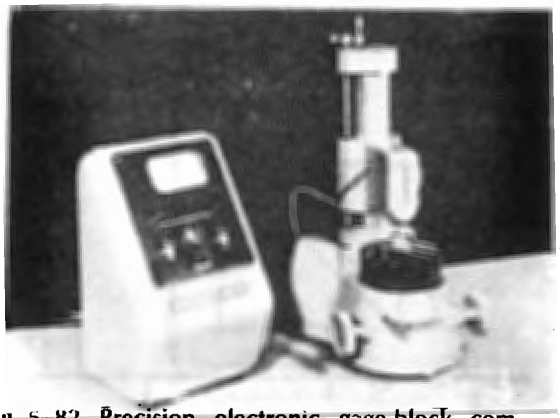
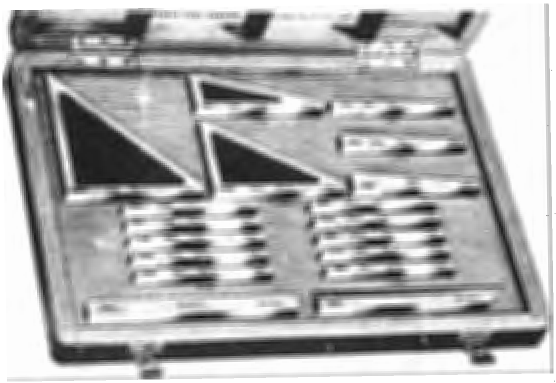


Fig. 5–82. Precision electronic gage-block comparator. (Sheffield Corp.)

Fig. 5–83. Angle gage blocks. (Webber Gage Co.)

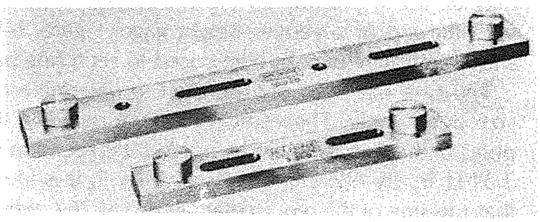


82. *What are angle gage blocks?*
Angle gage blocks (Fig. 5–83) are flat pieces of hardened steel measuring 4 in. on the base and ⅝ in. thick. A complete set consists of 16 blocks in three series (Fig. 5–84).

degrees	*minutes*	*seconds*
1° 3° 5°	**1′ 3′ 5′**	**1″ 3″ 5″**
15° 30° 45°	**20′ 30′**	**20″ 30″**

Fig. 5–84. Angle gage-block series.

Fig. 5–85. Sine bars. (Taft-Peirce Mfg. Co.)



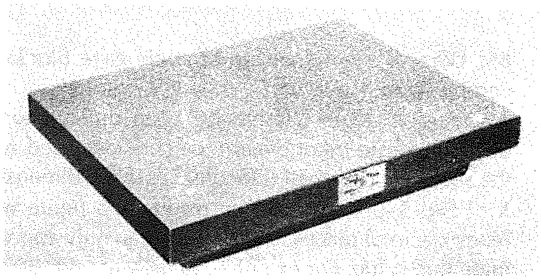


Fig. 5–86. A granite surface plate. (Brown & Sharpe Mfg. Co.)

surface such as a surface plate (Fig. 5–86), from which measurements are taken. The sine bar receives its name from the fact that, in setting a sine bar to a required angle, as in Fig. 5–87, dimension AB is calculated by multiplying the sine of the required angle

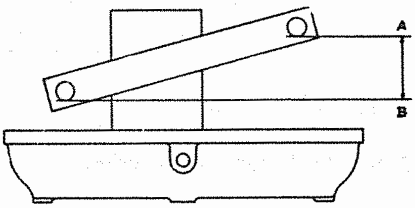


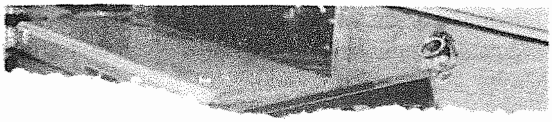
Fig. 5–87. The distance AB is equal to the sine of the angle multiplied by the length of the sine bar.

may be set in position by the use of gage blocks or with the aid of a vernier height gage. Figure 5–88 shows four gage blocks being used to set a sine bar.

The sine bar may also be used to determine the size of an angle. The vertical distance between the plugs of the 5-in. sine bar in Fig. 5–89 is found to be 3.3131 in. By dividing the distance by 5, it is found that the sine of the required angle is 0.66262, which is shown in a table of sines to represent an angle of 41° 30′.

85. *What is the advantage of angle gage blocks as compared to a sine bar?*
A precision angle has always been difficult to set because of the trigonometric calculations used with the sine bar. The chief difficulty lies in the dimension X of Fig. 5–90, which often results in a figure with many decimal places. Gage blocks can only approximate this value. For example, to measure 44° 30′ by the sine-bar method, the following steps are required when using a 5-in. sine bar.

Fig. 5–88. A sine bar may be set to an angle using precision gage blocks. (DoAll Co.)



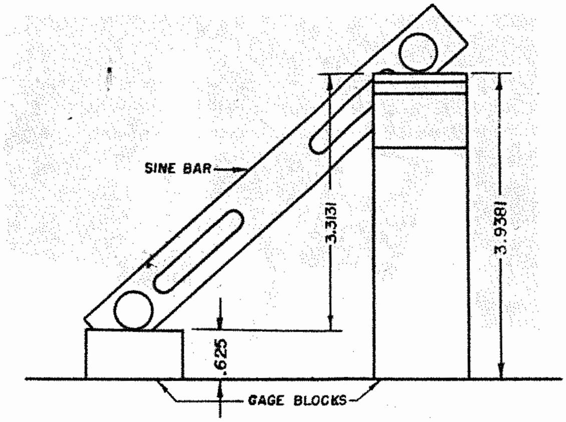
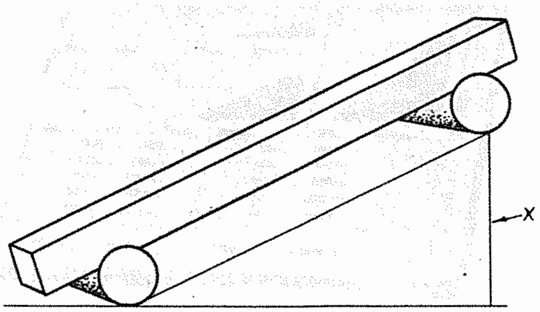


Fig. 5–89. The angle at which a sine bar is set may be determined by the vertical distance between the two plugs of the sine bar.

Fig. 5–90. Diagram for sine bar problem.



Find the sine of 44° 30′ from the trigonometric tables.

0.7009093

Multiply by 5 to find dimension X.

3.5045465

necessary

$$\begin{array}{r} 3.5045465 \\ -\underline{3.5045000} \\ 0.0000465 \end{array}$$

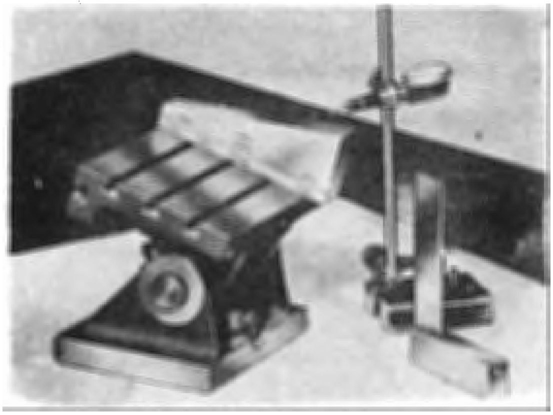
This error cannot be eliminated in sine-bar procedure. However, it can be eliminated with the use of angle gage blocks. With angle gage blocks, a 45° block is wrung on a 30′ block so that the plus end of the 45° block contacts the minus end of the 30′ block which forms an angle of 44° 30′. This is a simple procedure, and more important, it is absolutely accurate.

A complete set of 16 angle blocks yields 356,400 angles in steps of one second, with an accuracy measured in millionth parts of a circle. At first glance, the ability of a few blocks to measure hundreds of thousands of angles seems impossible. However, angles can be measured by subtraction as well as by addition, which allows a few blocks to perform this surprising job.

Some applications of the use of angle gage blocks are shown in Figs. 5–91 to 5–93.

86. *What are optical flats?*
Optical flats (Fig 5–94) are discs of high-quality optical quartz having extremely flat and parallel surfaces. They are made in sizes from 1 to 16 in. in diameter. The most commonly used sizes range from 1 to 3 in. in diameter. The several grades of accuracy of flatness vary from one to eight millionths of an inch. One or both of the flat transparent surfaces can be finished for measuring purposes. The measuring surface is indicated by a directional arrow on the side or edge of the flat.

Fig. 5–91. An adjustable angle plate is accurately set with angle gage blocks and a universal test indicator attached to a surface gage. (Webber Gage Co.)



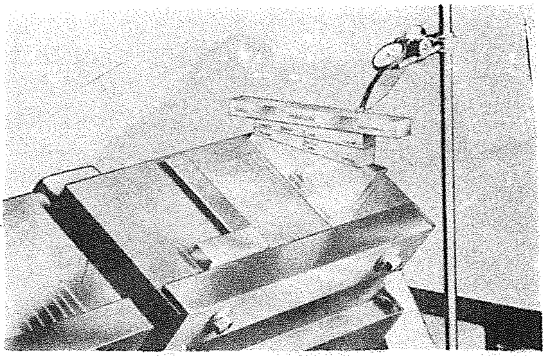


Fig. 5–92. A combination of angle gage blocks is used to adjust a magnetic chuck. (Webber Gage Co.)

Fig. 5–93. The toolhead of a shaper is accurately adjusted to a required angle with angle gage blocks. (Webber Gage Co.)

87. *What is needed to utilize this method of measurement?*
Three things are necessary: an optical flat, a monochromatic light source, and a rigid, precision-finished surface on which the job is supported. Cleanliness is a most important factor in obtaining reliable results.

Fig. 5-94. Optical flats. (DoAll Co.)

88. *What kind of a light source is used?*
A monochromatic, that is, single-colored, light is preferred. If helium gas is used as the light source, rays of a single wavelength, 0.0000231 in., are produced.

89. *How is the measurement obtained?*
The flat is placed on the surface to be checked with the monochromatic light directed at the flat. The flat is observed from a distance of 18 in. and as near to the vertical position as possible. Imperfections in the surface being measured will cause a wedge of air to form between job and flat. Shadow fringes, or interference bands, will appear. Each fringe represents a change in the vertical distance between the surface of the job and the optical flat of one half of a wavelength, or 0.0000116 in. The number of fringes, counted from the point of contact, multiplied by 0.0000116 gives the flatness error (Fig. 5–95).

90. *What type of measurement is the optical flat best suited to do?*

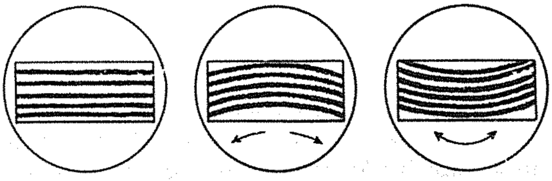


Fig. 5–95. Types of bands seen through optical flats. The patterns indicate surface conditions of the workpiece. (DoAll Co.)

Optical flats are often used in the toolroom and metrology laboratory for checking the flatness and parallelism of highly finished surfaces such as those found on gage blocks.

91. *What is an air gage?*
An air gage (Fig. 5–96) performs measuring or functional comparisons by sensing the escape of air between the gaging plug and the workpiece. This type of gage is considered a comparator in that the original setting and verification is made by taking readings using master gages of known accuracy such as gage blocks and comparing them with the workpiece readings. Figure 5–97 shows the construction and operating principles of the air gage.

92. *How does the air gage operate?*
An air gage depends on the flow of air between the gaging head and the part being checked. A metal plug, which is slightly smaller than the smallest diameter of the part, has two or more accurately calibrated jets through which air is forced at a controlled pressure. The velocity and the pressure of the air will depend upon the amount of clearance between the gaging head and the part being tested.

Fig. 5–96. Air gage. (Federal Products Corp.)

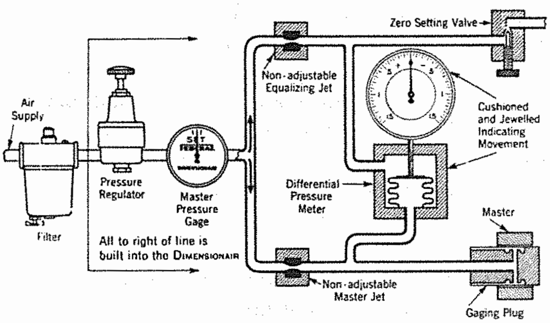


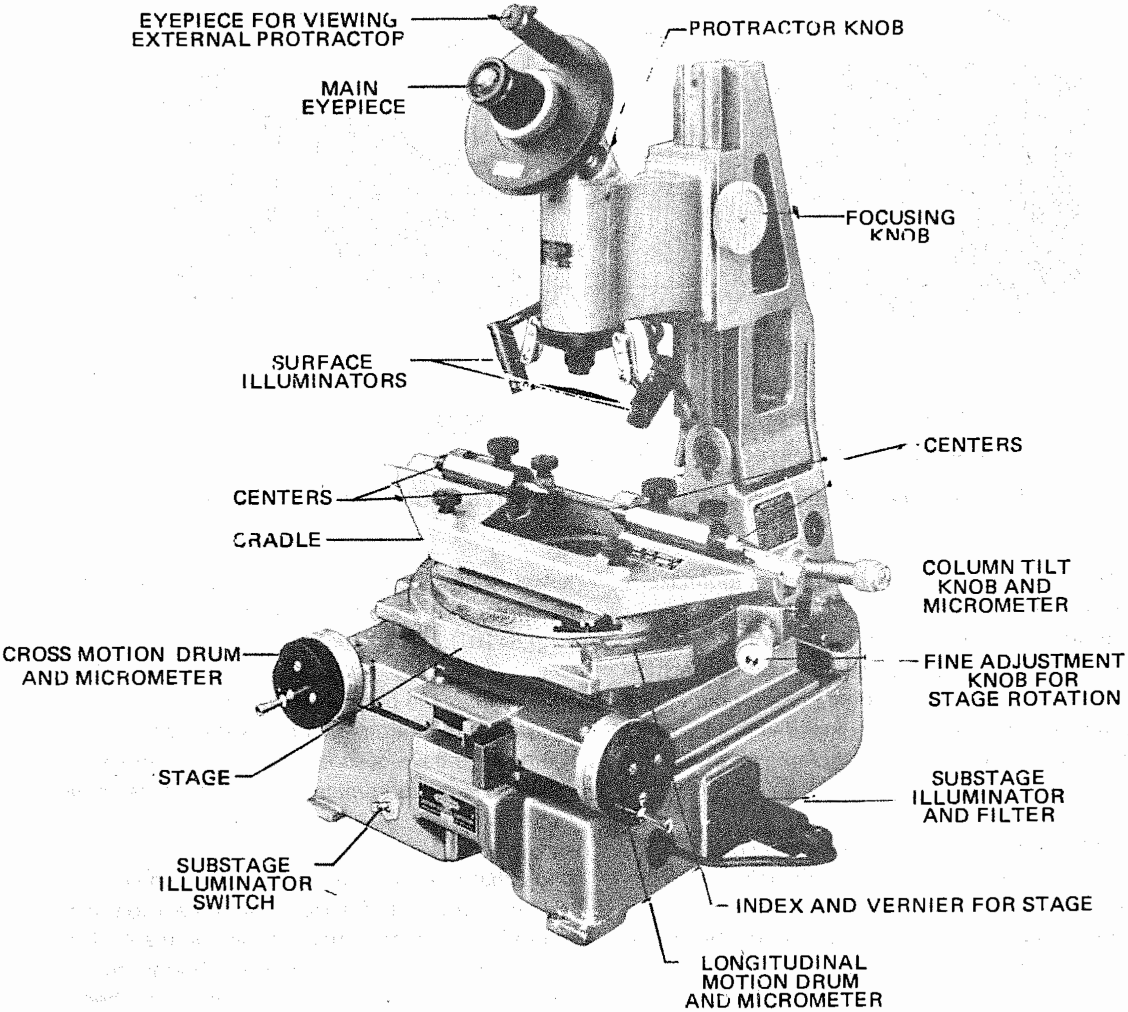
Fig. 5–97. Operating principle and components of an air gage. (Federal Products Corp.)

Air gages that indicate the velocity of air are called *flow gages. Pressure gages* indicate the pressure of the air.

93. *What are some of the advantages of air gaging?* An air gage has these advantages.

A. It can be used for close work in the laboratory, toolroom, and shop.
B. There is no limit to the size of a job that can be tested by an air gage.

Fig. 5–98. Toolmaker's microscope. (Gaertner Scientific Corp.)



C. Part can be gaged with a minimum of physical contact with finished surface of job.
D. The method needs little or no skill to operate.

94. *What is a toolmaker's microscope?*
It is a microscope designed for use by toolmakers and technicians in the shop, toolroom, or metrology laboratory (Fig. 5–98). It has high-powered magnification (30×) and can be adapted, by using accessories, to measure linear and angular dimensions, thread pitch, flank angle, and helix angle; it has many other applications (Fig. 5–99).

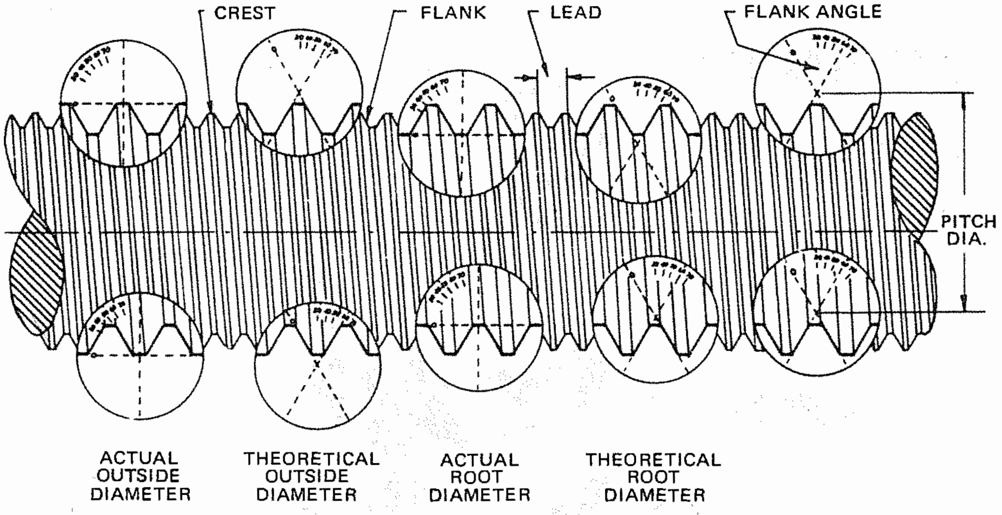


Fig. 5–99. Field of microscope when measuring screws. (Gaertner Scientific Corp.)

95. *What are the main parts of the toolmaker's microscope?*
The toolmaker's microscope has a protractor head, a support column with adjustable tilt, and a mechanical stage permitting longitudinal, cross motion, and angular measurements. It is equipped with a movable cradle and has accessories for holding various types of work on the stage.

96. *What is the function of the microscope?*
Viewed through the microscope, the job being measured is enlarged thirty times. A roof prism incorporated in the optical system (Fig. 5–100) bends the optical axis 60° to provide a convenient viewing position for the observer and produces an erect image with normal left and right position. The microscope, with its support bracket, is moved vertically on the support column by means of a rack and pinion with control knobs for either right- or left-hand operation. The microscope head has two angular scales, an internal protractor for rapid settings and reading over a limited range, and the protractor circle for high precision readings up to 360 °.

97. *How is the job illuminated for exact observation?*
By two lamps in individual housings, one on each side of the microscope (Fig. 5–98). Condensing lenses focus the light on the job. Each lamp is equipped with a filter, one red and one green (Fig. 5–101).

98. *What is the purpose of the stage?*
A coordinate motion micrometer stage and a circular rotary stage have been combined into one assembly to permit both coordinate and angular measurements to be made (Fig. 5–102).

99. *What is a universal measuring machine?*
It is an instrument of extraordinary precision, which is used for a wide variety of measurements. It was originally adapted from the jig boring machine (Fig. 5–103). Its precision is possible only because

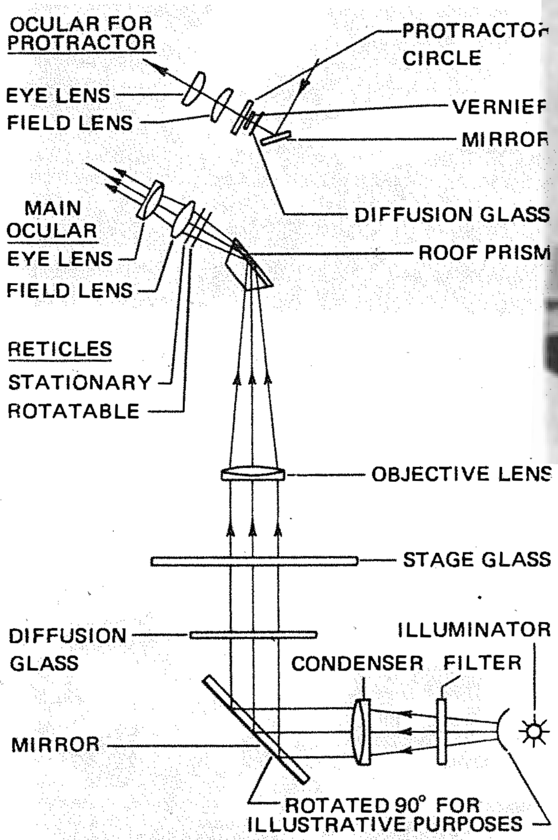


Fig. 5-100. The optical system of the toolmaker's microscope. (Gaertner Scientific Corp.)

Fig. 5-101. The bichromatic surface illuminator. (Gaertner Scientific Corp.)

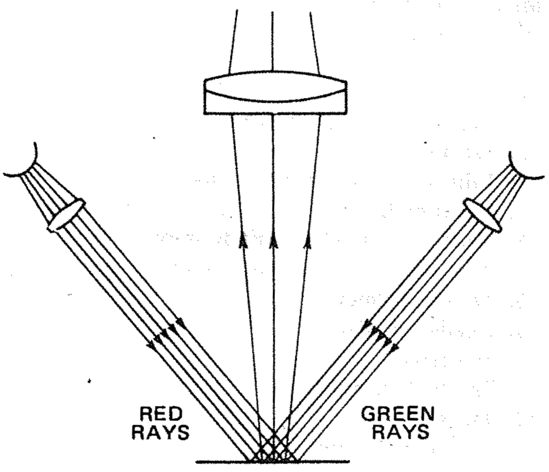
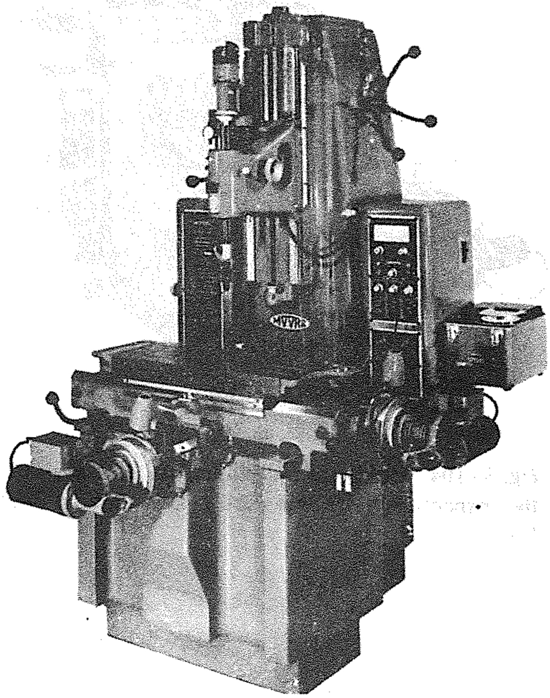


Fig. 5-102. Closeup of the stage showing all of the scales of measurement. (Gaertner Scientific Corp.)

Fig. 5-103. Universal measuring machine. (Moore Special Tool Co.)



of the tremendous care and outstanding skill that resulted in the production of the table-moving lead screws to tolerances in microinches. Besides checking straight and coordinate measurements, this machine can be used to measure and inspect cams and other curved parts (Fig. 5–104).

100. *What is a supermicrometer?*
The supermicrometer is a measuring instrument whose accuracy places it between a standard hand micrometer and a measuring machine. It is used for both floor inspection and gage testing in the metrology laboratory (Fig. 5–105).

101. *What is an Electrolimit supermicrometer?*
It is a refinement of the mechanical supermicrometer. Like the mechanical model, it can give a direct measurement reading accurate to 0.0001 in. The Electrolimit can be used as a comparator that will show deviations in size to an accuracy of 0.00002 in. on a calibrated scale (Fig. 5–106).

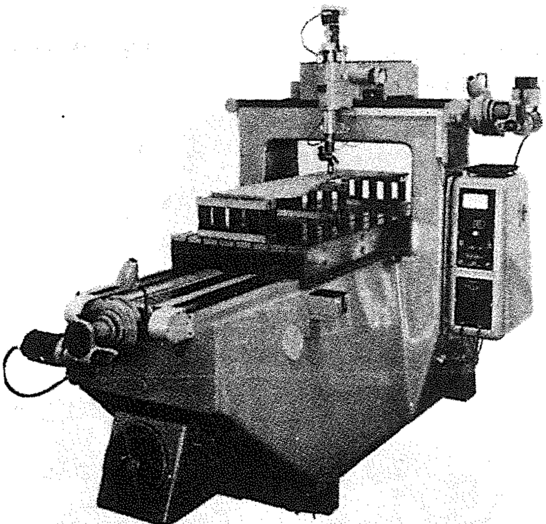


Fig. 5–104. Universal measuring machine used for the inspection of a large part. (Moore Special Tool Co.)

Fig. 5–105. Checking a plug gage with a supermicrometer.

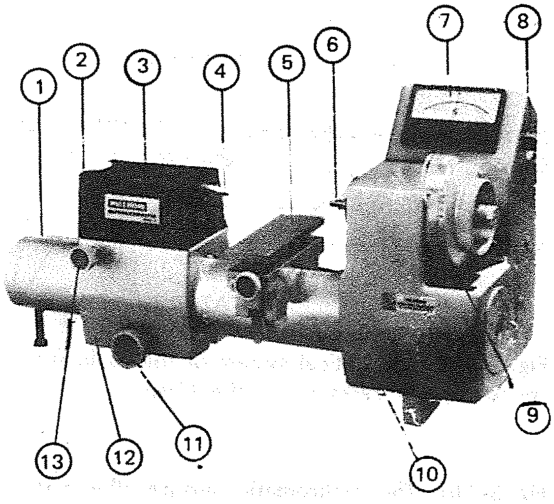


Fig. 5–106. Parts of the Electrolimit supermicrometer (Courtesy of Colt Industries and Pratt & Whitney Co.)

1. **Bed**
2. **Gaging pressure adjustment**
3. **Tailstock cover**
4. **Tailstock anvil (carbide tipped)**
5. **Elevating table**
6. **Headstock spindle (carbide tipped)**
7. **Zero meter and calibrated scaie**
8. **Zero adjustment**
9. **Headstock dial**
10. **Headstock**
11. **Tailstock clamp knob**
12. **Tailstock**
13. **Rack pinion knob**

chapter 6 metric measurement

The most important single item in machine shop work is measurement. It affects *all* aspects of the machine trades. Without measurement it would be impossible to have interchangeable manufacture and to have anything made to a specified size or a required shape. Those who earn their livelihood in the machine trades must be aware of proposals to change the present measuring system. Change, which has been advocated for more than 160 years in the United States, is bound to come.

The U.S. system of measurement is based on the system used in Great Britain and her colonies. It is called the inch-pound system: 12 inches equal 1 foot, 3 feet equal 1 yard, 1,760 yards equal 1 mile (plus many other units based on these); and 16 ounces equal a pound; 2,000 pounds equal 1 short ton: 2,240 pounds equal 1 long ton, or English ton. The machine trades are interested primarily in linear measurement, the measurement of length, which requires a familiarity with common fractions—1/64, 1/32, 1/16, 1/8, 1/4, 1/2, and so forth—as well as decimal fractions—0.1000, 0.0100, 0.0010, 0.0001, and so forth—all parts of inch.

The metric system was developed by French scientists, and France, in 1790, became the first country to adopt the system. This drastic change was made possible by, and resulted from, the French Revolution. Efforts to enforce its use were at least partially successful. In 1801, the system was officially adopted by France. Metric measurement was made compulsory.

The metric system is almost universally accepted. In fact, the United States is the last major industrial nation to still use the old English system. The need for international markets now makes it expedient to change from the inch-pound system to the metric system.

1. *Does most of the world use the metric system of measurement?*
More than 125 countries, colonies, and protectorates have adopted the metric system as their official system of weights and measures. This represents more than 90 percent of the world's population. Most of the remaining industrial countries are in the process of converting to the metric system.

2. *What is the status of the metric system in the United States?*
Before the American Revolution, the colonies used the inch-pound system, which was at that time used

in Britain. In 1784, Thomas Jefferson proposed to Congress that U.S. coinage be converted to a decimal system. His plan was adopted in 1785; and we have had a coinage based on the decimal system ever since. Five years later, Jefferson's proposal that the metric system of measurement be adopted was rejected by a congressional committee. Another President, John Quincy Adams, also supported the metric system. Although an act of Congress in 1866 made the metric system legal in the United States, the inch-pound system continues to be the standard used throughout the nation.

Many other famous Americans have urged that the metric system be adopted, among them Alexander Graham Bell, one of our great scientists and inventors. In 1906, Bell appeared before a Senate committee and used a blackboard and chalk to demonstrate the ease with which the system could be used to solve practical problems. Dr. Bell allowed only the metric system of weights and measures to be used in his laboratories and claimed that his mechanics found no difficulty in adjusting to the change.

In 1902, 1906, and 1938, bills were introduced in Congress to make conversion to the metric system mandatory, but all were defeated. Similar efforts were made in 1959, 1960, and 1961, with the same result. A national organization, The Metric Association, has for more than half a century advocated the use of the metric system in American schools, commerce, and industry.

In 1968 a bill was passed in Congress which authorized a program of investigation, research, and survey to determine what should be the future policy of the United States in view of the worldwide use of the metric system and its effect on the nation's economy. In 1971 the Secretary of Commerce presented to the Congress a report of this study which recommended that a systematic, national coordinated changeover to the metric system of measurement take place over a 10 year period.

3. *Why has the adoption of the metric system in the United States been opposed?*
The reasons given by opponents have been many and varied. Some reject the metric system on religious grounds. One of the strongest arguments involves the cost and inconvenience resulting from such a changeover.

Other reasons for opposing the conversion include:

A. Reluctance to abandon something deeply imbedded in our system.
B. The time and cost required to re-educate the public.
C. The need for double inventories of products and parts during the transition period.
D. Machines, parts, equipment, tools, and appliances would be declared obsolete.
E. Books, charts, tables, specifications, standards, signs, and so forth would have to be adapted to conform to the metric standard.
F. Adoption would give foreign metric countries an advantage in exporting to the United States.
G. Because the United States exports only 5 percent of the technical goods it produces, there is no reason to disrupt the remaining 95 percent.

4. *Why should the United States convert to the metric system?*
There are strong reasons favoring conversion.

A. Calculations would be simplified and faster because the metric system is based on multiples or submultiples of ten. This would help scientists, engineers, teachers, and students.
B. Conversion is simple and easy between units of weight, length, area, volume, and energy.
C. The terminology of the metric system is easier to learn.
D. The metric system would enhance our position in world trade markets with nations already using the metric system.
E. Conversion to the metric system in the United States is inevitable; it should be done now before the cost increases.
F. The benefits of conversion would offset the cost.
G. The decline in the U.S. share of world trade can be attributed to our reluctance to convert.
H. Certain sectors of science and industry have already successfully converted.

5. *What industries and professions in the United States now use the metric system?*
The metric system is universally used in the pharmaceutical industry. The medical profession uses metric units, though the family doctor may still weigh and measure his patients in pounds and inches. Scientific

research uses the metric system completely. Astronauts used metric measurements to describe sizes and distances while on the moon. Steel ball bearings are made to metric sizes. The thread sizes of an automobile spark plug are metric. Still and movie cameras use metric-sized film.

6. *What is the metric system based on?*
The metric system is a system of weights and measures which was based first on the dimensions of the earth—one meter (m) equals one ten-millionth (0.0000001) the distance measured on the surface from the Equator to the Pole. In 1960, the meter was defined by the CGPM as follows: "The metre is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels 2p10 and $5d_5$ of the Krypton-86 atom."* Such a description is not easily understood by the average person, so the legal definition was given as the length of a platinum bar kept in Paris, France. Precise copies of this bar are available for comparison and calibration purposes.

7. *How will metrication (conversion to the metric system) affect the life of the average American?*
Almost all of the units of measure we now use will be changed, both in name and amount. Automobile speeds will be given in kilometers per hour; a basketball player's height will be given in meters, his weight, in kilograms. The weight of packaged foods will be given in metric weights and comparison in value will more easily be achieved. Machine fasteners such as bolts and nuts, machine screws, washers, and so forth will be given in metric sizes. The holes will be made with metric-sized drills. The wrenches to fit the nuts will be made and identified in metric sizes. There will be no further use or need for the manipulation of fractions and their decimal equivalents. Emphasis will be directed solely toward the decimal system and the SI system of measurements.

8. *What is the SI system of measurements?*
The General Conference of Weights and Measures (CGPM) is a committee composed of representatives of many nations who meet every sixth year in Paris, France; it handles all matters that concern the metric system. In 1960, 36 countries, including the United States, met in Paris and agreed upon an international system of units, for which the abbreviation SI is used in all languages. These units represent the standards of weights and measures, based on the metric system, which are used internationally. The system was modernized to include definitions for additional units required for science and commerce. The abbreviation SI comes from the French name for the system, *Le Système International d'Unités*.

*U.S. Department of Commerce, National Bureau of Standards, The International System of Units.

The base units of the International System are as follows:

SI BASE UNITS

quantity	*unit*	*symbol*
Length	**meter***	**m**
Mass	**kilogram**	**kg**
Time	**second**	**s**
Electric current	**ampere**	**A**
Thermodynamic temperature	**Kelvin**	**K**
Luminous intensity	**candela**	**cd**
Amount of substance	**mole**	**mol**

**Although the SI spelling is metre, the standard American spelling is used in this country, as it is throughout this book.*

9. *What is dual dimensioning?*
A dual-dimensioning system combines inch and millimeter (mm) dimensions on one drawing. With this system, all conversions are worked out by the engineer or draftsman. Thus the drawing can be understood and the parts can be manufactured by technicians and mechanics who work in either of the measuring systems.

10. *How can inch and millimeter measurements be converted from one to another easily?*
Figure 6–1 is a table that can be used for converting millimeter values into inch values. Figure 6–2 makes it easy to convert inches, either in decimal or fractional form, to millimeters. Conversion from one unit to another must be accurate. Wherever it is necessary to round off sizes, the procedure should be standardized and within the tolerances allowed.

11. *What are the standard and basic units of measurement in both systems?*

Fig. 6–1. Millimeter-to-inch conversion table.

mm	inches	mm	inches	mm	inches	mm	inches	mm	inches
0.01	.00039	0.41	.01614	0.81	.03189	21	.82677	61	2.40157
0.02	.00079	0.42	.01654	0.82	.03228	22	.86614	62	2.44094
0.03	.00118	0.43	.01693	0.83	.03268	23	.90551	63	2.48031
0.04	.00157	0.44	.01732	0.84	.03307	24	.94488	64	2.51968
0.05	.00197	0.45	.01772	0.85	.03346	25	.98425	65	2.55905
0.06	.00236	0.46	.01811	0.86	.03386	26	1.02362	66	2.59842
0.07	.00276	0.47	.01850	0.87	.03425	27	1.06299	67	2.63779
0.08	.00315	0.48	.01890	0.88	.03465	28	1.10236	68	2.67716
0.09	.00354	0.49	.01929	0.89	.03504	29	1.14173	69	2.71653
0.10	.00394	0.50	.01969	0.90	.03543	30	1.18110	70	2.75590
0.11	.00433	0.51	.02008	0.91	.03583	31	1.22047	71	2.79527
0.12	.00472	0.52	.02047	0.92	.03622	32	1.25984	72	2.83464
0.13	.00512	0.53	.02087	0.93	.03661	33	1.29921	73	2.87401
0.14	.00551	0.54	.02126	0.94	.03701	34	1.33858	74	2.91338
0.15	.00591	0.55	.02165	0.95	.03740	35	1.37795	75	2.95275
0.16	.00630	0.56	.02205	0.96	.03780	36	1.41732	76	2.99212
0.17	.00669	0.57	.02244	0.97	.03819	37	1.45669	77	3.03149
0.18	.00709	0.58	.02283	0.98	.03858	38	1.49606	78	3.07086
0.19	.00748	0.59	.02323	0.99	.03898	39	1.53543	79	3.11023
0.20	.00787	0.60	.02362	1.00	.03937	40	1.57480	80	3.14960
0.21	.00827	0.61	.02402	1	.03937	41	1.61417	81	3.18897
0.22	.00866	0.62	.02441	2	.07874	42	1.65354	82	3.22834
0.23	.00906	0.63	.02480	3	.11811	43	1.69291	83	3.26771
0.24	.00945	0.64	.02520	4	.15748	44	1.73228	84	3.30708
0.25	.00984	0.65	.02559	5	.19685	45	1.77165	85	3.34645
0.26	.01024	0.66	.02598	6	.23622	46	1.81102	86	3.38582
0.27	.01063	0.67	.02638	7	.27559	47	1.85039	87	3.42519
0.28	.01102	0.68	.02677	8	.31496	48	1.88976	88	3.46456
0.29	.01142	0.69	.02717	9	.35433	49	1.92913	89	3.50393
0.30	.01181	0.70	.02756	10	.39370	50	1.96850	90	3.54330
0.31	.01220	0.71	.02795	11	.44307	51	2.00787	91	3.58267
0.32	.01260	0.72	.02835	12	.47244	52	2.04724	92	3.62204
0.33	.01299	0.73	.02874	13	.51181	53	2.08661	93	3.66141
0.34	.01339	0.74	.02913	14	.55118	54	2.12598	94	3.70078
0.35	.01378	0.75	.02953	15	.59055	55	2.16535	95	3.74015
0.36	.01417	0.76	.02992	16	.62992	56	2.20472	96	3.77952
0.37	.01457	0.77	.03032	17	.66929	57	2.24409	97	3.81889
0.38	.01496	0.78	.03071	18	.70866	58	2.28346	98	3.85826
0.39	.01535	0.79	.03110	19	.74803	59	2.32283	99	3.89763
0.40	.01575	0.80	.03150	20	.78740	60	2.36220	100	3.93700

Fig. 6–2. Inch-to-millimeter conversion table.

decimal inches	mm	decimal inches	mm
0.01	0.2540	0.51	12.9540
0.02	0.5080	0.52	13.2080
0.03	0.7620	0.53	13.4620
0.04	1.0160	0.54	13.7160
0.05	1.2700	0.55	13.9700
0.06	1.5240	0.56	14.2240
0.07	1.7780	0.57	14.4780
0.08	2.0320	0.58	14.7320
0.09	2.2860	0.59	14.9860
0.10	2.5400	0.60	15.2400
0.11	2.7940	0.61	15.4940
0.12	3.0480	0.62	15.7480
0.13	3.3020	0.63	16.0020
0.14	3.5560	0.64	16.2560
0.15	3.8100	0.65	16.5100
0.16	4.0640	0.66	16.7640
0.17	4.3180	0.67	17.0180
0.18	4.5720	0.68	17.2720
0.19	4.8260	0.69	17.5260
0.20	5.0800	0.70	17.7800
0.21	5.3340	0.71	18.0340
0.22	5.5880	0.72	18.2880
0.23	5.8420	0.73	18.5420
0.24	6.0960	0.74	18.7960
0.25	6.3500	0.75	19.0500
0.26	6.6040	0.76	19.3040
0.27	6.8580	0.77	19.5580
0.28	7.1120	0.78	19.8120
0.29	7.3660	0.79	20.0660
0.30	7.6200	0.80	20.3200
0.31	7.8740	0.81	20.5740
0.32	8.1280	0.82	20.8280
0.33	8.3820	0.83	21.0820
0.34	8.6360	0.84	21.3360
0.35	8.8900	0.85	21.5900
0.36	9.1440	0.86	21.8440
0.37	9.3980	0.87	22.0980
0.38	9.6520	0.88	22.3520
0.39	9.9060	0.89	22.6060
0.40	10.1600	0.90	22.8600
0.41	10.4140	0.91	23.1140
0.42	10.6680	0.92	23.3680
0.43	10.9220	0.93	23.6220
0.44	11.1760	0.94	23.8760
0.45	11.4300	0.95	24.1300
0.46	11.6840	0.96	24.3840
0.47	11.9380	0.97	24.6380
0.48	12.1920	0.98	24.8920
0.49	12.4460	0.99	25.1460
0.50	12.7000	1.00	25.4000

inches frac.	inches dec.	mm	inches frac.	inches dec.	mm
1/64	0.015625	0.3969	33/64	0.515625	13.0969
1/32	0.031250	0.7938	17/32	0.531250	13.4938
3/64	0.046875	1.1906	35/64	0.546875	13.8906
1/16	0.062500	1.5875	9/16	0.562500	14.2875
5/64	0.078125	1.9844	37/64	0.578125	14.6844
3/32	0.093750	2.3812	19/32	0.593750	15.0812
7/64	0.109375	2.7781	39/64	0.609375	15.4781
1/8	0.125000	3.1750	5/8	0.625000	15.8750
9/64	0.140625	3.5719	41/64	0.640625	16.2719
5/32	0.156250	3.9688	21/32	0.656250	16.6688
11/64	0.171875	4.3656	43/64	0.671875	17.0656
3/16	0.187500	4.7625	11/16	0.687500	17.4625
13/64	0.203125	5.1594	45/64	0.703125	17.8594
7/32	0.218750	5.5562	23/32	0.718750	18.2562
15/64	0.234375	5.9531	47/64	0.734375	18.6531
1/4	0.250000	6.3500	3/4	0.750000	19.0500
17/64	0.265625	6.7469	49/64	0.765625	19.4469
9/32	0.281250	7.1438	25/32	0.781250	19.8437
19/64	0.296875	7.5406	51/64	0.796875	20.2406
5/16	0.312500	7.9375	13/16	0.812500	20.6375
21/64	0.328125	8.3344	53/64	0.828125	21.0344
11/32	0.343750	8.7312	27/32	0.843750	21.4312
23/64	0.359375	9.1281	55/64	0.859375	21.8281
3/8	0.375000	9.5250	7/8	0.875000	22.2250
25/64	0.390625	9.9219	57/64	0.890625	22.6219
13/32	0.406250	10.3188	29/32	0.906250	23.0188
27/64	0.421875	10.7156	59/64	0.921875	23.4156
7/16	0.437500	11.1125	15/16	0.937500	23.8125
29/64	0.453125	11.5094	61/64	0.953125	24.2094
15/32	0.468750	11.9062	31/32	0.968750	24.6062
31/64	0.484375	12.3031	63/64	0.984375	25.0031
1/2	0.500000	12.7000	1	1.000000	25.4000

The inch is defined precisely as 25.4 mm. By act of Congress in 1893, the inch was defined as 25.4000508 mm. But international agreement in 1959 changed it to the present exact 25.4 mm. The millimeter is therefore equivalent to 0.039370079 in., normally rounded to five decimal places and expressed as 0.03937.

12. *Is there a standard method of identifying the metric and inch dimensions on the drawing?*
Usually it is by position. If the drawing is based on the inch system, the inch dimension should be above or to the left of the metric equivalent. For a metric-based drawing the metric dimension should be above or to the left of the inch equivalent. For quick visual recognition, identification is shown by enclosing the equivalent converted dimension within brackets: [ ] . Examples of the technique follow:

A. Inch-based design

1.000 [25.400]	or	1.000 [25.400]

B. Metric-based design

25.400 [1.000]	or	25.400 [1.000]

Each dual-dimensioned drawing should indicate, by note, that the equivalent converted dimension is enclosed in square brackets. For example,

"Dimensions in [ ] are millimeters"
or "Dimensions in [ ] are inches."

13. *How are angles shown in dual dimensioning?*
Angles, stated in degrees, minutes, and seconds (or in decimals of a degree), are common to the inch and metric systems of measurements. Thus only one value is shown for angular measurements.

14. *How are fractions of an inch shown?*
Drawings that are dimensioned in fractions of an inch may be dual dimensioned by adding the millimeter conversion adjacent to the fractional inch dimension (Fig. 6–3). For example,

$$2\frac{7}{16} \pm \frac{1}{64} \begin{bmatrix} 62.30 \\ 61.52 \end{bmatrix}$$

15. *What procedure is proposed for introducing the metric system?*
The first steps toward metrication will take place in the schools. The best method of learning the various metric values is by starting fresh and defining each value only in its relationship to other metric units. Children without prior training in units will accept the metric system readily, perhaps even better than the present inch-pound units. Those previously trained in the inch-pound system would find themselves automatically comparing the new with the old—millimeters, and meters with inches and feet. Therefore, for some length of time, double (dual) sizing would be needed. Initially, the size of a part to be machined would be given both in inches and in meters. Eventually, the inch-pound units would be phased out.

16. *How could inch and metric measurements be combined on the same machine shop drawing?*
The standard decimal inch would be used for the U.S. measurement and the metric sizes would be given in millimeters. The metric size would be above the dimension line and the inch size would be below the dimension line:

63.5 ± .025
2.500 ± .001

The method used for positioning will be identified on each drawing:

$$\frac{\text{MILLIMETER}}{\text{INCH}}$$

If this method cannot be used, the numerical value can be followed by the abbreviation *in.* if an inch size or *mm* if in millimeters. However, there are other dual-dimensioning methods.

17. *Is there more than one method of dimensioning a drawing in both inch and metric systems?*
Figure 6–4 shows a drawing of a machine part used by a company (Caterpillar Tractor Co.) that manufactures its products in both inch and metric measuring countries. The measurements on all drawings are in metric sizes. A conversion table from millimeters to inches is in the top left corner of each drawing. This technique, called *dual capability,* is used by engineering companies to ease the transition from inches to millimeters. The measurements of all parts are dimensioned in millimeters; the conversion table is placed on each drawing for the convenience of the technician or mechanic who is being "con-

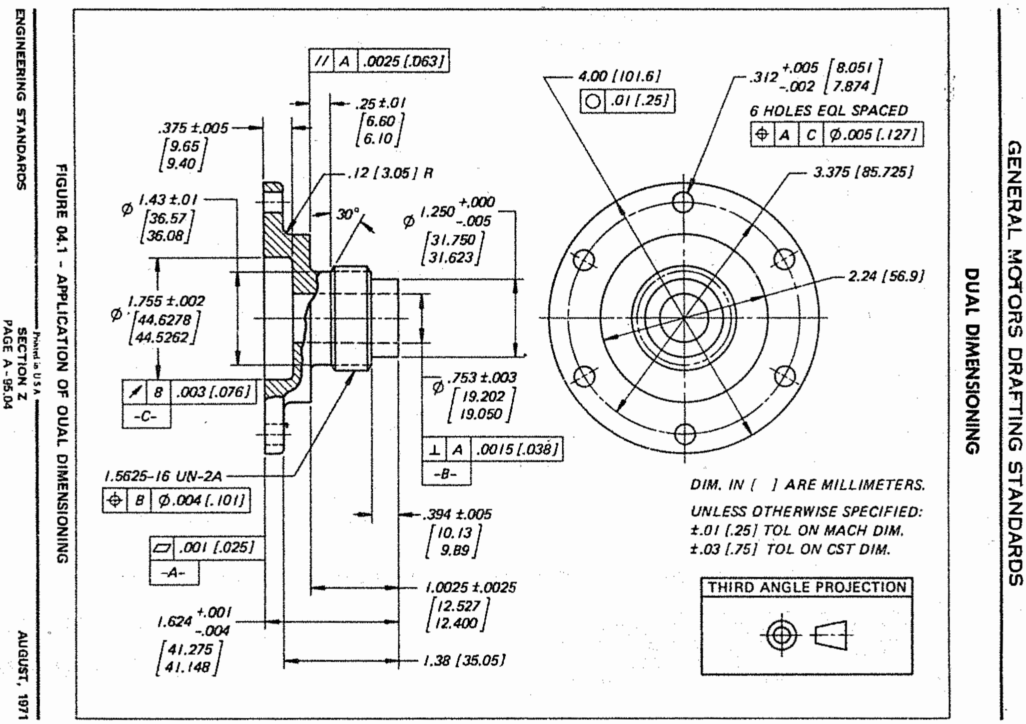
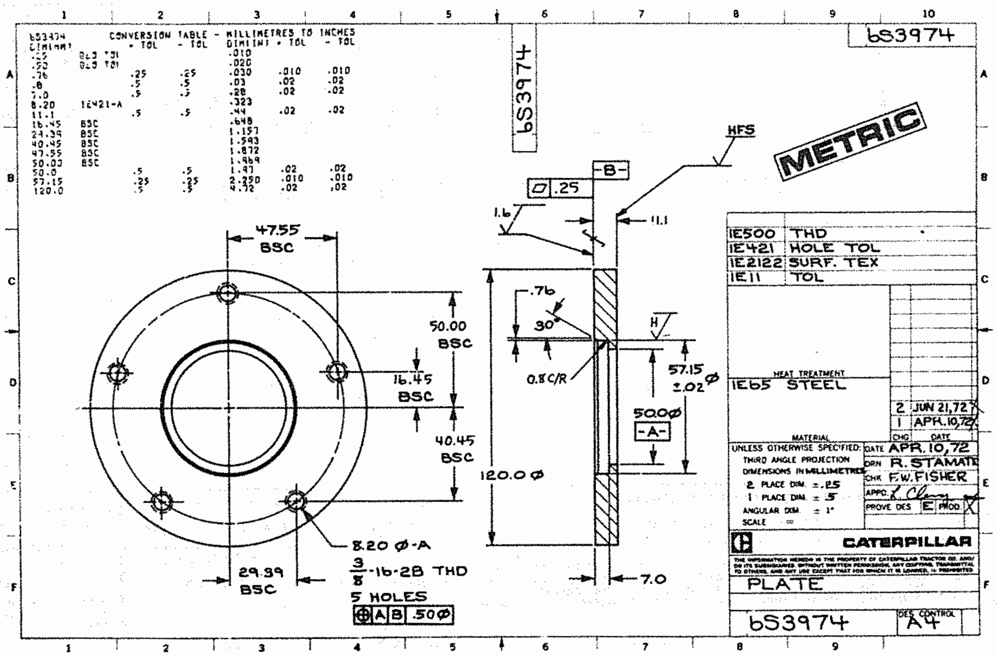


Fig. 6–3. Dual-dimensioned drawing from General Motors Drafting Standard. (General Motors Corp.)

Fig. 6–4. Dual capability drawing. (Caterpillar Tractor Co.)



verted" to the metric system. Dual-capability drawings can be worked in either system of measurement, but it is considered to be more efficient when worked in the metric system.

18. *What other methods are used to dimension drawings in both inch and metric sizes?*
Figure 6–5 shows a drawing dimensioned in inch measurements, with conversion sizes worked out by the draftsman and inserted close to the inch dimension.

19. *How will the change to metric dimensioning affect the scale of drawings?*
Fractional relationships such as ⅛" = 1'-0" will no longer be necessary. Instead, whole-number relationship will be used, typically in multiples of 10—for example, 1:100, 1:50, and so forth.

20. *How can inch measurements be converted to millimeters without using a table?*
Multiply the inch measurement by 25.4. For example

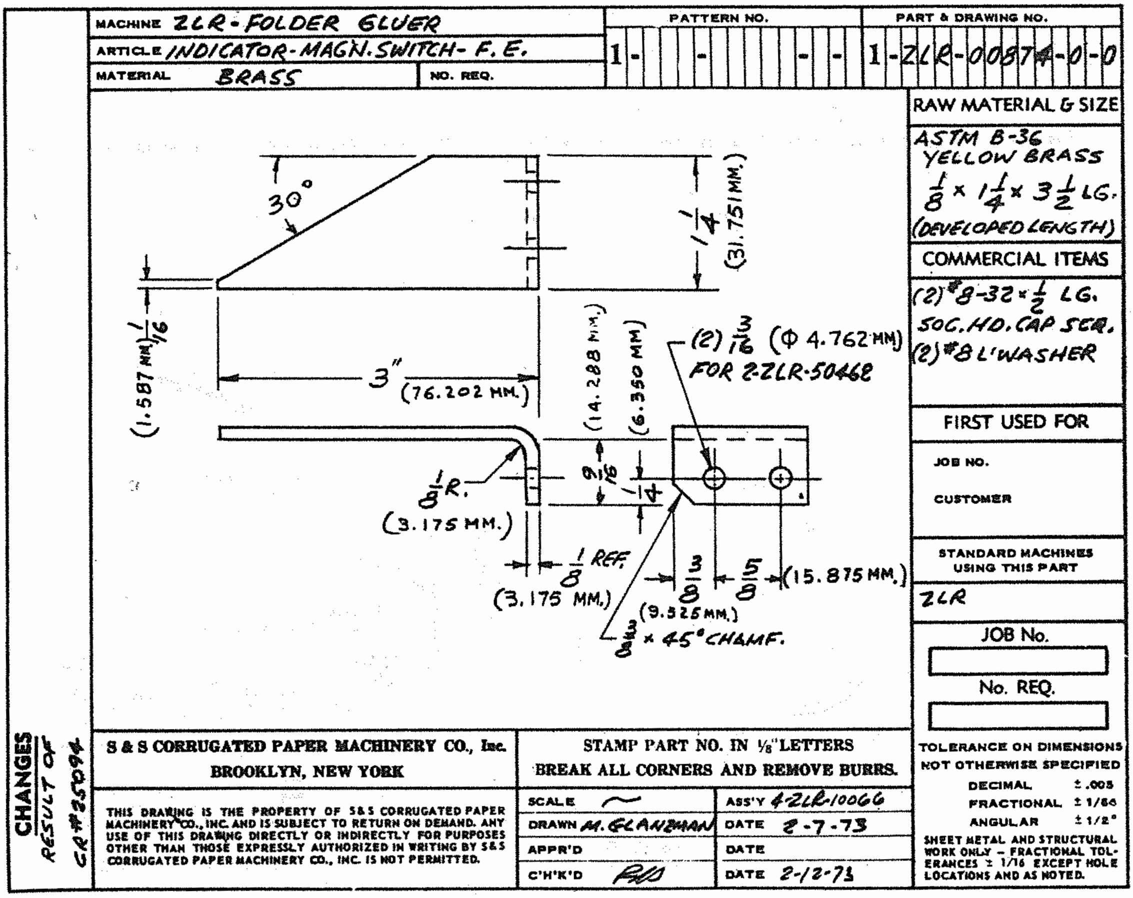
$$3 \text{ in.} \times 25.4 = 76.2 \text{ mm}$$
$$\tfrac{7}{8} \text{ in.} \times 25.4 = 22.225 \text{ mm}$$
$$1\tfrac{1}{4} \text{ in.} \times 25.4 = 31.75 \text{ mm}$$

21. *How can millimeters be converted to inches?*
Multiply millimeters by 0.03937. For example,

$$3 \text{ mm} \times 0.03937 = 0.11811 \text{ in.}$$
$$30 \text{ mm} \times 0.03937 = 1.18110 \text{ in.}$$
$$0.21 \text{ mm} \times 0.03937 = 0.0082677 \text{ in.}$$

22. *How are the various SI units related to one another, and to other units?*
There are many derived SI units; some have special names not currently used in the United States. The

Fig. 6–5. A draftsman converted drawing. (S & S Corrugated Paper Machinery Co.)



relationships, symbols, names, and derivations are shown in Fig. 6–6.

23. *What prefixes are commonly used in the metric system to extend the range of the basic unit?*
The following prefixes are in common use. Each represents a multiple of 10.

prefix	*power of 10 notation*	*multiple*	*symbol*
kilo	10^3	1,000	k
hecto	10^2	100	h
deka	10^1	10	da
deci	10^{-1}	0.1	d
centi	10^{-2}	0.01	c
milli	10^{-3}	0.001	m
micro	10^{-6}	0.000001	μ

24. *What are the most common SI symbols?*
Figure 6–7 is a table of common SI units.

25. *How are the prefixes and multiples used?*
Prefixes are used to save space and as a short-cut method of referring to very large or very small quantities of some basic unit. For example, instead of writing 0.0000005 and referring to it as "five ten-millionths of a meter," we can write 0.5×10^{-6} and refer to it as 0.5 micrometers (or "point five times ten to the minus-six meters"). The numerical value of the exponent, in this case 6, tells us how many places the decimal point must be moved to give us the quantity without any exponent. The negative sign means that the decimal point moves to the left, a positive sign (or no sign at all) means that the decimal point must move to the right. In the above example, the minus 6 exponent means we

Fig. 6–6. Relationships of SI units.

BASIC SI UNITS

Unit	**Name of Unit**	**Symbol**
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

In addition to the seven basic units, SI includes derived units which make it a more complete and coherent system of units, suitable for measurements in physical science and engineering. Some of the derived units have been given non-definitive names which carry specific definitions.

SOME DERIVED SI UNITS (with non-definitive names)

Unit	**Name of Unit**	**Symbol**
Force	newton	$N = kg\ m/s^2$
Work, Energy, Quantity of heat	joule	$J = Nm$
Power	watt	$W = J/s$
Electrical potential	volt	$V = W/A$

Other derived units carry no special names and must always be expressed in terms of units from which they were derived.

SOME DERIVED SI UNITS (without special names)

Unit	**SI Unit**	**Symbol**
Area	square meter	m^2
Volume	cubic meter	m^3
Density (mass density)	kilogram per cubic meter	kg/m^3
Pressure	newton per square meter	N/m^2

Fig. 6–7. Symbols and names of common SI units.

quantity	*unit*	*symbol*
Length	millimeter (one thousandth of a meter)	mm
	centimeter (one hundredth of a meter)	cm
	meter	m
	kilometer (one thousand meters)	km
	international nautical mile (1852 meters)	n mile
Area	square centimeter	cm^2
	square meter	m^2
	hectare (ten thousand square meters)	ha
Volume	cubic centimeter	cm^3
	cubic meter	m^3
Capacity	milliliter (one thousandth of a liter)	ml
	centiliter (one hundredth of a liter)	cl
	deciliter (one tenth of a liter)	dl
	liter	l
	hectoliter (one hundred liters)	hl
Weight	gram (one thousandth of a kilogram)	g
	kilogram	kg
	ton (one thousand kilograms)	t
Time	second	s
	minute	min
	hour	h
	(also day, month and year)	
Speed	meter per second	m/s
	kilometer per hour	km/h
	knot (international nautical mile per hour)	kn
Power	watt	W
	kilowatt (one thousand watts)	kW
Energy	kilowatt hour	kW h
Electric potential difference	volt	V
Electric current	ampere	A
Electric resistance	ohm	Ω
Frequency	hertz	Hz
Temperature	degree Celsius	°C

must move the decimal point six places to the left to get our original number.

0.5×10^{-6} m = 0.000000.5 or 0.0000005 m

26. *What is the Celsius temperature scale?*
The Celsius scale is a new name for the centigrade scale (Fig. 6–8). It is named Celsius in honor of the Swedish astronomer Anders Celsius (1701–1744), who invented the scale. The SI unit, degrees kelvin, is used for absolute temperature measurements in laboratory work.

27. *How do various key temperatures compare on the three scales?*
Absolute zero, freezing and boiling points of water, and normal body temperatures compare as follows:

	Fahrenheit scale (°F)	*Celsius scale (°C)*	*Kelvin scale (°K)*
absolute zero	**−459.67**	**−273.15**	**0**
water freezes	**32**	**0**	**273.15**
normal body temperature	**98.6**	**37**	**310.15**
water boils	**212**	**100**	**373.15**

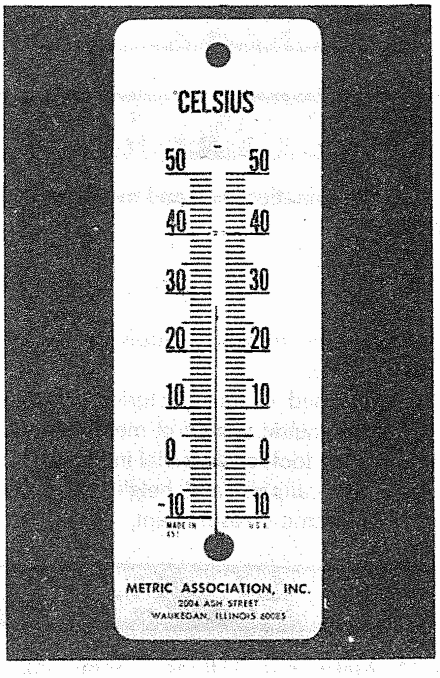


Fig. 6–8. The Celsius scale (formerly called the centigrade scale). (Metric Association, Inc., and the Wilking Studio.)

28. *What effect will the change to the metric system (metrication) have upon the production of tools?*
Many tool manufacturers are already producing metric-sized tools for use in shops where metric measurements are being used (Fig. 6–9). As the tempo of metrication increases, more and more tools and machines will be produced in metric sizes and calibrations.

29. *Are measuring tools available for the metric system?*
Most measuring tools are available in metric sizes and graduations. Figure 6–10 shows both sides of a rule that has dual dimensions: one side has mm and 1/64-in. graduations; the other has 1/2-mm and 1/32-in. graduations. Figure 6–11 shows a metric rule graduated in mm and ½-mm.

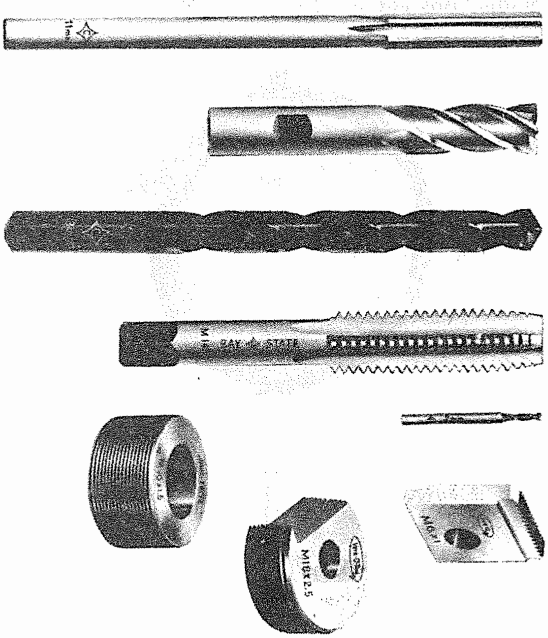


Fig. 6–9. Metric-sized tools: reamer, end mills, twist drill, tap, and dies. (Cleveland Twist Drill Co.)

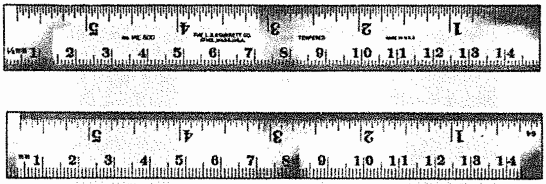


Fig. 6–10. Combination inch and metric rule. (L. S. Starrett Co.)

30. *Will precision measuring tools be required to have metric units?*
All new tools used in manufacturing will have to conform to the metric system of measurement. Precision measuring tools such as dial indicators, micrometers, vernier calipers, and height gages will be graduated for metric measurement.

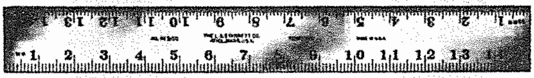
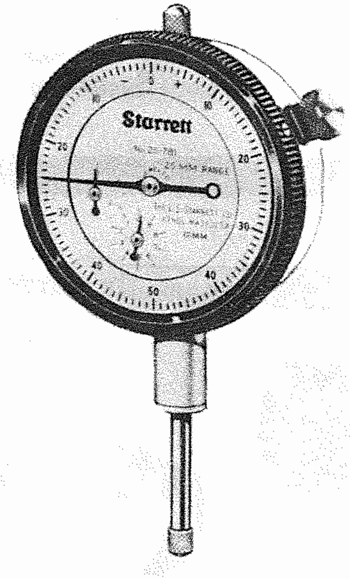


Fig. 6–11. Metric rule, 150 mm (15cm) long, graduated in millimeters and half-millimeters. (L. S. Starrett Co.)

Fig. 6–12. Metric dial indicator with 0.01-mm graduations and a range of 2.5 mm. (L. S. Starrett Co.)



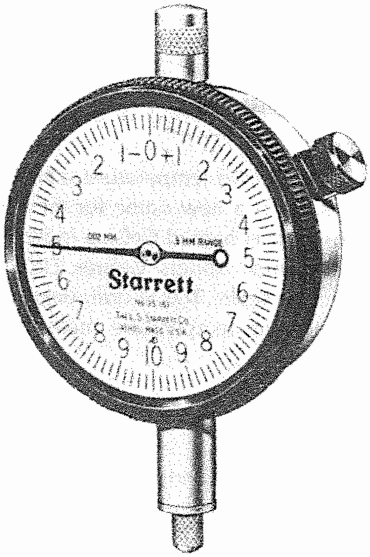


Fig. 6–13. Metric dial indicator with 0.002-mm graduations and a range of 0.5 mm. (L. S. Starrett Co.)

31. *How are dial indicators graduated for the metric system?*
Metric dial indicators have 0.01-mm graduations with a range of 2.5 mm or 0.002-mm graduations with a range of 0.5 mm (Figs. 6–12 and 6–13).

32. *How is the metric micrometer graduated and read?*
The pitch of the micrometer spindle thread is 1/2 mm. The index line on the sleeve has two sets of graduations; those above the line are in millimeters, the graduations below divide the millimeters in half. The thimble has 50 graduations; each fifth line is numbered. Each graduation on the thimble represents 1/50 of 1/2 mm or 1/100 mm (0.01 mm).

When reading the metric micrometer, (a) check the numbered line that is uncovered on the sleeve, (b) check if a half-millimeter line is showing, then (c) check the thimble graduation that coincides with the index line (Figs. 6–14A and 6–14B).

Numbered line on sleeve	5 × 1.00 mm =	5.00 mm
Half-line on sleeve	1 × 0.50 mm =	0.50 mm
Thimble graduation	28 × 0.01 mm =	0.28 mm
Complete micrometer reading		5.78 mm

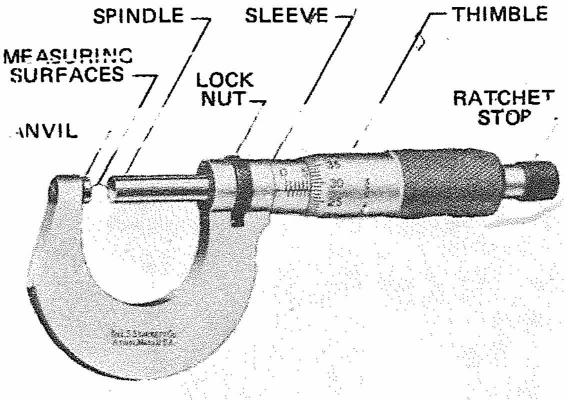
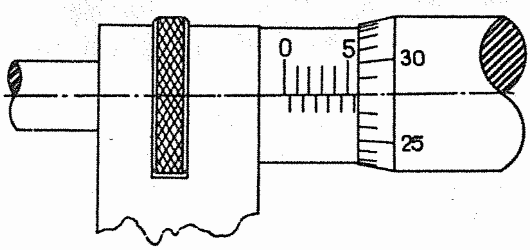


Fig. 6–14A. Metric micrometer, 0–25-mm size. (L. S. Starrett Co.)

Fig. 6–14B. Metric micrometer reading 5.78 mm. (L. S. Starrett Co.)



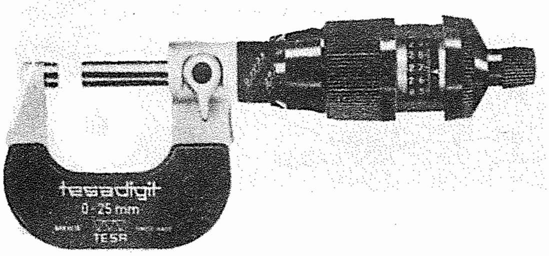


Fig. 6–14C. Direct-reading micrometer with metric scale. (L. S. Starrett Co.)

33. *Are metric micrometers made with vernier graduations?*
The metric vernier micrometer has the same pitch thread on the spindle but also has a vernier scale on the sleeve, which gives a measurement to 0.002 mm.

34. *How are the graduations of a vernier caliper read?*

Figure 6–15 shows a dual-measuring vernier caliper scale. Both sides have a 50-division vernier. Each graduation on the metric side of the main scale equals 1 mm; each tenth graduation is numbered. Each line on the vernier scale equals 0.020 mm.

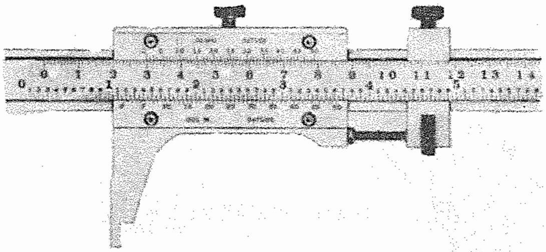


Fig. 6–15. Metric vernier caliper. (L. S. Starrett Co.)

35. *Will a conversion to the metric system change our thread standards?*
Yes, the new thread sizes will be based on metric measurement. The diameters of screws and bolts and pitch of threads will be in metric dimensions. Figure 6–16 shows how comparable dimensions are given for inch and metric threads.

36. *How can a metric thread be checked for size and pitch?*

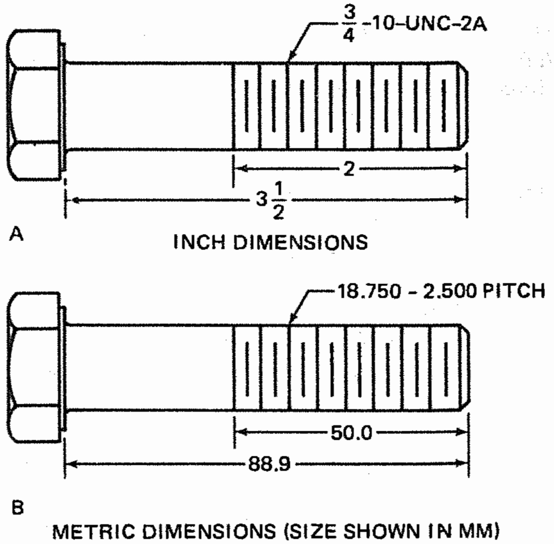


Fig. 6–16. Examples of (A) inch and (B) metric threads.

In the same way that inch-sized threads are tested—by thread plug and ring gages and screw-pitch gages. (Fig. 6–17).

37. *Can metric threads be cut on a standard American engine lathe?*
Yes, by installing metric transposing gears as shown in Fig. 6–18.

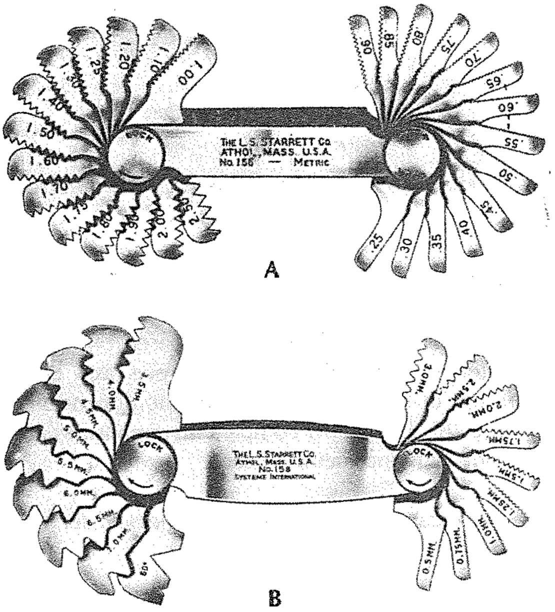


Fig. 6–17. (A) Screw-pitch gage for metric threads 0.025 to 2.50 mm. (B) Screw-pitch gage for metric threads 0.5 to 7.0 mm. (L. S. Starrett Co.)

38. *What is the best method of learning the metric system of measurement?*
By using it.

A. Obtain a metric tape measure (Fig. 6–19). Use it to measure lengths of convenient and familiar objects. Keep a record of each measurement, writing each in the approved format.
B. Obtain a metric ruler (Fig. 6–20) and measure familiar objects.
C. Estimate the lengths of unfamiliar objects in metric sizes and then check with metric tape measure or metric ruler.
D. Obtain a metric micrometer (see Fig. 6–14A) and measure familiar objects such as ½-in. flat cold-rolled steel. Use the formula to convert the size to its metric equivalent and compare this with the size obtained by the micrometer reading.

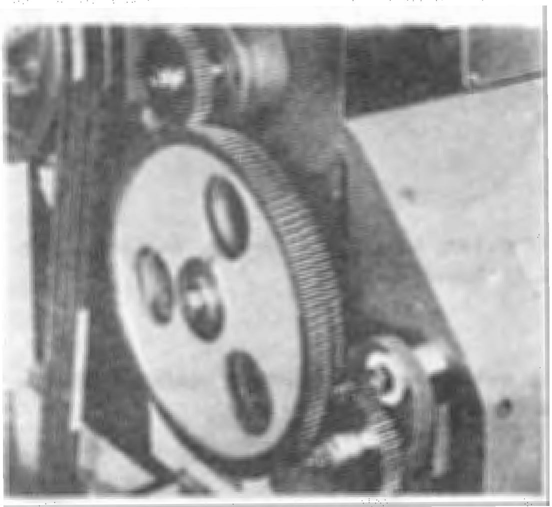


Fig. 6–18. Metric translating gears. These gears replace the gears in the end gear drive to permit the cutting of metric leads and threads with the English quick-change box and lead screw. (R. K. LeBlond Machine Tool Co.)

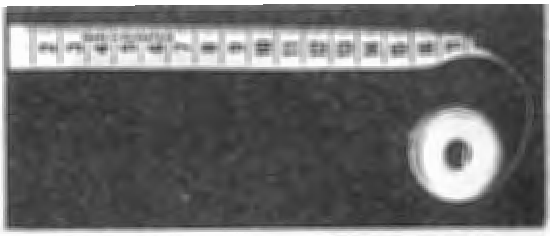
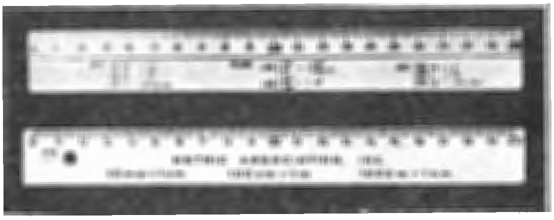


Fig. 6–19. Metric tape measure. (Metric Association Inc. and the Wilking Studio.)

Fig. 6–20. Metric ruler. (Metric Association, Inc. and the Wilking Studio.)



chapter 7 drills and drilling processes

Producing holes in workpieces made of various metals such as steel, brass, and aluminum can in some instances be a simple operation. However, considerable skill and knowledge is required in machine shops that do precision work. A large number of different drilling machines and cutting tools have been designed to produce accurate holes in all kinds of materials quickly and economically.

The setup and operation of all types of drilling machines is but one of the many duties of the competent machinist, toolmaker, or diemaker. Many manufacturing plants have drilling machine departments in which skilled operators specialize only in this type of work.

A skilled drilling-machine or drill-press operator should be able to set up and operate the various types and sizes of drilling machines according to blueprint and routing instructions. This includes (1) selecting and setting up the required cutting tools, (2) making all necessary adjustments, (3) setting workpieces in simple and complex drill jigs, (4) clamping workpieces in vises or to the machine table, (5) using tapping attachments, (6) checking the work with precision measuring and gaging tools, (7) keeping the workplace clean and orderly, and (8) being responsible for the quality and quantity of work produced.

TYPES OF STANDARD DRILLING MACHINES

The more common types are called sensitive (or upright or vertical), heavy-duty, gang, radial, multiple-drill-head, and tape-controlled drilling machines.

1. *What is a sensitive drilling machine?*
A sensitive drilling machine, or drill press (Fig. 7–1), is a belt-driven general-purpose tool used to produce a range of small-size holes. These drill presses are made in pedestal (or floor) models, bench models, and multiple spindle units. Figure 7–2 shows a bench model and its principal parts. These machines do not have an automatic-feed mechanism, so the cutting tools must be fed by hand, using the hand-feed lever. The range of spindle speeds varies according to the speed of the motor, the size ratio of the pulleys, and the number of steps on the pulleys.

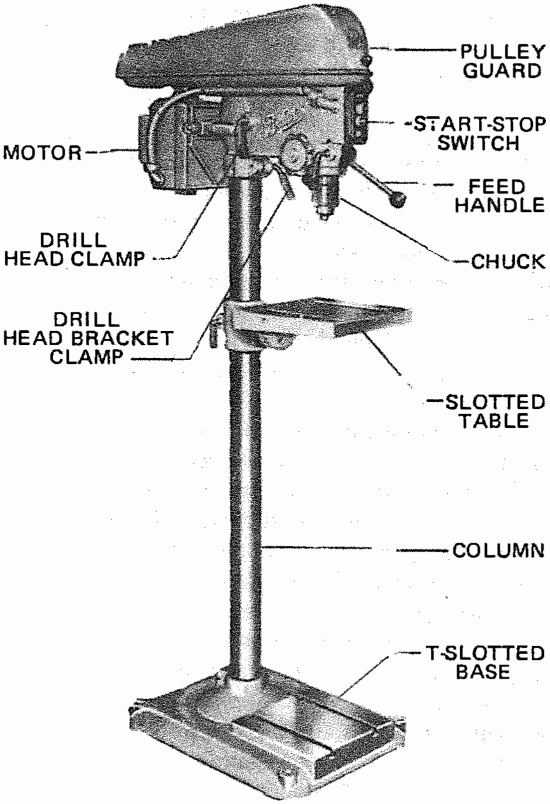


Fig. 7–1. Principal parts of a sensitive drill press. (Buffalo Forge Co.)

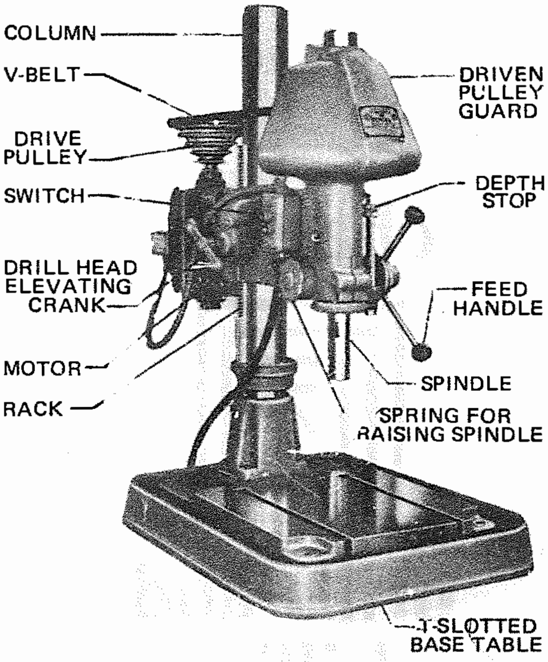


Fig. 7–2. Bench model sensitive drill press. (Cincinnati Lathe & Tool Co.)

2. *What skills are necessary to operate a sensitive drill press correctly?*
A skilled operator is one who has developed a "sense of feel" when feeding a drill into the workpiece. He can feel the cutting action of the drill or other cutting tool such as a counterbore or countersink and knows just how much pressure to apply to keep the tools cutting properly. This sense of feel is important because too heavy a feed may break the drill or damage the workpiece. Too little feed may result in chatter, too much heat, dulling of the cutting tools, and rapid wear of the drill margins, which ruins the drill. Another important skill is the ability to sense that the drill is beginning to break through the work. The skilled operator will reduce his pressure on the down-feed as the drill begins to break through, thus permitting the drill to cut its way freely and smoothly through the hole. Unless this is done, the drill is apt to grab or dig, which means that the drill will pull itself suddenly into the work or the work will be suddenly pulled upward—and damage the hole, break the drill, or injure the operator.

3. *What is a standard upright drilling machine?*
A standard upright drilling machine is a larger and heavier machine than a sensitive drill press (Fig. 7–3). It is a general-purpose machine used for all types of drilling, reaming, countersinking, counterboring, tapping, and lapping. It can machine large holes. The spindle-drive unit usually consists of a variable-speed transmission. The drill head can be raised or lowered on a machined column and clamped in position. The work table, which may be square, rectangular, or round, is raised or lowered by means of an elevating screw. Larger machines usually have T-slotted tables so that large workpieces can be clamped directly to the table using T bolts and strap clamps. Small workpieces are held in a vise.

4. *Describe a heavy-duty drilling machine.*
A heavy-duty drilling machine is a larger, heavier

Fig. 7–3. Upright drill press.

machine than the sensitive or the standard upright drill press. It has a gear-train drive and power feeds. It is a powerful machine for drilling, tapping, and machining large holes. The gear drive permits a wide range of spindle speeds, which vary from 60 to 1,000 revolutions per minute. The slower speeds and resultant increase in power are necessary for large-diameter cutting tools. Figure 7–4 gives the names of the principal parts of this machine. The spindle end has a large Morse taper bore, which receives taper-shank cutting tools or drill chucks equipped with Morse taper arbors. The spindle can be reversed so that holes can be threaded with taps.

5. *What is a gang drilling machine?*
The multiple-spindle, or gang, drilling machine consists of a large base supporting a long table. The back of the base is designed so that several spindles may be mounted on it, as in Fig. 7–5. Each spindle is driven by its individual direct-connected motor. The table has a groove around the outside for the return of the cutting lubricant and may have T slots on its surface for ease in clamping work to the table. It is adjusted for height by means of a

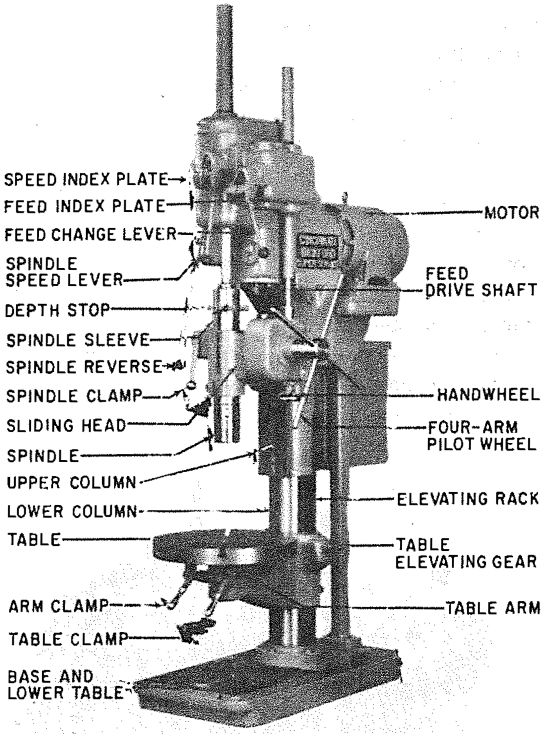


Fig. 7–4. Principal parts of a heavy-duty drilling machine. (Cincinnati Bickford Tool Co.)

Fig. 7–5. Gang drilling machine.

crank, which actuates screws through worms and gears fitted with ball bearings.

This type of machine is generally preferred when the work is to be moved from spindle to spindle for successive operations.

6. *What is a multiple-drill-head drilling machine?* The multiple-drill-head machine (Fig. 7–6) should not be confused with the multiple-spindle machine. The multiple-drill-head machine may have any number of spindles from 4 to 48, or more, all driven from the one spindle drive gear in one head. Multiple heads are specially designed for mass-production operations such as drilling, reaming, or tapping many holes at one time in a specific unit of work such as an automobile engine block. There may be two or more drill heads on one machine, each with many spindles. This is necessary when holes are drilled from more than one direction—for example, on the top, side, and end of a piece of work. Production units of this type are seldom used in a toolroom that usually does highly skilled custom work. Figure 7–7 shows a multiple-drill-head set up for a job.

7. *What is a radial drilling machine?* The radial drill (Fig. 7–8) is a precision machine that is designed so that the entire mechanism may be adjusted to bring the spindle into the required position over the work, which is fastened securely to the stationary base. The large arm of the machine is raised or lowered by a motor-driven mechanism, which operates on a long, stationary, elevating

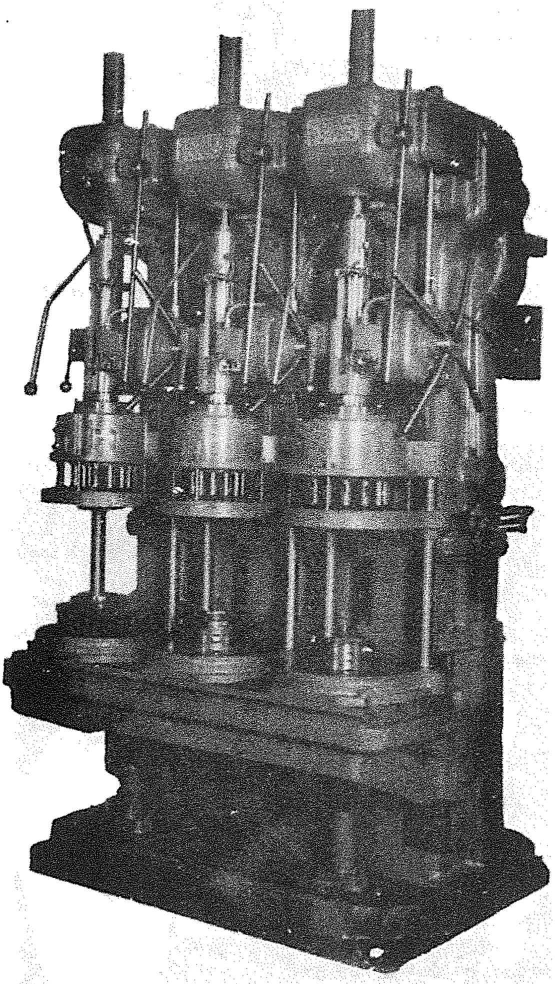


Fig. 7–6. Multiple drill-head drilling machine. (Cincinnati Bickford Tool Co.)

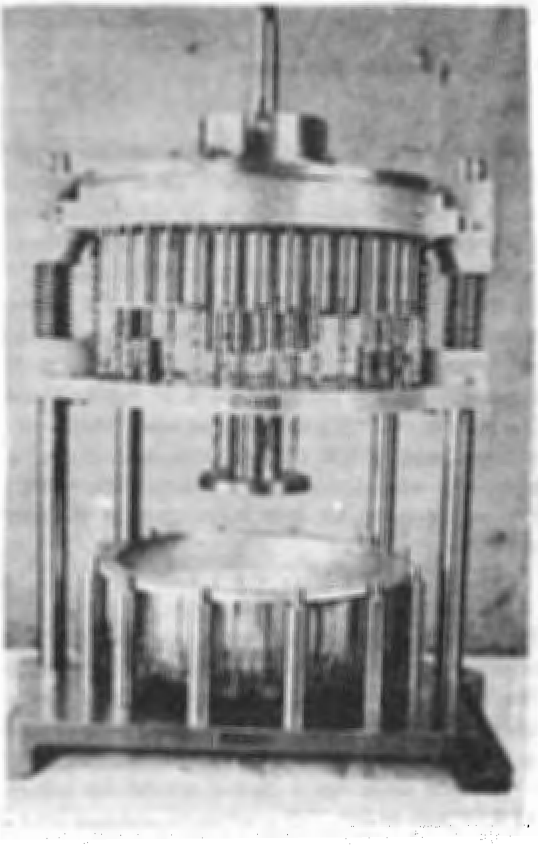


Fig. 7–7. A multiple drill-head setup and work to be drilled. (Ettco Tool Co.)

ig. 7–8. **Radial drilling machine. (Fosdick Machine ool Co.)**

crew. The arm is automatically clamped on ne vertical column when the elevating mechanism s stopped. The head, which contains the spindle nd power-feeding mechanism, can be moved ack and forth on the arm and clamped in place. 'he arm may be rotated around the column and lamped securely in the required location.

This type of drilling machine is generally used or work that is too large or too heavy to be placed n a vertical-spindle machine, but especially for obs where accuracy of a high degree is required. t has a capacity for drilling or tapping holes up to ½ in. in diameter in steel, and up to 2 in. in liameter in cast iron, within very close limits.

8. *What is a tape-controlled drilling machine?*
tape-controlled drilling machine (Fig. 7–9) is a umerically controlled machine tool, which automatically performs most of the operations a skilled perator would do manually. The workpiece is lamped into position on a fixture mounted on the able. Tape on which instructions have been

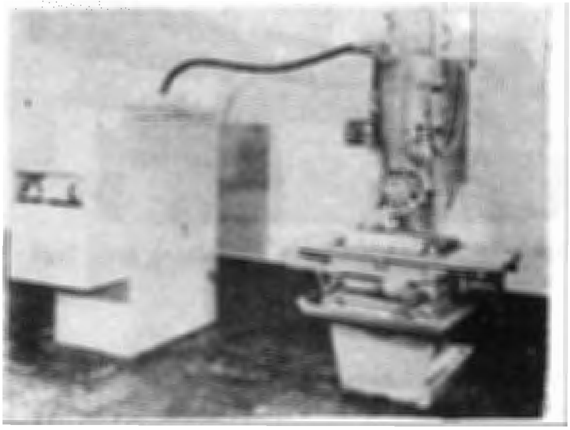


Fig. 7–9. A numerically controlled turret drilling machine. (Brown & Sharpe Mfg. Co.)

punched controls the motors that drive the table feed screws and position the workpiece for the machining operations. The tape also controls the movement for feeding the drill spindle the required distance into the workpiece, withdrawing it, and turning the coolant on and off at the desired time, plus other movements needed to produce a machined workpiece.

WORK-HOLDING ATTACHMENTS AND ACCESSORIES

Before accurate work can be produced, it is necessary to set up the work correctly. This requires the use of certain attachments and accessories such as a drill vise, parallel bars, a drill jig, and step blocks; or fasteners such as clamps and T bolts, washers, and nuts.

9. *What is a drill vise?*
A drill vise (Fig. 7–10) is a work-holding tool in which the workpiece may be seated square and parallel and held securely while the drilling and other operations are performed. Figure 7–11 shows a safety-type vise. Because it can be turned over on three sides, several holes can be drilled without removing the work.

10. *What is a drill jig?*
A drill jig (Fig. 7–12) is a work-holding tool, which locates the workpiece in proper position and holds

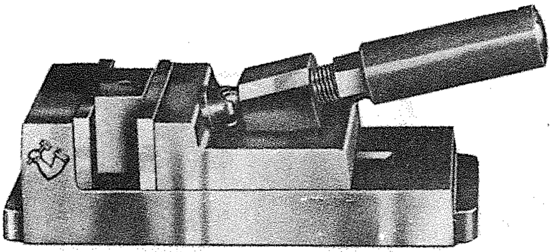
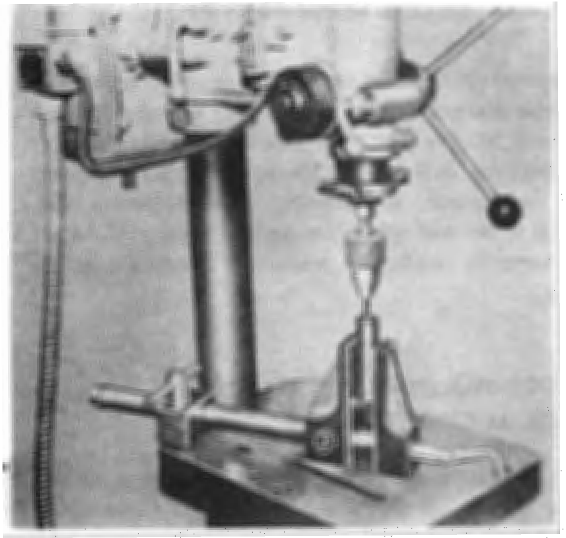


Fig. 7–10. A plain drill vise. (Armstrong Bros. Tool Co.)

Fig. 7–11. A safety-type drill vise can hold work in several positions. (American Machine & Foundry Co.)



it securely. The drill and other cutting tools are guided by hardened steel drill bushings so that the holes drilled in all of the parts are in the same exact location. Drill jigs are production tools used in the mass production of parts.

11. *What are parallel bars and for what purpose are they used?*
Parallel bars (Fig. 7–13) are hardened, accurately ground steel bars of various thicknesses, widths, and lengths, which are used to raise the workpiece and seat it square and parallel with the base of a vise as shown in Fig. 7–14. The workpiece should be tapped with a soft hammer to seat it firmly on the parallels.

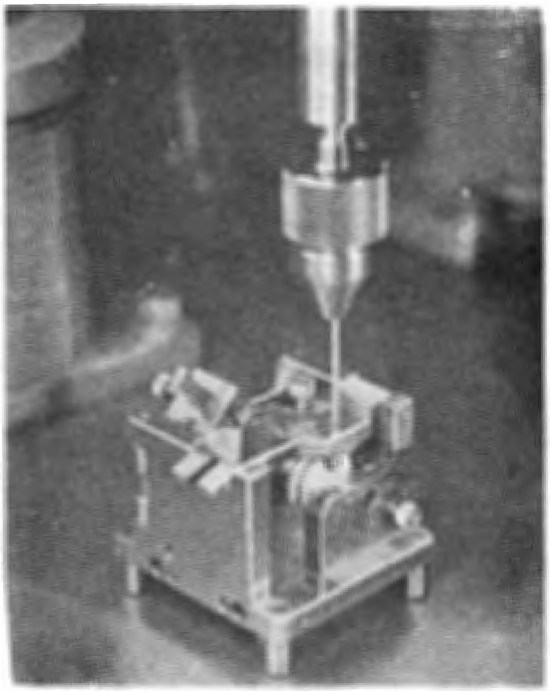
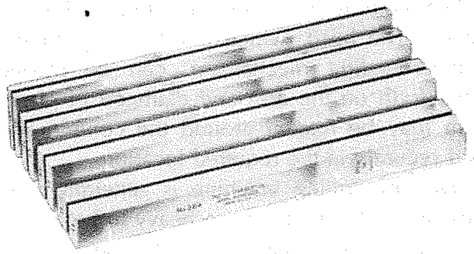


Fig. 7–12. A drill jig holds the work and accurately locates the drill for drilling large quantities of identical parts.

Fig. 7–13. Parallel bars. (L. S. Starrett Co.)



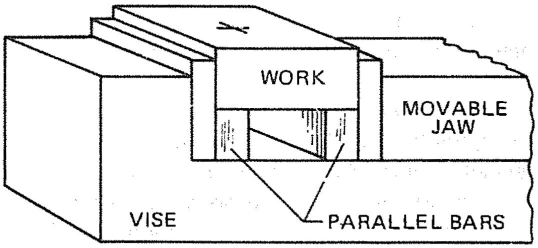
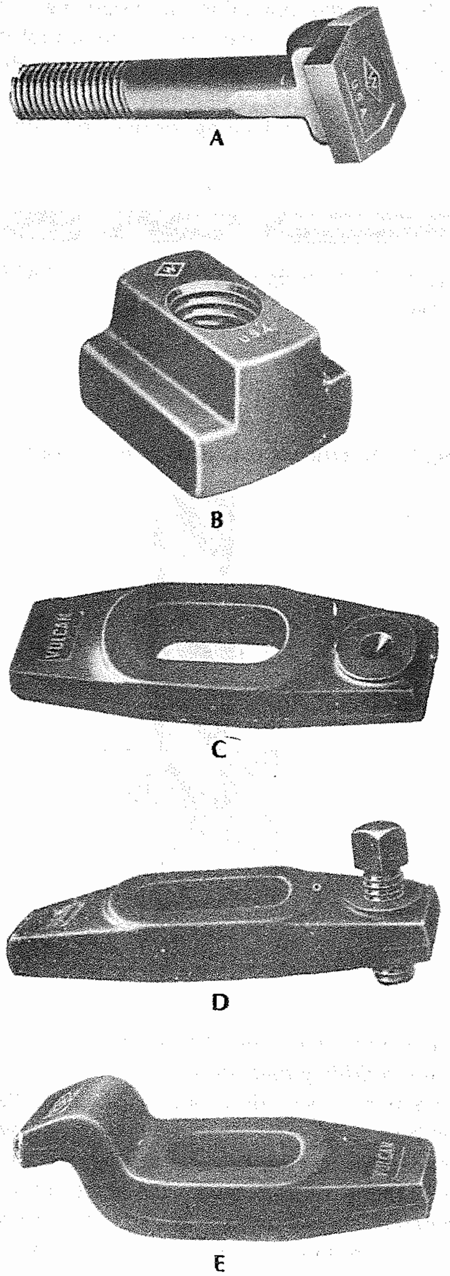


Fig. 7–14. Workpiece seated on parallel bars.

12. *Name the common kinds of accessories used for clamping workpieces on a T-slotted table.*

The commonly used accessories for clamping work on a T-slotted table are T bolts, studs and T nuts; step blocks, parallel bars, and a variety of clamps, as shown in Fig. 7–15.



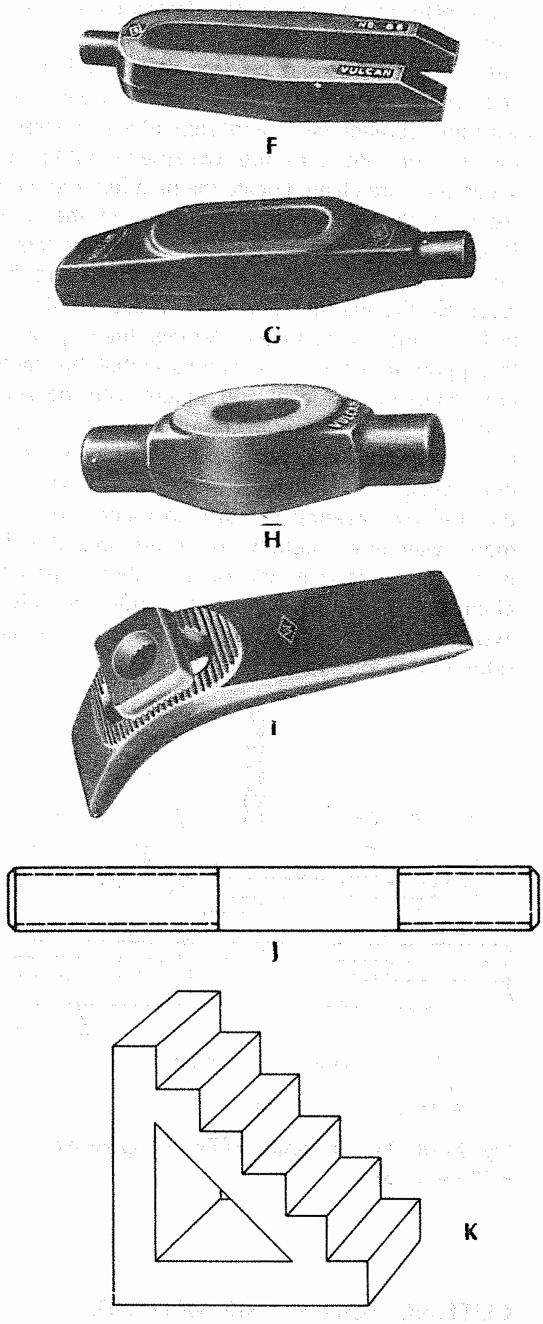


Fig. 7–15. Work-holding accessories. (A) T bolt. (B) T nut. (C) Strap clamp. (D) Adjustable strap clamp. (E) Goose-neck clamp. (F) U clamp. (G) Finger clamp. (H) Double-finger clamp. (I) Universal clamp. (J) Stud for T nut. (K) Step block. (J. H. Williams Co.)

13. *Explain the procedure for clamping a flat workpiece directly to the table of a drill press.*

The workpiece should be free of burrs, laid out, and center punched. Select the T bolts, nuts, washers, parallel bars, and step blocks necessary for the job. Be sure the workpiece, table, and accessories are clean. Locate the parallels and workpiece in the approximate position on the table. Place the T bolts in the T slots, making sure they fit freely. Place the clamps over the T bolts and then assemble the washers and nuts. These should also fit freely and not be forced. Arrange the step blocks to support the ends of the clamps so that the clamps are approximately level and square with the work. Good clamping technique requires that the T bolts be as close to the workpiece as possible. Make the final adjustment to align the center-punch mark with the drill by lowering the drill to touch the punch mark, watching carefully to ensure that the drill is not forced to one side or the other. When the alignment is correct, tighten the nuts carefully to avoid moving the work. Figure 7–16 shows a typical setup of this job.

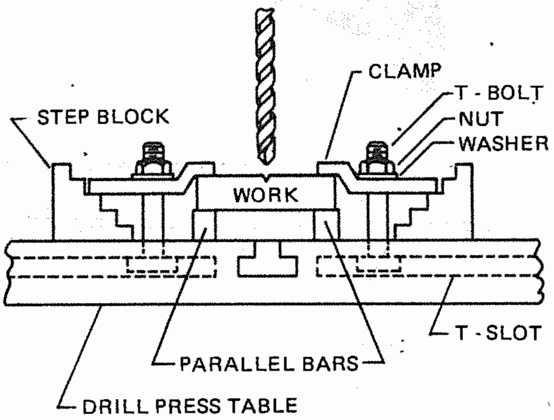


Fig. 7–16. Typical setup when clamping work on a drill press table.

CUTTING TOOLS AND METHODS OF HOLDING

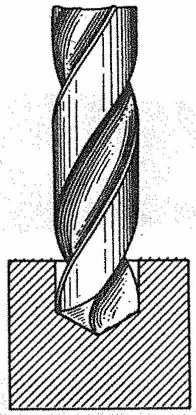
The most common cutting tool for making holes is the drill. It consists of a cylindrical piece of steel with spiral grooves (Fig. 7–17). One end of the cylinder is pointed; the other end is shaped so that it can be held in a portable or a stationary drilling machine. The grooves, usually called *flutes,* may be cut into the steel cylinder, or the flutes may be formed by twisting a flat piece of steel into a cylindrical shape. Drills of this kind are referred to as *twist drills.*

14. *Define the operation of drilling.*

Drilling is the operation of producing a hole in solid material by means of a cutting tool called a drill (Fig. 7–18). Twist drills and flat drills are commonly used for producing holes. Other methods include casting, punching (or piercing), and boring.

Fig. 7–17. A straight-shank twist drill. (Whitman & Barnes.)

Fig. 7–18. Drilling produces a hole in solid material.



15. *Name and describe several types of drills used in drilling machines.*

Commonly used drills are twist drills, flat drills, oil-hole drills, and straight-fluted drills. Twist drills made with straight or taper shanks are widely used for general-purpose work. The flutes are made with different helix angles for special-purpose work such as drilling soft metals and deep holes. A flat drill (Fig. 7–19) is preferred for drilling brass because it will not dig in or feed itself into the material. Another reason for its use is that, whereas hard spots in steel will cause an ordinary drill to slide off center, flat drills are not affected in this manner. Also, flat drills make fine chips instead of long coils. An oil-hole drill (Fig. 7–20) is one which has holes through the body of the drill from the shank to the point. This permits oil to flow down to lubricate and cool the point of the drill. Oil-hole drills are generally used for deep-hole drilling A straight-fluted drill (Fig. 7–21) is used for drilling brass and soft and thin sheet materials. Having no rake angle like the helix-fluted drills, these drills do not grab or dig in.

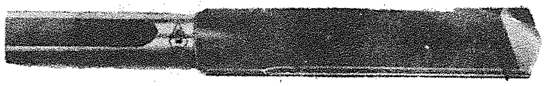


Fig. 7–19. Flat drill. (Whitman & Barnes.)

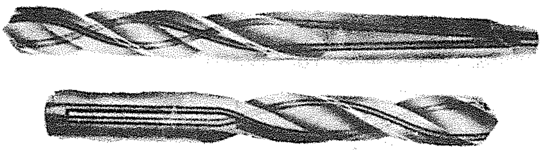


Fig. 7–20. Oil hole drills. (Whitman & Barnes.)

Fig. 7–21. Straight-fluted drill. (Cleveland Twist Drill Co.)

16. *What is a step drill and for what purpose is it used?*

A step drill (Fig. 7–22) is a twist drill with two or more diameters for drilling holes in solid material or for finishing cast or pierced holes. It is more widely used in mass producing holes with two or more diameters that must be concentric, and for combining operations such as drilling and reaming, countersinking, chamfering, and counterboring. Figure 7–23 shows types of holes produced by step drills.

17. *Can holes other than round holes be drilled by rotary motion?*

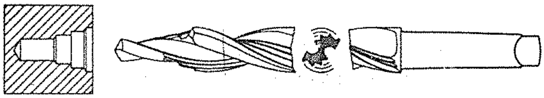
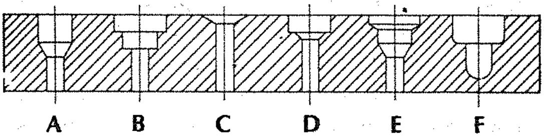


Fig. 7–22. A step, or multidiameter, drill and the hole it produces. (Cleveland Twist Drill Co.)

Fig. 7–23. Types of holes made with step drills: (A) drill, chamfer, and bore; (B) drill and multiple counterbore; (C) drill and countersink; (D) drill, counterbore, and chamfer; (E) drill multiple diameters; (F) radius drill and counterbore. (Cleveland Twist Drill Co.)



Yes. Square, hexagonal, pentagonal, and octagonal holes—called angular holes—can be drilled in a drill press, engine lathe, turret lathe, and milling machine.

18. *Explain the method and principle of drilling angular holes by rotary motion.*

In 1914, Henry J. Watts invented and developed the Watts method of drilling angular holes. This method is based on the fact that a circle may be made by connecting a series of very small straight lines, or chords, making 360° to complete the circle. Figure 7–24 shows the various positions of the cutting lips on the square drill as it rotates in a guide plate. Note that its lips will not follow a circle but a series of minute curves whose chords are parallel to the sides being drilled.

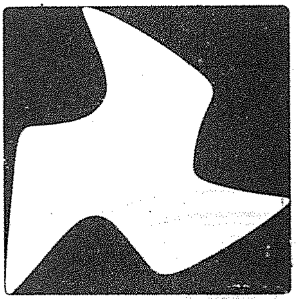


Fig. 7–24. End view of drill for making square holes. (Watts Bros. Tool Works.)

19. *Describe the tools necessary for drilling angular holes.*

The basic tools used for drilling angular holes consist of the Watts full-floating chuck, which is patented (Fig. 7–25), angular drills (Fig. 7–26), guide plates (Fig. 7–27), and slip bushings (Fig. 7–28)

The Watts full-floating chuck takes up the driving and floating motion, which permits the drill to operate as freely as a standard twist drill. Guide plates are necessary for each different size and type of angular drill because they control the path of the drill when it starts into the metal. The guide plate must be clamped directly onto the workpiece. The stepped guide plate can be used in a drill jig.

Watts angular drills for square holes have three flutes and cutting lips, whereas the drill for producing a hexagonal hole has five flutes and cutting lips. Sizes of angular drills vary by sixteenths of an inch, from ¼ to 2 in. All of the cutting is done on the end of the drill.

To obtain good results, angular drills require equal cutting surfaces on all sides. The float of the chuck must be central with the angular hole so that the drill can float freely into the various corners. The lead hole also must be in the center of the angular hole to ensure equal cutting surfaces for the angular drill.

Slip bushings are fitted into the guide plates so as to eliminate the need for laying out the lead hole and save time when setting up the tools. The use of slip

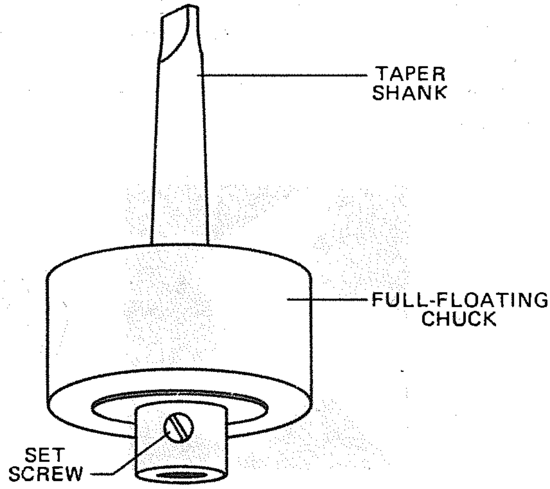


Fig. 7–25. A Watts full-floating chuck. (Watts Bros. Tool Works.)

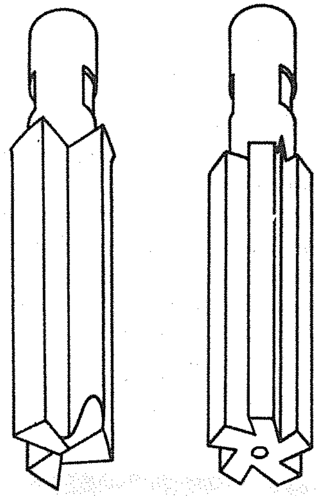
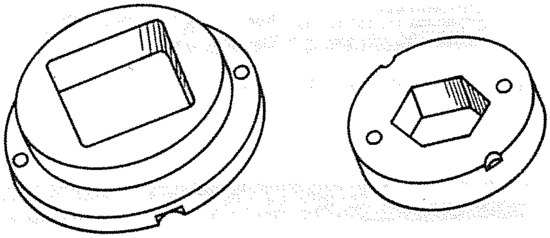


Fig. 7–26. Watts drills for drilling square and hexagonal holes. (Watts Bros. Tool Works.)

Fig. 7–27. Guide plates for square and hexagonal drills. (Watts Bros. Tool Works.)



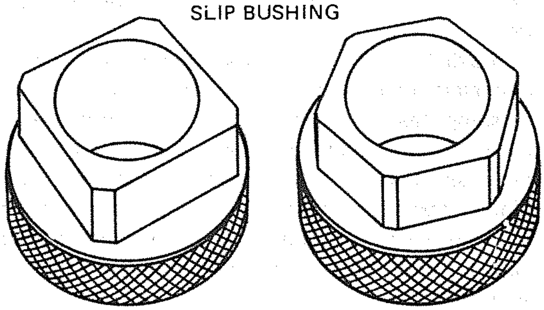


Fig. 7–28. Slip bushings for square and hexagonal drills. (Watts Bros. Tool Works.)

ıushings insures that the lead hole is automatically ɔcated in the center of the drill press spindle and ıat the float of the chuck will be equally distributed.

0. *Name the principal parts of a standard twist 'rill.*
'he names of the principal parts of a standard twist ɪrill are given in Fig. 7–29. The body is the cutting ınit, and the shank is the part held in the drilling ıachine for driving or rotating the drill.

1. *Describe the point of a drill.*
'he point of the drill should not be confused ʌith the dead center. The point is the entire cone-haped surface at the cutting end of the drill (Fig. –30).

2. *What is the dead center of a drill?*
'he dead center is the sharp edge at the extreme tip ɪnd of the drill (see Fig. 7–30). Formed by the ıtersection of the cone-shaped surfaces of the point, ıe dead center should always be in the exact ɐnter of the axis of the drill.

3. *What is the cutting lip of a drill?*
'he cutting lip of a drill (see Fig. 7–30) is the part f the point that actually cuts away the material ʼhen a hole is drilled. It is ordinarily as sharp as the ɗge of a knife. There is a cutting lip for each flute f the drill.

4. *What is the lip clearance of a drill?*
'he lip clearance is the surface of the point that is ground away or relieved just back of the cutting lip of the drill.

25. *What is the margin of a drill?*
The margin is the narrow strip shown in Fig. 7–30. It is the full diameter of the drill and extends the entire length of the flute. Its surface is part of a cylinder, which is interrupted by the flutes and by what is known as body clearance. The diameter of the margin at the shank end of the drill is 0.0005 to 0.002 in. smaller than the diameter at the point. This allows the drill to revolve without binding when drilling deep holes.

26. *What is the body clearance of a drill?*
The portion of the drill body from the margin in Fig. 7–30 is smaller in diameter than the margin. This reduction in size, called *body clearance*, reduces the friction between the drill and the walls of the hole being drilled; the margin ensures that the hole will be of accurate size.

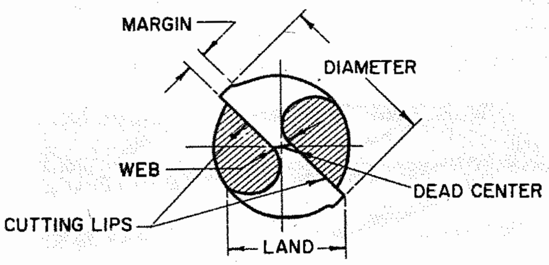
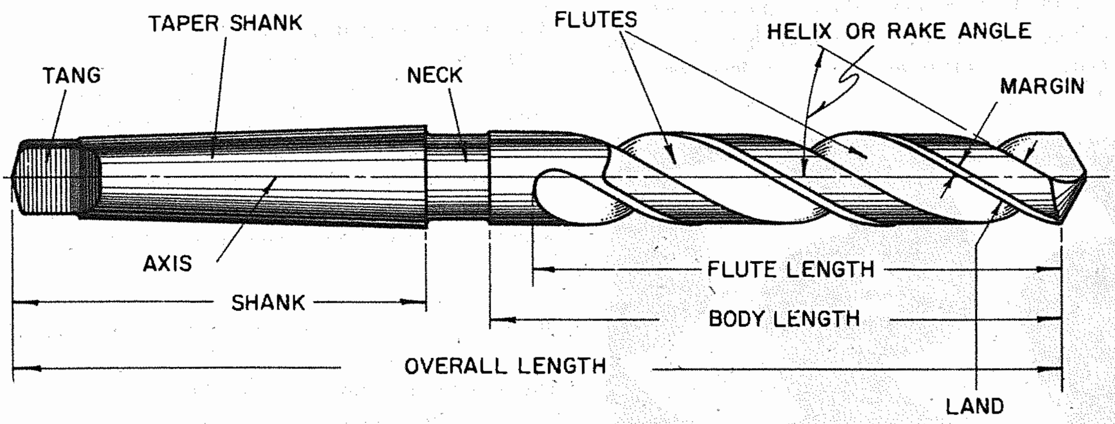


Fig. 7–30. The point of a twist drill. (Morse Twist Drill & Machine Co.)



g. 7–29. Principal parts of a twist drill. (Morse Twist Drill & Machine Co.)

27. *What is the web of a drill?*
The web is the metal column, which runs the entire length of the drill between the flutes (Fig. 7–31). It is the supporting section of the drill—the drill's backbone, in fact. The web gradually increases in thickness toward the shank (Fig. 7–32). This thickening gives additional rigidity to the drill.

28. *What is the rake angle of a drill?*
The rake angle is the angle of the flute in relation to the work (Fig. 7–33). For ordinary drilling, the rake angle established by the manufacturer of the drill is correct and should remain untouched. If the angle is 90° or more, it will not give a good cutting edge. If the angle is ground too small, however, the cutting edge becomes so thin that it breaks down under the strain of the work.

The rake angle also partially governs the tightness with which the chips curl and hence the amount of space they occupy. Other conditions being the same, a very large rake angle makes a tightly rolled chip, whereas a rather small rake angle makes a chip tend to curl into a more loosely rolled helix. Figure 7–34 shows how chips will be removed from the job by a correctly ground drill.

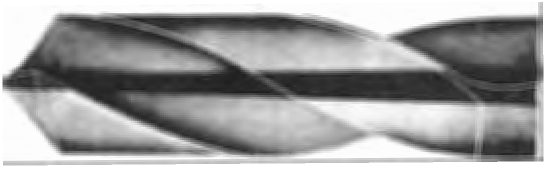
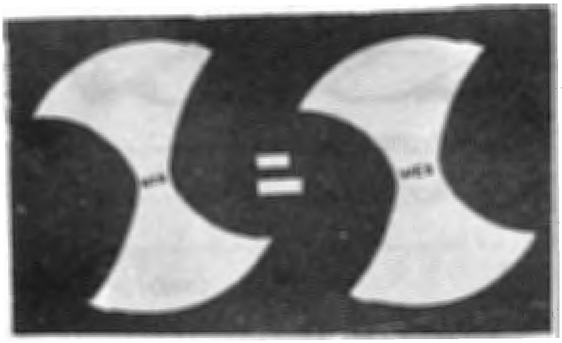


Fig. 7–31. Dark center section indicates the web of the drill. (Cleveland Twist Drill Co.)

Fig. 7–32. Drill section at the left shows web thickness near point of drill; section at right shows web thickness near shank end of drill. (Cleveland Twist Drill Co.)



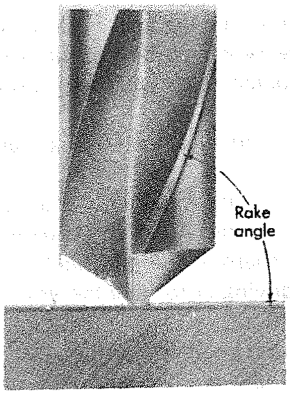
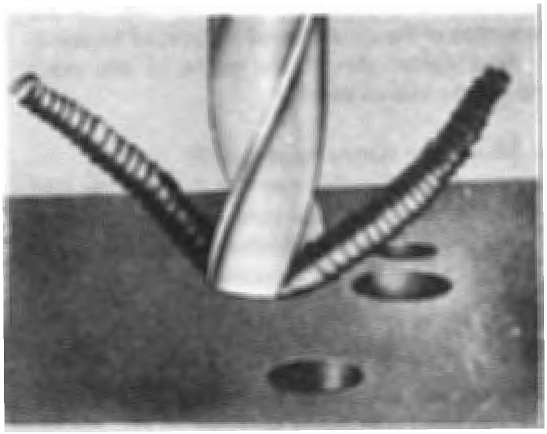


Fig. 7–33. Rake angle of drill. (Cleveland Twist Drill Co.)

Fig. 7–34. Type of chip formed by a correctly ground drill. (Cleveland Twist Drill Co.)



29. *What is the tang of a drill?*
A tang is found only on tapered-shank tools (Fig. 7–29). It is designed to fit into a slot in the socket or spindle of a machine. It may bear a portion of the driving strain, but its principal use is to make it easy to remove the drill from the spindle socket with the aid of a drill drift (Fig. 7–35). A safety drill drift, which is used without a hammer, is shown in Fig. 7–36.

30. *What are the four most common shanks used on drills?*
The four most common shanks (Fig. 7–37) are the bit shank, the straight shank, the tapered shank, and the ratchet shank.

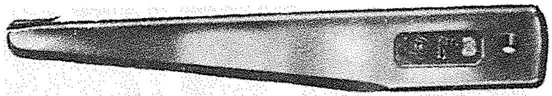
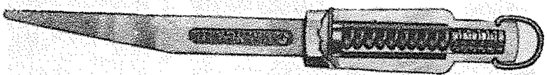


Fig. 7–35. **Drill drift. (Armstrong Bros. Tool Co.)**

Fig. 7–36. Safety drill drift. (Armstrong Bros. Tool Co.)



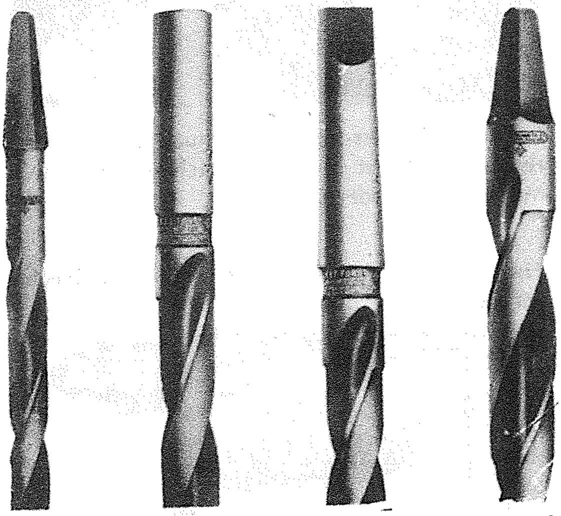


Fig. 7–37. Common drill shanks. (A) Bit shank. (B) Straight shank. (C) Tapered shank. (D) Ratchet shank. (Cleveland Twist Drill Co.)

31. *Why is the tapered shank used on drills?*
The tapered shank on a drill enables it to be quickly and accurately inserted into the spindle of a machine without using screws or clamps.

32. *What prevents a tapered-shank drill from falling out of the spindle?*
The hole in the spindle and the tapered shank match each other. When the drill is thrust into the spindle, drill and spindle become wedged together. When drilling, the pressure of the work against the drill increases the wedgelike action.

33. *What should be done to ensure perfect contact between the spindle socket and the drill shank?*
Before inserting a drill into a socket, wipe the shank to make certain that it is smooth and free from grit. Also, inspect the inside of the socket to be sure that it too is in good condition.

34. *Do all tapered-shank drills have shanks of the same size?*
No. When a small tapered-shank drill must be used in a machine with a large socket, a sleeve is used (Fig. 7–38). Sleeves are made in several combinations of internal and external sizes.

35. *Explain how a tapered-shank drill is removed from the spindle of a drill press.*
To remove a tapered-shank drill, place the drift in the slot of the spindle, as in Fig. 7–39; the sloping edge of the drift must match the slope on the end

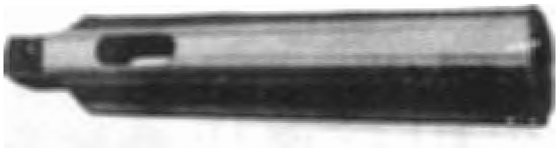


Fig. 7–38. Sleeve for tapered shanks.

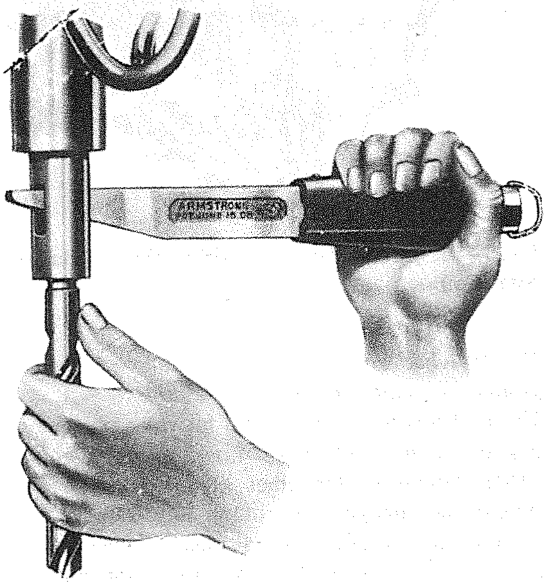


Fig. 7–39. Removing a drill from the drill press spindle. (Armstrong Bros. Tool Co.)

of the tang of the drill. A light hammer tap on the wide end of the drift is usually sufficient to loosen the shank from the spindle. Avoid having the drill drop onto the machine table because this may dull the point of the drill or damage the table. Also, if it is necessary to tighten a shank in a spindle, use a mallet of rawhide or some equally soft material to tap the point of the drill upward.

36. *How are straight-shank drills held in a drill press?*
Straight-shank drills are held in a drill press by a chuck. The jaws of the chuck are tightened around the drill by means of a key or wrench. Two varieties of drill chucks are shown in Fig. 7–40 and Fig. 7–41. Straight-shank drills are also used on most portable drilling machines—for example, the electric drill (Fig. 7–42) and the hand drill (Fig. 7–43).

Fig. 7–40. Jacobs key-type drill chuck. (Jacobs Mfg. Co.)

37. *At what angle should the cutting edge be ground in relation to the axis of a drill?*
The best angle to grind a drill for work on steel or cast iron (Fig. 7–44) is 59° (included angle equals 118°). However, for other materials, angle size should be changed. A cutting angle up to 70° is best for extremely hard metals, whereas the angle may be as small as 40° for a soft material like fiber. It is customary to use a drill-grinding gage (Fig. 7–45) to test the size of the angle.

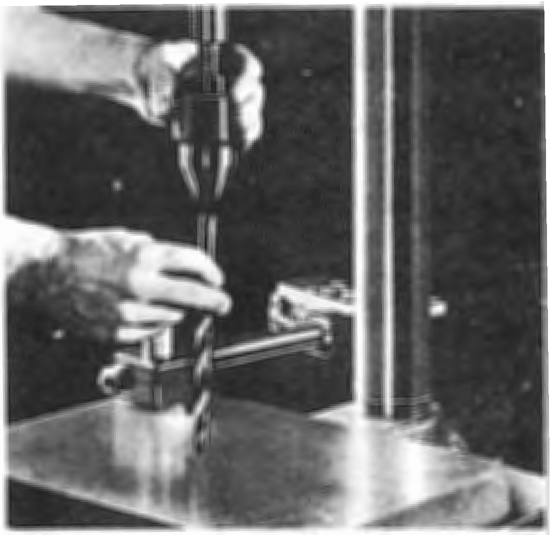
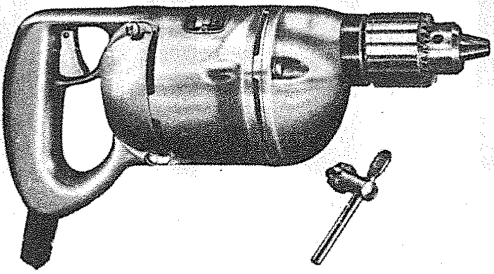


Fig. 7–41. Keyless-type drill chuck permits drill removal without stopping machine. (American Machine & Foundry Co.)

Fig. 7–42. Portable electric drill. (Black & Decker Mfg. Co.)



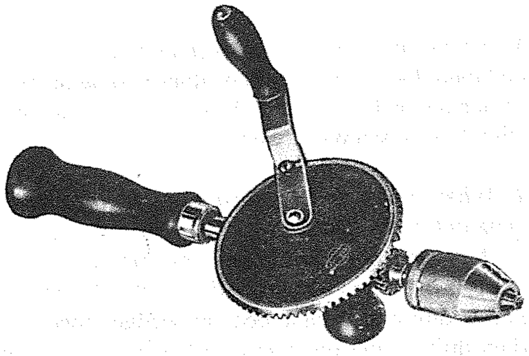


Fig. 7–43. Hand drill. (Stanley Tools.)

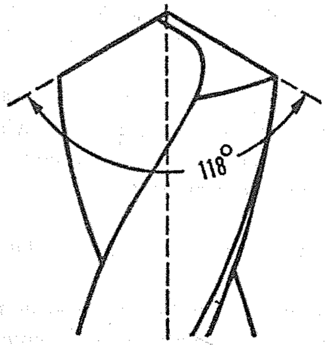
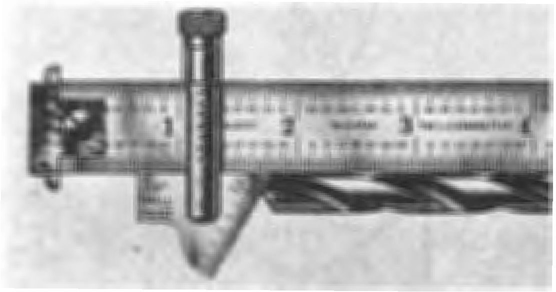


Fig. 7–44. Normal cutting angle of a drill. (Cleveland Twist Drill Co.)

Fig. 7–45. A drill-point gage used for checking a 59° cutting edge angle.



note: A drill made of high-speed steel should be ground on a dry grinding wheel of medium grain and soft grade. It should not be immersed in water after grinding because this may cause the drill point to crack.

38. *What is the approximate angle to grind the lip clearance of a drill?*
The heel (the surface of the point back of the cutting lip) should be ground away from the cutting lip at an angle of 8° to 12°, as shown in Figs. 7–46 and 7–47.

39. *What is liable to happen if the clearance angle is not correct?*
If there is little or no clearance, as in Fig. 7–48, the cutting edge is lost. When pressure is applied, the drill will not cut, sometimes cracking the drill, as in Fig. 7–49. If the clearance angle is too large, the corners of the cutting edges may break away for lack of support, as in Fig. 7–50.

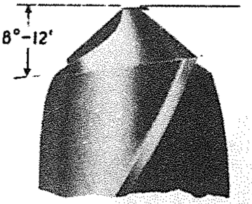
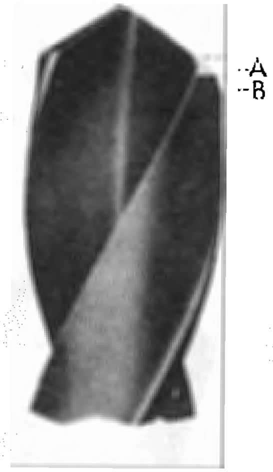


Fig. 7–46. Lip clearance angle of a drill. (Cleveland Twist Drill Co.)

Fig. 7–47. View showing proper lip clearance as indicated by space between A and B. (Cleveland Twist Drill Co.)



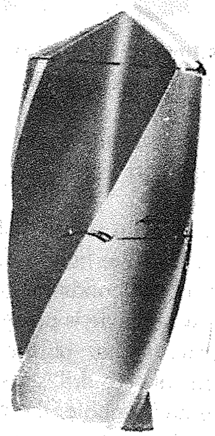


Fig. 7–48. View of drill with no lip clearance. (Cleveland Twist Drill Co.)

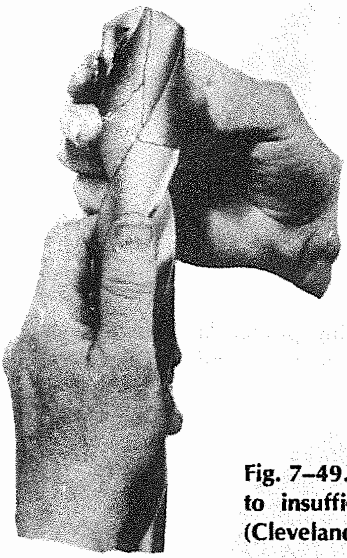


Fig. 7-49. Drill cracked due to insufficient lip clearance. (Cleveland Twist Drill Co.)

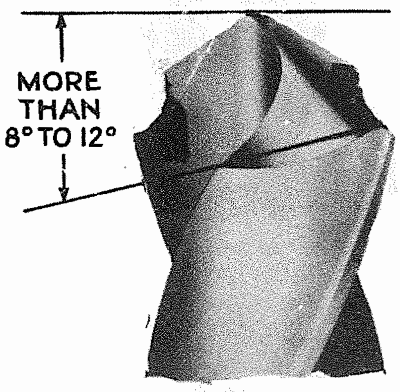


Fig. 7-50. Corners broken because of too much lip clearance. (Cleveland Twist Drill Co.)

40. *What will be the result if the angles of the cutting edges of a drill are equal but the lips are of unequal lengths?*
Both the point and the lip will be off center (Fig. 7-51), which will cause the hole to be larger than the drill. The effects of this condition are the same as those obtained if a wheel axle is placed at any point other than the exact center of the wheel. Also it will place a strain on the drill press, the spindle will tend to weave and wobble, the drill will wear away rapidly, and, with continued use, the machine will eventually break down because of the strains on the spindle bearings and other parts.

41. *If a drill is ground with its tip on center, but with the cutting edges at different angles, how will it affect the drilling operation?*
The drill will bind on one side of the hole, as in Fig. 7-52. Only one lip or cutting edge will do the work, resulting in rapid wear on that edge, and the hole will be larger than the drill.

42. *Explain what is meant by thinning the point of a drill.*
The thickness of the web is increased as the flute approaches the shank. After many sharpenings of the drill, the thicker part of the web thus exposed causes a corresponding increase in the width of the dead center, making penetration into the work more diffi-

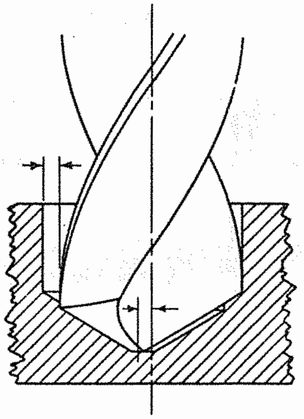


Fig. 7-51. Drill lips of unequal length make hole oversize. (Cleveland Twist Drill Co.)

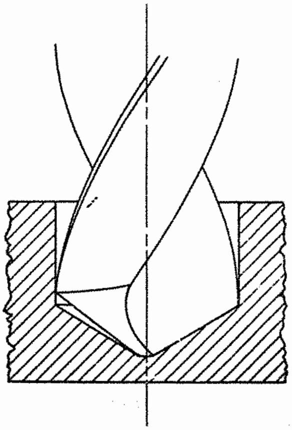


Fig. 7-52. Drill with cutting edges ground at different angles. (Cleveland Twist Drill Co.)

cult. This condition may be remedied by thinning the point, as in Fig. 7–53. The use of a convex grinding wheel (Fig. 7–54) is the most common method of thinning the point of a drill.

43. *What are some of the indications of a dull drill?*
A dull drill is indicated if: (a) it penetrates the work very slowly or not at all; (b) it becomes very hot; (c) it makes a squealing noise, or (d) the finished hole has a rough surface.

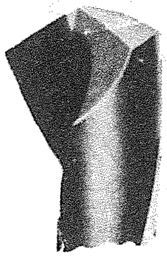


Fig. 7–53. Drill with thinned point. (Cleveland Twist Drill Co.)

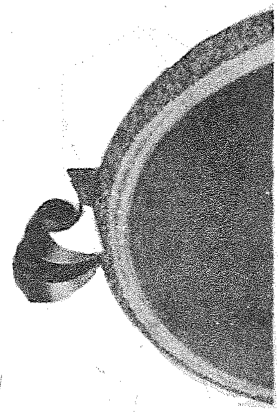


Fig. 7–54. Thinning the point of a drill, using a convex grinding wheel. (Cleveland Twist Drill Co.)

44. *When learning to sharpen a drill by hand, what are some important points to keep in mind?*
Sharpening drills by hand on the off-hand grinding machine is a common operation in many shops (Fig. 7–55). The following suggestions should be helpful. Rest the forefinger of one hand on the tool rest. Place the cutting-edge end of the drill between thumb and forefinger, which acts as a pivot. Hold the shank with the other hand. Position the drill for the point angle desired. Be sure the cutting-edge lip is straight across the face of the grinding wheel. Do not raise the shank end above the cutting edge while grinding. As the shank is moved down-

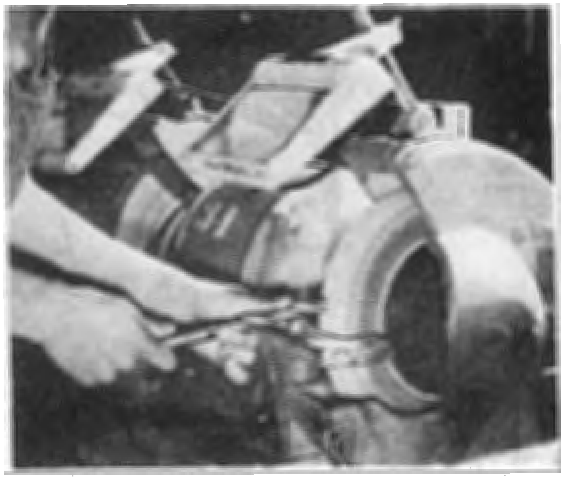


Fig. 7–55. Sharpening a drill on an off-hand tool grinder

ward, the natural movement of the wrist provides rotation needed for the clearance back of the cutting edge. Practice will develop the ability to grind equal cutting edges and angles.

45. *Are the points of twist drills ground the same for all materials?*
No. The included angle of the drill points, as well as the lip-relief angle, should vary according to the characteristics of the workpiece. Also, when a twist drill is used to drill brass and certain other soft metals, the rake angle must be reduced (see Fig. 7–56E). This prevents the drill's hogging or digging into the metal. When purchased, twist drills are usually ground to an included angle of 118°. This angle is satisfactory for drilling mild steel and for a general class of work. Figure 7–56 shows drill points and lip-relief angles for various materials.

46. *Name the different series of standard drill sizes.*
Four series of standard drill sizes are in common use—(a) the fractional series, (b) the wire gage (or number) series, (c) the letter series, and (d) the metric series.

47. *Explain the fractional series of drill sizes.*
The fractional series consists of straight shank drills in short and long lengths and tapered-shank drills. Short-length fractional drills increase in diameter by 1/64 in. from 1/64 to 11/16 in. Long-length

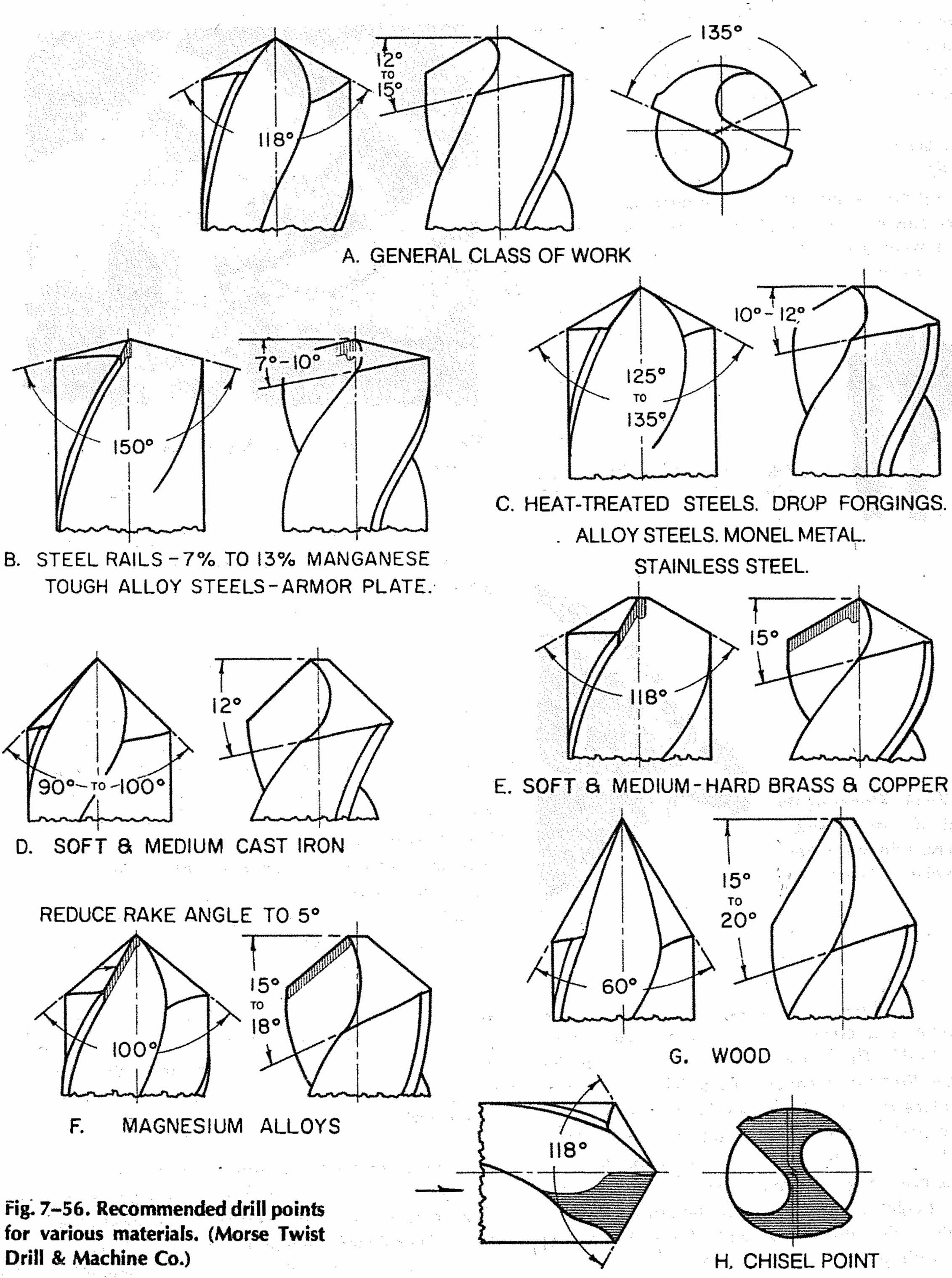


Fig. 7–56. Recommended drill points for various materials. (Morse Twist Drill & Machine Co.)

fractional drills increase in diameter by $1/64$ in. from $1/8$ to 2 in. The shank size is the same diameter as the drill size. Taper shank drills have a standard Morse taper shank, and the sizes increase by $1/64$ in. from $1/8$ to $3\,1/2$ in. in diameter. The size of the Morse taper shanks varies from a No. 1 for the smaller drill sizes to a No. 6 for the larger size drills.

48. *Explain the wire gage or number series.*
The wire gage or number series (Fig. 7–57), consists of drills numbered from 1 to 80. The No. 1 drill is the largest, with a 0.228-in. diameter, and the No. 80 is the smallest, with a 0.0135-in. diameter. There is no uniform variation in the drill diameters from number to number. To find the decimal equivalent of a number drill, consult a drill size chart or handbook.

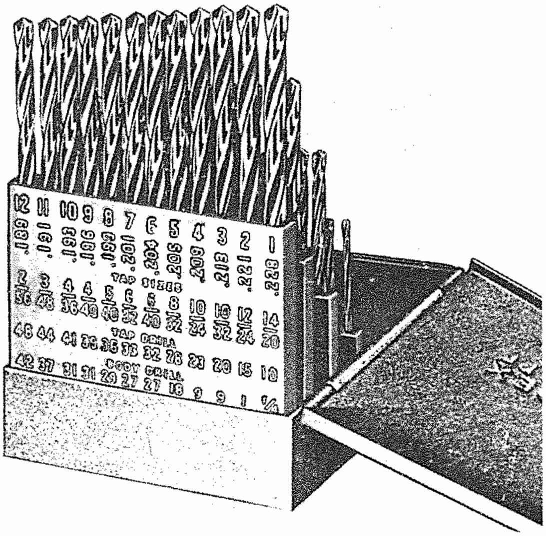


Fig. 7–57. A typical set of wire gage, or number, drills from No. 1 to 60.

49. *Explain the letter series of drill sizes.*
The letter series consists of drill sizes from "A," the smallest, with a 0.234-in. diameter, to "Z," the largest, with a 0.413-in. diameter. Diameter sizes are made in thousandths of an inch. The only drill in this series that coincides with a size in the fractional series is the "E" drill, which has a 0.250-in. diameter. To find the decimal equivalent, consult a drill size chart or handbook (Fig. 7–58).

50. *Explain briefly the metric series of drill sizes.*
The diameter sizes in the metric series are given in millimeters (mm); they range from 0.35 mm, or 0.0138 in. in the decimal system, to 25.0 mm, or 0.9843 in. (see Fig. 7–58). These sizes are probably the most commonly used, although metric size drills are made in sizes to 50 mm (1.9686 in.). See Chapter 6, "Metric Measurement."

51. *How are drill diameters measured or gaged?*
To determine the correct diameter, a micrometer should be used to measure across the margins of the drill. A drill size gage (Fig. 7–59) may also be used. Such gages are made for fractional-size drills up to ½ in., for number drills (Fig. 7–60), and for letter-size drills (Fig. 7–61).

52. *How should a job be laid out for drilling?*
The laying out of the holes to be drilled is done from a sketch or blueprint. The surface of the material to be drilled is first coated with layout dye. The center lines of the holes are then scribed on the surface according to the dimensions specified on the blueprint. The intersection of the lines is marked with a prick punch. To help the machinist see that the hole is being drilled on center, a circle the same size as the hole is scribed with dividers (Fig. 7–62). The circle itself is then identified by making small indentations on it with a prick punch at short intervals (Fig. 7–63).

53. *Describe briefly the general procedure for drilling a large-size hole in a workpiece.*
The hole location should be carefully laid out and center punched. A center-punch mark should be much deeper than a prick-punch mark because this helps the drill start in the correct location. Next, it is considered good practice to use a combined drill and countersink to center drill the hole first. Because this drill is short and rigid it will not be likely to *walk* off the punch mark as a twist drill will often do. Then select a small twist drill slightly larger in diameter than the web thickness of the large drill and drill the small hole, called a *pilot hole,* into or through the workpiece. The large drill will then follow the pilot hole, be easier to feed, and produce a more accurate hole in the correct location.

54. *Explain how a drill may be drawn back on center after it has moved away from center at the beginning of the drilling operation.*

Fig. 7–58. Decimal equivalents of drill sizes. (Ace Drill Corp.)

Drill Designation	*Decimal Equivalents*	*Drill Designation*	*Decimal Equivalents*	*Drill Designation*	*Decimal Equivalents*	*Drill Designation*	*Decimal Equivalents*	*Drill Designation*	*Decimal Equivalents*
No. 80	.0135	No. 49	.0730	4.10 mm	.1614	6.80mm	.2677	27/64	.4219
.35mm	.0138	1.90mm	.0748	4.20mm	.1654	6.90mm	.2717	11.00mm	.4331
No. 79	.0145	No. 48	.0760	No. 19	.1660	I	.2720	7/16	.4375
1/64	.0156	1.95mm	.0768	4.25mm	.1673	7.00mm	.2756	11.50mm	.4528
.40mm	.0158	5/64	.0781	4.30mm	.1693	J	.2770	29/64	.4531
No. 78	.0160	No. 47	.0785	No. 18	.1695	7.10mm	.2795	15/32	.4688
.45mm	.0177	2.00mm	.0787	11/64	.1719	K	.2810	12.00mm	.4724
No. 77	.0180	2.05mm	.0807	No. 17	.1730	9/32	.2812	31/64	.4844
.50mm	.0197	No. 46	.0810	4.40mm	.1732	7.20mm	.2835	12.50mm	.4921
No. 76	.0200	No. 45	.0820	No. 16	.1770	7.25mm	.2854	1/2	.5000
No. 75	.0210	2.10mm	.0827	4.50mm	.1772	7.30mm	.2874	13.0mm	.5118
.55mm	.0217	2.15mm	.0846	No. 15	.1800	L	.2900	33/64	.5156
No. 74	.0225	No. 44	.0860	4.60mm	.1811	7.40mm	.2913	17/32	.5312
.60mm	.0236	2.20mm	.0866	No. 14	.1820	M	.2950	13.5mm	.5315
		2.25mm	.0886	No. 13	.1850	7.50mm	.2953	35/64	.5469
No. 73	.0240	No. 43	.0890	4.70mm	.1850	19/64	.2969	14.0mm	.5512
No. 72	.0250	2.30mm	.0906	4.75mm	.1870	7.60mm	.2992	9/16	.5625
.65mm	.0256	2.35mm	.0925	3/16	.1875	N	.3020	14.5mm	.5709
No. 71	.0260	No. 42	.0935	4.80mm	.1890	7.70mm	.3031	37/64	.5781
70mm	.0276	3/32	.0938	No. 12	.1890	7.75mm	.3051	15.0mm	.5906
No. 70	.0280	2.40mm	.0945	No. 11	.1910	7.80mm	.3071	19/32	.5938
No. 69	.0292	No. 41	.0960	4.90mm	.1929	7.90mm	.3110	39/64	.6094
.75mm	.0295	2.45mm	.0965	No. 10	.1935	5/16	.3125	15.5mm	.6102
No. 68	.0310	No. 40	.0980	No. 9	.1960	8.00mm	.3150	5/8	.6250
1/32	.0312	2.50mm	.0984	5.00mm	.1968	O	.3160	16.0mm	.6299
.80mm	.0315	No. 39	.0995	No. 8	.1990	8.10mm	.3189	41/64	.6406
No. 67	.0320	No. 38	.1015	5.10mm	.2008	8.20mm	.3228	16.5mm	.6496
No. 66	.0330	2.60mm	.1024	No. 7	.2010	P	.3230	21/32	.6562
.85mm	.0335	No. 37	.1040	13/64	.2031	8.25mm	.3248	17.0mm	.6693
No. 65	.0350	2.70mm	.1063	No. 6	.2040	8.30mm	.3268	43/64	.6719
.90mm	.0354	No. 36	.1065	5.20mm	.2047	21/64	.3281	11/16	.6875
No. 64	.0360	2.75mm	.1083	No. 5	.2055	8.40mm	.3307	17.5mm	.6890
No. 63	.0370	7/64	.1094	5.25mm	.2067	Q	.3320	45/64	.7031
.95mm	.0374	No. 35	.1100	5.30mm	.2087	8.50mm	.3346	18.0mm	.7087
No. 62	.0380	2.80mm	.1102	No. 4	.2090	8.60mm	.3386	23/32	.7188
No. 61	.0390								
1.00mm	.0394	No. 34	.1110	5.40mm	.2126	R	.3390	18.5mm	.7283
No. 60	.0400	No. 33	.1130	No. 3	.2130	8.70mm	.3425	47/64	.7344
No. 59	.0410	2.90mm	.1142	5.50mm	.2165	11/32	.3438	19.0mm	.7480
1.05mm	.0413	No. 32	.1160	7/32	.2188	8.75mm	.3445	3/4	.7500
No. 58	.0420	3.00mm	.1181	5.60mm	.2205	8.80mm	.3465	49/64	.7656
No. 57	.0430	No. 31	.1200	No. 2	.2210	S	.3480	19.5mm	.7677
1.10mm	.0433	3.10mm	.1220	5.70mm	.2244	8.90mm	.3504	25/32	.7182
1.15mm	.0453	1/8	.1250	5.75mm	.2264	9.00mm	.3543	20.0mm	.7874
No. 56	.0465	3.20mm	.1260	No. 1	.2280	T	.3580	51/64	.7969
3/64	.0469	3.25mm	.1280	5.80mm	.2283	9.10mm	.3583	20.5mm	.8071
1.20mm	.0472	No. 30	.1285	5.90mm	.2323	23/64	.3594	13/16	.8125
1.25mm	.0492	3.30mm	.1299	A	.2340	9.20mm	.3622	21.0mm	.8268
1.30mm	.0512	3.40mm	.1339	15/64	.2344	9.25mm	.3642	53/64	.8281
No. 55	.0520	No. 29	.1360	6.00mm	.2362	9.30mm	.3661	27/32	.8438
1.35mm	.0531	3.50mm	.1378	B	.2380	U	.3680	21.5mm	.8465
No. 54	.0550	No. 28	.1405	6.10mm	.2402	9.40mm	.3701	55/64	.8594
1.40mm	.0551	9/64	.1406	C	.2420	9.50mm	.3740	22.0mm	.8661
1.45mm	.0571	3.60mm	.1417	6.20mm	.2441	3/8	.3750	7/8	.8750
1.50mm	.0591	No. 27	.1440	D	.2460	V	.3770	22.5mm	.8858
		3.70mm	.1457	6.25mm	.2461	9.60mm	.3780	57/64	.8906
No. 53	.0595	No. 26	.1470	6.30mm	.2480	9.70mm	.3819	23.0mm	.9055
1.55mm	.0610	3.75mm	.1476	1/4	.2500	9.75mm	.3839	29/32	.9062
1/16	.0625	No. 25	.1495	E	.2500	9.80mm	.3858	59/64	.9219
1.60mm	.0630	3.80mm	.1496	6.40mm	.2520	W	.3860	23.5mm	.9252
No. 52	.0635	No. 24	.1520	6.50mm	.2559	9.90mm	.3898	15/16	.9375
1.65mm	.0650	3.90mm	.1535	F	.2570	25/64	.3906	24.0mm	.9449
1.70mm	.0669	No. 23	.1540	6.60mm	.2598	10.00mm	.3937	61/64	.9531
No. 51	.0670	5/32	.1562	G	.2610	X	.3970	24.5mm	.9646
1.75mm	.0689	No. 22	.1570	6.70mm	.2638	Y	.4040	31/32	.9688
No. 50	.0700	4.00mm	.1575	17/64	.2656	13/32	.4062	25.0mm	.9843
1.80mm	.0709	No. 21	.1590	6.75mm	.2657	Z	.4130	63/64	.9844
1.85mm	.0728	No. 20	.1610	H	.2660	10.50mm	.4134	1	1.0000

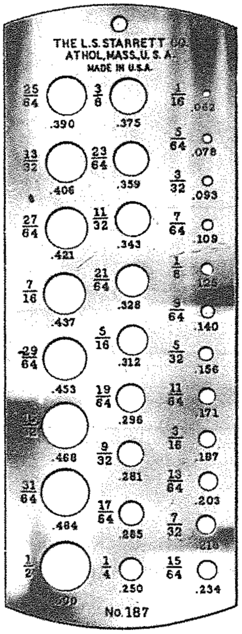


Fig. 7–59. Jobber's drill gage. (L. S. Starrett Co.)

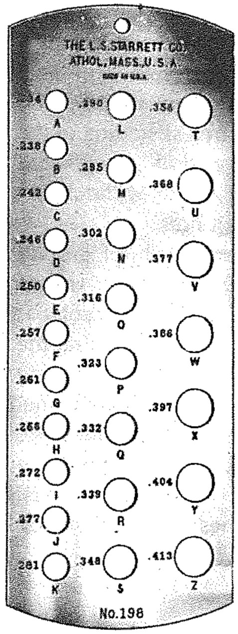


Fig. 7–61. Letter-size drill gage. (L. S. Starrett Co.)

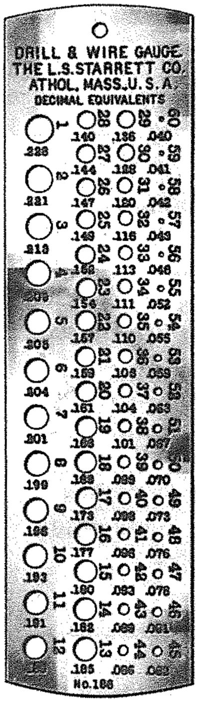


Fig. 7–60. Drill and wire gage for number-size drills. (L. S. Starrett Co.)

Fig. 7–62. Laying out holes for drilling. (L. S. Starrett Co.)

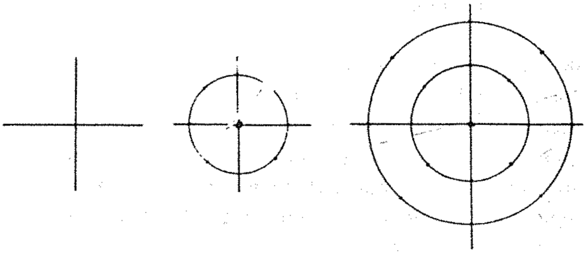


Fig. 7–63. Steps in laying out holes for drilling.

As a drill begins to cut, it forms a conical hole. If the hole is concentric with the layout, the drill has been started properly. However, a drill may start off center, as in Fig. 7–64A. This may be due to improper center punching, careless starting of the drill, improper grinding of the drill point, hard spots in the metal or starting a drill without first center drilling and drilling a pilot hole.

To correct this condition, use a chisel ground with a round nose (Fig. 7–64D), and cut a groove on the side of the hole toward which the center is to be drawn, as in Fig. 7–64B. The amount that the center has been moved may be judged by comparing the edge of the hole with the circular layout line. It may be necessary to move the center several times before the edge of the hole and the layout line are concentric, as in Fig. 7–64C. This correction must be made before the drill reaches its full diameter.

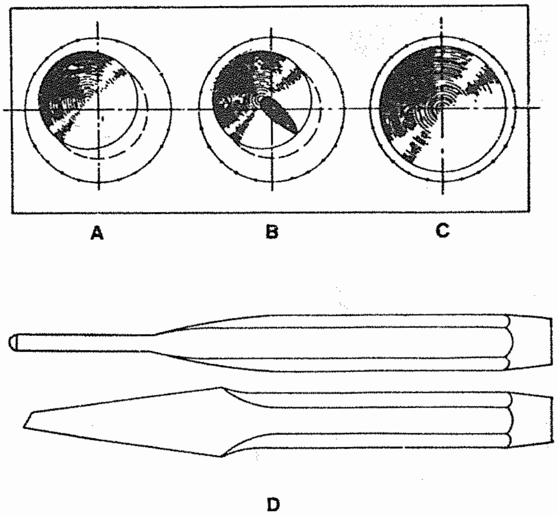


Fig. 7–64. Method of drawing a hole back to the true center by chipping a groove on one side.

55. *Why is a cutting coolant or oil used on the drill?*
Cutting coolants and oils are used to carry heat away from the drill point, preventing it from overheating. This permits higher cutting speeds and longer drill life. Practically all metals require the use of coolants or oil when being drilled. Cast iron may be drilled without using coolant because it contains a large percentage of graphite, which is a form of lubricant.

56. *What kinds of cutting coolants, oils, or compounds are used for drilling various metals?*
The proper cutting coolant, oil, or compound must be used because it affects the cutting action and produces better results. Figure 7–65 lists some of the more commonly used metals and the recommended cutting compounds.

Fig. 7–65. Recommended cutting compounds for commonly used metals.

material	*recommended cutting compound*
Aluminum	**Kerosene, Kerosene and Lard Oil, Soluble Oil**
Brass	**Dry, Soluble Oil, Kerosene and Lard Oil**
Soft Bronze	**Soluble Oil, Lard Oil, Mineral Oil, Dry**
Cast Iron (Soft)	**Dry, Soluble Oil**
Soft Steel	**Soluble Oil, Mineral Lard Oil, Sulfurized Oil, Lard Oil**
Malleable Iron	**Dry, Soda Water**
Cast Iron (Hard)	**Dry, Soluble Oil**
Tool Steel	**Soluble Oil, Mineral Lard Oil, Sulfurized Oil**
Steel Forgings	**Soluble Oil, Sulfurized Oil, Mineral Lard Oil**
Monel Metal	**Lard Oil, Soluble Oil**
Stainless Steel	**Sulfur and Lard Oil, Soluble Oil**

57. *What operations other than hole-drilling are commonly performed on drilling machines?*
Countersinking, reaming, counterboring, spot facing, tapping, and lapping.

58. *Describe the operation of countersinking.*
Countersinking is the operation of producing an angular surface at the end of a hole. A cutting tool called a *countersink* is used (Fig. 7–66). Countersinks are made in many diameter sizes and several angles. The angle size depends upon the reason for countersinking. Flat head screws require a countersink with an 82° included angle, whereas a center

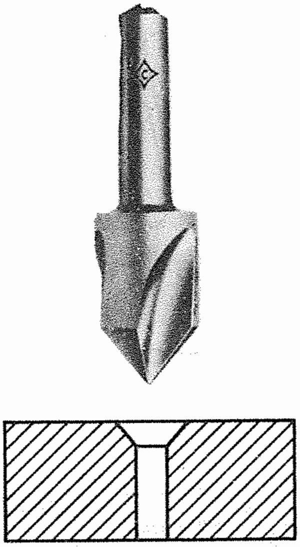


Fig. 7–66. Countersink and countersunk hole. (Cleveland Twist Drill Co.)

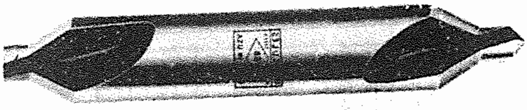


Fig. 7–67. Combined drill and countersink. (Whitman & Barnes.)

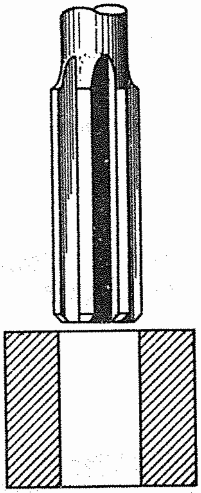


Fig. 7–68. A reamer and reamed hole.

hole must be 60°. Various types of rivet heads have included angles of from 90° to 145°.

59. *What is a combined drill and countersink and for what purpose is it used?*
A combined drill and countersink (Fig. 7–67), more commonly referred to in the shop as a *center drill*, is used to produce both a short drilled hole and a countersunk hole in one operation. The angle on these drills is always a 60° included angle. It is used largely for drilling center holes in work to be turned between centers in the lathe and for starting holes in the correct location on a drilling machine.

60. *Describe the operation of reaming.*
Reaming (Fig. 7–68) is the operation of finishing a drilled hole. A finished hole has the specified diameter size, is perfectly round, the diameter is the same size from end to end, and it has a smoothly finished surface. A drilled hole is seldom accurate enough in size or sufficiently smooth to be called a precision hole. When greater accuracy is required, the hole must be drilled undersize by a certain amount and finished by reaming.

61. *Name and describe several types of standard reamers used in drilling machines.*
Reamers commonly used in drilling machines are (a) fluted chucking reamers, (b) rose chucking reamers, (c) shell reamers, (d) chucking expansion reamers, (e) Jobber's reamers, and (f) taper-pin chucking reamers. The rose and expansion types have straight flutes, whereas the other types are made with straight or spiral flutes, as shown in Fig. 7–69.

A fluted chucking reamer (Fig. 7–70) is used to finish holes accurately and smoothly. This is a precision reamer designed to remove from 0.005 to 0.010 in. of material. Each tooth is ground with a clearance angle back of the cutting edge for the full length of the land. The ends of each tooth are chamfered slightly for end cutting.

A rose reamer (Fig. 7–71) is designed to cut on the ends of the teeth only. It has no clearance or cutting edges on the periphery. The flutes provide a means for chips to escape and for coolant to reach the end cutting edges. The diameter near the shank end is slightly smaller than at the front to provide clearance. This reamer is considered a roughing reamer; it will remove a considerable amount of material but will not produce a smooth, accurate hole.

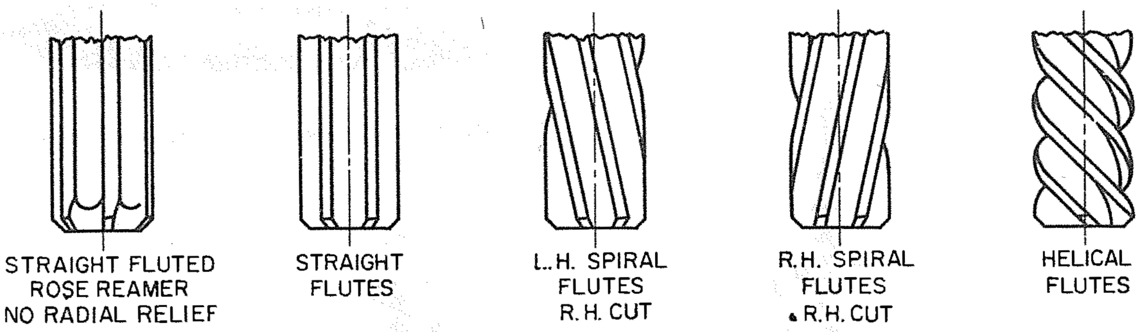
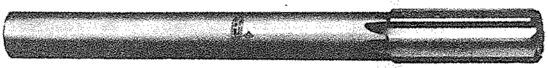


Fig. 7-69. Types of machine reamer flutes. (Morse Twist Drill & Machine Co.)

Fig. 7-70. Fluted chucking reamer. (Cleveland Twist Drill Co.)



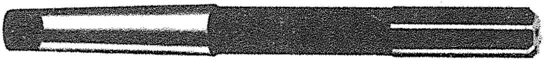
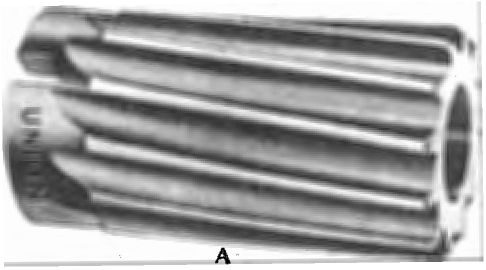


Fig. 7-71. Rose reamer. (Whitman & Barnes.)

A shell reamer (Fig. 7-72A), often called a hollow reamer, is actually a reamer without a shank. A slightly tapered hole through the center permits the reamer to be held on a separate shank or arbor (Fig. 7-72B) that has driving lugs. Several sizes of reamers may be used with one shank. Shell reamers are made with either the fluted teeth having clearance or the rose type, which cuts on the end only. A chucking expansion reamer (Fig. 7-73) is slotted, and has an adjusting screw for expanding the diameter. When the reamer becomes worn and undersize, it can be expanded and reground to size many times. This reamer machines holes accurately and smoothly to close tolerances.

A taper-pin chucking reamer (Fig. 7-74) is used to machine holes that are rather small in diameter but deep, such as parts to be held together by a taper pin. It has a taper of ¼ in. per foot. The short lead of the flutes produces a smooth, accurate hole for seating of the taper pin.

A jobber's reamer (Fig. 7-75) is a taper-shank machine reamer having flutes about the same length as a hand reamer; it is used as a precision finishing reamer.



A

B

Fig. 7-72. (A) Shell reamer. (B) Shell reamer shank. (Union Twist Drill Co.)

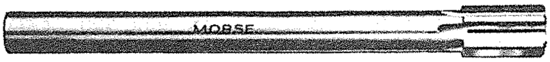


Fig. 7-73. Chucking expansion reamer. (Morse Twist Drill & Machine Co.)

Fig. 7-74. Taper-pin chucking reamer. (Whitman & Barnes.)

Fig. 7-75. Jobber's reamer. (Whitman & Barnes.)

62. *Describe the operation of counterboring.*
Counterboring is the operation of boring a second hole, larger in diameter than the first, but concentric with it (Fig. 7–76). When this operation is done on a drilling machine, a tool known as a counterbore is used (Fig. 7–77A). The small diameter on the end of the tool, known as a *pilot* (Fig. 7–77B), keeps the counterbore concentric with the original hole. Pilots are interchangeable with others of different sizes to fit various sizes of holes.

63. *What is the operation of spot-facing?*
Spot-facing (Fig. 7–78), is the operation of machining a flat, circular surface around a hole to provide a seat for a bolt head, nut, or washer. It is usually performed on castings. A counterbore may be used for spot-facing. The surface machined should be square with the hole.

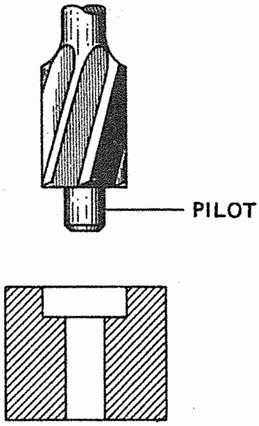


Fig. 7–76. Counterbore and counterbored hole.

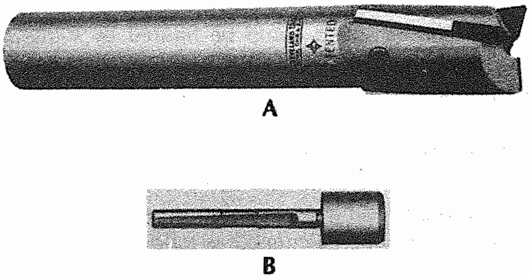


Fig. 7–77. (A) Counterbore. (B) Interchangeable type of pilot for counterbore. (Cleveland Twist Drill Co.)

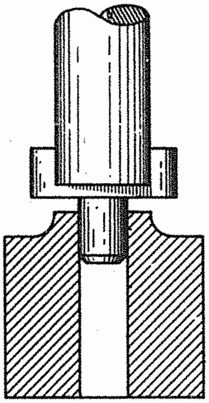


Fig. 7–78. Spot-facing tool.

64. *Describe the operation of tapping on a drill press.*
Holes that are to be tapped (threaded) are first drilled to a specified size (Fig. 7–79). In order to tap holes on a standard drilling machine, a tapping attachment must be used. An example of such an attachment is shown in Fig. 7–80. This attachment is held in the spindle of the drill press by a tapered arbor, which also drives the friction-type mechanism. The tap-holding chuck accurately centers the tap on the round part of the shank, and floating jaws hold the tap on its square end in a firm, rigid grip, which prevents the tap from pulling out of the chuck when reversing. The driving mechanism is constructed to revolve the tap clockwise (into the work) when the feed handle of the drill press is moved downward. When the handle is moved upward, the tap is reversed to remove it from the hole. It is possible, with practice, to control the forward and reverse movements of the tap by skillfully manipulating the feed handle. A tapping attachment is a time-saving device when a large number of identical holes are to be tapped.

65. *Describe the operation of lapping.*
Lapping is a method of removing very small amounts of material by means of an abrasive. The abrasive material is kept in contact with the sides of a hole that is to be lapped by the use of a lapping tool. There are many kinds of lapping tools. The copper-head laps in Fig. 7–81 are typical examples. In operation, the lap should just fit the hole. As the lap revolves in the hole, it should be constantly moved up and down so that the hole will be perfectly cylindrical.

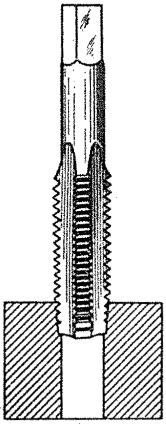
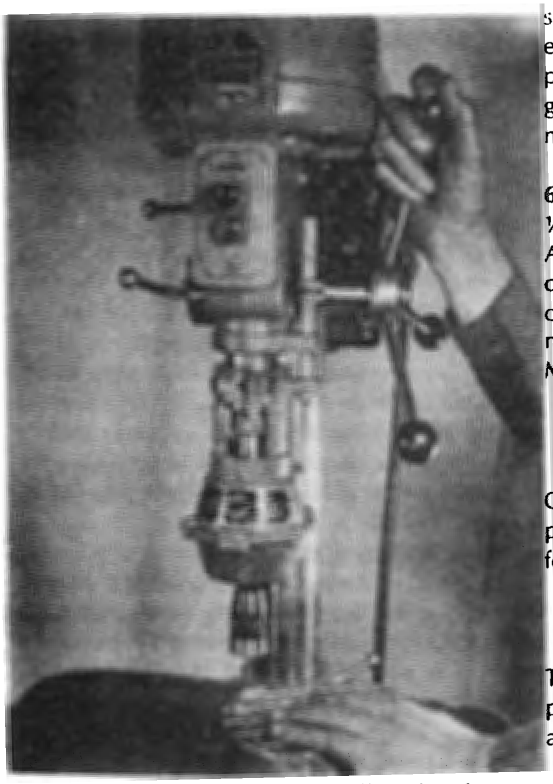


Fig. 7–79. Tapping produces threads in a hole.

Fig. 7–80. Tapping attachment for drill press. (Ettco Tool Co.)



Lapping is a slow, tedious job. Usually only a few thousandths of an inch are removed by this method. It is a common practice to lap small holes—those less than ⅜ in. in diameter—after the material has been hardened. Before hardening, small holes that are to be lapped are reamed with a lapping reamer. Lapping reamers are one or two thousandths of an inch smaller than standard-sized reamers.

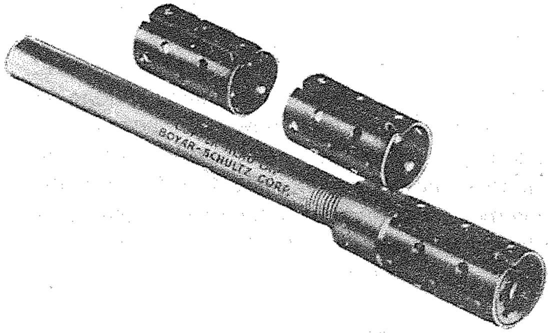


Fig. 7–81. Copper-head lapping tools. (Beyar-Schultz Corp.)

66. *What is meant by the cutting speed of a drill?* The cutting speed of a drill, often called *peripheral* speed, is the speed of the circumference. It may be explained as the distance that a drill would roll if placed on its side and rolled for one minute at a given rpm. The cutting speed is expressed in feet per minute (fpm) and does not mean rpm.

67. *Explain how to calculate the cutting speed for a ½-in. drill that revolves at 600 rpm.*
A ½-in. drill operating at 600 rpm would have a cutting speed expressed in feet per minute. The circumference in feet equals the diameter (½ in.) multiplied by π (3.1416, or $^{22}/_{7}$) and divided by 12. Multiply this result by the rpm (600), or

$$\text{Cutting Speed} = \frac{1}{2} \times \frac{22}{7} \times \frac{1}{12} \times 600 = 78 \text{ fpm}$$

Cutting-speed calculations as a rule need not be precise and the above method may be shortened as follows:

Dividing 3.1416 by 12 equals approximately $\frac{1}{4}$

Thus the cutting speed could be figured by multiplying ¼ by the drill diameter by the rpm, or stated as a formula.

$$\text{Cutting Speed} = \frac{1}{4} \times \text{drill diameter} \times \text{rpm}.$$

In this problem, using the simpler formula, the cutting speed would be calculated as follows:

$$\text{Cutting Speed} = \frac{1}{4} \times \frac{1}{2} \times 600 = 75 \text{ fpm}$$

The difference is so small as to be negligible.

68. *When the cutting speed is known, how can you calculate the rpm?*
When the cutting speed is known, the rpm may be calculated by using either of two formulas:

$$\text{rpm} = \frac{\text{Cutting speed} \times 4}{\text{Drill diameter}}$$

$$\text{rpm} = \frac{\text{Cutting speed}}{\tfrac{1}{4} \times \text{Drill diameter}}$$

Applying the formula to the problem in Question 67, the rpm would be

$$\frac{75 \times 4}{\tfrac{1}{2}} = \frac{300}{\tfrac{1}{2}} = 600 \text{ rpm}$$

69. *What cutting speeds are recommended for drilling some of the more commonly used metals?*
The following average cutting speeds are recommended when drills made of high-speed steel are used. For drills made of carbon tool steel, the cutting speeds should be about one-half less.

Aluminum	200–300 fpm
Brass—soft	200–300 fpm
Cast iron—soft	100–150 fpm
Copper	200 fpm
Machine steel	80–100 fpm
Monel metal	40–60 fpm
Stainless steel	30–50 fpm
Tool steel alloys	50–60 fpm

70. *If a toolmaker wanted to drill a ½-in. hole in a piece of machine steel at the recommended speed of 80 fpm, at what speed in rpm should he operate the drill press?*
While the answer may be calculated mathematically, it is more practical to use a cutting-speed table similar to Fig. 7–82. By locating the diameter of the

Fig. 7–82. Cutting speeds for high-speed steel fraction-size drills. (Cleveland Twist Drill Co.)

diameter (in.)	*cutting speed in feet per minute* 30	40	50	60	70	80	90	100	110	120	130	140	150
	spindle speed in revolutions per minute												
1/16	1,833	2,445	3,056	3,667	4,278	4,889	5,550	6,111	6,722	7,334	7,945	8,556	9,167
1/8	917	1,222	1,528	1,833	2,139	2,445	2,750	3,056	3,361	3,667	3,973	4,278	4,584
3/16	611	815	1,019	1,222	1,426	1,630	1,933	2,037	2,241	2,445	2,648	2,852	3,056
1/4	458	611	764	917	1,070	1,222	1,375	1,528	1,681	1,833	1,986	2,139	2,292
5/16	367	489	611	733	856	978	1,100	1,222	1,345	1,467	1,589	1,711	1,833
3/8	306	407	509	611	713	815	917	1,019	1,120	1,222	1,324	1,426	1,528
7/16	262	349	437	524	611	698	786	873	960	1,048	1,135	1,222	1,310
1/2	229	306	382	458	535	611	688	764	840	917	993	1,070	1,146
5/8	183	244	306	367	428	489	550	611	672	733	794	856	917
3/4	153	203	255	306	357	407	548	509	560	611	662	713	764
7/8	131	175	218	262	306	349	393	436	480	524	568	611	655
1	115	153	191	229	267	306	344	382	420	458	497	535	573
1 1/8	102	136	170	204	238	272	306	340	373	407	411	475	509
1 1/4	92	122	153	183	214	244	275	306	336	367	397	428	458
1 3/8	83	111	139	167	194	222	250	278	306	333	361	389	417
1 1/2	76	102	127	153	178	204	229	255	280	306	331	357	382
1 5/8	70	94	117	141	165	188	212	235	259	282	306	329	353
1 3/4	65	87	109	131	153	175	196	218	240	262	284	306	327
1 7/8	61	81	102	122	143	163	183	204	244	244	265	285	306
2	57	76	95	115	134	153	172	191	210	229	248	267	287
2 1/4	51	68	85	102	119	136	153	170	187	204	221	238	255
2 1/2	46	61	76	92	107	122	137	153	168	183	199	214	229
2 3/4	42	56	69	83	97	111	125	139	153	167	181	194	208
3	38	51	64	76	89	102	115	127	140	153	166	178	191

drill on the left side of Fig. 7–82 and then reading toward the right, we find that the spindle speed of the drilling machine should be 611 rpm for a cutting speed of 80 fpm.

71. *What will happen to a drill if the operating speed is too fast?*
If a drill is operated at too fast a speed, the drill will become overheated and the temper will be drawn from the steel. This will cause the outer corners of the drill to wear away quickly (Fig. 7–83).

72. *What is meant by the feed of a drill?*
The feed of a drill is the distance that the drill enters the work on each revolution of the drill, measured in decimal fractions of an inch. For example, a drill operated at 600 rpm with a feed of 0.005 in. would make a hole 3 in. deep in 1 minute. This is determined by multiplying the feed of one revolution by the number of revolutions made in one minute:

$0.005 \times 600 = 3.00$ in.

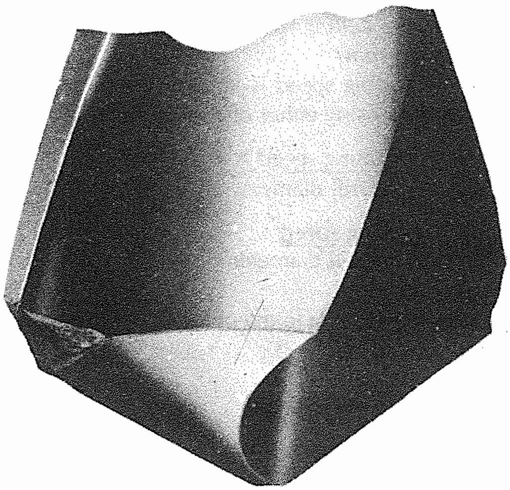


Fig. 7–83. Corners of drill are damaged when speed is too great. (Cleveland Twist Drill Co.)

chapter 8

engine lathe processes

The most versatile machine tool in a modern machine shop is the screw-cutting engine lathe. Its oldest ancestor is the potter's wheel, which can be traced back in history to 4000 B.C. By turning the potter's wheel onto its side, the ancients made the first horizontal lathe. It was followed by the pole lathe, which could be operated by a cord and a foot treadle. In the fifteenth century, the driving cord was connected to a springy lath, which was attached to the ceiling. From this development came the name of lathe. Most early improvements in the lathe were designed to hold and drive the work. Many crude devices were experimented with in an effort to cut threads in a lathe. They were never completely successful. The clock- and watchmakers of France devised a screw-cutting lathe (Fig. 8–1), but its design limited it to the cutting of threads having the same pitch.

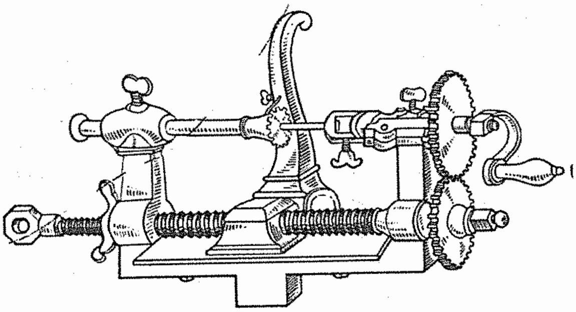


Fig. 8–1. French screw-cutting lathe, 1740. (Roe's *English and American Tool Builders*, by permission of McGraw-Hill Book Co.)

The father of the modern engine lathe was Henry Maudslay, who invented the slide rest in the early nineteenth century. Maudslay, an English mechanic, later combined the movable slide rest with a lead screw by means of change gears. This combination permitted Maudslay to cut screw threads from 16 to 100 threads per inch (Fig. 8–2). It made the lathe the most important machine in the Industrial Revolution: Without it, James Watt's steam engine would never have been built. Because it machined the parts of Watt's engine it became known as the engine lathe. Since that time, the engine lathe has been improved and refined. Each important improvement has added to the scope of its usefulness, enabling more complicated operations to be performed with finer degrees of accuracy and finish.

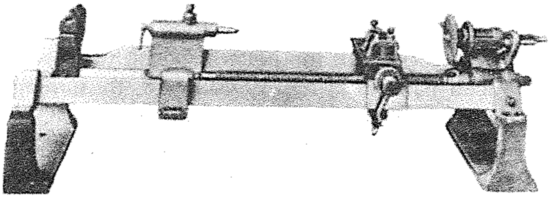


Fig. 8–2. Screw-cutting lathe by Henry Maudslay, about 1797. (South Bend Lathe, Inc.)

1. *What is an engine lathe?*
An engine lathe is a power-driven, general-purpose machine tool used for producing cylindrical workpieces. As the piece of metal to be machined is rotated in the lathe, a single-point cutting tool is advanced radially into the workpiece a specified depth and moved longitudinally along the axis of the workpiece, removing metal in the form of chips (Fig. 8–3). Both inside and outside surfaces can be machined on a lathe. By using attachments and accessories, other operations such as drilling, reaming, boring, taper and angle turning, screw-thread chasing, form turning, knurling, milling, grinding, and polishing may be performed.

2. *Describe the various types of engine lathes.*
Engine lathes are manufactured in a variety of types and sizes, from very small bench lathes (Fig. 8–4) used in precision instrument and watchmaking industries, to gigantic lathes (Fig. 8–5) used for turning large steel shafts, which weigh many tons.

The different types of engine lathes are

A. Bench lathes: small engine lathes, which can be mounted on a bench or metal cabinet.
B. Standard engine lathes: larger, heavier, and more powerful than the bench lathe; may have bed lengths from 5 to 20 or more feet (Fig. 8–6).
C. Toolroom lathes: precision engine lathes equipped with additional attachments needed for tool- and die-making operations (Fig. 8–7).
D. Manufacturing lathes: engine lathes of various sizes equipped with special-purpose attachments for turning workpieces in large quantities, which is often called production work (Fig. 8–8).

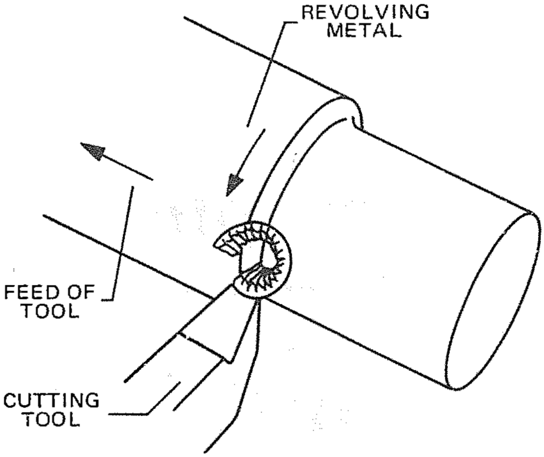


Fig. 8–3. Machining a workpiece in a lathe produces cylindrical shapes.

Fig. 8–4. A small bench lathe. (F. W. Derbyshire, Inc.)

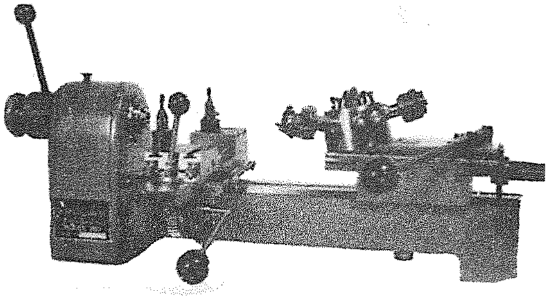


Fig. 8–5. A lathe for turning large workpiece weighing many tons. (R. K. LeBlond Machine Too Co.)

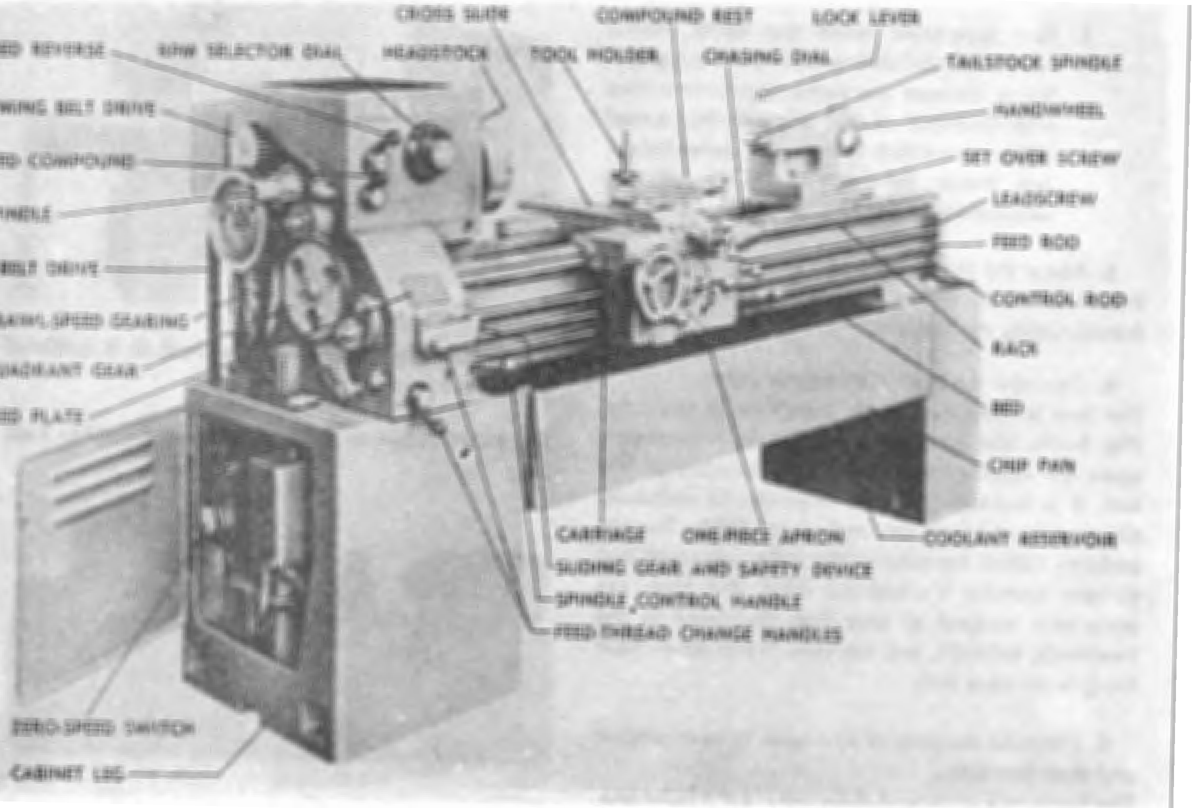


Fig. 8–6. A standard engine lathe. (R. K. LeBlond Machine Tool Co.)

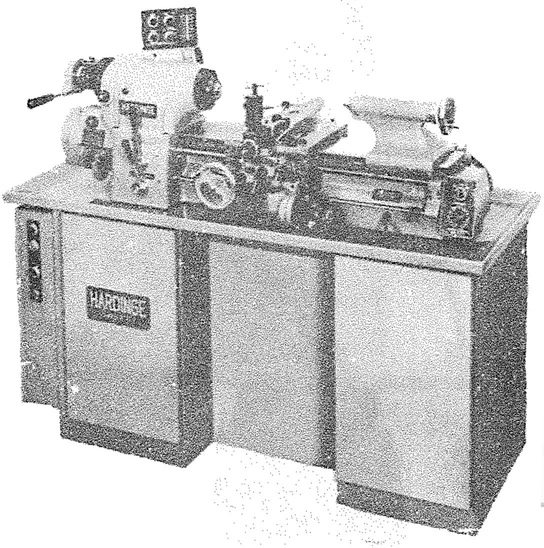


Fig. 8–7. A smaller precision toolroom lathe. (Hardinge Brothers, Inc.)

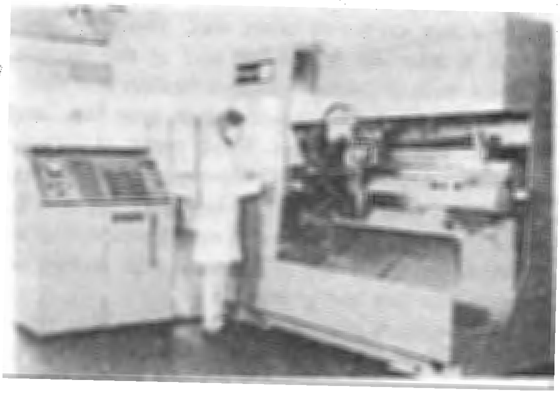


Fig. 8–8. A numerically controlled lathe for production work. (Monarch Machine Tool Co.)

E. Special-purpose lathes: gap lathes, which have a special sliding bed, making it possible to increase the swing to accommodate large-diameter work (Fig. 8–9); wheel lathes, crankshaft lathes, gun barrel lathes, and tracer lathes (Fig. 8–10)—all are adaptations of the engine lathe.

3. *Name the five major parts of an engine lathe.*
Bed, headstock, tailstock, carriage, and feed and thread-cutting mechanism.

4. *Describe the bed of an engine lathe.*
The bed is often called the *backbone* of the lathe (Fig. 8–11). The accuracy of a lathe depends mainly upon the rigidity, alignment, and accuracy of the bed. It is sturdily cast with cross-ribs to withstand the stresses of heavy cuts and coarse feeds. The top surfaces, called the *ways* of the lathe, are machined to form inverted V's and flat sides. The ways are accurately scraped to give true alignment to the headstock, tailstock, and carriage. Some lathes have flat-ground ways only.

5. *Describe the parts of an engine lathe headstock and their functions.*
The headstock is located at the end of the lathe bed, to the operator's left. It is clamped solidly on the inner ways and supports and houses the spindle and the means for turning the spindle (Fig. 8–12). The spindle, which is supported by precision bearings located at two or three points in the headstock, is hollow through its entire length to allow bar stock or work-holding attachments to pass through. The end of the spindle has an internal taper bore that holds a live center or other tool. The spur gear, which is attached at the left end of the spindle, drives a train of gears to provide motion and direction to the feed rod, quick-change gear box, and thread-cutting mechanism. Three types of spindle noses are used on lathes by various manufacturers: (a) threaded (see Fig. 8–12), (b) key-drive (Fig. 8–13), and (c) cam-lock. Headstocks may be classified as pulley-driven (Fig. 8–12), geared (Fig. 8–14), or combination belt and geared.

The headstock of a pulley-driven lathe uses cone or step pulleys with three or four diameter sizes and either a flat or V-type belt drive. Spindle speeds are changed by moving the belt from one pulley step to another. This must be done when the lathe is stopped. A four-step pulley permits four speed

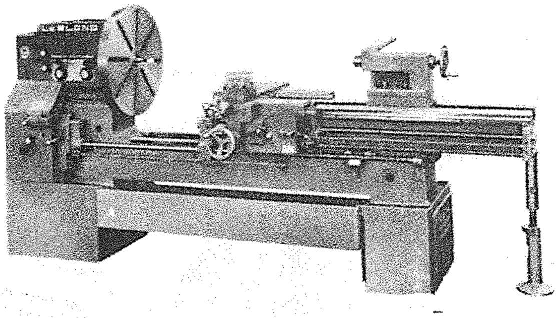
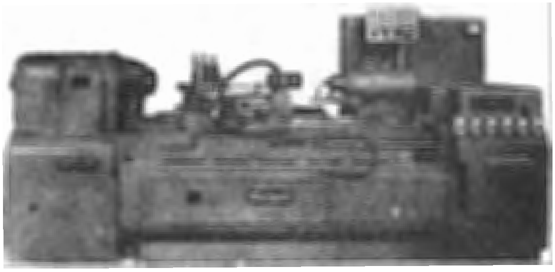


Fig. 8–9. A gap lathe with sliding bed. (R. K. LeBlond Machine Tool Co.)

Fig. 8–10. A tracer lathe. (Monarch Machine Tool Co.)



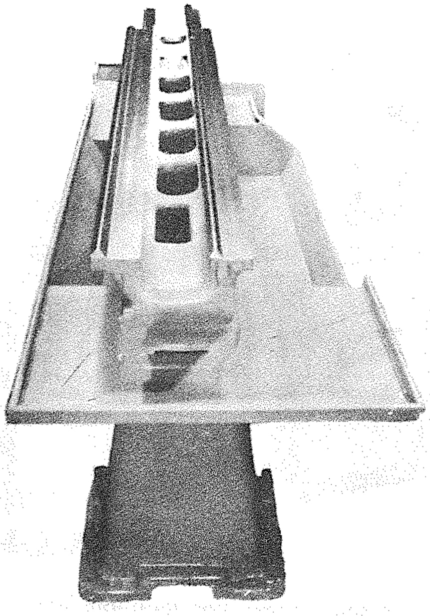


Fig. 8–11. The bed of an engine lathe. (Monarch Machine Tool Co.)

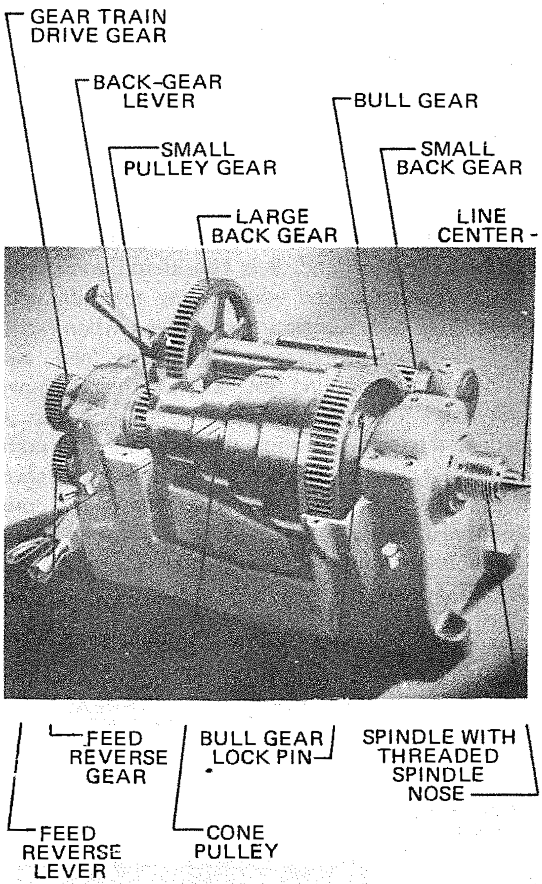
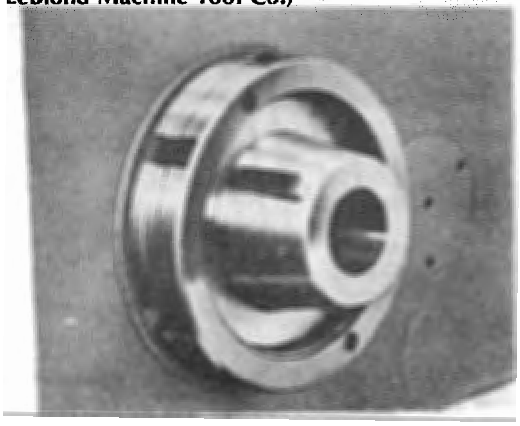


Fig. 8–12 The headstock of a pulley-driven lathe. (South Bend Lathe, Inc.)

Fig. 8–13. A tapered-key spindle nose. (R. K. LeBlond Machine Tool Co.)



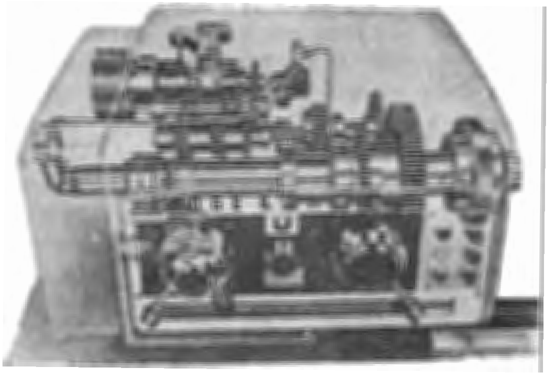


Fig. 8–14. A geared headstock. (Lodge and Shipley Co.)

changes when in direct drive, and four additional speed changes when the back-gears are engaged. A back-gear drive (Fig. 8–12) provides slower spindle speeds and more power through a four-gear drive mechanism. It is important to understand how the back-gear mechanism works so the gears will not be damaged. At the left end of the pulley, at its smallest diameter step, a small gear is permanently fastened to the pulley; the gear always turns when the pulley turns. At the opposite end of the pulley, at its largest diameter step, a large gear, called the *bull-gear,* is keyed to the spindle; the bull-gear drives the spindle only when the lock-pin is pushed in, locking the gear to the pulley. In this position, the headstock spindle is in direct drive. When slower speeds are required, the bull-gear pin is pulled out. Using the back-gear lever, the back-gears are moved forward and carefully meshed with the spindle gears by moving the cone pulley back and forth by hand. Never attempt to mesh the back-gears while the spindle is turning under power because this may strip teeth from one or more of the gears. The two back-gears are mounted on an eccentric shaft at the back of the headstock. When the bull-gear pin is pushed in and the back-gears are engaged, the spindle is locked and cannot move. Do not start the lathe while the spindle is locked. It is often necessary to lock the spindle, using the back-gears when changing collets or threading holes by hand with a tap.

6. *Describe the parts of an engine lathe tailstock and their functions.*

The tailstock has two major parts: a bottom casting and a top casting (Fig. 8–15). The bottom casting is machined very accurately to fit the ways of the lathe bed. Two bolts at the front and rear of the base permit the tailstock center to be aligned with the headstock center or the tailstock to be "set over" for taper turning. A clamping bolt and nut secures the tailstock in any desirable position along the ways. The top casting contains the spindle, feed-screw, handwheel, and a spindle clamp for locking the spindle in position. The end of the spindle has a taper bore (for holding the taper shank dead center), drills, reamers, drill chucks, and other tools.

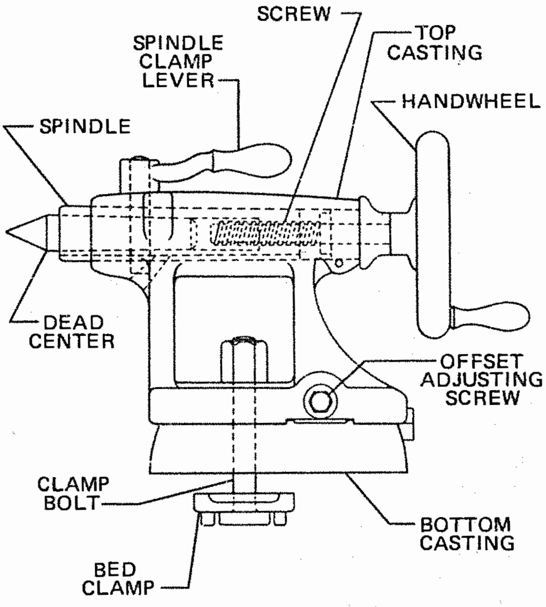


Fig. 8–15. Cross-section view of a tailstock. (Sheldon Machine Co., Inc.)

Good judgment and care must be used when mounting tools in the tailstock spindle. Taper shanks must be clean and free of dirt, burrs, and chips. The taper hole in the spindle must also be clean. The tailstock spindle must be run out a short distance before taper shanks can be firmly seated into the taper hole. To remove the tools from the spindle, it is necessary only to back up the handwheel just far enough to permit the end of the inner screw to loosen the tool, after which it may be easily removed.

7. *Explain the purpose and construction of the lathe carriage.*

The carriage (Fig. 8–16) carries the cutting tool and precisely controls its movement either parallel to the ways, called *straight turning,* or at right angles to the ways, called *facing.* The carriage has three major parts: saddle, compound rest, and apron. The saddle rests and slides on the ways and contains the cross-feed mechanism for moving the cutting tool at right angles to the ways. This is done by turning the cross-feed handle manually or by engaging the automatic power feed. It is considered good practice to use hand feed when facing small-diameter workpieces and automatic power feed when facing large-diameter workpieces. The cross-feed also supports the compound rest slide, which is equipped with hand feed only and can be swiveled on its graduated base to any angle through 360°. The compound rest slide is used for turning and boring short angles and tapers. A T slot at the top of the corn-pound rest holds the standard tool post or a cutting-tool holding block such as a four-way turret tool post. The apron contains a gear train and clutches,

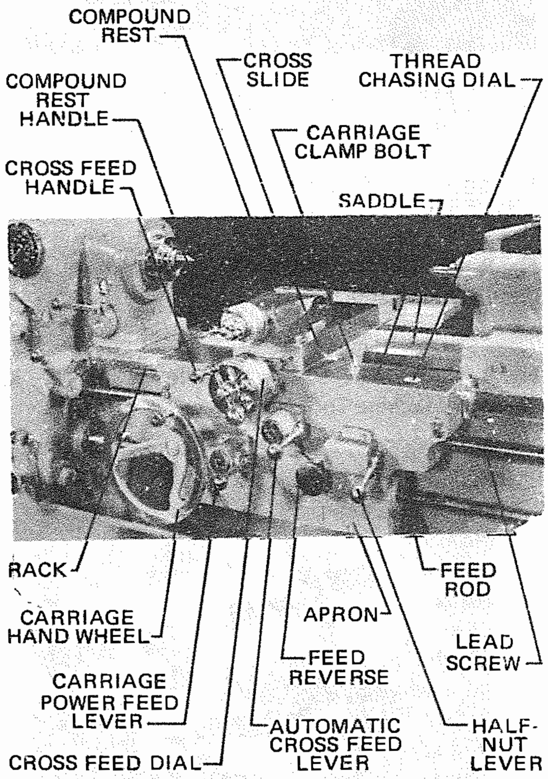


Fig. 8–16. Principal parts of a lathe carriage. (Monarch Machine Tool Co.)

which provide automatic power feed to the carriage and cross-feed slide (Fig. 8–17). Levers at the front of the apron are used to engage or disengage the power feeds. A worm keyed to the feed rod transmits power through a worm gear to the spur gears, which drive the cross-feed gear and the rack gear for moving the carriage. A half-nut inside the apron is operated by a lever on the outside of the apron; it is used only when cutting screw threads. When closed, or meshed, with the lead screw, the half-nut provides a *positive* drive to the carriage. This means that for each revolution of the workpiece, the carriage will move an exact distance along the ways (or along the workpiece). Positive drive is necessary when cutting screw threads. The half-nut should never be used as a feed when turning work. To do so destroys the accuracy of the lead screw and half-nut, making it impossible to cut precision screw threads.

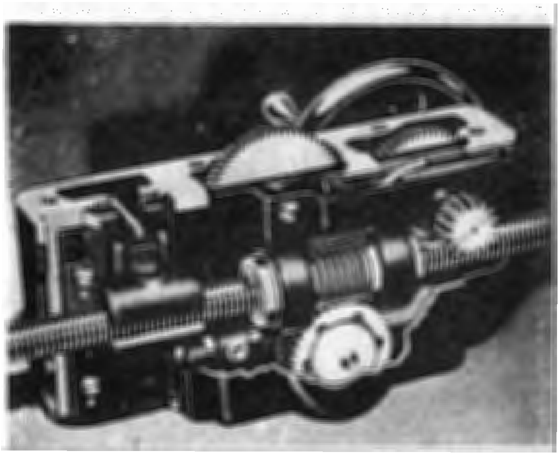


Fig. 8–17. Apron construction. (South Bend Lathe, Inc.)

8. *Explain the power-feed and thread-cutting mechanism.*

Most standard engine lathes are equipped with a feed rod and a leadscrew (see Fig. 8–6). The feed rod is used to provide automatic power feed to the carriage when turning or machining workpieces. The lead screw is used to drive the carriage only when cutting, or chasing, screw threads. Engine lathes with no separate feed rod use, instead, the lead screw for both feeds and thread chasing.

Both the feed rod and lead screw get their power from the spindle gear through a compound gear train located at the left end of the lathe. On olde lathes, gears had to be selected, mounted in place, and adjusted each time a different feed or thread pitch was required. The quick-change gear box (Fig. 8–18) at the front of the modern lathe makes it possible to obtain a wide range of feeds and thread pitches merely by moving and positioning several levers, according to a feed and thread index chart attached to the quick-change gear box (Fig. 8–19).

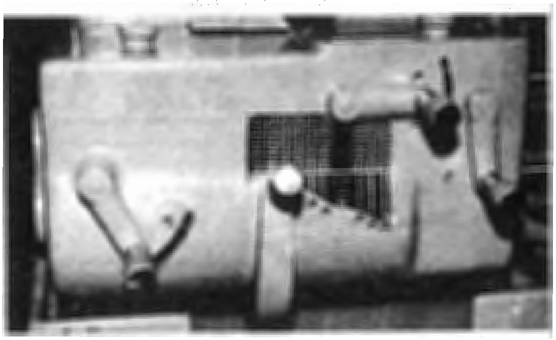
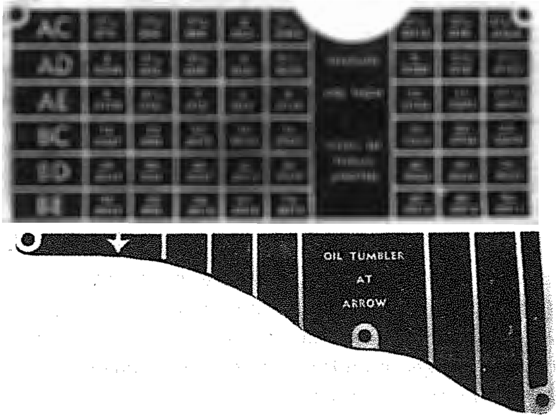


Fig. 8–18. Quick-change gear box facilitates the selection of feeds and threads. (Monarch Machine Tool Co.)

Fig. 8–19. Feed and thread index chart. (Monarch Machine Tool Co.)



9. *How is the size of an engine lathe designated?*

In the United States, the size of an engine lathe i designated by the largest diameter of work that can be revolved over the ways of the lathe bed (Fig. 8–20). In Europe, the size is given as the radius of the largest job that can be swung over the ways.

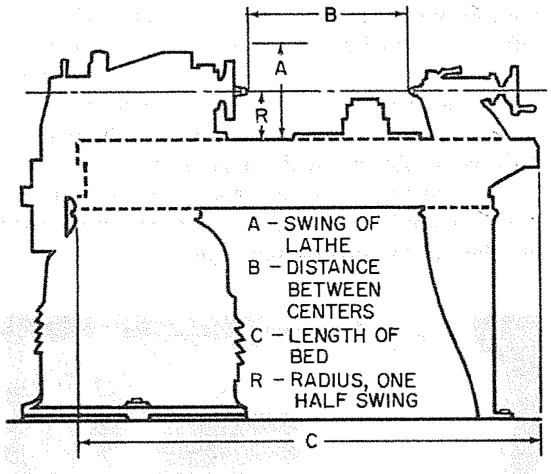


Fig. 8–20. How the size of a lathe is determined. (South Bend Lathe, Inc.)

There are different methods of denoting the length of a lathe. Some manufacturers give the length of the ways; others give the distance from the face plate to the end of the bed. Lathe specifications include the longest distance between headstock and tailstock centers.

ATTACHMENTS AND ACCESSORIES

An attachment is a device mounted on the lathe so that a wider range of operations may be performed. Examples of lathe attachments are (a) drive plate, (b) faceplate, (c) chucks, (d) collet attachment, (e) steady rest, (f) follower rest, (g) carriage stop, (h) taper attachment, (i) tool post, (j) grinding attachment, (k) relieving attachment, and (l) milling attachment.

Many of the small tools used to hold cutting tools and to turn workpieces are often referred to as accessories rather than attachments. Such tools as lathe dogs, mandrels, toolholders, centers, drills, and drill holders may be classed as lathe accessories.

10. *Explain the purpose of a drive plate.*
A drive plate (Fig. 8–21) is used to drive a lathe dog, which, in turn, is securely clamped to the workpiece. It is a round, slotted plate attached to the spindle. The bent tail of the dog fits into one of the slots in the face of the plate (Fig. 8–22). A drive plate is often called a *dog plate*

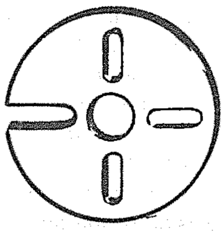


Fig. 8–21. Lathe drive plate. (Sheldon Machine Co., Inc.)

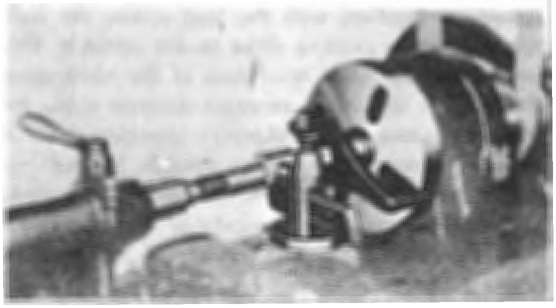


Fig. 8–22. Application of drive plate. (South Bend Lathe, Inc.)

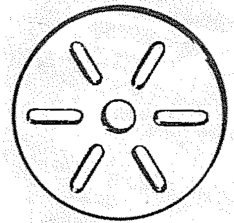


Fig. 8–23. Lathe faceplate. (Sheldon Machine Co., Inc.)

11. *What is a faceplate?*
A faceplate (Fig. 8–23) is similar to a drive plate but larger in diameter. It contains more open slots or T slots so that bolts or T bolts may be used to clamp the workpiece to the face of the plate. Many types of work that cannot be held in chucks may be machined conveniently when mounted on a faceplate (Fig. 8–24).

12. *What is the procedure for setting up work on a faceplate?*
Place the faceplate on the bench face up (Fig. 8–25). Set the workpiece on the plate. Arrange the bolts, washers, and nuts in the slots for suitable clamping. Arrange the clamps and step blocks or packing pieces. Center the workpiece by eye and tighten the clamping nuts just securely enough to hold the workpiece in place. Mount the faceplate on the

Fig. 8–24. Application of faceplate. (South Bend Lathe, Inc.)

Fig. 8–25. Locating and clamping work on a faceplate. (South Bend Lathe, Inc.)

spindle. True up the workpiece. Tighten all clamping nuts. Arrange and clamp the counterweights to balance the workpiece if necessary.

13. *Why are counterweights necessary on a faceplate?*
Counterweights are used to balance the faceplate when workpieces are mounted off-center. They aid in distributing the weight evenly so that the faceplate will turn smoothly while machining takes place (Fig. 8–26).

Fig. 8–26. Faceplate with off-center workpiece and counterweights. (South Bend Lathe, Inc.)

14. *Name the chucks commonly used for holding workpieces.*
The commonly used chucks are three-jaw universal chuck, four-jaw independent chuck, and magnetic chuck.

15. *What is a three-jaw universal chuck?*
A three-jaw universal chuck (Fig. 8–27) holds cylindrical or hexagonal work. All three jaws move

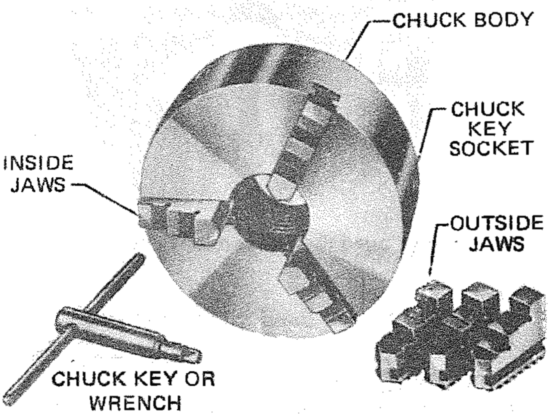


Fig. 8–27. Three-jaw universal chuck with inside and outside jaws. (L. W. Chuck Co.)

together to bring the work on center. Two sets of interchangeable jaws are provided because the jaws are not reversible. These are called *inside* and *outside* jaws. One set is used to grip the work inside while the other is used to grip the work on the outside.

16. *How are the jaws changed on the three-jaw universal chuck?*
The slots on the chuck are numbered 1, 2, and 3. Each jaw has a corresponding number. Remove the jaws from the chuck by backing them out with the chuck wrench. Turn the chuck so that slot No. 1 is at the top. Turn the wrench until the top thread of the scroll plate is just short of entering the No. 1 slot. Insert the No. 1 jaw and set it down against the scroll thread. Turn the wrench to catch the thread into the thread or groove of the jaw. Turn the wrench just enough to meet slot No. 2, no further. Insert and catch the No. 2 jaw. Repeat for the No. 3 jaw.

17. *What is a four-jaw independent cnuck?*
The four-jaw independent chuck (Fig. 8–28) is used to hold most of the work for which a chuck is required. The hardened steel jaws are reversible and will hold work of different sizes and shapes. Each jaw may be moved independently of the others so that workpieces may be trued to run accurately.

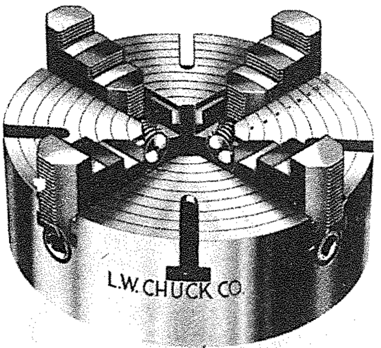


Fig. 8–28. Four-jaw independent chuck.

18. *How is work trued in a four-jaw independent chuck?*
A four-jaw independent chuck has several circular grooves around the face of the body. The jaws may be approximately centered by adjusting the jaws to these grooves. The workpiece is then inserted and the jaws tightened just enough to hold the work in place. Reverse the toolholder, tighten it finger-tight only, and turn it in until it just touches the workpiece. Revolve the chuck by hand to locate the high or low spot of the workpiece. Adjust the jaws until the workpiece runs true. If greater accuracy is required, use a test indicator.

19. *What is a combination chuck?*
A combination chuck is usually a four-jaw chuck in which the jaws may be adjusted either independently, as in a four-jaw independent chuck, or together, as in the three-jaw universal chuck. It is useful for holding duplicate workpieces. The first piece is located accurately by adjusting each of the jaws. The following pieces are then positioned like the first piece and the self-centering socket in the chuck body is used to tighten the work in the chuck. Figure 8–29 shows a six-jaw combination chuck.

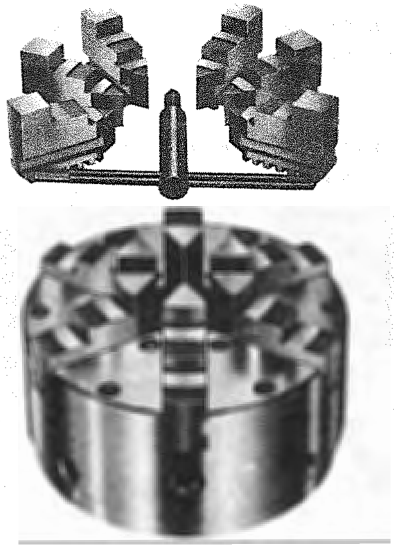
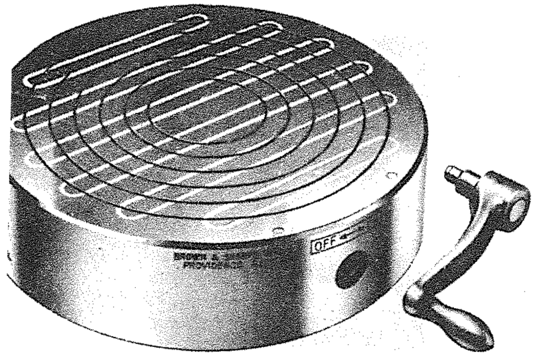


Fig. 8–29. Six-jaw combination chuck. (Buck Tool Co.)

20. *What is a magnetic chuck?*
A magnetic chuck (Fig. 8–30) holds steel workpieces by means of permanent magnets contained within the chuck. The face of the chuck is magnetized by inserting a key in the chuck and turning it 180°. The amount of magnetism may be controlled by turning the key only part of the required distance. In this manner, a workpiece may be held lightly on the face

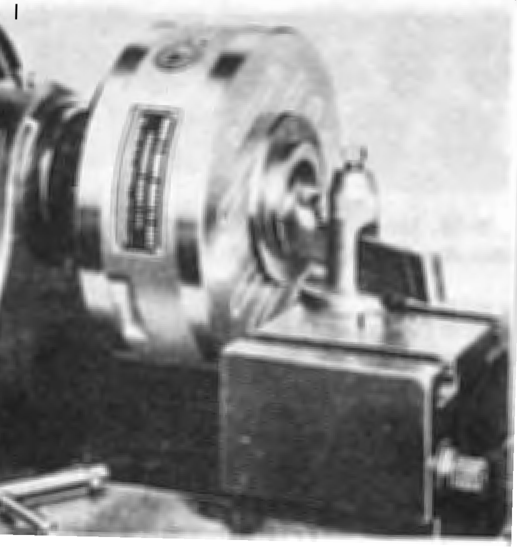


g. 8–30. Magnetic chuck. (Brown & Sharpe Mfg. o.)

f the chuck while it is being adjusted or trued to the equired position. Then, the full power of the mag- ets may be turned on. This type of chuck is suitable or work that requires only light cuts. The magnetic huck is especially good for holding parts that are oo thin to be held in an ordinary chuck, as shown in ig. 8–31.

21. *How is the size of a chuck designated?*
The size of a chuck is specified by the diameter of he chuck body.

Fig. 8–31. The magnetic chuck is useful for holding



22. *What is a collet attachment?*
A collet attachment provides a quick means of chucking workpieces with standard diameters or sizes. Figure 8–32 shows a collet attachment mounted in the headstock. One type of collet attachment (Fig. 8–33) consists of a taper sleeve, which fits into the spindle hole of the lathe, a draw-bar, and a set of collets. Another type of collet attachment (Fig. 8–34) consists of an attachment that fastens to the spindle and a set of collets, which may be inserted and clamped to the workpiece by turning a large-diameter handwheel.

23. *For what types of work should a collet attachment be used?*
Collet attachments are used to hold small metal parts. They are used in the toolroom for fine accurate work. A long bar of stock can be passed through

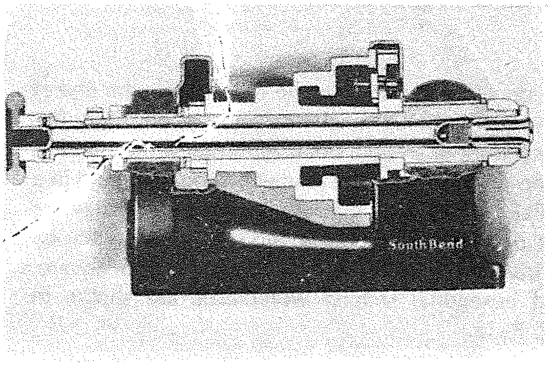


Fig. 8–32. Cross-section view of collet attachment mounted in the lathe spindle. (South Bend Lathe, Inc.)

Fig. 8–33. Collets, drawbar, and adapter for use with toolroom lathes. (Hardinge Brothers, Inc.)

Fig. 8–34. Sjogren spindle-nose collet chuck. (Cincinnati Lathe & Tool Co.)

the drawbar and held by the collet while the end of the stock is being machined and cut off. Only finished work or smooth stock within a few thousandths of an inch of the collet diameter should be held in a collet. Workpieces that are undersize, oversize, or out of round will destroy the collet's accuracy by springing it out of shape. Collets for round, square, and hexagonal shaped workpieces are shown in Fig. 8–35.

24. *What are rubber-flex collets?*
The Jacobs spindle-nose collet chuck and rubber-flex collets (Fig. 8–36) can handle a wide range of work diameters other than standard diameters. The eleven collets shown will hold workpieces ranging in diameter from 1/16 through 1⅜ in.

25. *What is a steady, or center, rest?*
A steady rest is a device that is clamped to the ways of the lathe to support long shafts during turning boring, or threading operations (Fig. 8–37). By holding the work more rigidly, a steady rest prevents the work from springing away from the cutting tool. A steady rest with rollers in the jaw (Fig. 8–38) is recommended for operations requiring high work speeds.

26. *What is a follower rest?*
A follower rest is a work-supporting device, which is

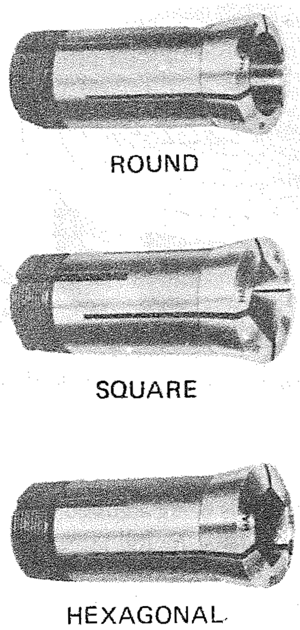


Fig. 8–35. Spring-type collets for round, square, and hexagonal stock. (Hardinge Bros., Inc.)

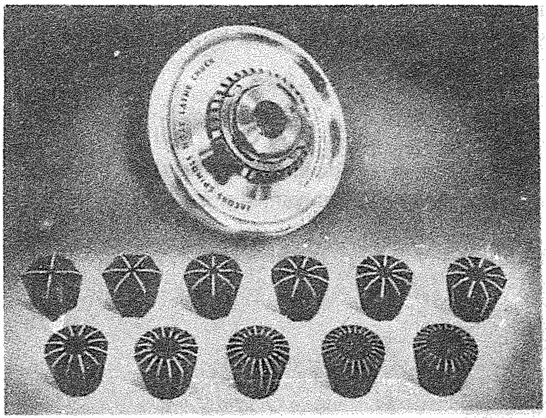


Fig. 8–36. Jacobs spindle-nose lathe chuck and rubber-flex collets. (Monarch Machine Tool Co.)

bolted to the saddle. It travels with the cutting tool. The adjustable jaws bear directly on the finished diameter of the workpiece behind the cutting tool. They prevent the workpiece from springing away from the cutting tool (Fig. 8–39).

27. *When using a drive plate and a steady rest, what is a good method for holding the shaft on the*

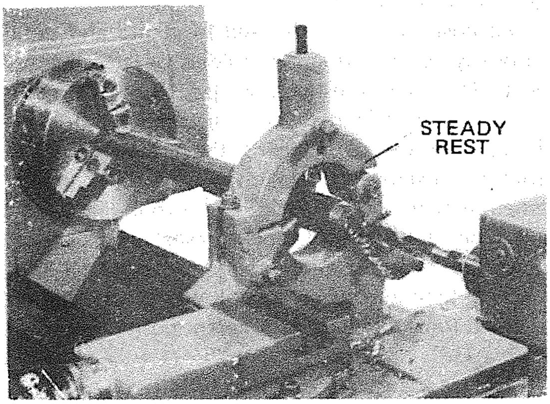


Fig. 8–37. Steady rest supporting workpiece during drilling operation. (R. K. LeBlond Machine Tool Co.)

Fig. 8–38. Roller-jaw steady rest. (Monarch Machine Tool Co.)

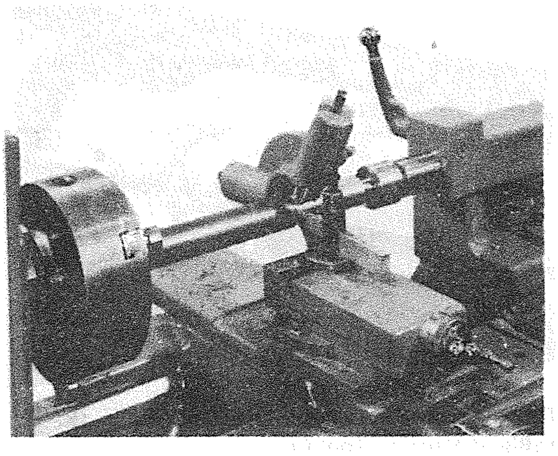
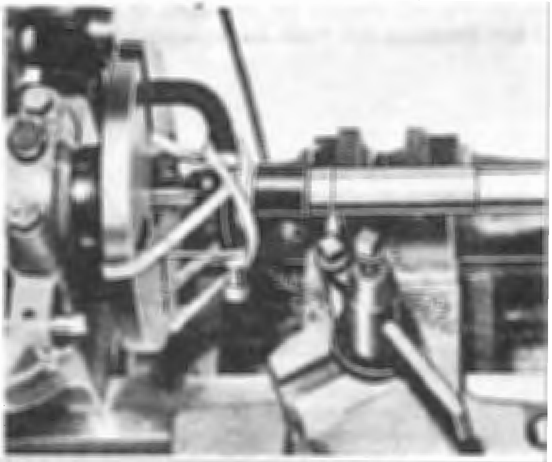


Fig. 8–39. Application of follower rest. (R. K. LeBlond Machine Tool Co.)

Fig. 8–40. Work held against live center with rawhide lacing. (Sheldon Machine Co., Inc.)



headstock center so that the end of the shaft may be faced and bored?
Tie the shaft and lathe dog to the drive plate as shown in Fig. 8–40. The plate is unscrewed about three or four revolutions from the shoulder of the spindle. Then the work is held tight against the live center and tied securely to the drive plate with rawhide lacing. Finally, the drive plate is screwed back against the shoulder of the spindle. This tightens the lacing on the work and holds it firmly.

28. *What is the purpose of a micrometer carriage stop?*
A micrometer carriage stop (Fig. 8–41) is a device attached to the ways of a lathe to stop the carriage at a definite place and limit the travel of the cutting tool. It is helpful for accurate facing, shoulder turning, and boring operations. The micrometer collar permits adjustments of one thousandth of an inch.

29. *Describe the taper attachment.*
The taper attachment (Fig. 8–42) is a fixed casting attached to the back of the lathe carriage. It is used to turn and bore tapers. Into the fixed casting is fitted a sliding part on top of which is a guide bar. Either

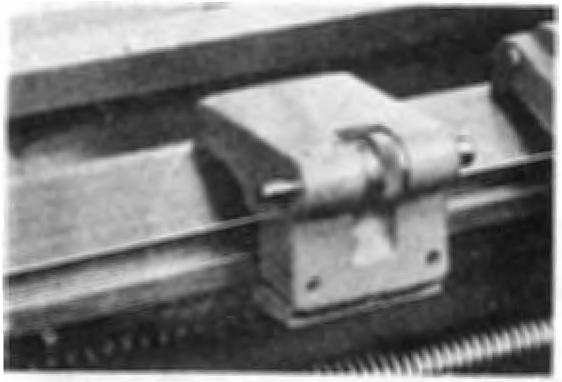


Fig. 8–41. A micrometer carriage stop. (R. K. LeBlond Machine Tool Co.)

the guide bar or the sliding part is graduated in degrees at one end, and inches per foot of taper at the other. A clamp holds the sliding part to the ways of the lathe in a fixed position. When the guide bar is set to the desired taper, the cross-feed containing the cutting tool follows the set angle, or taper, and in turn produces this taper on the workpiece.

30. *What is a tool post?*
A tool post (Fig. 8–43) is used to clamp and hold various types of cutting-tool holders or lathe attachments. The holders rest on a wedge, which is shaped on the bottom to fit into a concave-shaped ring, providing a means of adjusting the toolholder to a required position in relation to the work being turned. A four-way tool block is shown in Fig. 8–44. This type of turret tool block makes it possible to mount four different cutting tools instead of one, thus reducing time and labor costs. It can be indexed or swiveled to as many as 12 different positions.

31. *What is a grinding attachment?*
A grinding attachment (Fig. 8–45), often called a *tool-post grinder,* is a motor-driven, self-contained unit that is held in the tool post. It is used for outside and inside grinding. Some grinders are especially designed for grinding screw threads (Fig. 8–46).

32. *What precautions must be taken when using a grinding attachment?*
Care must be taken to protect the ways and other bearing surfaces from the particles of abrasive mate-

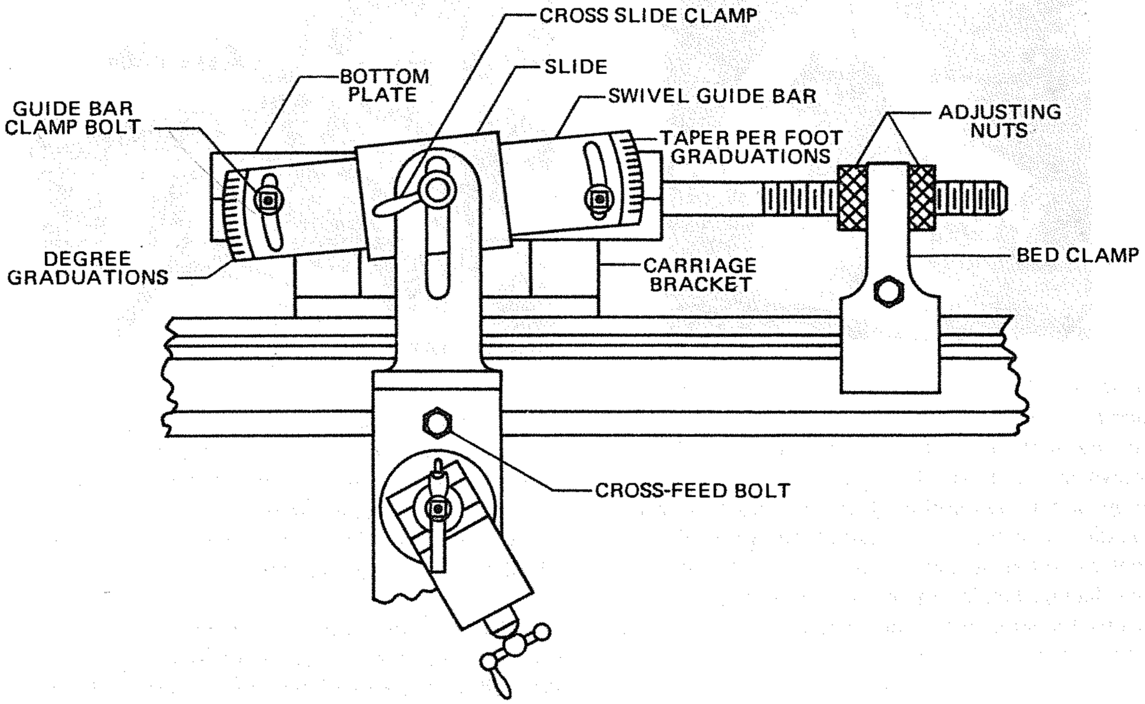


 Fig. 8–42. Construction and parts of a lathe taper attachment.

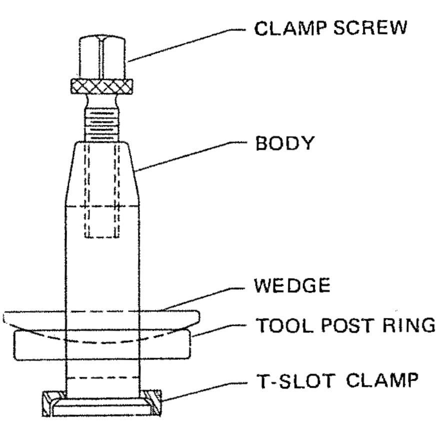
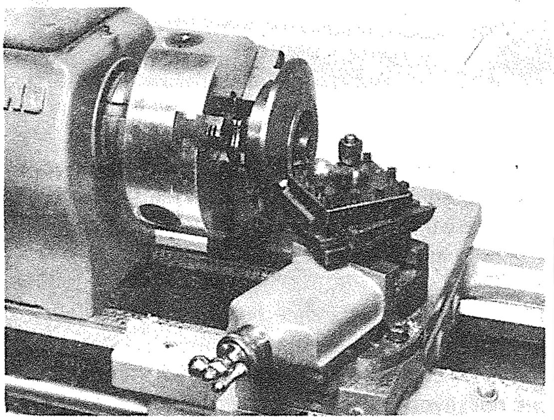


Fig. 8–43. Standard tool post.

Fig. 8–44. Four-way turret tool block. (R. K. LeBlond Machine Tool Co.)



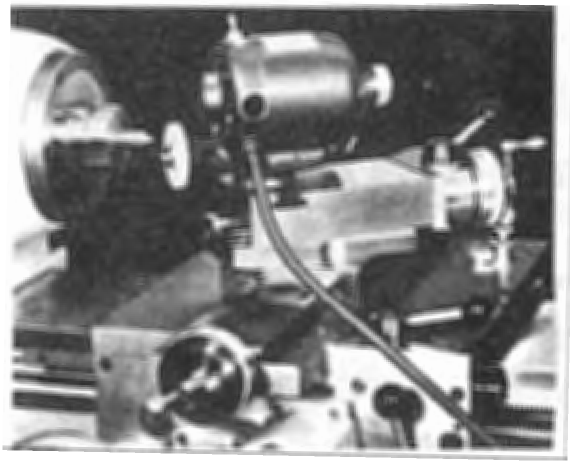
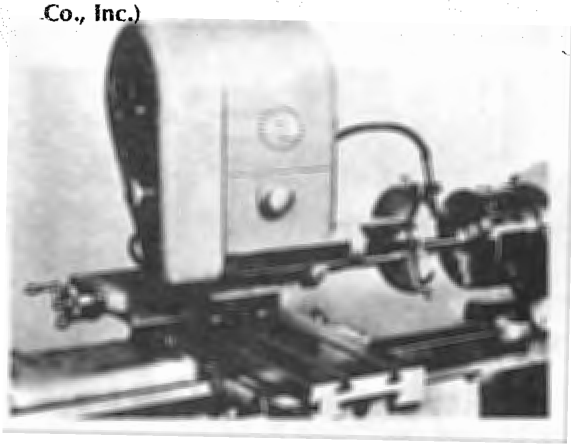


Fig. 8–45. Tool-post grinder for precision work. (Hardinge Brothers, Inc.)

Fig. 8–46. Thread-grinding attachment. (Kurt Orban Co., Inc.)



rial coming from the grinding wheel. The ways should be covered with a protective cloth. A small piece of metal should be placed directly under the stream of sparks to avoid burning the cloth.

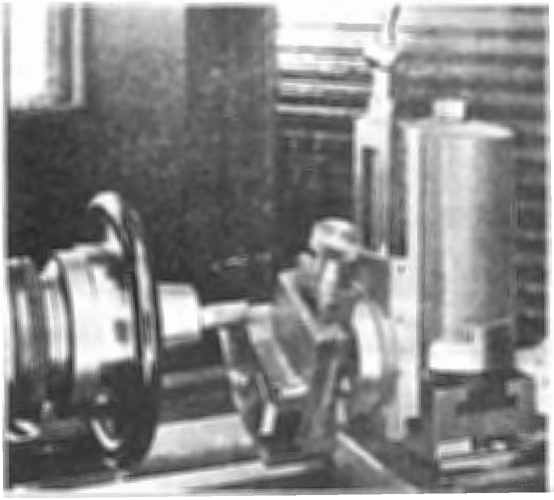
33. *What is a relieving attachment?*
A relieving, or backing-off, attachment is used for external, internal, and end relieving of milling cutters and taps. The oscillating movement of the tool slide is obtained by a cam, which is operated by a drive shaft with universal joints connected to the headstock (Fig. 8–47). To mount the relieving attachment to the lathe requires little of the lathe operator's time, and it may readily be disconnected when the work is done.

34. *What is a milling attachment?*
A milling attachment (Fig. 8–48) consists of a slide and a swivel vise mounted on the compound rest in place of the tool post. The base of the swivel vise has degree graduations and so can be set at any desired angle. The vertical hand feed screw dial is graduated for thousandths of an inch. This attachment can be used for face milling, squaring work, and cutting slots and keyways.

35. *What attachments and accessories are used to hold work to be turned between centers?*
The equipment required to hold work between cen-

Fig. 8–47. Relieving attachment is operated by a drive shaft connected to a change-gear mechanism attached to the end of the headstock. (Monarch Machine Tool Co.)

Fig. 8–48. Milling attachment for the lathe fastened to T slot of compound rest. (Cincinnati Lathe & Tool Co.)



ters consists of (a) a live center, (b) a dead center, (c) a drive plate, and (d) a bent-tail lathe dog (Fig. 8–49).

36. *What are lathe centers?*
Lathe centers (Fig. 8–50) are hardened steel devices with a taper shank on one end and a 60° point at the other end. The taper shanks fit the taper spindle holes in the headstock and tailstock. The 60° point

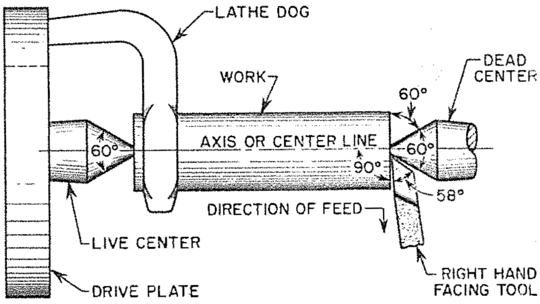
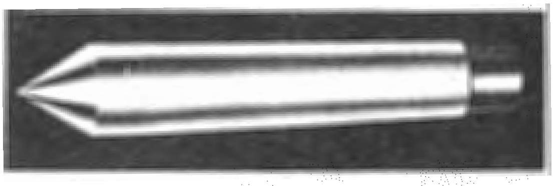


Fig. 8–49. Correct setup for facing and turning between centers.

Fig. 8–50. Typical lathe center. (Hardinge Brothers, Inc.)



fits into the 60° center holes drilled into the workpiece to provide bearing surfaces, which support the revolving workpiece. Other types of lathe centers are shown in Fig. 8–51.

37. *What is the difference between a dead center and a live center?*
The dead center is used in the tailstock spindle and does not revolve. The live center fits into the headstock spindle and revolves with the work. The dead center should always be a hardened center. The points are often made from high-speed steel or tungsten carbide to withstand wear and provide strength. Live headstock centers may be made from soft steel alloy. This permits truing the center point by taking a cut with the lathe tool bit, using the compound slide set at 30° (Fig. 8–52). Hardened centers must be ground.

38. *What is a spindle sleeve?*
For lathes with a very large taper hole in the spindle, a taper sleeve serves as an adapter to receive the smaller taper of the center. The outside taper of the sleeve fits the taper bore of the spindle, and the internal taper is made to fit the taper shank of the center (Fig. 8–53).

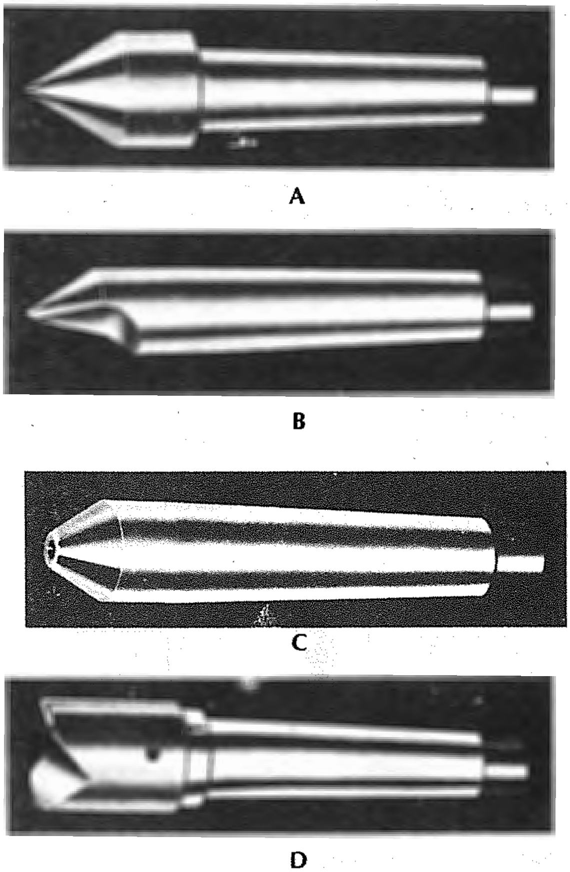


Fig. 8–51. Types of tailstock centers. (A) Large-point dead center. (B) Half center. (C) Female center. (D) Swivel V center. (Hardinge Brothers, Inc.)

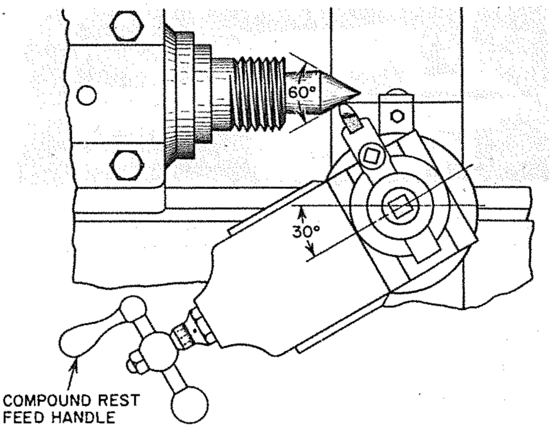
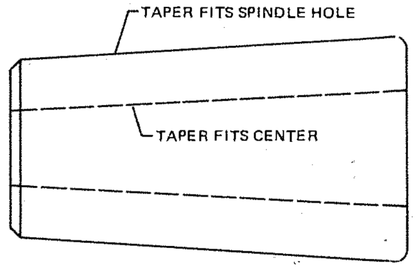


Fig. 8–52. Setup for truing the point on nonhardened headstock center.

Fig. 8–53. Headstock center sleeve.



39. *What is the correct procedure for using and adjusting the dead center to support a workpiece?* Clean the taper hole and taper shank of the dead center. Run the tailstock spindle out a short distance and then set the dead center firmly into the taper hole. Locate and clamp the tailstock in position. The dead center must be lubricated and carefully seated in the workpiece center hole so that the workpiece will turn freely without too much play. If it is seated in the center hole too tightly, friction between the work and center point will cause both parts to become hot and to expand soon after the lathe is started. Unless corrected quickly, the center point will get extremely hot and break off, ruining the center point, damaging the work, and possibly injuring the operator. If the center is adjusted too loosely, it could cause the cutting tool to chatter or dig in, producing a very rough finish on the work. A mixture of oil and white lead makes a good lubricant. A small amount placed into the center hole or on the center point is sufficient. Overheating results in a squeaking sound followed soon by smoke. When this happens, stop the lathe quickly, back the center out a bit, relubricate, and readjust the center to the work.

40. *What is a live tailstock center?*
A live tailstock center has a ball-bearing mechanism that permits the 60° point to revolve with the workpiece (Fig 8–54). This eliminates friction, permits work to be turned at high speeds, and does not require oiling and constant adjustment as does the

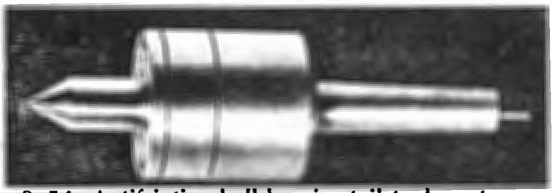


Fig. 8–54. Antifriction ball-bearing tailstock center, which turns with the work. (Hardinge Brothers, Inc.)

standard dead center. One lathe manufacturer equips the tailstock with a built-in live center mechanism (Fig. 8–55).

41. *What is meant by alignment of centers?*
Alignment of centers means that both the dead (tailstock) center and the live (headstock) center have one common center line. When centers are in exact alignment, the workpiece being turned will have the same diameter throughout its entire length. This is called *straight turning* (Fig. 8–56).

42. *When centers are out of alignment, what kind of workpiece is produced?*
A tapered workpiece results. The diameter at each end will be a different size.

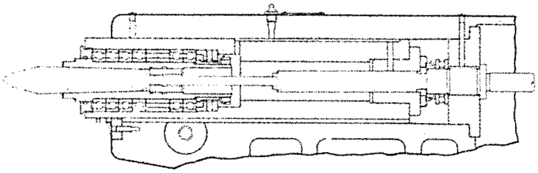


Fig. 8–55. Tailstock spindle with built-in revolving center. (The Lodge & Shipley Co.)

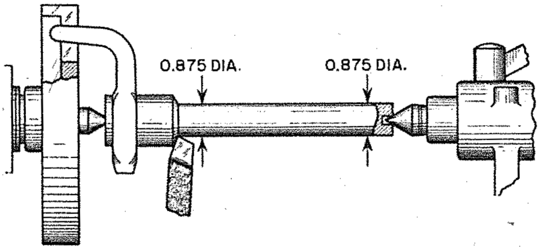


Fig. 8–56. Straight turning produces a workpiece that is uniform in diameter.

43. *How may centers be placed in approximately correct alignment?*
Centers may be placed in approximately correct alignment by (a) moving the dead center close to the live center to see if the center points meet (Fig. 8–57), and (b) looking at the graduated lines on the bottom and top of the tailstock casting to see if the zero points align (Fig. 8–58). For accurate work, these methods should not be depended upon.

44. *How may centers be precisely aligned?*
Centers may be precisely aligned by (a) taking a light cut for a certain distance and measuring each end of the machined section of the workpiece with a micrometer, (b) using a test bar and indicator to take a reading at both ends of the test bar, (c) moving the tailstock to correct any error, and (d) rechecking.

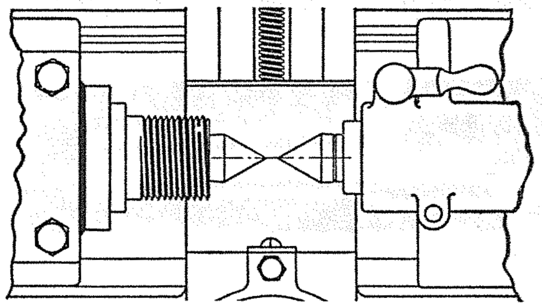


Fig. 8–57. An approximate method of checking center alignment.

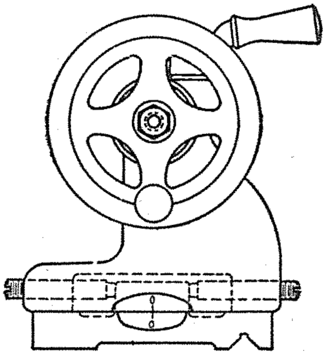


Fig. 8–58. Lines on tailstock may be used to align centers approximately correct. (South Bend Lathe, Inc.)

45. *Explain how centers may be aligned precisely by using a test bar and indicator.*
To align centers precisely, place the test bar between centers. Mount a dial indicator by clamping to the toolholder or tool post. Set the contact point of the indicator against the test bar at center height. Obtain a reading at one end of the test bar. Feed the carriage by hand feed along the test bar and note the indicator reading. The reading should be the same at each end for accurately aligned centers. If the indicator reading is not the same, adjust the tailstock and recheck (Fig. 8–59).

46. *Why must the live center run true to produce a true cylindrical workpiece when turned between centers?*
Unless the live center runs perfectly true, it will be impossible to turn a cylinder that is concentric throughout its entire length. When the work is reversed between centers, the two cuts will not meet exactly, resulting in an eccentric rather than a concentric workpiece.

47. *How is the work mounted on centers?*
When mounting work between centers, be careful to see that the centers are in good condition. Figure 8–60 shows a shaft correctly mounted between centers A and B. The lathe dog is fastened to the work, and the tail should clear the bottom of the slot (as shown at C). The work is held firmly but not too tightly on the live and dead centers.

An incorrect mounting of work on centers is shown in Fig. 8–61. In this case, the lathe dog is of such a size that the tail will not clear the bottom of the drive-plate slot (as shown at C). This situation causes the work to be pulled away from the center, as indicated at point A, and so to revolve eccentrically. This condition may be overcome by using a larger dog or by placing the tail of the dog in a deeper drive-plate slot.

48. *What extra care should be taken in inserting a piece of work between the centers?*
If the dead center is carelessly forced against the end of the work close to the edge of the center hole, the hole may be burred or nicked. Should this happen, the work will not run true.

49. *What are lathe dogs?*
Lathe dogs are devices attached to the workpieces to be turned between centers (see Fig. 8–49). A set screw, or two clamping screws, holds the dog securely to the workpiece. The bent tail fits loosely into one of the drive-plate slots to drive the workpiece.

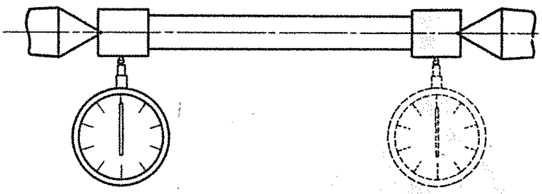
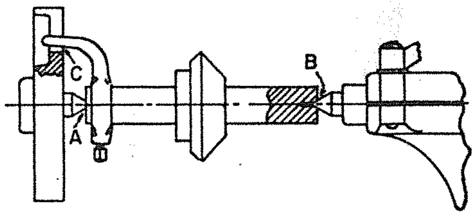


Fig. 8–59. Aligning centers with a test bar and indicator is an accurate method.

Fig. 8–60. Shaft correctly mounted between centers.



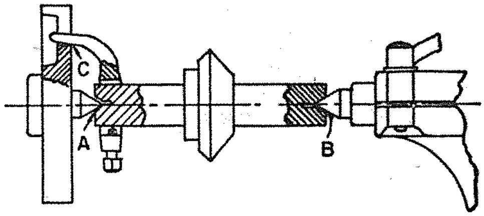


Fig. 8–61. Incorrect setup. Lathe dog tail is bearing on bottom of drive-plate slot, throwing work off center.

50. *What types of dogs are used for lathe work?*
Bent-tail lathe dogs (Fig. 8–62), the most commonly used, are made in several styles and many sizes. The clamp-type dog (Fig. 8–63) is used for driving square or rectangular workpieces. Dogs with safety set screws (Fig. 8–64) are preferred.

51. *How should you protect a finished surface from being marred by the set screw of the lathe dog?*
Place a small piece of copper or soft metal between the screw and the work (Fig. 8–65).

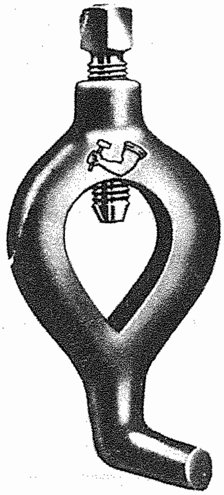


Fig. 8–62. Bent-tail lathe dog. (Armstrong Bros. Tool Co.)

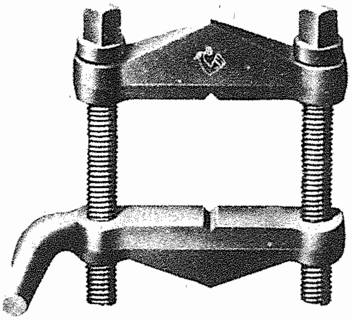


Fig. 8–63. Clamp-type dog. (Armstrong Bros. Tool Co.)

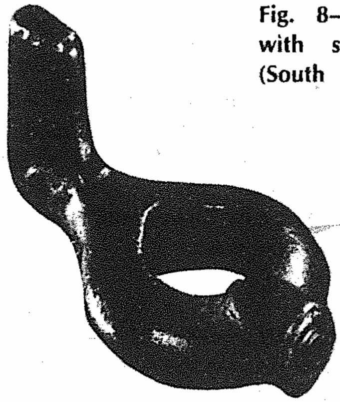


Fig. 8–64. Bent-tail dog with safety set screw. (South Bend Lathe, Inc.)

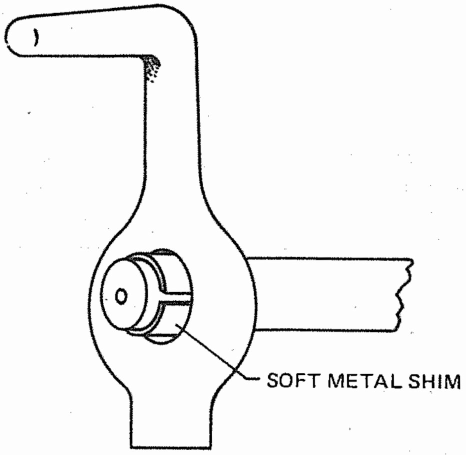


Fig. 8–65. A soft metal strip between dog screw and workpiece prevents damage to work.

52. *What is a lathe mandrel?*

A lathe mandrel (Fig. 8–66) is a hardened and tempered steel work-holding device. It is used for the further machining of a workpiece between centers after it has been bored or reamed while held in a chuck. The mandrel is ground to a taper of 0.006 inch per foot. It is pressed or driven into a finished hole tight enough so the work will not slip while it is being machined (Fig 8–67). The mandrel size is stamped on the large end.

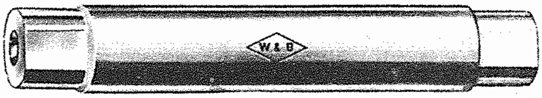


Fig. 8–66. Plain mandrel. (Whitman & Barnes.)

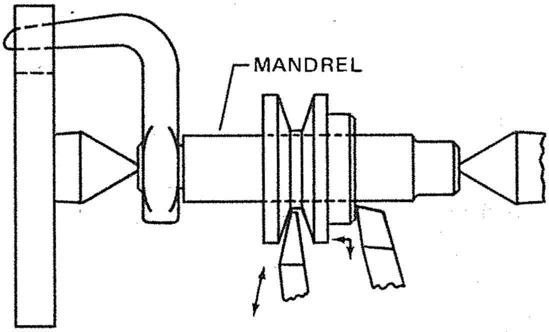


Fig. 8–67. Facing and turning a pulley held on a mandrel between centers.

53. *What is an expanding mandrel?*
An expanding mandrel (Fig. 8–68) consists of a solid tapered piece and a slotted tapered sleeve, which expands in diameter when forced onto the solid tapered mandrel. Usually made in sets, each mandrel can be used for a variety of hole sizes. The amount of expansion is from about 1/16 in. for the smaller size mandrels up to ½ in. for the larger size mandrels.

54. *What is a nut mandrel?*
A nut mandrel (Fig. 8–69) is a straight mandrel threaded at one end so that a number of workpieces may be mounted and securely held for turning between centers.

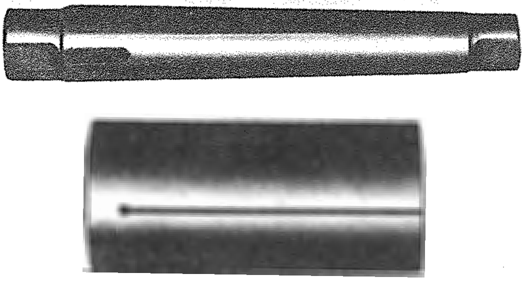


Fig. 8–68. Expanding mandrel. (Brown & Sharpe Mfg. Co.)

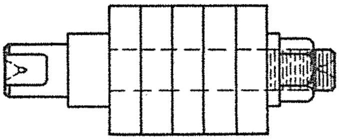


Fig. 8–69. A nut mandrel holds several workpieces for machining in one operation. (South Bend Lathe, Inc.)

55. *What is the difference between a mandrel and an arbor?*
A mandrel is a work-holding device. An arbor (Fig. 8–70) is designed to hold and drive cutting tools such as milling cutters. The terms are often improperly used.

56. *What care should be used before pressing mandrels into a finished hole?*
Lubricate both the mandrel and the hole to prevent the mandrel from freezing in the hole. Without the use of a lubricant both the hole and the mandrel may be damaged. Use an arbor press to drive and remove mandrels from workpieces (Fig. 8–71).

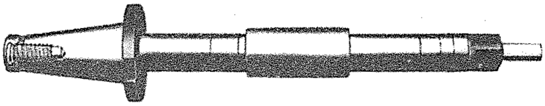


Fig. 8–70. Milling machine arbor. (Brown & Sharpe Mfg. Co.)

Fig. 8–71. Arbor press.

LATHE OPERATIONS AND PROCESSES

Usually several steps are required to produce a finished workpiece. These specific steps are referred to as *operations*. Examples of operations might be facing, center drilling, or rough turning.

The broader aspects of lathe work may be referred to as *processes*. Examples of lathe processes might be straight turning, taper turning, boring, and thread cutting.

Often there are several processes by which an operation may be performed. For example, straight turning may be done between centers, either in a chuck or in a collet. Or threads may be cut with a threading die or by a cutting tool.

57. *What is the operation of facing?*
Facing is the operation of machining the end of a workpiece to make the end square with the axis, or center line. Work may be faced while being held between centers, in a chuck, on a face plate, in a collet, or while being supported by a steady rest.

58. *What is a good procedure for facing?*

A. Measure the length to determine how much stock is to be removed.
B. Machine off just enough stock from the first end to clean up that end (Fig. 8–72).
C. Feed the facing tool from the center out, rather than from the outside toward the center.
D. Machine the remaining stock from the opposite end to face it to the length required.

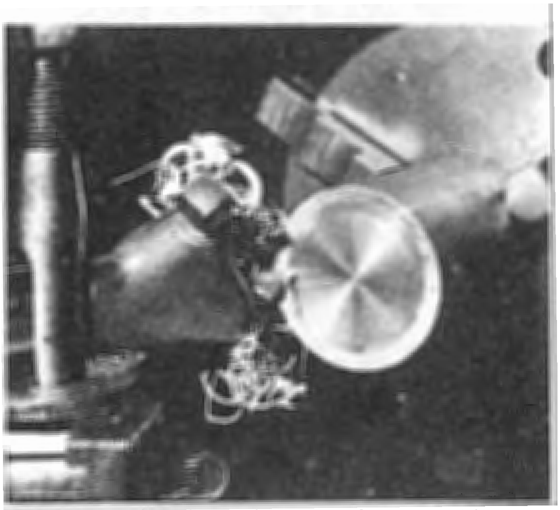


Fig. 8–72. Facing the end of a workpiece held in a chuck.

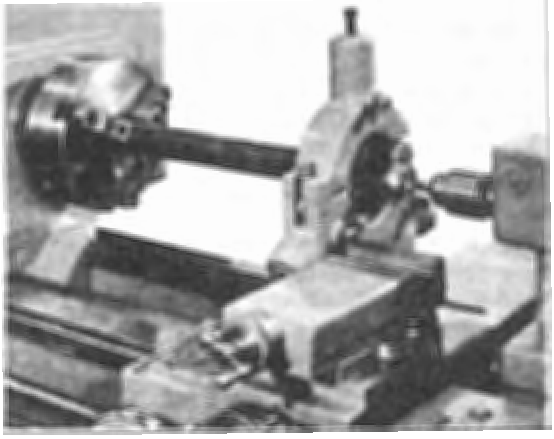
59. *What is step facing?*
When a large amount of material is to be removed by facing, it can be rough machined faster by making a series of deep cuts longitudinally rather than from the center out (Fig. 8–73). This process is called step facing.

60. *What is center drilling?*
Center drilling is the operation of drilling and countersinking each end of the stock to be turned between centers (Fig. 8–74). Center drilling provides bearing surfaces for the lathe centers.

Fig. 8–73. Step facing rapidly removes excess metal.

61. *What is a combined drill and countersink?*
A combined drill and countersink is generally used to drill center holes. The included angle of this drill is 60°. This angle is the same as that of the dead and live centers. The drill part of this tool provides clearance for the center point and also acts as a small oil well for the lubricant. Figure 8–75 shows the plain type and the bell type of combined drill and countersink.

Fig. 8–74. A method of drilling center holes in a long workpiece. (R. K. LeBlond Machine Tool Co.)



62. *How are the sizes of combined drills and countersinks specified?*
The body diameter and the drill-point diameter are specified by numbers, as shown in Fig. 8–76.

63. *How large should center holes be drilled?*
There is no set rule for the size of center holes. Good judgment is necessary, and the size depends on the size of the workpiece. The hole should be only large enough to provide an adequate bearing surface. Figure 8–77 shows conditions that may result unless good judgment is used when center drilling holes.

64. *How are small workpieces usually center drilled?*
Small workpieces may be center drilled by holding the work in a three-jaw universal chuck or a spring collet. A drill chuck mounted in the tailstock spindle holds the combined drill and countersink (Fig. 8–78). The work is usually faced before center holes are drilled. Because these drills are hard and break easily the tailstock must be aligned so the drill point meets the exact center of the work. Fast speed and oil on the drill point are required. Small-diameter center drills must be started and fed into the work with utmost care to prevent breakage.

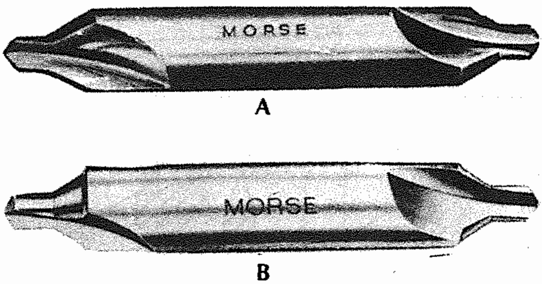
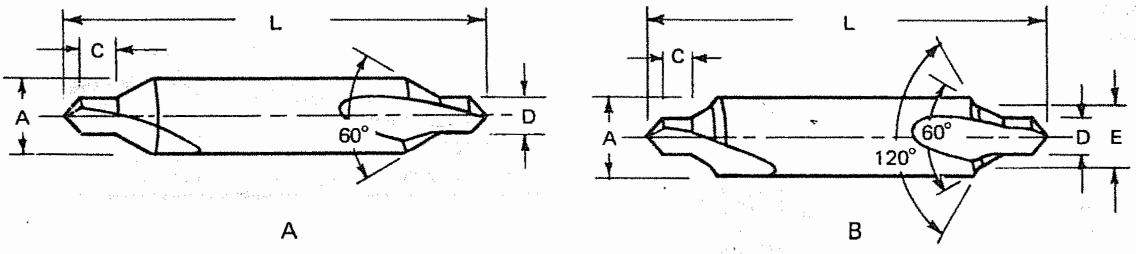


Fig. 8–75. Combined drill and countersink. (A) Plain type. (B) Bell type. (Morse Twist Drill & Machine Co.)



COMBINED DRILL AND CONTERSINK, PLAIN TYPE

STANDARD SIZES AND DIMENSIONS
HIGH SPEED STEEL

SIZE DESIGNATION	DIMENSIONS — INCHES BODY DIAM. A	DRILL DIAM. D	DRILL LENGTH C	OVERALL LENGTH L
00	1/8	0.025	0.040	1 7/32
0	1/8	1/32	3/64	1 7/32
1	1/8	3/64	3/64	1 1/4
2	3/16	5/64	5/64	1 7/8
3	1/4	7/64	7/64	2
4	5/16	1/8	1/8	2 1/8
5	7/16	3/16	3/16	2 3/4
6	1/2	7/32	7/32	3
7	5/8	1/4	1/4	3 1/4
8	3/4	5/16	5/16	3 1/2

COMBINED DRILL AND COUNTERSINK, BELL TYPE

STANDARD SIZES AND DIMENSIONS

SIZE DESIGNATION	DIMENSIONS — INCHES BODY DIAM. A	DRILL DIAM. D	DRILL LENGTH C	OVERALL LENGTH L	BELL DIAM. E
11	1/8	3/64	3/64	1 1/4	0.100
12	3/16	1/16	1/16	1 7/8	0.150
13	1/4	3/32	3/32	2	0.200
14	5/16	7/64	7/64	2 1/8	0.250
15	7/16	5/32	5/32	2 3/4	0.350
16	1/2	3/16	3/16	3	0.400
17	5/8	7/32	7/32	3 1/4	0.500
18	3/4	1/4	1/4	3 1/2	0.600

Fig. 8–76. Standard sizes for combined drills and countersinks. (Morse Twist Drill & Machine Co.)

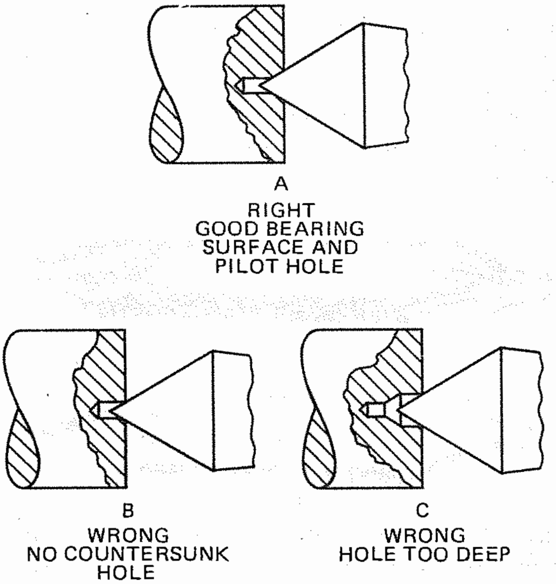
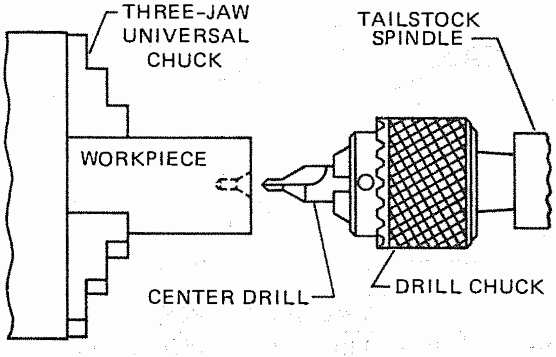


Fig. 8–77. Right and wrong center holes.

Fig. 8–78. A good setup for center drilling small work.



65. *How are centers located when laying out is necessary?*
Some types and sizes of workpieces require that the centers be laid out and center punched before center drilling. Color the work with layout dye or use ordinary chalk. Centers can be located by using a hermaphrodite caliper, a surface gage and V block, or a center head from a combination square (Fig. 8–79). A hermaphrodite caliper should be set to a distance slightly more than half the diameter and four lines should be scribed by moving the caliper leg approximately 90° for each line. The center of the four lines

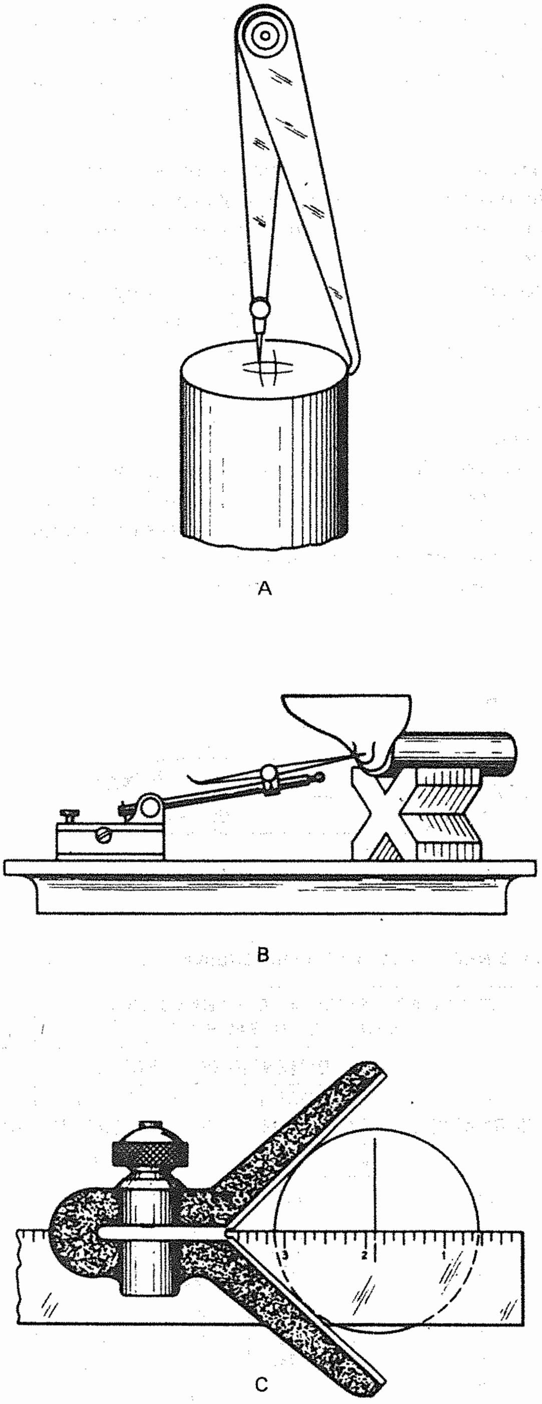


Fig. 8–79. Three methods of locating centers. (A) Hermaphrodite caliper. (B) Surface gage. (C) Center head.

is then center punched. Round work and workpieces of irregular shape but having a round part may be held in a V block on a surface plate, and lines may be scribed with a surface gage. Rotate the workpiece about 90° for each line scribed. A center head and rule from a combination square set may be used to scribe lines across the face of a round shaft.

66. *How are center holes drilled after layout?*
After laying out and center punching the location, center holes may be drilled as shown in Fig. 8–80. Mount a drill chuck in the headstock spindle or hold the combined drill and countersink in the three-jaw chuck. Locate and hold the center-punch mark against the tailstock center point. Feed in the tailstock spindle until the workpiece lightly touches the center drill. Use a sufficiently fast speed and feed the workpiece carefully against the turning drill until the center hole is drilled to the desired size. Reverse the workpiece and drill the opposite end.

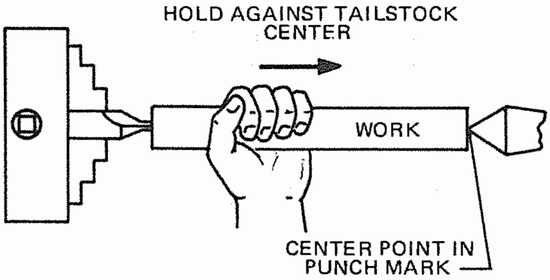


Fig. 8–80. A method of drilling center holes after layout and center punching.

67. *What is straight turning?*
Straight turning is the process of producing a cylindrical piece of work on which the diameter is uniform in size throughout its entire length. When the diameter at one end of a cylinder differs from the diameter at the other end, it is said to be tapered.

68. *What methods may be used for holding the work when straight turning?*
Straight turning may be done while the work is held between centers, in chucks, in collets, or when using the steady or follower rests.

69. *To turn a piece of work straight between centers, what precautions must be carefully observed?*
The centers must be aligned accurately. The headstock center should run true. Take a light cut for a suitable length and measure each end as well as a few points in between, to make certain the diameter is of the same size throughout.

70. *If, after taking a cut over the workpiece, you find the end nearest the tailstock to be larger than the end nearest the headstock what should you do?*
Adjust the tailstock toward you and take another light cut, then measure again.

71. *In which direction should you adjust the tailstock when the workpiece is smaller in diameter at the tailstock end?*
Adjust the tailstock away from you.

72. *What is meant by rough turning?*
Rough turning is the operation of removing excess stock rapidly and efficiently, leaving enough stock for finishing to the specified size.

73. *What are the general rules for rough turning?*
Rough turning requires as deep a cut as possible, a coarse feed, and a speed that is consistent with good safety practices. The finish produced by rough turning need not be smooth.

74. *What is meant by finish turning?*
Finish turning is the operation of machining a workpiece to the required dimensions within the tolerance specified. The surface finish may be specified or may result from the machinist's judgment.

75. *What are the general rules for finish turning?*
Finish turning generally requires a light cut and a faster speed and finer feed than used for rough turning. The cutting tool should be sharp and of a suitable form or shape to produce a smooth finish.

76. *What is meant by shoulder turning?*
Shoulders are turned when two or more diameters are cut on a workpiece. The shoulder is formed at the point where the size changes from one diameter to another.

77. *What are the different kinds of shoulders?*
Shoulders produced on turned work may be square, filleted, or undercut.

78. *What is a square shoulder?*
A square shoulder has a sharp square corner.

A facing or side tool ground to a sharp point is used to machine a square shoulder (Fig. 8–81).

79. *What is a filleted shoulder?*
A filleted shoulder has a rounded corner turned to a specified radius (Fig. 8–82).

80. *What is meant by undercutting?*
Undercutting, often called *necking* or *grooving*, is the cutting of a groove next to a shoulder on a piece of work, as in Fig. 8–83. This is done when the smaller diameter has to be ground, inasmuch as the corner of a grinding wheel cannot produce a sharp corner.

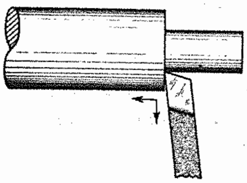


Fig. 8–81. Squaring the corner of a shoulder.

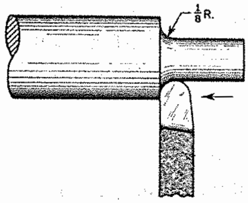


Fig. 8–82. Turning a shoulder radius, or fillet.

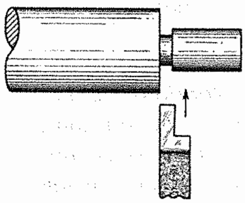


Fig. 8–83. Undercutting, or necking, a shoulder.

81. *When a drawing calls for grinding on a diameter and against a shoulder, what kind of an undercut should be made?*
The undercut should be made with a narrow, roundnose tool fed in at an angle of 45°.

82. *Why is it necessary to use a roundnose tool to undercut corners on a workpiece that is to be hardened and ground?*
The use of a square-nose tool will leave a sharp corner that will tend to cause the steel to crack or break when it is hardened.

83. *What is the operation of chamfering?*
Chamfering is the operation of producing a beveled edge at a specified angle on the end of a turned diameter. This is done to break off or remove the sharp edge and finish the workpiece. Chamfering is also done to aid in starting a round piece, such as a dowel pin, straight in a hole.

84. *How is chamfering done in the lathe?*
Chamfering may be done by setting the compound slide at the required angle and feeding the tool bit by hand to produce a specified chamfer. When the chamfer angle and the length are not specified, the tool bit may be set at an angle (Fig. 8–84) and fed against the revolving workpiece, or a file may be used. A corner may also be rounded (Fig. 8–85).

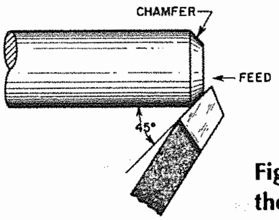


Fig. 8–84. Chamfering with the tool bit set at an angle.

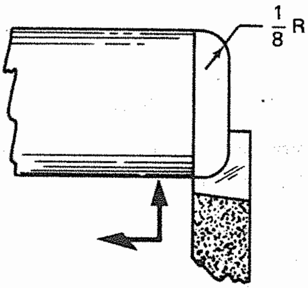


Fig. 8–85. Method of rounding a corner with a form-ground tool bit.

85. *What is knurling?*
Knurling is a process of rolling depressions or indentations of various shapes into metal by the use of revolving hardened-steel wheels pressed against the work (Fig. 8–86). The design on the knurl will be reproduced on the work. A knurling tool (Fig. 8–87) held in the tool post is used for this operation. Knurling is done to provide a grip on handles, screw heads, and other cylindrical parts to be gripped by hand. Figure 8–88 shows an adjustable knurling tool.

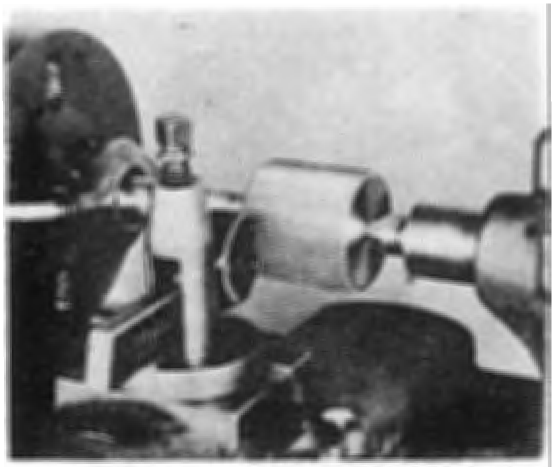


Fig. 8-86. Knurling a workpiece. (South Bend Lathe, Inc.)

Fig. 8-87. Knurling tool. (J. H. Williams & Co.)

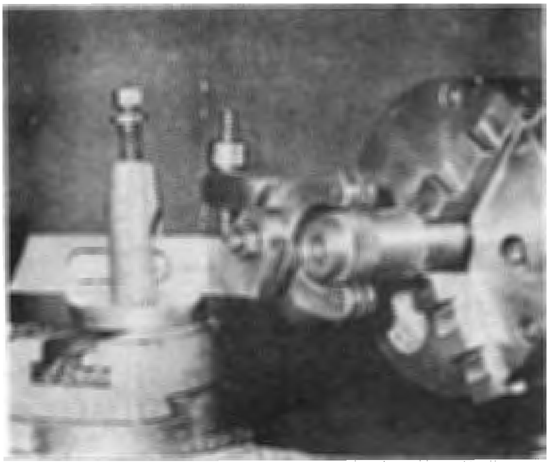


Fig. 8-88. Knurling with an adjustable knurling tool. (Joseph Fakes & Co.)

86. *How are knurls classified?*
Knurls are classified according to pattern—for example, diamond pattern or straight pattern—and according to pitch. Commonly used knurls are generally classed as coarse, medium, or fine (Figs. 8-89 and 8-90).

87. *How should knurling be done on the lathe?*
Position the knurling tool in the tool post so that it is at right angles to the work. The center of the knurling rolls should be set at the height of the work center to permit the knurling rolls to center themselves on

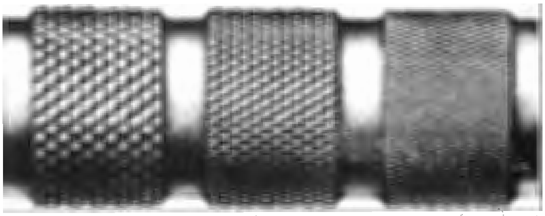
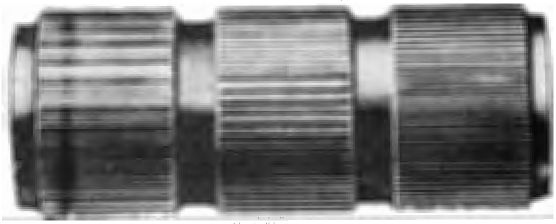


Fig. 8-89. Coarse, medium, and fine diamond-pattern knurling. (J. H. Williams & Co.)

Fig. 8-90. Coarse, medium, and fine straight-pattern knurling. (J. H. Williams & Co.)



the work and equalize the pressure on each of the rolls. The speed depends on the kind of material being knurled. Soft metals such as aluminum can be knurled at faster speeds than the hard alloy steels. The surface to be knurled should be machine finished. Force the knurling wheels slowly into the revolving work until a good impression is obtained; then feed the tool across the length to be knurled. After each pass, feed the tool in until a clean, clearly shaped knurl is obtained. Use a cutting lubricant while knurling.

88. *What is the operation of recessing?*
External recessing (Fig. 8-91) is the operation of

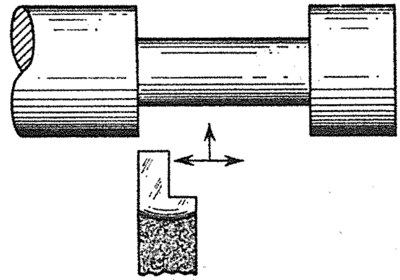


Fig. 8–91. Turning a recess with square corners.

machining a smaller diameter on a workpiece, for a specified length. Internal recessing (Fig. 8–92) is the machining of a larger diameter, for a specified length, inside a hole. Recesses may have square or rounded corners (Fig. 8–93).

89. *What is the operation of parting?*
Parting, or cutting-off (Fig. 8–94), is the operation of separating a piece of finished work from the bar stock from which the piece was machined. A parting tool with a long narrow blade is used (Fig. 8–95). For small-diameter work, parting tools may be ground from a standard tool bit (Fig. 8–96). Parting tools are ground to cut on the end only (Fig. 8–97) as they are fed into the workpiece.

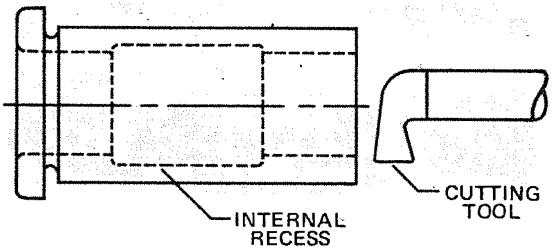


Fig. 8–92. Internal recess and shape of boring tool.

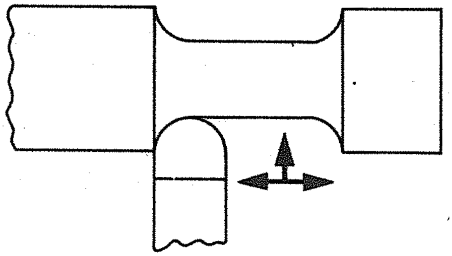


Fig. 8–93. Turning a recess with round corners.

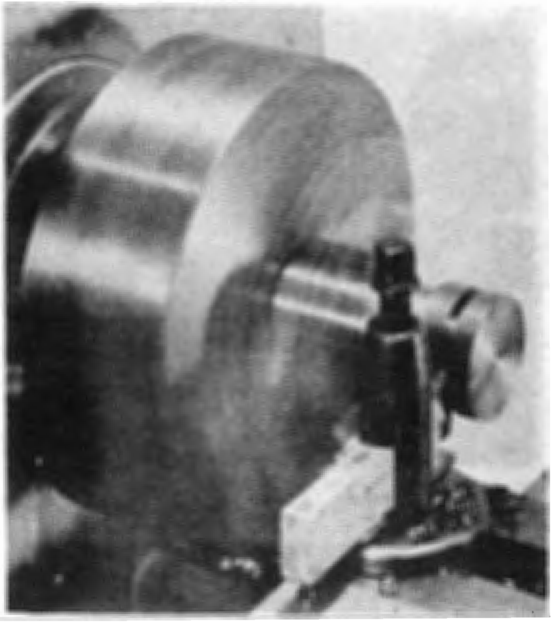


Fig. 8–94. Parting, or cutting-off, operation. (R. K. LeBlond Machine Tool Co.)

Fig. 8–95. A cutoff tool. (Armstrong Bros. Tool Co.)

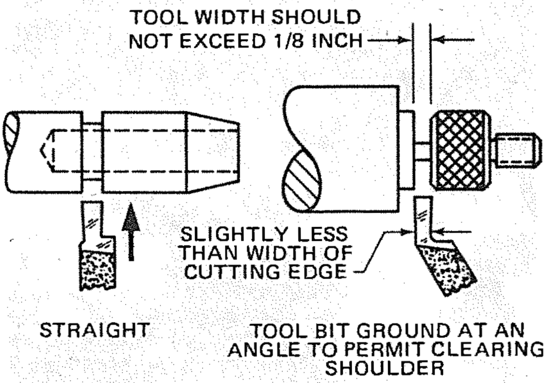


Fig. 8–96. Tool bits can be ground for cutting off small-diameter workpieces after machining.

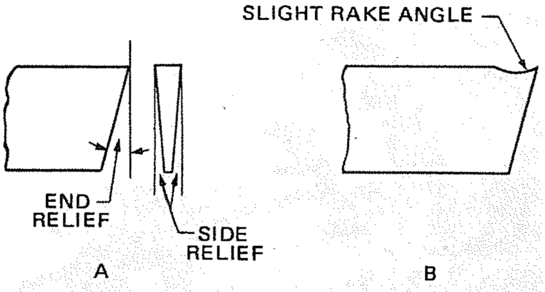


Fig. 8–97. (A) Side-relief angle on parting tool blade prevents binding. (B) Slight back-rake aids the cutting action. (Sheldon Machine Co., Inc.)

90. *What is the procedure for drilling and reaming on a lathe?*
Holes are drilled on a lathe in a manner opposite to the way holes are drilled on a drill press. On a lathe the work revolves and the drill is held stationary. Small sizes of drills are held in a drill chuck of the same design as those used on a drill press. The chuck is held in the tailstock spindle as in Fig. 8–98. Larger drills are held in a drill holder (Fig. 8–99), which is supported by the toolholder on the left side of the handle, and by the dead center of the tailstock on the right side.

caution: Care must be taken to prevent the holder from slipping off the dead center.

When a drill holder is not available, a dog may be used, as in Fig. 8–100. Holes may be reamed by holding a straight-shank reamer in the drill chuck

Fig. 8–98. Setup for drilling a hole.

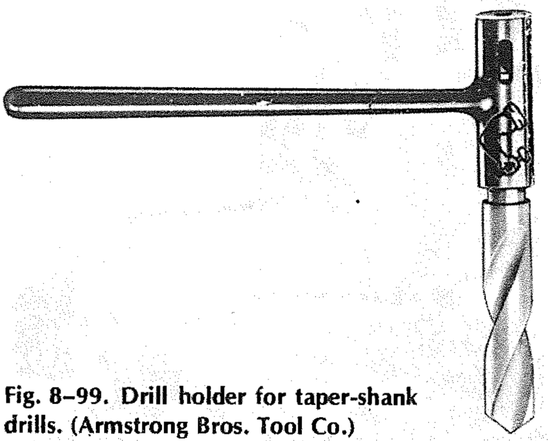


Fig. 8–99. Drill holder for taper-shank drills. (Armstrong Bros. Tool Co.)

Fig. 8–100. Using a lathe dog as a drill holder. (Sheldon Machine Co., Inc.)

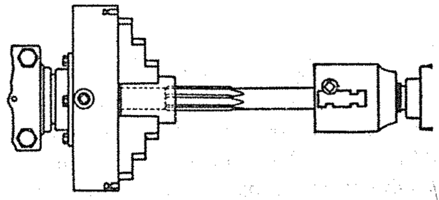


Fig. 8–101. Small straight-shank reamers may be held in a drill chuck. (South Bend Lathe, Inc.)

(Fig. 8–101) or by inserting a taper-shank reamer in the tailstock spindle (Fig. 8–102) and feeding it slowly into the drilled hole. A cutting lubricant should be used when drilling and reaming all metals except cast iron.

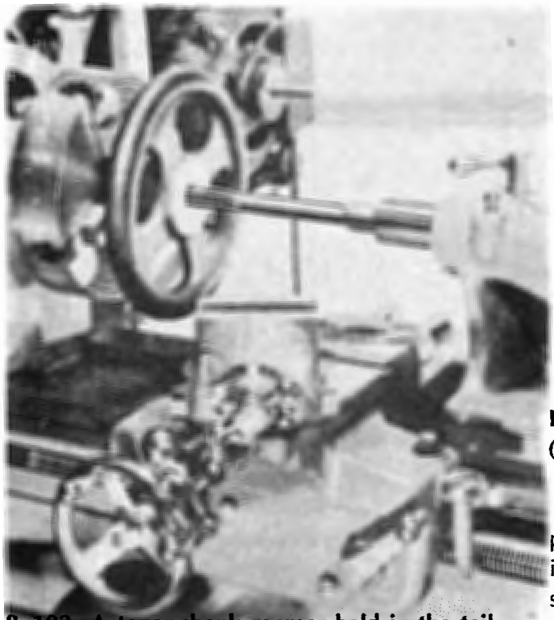


Fig. 8–102. A taper-shank reamer held in the tailstock spindle. (Sheldon Machine Co., Inc.)

Fig. 8–103. Boring with a rigidly held boring bar. (R. K. LeBlond Machine Tool Co.)

91. *What is the operation of boring?*
Boring is the operation of enlarging a hole previously made by drilling, casting, or some other means. Usually a single-point tool is used to remove the stock as it is fed against the revolving work. Holes are bored to make them accurate in size and concentric with the outside surface. Tapered holes may be bored by adjusting the compound slide or the taper attachment in the same manner as for taper turning. An example of boring is shown in Fig. 8–103.

92. *What are some good general rules for boring?*
The operation of boring holes of various diameters and lengths presents special problems requiring good judgment and skill. A good general rule is to use the largest diameter boring bar that will fit into the hole and hold it as short and rigid as possible. Light cuts, together with the right amount of feed, will help reduce chatter and give a better finish. The shape of the cutting tool and the amount of radius at the cutting edge are important factors.

93. *How is filing and polishing done on the lathe?*
A smooth bright finish can be obtained on metal parts by filing and polishing. When filing and polishing is required, the diameter should be left oversize 0.002 or 0.003 in. A smooth mill file or a long-angle lathe file is then used to remove the tool marks. The file should be held at a slight angle, not at right angles, to the workpiece (Fig. 8–104) and gently stroked across and along the workpiece, using little pressure at the start. Too heavy a pressure on the file clogs the teeth and produces a scored finish. Keep the file clean by using a file card and brush as often as necessary. The lathe speed should be fast enough so the work makes several revolutions to one stroke of the file. Too much filing can ruin the accuracy of a workpiece by making it out-of-round. Final polishing can be done by using a strip of fine abrasive cloth under the file. Use a few drops of oil on the abrasive cloth and run the lathe at a fast speed.

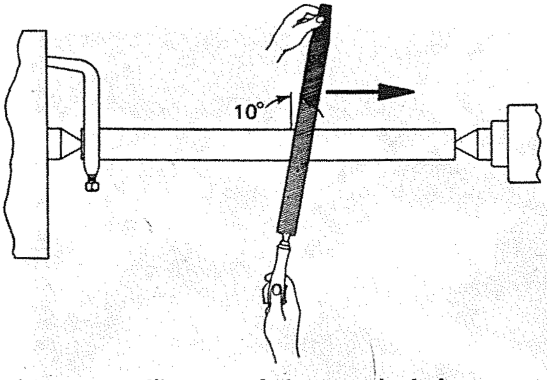


Fig. 8–104. Filing a workpiece on the lathe.

94. *Explain the tailstock offset method of taper turning.*
When a workpiece is placed between the centers of a lathe with the tailstock top out of true alignment, a tapered piece is produced (Fig. 8–105). The amount the tailstock is offset to produce a given taper depends on the overall length of the workpiece and the taper per foot or taper per inch. For a given offset, workpieces of different lengths will be turned with different tapers.

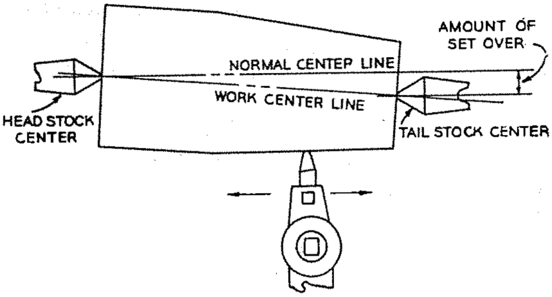


Fig. 8–105. How a taper is formed when the tailstock is offset.

95. *What is a good method of making the offset?*
Assuming the centers are in alignment, the offset may be made as follows:

A. Either clamp the toolholder sideways on the tool post or reverse it so that the body of the tool post can be moved in to touch the extended tailstock spindle (Fig. 8–106), or reverse the toolholder and use the end of the toolholder instead of the tool post.
B. Using the cross-feed screw, feed the tool post in until it is almost touching the tailstock spindle.
C. Turn the cross-feed back just far enough to remove all the backlash.
D. Set the cross-feed graduated dial at zero.
E. Feed in the compound slide until the tool post touches a paper feeler or feeler gage held between the tool post or toolholder and tailstock spindle (Fig. 8–107).
F. Turn the cross-feed out at the required number of thousandths of an inch previously calculated. The space between tool post and tailstock spindle should now equal the amount calculated for the offset.
G. Loosen the tailstock clamp nuts and move the tailstock toward the tool post using the same paper feeler or feeler gage to establish contact (Fig. 8–108).
H. Tighten the tailstock clamp nuts.

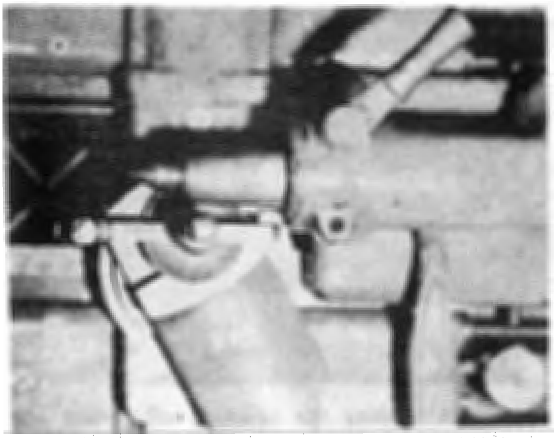


Fig. 8–106. Position of tool post and spindle when preparing to make an offset for taper turning.

Fig. 8–107. Using a paper feeler to tell when contact has been made.

96. *Explain how to use the taper attachment.*
Each end of the swivel guide bar is graduated. One end has graduations in degrees and the opposite end has graduations in inches per foot, with each graduation representing $\frac{1}{16}$-in. taper per foot. (See Fig. 8–42.) When the attachment is set for a given taper and clamped to both the bed and cross-feed slide, the cutting tool will follow the angle, or taper, at which the swivel guide bar is set, thus producing a taper.

A. Loosen the swivel guide bar clamping bolts and set the swivel guide bar to the taper desired.

Fig. 8–108. Moving the tailstock off center and checking for contact with a feeler gage. In this view the end of the toolholder is used instead of the tool post (South Bend Lathe, Inc.)

B. Center the attachment with the workpiece so the slide block will operate near the center of the swivel guide bar rather than near the end.
C. Tighten the bed clamp screw.
D. Tighten the cross-feed clamp lever.

There are two types of taper attachments, a plain type and a telescopic screw type. On the plain type, it is necessary to remove the cross-feed bolt to free the cross-feed screw so the cross slide can move in and out to follow the swivel bar angle. If the lathe is equipped with a telescopic cross-feed screw, the cross-feed screw need not be disconnected when the taper attachment is used.

97. *How should the compound slide be set to turn an external angle having a 60° included angle?*
Adjust and set the compound to a 30° angle from the center line of the lathe (see Fig. 8–52). The compound slide must be set to one-half of the specified included angle and always be parallel to the surface to be machined.

98. *What is the procedure for machining a tapered shank?*
The shank is first machined on a lathe to the required length and to the size of the diameter of the large end of the taper. The lathe is then adjusted to cut a taper according to the specified taper per foot in the case of a standard taper, or according to the number of degrees of taper for special tapers.

The size of the large and small diameters of the tapered shank may be measured with calipers or micrometer, but it is difficult to be sure that the instruments are exactly on the correct spot. A taper ring gage (Fig. 8–109) is used when an accurate test is required of both the diameter and amount of taper.

99. *What is the procedure for machining a tapered hole?*
A hole equal in size to the small diameter of the taper is first drilled or bored to the required depth. For example, a hole for a No. 3 Morse taper would be made 0.778 in. in diameter and 3¼ in. deep (see Table 15 of Appendix). The hole may then be bored to the finished taper size; or finish reamed with a taper reamer after roughing out the taper by boring. Taper reamers are shown in Figs. 8–110 and 8–111. A taper plug gage should be used to check the size (Fig. 8–112).

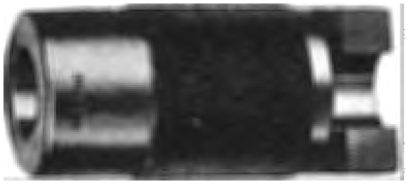


Fig. 8–109. Taper-ring gage. (Morse Twist Drill & Machine Co.)

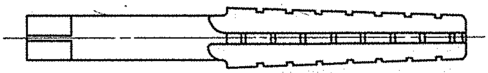
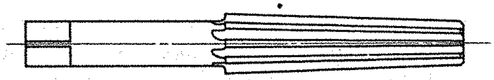


Fig. 8–110. A taper-roughing reamer. (Morse Twist Drill & Machine Co.)

Fig. 8–111. A taper-finishing reamer. (Morse Twist Drill & Machine Co.)



100. *What is the operation of threading?*
External threading is the cutting of threads on the outside of a bar of material. Internal threading is the cutting of threads on the inside of a hole. Special devices such as the quick-change gear mechanism, the lead screw, and thread dial are built into lathes

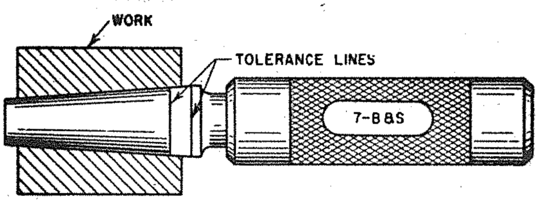


Fig. 8–112. A taper-plug gage is used to check the diameter and the amount of taper.

designed to do this type of work. An example of threading on a lathe is shown in Fig. 8–113.

101. *Explain how tapping may be done on a lathe.* First center drill, then drill the hole to be tapped with the correct-size tap drill. Small holes may be tapped by holding the tap in a T-tap wrench (Fig. 8–114). Support the end of the T-tap wrench with the tailstock center. As the tap wrench is turned with your left hand, feed the tailstock hand-wheel with your right hand. It is not always necessary to clamp the tailstock in position. Leaving it loose prevents applying too much forward pressure on the tap. To remove the tap, leave the tailstock loose and merely back out the tap. For large taps, support the tap with the tailstock center and turn the tap into the hole, using a suitable wrench on the square of the tap. Feed the hand-wheel forward to keep the tap supported. Back the tap and hand-wheel after every turn or two to break the chip. Always use a suitable cutting lubricant. A hole also may be tapped by turning the chuck (Fig. 8–115).

102. *Explain how a threading die can be used to thread a piece in the lathe.*
Adjust the toolholder in the tool post so that it is parallel to the center line of the lathe and set it to the extreme right of the compound slide T slot. Back out the cross-feed as far as possible. Let the handle of the die-stock rest on the toolholder (Fig. 8–116). Set the tailstock as close to the workpiece as possible and clamp it to the bed. Using a slow spindle speed, feed the tailstock spindle against the die with your right hand as you control the lathe spindle movement with your left hand. In this manner, the die will be started straight.

103. *What information is necessary before cutting a screw thread on a lathe?*
Most blueprints specify the following information needed before a screw thread can be cut on a lathe:

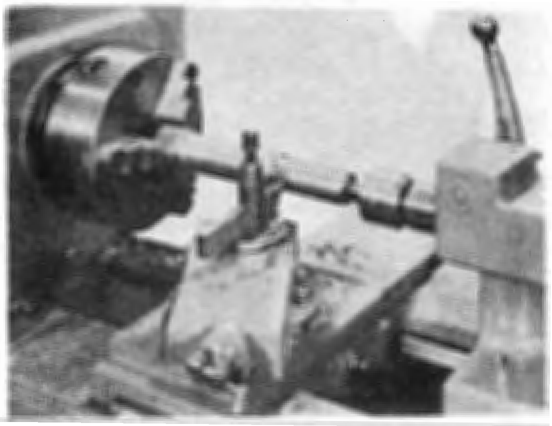


Fig. 8–113. Cutting a screw thread on the lathe. (R. K. LeBlond Machine Tool Co.)

Fig. 8–114. Setup for tapping using a T-tap wrench supported by the tailstock center.

Fig. 8–115. Setup for tapping using an adjustable tap wrench. The chuck is rotated with the left hand while the center is moved in with the right hand.

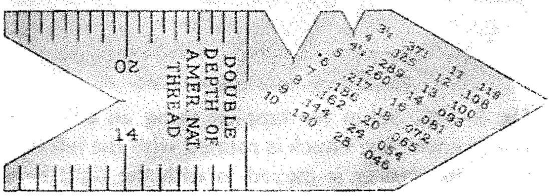
Fig. 8–116. Starting a thread square with a thread die and die-stock.

(a) major diameter; (b) number of threads per inch; (c) form or shape of thread; (d) class of fit required.

For example, a blueprint may specify a ¾-10 NC-3 thread. This means the major diameter is ¾ in. with 10 threads per inch in the National Coarse series and the fit must be a No. 3 fit. From this information a machinist may, if required, calculate such additional information as single or double depth of the thread, the pitch, the lead, and the micrometer measurement if the three-wire system is used for measuring the thread.

104. *What is a center gage, and for what purpose is it used?*
A center gage (Fig. 8–117) is a small, flat, steel tool, which usually has three different-sized 60° included angles cut in it. It is used as a tool-grinding gage and a tool-setting gage when cutting American National and Sharp-V thread forms. It contains graduations for finding or checking the number of threads per inch and a table of double depths of threads. It is also used to check the 60° included angle when regrinding lathe center points.

Fig. 8–117. Center gage. (L. S. Starrett Co.)



05. *What is the purpose of the adjustable stop?*
he adjustable stop (Fig. 8–118) provides a means f preventing the tool from being fed too far into the vorkpiece when the tool is being reset for successive :uts.

106. *What is the purpose of the thread chasing dial?*
On lathes not equipped with a chasing dial, it is necessary to leave the split or half-nut engaged with the lead screw and reverse the lathe spindle or lead screw for each successive cut. The thread-chasing dial (Fig. 8–119) makes it possible to disengage the half-nuts at the end of the cut thread and to run the carriage back to the starting point by hand feed, thus saving much time. When the worm gear at the lower end of the dial is meshed with the lead screw, any movement of the lead screw is shown by a movement of the dial. The graduated lines are used to indicate when the half-nuts may be engaged to start the cutting tool so that it enters the same groove previously cut. The graduation or graduations that may be used depends upon the number of threads and relationship of this number to the number of threads in the lead screw.

107. *When cutting a thread on a lathe, what precaution should be taken to check the setting of the lead screw?*
To insure proper setting of the lead screw, make a very light first cut (Fig. 8–120). The number of threads per inch may then be measured by placing a rule on the work and counting the number of threads in 1 in., ½ in., and so forth (Fig. 8–121), or a scale on a center gage may be used if the threads per inch are the same or a multiple of the graduations used. A screw pitch gage may also be used to count the threads (Fig. 8–122).

108. *Describe the procedure for cutting right-hand external National form threads on a lathe.*
After the workpiece has been set up in the lathe, the procedure for cutting right-hand external National form threads is as follows:

A. Machine the part to be threaded to the major diameter of the thread.
B. Grind a tool bit to fit a center gage accurately (Fig. 8–123). Tool bits may also be ground as shown in Fig. 8–124.
C. Set the compound slide 30° to the right. Some machinists prefer to set it at 29°.

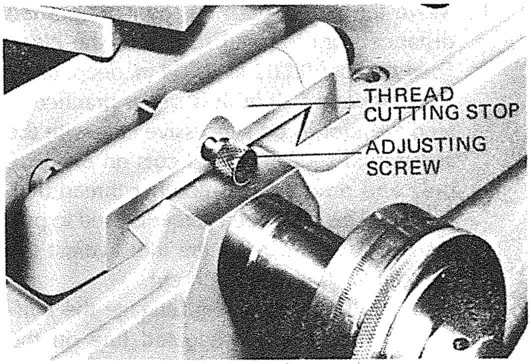


Fig. 8–118. A thread-cutting stop makes it easy to quickly relocate the cutting tool after each pass. (R. K. LeBlond Machine Tool Co.)

Fig. 8–119. Thread chasing dial. (South Bend Lathe, Inc.)

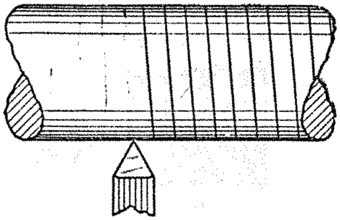


Fig. 8–120. Make the first cut lightly for checking purposes. (South Bend Lathe, Inc.)

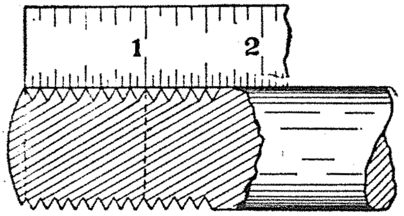


Fig. 8–121. The number of threads per inch may be checked with a steel rule. (South Bend Lathe, Inc.)

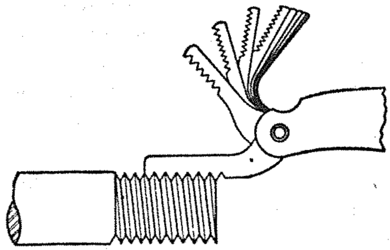


Fig. 8–122. Using a screw-pitch gage to check number of threads per inch. (South Bend Lathe, Inc.)

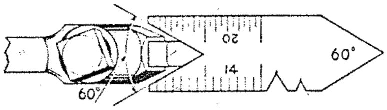


Fig. 8–123. Thread-cutting tool must be ground to fit a center gage very accurately. (South Bend Lathe, Inc.)

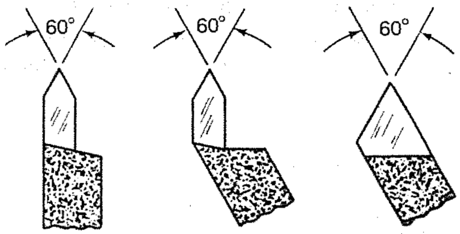


Fig. 8–124. Other ways to grind thread-cutting tool bits.

D. Place the tool bit in the holder and adjust the height by setting it to the point of the tailstock center (Fig. 8–125).

E. Set the tool bit square with the axis of the work, using the center gage (Fig. 8–126). In actual practice, the center gage should not touch the workpiece. It should be held square against the tool bit with a small space between the gage and the work, and the toolholder should be tapped until the gage lines up parallel with the work surface.

F. Gear the lathe for the required number of threads per inch to be cut. Refer to the index plate on the quick-change gear box.

G. Mesh the worm gear of the chasing dial with the lead screw and determine which of the lines are to be used.

H. Start the lathe and touch the cutting tool to the revolving work. Set the graduated dials on the cross-feed and compound slide to zero. (Be sure all backlash is removed.)

I. Most lathes have an adjustable stop to prevent feeding the tool too far into the work on successive cuts. Set the stop at this point (see Fig. 8–118).

J. Move the cutting tool off the work a short distance from the end so it is in the clear. Feed the tool 0.002 to 0.004 in. deep, using the compound slide. It is better practice to feed the tool in on successive cuts with the compound slide. The tool cuts on one side only and produces a smoother thread (Fig. 8–127). The cross-feed screw is used to pull the tool out and reset the tool against the adjustable stop after each cut.

K. With the lathe revolving, engage the half-nuts at the correct graduated line on the chasing dial and make the first cut.

L. Withdraw the cutting tool and disengage the half-nut from the lead screw. Return the carriage to the starting position by hand feed.

M. Check to see that the correct number of threads per inch are being cut, as noted in Question 107.

N. Make successive cuts by feeding the tool in 0.002 or 0.003 in. per cut. Use cutting oil on the tool bit for a smoother thread.

O. When the thread is cut nearly to the correct depth, use a thread ring gage or a nut to

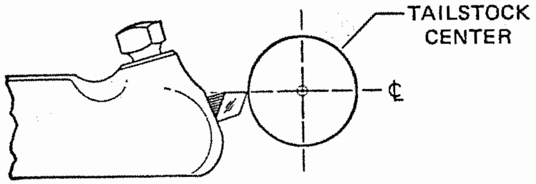


Fig. 8–125. Thread-cutting tool bit must be set at the horizontal center of the workpiece to cut an accurate thread. Use the point of the tailstock center to set proper height. (South Bend Lathe, Inc.)

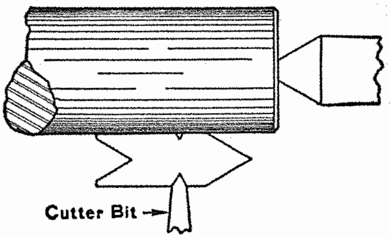


Fig. 8–126. A center gage is used to set cutting tool square with the work. (South Bend Lathe, Inc.)

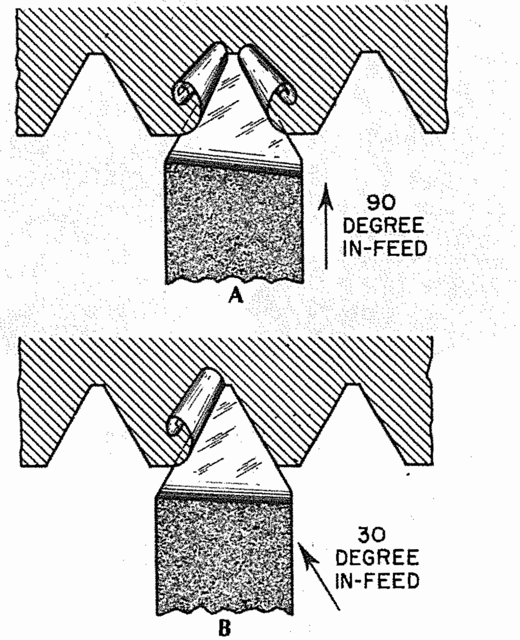


Fig. 8–127. (A) Thread tool fed straight in cuts on both sides. (B) When fed at a 30° angle, tool cuts on one side, producing a smoother thread.

check the fit, depending upon the degree of accuracy required. Precision threads may be measured by the three-wire method. A finished screw thread should have the end chamfered 45°.

109. *Describe the procedure for cutting internal National form threads on a lathe.*
After the workpiece has been set up in the lathe the operations are as follows:

A. Bore the hole to be threaded to the minor diameter of the thread or the blueprint dimension.
B. Select the boring bar to be used. This should be as large in diameter as the hole will permit. Allow space to move the tool out for the return.
C. Grind a tool bit for the boring bar using a center gage for accuracy.
D. Set the tool bit to center height. A surface gage set to the height of the tailstock center point may be used as a gage to set the height of the tool bit (Fig. 8–128). Adjust the compound slide 30° to the left.
E. Set the cutting tool square with the workpiece, using a center gage (Fig. 8–129).
F. Gear the lathe for the required number of threads per inch.
G. Mesh the worm gear of the thread chasing dial with the lead screw.

Fig. 8–128. A surface gage can be used to set thread tool to the center height for internal thread cutting.

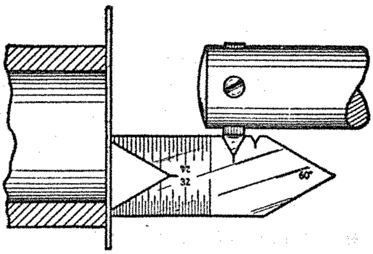


Fig. 8–129. Using a center gage to set the tool bit square for internal thread cutting. (South Bend Lathe, Inc.)

H. Place a pencil mark on the ways of the lathe at the point where the tool or carriage is to be stopped. Because the cutting tool cannot be seen this mark makes it possible to stop the carriage and withdraw the tool at the same place for each of the successive cuts. Some machinists prefer to place a mark on the boring bar to indicate depth.
I. Start the lathe and touch the cutting tool to the revolving work. Set the graduated dials on the cross-feed and compound slide to zero. (Be sure all backlash is removed.)
J. Set the adjustable stop to prevent the tool from being fed outward too far. This will be the opposite of the setting for external threading. Proceed to cut the thread as for an external thread. Use a thread plug gage or a mating part to check the accuracy of the finished thread.

110. *How may the distance be calculated for the depth of thread when using the compound slide set at 30°?*
When cutting a 60° National thread, the distance to feed the compound slide to obtain the correct depth of thread may be calculated by dividing 0.750 by the number of threads, N:

$$\text{Depth to feed tool} = \frac{0.750}{N}$$

111. *When it is necessary to regrind the thread cutting tool during the threading operation, how may the tool be reset to follow the original groove?*
Regrind and set the tool bit square and to center height. With the tool bit clear of the workpiece, start the lathe and engage the half-nut lever to move the

carriage. When the cutting tool is over the threaded portion, stop the lathe. Reset the tool bit into the thread groove by adjusting the compound and cross-feed slides until the tool bit fits perfectly into the groove. Reset the graduated dials to their previous readings.

112. *Are all threads cut right-hand?*
No. Threads are cut right-hand unless otherwise specified. When a left-hand thread is required, it is indicated in the specification. For example, ¾-10 NC-LH thread.

113. *How are left-hand threads cut on a lathe?*
When a *right-hand thread* is cut, the cutting tool travels from right to left. To cut a *left-hand thread,* the lead screw is reversed so that the cutting tool travels from left to right. The lathe is set up in the same manner as for cutting right-hand threads. Some machinists prefer to set the compound slide 30° to the left when cutting left-hand threads.

114. *How should the cutting tool be set to cut a tapered thread?*
The cutting tool should be set square with the axis of the workpiece (Fig. 8–130) and not with the tapered portion.

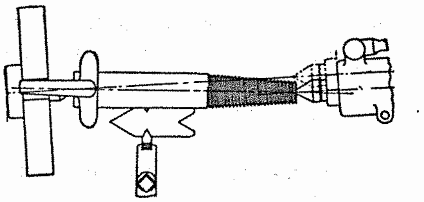


Fig. 8–130. When cutting threads on a taper, set the cutting tool square with the axis of the workpiece. (South Bend Lathe, Inc.)

115. *What are multiple threads?*
When two or more thread grooves are cut around the circumference of a workpiece, they are called multiple screw threads. When two threads are cut, it is called a double thread; three threads are called triple threads, and four threads are called quadruple threads. Multiple threads provide a greater lead while the pitch remains constant. A double thread has a lead equal to twice the pitch; a triple thread has a lead three times the pitch, and so forth. (See chapter 11.)

116. *Describe three methods of cutting a double thread.*
The following examples will show how to cut a double thread with ¼ in. lead and ⅛ in. pitch: Swivel the center line of the compound rest to a line parallel with the dead and live centers. By dividing 1 in. by the lead, which is ¼ in., four single threads per inch will be obtained. Set the lathe to cut four threads per inch. Feed the tool into the work the required depth by using the cross-slide feed. By using the feed screw on the compound rest, on which a graduated collar is attached, move the tool over the length of the pitch and proceed to cut as before.

Another way to do this is to use a faceplate with two equally spaced slots in which to insert the tail of the lathe dog. Do not disturb the dog on the work. Cut the first thread to correct depth. Move the tail of the dog to the opposite slot in the drive plate for cutting the second thread.

Still another way to do this job is to mark two teeth equally spaced on the gear that is attached onto the end of the spindle. After cutting the first groove, disengage the marked gear on the spindle, and turn both spindle and gear one-half a revolution; and then remesh the gears. The second groove may then be cut.

SINGLE-POINT CUTTING TOOLS

Many kinds of cutting tools are used in machine shop work. They can be separated into two distinctive categories: (1) Those with one cutting edge —the single-point cutting tool such as the lathe tool bit; and (2) Those with many cutting edges—the multiple-edge cutting tool such as the milling cutter.

The cutting efficiency of the single-point tool is most often the responsibility of the individual machinist. The success of a machining operation will depend upon the efficiency of the cutting tool. Cutting tool efficiency is judged (1) by the tool's ability to remove material, (2) the quality of the finish of the machined job, and (3) the amount of machining achieved by the cutting tool before regrinding becomes necessary.

Many factors contribute to cutting tool efficiency. Among the most important of these are the following, all of which are the machinist's responsibility.

1. The correctness of the several angles ground on a single-point cutting tool.
2. The shape of the cutting edge that removes the excess material.
3. The smoothness and the keenness of the edge that separates the excess material from the job.
4. The correct selection of the type of cutting tool for the material to be machined; the selection may be made from (a) carbon tool steel, (b) high-speed steel, (c) cast alloy, or (d) cemented carbide.

The first three factors involve the grinding of the cutting tool. Unless the cutting tool is ground to the correct shape with the correct angles and unless it is ground with a keen, smooth cutting edge, time will be wasted, accuracy will be impossible, and a poor finish will result.

Other factors that affect cutting tool efficiency include:

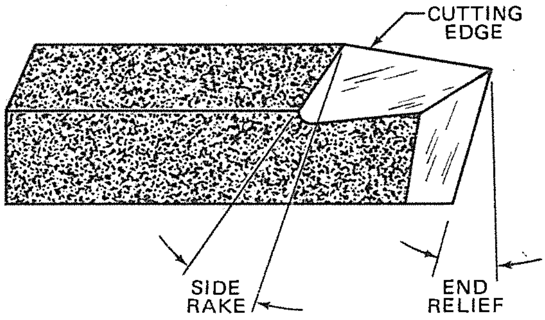
1. The correct speed and feed.
2. The heat treatment given the cutting tool.
3. The correct choice and efficient use of coolants.
4. The shape of the job.
5. The condition of the machine.

117. *What is a single-point cutting tool?*
A single-point cutting tool is a tool with one face and one continuous cutting edge that removes metal from a workpiece being machined in a lathe, planer, shaper, or other machine tool.

118. *Describe several types of single-point cutting tools.*
There are solid-type and tipped single-point cutting tools. The solid type is made entirely of the cutting material; the tipped type consists of a small tip of cutting tool material attached to a steel shank by brazing, welding, or clamping. A tool bit is a piece of cutting tool material, which can easily be clamped in a toolholder. Tool bits can be made entirely of a cutting tool material or they can have tips only, made of cutting tool material brazed to a shank. A tool-bit blank is the material from which a tool bit is made by grinding to shape and size (Fig. 8–131).

Fig. 8–131. A tool-bit blank. (Armstrong Bros. Tool Co.)

Fig. 8–132. A ground tool bit.



119. *How is a tool blank prepared for use?*
It is ground on three surfaces to form one cutting edge. The nose is ground to a radius or a point, depending on the job requirements (Fig. 8–132). After grinding, the surfaces are honed to give a smooth, keen edge.

120. *What are the angles to which the surfaces of a tool bit are ground?*

The angles are shown in Fig. 8–133.

Angle A is the back rake angle.
Angle B is theside rake angle.
Angle C is the end relief angle.
Angle D is the side relief angle.
Angle E is the side cutting-edge angle.
Angle F is the end cutting-edge angle.

121. *How are the angles of a cutting tool measured?*
The unit of measurement is the degree. The measurements for the proper angles for a cutting tool may be estimated. It is more accurate to use a measuring tool such as the steel protractor.

122. *How can the angles of a tool bit be measured with sufficient accuracy?*
Many machinists visualize the angles to which they grind the surfaces of single-point cutting tools, often by comparison with the hands of a clock. For example, the space between the center line of the hands set for one o'clock equals 30°. It is much more reli-

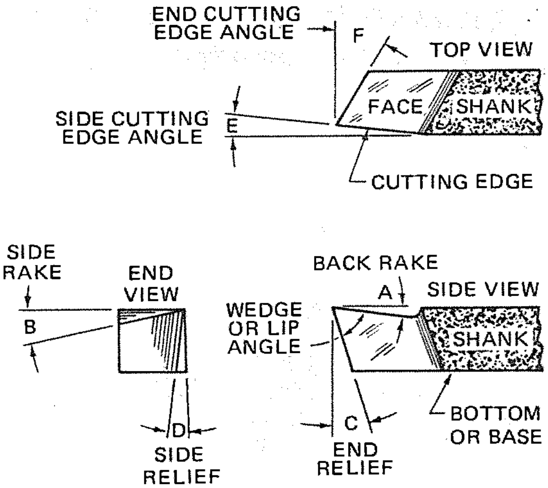


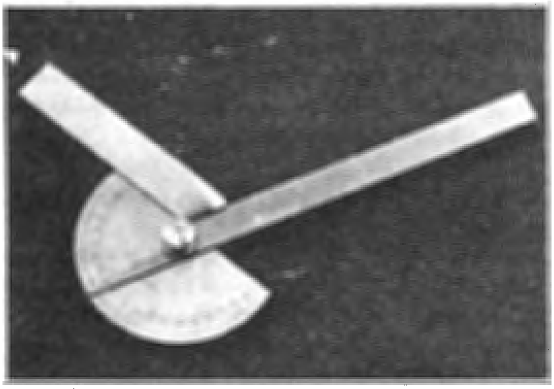
Fig. 8–133. Parts of a tool bit and angles formed by grinding.

able to use an angle protractor. By placing the protractor base on the side of the tool bit and moving the protractor arm to the surface being ground, a true angular measurement can be made (Fig. 8–134).

123. *What is the back rake angle?*
The back rake angle is the angle formed by the top surface of the tool bit and the ground top face of the tool (see Fig. 8–133).

124. *What is the purpose of the back rake angle?*
The purpose of the back rake angle is mainly to guide the direction of the chip flow. It also serves to protect the point of the cutting tool (Fig. 8–135). The size of the angle depends upon the material to be machined; the softer the material, the greater should be the rake angle. Aluminum requires more back rake than cast iron or steel. The back rake can be positive, neutral, or negative (Fig. 8–136). A negative back rake is used for some soft metals to prevent the tool from digging in.

Fig. 8–134. Measuring the end-relief angle of a cutting tool with a protractor.



125. *What is the side rake angle?*
The side rake is the angle formed by grinding the top

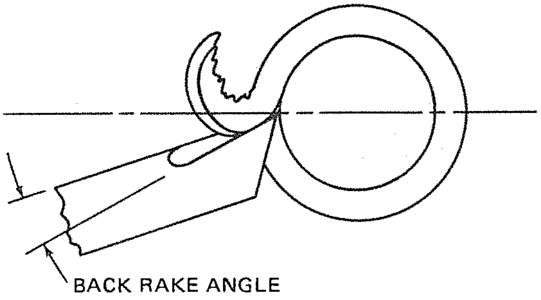


Fig. 8–135. The back-rake angle guides the chip away from the workpiece.

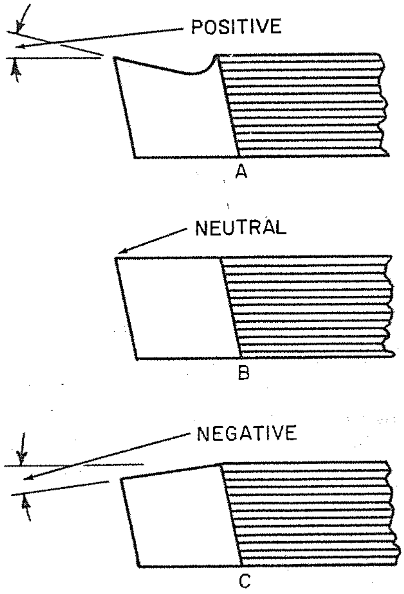


Fig. 8–136. Back-rake angles. (A) Positive. (B) Neutral. (C) Negative.

surface of the tool so that it slopes away from the side cutting edge.

126. *What is the purpose of the side rake angle?*
The side rake angle performs a similar function to that of the back rake angle; it guides the direction of the chip away from the job. It is usually ground from 6° to 15°. Together with the side relief angle it forms the cutting edge so that a shearing action occurs as the tool moves sideways against the material. The amount that a chip is curved depends on the angle of the side rake (Fig. 8–137). The side rake angle determines whether a cutting tool is right-cut or left-cut.

127. *Define a right-cut and a left-cut tool bit.*
A right-cut tool bit is ground to cut from right to left (Fig. 8–138A) or toward the headstock of the lathe. A left-cut tool bit is ground to cut from left to right or toward the tailstock of the lathe (Fig. 8–138B).

128. *What is the side relief angle?*
The side relief angle is that surface of the cutting tool found below the cutting edge.

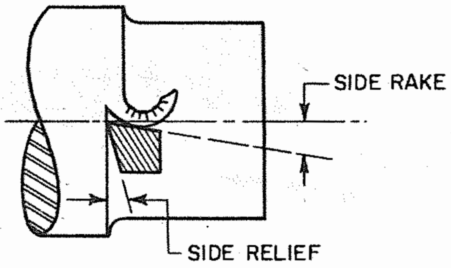


Fig. 8–137. The side-rake angle curls the chip.

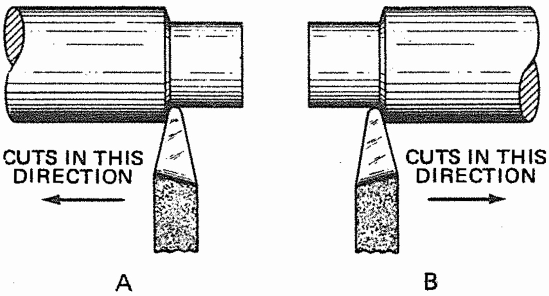


Fig. 8–138. (A) Right-cut tool bit. (B) Left-cut tool bit.

129. *What is the purpose of the side relief angle?*
The side relief angle permits the tool to be fed sideways into the job so that it can cut without rubbing. If this angle is too small, the tool cannot be fed into the job. The tool will rub against the job, become overheated, and blunt. The finish of the job will be rough and furry. If the side relief is too large, the cutting edge will break off into small chips because of insufficient support (Fig. 8–139).

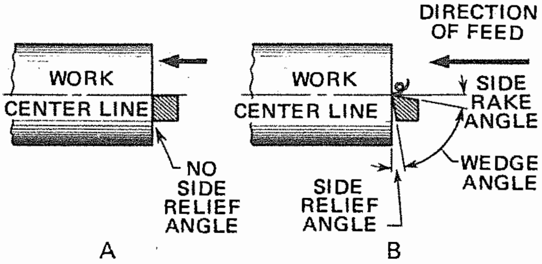


Fig. 8–139. (A) Without side-relief angle a tool cannot cut. (B) With side-relief angle the tool cuts and can be fed into the workpiece.

130. *What is the end relief angle?*
The end relief angle is formed by the front of the cutting tool and an imaginary line drawn at a tangent to the job at right angles to the center line of the lathe (see Fig. 8–133).

131. *What is the purpose of the end relief angle?*
The end relief angle prevents the tool from rubbing against the job. The size of the angle may vary between 8° and 15°. The diameter of the job is one factor that determines the size of the angle. If the angle is too small, the tool will rub on the job, prevent its cutting, and leave a poor finish. If the angle is too large, the point or cutting edge of the tool will be unsupported and break off. Excessive end relief will also cause chatter marks on the finished surface of the job (Fig. 8–140).

132. *What is a chip breaker?*
A chip breaker is a groove that is ground just behind the cutting edge of the tool bit. The groove need not be carried to the extreme edge of the tool. The width of the land between the cutting edge and the groove will depend upon the rate of feed and the type of metal being cut (Fig. 8–141).

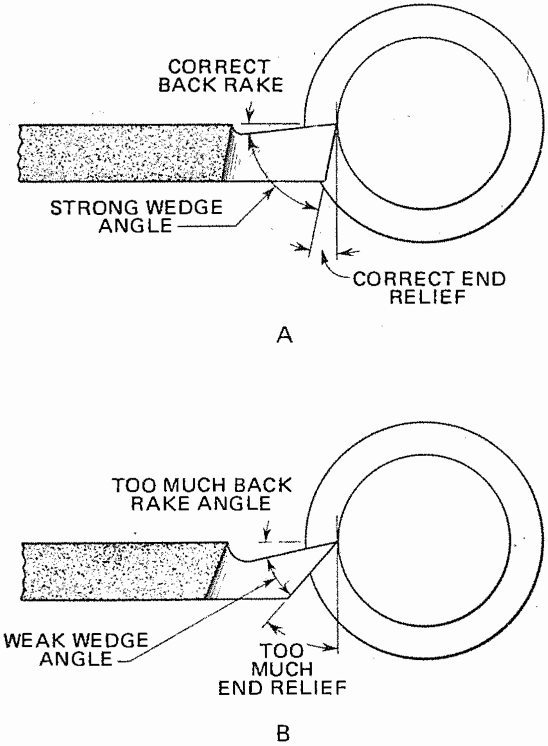
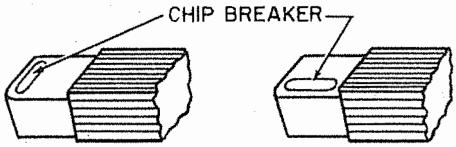


Fig. 8–140. (A) Correct rake and relief angles are necessary for strength and longer tool life. (B) Tools having excessive rake and relief angles break down and cause problems.

Fig. 8–141. Chip breaker keeps the chips small.



133. *What is the purpose of the chip breaker?*
Chip breakers are ground into tool bits in order to control the continuous ribbon-like chips formed at high cutting speeds. Continuous chips are dangerous to the operator. These chips are sharp, hard, and hot. They become entangled around the revolving workpiece, the cutting tool, and moving parts of the machine such as the lathe chuck. The chip breaker acts as an obstruction to the smooth flow of the chip. It causes the chip to break up into short, manageable chips.

134. *How does a cutting-off, or parting, tool differ from other cutting tools?*
A parting tool cuts in one direction only, straight forward into the job. The back rake is kept to a minimum to prevent the tool from digging into the job. End relief is kept at 10°. Parting tool blades are made with a side relief on both sides (see Fig. 8–97).

135. *What is a boring tool?*
A boring tool is a lathe tool used to enlarge the size of holes. The model shown in Fig. 8–142 is used for small lathes and light work. A heavy cut causes this tool to spring away from the job. This results in the back of the hole being smaller in size than the front—a tapered hole. The rake angles and cutting edges of the boring tool are sharpened as are other cutting tools, and for the same reasons. The end relief angle will depend upon the size of the hole to be bored (Fig. 8–143). The boring tools come in several sizes and are held in a special toolholder.

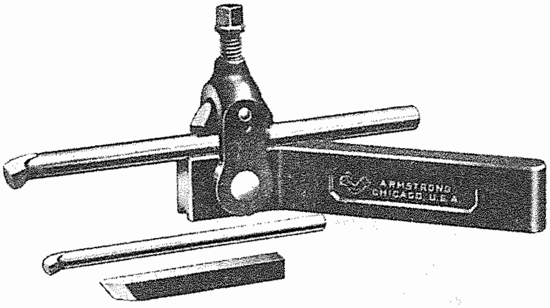


Fig. 8–142. Boring tool and holder. (Armstrong Bros. Tool Co.)

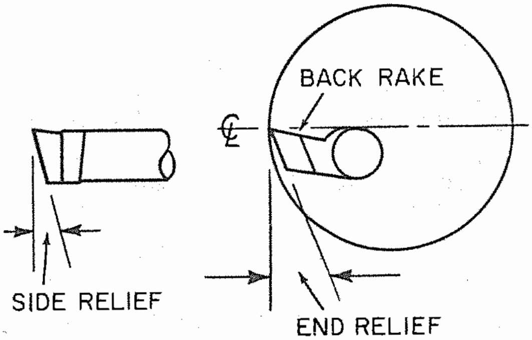


Fig. 8–143. Rake and relief angles for boring tools.

Tool bits are also used for boring. They are held ı boring bars similar to the one shown in Fig. 8–144. 'his style of boring tool is used for heavier and larger vork. It makes possible heavier cuts with faster feeds ınd little possibility of springing away from the job. 'he slots in the boring bar permit the tool bit to be nserted at 45°, 60°, or 90° to the centerline of the ›ar.

!36. *What is the correct shape of a tool bit?*
'he shape of a tool bit will depend upon the work t is required to do. Regardless of the shape of a tool ›it, it must be remembered that every cutting edge nust have a relief angle. The direction in which the ool will be fed into the work must be considered. [he size of the rake and relief angles will depend on he material, the material's size, the amount of the eed, and the depth of the cut. Tool bits can be ʒround to form special shapes (Fig. 8–145). Common ool bit shapes used in lathe work are shown in 'ig. 8–146.

137. *What care must be used when grinding tool ɔits?*
Cutting tools should not be overheated. Excessive ʒrinding heat causes a breakdown of the cutting ɜdge. Overheating can be caused by a loaded grinding wheel, a wheel that is too hard, or by excessive ɔressure applied to the tool bit. A wet grinding wheel is preferred for roughing out the shape of tool bits. When using a dry wheel for finish grinding, the tool should be cooled frequently by dipping in water. If the tool bit is allowed to get overheated, dipping in water will cause small cracks to appear along the cutting edge.

138. *How are rake and relief angles ground on a high-speed steel tool bit?*
High-speed steel tool bits are easily ground on an off-hand tool grinder. The tool-bit blank is held at an angle and moved back and forth across the face of the grinding wheel. The tool rest provides a means of resting the hand or fingers to steady the tool bit. The tool bit should not be moved up and down while grinding. To do so results in many small angles

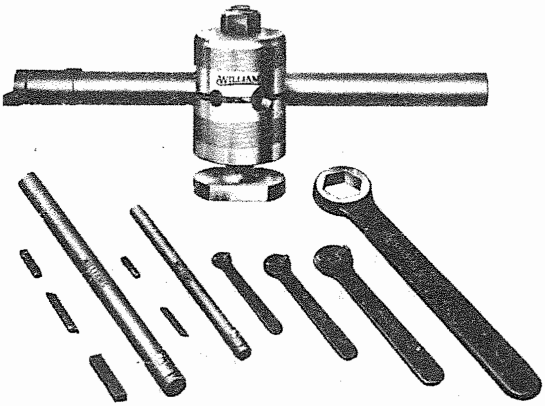


Fig. 8–144. A set of boring bars, tool bits, wrenches, and a holder. (J. H. Williams & Co.)

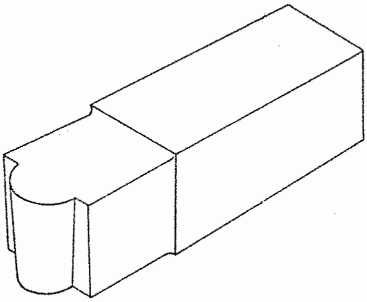


Fig. 8–145. A form tool for cutting a special shape in the workpiece.

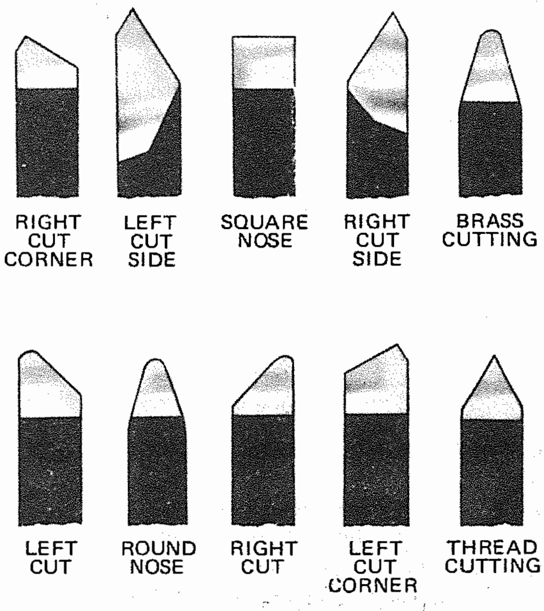


Fig. 8–146. Common tool-bit shapes. (Armstrong Bros. Tool Co.)

or a rounded, unsatisfactory surface. Off-hand tool grinders usually have a coarse-grit grinding wheel and a fine-grit wheel. The coarse wheel should be used to rough out the tool bit, and the fine-grit wheel should be used to finish the tool bit. Figure 8–147 shows the steps and positions for holding the tool-bit blank to grind a round-nose turning tool. Figure 8–148 shows how the tool bit should be held against the grinding wheel to obtain a steady, uniform cutting action. Toolholders for high-speed steel tool bits are made with the slot, or square hole, at an angle of about 20° (Fig. 8–149). This angle provides enough back rake angle for most general work made of steel, so it is unnecessary to grind a back rake angle into the tool bit itself, as shown in Step 5, Fig. 8–147. When turning aluminum or other soft materials, more back rake may be advisable.

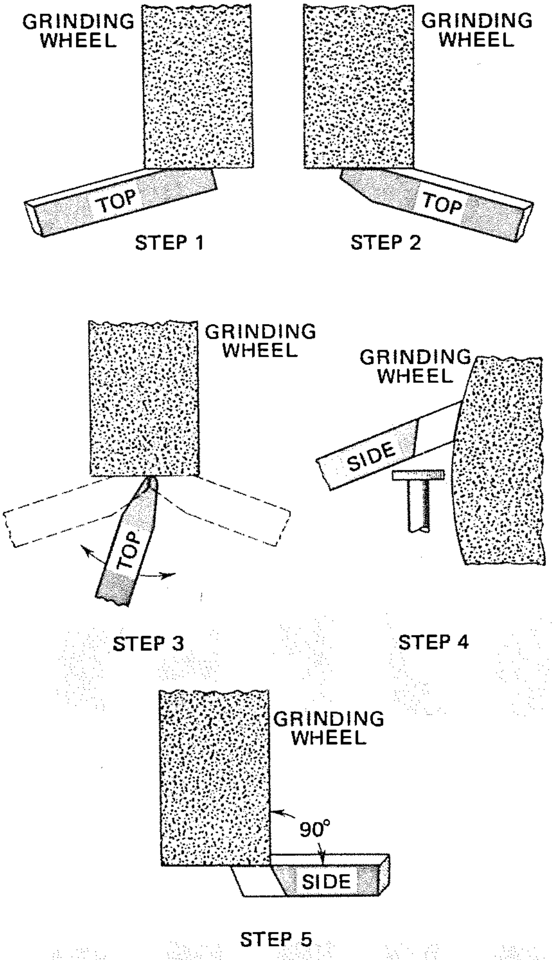


Fig. 8–147. Steps for grinding a right-cut round-nose tool bit.
Step 1. Grind the left side-relief angle.
Step 2. Grind the right side-relief angle.
Step 3. Grind the round nose.
Step 4. Hold tool bit at an angle to get the end-relief angle.
Step 5. Grind the rake angle for a right-cut tool bit.

139. *What is a carbide-tipped tool?*
A carbide-tipped tool has a piece of carbide brazed to the nose of a steel shank. The carbide tip forms the cutting edges (Fig. 8–150). Carbide is a mixture of several different alloys of carbon and metallic elements such as tungsten, titanium, or tantalum. It is exceptionally hard and will maintain a sharp cutting edge under conditions that would cause ordinary cutting tools to burn away. Cemented carbides make possible a tremendous increase in the cutting speeds. Cemented carbide tool bits are avail-

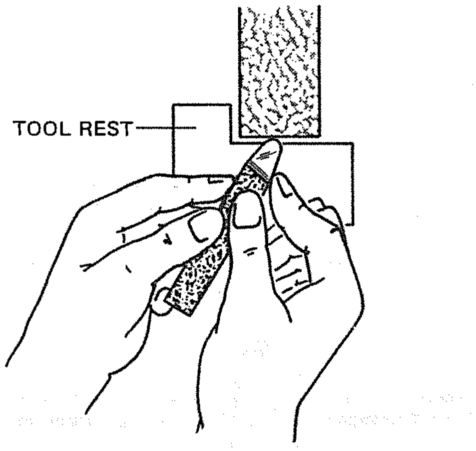
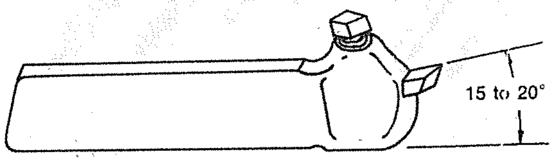


Fig. 8–148. The correct way to grip a tool bit when grinding.

Fig. 8–149. Tool-bit slot in toolholder is made at an angle to provide back-rake to the cutting tool.



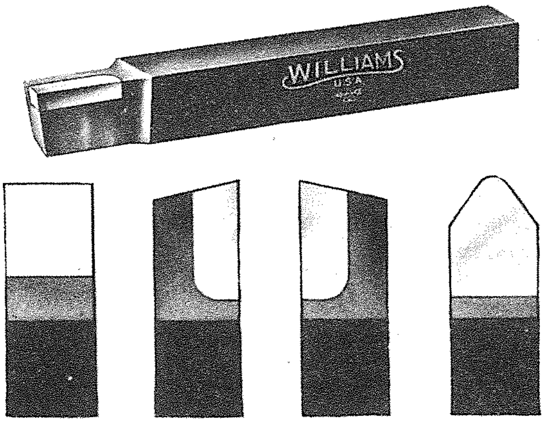
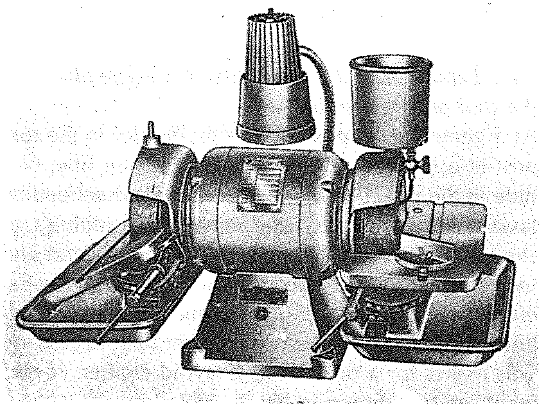


Fig. 8–150. Carbide-tipped tool bits. (J. H. Williams & Co.)

able under several trade names such as Carboloy, Firthrite, and Vascolloy-Ramet.

140. *How are rake and relief angles ground on a cemented carbide tool bit?*
Grinding and sharpening cemented carbide tools requires a grinding machine and grinding wheels different from those used for grinding high-speed steel tools. Grinders for cemented carbide tools are equipped with adjustable tables that can be tilted to the correct rake and relief angles by means of a protractor-type quadrant attached to the table (Fig. 8–151). Carbide tools must be held firmly against a solid base when grinding. A diamond wheel made of small diamond particles produces a very keen, efficient cutting edge; special silicon carbide wheels, which cost less, are often used.

Fig. 8–151. A carbide tool grinder with protractor-type tool rests. (Baldor Electric Co.)



141. *What is the carbide insert method for cutting tools?*
The carbide insert method consists of small tips of carbide held in specially designed toolholders (Fig. 8–152). The inserts are made in regular or special geometric shapes (Fig. 8–153). Each insert has several cutting edges. When the cutting edge becomes dull, worn, or chipped, the insert can be moved to bring a new cutting edge into use. Some toolholders are designed so that inserts can be turned over, making it possible to use both sides of the insert. Although inserts can be resharpened, many shops are not equipped for grinding carbide tools; thus the inserts are thrown away.

142. *What are ceramic cutting tools?*
Ceramic materials such as aluminum oxide are made in the form of inserts similar to carbide inserts and

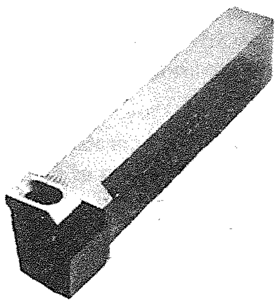


Fig. 8–152. Carbide insert toolholder for heavy duty machining. (Metal Carbides Corp.)

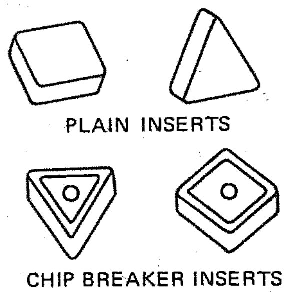


Fig. 8–153. Shapes of carbide cutting-tool inserts.

are held in solid-base, pocket-type toolholders with carbide seats. To cushion the insert from vibration and shock, an aluminum foil shim 0.002 to 0.005 in. thick is sometimes placed under the insert (Fig. 8–154). Ceramic, a very hard material, performs excellently at very high cutting speeds. Because ceramic is more brittle than carbide, the design of the insert, the method of holding the insert, and the rigidity of the machine are important factors for successful machining with this material. Because of the greater wear resistance of ceramic, accuracy of successive workpieces can be controlled to a greater extent than with other cutting tool materials.

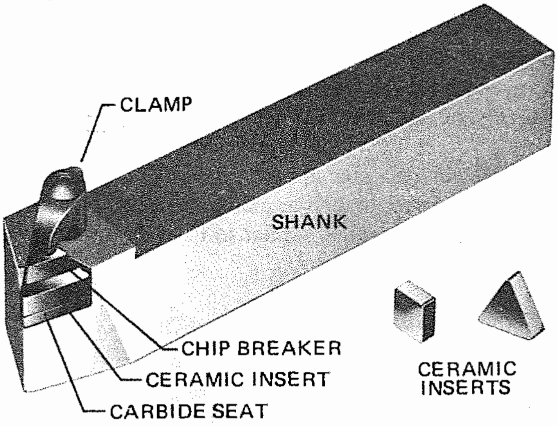


Fig. 8–154. Pocket-type ceramic toolholder and inserts. (V/R Wesson Division of Fansteel)

143. *What is meant by honing a tool bit?*
Honing a tool bit means smoothing the cutting edges with an oilstone. Best results are obtained by holding the stone at 1° to 3° less than the rake, and honing a narrow flat 1/32 in. adjacent to the cutting edge (Fig. 8–155). Use a fine oilstone for high-speed steel and cast alloy tool bits. Use a fine-grit diamond hand hone when honing carbide-tipped tool bits.

144. *What is a diamond hand hone?*
A diamond hand hone is used to smooth the cutting edge of a carbide cutting tool bit. The diamond impregnated pad is mounted on the end of a holder. The holder is from 3/8 to 1/2 in. square and 4 in. long (Fig. 8–156). Some holders support a diamond abrasive pad on each end. The diamond abrasive pad is the width of the holder and approximately 1 in. long. The abrasives come in a variety of grit sizes from 100 (coarse) to 320 (fine).

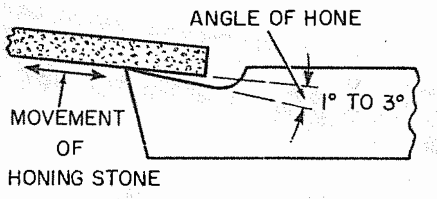
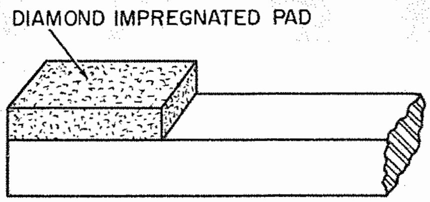


Fig. 8–155. Honing the cutting edge of a single-point tool bit.

Fig. 8–156. Diamond hand hone.



145. *What is a toolholder?*
A toolholder is a device for rigidly holding a cutting tool in a desired position in the tool post of the lathe.

146. *Describe some common toolholders.*
Lathe toolholders are made in several styles, each adaptable to a particular turning operation. The purpose of each toolholder is to make it easier to apply the cutting tool to the workpiece being turned. Figure 8–157 shows some common types of toolholders. Holders for cemented carbide tool bits are similar to holders for high-speed steel tool bits, except for the square slot, which is parallel to the base of the holder (Fig. 8–158).

147. *Explain how the toolholder should be placed in the tool post for turning work.*
As a general rule, position the toolholder in the tool post at approximately 90° with the center line, or a little in the direction of the dead center when feeding toward the headstock. The point of the cutting tool should be on the center line between the dead and live centers and the tool bit should extend just far enough to expose the cutting end. Also, the toolholder should not extend any further than necessary. This makes for a rigid setup to avoid chatter. A very good setup is shown in Fig 8–159.

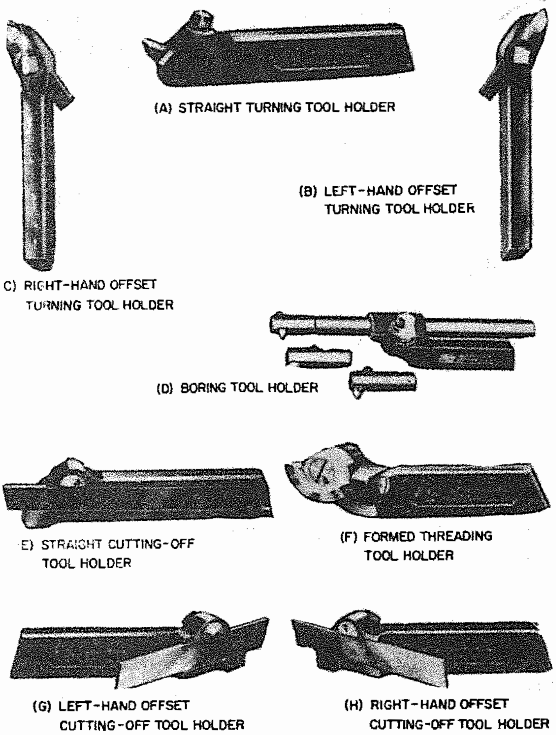
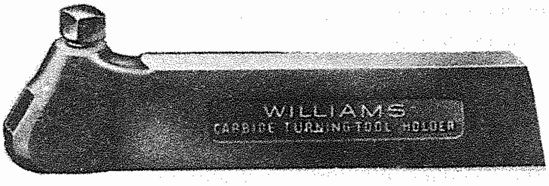


Fig. 8–157. Common toolholders. (Armstrong Bros. Tool Co.)

Fig. 8–158. Straight toolholder for carbide-tipped tool bits has the slot parallel to the base. (J. H. Williams & Co.)



148. *What caution should be taken to position the toolholder when taking a heavy cut?*
When taking a heavy cut, do not have the tool pointing in the direction of the live center. If the tool is pointed in that direction and runs into a hard spot, the material will have a tendency to move the tool away, forcing it to dig into the work (Fig. 8–160). This precaution is unnecessary when taking a light cut.

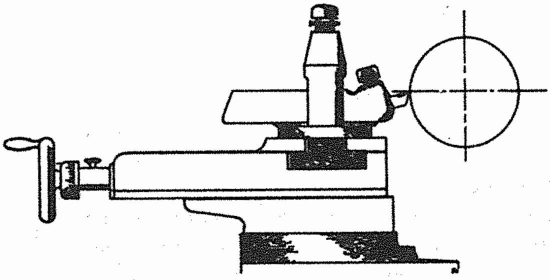
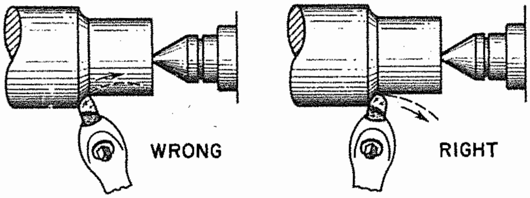


Fig. 8–159. A rigid setup of cutting tool and toolholder in the tool post.

Fig. 8–160. Wrong and right way to position the toolholder for heavy cuts. (South Bend Lathe, Inc.)



149. *Can all materials be machined at the same speed?*
No. The speed with which a material can be machined will depend on its (a) structure, (b) hardness, (c) tensile strength, and (d) abrasive qualities.

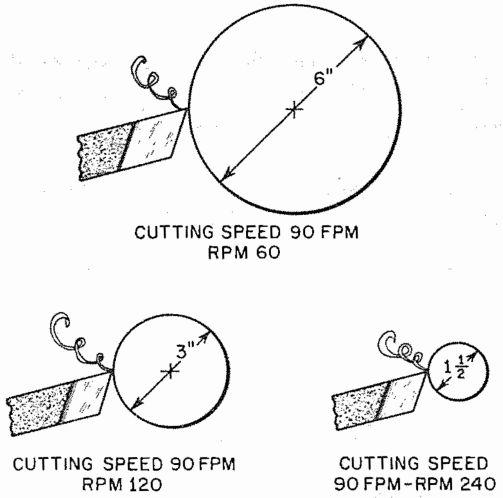
150. *Will the condition of the machine affect the speed of machining?*
Yes. Old machines or machines in poor condition slow down production. Worn bearings and loose slides cause vibrations to develop that spoil the finish of the job.

151. *Can the shape and condition of the cutting tool slow down the machining of metal?*
Yes. A cutting tool ground with the wrong relief and rake angles can spoil the finish and cause breakage and damage to the job.

152. *How can the speed of the machine be safely approximated before starting to cut the material?*
Researchers have established suitable cutting speeds for machining various materials. These speeds are published in handbooks and other technical publi-

cations. Cutting speed is measured in surface feet per minute (sfpm).

153. *Define cutting speed.*
Cutting speed is the rate at which a point on the circumference of the work passes the tool bit. It is measured in surface feet per minute. If the length of the chip removed in one minute could be measured, this number of feet would be the cutting speed. The relationship between diameter, revolutions per minute, and cutting speed is shown in Fig. 8–161.



$$\text{RPM} = \frac{\text{CS} \times 4}{\text{DIA.}}$$

Fig. 8–161. For a given cutting speed the revolutions per minute will vary according to the diameter of the work.

154. *Explain how cutting speed may be calculated.*
When the diameter *(D)* of a workpiece and the revolutions per minute (rpm) are known, the cutting speed *(CS)* may be calculated as follows:

A. Find the circumference by multiplying 3.1416 by the diameter in inches.
   Circumference (in.) $= 3.1416 \times D$
B. Divide the result by 12, to get the circumference in feet.

$$\text{Circumference (ft.)} = \frac{\text{circumference (in.)}}{12}$$

C. Multiply the result by the rpm. The answer is the cutting speed. The three steps can be combined in the following formula:

$$CS = \frac{3.1416 \times D \times \text{rpm}}{12}$$

This formula may be simplified by rounding out some of the intermediate steps:

$$\frac{3.1416}{12} = 0.26$$

or approximately ¼ (0.25). The simplified formula is then

$$CS = \frac{1}{4} \times D \times \text{rpm}$$

155. *Calculate the cutting speed for a 3-in.-diameter workpiece revolving at 120 rpm.*
Using the simplified formula

$$CS = \frac{1}{4} \times 3 \times 120 = \frac{360}{4} = 90 \text{ fpm}$$

156. *What are the recommended cutting speeds for some of the commonly used materials?*
The cutting speeds in feet per minute (fpm) for machining some common materials, using high-speed steel tool bits, are shown in Fig. 8–162.

157. *How is the rpm of a lathe calculated for a given material?*
To calculate the rpm when the cutting speed *(CS)* and the diameter *(D)* of the workpiece is known, the following formula may be used:

$$\text{rpm} = \frac{CS \times 4}{D}$$

158. *Calculate the rpm for machining a cast-iron workpiece 5 in. in diameter.*
From Fig. 8–162, the lowest cutting speed for cast iron is 50 fpm. Using the above formula

$$\text{rpm} = \frac{50 \times 4}{5} = \frac{200}{5} = 40 \text{ rpm}$$

159. *What factors can modify the recommended cutting speeds?*
The recommended cutting speeds are based on ideal machine and job setup conditions as well as correctly shaped cutting tools. Cutting speeds are

material	cutting speed (fpm)
Aluminum	**300–1,000**
Brass, leaded	**300–700**
Brass, red and yellow	**150-300**
Bronze, leaded	**300–700**
Bronze, phosphor	**75–150**
Cast iron	**50–110**
Cast steel	**45–90**
Copper, leaded	**300–700**
Chrome steel	**65–115**
Die castings	**225–350**
Duralumin	**275–400**
Fiber	**200–300**
Machine steel	**115–225**
Malleable iron	**80–130**
Manganese steel	**20–40**
Molybdenum steel	**100–120**
Monel metal	**100–125**
Nickel steel	**85–110**
Plastics hot-set molded	**200–600**
Rubber, hard	**200–300**
Stainless steel	**100–150**
Tool steel	**70–130**
Tungsten steel	**70–130**
Vanadium steel	**85–120**

Fig. 8–162. Recommended average cutting speeds for various materials.

changed to suit the depth of cut and the feed per revolution.

160. *Why should the recommended cutting speed be changed when taking a roughing cut?*
When roughing-out a job, the cut taken is deeper and the feed per revolution is increased. The rpm is reduced in order to maintain the life of the cutting tool.

161. *What is the effect of excessive speed on the life of the cutting tool?*
The friction between the job and the cutting tool creates heat. The hot chip passing over the cutting tool adds more heat. The hardness of the cutting tool is affected by the increased temperature. The keenness of the edge of the tool becomes dulled and its cutting efficiency is reduced.

162. *What can be done to carry away the heat from the cutting tool?*
The temperature of the job, the chip, and the cutting tool is reduced when a stream of liquid is directed as shown in Fig. 8–163.

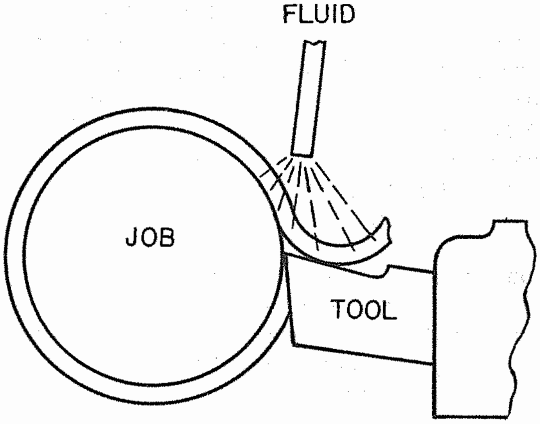


Fig. 8–163. Cutting fluid correctly applied at the point of the cutting action.

163. *Will any liquid give satisfactory cooling results?*
There are several types of coolant liquids called *cutting fluids*. The two most commonly used are (a) water-soluble oils and (b) cutting oils, used undiluted.

164. *What is a water-soluble oil cutting fluid?*
Water-soluble oils are mineral oils to which an emulsifying agent has been added. Water is also added to this mixture to form a milky white fluid, which is referred to by shop men as soapy-water or milky-water.

165. *What is the ratio of water to soluble oil when mixing a soluble oil cutting fluid?*
The ratio of water to soluble oil varies from 4 (water) and 1 (oil) to 80 (water) and 1 (oil). The proportion varies according to the type of oil and the machining operation for which it is being used.

166. *Will the water in a soluble oil cutting fluid cause rust to form on the job or the machine?*
When the cutting fluid is mixed thoroughly, the water and oil are in proper balance, and there will be no evidence of rust.

167. *What other advantages result from the use of cutting fluids?*
Cutting fluids carry off the excessive heat from

the cutting tool, the chip, and the job. The use of cutting fluids will (a) wash the chips away from the cutting tool; (b) increase the effective usefulness of the cutting tool; (c) provide lubrication and reduce friction between the chip and the top surface of the cutting tool; (d) prevent a metallic buildup on the cutting edge of the tool; (e) improve the quality of the surface finish.

168. *What machining operations are benefited by the use of water-soluble fluids?*
Water-soluble cutting fluids are used on (a) lathe work, (b) milling, (c) grinding (all kinds), (d) shaping, (e) planing, (f) power sawing, and (g) drilling.

169. *How do cutting oils differ from water-soluble oils?*
Cutting oils are a mixture of mineral oils with chemical compounds. They are used without dilution, mostly on production work and production-type machines such as automatic screw machines and turret lathes. Cutting oils are used where lubrication between chip and cutting tool is an important factor in maintaining the life of the cutting tool edge.

170. *Will one cutting fluid prove satisfactory for all metals?*
Many different cutting fluids have been developed to meet specialized demands. Some are suitable for ferrous metals such as carbon and alloyed steels; others are most effective when used on copper, brass, bronze, and the wide range of alloyed metals having copper, brass, or bronze as a base.

171. *Is it possible to use water-soluble cutting fluids more than once?*
Yes. The cutting fluid is usually pumped over the cutting area by a small pump. The fluid runs over the tool and job and, after passing through a straining screen, is collected in a storage tank where it is cooled and made ready for reusing. Soluble cutting fluids are also applied by oilcan or brush, but in such applications the fluid is usually not reused.

172. *Can soluble oils be used too often or kept for too long a period?*
Yes. When heavy cuts and severe feeds are being used, high temperatures will result. This can cause the water to evaporate and change the desired oil-water ratio. Normal water evaporation over a long period of time will also change the desired oil-water ratio. Therefore soluble oil cutting fluids should be periodically inspected to insure that the desired oil-water ratio is maintained.

173. *Will the oil in the cutting fluid become rancid after it has been repeatedly used?*
It is possible for bacteria to develop in cutting fluids, and this may cause undesirable odors.

174. *Are cutting fluids injurious to human skin?*
Cutting oils can contribute to skin infection. Some soluble oils have disinfectants added to kill the bacteria and eliminate odors. When an excess amount of disinfectant is added, the soluble oil may irritate the skin.

175. Can *mineral-oil cutting fluids* cause *skin infection?*
Insoluble cutting oils consisting of mineral oil, fatty oil, sulphur, and chlorine are the principal causes of skin irritation and inflamation among shop workers.

176. *How can skin infection from cutting oils be prevented?*
Personal cleanliness is the most important weapon against skin disease. Oil should be kept away from pimples, blackheads, cuts, and other skin eruptions or openings. Wash frequently with hot and cold running water, utilizing a mild, nonirritating soap. Machines and tools should be kept clean and free from dirt and grease. The cutting oil should be changed at least once a week. Overalls and aprons also should be changed often; they should not be permitted to act as a storehouse of oils and grease. Dermatitis can be a serious, painful, and disfiguring disease.

177. *What should be done when skin irritation develops after contact with soluble oils?*
All skin irritations should be medically treated as soon as they are observed. The advice of the family doctor should be obtained immediately.

178. *What is mist cooling?*
A heavy flow of cutting fluid is not always necessary to keep a job and cutting tool from overheating. On jobs where a small amount of metal is being removed, the temperature is kept down by spraying a cloudlike mist of compressed air and atomized fluid on the job and cutting tool.

CARE OF THE LATHE

The lathe is designed to produce machined parts to a high degree of accuracy. The working parts of a lathe are machined, ground, lapped, polished, and scraped to fine precision tolerances. They require attention; they must be kept clean and well lubricated.

179. *How often should a lathe be oiled?*
The answer will depend upon the length of time that the lathe is used. When in use, the headstock bearings must be oiled daily. The following lathe parts should also be oiled every day: the bearings and gears, from the spindle to the lead screw; the motor bearings, the tailstock spindle, lead screw, and feed rod bearings; and the apron and saddle, with cross-feed and compound slides (Fig. 8–164). Many of the parts have oil fittings with spring caps.

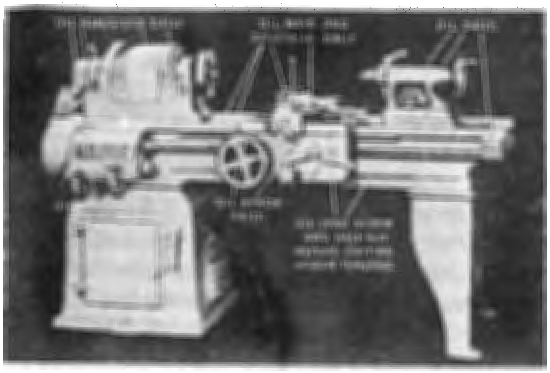


Fig. 8–164. Parts of the lathe that require frequent oiling. (South Bend Lathe, Inc.)

180. *What is the correct procedure in oiling a lathe?*
STOP THE LATHE. Beginning at the headstock end, oil the gear train and bearings from spindle to feed gear box (Fig. 8–165). Proceed systematically along the length of the lathe to the tailstock handwheel. Wipe off all oil drippings.

181. *How often should the bed-dovetails and ways be lubricated?*
This will depend upon what type of metal is being machined. The bed should be lubricated at least once every eight-hour day or eight-hour work shift.

182. *What is the correct procedure for lubricating the ways of the lathe bed?*

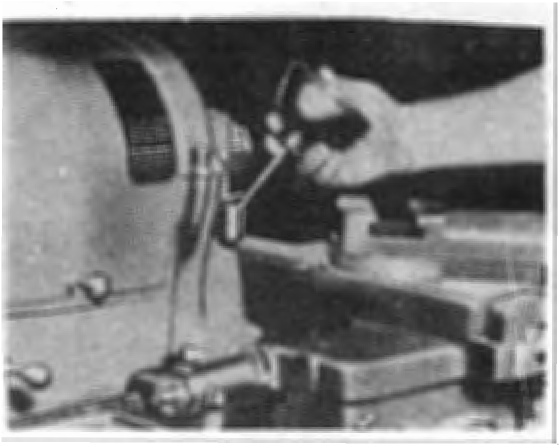


Fig. 8–165. Headstock bearings must have oil at all times. Make this a starting point for daily oiling. (South Bend Lathe, Inc.)

Leave the carriage in position and wipe the ways clean to both the left and the right of the carriage; oil the ways. Then move the carriage, wipe, and lubricate the rest of the bed ways.

183. *Is the same procedure followed when lubricating the dovetails of the cross slide and compound slide?*
It is always good practice to wipe clean the machined surfaces (such as the ways of the lathe and the dovetail slide of a compound rest) *and* lubricate them before moving the surfaces that are in contact with them.

184. *How are the ways of a lathe lubricated and kept free of chips when the lathe is being operated?*
Felt oil pads at each end of the apron clean off the chips and lubricate the ways. The felt pads should be removed and washed in kerosene periodically.

185. *What causes the deep marks often seen on the bed ways of a lathe?*
The ways of the lathe can be scored by small steel chips becoming imbedded in the saddle or the base of the tailstock. All grit and chips should be removed and the bed ways lubricated before the saddle or tailstock is moved along the ways (Fig. 8–166).

186. *What other bad practice spoils the surface condition and accuracy of the bed ways?*
The careless habit of placing tools on the bed ways

Fig. 8–166. Spread a thin film of oil over the ways using your finger. (South Bend Lathe, Inc.)

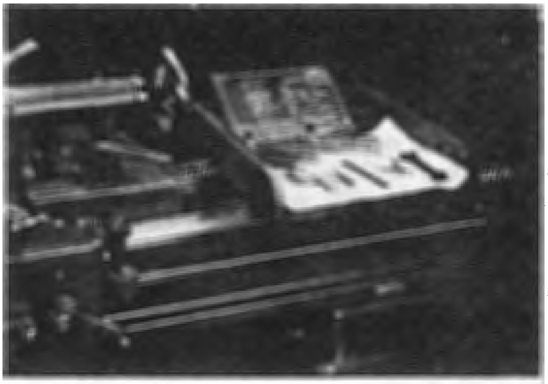


Fig. 8–168. A tool board protects the lathe and provides a place for the neat arrangement of tools needed for the job. (South Bend Lathe, Inc.)

raises burrs that affect the smooth action and accuracy of the saddle and the tailstock (Fig. 8–167). Such burrs should be removed with a scraper or oilstone. Always place tools on a board provided for this purpose (Fig. 8–168).

187. *What other important parts of the lathe require daily lubrication?*
The bearings, threads, and keyway of the lead screw and feed rod are important. The threads of the lead screw should be periodically oiled during the operation of thread cutting.

188. *Is there a way to clean the chips from the lead screw without injuring the threads?*
The best way to clean the threads on a lead screw is to take one turn around the thread of the lead screw with a piece of heavy string (Fig. 8–169). Start at one end and pull the ends of the string back and forth as the lead screw revolves.

Fig. 8–167. Only a careless worker would place tools on the lathe like this.

189. *Should the lathe operator oil the motor of the lathe?*
This will depend upon the type of motor and the practice of the shop. Lubrication instructions are usually given on a plate attached to the motor frame. Observe the type of bearing; this will indicate how the motor should be lubricated. Do not flood the bearings with oil; this will damage the brushes, windings, and the commutator of the motor (Fig. 8–170).

190. *Why is it important to close the covers and replace the oil plugs after lubricating?*
The plugs and covers prevent dust and chips from entering the oil hole. Dust and chips ruin bearings.

191. *What special care should be given to the spindle nose?*
The spindle nose should be wiped clean and lubricated before a chuck or faceplate is mounted. (Fig. 8–171). If the spindle nose is threaded, the threads should be examined closely for small chips before and after it has been wiped and lubricated. The same care should be given the chuck and faceplate threads. An undiscovered chip can result in the run-out of the job. Use a spring thread cleaner (Fig. 8–172).

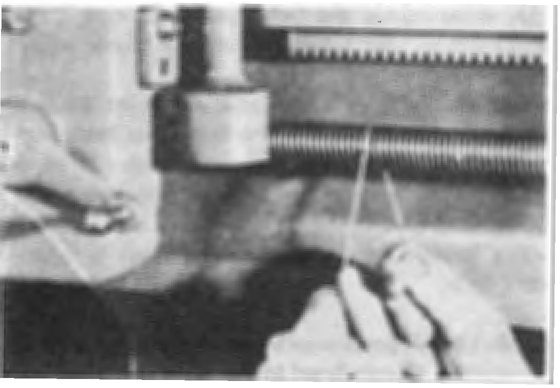


Fig. 8–169. A good way to clean the lead-screw threads. (South Bend Lathe, Inc.)

Fig. 8–171. Apply a few drops of oil to the spindle threads. (South Bend Lathe, Inc.)

Fig. 8–170. Oiling the motor and countershaft is important too.

Fig. 8–172. Cleaning the threads in a chuck with a spring-thread cleaner. (South Bend Lathe, Inc.)

192. *How should the internal taper of the spindle be cleaned?*
A piece of cloth wrapped around a stick and inserted in the headstock spindle hole will clean out all chips except those that have been permitted to embed themselves in the surface of the taper (Fig. 8–173). Embedded chips can be removed with a three-square scraper.

193. *How can a chip become embedded in the surface of internal spindle taper; how can this be prevented?*
If a chip remains in the tapered hole, and the taper shank of a drill or other taper-shank tool is driven home (set in tightly), the chip will become embedded in the surface of the taper hole. Any taper-shank tool placed in the spindle hole will be out of true, and accuracy will be affected. After wiping out the tapered spindle hole, check by using your finger to make certain no chips remain. *The lathe must be stopped while the spindle hole is being cleaned.*

194. *What causes the lathe spindle to slow down or sometimes stall when the tool bit begins to cut the metal?*
When the lathe spindle slows down or stalls as the tool bit begins to cut, the belt is probably slipping on the pulley. Slippage may be due to oil or grease on the belt or the belt may have stretched. Grease and oil may be removed from a leather belt with a solvent. Adjustments may be made to tighten loose belts.

Fig. 8–173. A good way to clean the taper hole in the spindle. (South Bend Lathe, Inc.)

chapter 9 turret lathes

The turret lathe is an adaptation of the engine lathe. As interchangeable manufacturing and mass-production principles were developed, it became necessary to create machine tools capable of producing parts in large quantities. The first turret lathe consisted of a simple metal turning lathe to which a turret was added in place of the tailstock. The turret made it possible to hold a number of cutting tools and to index them into position as needed. Once the cutting tools were set up in the turret, identical parts could be machined in large quantities. Throughout American industry, turret lathes play a very important part in the mass production of parts.

1. *What are the various types of turret lathes?*
Turret lathes can be classified into two main groups: horizontal and vertical. There are many types and sizes of turret lathes in each group. The commonly used horizontal turret lathes include the ram type, saddle type, and the automatic chucking machine.

2. *What is a ram-type turret lathe?*
A ram-type turret lathe (Fig. 9–1) has the indexing hexagonal turret mounted on a ram slide. The saddle, which guides the ram slide, is clamped to the bed (or ways) of the machine. The saddle guide, which may be moved to position the saddle when setting up the machine, is always clamped in one position for any particular job. The indexing of the turret is hand operated by means of the turnstile rack and pinion. One of the limitations of the ram-type machine lies in the length of the movement of the ram, which varies from 4 to 15 in., depending on the size of the machine. The larger ram-type turret lathes can handle bar stock up to 2½ in. diameter and accommodate chucks up to 20 in. diameter.

3. *What is a saddle-type turret lathe?*
A saddle-type turret lathe (Fig. 9–2) has the turret mounted on a saddle that travels on the ways of the lathe. The saddle is equipped with an apron and gear box to provide power feeds. A large feed wheel is used for hand feeding. This type of turret lathe provides a more rigid mounting for the turret. It can make long turning and boring cuts.

Saddle-type machines are classified as (a) fixed-center turret machine, (b) cross-sliding hexagonal turret machine, and (c) compound cross-slide machine. The fixed-center turret machine is one in which the turret remains in a fixed alignment with the true center line, or axis, of the headstock spindle.

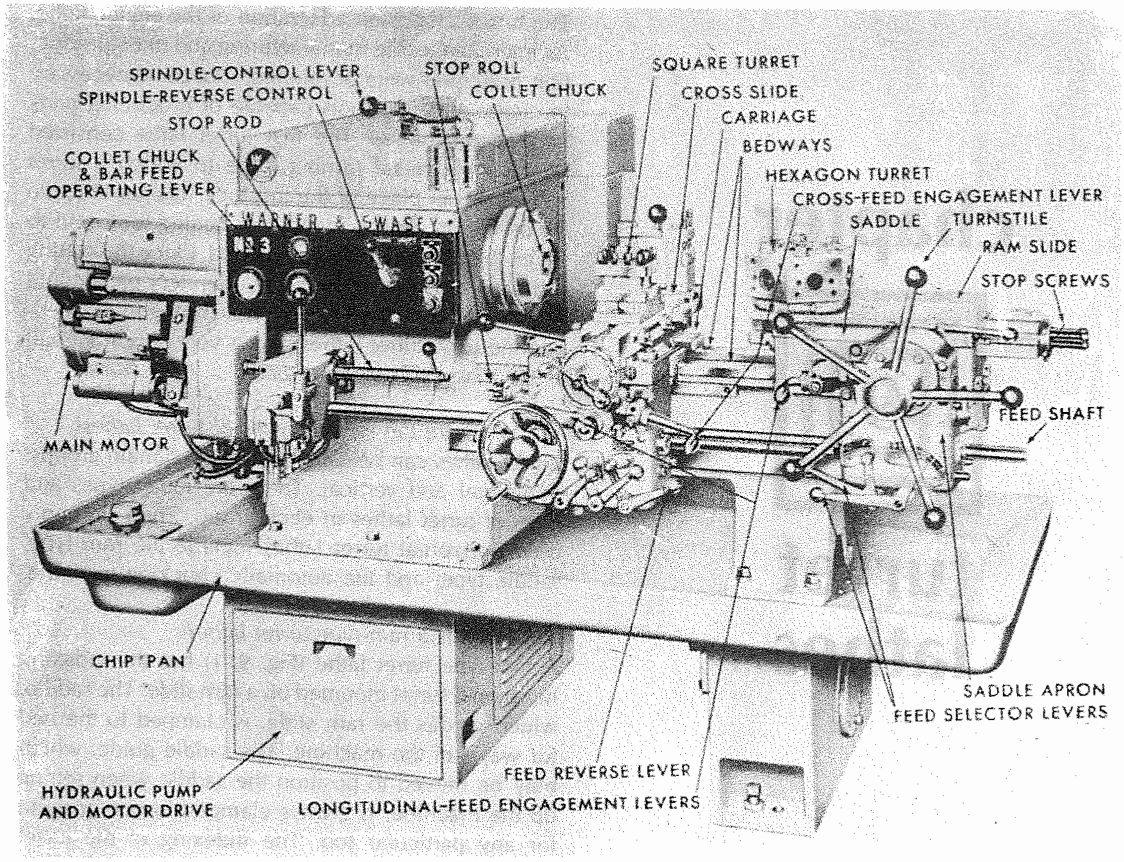


Fig. 9–1. Principal parts of a ram-type turret lathe. (Warner & Swasey Co.)

The cross-sliding hexagonal turret has power and hand feed across the bed as well as lengthwise. It is principally used for work in which numerous facing cuts are necessary when the turning and boring cuts are not of major importance. Internal tapers, threads, and contours can also be cut. The compound cross-slide machine is used for turning angles and for tapers having greater angles than can be turned with a taper attachment. Multiple cuts can be made by using both cross-slide tools and saddle tools, which saves much time and cost (Fig. 9–3).

3. *What are the principal parts of a horizontal turret lathe?*

The horizontal turret lathe consists of four major assemblies: (a) the bed, (b) the headstock, (c) the carriage and (d) the turret. Each of the major assemblies contains a number of principal parts such as those shown in Figs. 9–1 and 9–2. One of the first requirements for understanding the operation of this machine is that the operator know the names and functions of its principal parts.

4. *Describe the bed.*

The bed is a long, boxlike casting fitted with rectangular ways upon which are mounted the carriage and turret. It also supports the headstock.

5. *What is the headstock?*

The headstock is a large casting located on the left end of the bed. It houses the transmission mechanism (see Fig. 9–1), which operates the spindle at various speeds. These speeds are controlled by the built-in speed selector.

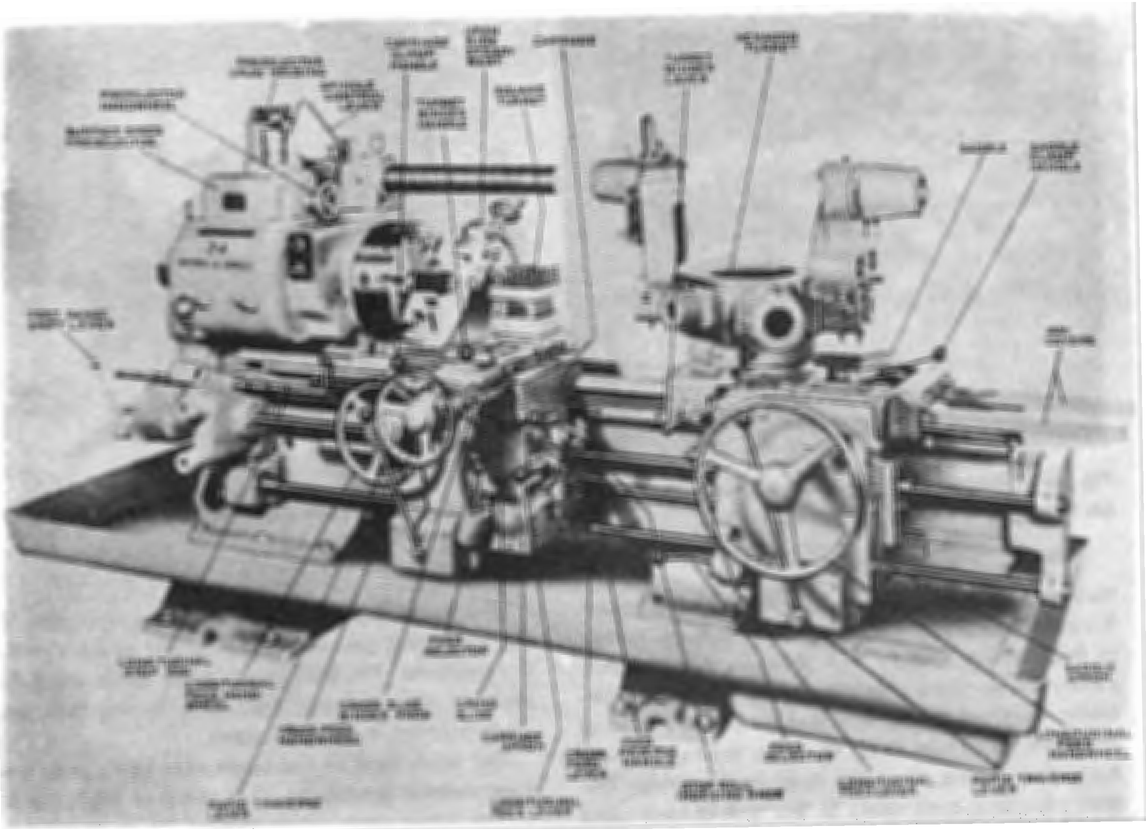
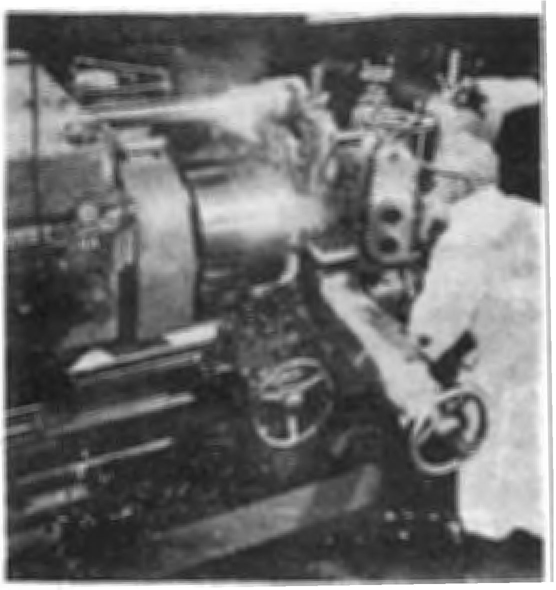


Fig. 9–2. Principal parts of a saddle-type turret lathe. (Warner & Swasey Co.)

Fig. 9–3. Multiple cuts using both cross-slide and saddle tools at same time. (Warner & Swasey Co.)



6. *What is the carriage?*
The carriage (see Fig. 9–1) is a unit that is fitted over the ways of the bed. Mounted upon it is the tool post. The front of the carriage includes the apron, which contains the feed mechanism. The carriage has reversible power longitudinal-feeds ranging from 0.005 to 0.176 in. and also reversible power cross-feeds ranging from 0.002 to 0.088 in. per revolution of the spindle. Most models have longitudinal- and cross-feed positive stops, which act to disengage the feed according to the specifications of the work.

7. *What is the turret?*
The turret (Fig. 9–4) is a hexagon-shaped toolholder

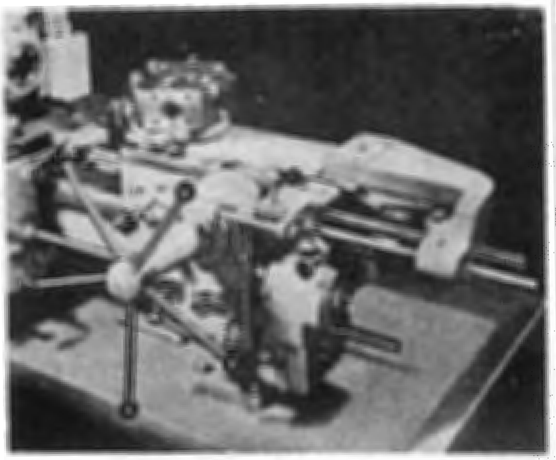


Fig. 9–4. Turret unit with leading-on attachment on the right. (Warner & Swasey Co.)

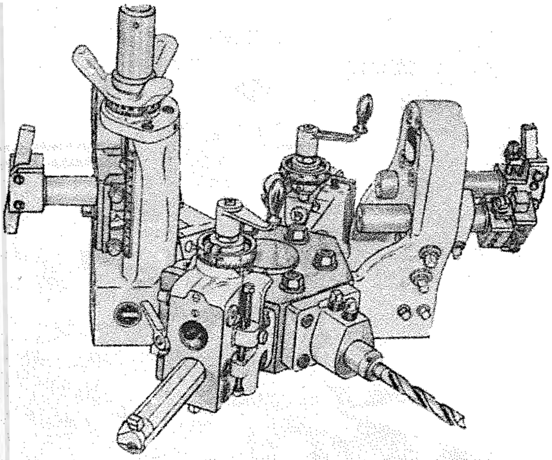


Fig. 9–6. Turret with a variety of tools for bar work. (Warner & Swasey Co.)

mounted on a saddle that slides on the bed ways. It has power longitudinal- and cross-feeds similar to the carriage. Figure 9–5 shows a turret with a variety of standard chucking tools. These are specially designed to be attached to the six sides of the turret. Different kinds of drills, reamers, boring bars, and cutting tools are held in the turret. The term *chucking tools* refers to the type of tools used for machining workpieces best held in a chuck.

Figure 9–6 shows a turret with a standard set of bar tools. It may be seen that these tools are also held by holders that have been purposely made to fit the turret. Tools of this kind are used for machining round bars of steel or other material.

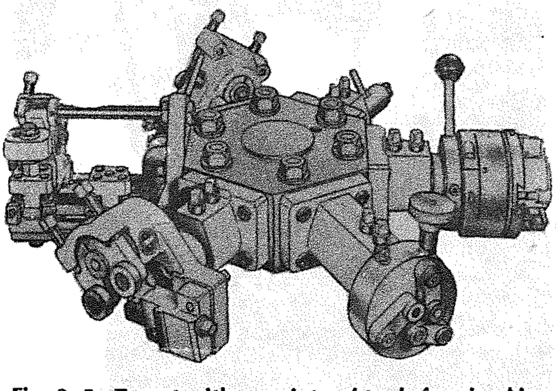


Fig. 9–5. Turret with a variety of tools for chucking work. (Warner & Swasey Co.)

The turret rotates on a hardened, ground-and-lapped center pin. It may be locked in each of the six positions. The tools used in the turret are drills, reamers, counterbores, taps, dies, boring bars, and many forming tools and cutters.

The tools held in the turret may be used to perform certain operations on a piece of work, while, at the same time, other tools held in the square tool post mounted on the carriage do other operations. A selection of universal tooling equipment for bar work, with an identification of each one, is shown in Fig. 9–7. A selection of universal chucking tools, with their identifications, is shown in Fig. 9–8.

A permanent setup of universal tooling equipment can be arranged so that the large, heavy tools of the flanged type are permanently mounted in their logical order on the machine. If necessary for

Fig. 9–7. Universal tooling equipment for bar work. (Warner & Swasey Co.)

1. Single cutter turner

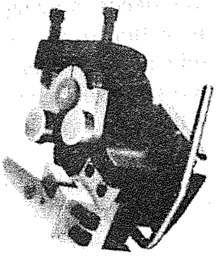
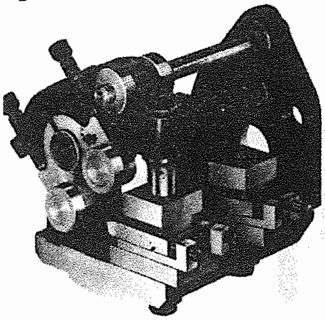
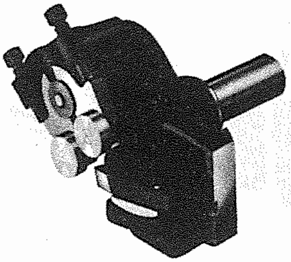
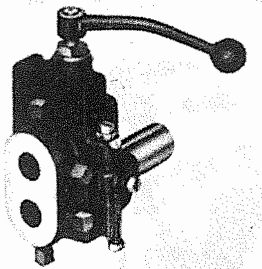
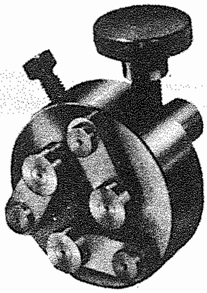


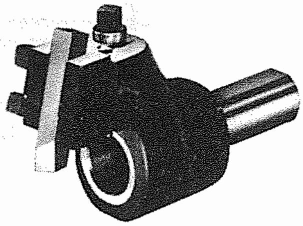
Fig. 9–7 (cont.).

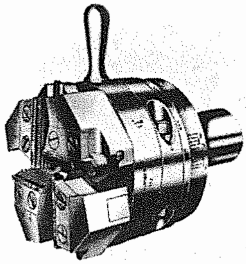

2. Multiple cutter turner

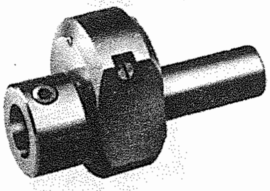

3. Combination end face and turner

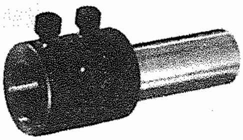

4. Quick-acting slide tool

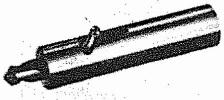

5. Center drilling tool

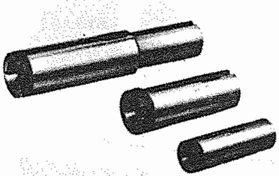

6. Adjustable knee tool

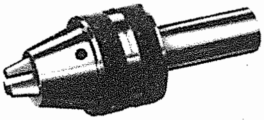

7. Die head

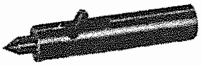

8. Clutch tap and die holder

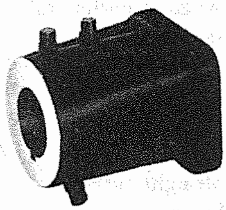

9. Floating toolholder


10. Combination stock stop and starting drill


11. Taper-shank-drill sockets


12. Drill chuck


13. Combination stock stop and center


14. Flanged toolholder

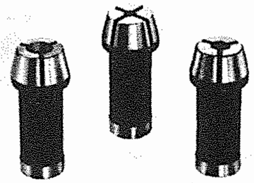
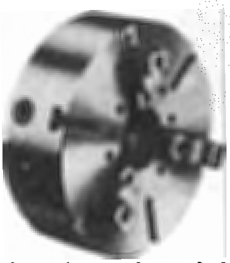
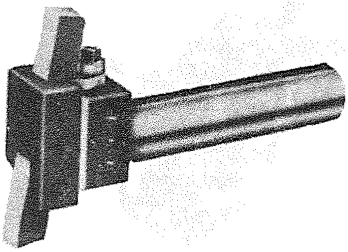

15. Collets

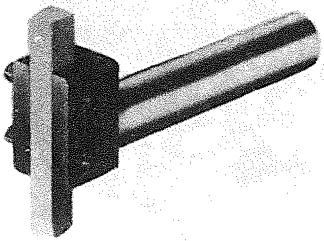
Fig. 9-8. Universal chucking tools. (Warner & Swasey Co.)



1. Three-jaw universal chuck

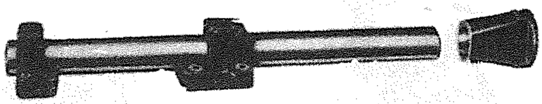


2. Reversible adjustable angle-cutter holder

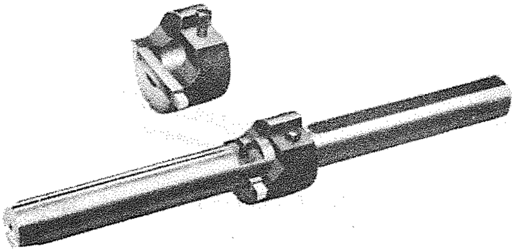


3. Reversible straight cutter holder

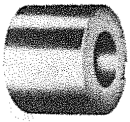
4. Flanged toolholder



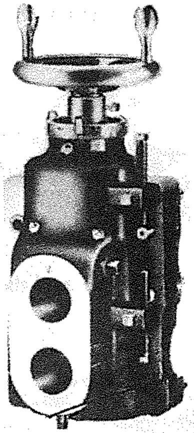
5. Stationary overhead pilot bar and pilot sleeve



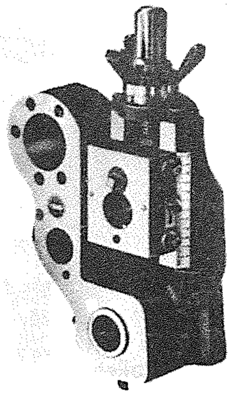
6. Piloted boring bar



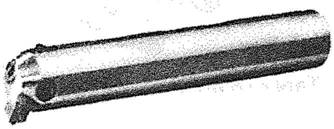
7. Spindle pilot bushing



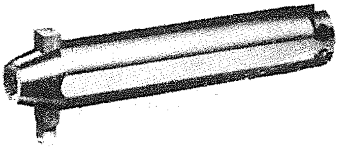
8. Slide tool



9. Adjustable single turning head

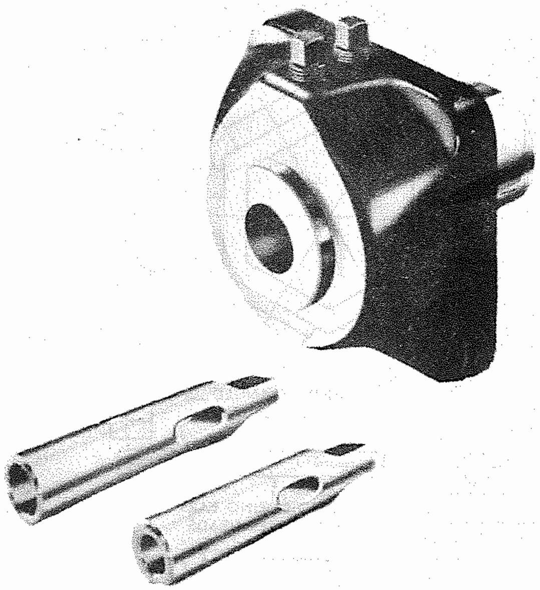


10. Angular cutter stub boring bar



11. Straight cutter stub boring bar

Fig. 9–8 (cont.).



12. Straight-shank taper socket and holder with taper sleeves

certain jobs, the tool stations can be back-indexed, or skip-indexed, to suit the requirements of the job, but the flanged tools themselves are not changed from one turret face to the other. Ordinarily, the extra machine-handling time required to remove these tools from the machine or to change their position on the turret is more than the time required to skip-index a station. The lighter tools, which can be quickly mounted in the turret or holder, are of the shank type. Figure 9–9 shows a permanent setup for bar work; Fig. 9–10 shows a permanent setup for chucking work.

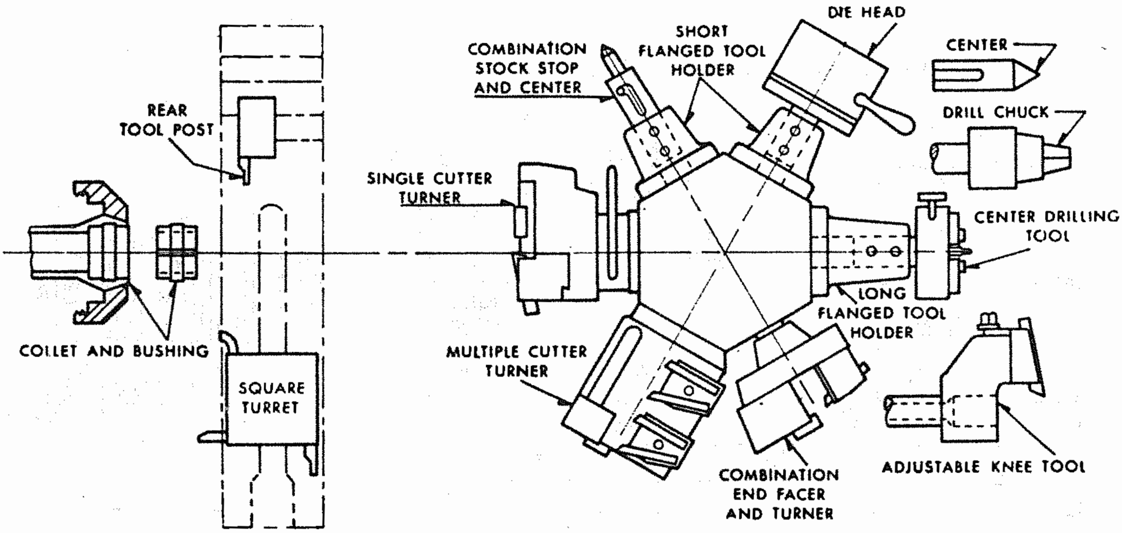
A complete bar-tooling layout for machining the steel shaft of Fig. 9–11 is shown in Fig. 9–12. All of the tool stations are used. The cutters are made of high-speed steel and are standard stock shapes. The order of operation is shown in Fig. 9–13.

When the accuracy requirements of the job are studied, it is found that the diameters do not have to be turned to very close limits because they are to be ground after hardening. However, it is necessary to keep the diameters closely concentric in order to allow for cleanup in the grinding operations. The thread diameter, which is not ground, must run true with the other diameters.

8. *What is a preselector?*

A preselector is a device that permits the machine operator to preselect the spindle speed for the next operation while the present operation is in progress.

Fig. 9–9. A permanent setup of universal bar equipment. (Warner & Swasey Co.)



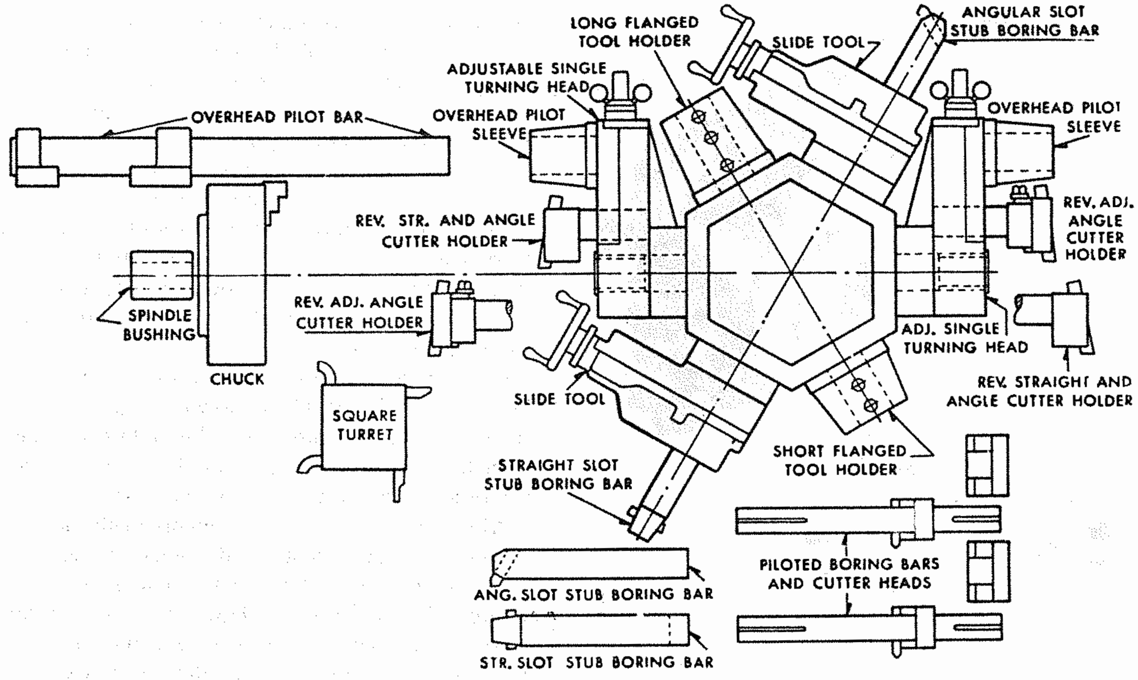
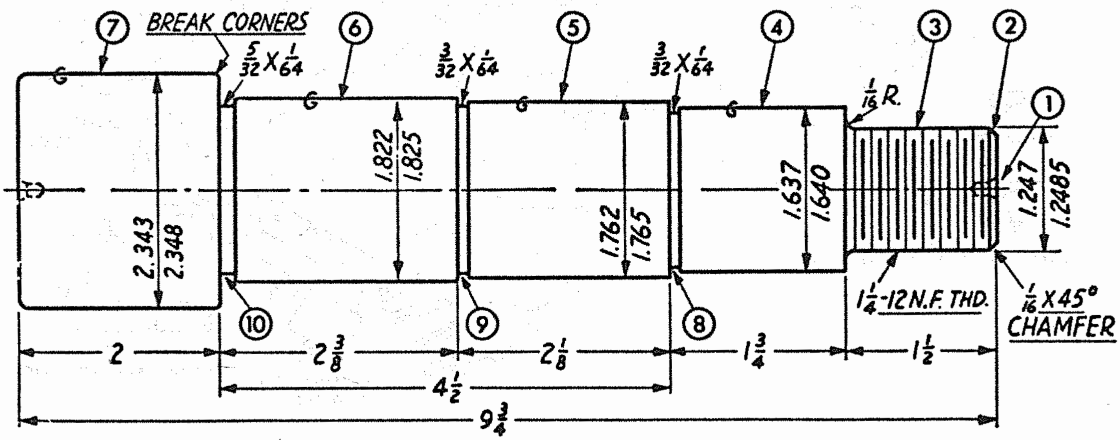


Fig. 9–10. A permanent setup of universal chucking equipment (Warner & Swasey Co.)

Fig. 9–11. This shaft is a typical bar job. (Warner & Swasey Co.)



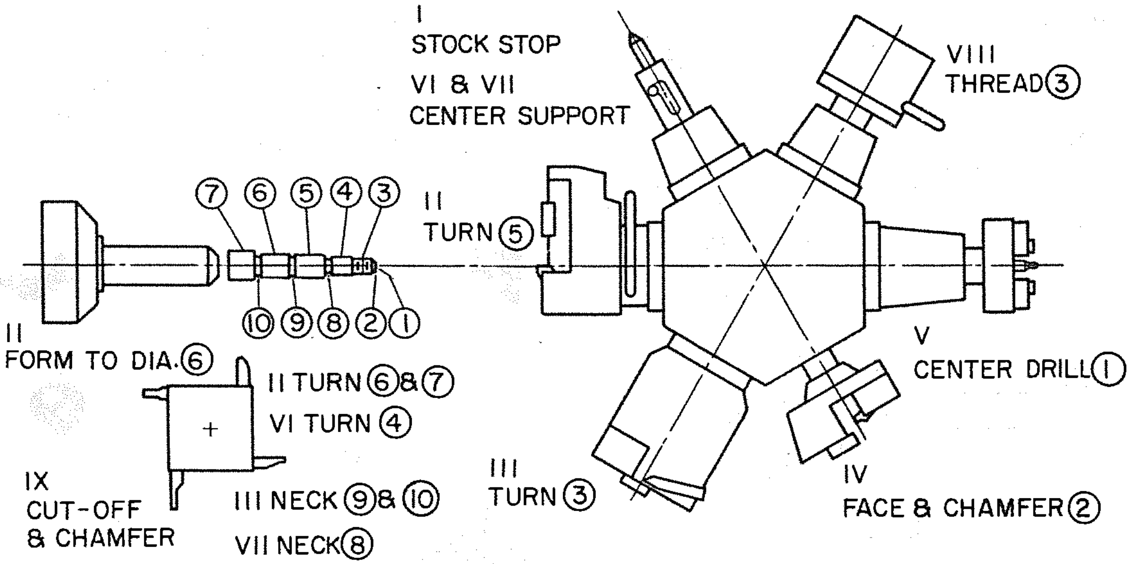
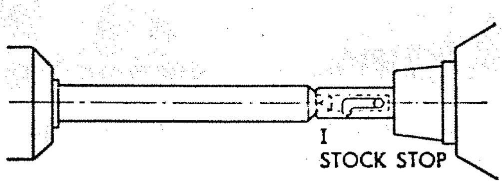
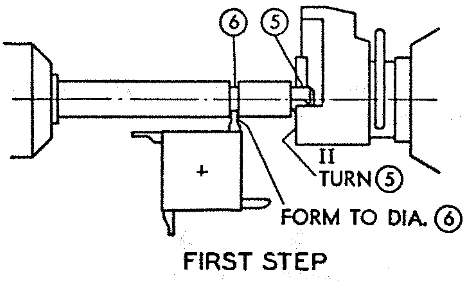


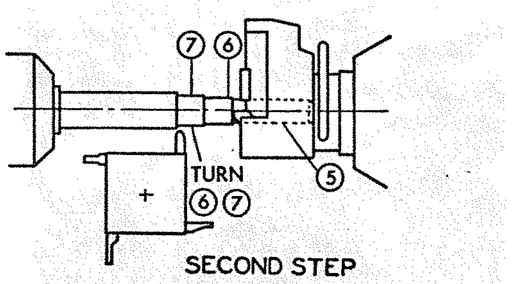
Fig. 9–12. Tooling setup for the shaft in Fig. 9–11. (Warner & Swasey Co.)

Fig. 9–13. Sequence of operations (I through IX.) for machining the shaft in Fig. 9–11. (Warner & Swasey Co.)

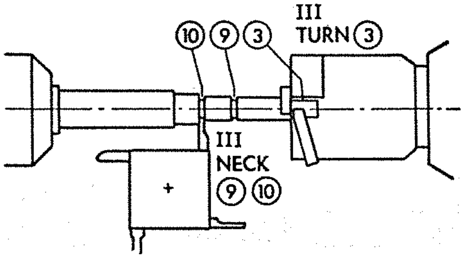


Operation I

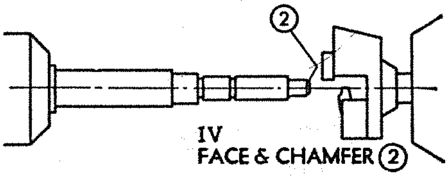




Operation II



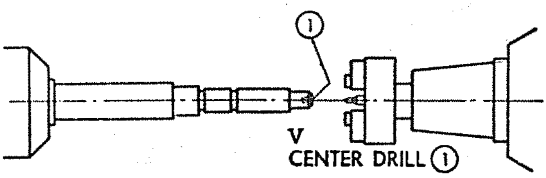
Operation III



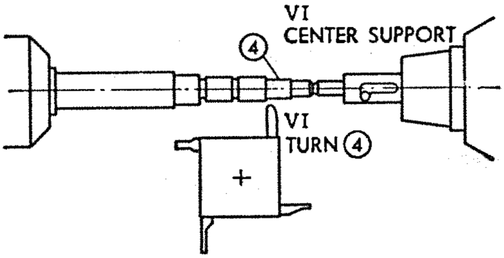
Operation IV

Fig. 9–13 (Cont.).

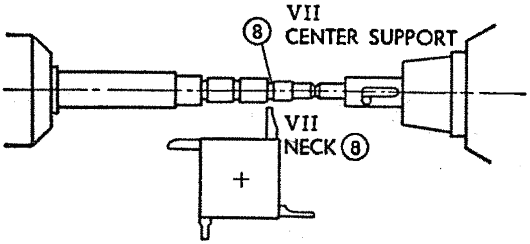
Fig. 9-13 (cont.).



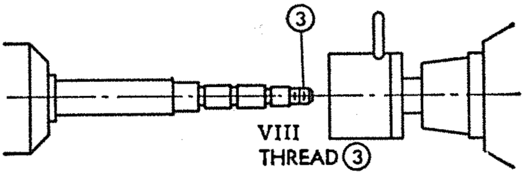
Operation V



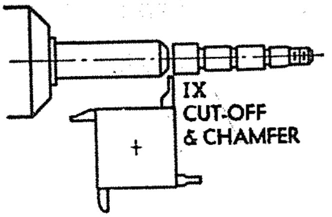
Operation VI



Operation VII



Operation VIII

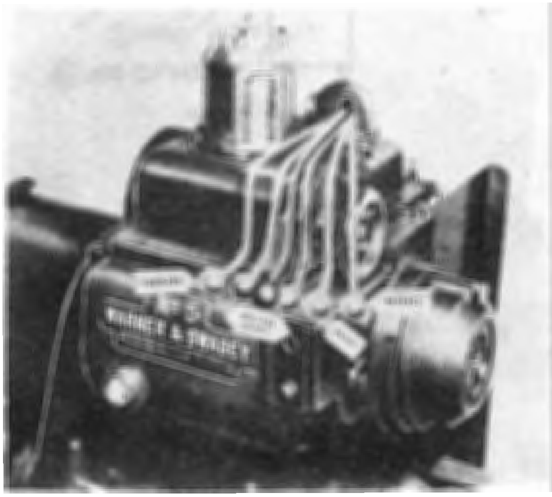


Operation IX

The new speed is then automatically actuated while the operator is turning the tools into position for the next operation. Each manufacturer of turret lathes has his own design of a preselector. Two different designs of preselectors are shown in Figs. 9-14 and 9-15.

Fig. 9-14. Preselector for spindle speeds, Jones & Lamson design. (Jones & Lamson Machine Co.)

Fig. 9-15. Preselector for spindle speeds, Warner & Swasey design. (Warner & Swasey Co.)



A working outline of the Warner and Swasey preselector follows:

A. Set the preselector when setting up tools. First, rotate the drum until the desired surface speed in feet per minute showing on the dial corresponds to the work diameter to be cut. Then, number that cut, using master numeral 1 at the top of the drum.
B. Set the indicator for the second cut by selecting the desired surface speed in feet per minute for the second work diameter. Number this cut with master numeral 2. Continue similarly for additional operations.
C. Cuts are now shown in order by the master numerals, 1, 2, 3, and so forth. Now, use these numerals in their turn from one cut to the next. In this way, the correct surface speed in feet per minute will be set for each cut, regardless of the number of speed changes.
D. In actual use, it is possible to preselect the next speed by turning to the next numeral while the machine is cutting. Then, when the cut is finished, it is necessary merely to move the lever, bringing the next speed into play, without stopping the spindle: forward—reverse—stop—start, with the one lever.

The preselector is set for surface speeds as shown in Fig. 9–16.

The operator can select the correct spindle rpm to produce the proper surface feet per minute for any diameter to be cut by turning the handwheel.

9. *What are machine stops?*
Machine stops are adjustable screws of suitable length that provide a positive stop to the cutting tool movement so that the operator does not need to measure each cut made on a workpiece. Once machine stops are adjusted and locked into position, the movement of the cutting tool will be the same

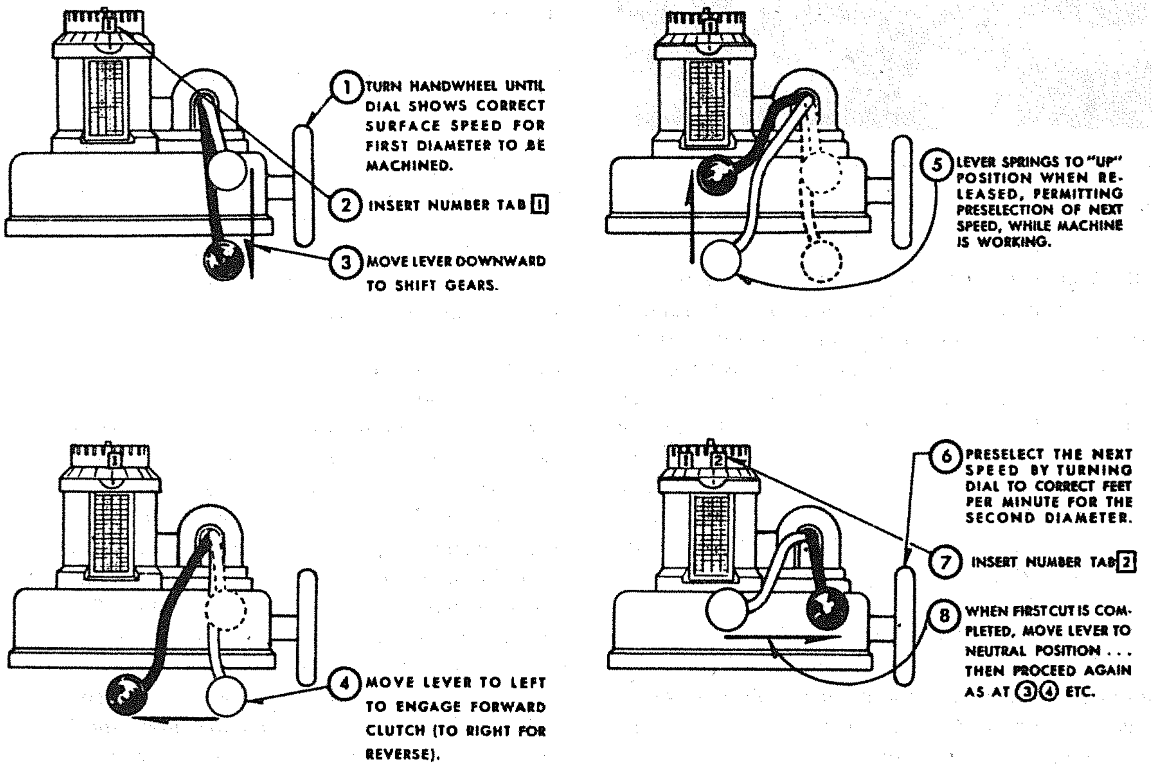


Fig. 9–16. Setting the preselector for surface speeds. (Warner & Swasey Co.)

for each piece. The turret stop usually consists of six different screws mounted in a cylindrical roll. There is one screw for each face of the hexagonal turret. During the setup, each of the screws is adjusted to stop the cutting tool movement at a specified point (Fig. 9–17). The stop mechanism rotates as the turret is indexed to bring the correct stop screw into position. The carriage stop rod and stop roll can duplicate sizes cut with a longitudinal movement of the carriage.

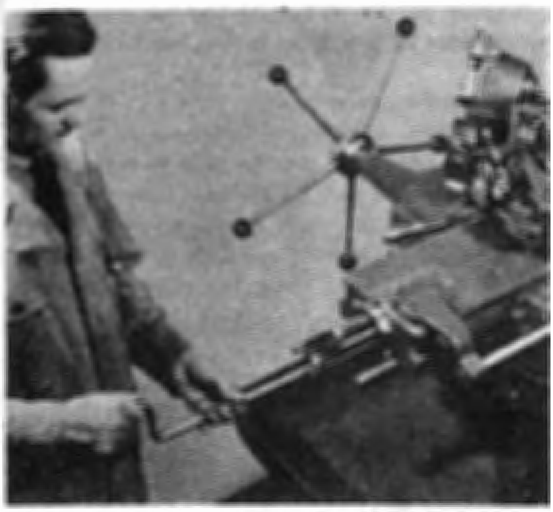


Fig. 9–17. Setting the stops for turret travel. (Warner & Swasey Co.)

10. *What is the stationary overhead pilot bar?*
The purpose of the overhead pilot bar is to support the multiple turning head, thus providing greater rigidity so that deeper cuts can be taken with heavier feeds. The stationary overhead pilot bar, which fastens to the head of the machine, can be heavier than the pilot bars which are attached to the turning heads because this bar does not add any weight to the hexagonal turret and its tools. This type of pilot bar can be adjusted endwise in the machine for various lengths of work and clamped in place.

11. *What is a full universal-threading turret lathe?*
A full universal-threading turret lathe combines toolroom threading performance with the advantages of high-speed production in a thread-cutting lead-screw machine. The single-thread fine-pitch lead screw is used for thread cutting only. The remote-control lever, located at the operating position, gives forward and reverse motion to the carriage. It is not necessary to disengage the double half-nuts or reverse the spindle for the threading operation. This remote-control lever is also used in cutting left-hand threads. An automatic knock-off for right-hand threads permits threading to accurate shoulder lengths. The change from threading to regular feeding is accomplished by shifting a single lever on the head-end lead-screw gear box. A safety interlock prevents the screw-cutting and feeding mechanisms from engaging at the same time. The threading range is 2 to 56 threads per in. in lengths to 20 in.

12. *How may screw threads be cut on a turret lathe?*
Screw threads may be cut from the hexagonal turret by using taps and dies. Or they may be cut by using a single-point cutting tool with lead control from the cross-slide carriage on ram-type machines and from the hexagonal turret of a saddle-type machine when the saddle type is equipped with a cross-sliding turret. There are four kinds of threading attachments: (a) leading-on attachments, (b) leader and follower attachments, (c) change-gear full-length lead screws, and (d) full-length lead screw with quick-change gear box. Figure 9–18 shows one design of a thread-chasing mechanism.

13. *What is a taper attachment?*
A taper attachment (Fig. 9–19) is a device for turning and boring tapers, which may be attached to the carriage. The usual capacity of the taper attachment is 3 in. taper per ft, 8 in. long. The graduated scale may be adjusted for degrees or for taper per foot.

14. *What types and shapes of cutting tools are used for various metals and materials?*
Five types of cutting tool materials are commonly used. Formerly, carbon tool steel was widely used for cutting tools, but it has given way to better materials. However, it is still used for jobs such as brass finishing. High-speed steel is probably used more than any other cutting tool material. It can cut metals at twice the speed of carbon steel. Stellite, which is made of an alloy of several metals, including chromium and cobalt, is used for solid tools or for tips for cutting tools. It is useful for machining such metals as cast iron, malleable iron, and hard bronzes. Carbide-tipped cutters, which can be run from one and one-half to four times faster than cutters

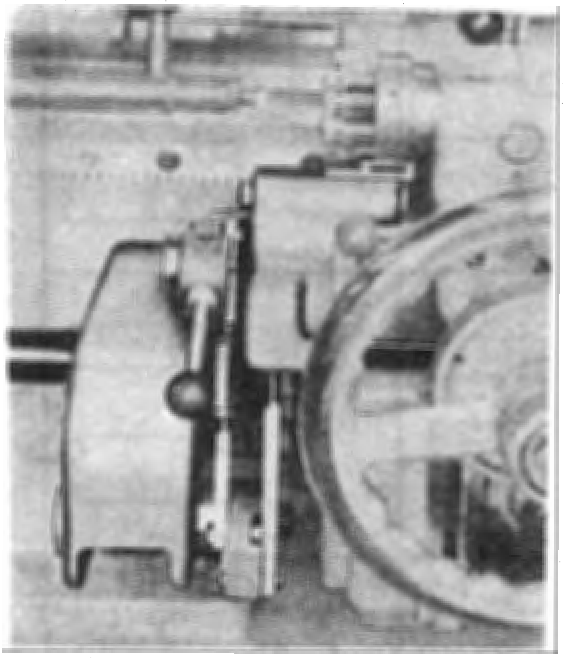
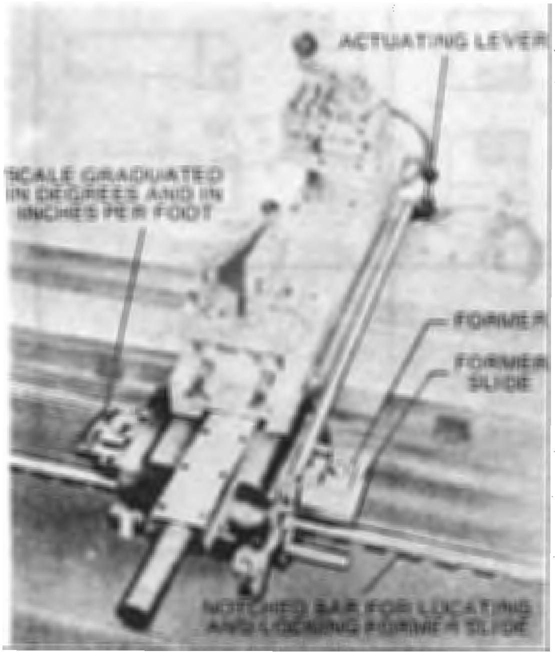


Fig. 9–18. Thread-chasing attachment. (Jones & Lamson Machine Co.)

Fig. 9–19. Taper attachment. (Jones & Lamson Machine Co.)



of high-speed steel, are widely used today for many types of production jobs. Figure 9–20 shows the shapes of some standard types of carbide tools. Diamond tools are used on small high-speed turret lathes for light cutting operations on such materials as aluminum, brass, hard rubber, and Bakelite.

15. *What is an automatic chucking machine?*
An automatic chucking machine (Fig. 9–21), commonly referred to as a single-spindle automatic chucking machine and also as an automatic turret lathe, is a fairly recent development of the turret lathe. This type of machine handles a large variety of work, which is basically the same as that done on standard turret lathes equipped for chuck work. The workpieces requirc hand loading and unloading, but the machining is entirely automatic. A machine of this type is used for quantity production. It is economical to use for quantities too large for the hand-operated machine and too small for the multiple spindle automatic machines.

The automatic chucking machine is used primarily for machining castings, forgings, and short lengths of bar stock which have been cut to length. It may also be used for second-operation work—that is, workpieces that have been partly machined on other machines.

This machine is equipped with a control unit, which automatically selects speeds, feeds, length of cuts, and other movements such as dwell, cycle stop, index, and reverse. Figures 9–22 through 9–25 show several of the units that make up the control mechanism for this machine.

For gripping and holding the workpieces, an air-operated chuck is generally used. Other types of power and hand-operated chucks may also be used. Arbors, fixtures, and collet chucks may be adapted for special application.

Holders for the cutting tools may be especially designed for the machine, or standard holders used on other machines can be adapted for use on the automatic machine. Multiple toolholders for the turret are more or less universal types and are capable of holding four or more tools for the multiple cuts. In addition to the turret tooling, there are cross-slide blocks, which hold the necessary cutting tools for facing and forming operations.

A different type of a fully automatic chucking machine for producing small precision workpieces is shown in Fig. 9–26. This machine has simple, direct programming without cams, gears, or pulleys

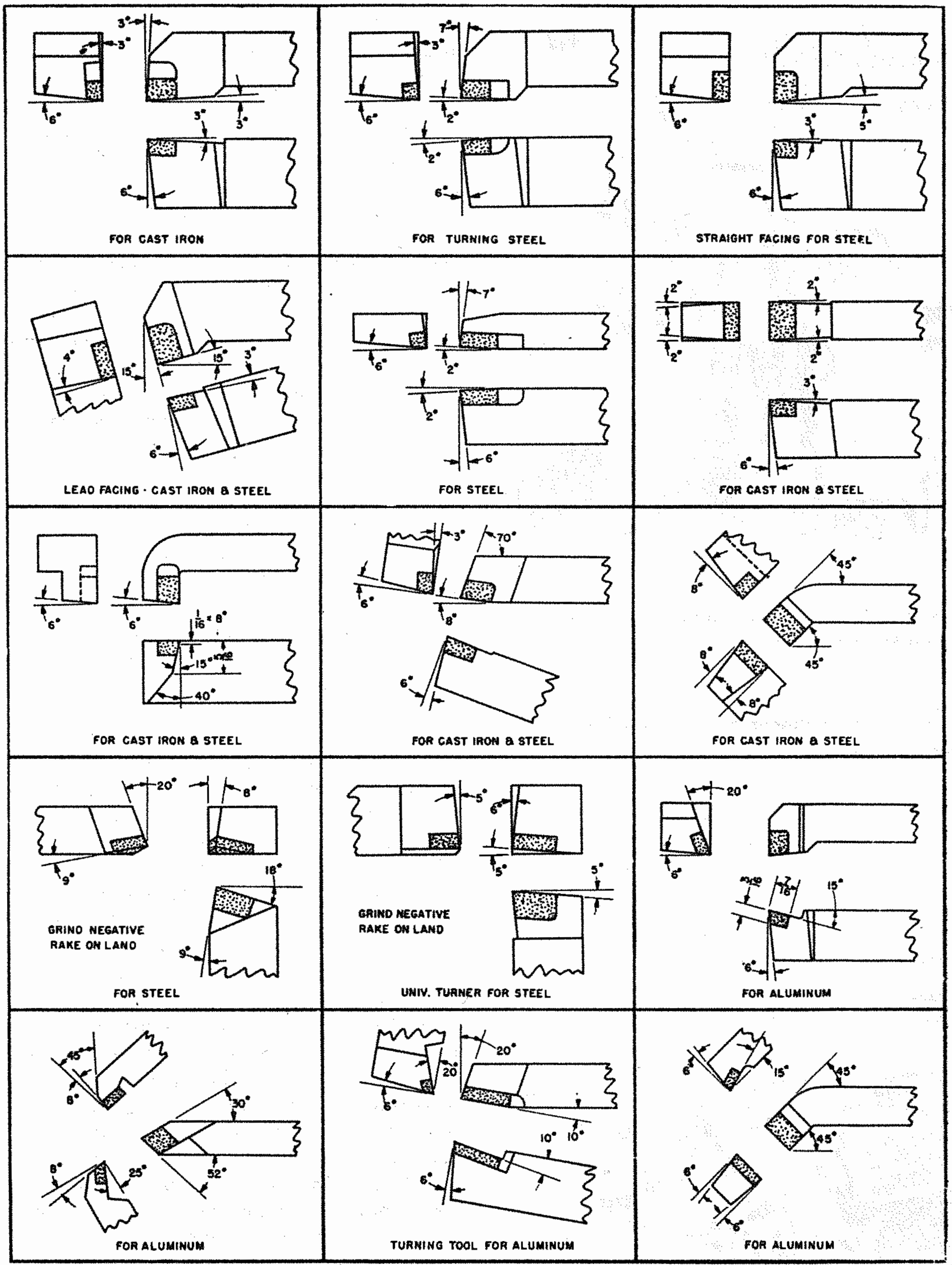


Fig. 9-20. Standard carbide cutting tools for various materials. (Warner & Swasey Co.)

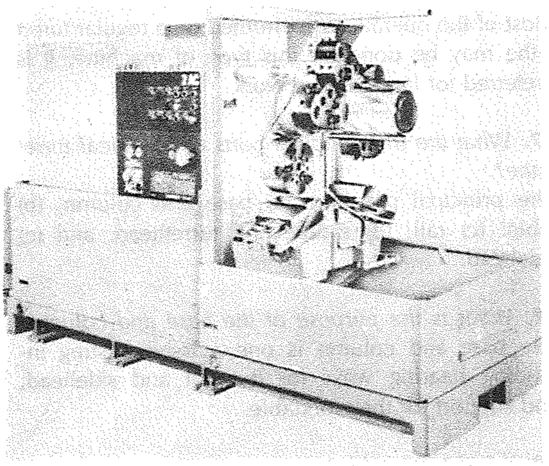


Fig. 9–21. A single-spindle automatic chucking machine. (Warner & Swasey Co.)

Fig. 9–22. Control end of single-spindle automatic chucking machine. (Warner & Swasey Co.)

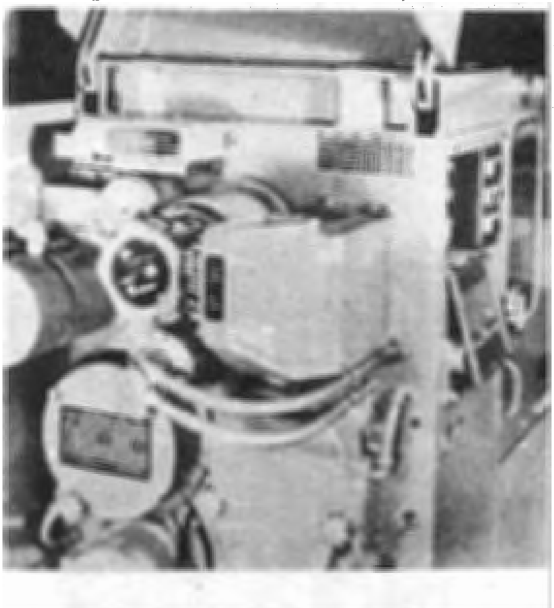
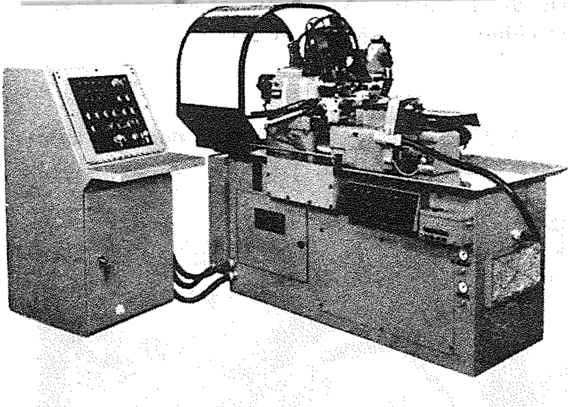


Fig. 9–23. Control panel for automatic chucking machine. (Warner & Swasey Co.)

Fig. 9–24. Setting speed and feed dogs on automatic chucking machine. (Warner & Swasey Co.)

Fig. 9-25. Cam drum assembly and main control drum for automatic chucking machine. (Warner & Swasey Co.)

Fig. 9-26. A single-spindle automatic chucking machine with direct programming for small precision work. (Hardinge Brothers, Inc.)



to change, and does not use tape or punched cards. A programmed system of trip blocks operates microswitches controling the carriage, cross-slide, vertical slide, spindle speed change, and threading head, which automatically produce superprecision operations on a workpiece. Once the machine has been set up and programmed, the operator is required only to push the cycle start button for completely automatic production.

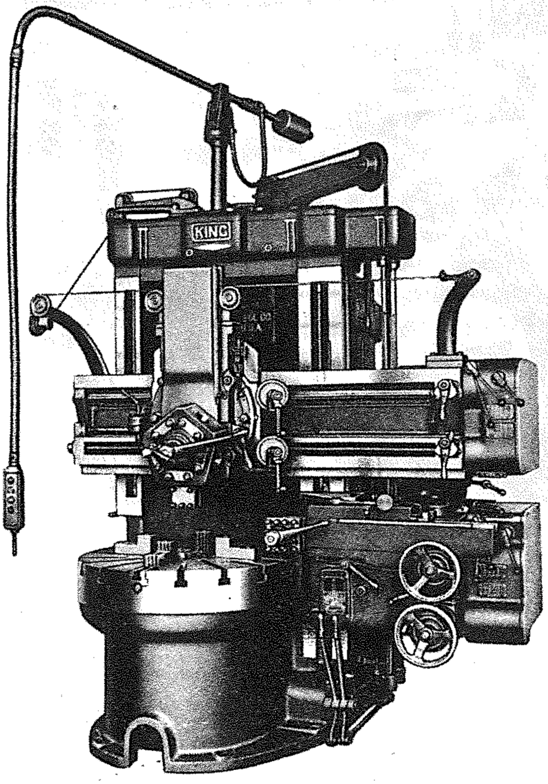
16. *What is a vertical turret lathe?*
A vertical turret lathe (Fig. 9-27) is a machine with a vertical turrethead and a horizontal worktable. Most of the operations performed on a regular turret lathe may be done on this type of machine. It is preferred for large, heavy work.

17. *What are the principal parts of a vertical turret lathe?*
The principal parts are (a) base and column, (b) table, (c) rail, (d) saddle and turrethead, and (e) sidehead.

18. *What is the purpose of the base and column?*
The base and column is one massive casting including bearing ways for the rail and sidehead, and support for the worktable.

19. *What is the table?*
The table is a cylindrical casting which is attached to the main spindle of the machine. It rotates at speeds ranging from 3 to 180 rpm. Its upper surface may vary according to the requirement of the user. The one shown on the machine in Fig. 9-27 is fitted

Fig. 9-27. Vertical turret lathe. (American Steel Foundries.)



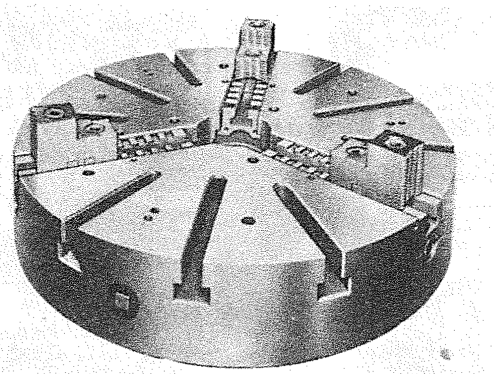


Fig. 9–28. Vertical turret lathe table with three-jaw universal chuck and T slots. (American Steel Foundries.)

Fig. 9–29. Vertical turret lathe table with four face-plate jaws and T slots. (American Steel Foundries.)

with four independent chuck jaws and has T slots. Other tables are available with a three-jaw universal chuck and T slots, as in Fig. 9–28, with four faceplate jaws and T slots, as in Fig. 9–29, and with T slots only.

20. *What is the rail?*
The rail is a box-type casting attached in a horizontal position to the vertical bearing ways of the column. It may be raised or lowered, under power, by feed screws located within the ways of the column. The rail supports the saddle for the turrethead and contains the feed screws by means of which the saddle may be moved from side to side, either by rapid traverse or by automatic feed.

21. *What are the saddle and turrethead used for?*
The saddle and turrethead are attached to the rail. The saddle may be swiveled from side to side; the turrethead may be raised or lowered on the saddle. The five-sided head itself may be revolved to any of five positions. Various cutting tools may be attached to the head.

22. *What is the sidehead?*
The sidehead is located below the rail. It is a non-swiveling unit with complete feed and rapid-traverse mechanism. It is fitted with a square toolholder for cutting tools.

23. *What attachments are available for a vertical turret lathe?*
Many attachments are used on vertical turret lathes. Some of them are:

A. A screw-cutting attachment for cutting threads from 2 to 18 per in.
B. A tool-lubricating attachment for reducing the friction of the work and chips against the cutting tool, and also for absorbing and diffusing the heat generated at the point of cutting. The lubricating attachment also permits greater feeds and speeds and helps lengthen the life of the cutting tools.
C. A drum-scoring attachment for machining coarse leads ranging from 1/2 to 2 in. in 1/32-in. increments.
D. A gear-type taper attachment for cutting tapers within a range of 5° to 45° from the horizontal.

Some manufacturers use a combination unit, which can be adapted for thread cutting, drum scoring, or angular turning. The threads may be either Metric or National form. The angles may be cut either on the horizontal or vertical.

24. *Can very large workpieces be machined efficiently on the vertical turret lathe?*
Figures 9–30 to 9–32 illustrate some of the operations that may be performed on the vertical turret lathe. It will be noticed that in each of these examples the article being machined is quite large. Jobs of this kind are usually difficult to machine on an ordinary engine lathe but offer no problems when they are done on a vertical turret lathe. In Figs. 9–30 and 9–32 the side surface, or circumference, of the workpiece is being machined while in Fig. 9–31 the top surface is being machined.

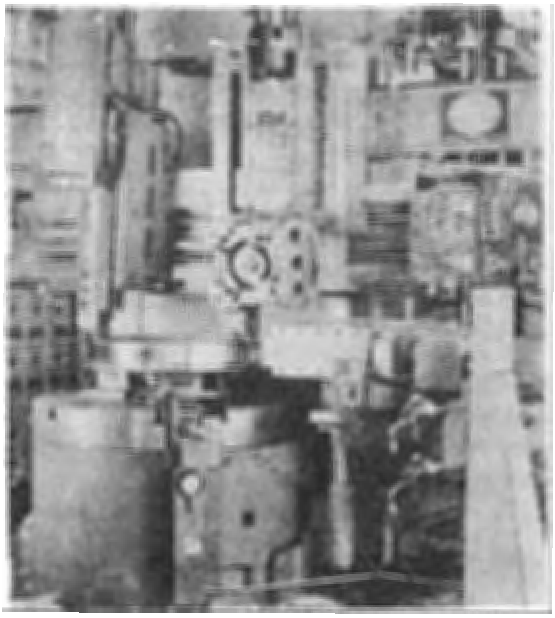


Fig. 9–30. Machining a railroad car wheel on a vertical turret lathe. (Bullard Co.)

Fig. 9–32. Machining grooves for an elevator sheave on a vertical turret lathe. (Bullard Co.)

Fig. 9–31. Machining a compressor-intake casting for a jet engine on a vertical turret lathe. (Bullard Co.)

chapter 10 tapers and angles

If a job changes size gradually, but uniformly, along its length, it is said to be tapered. A cone is tapered; its *diameter* decreases at a regular and gradual rate from the base to the apex. A wedge is tapered; its thickness increases regularly and gradually from the thin end to the thick end.

Tapers have many uses in a machine shop and also as parts of machines. The spindles of drill presses, lathes, and grinding and milling machines have internal tapers. These internal tapers give perfect fit and grip to the matching external taper found on drills, reamers, arbors, milling cutters, centers, and so forth (Fig. 10–1). The matching tapers also centralize as they come together, making it unnecessary to test for trueness. Taper fits make possible the speedy assembly and disassembly of machine parts.

Most tapers used in machine shop work are cylindrical. Square and rectangular-shaped tapers are used as keys to fasten machine parts together (Fig. 10–2).

1. *What method is used to express the amount a piece of work is tapered?*

Fig. 10–1. Machine accessories with tapered shanks.

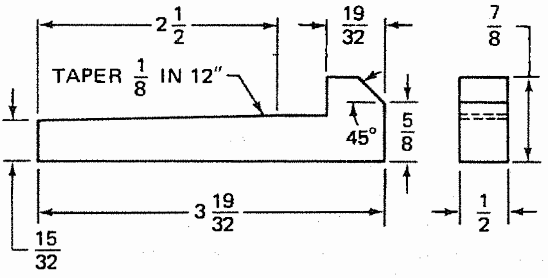


Fig. 10–2. A gib-head key.

The amount a job differs in diameter from the large to the small diameter is known as the taper. If the large end is 1⅛ and the small end ¾, then the taper is 1⅛ minus ¾, which equals ⅜ (Fig. 10–3). The tapered plug shown in Fig. 10–3 is 2 in. long. Therefore, if the amount of the taper is divided by the length of the taper, we would figure ⅜ ÷ 2 = 3/16. This represents the amount the job tapers every inch and is known to the machinist as *taper per inch*. In order to find out how much the job

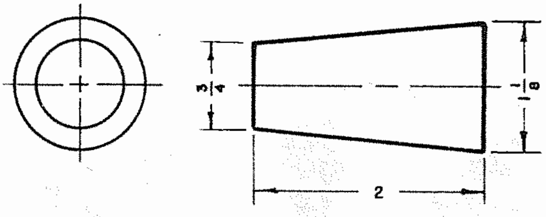


Fig. 10–3. Tapered plug.

tapers per foot, it is necessary to multiply the taper per inch by 12 (there are 12 inches in a foot). In other words,

$$\frac{3}{16} \times \frac{12}{1} = \frac{9}{4} = 2\frac{1}{4} \text{ taper per foot}$$

Taper: the difference in size from large diameter to small diameter, if the job is cylindrical; from large to small thickness, if the job is rectangular or square in section.

Taper per inch (tpi): the amount the size changes every inch of its tapered length

Taper per foot (tpf); the amount the size changes every foot of its tapered length.

2. *What is the correct method of expressing the amount of taper on the job?*

The correct method of expressing the amount of taper will depend on the size of the job, the policy of the shop, or the standard given in the handbook. On large-sized work, the taper is usually stated in taper per foot. On small work, instrument work, and so forth, taper per inch is used.

A job that is tapered can also be dimensioned in degrees. This is usually done when the amount of taper exceeds 15° degrees.

3. *Is tapered work more commonly dimensioned in fractional or in decimal sizes?*

The degree of accuracy required for the finished job will, in most cases, determine the method of dimensioning the job. If only common fractions are used, the usual size tolerance is 0.005 on diameters and 1/64 on lengths. Where extreme accuracy is required, all measurements are given in decimals.

4. *The drawing for the job shown in Fig. 10–4 gives the dimension for both the large and small diameters and the length of the taper. How is the taper per inch determined?*

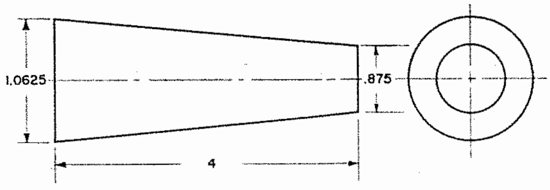


Fig. 10–4. A taper problem.

The taper per inch is found by subtracting the small diameter from the large diameter and dividing by the length of the taper.

$$1.0625 - 0.875 = 0.1875 \div 4 = 0.0468 \text{ tpi}$$

To help the machinist memorize the various trade practices, symbols have been established and used to develop formulas.

T = taper, the difference between the large and small diameters, or the large and small thickness of the tapered piece.

T'' = taper per inch, the difference between the large and small diameters, or the large and small thickness, when they are 1 in. apart

T' = taper per foot, the difference between the large and small diameters, or the large and

small thickness, when they are 1 ft apart
D = large diameter
d = small diameter
$L_{T''}$ = length of the taper in inches

These symbols help in memorizing the following formulas:

A. Taper = large diameter minus small diameter

$$T = D - d$$

B. Taper per inch = large diameter minus small diameter, divided by length of taper in inches

$$T'' = \frac{D - d}{L_{T''}}$$

C. Taper per foot = taper per inch multiplied by 12

$$T' = T'' \times 12$$

D. Large diameter = taper per inch multiplied by length of the taper plus small diameter

$$D = (T'' \times L_{T''}) + d$$

E. Small diameter = large diameter minus length of taper in inches multiplied by taper per inch

$$d = D - (L_{T''} \times T'')$$

Using the dimensions of Fig. 10–4 as an example to demonstrate the formulas:

$$\begin{aligned} T &= D - d \\ &= 1.0625 - 0.875 \\ &= 0.1875 \end{aligned}$$

$$\begin{aligned} T'' &= \frac{D - d}{L_{T''}} \\ &= \frac{1.065 - 0.875}{4} \\ &= \frac{0.1875}{4} \\ &= 0.046875\text{, taper per inch} \end{aligned}$$

$$\begin{aligned} T' &= T'' \times 12 \\ &= 0.046875 \times 12 \\ &= 0.5625\text{, taper per foot} \end{aligned}$$

$$\begin{aligned} D &= (T'' \times L_{T''}) + d \\ &= (0.046875 \times 4) + 0.875 \\ &= 0.1875 + 0.875 \\ &= 1.0625 \text{ inches, large diameter} \end{aligned}$$

$$\begin{aligned} d &= D - (L_{T''} \times T'') \\ &= 1.0625 - (4 \times 0.046875) \\ &= 1.0625 - 0.1875 \\ &= 0.875 \text{ inches, small diameter} \end{aligned}$$

5. *In the job shown in Fig. 10–5, the taper per foot is given, but before the machinist can turn the taper, he must first determine the exact size of the large end. Find the size of the large end of the job (D).*

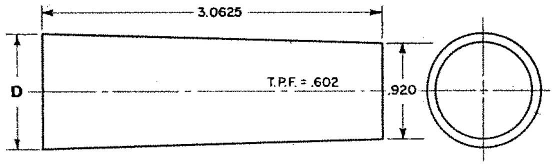


Fig. 10–5. A taper problem (question 5).

The size of the large end of the taper is equal to the size of the small end plus the amount of the taper increase. Because the taper is given in taper per foot and the job is just a few inches long, it will first be necessary to find how much the job tapers every inch.

$$\begin{aligned} T'' &= \frac{T'}{12} \\ &= 0.602 \div 12 \\ &= 0.05017 \end{aligned}$$

Use the appropriate formula to find the large end of the taper.

$$\begin{aligned} D &= (T'' \times L_{T''}) + d \\ &= (0.05017 \times 3.0625) + 0.920 \\ &= 0.15364 + 0.920 \\ &= 1.07364 \text{ inches, large diameter} \end{aligned}$$

6. *Find the diameter of A shown in Fig. 10–6.* Diameter A is equal to the diameter of the small end of the taper plus the amount that the job size increases in ¾ in. First find the taper per inch,

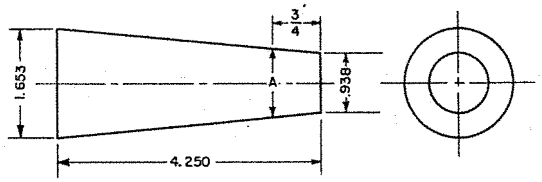


Fig. 10–6. A taper problem (question 6).

then determine the taper in ¾ in. Add this to the small diameter and that will equal diameter *A*.

$$T'' = (D - d) \div L_{T''}$$
$$= (1.653 - 0.938) \div 4.25$$
$$= 0.715 \div 4.250$$
$$= 0.1682 \text{ taper per inch}$$

Amount of taper in ¾ in.

$$= 0.1682 \times 3/4$$
$$= \frac{0.5046}{4}$$
$$= 0.1261$$

Diameter of *A*

$$= 0.938 + 0.1261$$
$$= 1.0641 \text{ inches}$$

7. *In order to bore the tapered hole in Fig. 10–7, a straight hole must first be drilled or bored. Find the size of the straight hole.*

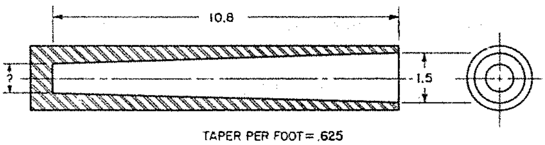


Fig. 10–7. A taper problem (question 7).

The diameter of the straight hole will equal the diameter of the large end minus the amount that the hole tapers in its length of 10.8 in. Find the taper per inch, multiply it by the length of the taper, and subtract from the large diameter.

$$T'' = T' \div 12$$
$$= 0.625 \div 12$$
$$= 0.0520 \text{ taper per inch}$$
$$T'' \times L_{T''} = 0.0520 \times 10.8$$
$$= 0.5616 \text{ inch, taper}$$
$$1.5 - 0.5616 = 0.9384 \text{ inches, diameter of straight hole}$$

8. *The problem in Fig. 10–8 is to determine how deep to bore the 1.4-in. diameter hole before cutting the taper.*

The length of a taper can be determined by dividing the amount of the taper by the taper per inch. The formula is:

$$L_{T''} = \frac{D - d}{T''}$$

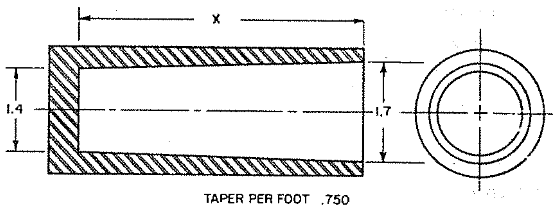


Fig. 10–8. A taper problem (question 8).

$$= \frac{1.7 - 1.4}{0.750 \div 12}$$
$$= \frac{0.3}{0.0625}$$
$$= 4.8 \text{ inches}$$

9. *How many different kinds of tapers are used in the machine trades?*

A specific number is difficult to give. Six standard tapers are commonly used in industry. There are also manufacturers who prefer to use their own taper standards on their machines.

10. *What are the recognized standard tapers used throughout the machine trades?*

There are several standard tapers which have been adopted by industry. The most important and most widely used among these are the Brown & Sharpe, Morse, ¾ in. per ft, Taper pin standard, Jarno, and Jacobs tapers. Some of these are used for a specific type of work; others have a more varied application.

11. *Describe the Brown & Sharpe taper.*

The Brown & Sharpe is a standard form of taper which is used mostly on milling machines (Fig. 10–9). There are 18 sizes in the series, numbered from 1 to 18. The number of the taper indicates its size only in a relative manner. The smallest is No. 1 and the largest is No. 18.

The amount of taper is approximately 0.500 in. per foot for all Brown & Sharpe tapers except No. 10, which has a taper of 0.5161 in. per ft. The Brown & Sharpe taper may be designed with or without tang. The complete dimensions of the Brown & Sharpe taper series will be found in Appendix Table 14.

12. *Describe the Morse taper.*

The Morse is the most common of the standard

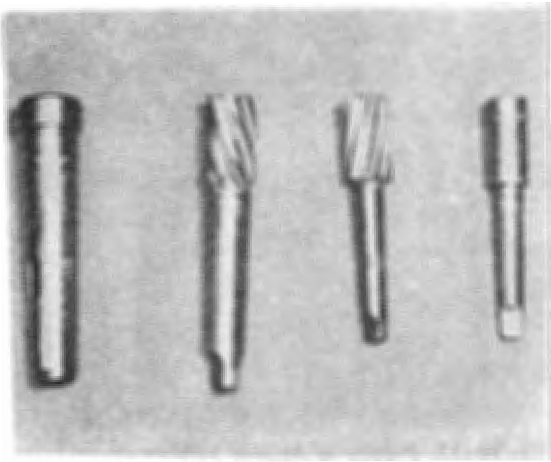
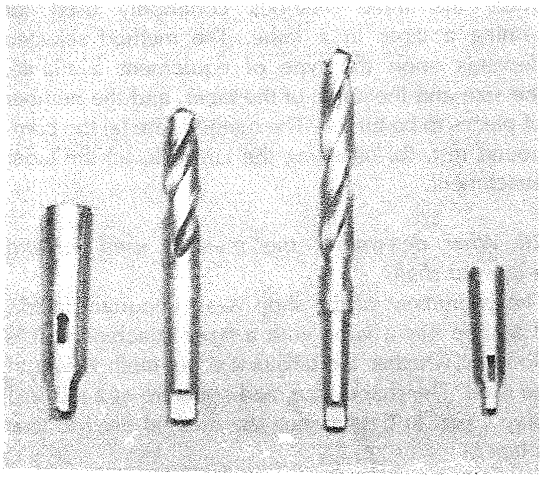


Fig. 10–9. Brown & Sharpe tapers on milling machine end mills and sleeves.

tapers. It is used on all drill press spindles and on some lathes (Fig. 10–10).

Practically all tapered shank drills, reamers, and special toolholders are made with Morse tapered shanks. The small end of the tapered shank has a tang. There are eight sizes in the Morse taper series, numbered from 0 to 7, 0 being the smallest, 7 the largest. The amount of taper on each of the Morse tapers varies slightly. However, each is approximately ⅝ in. per ft. For full details of sizes and design see Appendix Table 15.

Fig. 10–10. Morse tapers on twist drills and sleeves.



13. *Describe the ¾ in. per ft. taper.*
This taper standard has the same taper per foot for all sizes, exactly 0.750 in. per ft. There are 11 numbered sizes in the series, and the number of the taper indicates the diameter at the large end. Numbers range from 200 (2.000 in.) to 1200 (12.000) No. 450 is 4.5 in. at the large diameter.

14. *Describe the standard taper pin.*
The standard taper pin series runs from size 8/0 to 14; each size comes in many lengths. The amount of taper is the same for all, ¼ in. taper per ft. Taper pins are used as dowels to align various machine parts, which are fastened together (Fig. 10–11). The taper pin is preferred because it can be removed and replaced without losing any of its holding power. The dimensions for standard taper pins may be found in Appendix Table 15.

15. *Describe the Jarno taper series.*
The Jarno taper series was designed with the hope that it would bring complete standardization wherever tapers were used. The Jarno simplifies taper calculations. There are 20 sizes numbered from 1 to 20. The Jarno tapers at the rate of 0.600 in. per ft. The number of the taper indicates the important dimensions of the taper. It indicates the number of tenths of an inch contained in the diameter of the small end, the number of eighths of an inch contained in the diameter of the large end, and the number of half inches in the length of the taper.

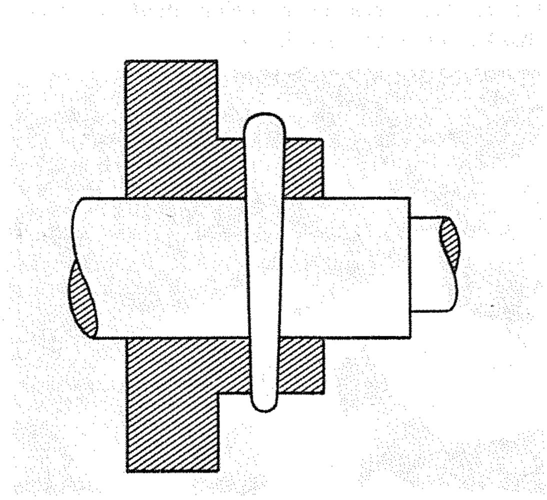


Fig. 10 A correctly fitted taper pin.

Diameter of small end of Jarno taper

$= \frac{\text{No. of taper}}{10}$

Diameter at large end of Jarno taper

$= \frac{\text{No. of taper}}{8}$

Length of Jarno taper

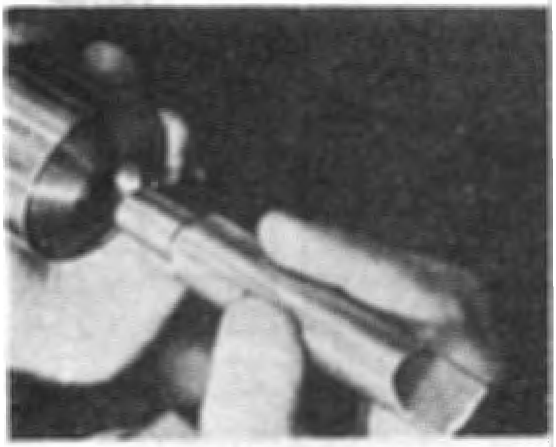
$= \frac{\text{No. of taper}}{2}$

Accordingly, a No. 8 Jarno taper measures $^8/_{10}$, or 0.800 in., at the small end, $^8/_8$, or 1 in., at the large end, and $^8/_2$, or 4 in., in length. The actual dimensions of Jarno tapers may be found in Appendix Table 16.

16. *Describe the Jacobs taper.*
The Jacobs series is made up of 10 sizes: Nos. 0, 1, 2, 2 short, 3, 4, 5, 6, 33, and E. The amount of taper varies with each size. The Jacobs taper is used to fit drill chucks onto a mating arbor adapter or machine spindle (Fig. 10–12). The dimensions of the Jacobs taper series may be found in Appendix Table 17.

17. *What is the difference between a self-holding taper and a steep (quick release) taper?*
The term *self-holding* has been given to the series of tapers that, when driven into or onto their mating parts, seat firmly and hold (Fig. 10–13). The larger sizes are designed with a tang to assist in both the driving and the holding functions of the taper.

Fig. 10–12. A drill chuck being fitted to a taper-shank arbor with a Jacobs taper.



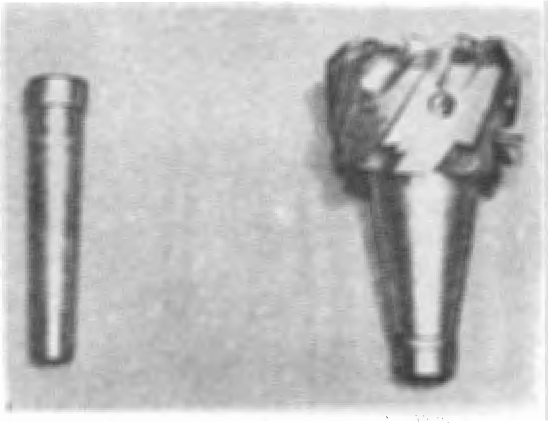


Fig. 10–13. Brown & Sharpe milling machine tapers. Left: Self-holding. Right: Quick release.

The term "steep" is given to the types of tapers that have a much larger taper angle. These tapers depend upon an outside locking device to hold them in place. The tapered shape still serves as an effective aligning device, but the steep taper permits a quick release. The steep taper, used on milling machine spindles and arbors, has a standard taper of 3½ in. per ft.

18. *What is meant by the American National Standard Machine Tapers?*
In 1943, the American National Standards Institute (ANSI) classified 22 self-holding tapers as standard. They were selected from the Morse, Brown & Sharpe, and ¾ in. per ft series.

19. *How are tapered pieces machined?*
There are three methods commonly used for turning a taper in a lathe. The method selected depends upon the type of equipment available, the size and the angle of the taper, and the number of pieces to be turned. The methods are (a) the compound rest, (b) offsetting the tailstock, (c) the taper attachment.

20. *What determines the method used to turn a tapered shaft?*
The equipment of the shop is an important factor. If a shop has a lathe with a taper attachment, it is doubtful whether the tailstock offset method would be used. The shape, size, and structure of a job also play a part in determining the method used to turn a taper.

21. *How is a taper turned with the compound rest?*
The compound rest is used to turn short tapers, steep tapers, or angles (Fig. 10–14). The degrees of taper that can be turned by using the taper attachment or by offsetting the tailstock are limited. The base of the compound rest is graduated in degrees, which allows a large range of tapers to be turned. Steep tapers are turned by swiveling the upper part of the compound rest to the required number of degrees *measured from the center line.* This equals half the included angle (Fig. 10–15). The compound rest must be set at an angle measured from either a line that is parallel to the axis of the work or a line that runs through the center of the lathe and is in alignment with the ways of the lathe. It can be swiveled clockwise or counterclockwise in a complete circle. Before swiveling the compound rest to the required angle, observe how its base is graduated. On some lathes, the graduations show 0–0 when the compound rest is set to travel at right angles to the center line of the lathe. On other lathes, the graduations read 90–0 when the compound rest is in the right angle position.

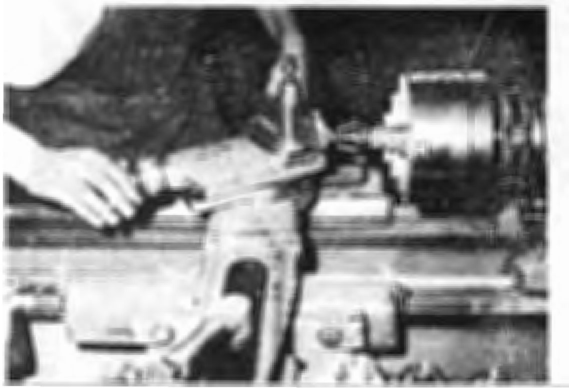


Fig. 10–14. Turning a short taper by the compound-rest method.

Fig. 10–15. Turning a 60° angle with the compound rest swiveled to 30° from the center line of the lathe.

22. *How is the angular measurement of the compound rest obtained if only the amount of the taper is given?*
When the large and small diameters and the length of the tapered part are given, the compound rest setting is obtained in the following manner: Divide half of the taper by the length of the taper to obtain the tangent of the angular measurement of the compound rest required. Figure 10–16 shows a job that can be turned by means of the compound rest.

$$
\begin{aligned}
\text{Tan of the angle} &= \frac{1}{2} \times \frac{D-d}{L_{T}} \\
&= \frac{1}{2} \times \frac{1.7500 - 1.000}{1.3125} \\
&= \frac{1}{2} \times \frac{0.7500}{1.3125} \\
\text{Tan of the angle} &= 0.285714 \\
\text{Angle} &= 15^\circ\ 56'
\end{aligned}
$$

23. *What is the procedure for turning a taper by offsetting the tailstock?*
To offset the tailstock, the tailstock clamp is loosened. This permits a change in the relationship between the upper and lower sections of the tailstock. The change is made by the adjustment of screws, one on each side of the upper section of the tailstock (Fig. 10–17). The accuracy of the setting will depend upon the care of the operator and the method used to measure the amount of movement.

24. *How is the amount of the tailstock offset determined?*
The two factors necessary to find the amount of tailstock offset are:

A. The taper per inch of the tapered section.
B. The length of the job.

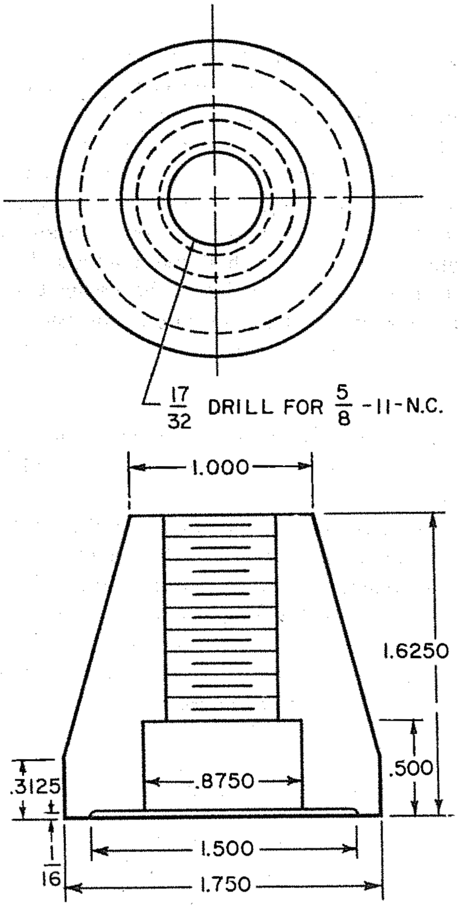


Fig. 10–16. A tapered job, which can be turned by using the compound rest.

The formula is:

Tailstock offset

$$= \frac{\text{Taper per inch } (T'') \times \text{Overall length } (L'')}{2}$$

Figure 10–18 shows a job that can be turned by offsetting the tailstock. The amount of tailstock offset is determined as follows:

$$\text{Taper per inch} = \frac{D - d}{L_{T''}}$$
$$= \frac{1.25 - 1}{6}$$
$$= \frac{0.25}{6}$$
$$= 0.041666$$
$$\text{Tailstock offset} = \frac{T'' \times L''}{2}$$

$$= \frac{0.041666 \times 10}{2}$$
$$= 0.2083 \text{ inch}$$

Turning a taper by the tailstock offset method throws the work out of alignment with the axis of the lathe centers. This causes an uneven wear of the center holes, which can cause inaccuracy. The cutting tool must be set exactly on center when cutting tapers.

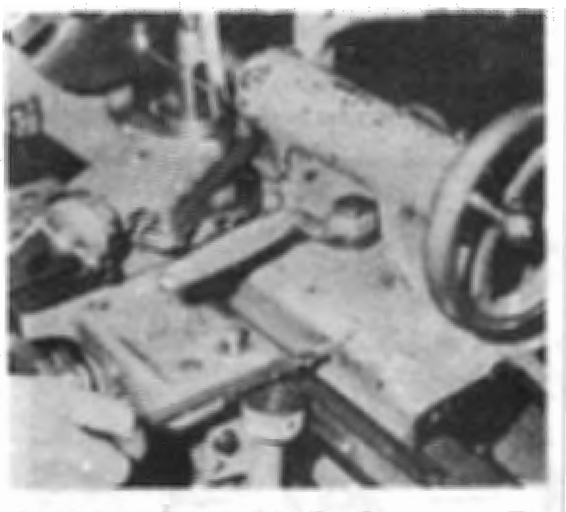
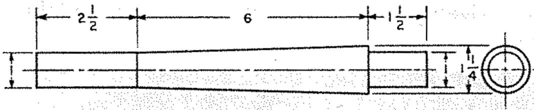


Fig. 10–17. Adjusting the tailstock screws to offset the tailstock center.

Fig. 10–18. A tapered job to be turned by offsetting the tailstock.



25. *What is the taper attachment?*
The taper turning attachment is one of the most valuable of the many engine lathe attachments (Fig. 10–19). It permits the turning of tapers longer than those that can be handled by the compound method. Both internal and external tapers can be turned with the taper attachment. Taper jobs can be turned when held between centers, without distorting the centers. One end of the guide bar is graduated in inches of taper per foot (Fig. 10–20); the other end is graduated in degrees (Fig. 10–21). By disconnecting the cross slide of the lathe from the

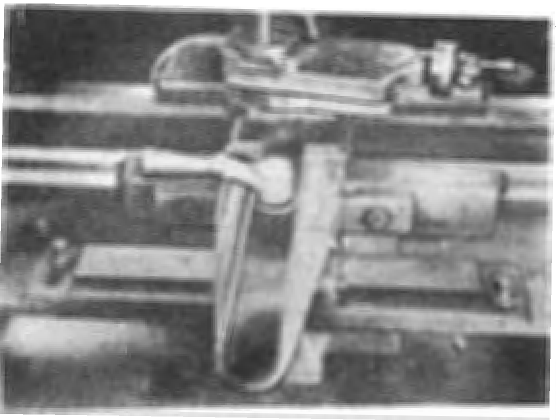
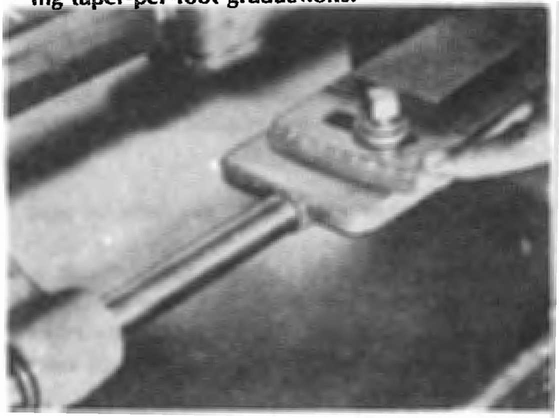


Fig. 10–19. The taper attachment.

Fig. 10–20. The taper-attachment guide bar showing taper-per-foot graduations.



cross-feed screw, and tightening the cross slide to a guide block, the cutting tool follows the angle to which the guide bar is set.

Care must be taken to eliminate and make allowance for any backlash caused by wear in either the cross-feed screw and nut, or the guide bar and guide block.

26. *How is the size of a standard tapered hole measured?*

The important measurements of a taper, whether it be a tapered shank or the tapered hole it fits into, are the diameter of the small end, the diameter of the large end, and the *exact* distance separating these two diameters. A tapered hole can be measured with calipers, micrometer, and rule. This method is not

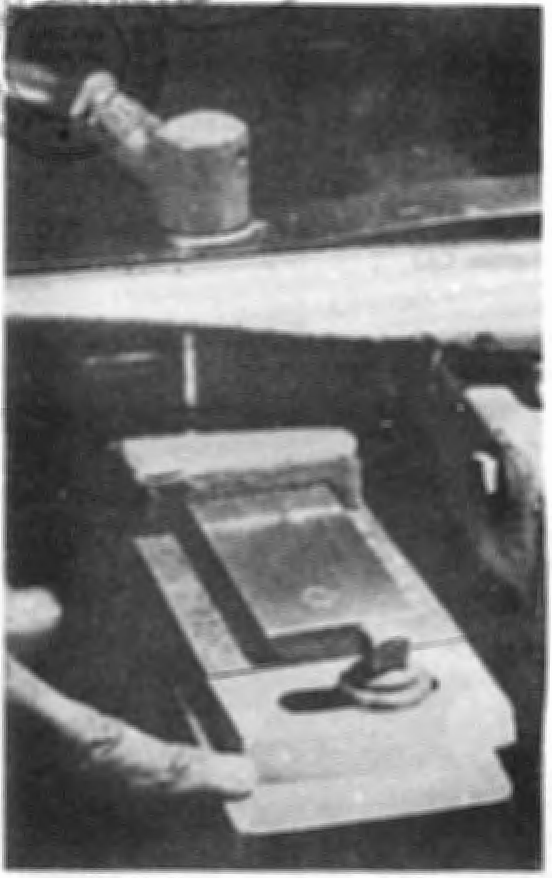


Fig. 10–21. The taper-attachment guide bar showing the angle of taper in degrees.

satisfactory when the fit of the mating tapers will determine the effectiveness of the holding power. For a reliable test of the accuracy of a tapered hole, a taper plug gage should be used (Fig. 10–22). To test the accuracy of a tapered shank, a taper ring gage should be used (Fig. 10–23). To test the accuracy of a taper shank, a chalk line is drawn the length of the taper plug gage, and it is then inserted into the hole (Fig. 10–24). The gage must not be jammed into the hole tightly, but just enough to

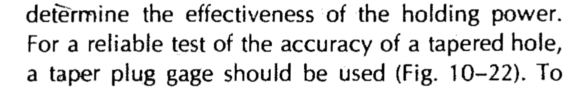


Fig. 10–22. A taper-plug gage. (Morse Twist Drill & Machine Co.).

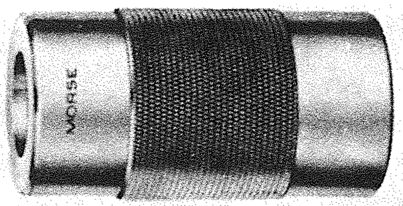


Fig. 10–23. A taper-ring gage. (Morse Twist Drill & Machine Co.)

Fig. 10–24. Testing a taper by means of a taper-ring gage.

make contact with the gage on the sides of the hole. When contact is made, the gage should be rotated counterclockwise, keeping it firmly in contact with the sides of the hole. When the gage is removed from the hole, the chalk mark will have been removed wherever close contact was made and will indicate where adjustment is necessary in the amount of taper. When the amount of taper is correct, the chalk line will show contact along the full length of the gage. Prussian blue or carbon pencil can be used in place of chalk. The diameter of the hole is tested for size by noting how far the gage enters the hole. A mark on the gage shows the correct diameter for the large end of the taper. Figure 10–25 shows how the ring gage detects errors when the amount of taper is too small or too large and how a correctly fitted taper fits the entire length of the gage.

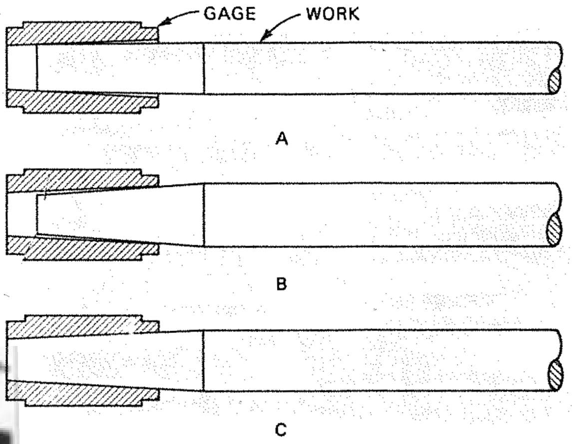


Fig. 10–25. Gaging an external taper with a taper-ring gage: Amount of taper (A) too small, (B) too large, (C) correct.

27. *Are all tapered holes bored on a lathe?*
Many tapered holes are finished on a cylindrical grinding machine. Small tapered holes are drilled to the small diameter size and finished with a tapered reamer (Figs. 10–26 and 10–27).

28. *How can one memorize all the formulas used in taper calculations?*
By thinking of the initials of the different parts of the taper—for example, tpf is taper per foot, *D* is large diameter, and so on. Then associate the letters with the words, as in the following chart of taper formulas (Fig. 10–28).

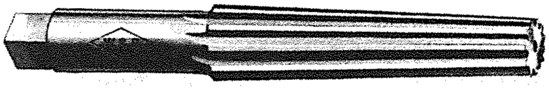


Fig. 10–26. Morse taper reamer. (Whitman & Barnes.)

Fig. 10–27. Taper-pin reamer. (Whitman & Barnes.)

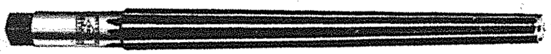


Fig. 10–28. Chart of taper formulas.

given	*to find*	*rule*	*formula*
1. Taper per foot	Taper per inch	Divide taper per foot by 12	$\text{tpi} = \frac{\text{tpf}}{12}$
2. Taper per inch	Taper per foot	Multiply taper per inch by 12	$\text{tpf} = \text{tpi} \times 12$
3. Small and large diameters and length of taper in inches	Taper per foot	Subtract small diameter from large diameter; divide by length of taper multiplied by 12	$\text{tpf} = \frac{D - d}{L \times 12}$
4. Large diameter, length of taper in inches, and taper per foot	Diameter of small end	Divide taper per foot by 12, multiply by length of taper, and subtract from large diameter	$d = D - \frac{\text{tpf}}{12} \times L$
5. Small diameter, length of taper, and taper per foot	Diameter at large end	Divide taper per foot by 12; multiply by length of taper; add result to small diameter	$D = d + \frac{\text{tpf}}{12} \times L$
6. Taper per foot, large diameter, and small diameter	Distance between two given diameters	Subtract small diameter from large diameter; divide by taper per foot; multiply quotient by 12	$L = \frac{D - d}{\text{tpf}} \times 12$
7. Included angle of taper	Taper per inch	Find the tangent of included angle	tpi = tan of angle
8. Taper per foot and length of tapered part	Amount of taper in inches for the given length	Divide taper per foot by 12; multiply by given length of taper	$at = \frac{\text{tpf}}{12} \times L$

chapter 11

screw thread processes

Screws and screw threads have been used for centuries as a means of joining or fastening metal parts together. As far back as the Middle Ages, nuts and bolts were used to hold parts of armor suits together. The chief advantage of using threaded screws is that parts can be disassembled and reassembled without damage.

Modern industry has developed a system of standardized, interchangeable screw threads, which makes possible mass production of threaded fasteners and power-driven screws for all kinds of precision machinery. Screw threads are used also as a means of precision measurement. The micrometer for example, depends upon the screw thread principle for obtaining measurements within ten-thousandths of an inch.

1. *Define a screw thread.*
A screw thread is a ridge of uniform section in the form of a helix cut around the circumference of a cylinder and advancing along the axis. A straight thread is one cut on a cylinder. A taper thread is one cut on a cone or frustum of a cone, more commonly called a *taper.*

2. *What are external and internal threads?*
An external thread is a thread on the outside of a part. An example is the thread on a machine bolt. An internal thread is a thread on the inside of a part. An example is the thread in a nut.

3. *Explain the meaning of right-hand and left-hand screw threads.*
A right-hand thread is one that, when assembled with a fixed mating thread, is turned in a clockwise direction. A left-hand thread is one that, when assembled with a fixed mating thread, is turned in a counterclockwise direction.

4. *What is meant by a single thread?*
A single thread is a thread that has a lead equal to the pitch.

5. *What are multiple threads?*
Multiple threads are threads in which the lead is an integral multiple of the pitch. A multiple thread having two starts, or separate threads, is called a double thread; one having three starts is called a triple thread; one with four starts is called a quadruple thread. Figure 11–1 shows examples of single and multiple threads.

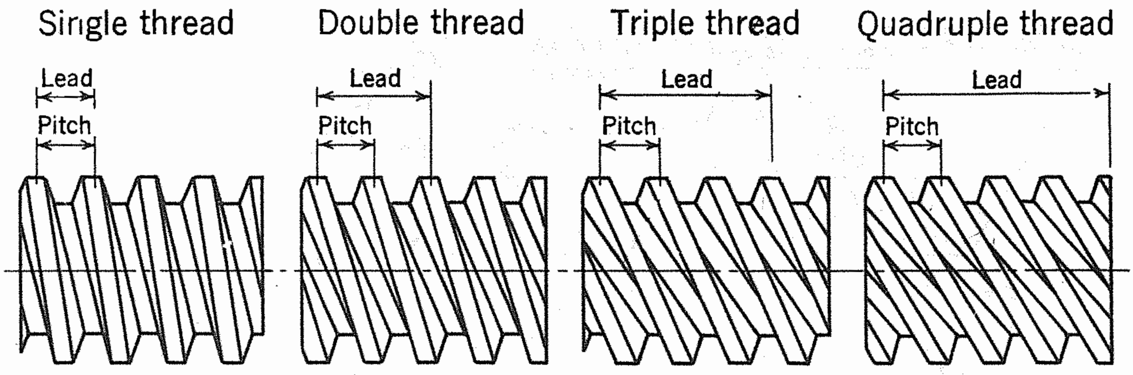


Fig. 11–1. Relationship of lead and pitch of multiple threads.

6. *Describe the American National form of screw thread.*
The American National form of screw thread (Fig. 11–2) resulted from a consolidation of several thread systems previously known as Sellers, United States Standard, ASME machine-screw numbered sizes, and SAE threads. This form of thread is the most widely used in American industry and has beer adopted as a standard by the Screw Threads Commission and the American National Standards Institute (ANSI). It consists of size and pitch combinations, which use the letter symbol N. Figure 11–2 shows the principal parts of this thread.

7. *What is the Unified and American screw thread?*
The most common type of thread in use today is the American National form of thread, of which there are several series. Of these, the coarse-thread series and fine-thread series are widely used. The Unified and American thread, which incorporates the American National form, resulted from an agreement between Canada, the United States, and the United Kingdom (November 18, 1948) to standardize threads on a universal basis. The form of this thread and the formulas for determining the dimensions of each part of the thread are shown in Fig. 11–3. An illustration of some general screw-thread symbols and their explanations is shown in Fig. 11–4.

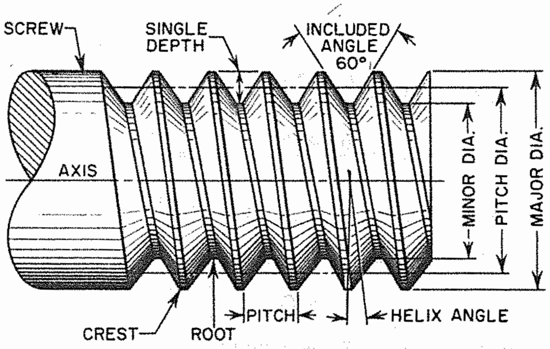


Fig. 11–2. Principal parts of American National screw thread.

8. *What are terms and definitions of the more common elements or parts of the American National screw thread?*
The terms and definitions of the more common elements or parts of the American National screw thread are as follows:

A. **Major diameter** (formerly known as outside diameter). The largest diameter of the thread of the screw or nut. The term *major diameter* replaced the term *outside diameter,* as applied to the thread of a screw, and also the term *full diameter,* as applied to the thread of a nut.
B. **Minor diameter** (formerly known as core diameter or root diameter). The smallest diameter of the thread of the screw or nut. The term *minor diameter* replaced the term *core diameter,* as applied to the thread of a screw, and also the term *inside diameter,* as applied to the thread of a nut.
C. **Pitch diameter.** On a straight screw thread, it is the diameter of an imaginary cylinder, the surface of which would pass through the threads at such points as to make equal

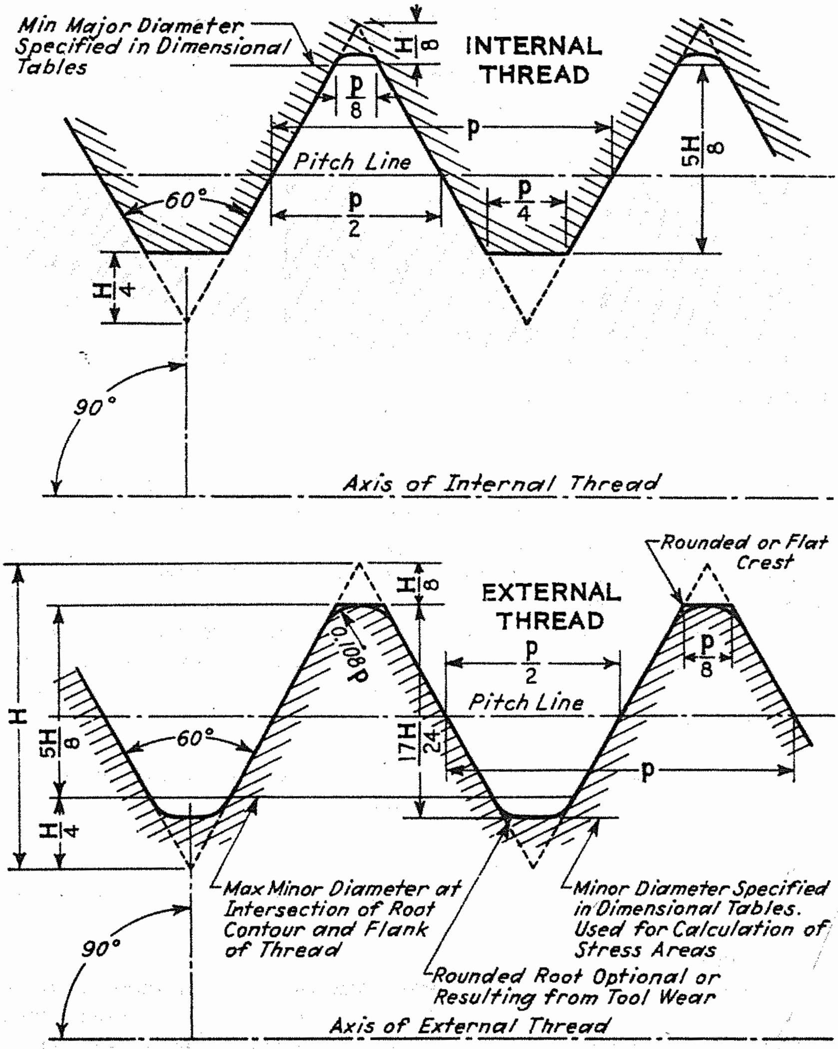


Fig. 11–3. Unified and American internal and external screw-thread design forms and formulas. (American Society of Mechanical Engineers.)

α = Half angle of thread
n = Number of threads per inch
p = Pitch of thread
H = Height of sharp V thread
h_s = Height of external thread (screw)
h_n = Height of internal thread (nut)
D = Major diameter (nominal diameter)
E = Pitch diameter
K = Minor diameter

$\alpha = 30°$

$2\alpha = 60°$

$H = 0.86603p \qquad H = \dfrac{0.86603}{n}$

$n = \dfrac{1}{p}$

$p = \dfrac{1}{n}$

$h_s = 0.61343p \qquad h_s = \dfrac{0.61343}{n} \qquad h_s = \dfrac{17}{24}H$

$h_n = 0.54127p \qquad h_n = \dfrac{0.54127}{n} \qquad h_n = \dfrac{5}{8}H$

$E = D - 0.64952p \qquad E = D - \dfrac{0.64952}{n}$

$K_s = D_s - 2h_s \qquad K_s = D_s - 1.22687p$

$K_s = D_s - \dfrac{1.22687}{n}$

$K_n = D_n - 2h_n \qquad K_n = D_n - 1.08253p$

$K_n = D_n - \dfrac{1.08253}{n}$

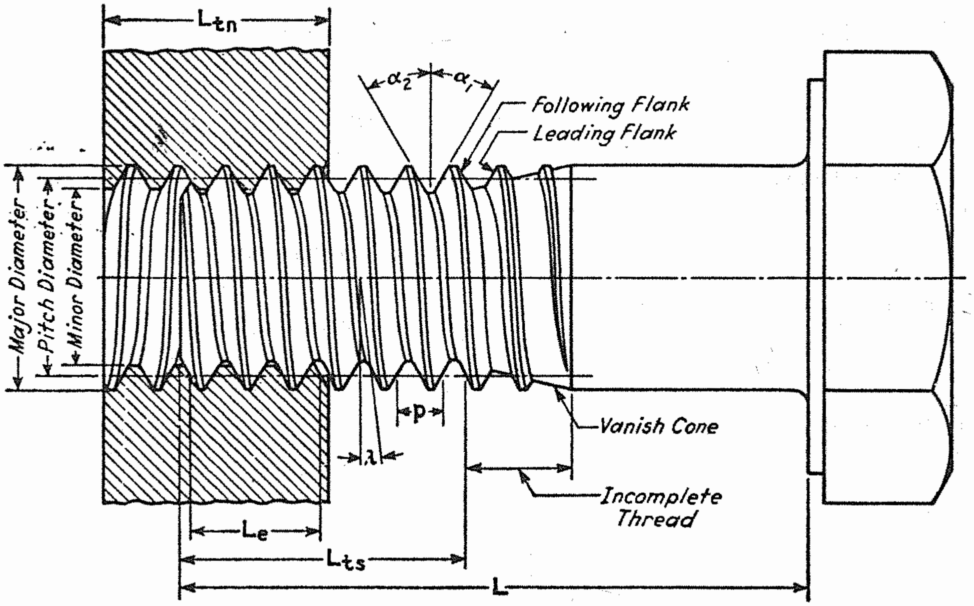


Fig. 11–4. General screw-thread symbols. (American Society of Mechanical Engineers.)
L_{tn} = Length of internal thread (nut)
L_e = Length of engagement
L_{ts} = Length of external thread (screw)
L = Length of screw
λ = Helix angle

the width of the threads and the width of the spaces cut by the surface of the cylinder. On a tapered screw, it is the diameter of an imaginary cone at a given distance from a reference plane perpendicular to the axis. The surface of the imaginary cone would pass through the threads at such points as to make equal the width of the threads and the width of the spaces cut by the surface of the cone.

D. **Pitch.** The distance from a point on a screw thread to a corresponding point on the next thread, measured parallel to the axis.

$$\text{Pitch (inches)} = \frac{1.0}{\text{threads per inch}}$$

E. **Lead.** The distance a screw thread advances axially in one turn. On a single-thread screw, the lead and pitch are identical; on a double-thread screw, the lead is twice the pitch; on a triple-thread screw, the lead is three times the pitch; and so forth.

F. **Angle of thread.** The angle included between the sides of the thread, measured in an axial plane.

G. **Helix angle.** The angle made by the helix of the thread at the pitch diameter, with a plane perpendicular to the axis.

H. **Crest.** The top surface joining the two sides of a thread.

I. **Root.** The bottom surface joining the sides of two adjacent threads.

J. **Side.** The surface between crest and root.

K. **Axis of a screw.** The longitudinal center line through the screw.

L. **Base of thread.** The bottom section of the thread; the greatest section between the two adjacent roots.

M. **Depth of thread.** The distance between the ~~crest and~~ the base of the thread, measured perpendicular to the axis.

N. **Number of threads.** Number of threads in 1 in. of length.

O. **Length of engagement.** The length of contact between two mating parts, measured axially.

P. **Depth of engagement.** The depth of thread contact between two mating parts, measured radially.

Q. **Pitch line.** An element of the imaginary cylinder or cone specified in definition C.

R. **Thickness of thread.** The distance between the adjacent sides of the thread, measured along or parallel to the pitchline.

S. **Allowance.** An intentional difference in the dimensions of mating parts. It is the minimum clearance or the maximum interference which is intended between mating parts. It represents the condition of the tightest permissible fit, or the largest internal member mated with the smallest external member. This is illustrated by the two following examples.

example 1: One-half inch, class 1A and class 1B (loose fit), American National coarse-thread series:

Minimum pitch diameter of nut	0.4500
Maximum pitch diameter of screw	0.4478
Allowance (positive)	0.0022

example 2: One-half inch, class 3A and class 3B (close fit), American National coarse-thread series:

Minimum pitch diameter of nut	0.4500
Maximum pitch diameter of screw	0.4504
Allowance (negative)	0.0004

T. **Tolerance.** The amount of variation permitted in the size of a part.

example: One-half-inch screw, class 1A and class 1B (loose fit), American National coarse-thread series:

Maximum pitch diameter	0.4478
Minimum pitch diameter	0.4404
Tolerance	0.0074

U. **Basic size.** The theoretical or nominal standard size from which all variations are made.

V. **Crest allowance.** Defined on a screw form as the space between the crest of a thread and the foot of its mating thread.

W. **Finish.** The character of the surface of a screw thread or other product.

X. **Fit.** The relation between two mating parts with reference to the conditions of assembly, as wrench fit, close fit, medium fit, free fit, and loose fit. The quality of fit depends upon both the relative size and finish of the mating parts.

Y. **Neutral zone.** A positive allowance (see definition S).

Z. **Limits.** The extreme permissible dimensions of a part.

example: One-half-inch screw, class 1A (loose fit), American National coarse-thread series:

Maximum pitch diameter, 0.4478
Minimum pitch diameter, 0.4404
These are the limits.

9. *Explain the difference between the minor diameters of a screw and of a nut.*
The minor diameter of a nut is made larger than the minor diameter of a screw. This is done to provide a working clearance between the two parts (Fig. 11-5). For many jobs, the recommended size of tap drill will make a hole with a reasonable clearance. For more precise work, the actual size of hole to be bored may be calculated.

10. *Describe the difference between the lead and the pitch of a screw.*
The pitch is the distance between a point on one thread and the corresponding point on the next thread, measured parallel to the axis. The lead is

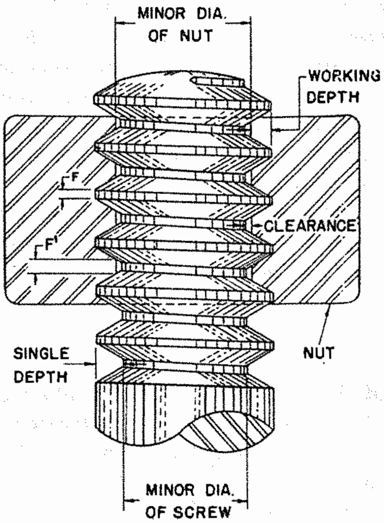


Fig. 11-5. Comparison between the minor diameter of a nut and a screw.

the distance a nut will advance on a screw, parallel to its axis, in one revolution. On a single-thread screw, the lead equals the pitch; on a double-thread screw, it equals twice the pitch; on a triple-thread screw, three times the pitch, and so forth (Fig. 11–1).

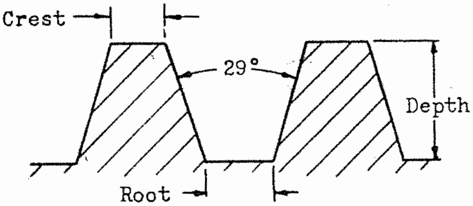
11. *What is a sharp V thread?*
The sharp V thread (Fig. 11–6) is similar to the National form of thread. Because its sharp point is easily damaged this type of thread is becoming obsolete. It was favored by watchmakers and instrument makers for very small screws.

12. *What is an acme thread?*
An acme thread (Fig. 11–6) is a modification of the square form of thread. It is preferred for many jobs because it is fairly easy to machine. It has a 29° included angle and is largely used for feed and lead screws on machine tools. An acme thread gage (Fig. 11–7) is used when grinding the cutting tool and also for adjusting the tool square with the work. The notches on the edge of the gage are for checking the correct width of the point of the tool according to the number of threads per inch specified for the acme thread.

13. *What size of hole should be bored before cutting a 2½-in. internal acme thread having three threads per inch?*

Fig. 11–6. Standard forms of threads.

Acme Thread

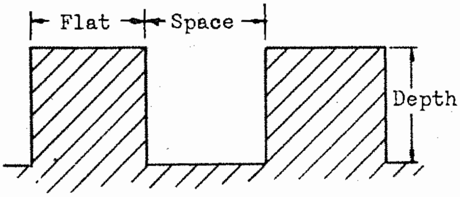


$$\text{Depth} = \frac{0.500}{N} + 0.010 \text{ in.}$$

$$\text{Crest} = \frac{0.3707}{N}$$

$$\text{Root} = \frac{0.3707}{N} - 0.0052 \text{ in.}$$

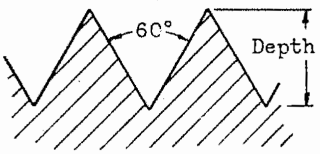
Square Thread



$$\text{Depth} = \frac{0.5000}{N} \qquad \text{Width of flat} = \frac{0.5000}{N}$$

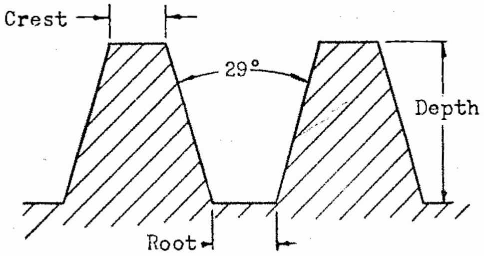
$$\text{Width of space} = \frac{0.5000}{N}$$

Sharp V Thread



$$\text{Depth} = \frac{0.8660}{N}$$

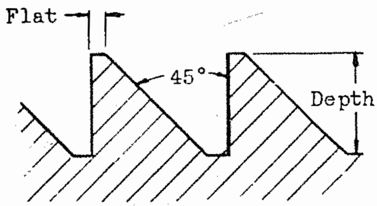
Brown & Sharpe Worm Thread



$$\text{Depth} = \frac{0.6866}{N} \qquad \text{Root} = \frac{0.310}{N}$$

$$\text{Crest} = \frac{0.335}{N}$$

Buttress Thread



$$\text{Depth} = \frac{0.7500}{N}$$

$$\text{Width of flat} = \frac{\text{Pitch}}{8}$$

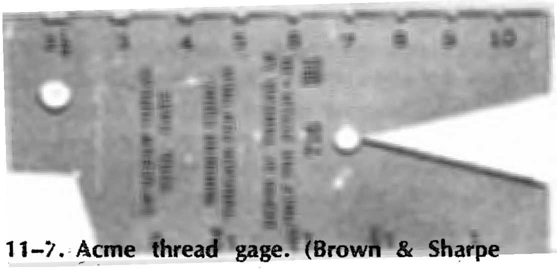
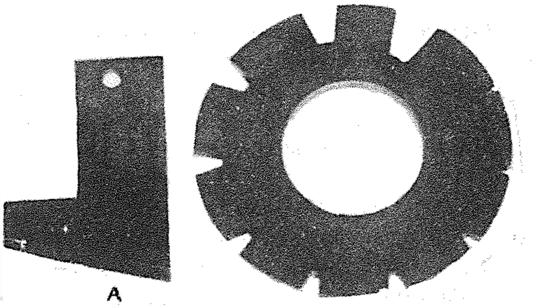


Fig. 11–7. Acme thread gage. (Brown & Sharpe Mfg. Co.)



A

B

Fig. 11–8. Brown & Sharpe setting-tool gage (A) and worm-thread gage (B). (Brown & Sharpe Mfg. Co.)

The diameter of the hole to be bored is equal to the major diameter of the required thread minus the double depth of the thread. In this case,

$$\begin{aligned}\text{Size of hole} &= 2.5 - 2 \times \frac{0.500}{3}\\ &= 2.5 - 0.3333\\ &= 2.1667 \text{ inches}\end{aligned}$$

14. *What is a Brown & Sharpe worm thread?*
The Brown & Sharpe worm thread (Fig. 11–6) is another modification of the square thread. It is similar to the acme thread in shape but is cut deeper. The circular gage in Fig. 11–8 is used to grind the cutting tool to the required shape and size. The tool-setting gage is used for setting the cutting tool square with the work.

15. *What is the minor diameter of a Brown & Sharpe worm thread that has a major diameter of 3 in., with two threads per inch?*
The minor diameter of the thread is equal to the major diameter minus the double depth of the thread. In this case,

$$\begin{aligned}\text{Minor diameter} &= 3 - 2 \times \frac{0.6866}{2}\\ &= 3 - 0.6866\\ &= 2.3134 \text{ inches}\end{aligned}$$

16. *What is a square thread?*
A square thread (Fig. 11–6) is one in which the width of the thread, the depth of the thread, and the space between threads are approximately equal. This type of thread is very strong. It is difficult to machine square threads accurately. The space of the square threaded nut must be made a few thousandths larger than the screw thread to provide for clearance.

17. *What size of hole should be bored before cutting a 2-in. internal square thread having four threads per inch?*
The diameter of the hole to be bored is equal to the major diameter of the thread minus the double depth of the thread. In this case,

$$\begin{aligned}\text{Size of hole} &= 2 - 2 \times \frac{0.500}{4}\\ &= 2 - 0.250\\ &= 1.750 \text{ inches}\end{aligned}$$

18. *What is a buttress thread?*
A buttress thread is cut square on one side and slanting on the other side, as in Fig. 11–6. It is used where a thread requiring great strength in one direction is required, as in certain types of vises, gun breeches, and ratchets.

19. *How are the specifications for a thread given on a blueprint?*
The specifications for a thread are given on a blueprint in a definite, abbreviated form. For example, the specifications may read 1/2–13NC–3B–4 holes. The workman who reads these specifications is informed that the major diameter of the thread is ½ in., the number of threads per inch is 13, the kind of thread is the National form, it is a standard member of the coarse series of threads, the thread gage is to have a class 3 fit. The symbol *B* indicates an internal thread. Four such holes are required (Fig. 11–9).

20. *What information is required on a blueprint for cutting square, acme, Brown & Sharpe, and buttress threads?*

of the tap, preventing clogging of the flutes. This tap is generally used on through holes, but may be used for tapping blind holes when the hole is deep enough to allow for the chips. These taps may also be operated at higher speeds, and they require less power than regular hand taps.

29. *What are nut taps?*
Nut taps (Fig. 11–18) are power-driven taps used in nut-threading machines or on drill presses. The tap has a long chamfer to prevent overloading the end teeth. A small point or end diameter aids in starting the tap in the hole. The shank diameter is less than the minor diameter of the nut, so as the nuts are tapped they slide upward on the shank. When the shank becomes filled, it is necessary to take the tap out of the machine to remove the nuts.

30. *What are tapper taps?*
Tapper taps have longer shanks and shorter thread lengths than nut taps. They are made with straight or bent shanks (Figs. 11–19 and 11–20) for use in production and automatic tapping machines.

Fig. 11–18. Nut tap. (Greenfield Tap & Die Corp.)

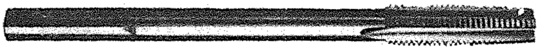


Fig. 11–19. Tapper tap—straight shank. (Greenfield Tap & Die Corp.)

Fig. 11–20. Tapper tap—bent shank. (Greenfield Tap & Die Corp.)

31. *What are straight and taper pipe taps?*
Straight and taper pipe taps (Figs. 11–21 and 11–22) are used for tapping pipe fittings. The taper pipe tap is tapered ¾ in. per ft, which provides a tight joint. The straight pipe tap is used for such fittings as locknuts and couplings that are to be assembled with taper thread parts.

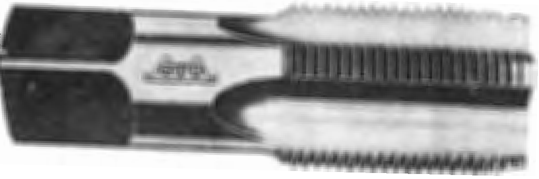
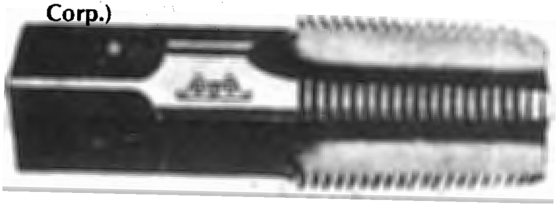


Fig. 11–21. Straight pipe tap. (Greenfield Tap & Die Corp.)

Fig. 11–22. Taper pipe tap. (Greenfield Tap & Die Corp.)



32. *What is meant by the grade of a tap?*
There are two grades of taps: cut-thread and ground-thread. Cut-thread taps, usually made from carbon-steel, are threaded before hardening. They have wider tolerances due to the changes that take place during the heat-treatment process. Cut-thread taps work well in brass and other nonabrasive materials, as well as for machine tapping where loose fits are satisfactory and moderate pressure is used to drive the tap.

Ground-thread taps, made of high-speed steel, are finish ground to size after heat treatment. These taps can be made to much closer tolerances for the pitch diameter and lead dimensions. They are more widely used than cut-thread taps because they stand up better when tapping tough steel alloys and abrasive materials.

33. *Describe the different kinds of tapped holes.*
In general practice, there are four kinds of tapped holes (Fig. 11–23). These are (a) through holes, which pass all the way through a part; (b) blind bottoming holes, which are drilled to a specified depth and tapped within 1 to 1½ threads from the bottom; (c) blind but not bottoming, in which the tapped thread stops a given distance from the bottom of the hole; and (d) blind holes, which are recessed at the bottom to provide a full thread and permit the mating part to be turned to the full depth of the hole.

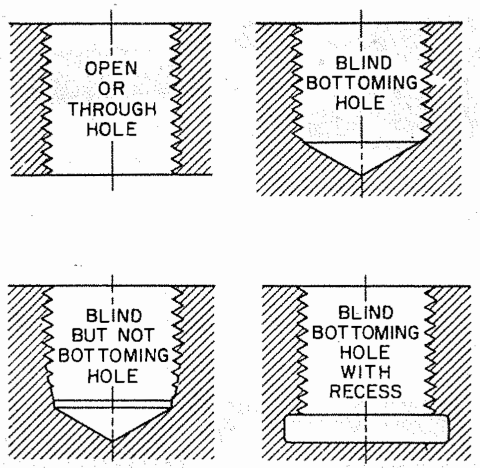


Fig. 11–23. Types of tapped holes. (Greenfield Tap & Die Corp.)

34. *What is a tap wrench?*
A tap wrench is a hand tool for gripping and holding a tap securely. For the smaller sizes of taps, a T-handle type (Fig. 11–24) is used. For large sizes of taps, the adjustable tap wrench shown in Fig. 11–25 is preferred.

35. *Describe the technique of tapping a hole.*
After the location of the hole has been properly laid out, a hole is drilled. The correct size of the drill to use is usually determined by consulting a table similar to that in Fig. 11–26. For example, a $^{27}/_{64}$ drill would be used for a ½–13 tap and a $^{29}/_{64}$ drill for a $^{1}/_{2}$–20 tap. The hole is usually drilled $^{1}/_{8}$ to $^{1}/_{4}$ in. deeper than the required depth of the thread (Fig. 11–27). When starting the tap into the hole, care must be used to keep the tap perpendicular to the work. The tap should be revolved only one-half a

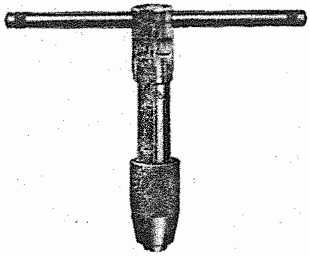


Fig. 11–24. T-handle tap wrench. (Greenfield Tap & Die Corp.)

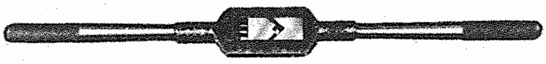


Fig. 11–25. Adjustable tap wrench. (Greenfield Tap & Die Corp.)

revolution at a time, after which it should be reversed in order to break the chips of metal before revolving forward again.

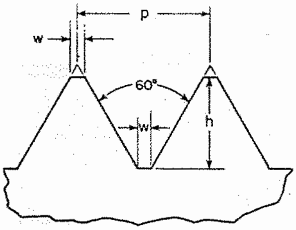
36. *How may a tapped hole be checked for being perpendicular to the surface of the work?*
It may be tested with a steel square. The vertical edge of the square should touch the solid body of the tap. The hole should be tested before all the threads have been cut, and after the job is done.

37. *What kind of lubricant should be used for general threading?*
Mineral lard oil is a very good lubricant for threading. It is made of white lead, graphite, and fatty oil. The Geometric Tool Company advises the use of the following compound for screw-thread cutting: 40 gal of water mixed with 10 gal of mineral lard oil and 2½ lb of soda.

38. *How may a broken tap be removed from a tapped hole?*
If there is not enough of the tap protruding above the hole so that it may be gripped with pliers, a tap extractor should be used (Fig. 11-28). The extractor is held in a tap wrench. The steel prongs are pushed down each flute of the tap as far as possible and held in place by the long bushing. The extractor must be turned carefully to avoid breaking its prongs.

39. *How may a broken screw be removed from a tapped hole?*
A broken screw may be removed with an Ezy-out screw extractor (Fig. 11–29). A hole is first drilled into the broken screw. It should be a little smaller than the minor diameter of the thread. An Ezy-out screw extractor of the proper size is then inserted in the hole. The left-hand spirals of the Ezy-out will grip the sides of the hole, and, as it is turned counterclockwise, the screw will be backed out.

40. *What is a threading die?*
A threading die is a flat piece of hardened steel, internally threaded, with grooves or flutes intersecting the threads to form cutting edges. It is used



$$p = \frac{1}{n}$$

$$h = p \times 0.649519 = \frac{0.649519}{n}$$

$$w = \frac{p}{8}$$

Where p = pitch
n = number of threads per inch
h = depth of thread
w = flat width

NUMBERED SCREW SIZES

NOMINAL SIZE	OUTSIDE DIA., IN.	PITCH DIA., IN.	ROOT DIA., IN.	TAP DRILL, IN.	DECIMAL EQUIVALENT OF TAP DRILL, IN.	NOMINAL SIZE	OUTSIDE DIA., IN.	PITCH DIA., IN.	ROOT DIA., IN.	TAP DRILL, IN.	DECIMAL EQUIVALENT OF TAP DRILL, IN.
†0-80	0.0600	0.0519	0.0438	3/64	0.0469	†10-24	0.1900	0.1629	0.1359	25	0.1495
†1-56	0.0730	0.0614	0.0498	54	0.0550	28	0.1900	0.1668	0.1436	23	0.1540
64	0.0730	0.0629	0.0527	53	0.0595	30	0.1900	0.1684	0.1467	22	0.1570
72	0.0730	0.0640	0.0550	53	0.0595	32	0.1900	0.1697	0.1494	21	0.1590
†2-56	0.0860	0.0744	0.0628	50	0.0700	†12-24	0.2160	0.1889	0.1619	16	0.1770
64	0.0860	0.0759	0.0657	50	0.0700	28	0.2160	0.1928	0.1696	14	0.1820
†3-48	0.0990	0.0855	0.0719	47	0.0785	32	0.2160	0.1957	0.1754	13	0.1850
56	0.0990	0.0874	0.0758	45	0.0820	†14-20	0.2420	0.2095	0.1770	10	0.1935
†4-32	0.1120	0.0917	0.0714	45	0.0820	24	0.2420	0.2149	0.1879	7	0.2010
36	0.1120	0.0940	0.0759	44	0.0860	†16-18	0.2680	0.2319	0.1958	3	0.2130
40	0.1120	0.0958	0.0795	43	0.0890	20	0.2680	0.2355	0.2030	7/32	0.2187
48	0.1120	0.0985	0.0849	42	0.0935	22	0.2680	0.2385	0.2090	2	0.2210
†5-36	0.1250	0.1070	0.0889	40	0.0980	†18-18	0.2940	0.2579	0.2218	B	0.2380
40	0.1250	0.1088	0.0925	38	0.1015	20	0.2940	0.2615	0.2290	D	0.2460
44	0.1250	0.1102	0.0955	37	0.1040	†20-16	0.3200	0.2794	0.2389	G	0.2610
†6-32	0.1380	0.1177	0.0974	36	0.1065	18	0.3200	0.2839	0.2478	17/64	0.2656
36	0.1380	0.1200	0.1019	34	0.1110	20	0.3200	0.2875	0.2550	I	0.2720
40	0.1380	0.1218	0.1055	33	0.1130	22-16	0.3460	0.3054	0.2648	9/32	0.2812
†7-30	0.1510	0.1294	0.1077	31	0.1200	18	0.3460	0.3099	0.2738	L	0.2900
32	0.1510	0.1307	0.1104	31	0.1200	†24-16	0.3720	0.3314	0.2908	5/16	0.3125
36	0.1510	0.1330	0.1149	1/8	0.1250	18	0.3720	0.3359	0.2998	O	0.3160
†8-30	0.1640	0.1423	0.1207	30	0.1285	26-14	0.3980	0.3516	0.3052	21/64	0.3281
32	0.1640	0.1437	0.1234	29	0.1360	16	0.3980	0.3574	0.3168	R	0.3390
36	0.1640	0.1460	0.1279	29	0.1360	28-14	0.4240	0.3776	0.3312	T	0.3580
40	0.1640	0.1478	0.1315	28	0.1405	16	0.4240	0.3834	0.3428	23/64	0.3594
†9-24	0.1770	0.1499	0.1229	29	0.1360	30-14	0.4500	0.4036	0.3572	V	0.3770
30	0.1770	0.1553	0.1337	27	0.1440	16	0.4500	0.4094	0.3688	25/64	0.3906
32	0.1770	0.1567	0.1364	26	0.1470						

FRACTIONAL SCREW SIZES

NOMINAL SIZE	OUTSIDE DIA., IN.	PITCH DIA., IN.	ROOT DIA., IN.	TAP DRILL, IN.	DECIMAL EQUIVALENT OF TAP DRILL, IN.	NOMINAL SIZE	OUTSIDE DIA., IN.	PITCH DIA., IN.	ROOT DIA., IN.	TAP DRILL, IN.	DECIMAL EQUIVALENT OF TAP DRILL, IN.
1/16-64	0.0625	0.0524	0.0422	3/64	0.0469	27	0.5625	0.5384	0.5144	17/32	0.5312
72	0.0625	0.0535	0.0445	3/64	0.0469	5/8-11	0.6250	0.5660	0.5069	17/32	0.5312
5/64-60	0.0781	0.0673	0.0563	1/16	0.0625	12	0.6250	0.5709	0.5168	35/64	0.5469
72	0.0781	0.0691	0.0601	52	0.0635	18	0.6250	0.5889	0.5528	37/64	0.5781
3/32-48	0.0938	0.0803	0.0667	49	0.0730	27	0.6250	0.6009	0.5769	19/32	0.5937
50	0.0938	0.0808	0.0678	49	0.0730	11/16-11	0.6875	0.6285	0.5694	19/32	0.5937
7/64-48	0.1094	0.0959	0.0823	43	0.0890	16	0.6875	0.6469	0.6063	5/8	0.6250
1/8-32	0.1250	0.1047	0.0844	3/32	0.0937	3/4-10	0.7500	0.6850	0.6201	21/32	0.6562
40	0.1250	0.1088	0.0925	38	0.1015	12	0.7500	0.6959	0.6418	43/64	0.6719
9/64-40	0.1406	0.1244	0.1081	32	0.1160	16	0.7500	0.7094	0.6688	11/16	0.6875
5/32-32	0.1563	0.1360	0.1157	1/8	0.1250	27	0.7500	0.7259	0.7019	23/32	0.7187
36	0.1563	0.1382	0.1202	30	0.1285	13/16-10	0.8125	0.7476	0.6826	23/32	0.7187
11/64-32	0.1719	0.1516	0.1313	9/64	0.1406	7/8-9	0.8750	0.8028	0.7307	49/64	0.7656
3/16-24	0.1875	0.1604	0.1334	26	0.1470	12	0.8750	0.8209	0.7668	51/64	0.7969
32	0.1875	0.1672	0.1469	22	0.1570	14	0.8750	0.8286	0.7822	13/16	0.8125
13/64-24	0.2031	0.1760	0.1490	20	0.1610	18	0.8750	0.8389	0.8028	53/64	0.8281
7/32-24	0.2188	0.1917	0.1646	16	0.1770	27	0.8750	0.8509	0.8269	27/32	0.8437
32	0.2188	0.1985	0.1782	12	0.1890	15/16-9	0.9375	0.8654	0.7932	53/64	0.8281
15/64-24	0.2344	0.2073	0.1806	10	0.1935	1-8	1.0000	0.9188	0.8376	7/8	0.8750
1/4-20	0.2500	0.2175	0.1850	7	0.2010	12	1.0000	0.9459	0.8918	59/64	0.9219
24	0.2500	0.2229	0.1959	4	0.2090	14	1.0000	0.9536	0.9072	15/16	0.9375
27	0.2500	0.2260	0.2019	3	0.2130	27	1.0000	0.9759	0.9519	31/32	0.9687
28	0.2500	0.2268	0.2036	3	0.2130	1 1/8-7	1.1250	1.0322	0.9394	63/64	0.9844
32	0.2500	0.2297	0.2094	7/32	0.2188	12	1.1250	1.0709	1.0168	1 3/64	1.0469
5/16-18	0.3125	0.2764	0.2403	F	0.2570	1 1/4-7	1.2500	1.1572	1.0644	1 7/64	1.1094
20	0.3125	0.2800	0.2476	17/64	0.2656	12	1.2500	1.1959	1.1418	1 11/64	1.1719
24	0.3125	0.2854	0.2584	I	0.2720	1 3/8-6	1.3750	1.2667	1.1585	1 7/32	1.2187
27	0.3125	0.2884	0.2644	J	0.2770	12	1.3750	1.3209	1.2668	1 19/64	1.2969
32	0.3125	0.2922	0.2719	9/32	0.2812	1 1/2-6	1.5000	1.3917	1.2835	1 11/32	1.3437
3/8-16	0.3750	0.3344	0.2938	5/16	0.3125	12	1.5000	1.4459	1.3918	1 27/64	1.4219
20	0.3750	0.3425	0.3100	21/64	0.3281	1 5/8-5 1/2	1.6250	1.5069	1.3888	1 29/64	1.4531
24	0.3750	0.3479	0.3209	Q	0.3320	1 3/4-5	1.7500	1.6201	1.4902	1 9/16	1.5625
27	0.3750	0.3509	0.3269	R	0.3390	1 7/8-5	1.8750	1.7451	1.6152	1 11/16	1.6875
7/16-14	0.4375	0.3911	0.3447	U	0.3680	2-4 1/2	2.0000	1.8557	1.7113	1 25/32	1.7812
20	0.4375	0.4050	0.3726	25/64	0.3906	2 1/8-4 1/2	2.1250	1.9807	1.8363	1 29/32	1.9062
24	0.4375	0.4104	0.3834	X	0.3970	2 1/4-4 1/2	2.2500	2.1057	1.9613	2 1/32	2.0312
27	0.4375	0.4134	0.3894	Y	0.4040	2 3/8-4	2.3750	2.2126	2.0502	2 1/8	2.1250
1/2-12	0.5000	0.4459	0.3918	27/64	0.4219	2 1/2-4	2.5000	2.3376	2.1752	2 1/4	2.2500
13	0.5000	0.4500	0.4001	27/64	0.4219	2 3/4-4	2.7500	2.5876	2.4252	2 1/2	2.5000
20	0.5000	0.4675	0.4351	29/64	0.4531	3-4	3.0000	2.8376	2.6752	2 3/4	2.7500
24	0.5000	0.4729	0.4459	29/64	0.4531	3 1/4-4	3.2500	3.0876	2.9252	3	3.0000
27	0.5000	0.4759	0.4519	15/32	0.4687	3 1/2-4	3.5000	3.3376	3.1752	3 1/4	3.2500
9/16-12	0.5625	0.5084	0.4542	31/64	0.4844	3 3/4-4	3.7500	3.5876	3.4252	3 1/2	3.5000
18	0.5625	0.5264	0.4903	33/64	0.5156	4-4	4.0000	3.8376	3.6752	3 3/4	3.7500

Fig. 26 American National thread dimensions and tap drill sizes.

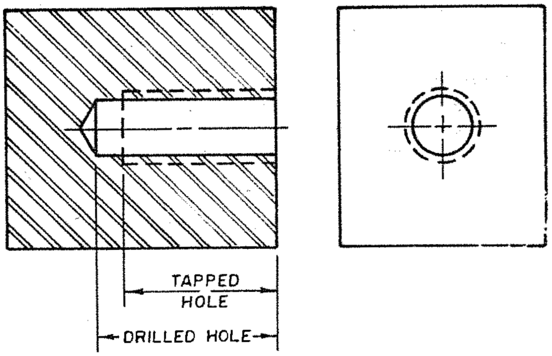


Fig. 11–27. Cross section of tapped hole.

Fig. 11–28. Tap extractor. (Walton Co.)

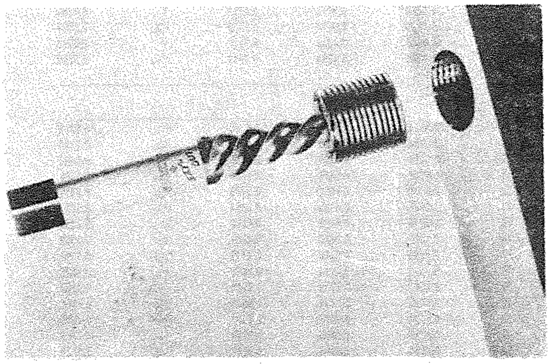


Fig. 11–29. Ezy-out screw extractor. (Cleveland Twist Drill Co.)

for cutting external threads on round bars of metal. The die is split on one side. The purpose of this split is to permit turning a set screw on the side of the die. This expands the die so that the first cut may be more easily made. A set of threading tools (taps, tap holder, dies, and die holder or diestock) is shown in Fig. 11–30.

41. *Are both sides of a threading die the same?*
No. On one side, the hole in the die is chamfered more than on the other side. The deep chamfer helps to get the die started on the work.

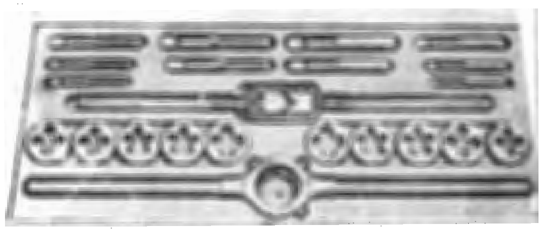


Fig. 11–30. Threading tools. (Morse Twist Drill & Machine Co.)

42. *What is a diestock?*
A diestock is a tool for holding threading dies. An example of its use is shown in Fig. 11–31. The bar to be threaded is held in a vise, and the threading die, held in the diestock, is turned around the bar clockwise. It is customary to reverse the movement occasionally, in order to break the metal chips which might clog the die.

43. *What are self-opening die heads?*
Self-opening die heads are devices that contain a set of thread-cutting tools called *chasers*. The mechanism is designed to release the chasers (cutters) and clear them of the workpiece after the thread has been cut to the proper length. This permits the die head to be withdrawn to the starting position without stopping or reversing the machine. This type of threading die is largely used for production work.

Figure 11–32 shows a hand-operated die head in which the lever is used to reset the chasers. Figure 11–33 shows an automatic releasing die head. There are several advantages in using these die heads rather than solid threading dies. Much time can be saved; the individual sets of chasers can be easily removed for resharpening; the chasers can be easily and readily adjusted for correct pitch diameter; and closer limits of accuracy can be maintained, which improves the quality of the thread produced.

44. *Explain briefly how a 60° external thread may be produced on an engine lathe.*
A 60° external thread may be cut on an engine lathe by gearing the lead screw to the spindle. The gearing, made through the quick-change gear box, controls the movement of the lathe carriage and cutting tool. The pitch of the thread produced depends upon the gearing selected. For each revolution of the spindle (and workpiece) the carriage (and cutting tool)

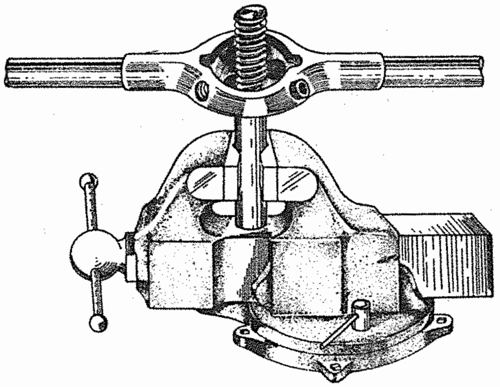


Fig. 11-31. Cutting external threads with a die held in a die stock.

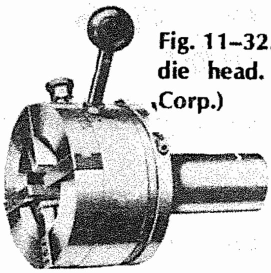


Fig. 11-32. Hand-operated releasing die head. (Greenfield Tap & Die Corp.)

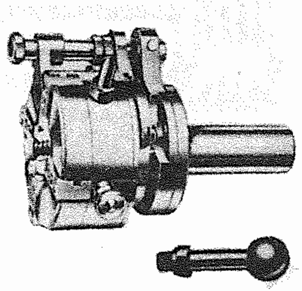


Fig. 11-33. Automatic releasing die head. (Greenfield Tap & Die Corp.)

advances a distance equal to the lead of the thread. A tool bit ground to a 60° included angle and checked tor accuracy with a center gage (Fig. 11-34) shapes the thread. The compound slide is adjusted to an angle of 30° as in Fig. 11-35. The cutting tool is set square with the work, using the center gage, as in Fig. 11-36. A setup for cutting a 60° thread is shown in Fig. 11-37.

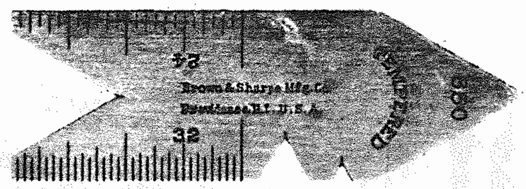


Fig. 11-34. Center gage. (Brown & Sharpe Mfg. Co.)

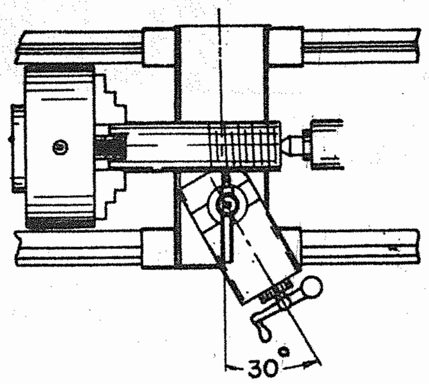


Fig. 11-35. Position of lathe compound for external threading.

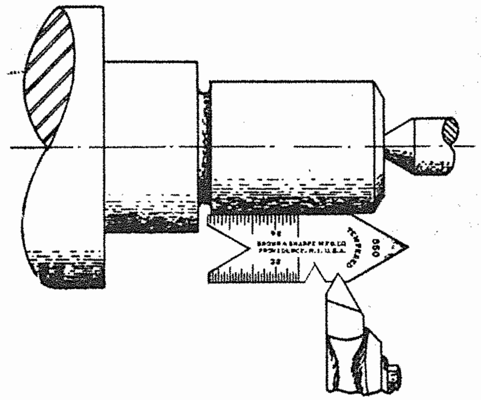


Fig. 11-36. Setting the cutting tool for external threading.

45. *Explain briefly how a 60° internal thread may be produced on the engine lathe.*

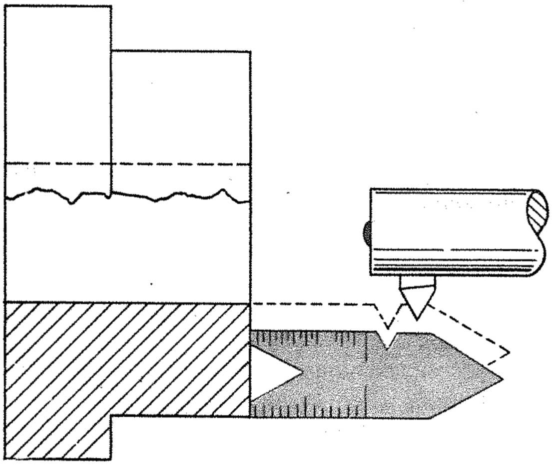
A 60° internal thread may be cut on the lathe by first boring a hole to the required minor diameter of the thread. The cutting tool is usually held in a boring bar holder and set square with the hole using a center

Fig. 11–37. Cutting an external thread on the lathe. (South Bend Lathe, Inc.)

gage, as in Fig. 11–38. The compound slide is adjusted to an angle of 30°. The lead screw for the desired pitch is geared through the quick-change gear box in the same manner as for cutting external threads.

46. *What precaution is necessary to make certain the lathe is geared correctly for the correct number of threads per inch?*
The first cut made should be just deep enough (0.002 to 0.003 in.) to make a thin line. The number of threads per inch being cut may then be checked by using a steel rule or a screw-pitch gage.

Fig. 11–38. Setting the cutting tool for internal threading.



47. *How is the accuracy of the finished thread determined?*
An external thread is checked for accuracy with a ring thread gage (Fig. 11–39), according to the fit specified on the blueprint. An internal thread is checked for accuracy with a plug-thread gage of the go-not-go type (Fig. 11–40). For free fits when accuracy is not required, a nut is often used as a gage. When mating parts are to be threaded and no gages are available, it is customary to cut the external thread first, then cut the internal thread, using the external thread as a gage.

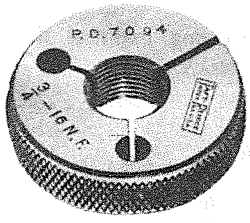
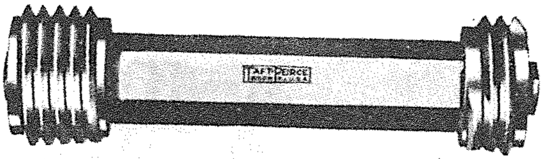


Fig. 11–39. Ring thread gage. (Taft-Peirce Mfg. Co.)

Fig. 11–40. Plug thread gage. (Taft-Peirce Mfg. Co.)



48. *What is the process of producing rolled threads?*
Rolled threads are produced by passing cylindrical material through flat-grooved dies (Fig. 11–41). As the material is rolled through the dies, the top of the grooves of the die is forced into the surface of the material. The material displaced by the die in this manner is compressed into the bottom of the grooves to form the top of the finished thread, as in Fig. 11–42.

Cylindrical dies are also used for rolling threads. They are held in a thread-rolling attachment (Fig. 11–43) which is attached to the tool post of a turret lathe or to an automatic screw machine. A variety of cylindrical thread-rolling dies is shown in Fig. 11–44.

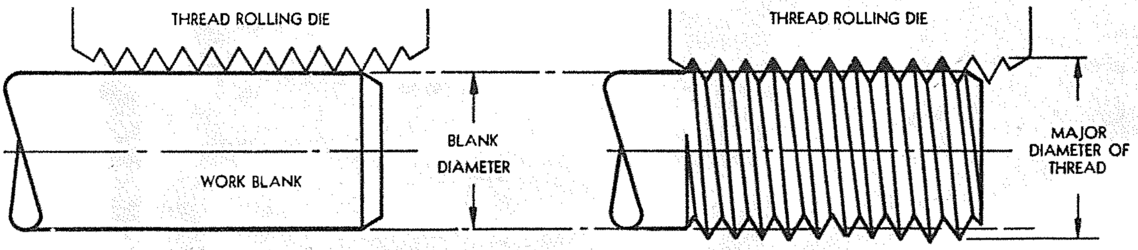
Fig. 11–41. Flat thread-rolling dies. (Reed Rolled Thread Die Co.)

49. *What size of material should be used for rolled threads?*
The outside diameter of material for rolled threads should equal approximately the pitch diameter of the required thread. After the threads have been rolled, the outside diameter of the threaded material will equal the major diameter of the thread. Figure 11–45 shows a comparison between the size of material required for cut threads and rolled threads.

50. *What is the process of grinding threads?*
The production of threads by the grinding process is comparatively new. During the last 30 years, this method for producing threads has been developed to a high degree of perfection, so that it is being accepted and used throughout industry. Special machines are required for this purpose. Figure 11–46 shows an external-thread grinder and Fig. 11–47 an internal-thread grinder.

There are two main types of thread grinding, single rib and multiple rib. Single-rib grinding involves the use of a narrow grinding wheel which is shaped to the form of the required thread. An example of this type of thread grinding is shown in Fig. 11–48.

Fig. 11–42. Displacement of material by thread rolling. (Reed Rolled Thread Die Co.)



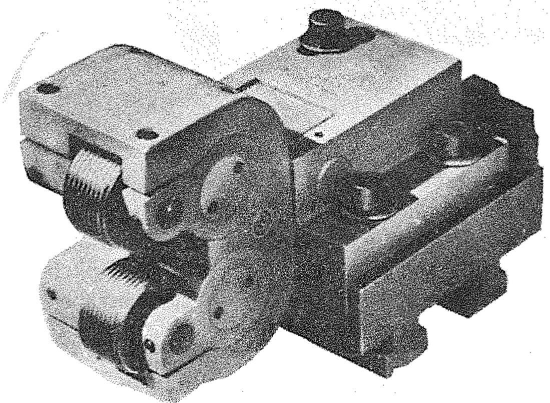


Fig. 11–43. Thread-rolling attachment. (Reed Rolled Thread Die Co.)

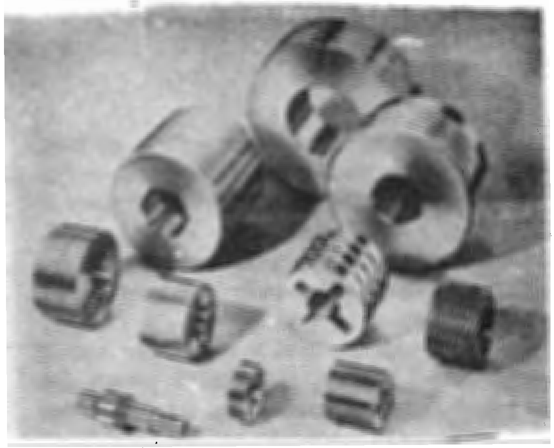


Fig. 11–44. Cylindrical thread-rolling dies. (Reed Rolled Thread Die Co.)

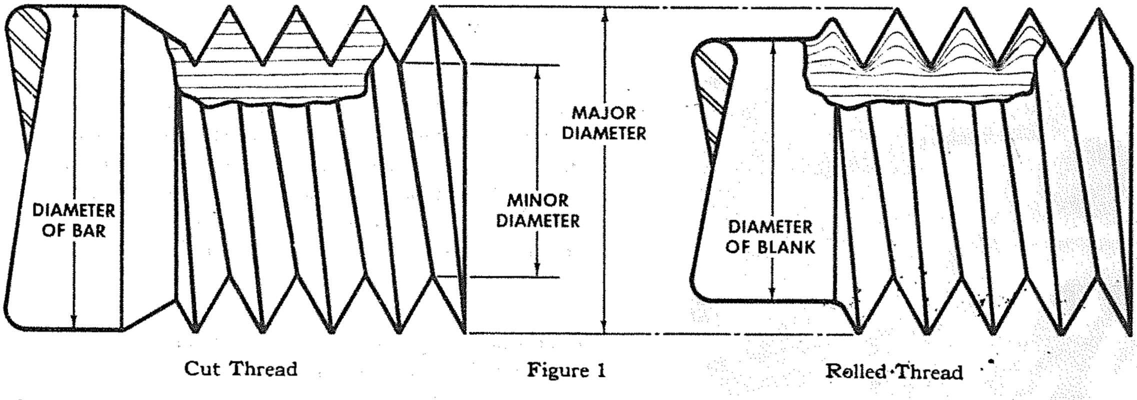


Fig. 11–45. Comparison between the size of material required for cut threads and rolled threads. (Reed Rolled Thread Die Co.)

Fig. 11–46. External-thread grinder. (Kurt Orban Co., Inc.)

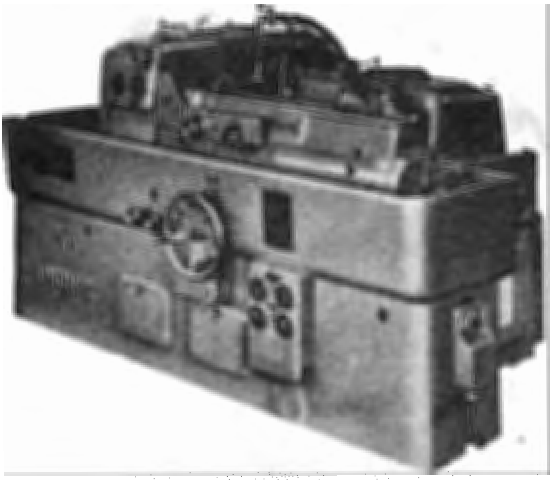
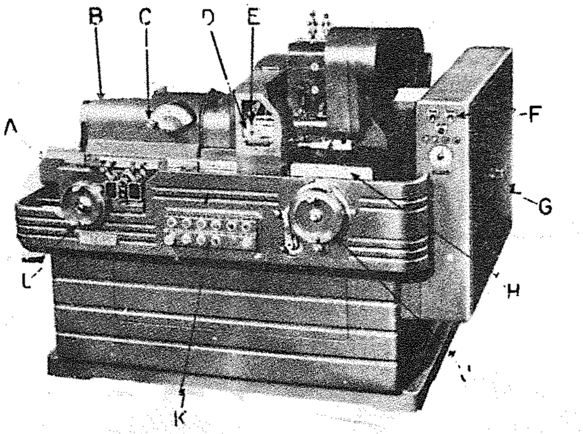


Fig. 11–47. Internal-thread grinder. (Ex-Cell-O Corp.)

A. Work-drive housing
B. Work-head slide
C. Thread and index control
D. Workpiece
E. Grinding wheel
F. Controls and lights
G. Electrical compartment
H. Wheel slide
J. Size-control wheel
K. Operator's control panel
L. Lead and backlash control



Multiple-rib grinding is done with a grinding wheel with many grooves on its face, as in Fig. 11–49. This type of wheel grinds many threads at one time, as on the shaft shown in Fig. 11–50. Internal threads may also be ground with a multiple-rib grinding wheel. An example of internal-thread grinding is shown in Fig. 11–51.

Single-rib wheels are kept true to shape with a diamond wheel dresser. Multiple-rib wheels are shaped with crushing rollers (Fig. 11–52). These rollers are mounted behind the grinding wheel and may be forced against the wheel to keep it true to shape as occasion may require.

51. *Explain the meaning of thread classes and indicate the applications for each class.*

The *class* of thread refers to the amount of deviation in tolerance and allowance from the basic pitch-diameter dimension. Under the old standard there were four classes of fits, as follows:

No. 1. Loose fit. Usually specified for small tapped boles, such as the numbered sizes made by mass-production methods.

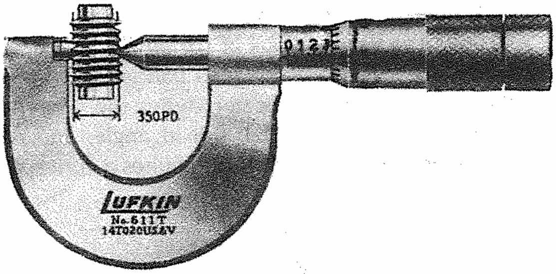
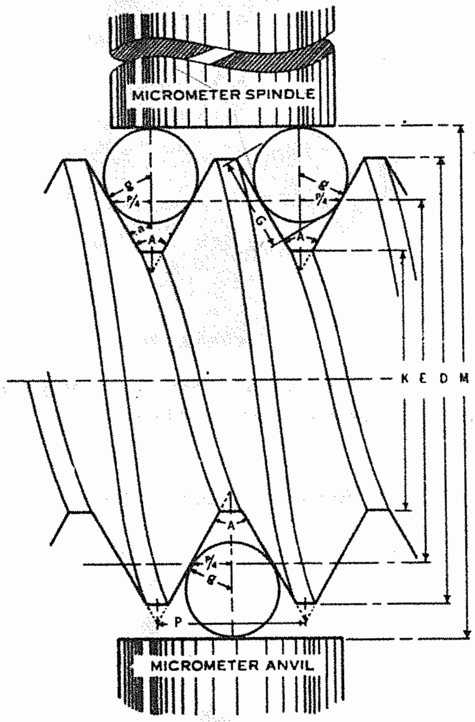


Fig. 11–54. Thread micrometer. (Lufkin Rule Co.)

Fig. 11–55. Three-wire system of measuring the pitch diameter of a thread.



57. *Calculate the micrometer reading over three wires to check the pitch diameter of a 3/4–10 NC thread.*

First determine the wire size to use by referring to Fig. 11–56. Read down the column marked "Threads per inch" to the required number of threads; then follow horizontally to the number in the column marked "Diameter of best-size wires." The number is 0.057735. Next, use the formula given in the answer to question 56.

$$M = 0.750 + (3 \times 0.057735) - \frac{1.5155}{10}$$
$$= 0.750 + 0.1732 - 0.15155$$
$$= 0.7717$$

Measurement over three wires = 0.7717 in.

58. *When the size of wire required to gage the thread on the pitch diameter cannot be obtained, state the method of finding the commercial size of wire that can be successfully used to check threads by the three-wire system.*

The minimum diameter of the wire must be such that the wires extend beyond the top of the screw to prevent the micrometer from bearing on the

threads per inch	pitch	diameter of best-size wires	single depth National form thread	width of flat on crest and root NC and NF	single-depth V thread
4	0.250000	0.1443375	0.162379	0.0312	0.216506
4½	0.222222	0.1282998	0.144337	0.0278	0.192449
5	0.200000	0.1154700	0.129903	0.0250	0.173205
5½	0.181818	0.1049726	0.118094	0.0227	0.157458
6	0.166666	0.0962246	0.108253	0.0208	0.144336
7	0.142857	0.0824784	0.092788	0.0179	0.123717
8	0.125000	0.0721687	0.081189	0.0156	0.108253
9	0.111111	0.0641499	0.072168	0.0139	0.096224
10	0.100000	0.0577350	0.064951	0.0125	0.086602
11	0.090909	0.0524863	0.059047	0.0114	0.078729
11½	0.086956	0.0502040	0.056479	0.0108	0.075306
12	0.083333	0.0481123	0.054126	0.0104	0.072168
13	0.076923	0.0444114	0.049963	0.0096	0.066617
14	0.071428	0.0412389	0.046394	0.0089	0.061858
16	0.062500	0.0360843	0.040594	0.0078	0.054126
18	0.055555	0.0320746	0.036084	0.0069	0.048112
19	0.052631	0.0303865	0.034185	0.0065	0.045579
20	0.050000	0.0288675	0.032475	0.0062	0.043301
22	0.045454	0.0262428	0.029523	0.0057	0.039364
24	0.041666	0.0240558	0.027063	0.0052	0.036083
27	0.037037	0.0213833	0.024056	0.0046	0.032074
28	0.035714	0.0206194	0.023197	0.0045	0.030929
30	0.033333	0.0192446	0.021650	0.0042	0.028867
32	0.031250	0.0180421	0.020297	0 0039	0.027063
34	0.029411	0.0169804	0.019103	0.0037	0.025470
36	0.027777	0.0160370	0.018042	0.0035	0.024055
40	0.025000	0.0144337	0.016237	0.0031	0 021650
44	0.022727	0.0131214	0.014761	0.0028	0.019682
48	0.020833	0.0120279	0.013531	0.0026	0.018041
50	0.020000	0.0115470	0.012990	0.0025	0.017320
56	0.017857	0.0103097	0.011598	0.0022	0.015464
64	0.015625	0.0090210	0.010148	0.0020	0.013531
72	0.013888	0.0080182	0.009021	0.0017	0.012027
80	0.012500	0.0072168	0.008118	0.0016	0.010825

Fig. 11–56. Diameters of best-size wire.

threads instead of on the wires, and the maximum limit must be such that the wires bear on the sides of the thread and not on the crest. The following formulas do not give the extreme theoretical limits, but they do give the smallest and the largest sizes that are practicable.

The smallest diameter of wire to use is equal to 0.56 divided by the number of threads per inch.

The largest diameter of wire to use is equal to 0.90 divided by the number of threads per inch.

59. *What is a comparator?*

A comparator (Fig. 11–57) is an instrument for checking the accuracy of machined parts by comparing the magnified picture of the part with a master gage. This method is sometimes used to check the accuracy of threads.

The comparator in Fig. 11–58 has two lines drawn at right angles to each other, intersecting at the center of the screen. Around the edge of the screen is a vernier protractor. This is used to measure accurately the angle of a thread. The screen is rotated until the lines on the screen exactly match the edge of the enlarged shadow of the thread being checked. The thread being measured in the illustration is a 29° acme thread.

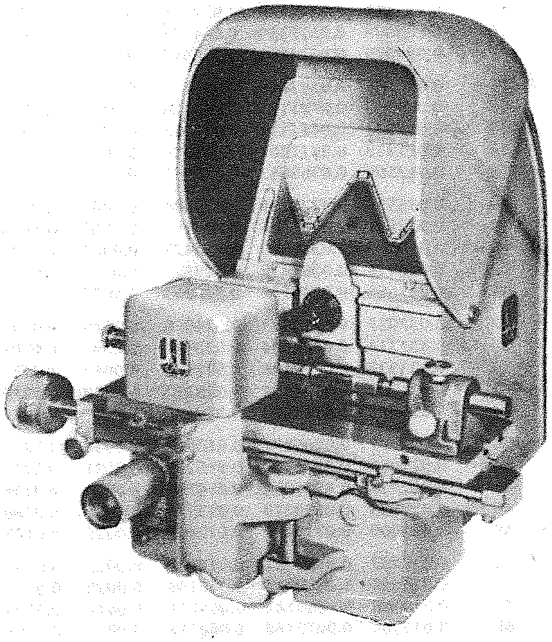


Fig. 11–57. Bench optical comparator. (Jones & Lamson Machine Co.)

Another type of comparator is shown in Fig. 11–59. The two sections of the anvil are similar to a ring gage. When a threaded part is placed within the anvil, the dial indicator shows the amount of error, if any, of the lead, thread angle, and pitch diameter. Each size of thread requires a corresponding size of anvil.

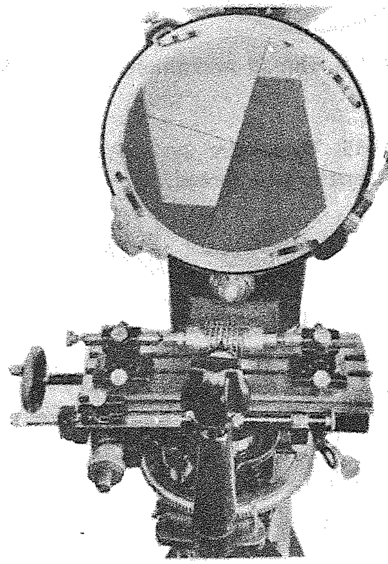
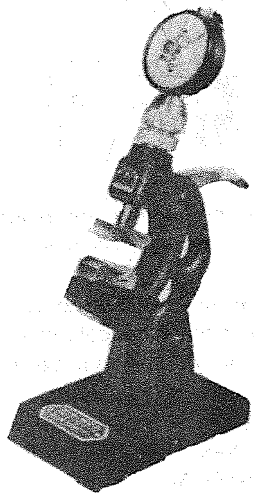


Fig. 11–58. Comparator with angle-measuring attachment. (Jones & Lamson Machine Co.)

Fig. 11–59. Thread comparator. (Hanson-Whitney Co.)



Some gages are designed to inspect only one element of a thread. The device in Fig. 11–60 is a thread-lead gage which is used to test the accuracy of the lead of a thread within 0.0001 in. The thread to be tested is placed on the horizontal table and brought into contact with the contact points. Any variation of lead is shown on the indicating dial. A gage for testing the pitch diameter of threads is shown in Fig. 11–61. The thread to be measured is placed between the upper and lower rollers. Any variation from the required pitch diameter is shown on the indicating dial.

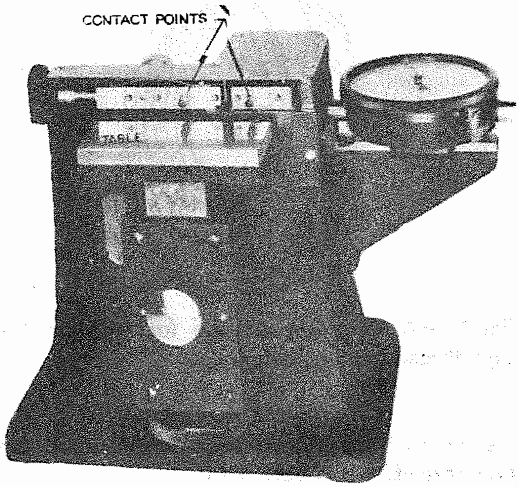


Fig. 11–60. Thread-lead gage. (Federal Products Corp.)

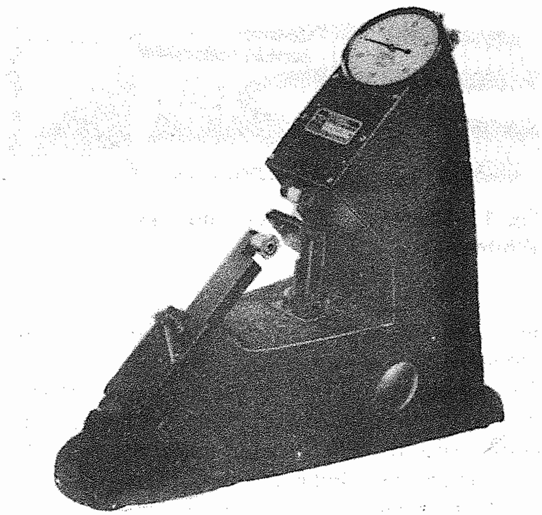


Fig. 11–61. Pitch-diameter thread gage. (Federal Products Corp.)

60. *How are square, acme, Brown & Sharpe, and buttress threads tested for accuracy?*
Threads of this kind are usually expected to have close fits. If gages are available, they are used in the same manner as other thread gages. When gages are not available, it is customary to match the mating parts. The external thread is made first, and then it is used as a gage for checking the matching thread.

61. *What is a pipe thread?*
A pipe thread is similar in shape to the National form of thread (Appendix Table 10). The threads are cut on a taper to ensure a watertight fit between a pipe and pipe fittings.

62. *What specifications are required for cutting pipe threads?*
The only specifications required for cutting pipe threads are (a) nominal size of the pipe, (b) kind of thread, and (c) operation to be performed. An example is ½ pipe tap.

63. *Is the nominal size of pipe equal to the inside or to the outside diameter of pipe?*
Neither. At one time, the nominal size of pipe equalled the inside diameter. Today, the inside diameter of a pipe is larger than the nominal size. The quality of material used in making pipe today is superior to that used many years ago, so the thickness of the material is less than it was originally. The size of the outside of the pipe has not been changed because this would cause trouble in fitting pipes together. The basic measurements, formulas of pipe threads, and numerical values for these dimensions can be found in any standard handbook for machinists.

64. *How are pipe threads usually cut?*
Pipe threads are usually cut with threading dies or taps. They may also be cut on a lathe in much the same manner as other threads. A tap for cutting pipe threads is shown in Fig. 11–62.

65. *When pipe threads are cut on a lathe, should the cutting tool be set at 90° with the center line of the work or at 90° with the taper?*
The tool should be set at 90° with the center line of the work.

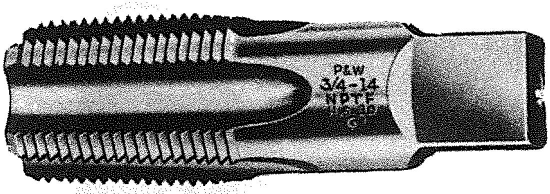


Fig. 11–62. Standard taper pipe tap. (Pratt & Whitney Co.)

66. *What size of hole should be drilled to accommodate a ¾-in. pipe tap?*
The correct size of drill to use is usually obtained from a table similar to Fig. 11–63. In this case, the correct size to use is 29/32 in., unless the hole is to be reamed after drilling, in which case the hole would be made 1/64 in. smaller, or 57/64 in.

Fig. 11–63. Suggested diameters of twist drills for tapped holes for pipe threads.

nominal pipe size	*taper thread with use of reamer*		*taper thread without use of reamer*		*straight pipe thread*	
1/16	....	0.240†	....	0.246†	1/4	0.250†
1/8	21/64	0.328†	....	0.332†	11/32	0.344†
1/4	27/64	0.422	7/16	0.438†	7/16	0.438†
3/8	9/16	0.562	9/16	0.562	37/64	0.578
1/2	11/16	0.688	45/64	0.703	23/32	0.719
3/4	57/64	0.891	29/32	0.906	59/64	0.922
1	1 1/8	1.125	1 9/64	1.141	1 5/32	1.156
1 1/4	1 15/32	1.469	1 31/64	1.484	1 1/2	1.500
1 1/2	1 23/32	1.719	1 47/64	1.734	1 3/4	1.750
2	2 3/16	2.188	2 13/64	2.203	2 7/32	2.219
2 1/2	2 19/32	2.584	2 5/8	2.625	2 21/32	2.656

**All dimensions are given in inches. Courtesy American Society of Mechanical Engineers.*
†*American Standard twist drill sizes.*

67. *Describe the gaging of external pipe threads.*
In gaging external, or male, pipe threads, the ring gage (Fig. 11–64) should be screwed tight, by hand, on the male pipe thread until the end of the gage is flush with the end of the thread.

68. *Describe the gaging of internal pipe threads.*
In gaging internal, or female, pipe threads, the plug-thread gage (Fig. 11–65) should be screwed tight, by hand, into the fitting or coupling, until the notch on the gage is flush with the face. When the thread is chamfered, the notch should be flush with the bottom of the chamfer.

69. *What material is used between the threads of pipe and pipe fittings to prevent leakage at the joints?*
Either red lead or white lead spread over the threads before screwing the parts together will effectively seal the joints.

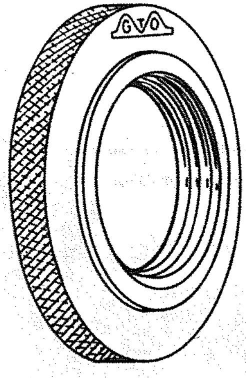
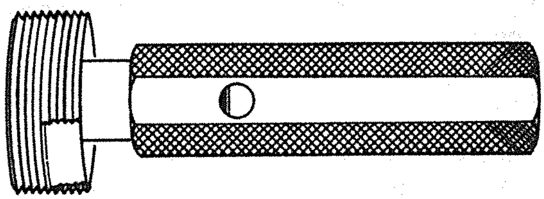


Fig. 11–64. Ring thread gage for standard taper pipe threads. (John Bath & Co.)

Fig. 11–65. Plug thread gage for standard taper pipe threads. (John Bath & Co.)



chapter 12 band machining

The saw was one of the first tools developed by primitive man. It is believed that the first saw was developed some time during the Stone Age. The teeth of the saw were probably made of chips of flint with rough, jagged edges.

The finding of metals made possible the making of saws in bronze and copper. The use of iron and its refinement to steel brought the next development in saw making.

Saws were made in a variety of shapes and sizes. They were used to take straight cuts and for cutting-off purposes. The teeth of the saw were varied in size and pitch according to the type of work to be done. Circular saws were developed between the fifteenth and sixteenth centuries and were powered by hand.

In 1808, a British patent was issued to William Newberry for an endless band saw. This very crude machine consisted of two pulleys over which was stretched a steel band with teeth on the edge. Many years were to pass before this machine became a practical and useful tool.

The power-driven band saw was an important tool in the lumbering industry because its thin blade allowed more boards to be cut from each log.

Metal-cutting band saws came into use at the beginning of the twentieth century. The band saw blade was then 1 inch wide and could be used only for the cutting-off operation. It was only after further developments in the alloying of steel, which enabled the making of narrower saw blades, that the band saw became an important machine shop tool. Manufacturers were able to produce metal-cutting saws that were $^1/_{16}$ in., $^3/_{32}$ in., and $^1/_8$ in. wide. These saws could cut metals to a curved line with accuracy and speed.

History does not tell which came first, the saw or the file. There is a similarity between the shape of the file tooth and the saw tooth. Machines for filing and sawing were developed separately, yet they paralleled each other in the progress of their development. Files were fastened together into an endless belt that made filing a continuous operation.

The band machine used in present-day machine shops is more than a power-driven saw. It permits the replacement of the saw band with a file band or with an abrasive band for polishing to size and to a specified quality finish.

1. *How many makes of band saws are in use?*
There are many makes of band saws. Among the

best known manufacturers are Armstrong-Blum, Boice-Crane, DoAll (Fig. 12–1), Peerless Powermatic (Fig. 12–2), and Tannewitz (Fig. 12–3). The DoAll is the most widely used and is universally known.

2. *How many types of band saws are in use?*
There are two basic types of band saws, (a) horizontal (Fig. 12–4) and (b) vertical (Fig. 12–1). They derive their names from the direction of the saw blades.

3. *What is the main purpose of the horizontal band saw?*
The most common operation of any saw is to cut off pieces or sections. The horizontal band saw is the most efficient cut-off machine (Fig. 12–5).

4. *Why is the horizontal band saw more efficient than the reciprocating power saw?*
The blade of a reciprocating power saw is never used to its full cutting potential. It is never possible to make use of *all* of its teeth. Allowance must be made for the positioning of the vise when holding work of various thicknesses and diameters. The

Fig. 12–1. A 16-in. power table band saw. (DoALL Co.)

Fig. 12–2. Powermatic 20-in. band saw. (Powermatic, Inc.)

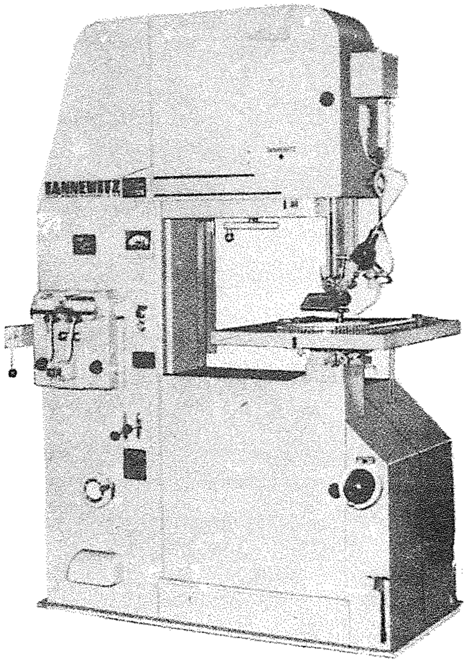


Fig. 12–3. Contour band saw. (Tannewitz Works, Inc.)

Fig. 12–4. **Light-duty horizontal band saw. (DoALL Co.)**

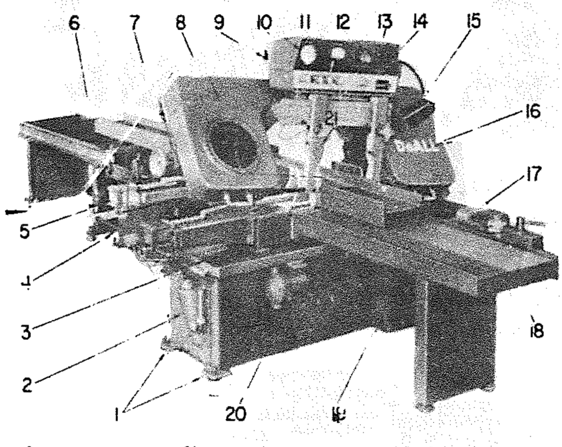


Fig. 12–5. Cutoff power saw. (DoALL Co.)

1. Mounting pads	**12. Work height selector**
2. Hydraulic tank	**13. Starter**
3. Catch pan	**14. Cycle starter**
4. Holding vise	**15. Area light**
5. Indexing vise	**16. Drive-wheel guard**
6. Stock table	**17. Manual workstop**
7. Band tensioning	**18. Discharge table**
8. Idler wheel guard	**19. Coolant reservoir**
9. Control console	**20. Hydraulic filter**
10. Feed-rate gage	**21. Saw-guide arms**
11. Speed indicator	

blade of a reciprocating power saw cuts only in one direction; cutting time is totally lost on the return stroke. The band saw has a continuous cutting action. The blade runs in one direction, counterclockwise (Fig. 12–6), cutting continuously. Specially alloyed high-speed steel blades, cooled by the proper cutting fluid, make possible sawing rates up to 30 sq in. per min.

5. *Can the horizontal band saw cut off pieces repetitively to the same size?*
Yes. The work-holding vise on the horizontal band saw can be adjusted manually or automatically. On a machine equipped with the automatic indexing cut-off attachment there are two vises. After the cut is made, the work-holding vise is drawn back while the work-indexing vise advances the job to the preset distance for the next cut. This indexing, work-feeding table can be set to make repeated cuts accurate to $\frac{1}{64}$ in. for a distance of 24 in.

6. *Can the speed of the saw blade on a horizontal band saw be varied?*
Yes. The size of the motor driving the band saw will depend upon the size and capacity of the machine. The motors range from 1 to 10 horsepower. The smallest machines have a four-step V-belt system that gives band speeds of 65, 90, 130, and 180 fpm. Other size machines possess a variable-speed pulley drive that ranges from 60 to 350 fpm. The large cut-off machines have a variable-speed drive that can be set to travel from 35 to 400 fpm.

Fig. 12–6. Horizontal power saw cutting off steel disks. (DoALL Co.)

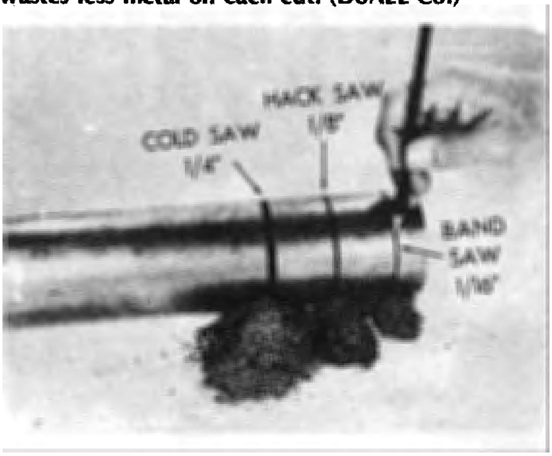
7. *Can the rate of feed be varied on a horizontal band saw?*
Yes. The progress of the saw head (feed) is controlled by a hydraulic system adjusted through a number-indexed power control knob. The control knob can be set to give a smooth, continuous downward movement of the saw head without placing undue strain upon the saw blade.

8. *What is the most important factor to consider when deciding which feed pressure to use?*
The characteristics of the material to be cut is the most important factor in determining both the speed and feed of the saw blade. These characteristics will include toughness, abrasiveness, machining, and hardening qualities. The harder the metal the greater will be its effect on the longevity of the saw's cutting efficiency.

9. *What is an important economic advantage of the horizontal band saw?*
The band saw blade is much thinner than the power saw blade. This means that each cut of the band saw leaves a minumum amount of nonusable scrap metal saw chips, a significant saving when many short pieces are being cut from large-diameter stock (Fig. 12–7).

10. *Are all horizontal cut-off band saws the same size?*
Horizontal band saws are made in a wide variety of sizes to fill the needs of different types of industry. For instance, small jobbing shops, where only light work is produced, will be satisfied with 2 small band saws. Heavy industry requires a machine capable of sawing large pieces of tough metals at high speed (Fig. 12–8). Horizontal band saws such as the angle-cutting saw shown in Fig. 12–9 are also made to satisfy special requirements.

Fig. 12–7. The band saw has a thinner blade and wastes less metal on each cut. (DoALL Co.)



11. *How does the vertical band saw differ from the horizontal band saw?*
The horizontal band saw is used almost exclusively for cutting-off. The vertical band machine is often used for cutting-off but has more valuable applica-

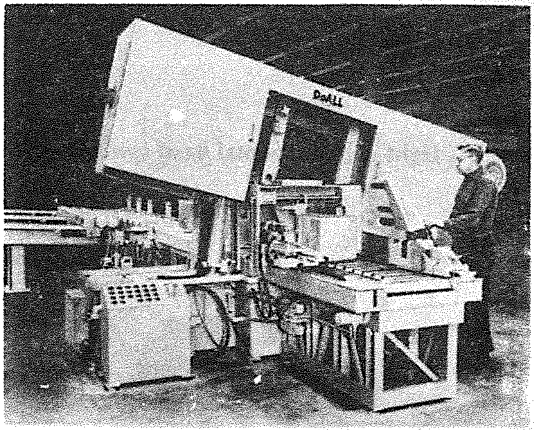


Fig. 12–8. Horizontal band machine capable of sawing large pieces of tough metal. (DoALL Co.)

Fig. 12–9. A horizontal band saw for cutting off at an angle. (DoALL Co.)

on in other fields. The narrow blades make possible e accurate sawing of curved shapes. This permits e sawing of radii starting at 1/16 in. and increasing ithout restriction. Unusual and irregular curves at are impossible to machine by any other method an be cut on the vertical band saw (Fig. 12–10). he job can be fed so that the saw blade cuts acurately on the line or to the line.

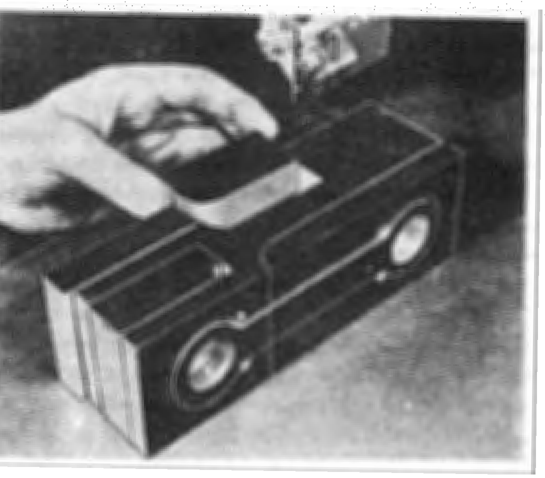


Fig. 12–10. Curved surfaces cut out of the solid, an operation made possible by the thin, narrow saw blade of the vertical band machine. (DoALL Co.)

12. *Are vertical band machines made in one standard size?*

Vertical band machines are made in a wide range of sizes and models, from those used in the modern butcher shop, in model making (Fig. 12–11), and in the average toolroom (Fig. 12–12), to large production machines that can cut through large pieces of any and all materials at a fast and continuous pace (Fig. 12–13). The throat sizes of these machines range from 16 to 60 in., the band speeds are from 35 to 15,000 feet per minute, and the driving horsepower from 1½ to 15. There are also special purpose band machines that are constructed for specific machining tasks. These range from the band saw used by the local butcher to the 8-ton, 15-ft-high

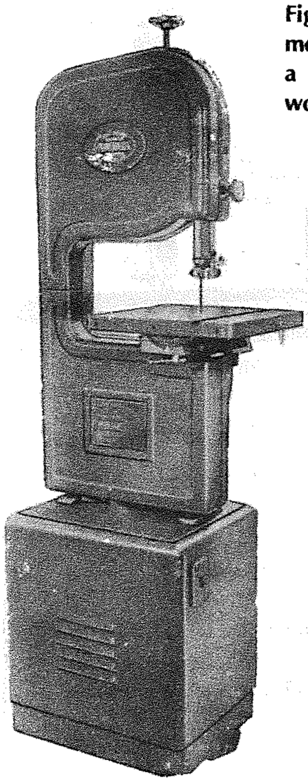


Fig. 12–11. A small-model band saw used for a wide variety of light work. (Powermatic, Inc.)

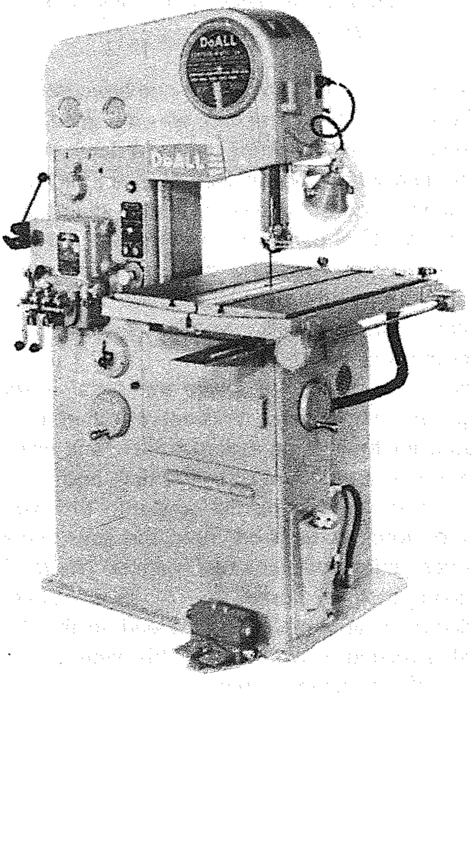


Fig. 12–12. The band saw most often found in the average sized toolroom and jobbing shop. (DoALL Co.)

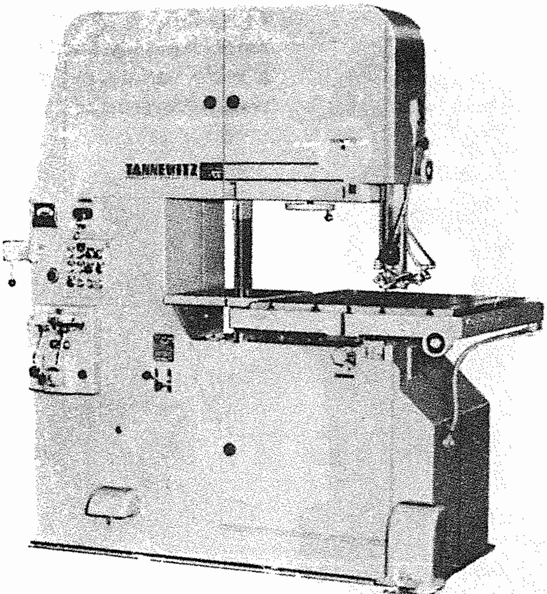


Fig. 12–13. The large band saw with the hydraulic-powered table used for continuous heavy cutting on the production line. (Tannewitz Works, Inc.)

machine developed, designed, and constructed to cut 10-ton steel extrusion dies.

13. *Are band saw machines all of one basic design?*
No. The original band machine was designed with a stationary work-supporting table. A later model was designed with a power feed that can be preset to maintain a constant feed pressure against the saw blade. Vertical band saw machines are made in a wide variety of sizes and designs to suit many different types of industry. High-speed band saws are suitable for the plastic, wood, soft material, or garment industries.

Friction sawing is used where the metal is soft and thin and high speed is essential. Other band saws used for the cutting of large, thick, and heavy slabs of metal are designed so that time and space are conserved by moving the saw into the work instead of forcing the work onto the saw blade. Where very thin, honeycombed material has to be cut, fusion sawing is used. The blade is charged with electricity and run at high speed so that the material is melted or worn away. This method does the job without leaving a burr or an uneven edge.

14. *Describe the construction of the vertical band machine.*
The running direction of the saw band gives this machine its name. The saw band runs over two carrier wheels that guide, drive, and give tension to the blade during the cutting action. The lower carrier wheel drives the saw band. The upper carrier wheel is an idler, which can be adjusted to control the true alignment of the saw band (Fig. 12–14). As the band leaves the upper carrier wheel it passes through two sets of saw guides, one set above, the other below the table. The table supports the work and feeds it to the saw band. The table has a machined surface with T slots running parallel to the direction of the feed. Light-duty models have two T slots, heavier models have four slots. These are used to accommodate workholding fixtures, bolts, or parallel strips, to clamp and align work. The work table can be tilted to the right 45°; to the left 5° on heavy-duty power-table machines; 10° to the left on all other machines. The tables of heavy-duty models are controlled by hydraulic power (Fig. 12–15), making it easier to tilt the table to the required angle even when the work load is large and cumbersome. The table can be set at the required angle by means of a protractor and a pointer that is fastened to the trunnion casting below the work table. After setting, the table can be locked in position by means of the table tilt locking wheel (Fig. 12–16). Stops can be adjusted to limit the travel of the table to suit the length of saw cut required. This permits exact duplication from one workpiece to another. Below the table, encased in the base of the machine, can be found the lower saw band carrier wheel, driving mechanism, hydraulic pump, filter and gage, air pump, and coolant controls (Fig. 12–15).

Band saw models with a fixed table do not have power table feed or pressure coolants; therefore, they will not be fitted with the mechanisms that supply these facilities. The fixed-table models have a weighted feed that pulls the work toward the saw. The feed is operated by a foot pedal, thus enabling the operator to keep both hands on the job (Fig. 12–17).

The column, or backbone, of the vertical band saw encases the returning section of the saw blade and supports several of the control points such as the stop and start buttons, band tension indicator, speed and feed controls, and the band joining units composed of cutter, welder, and grinder.

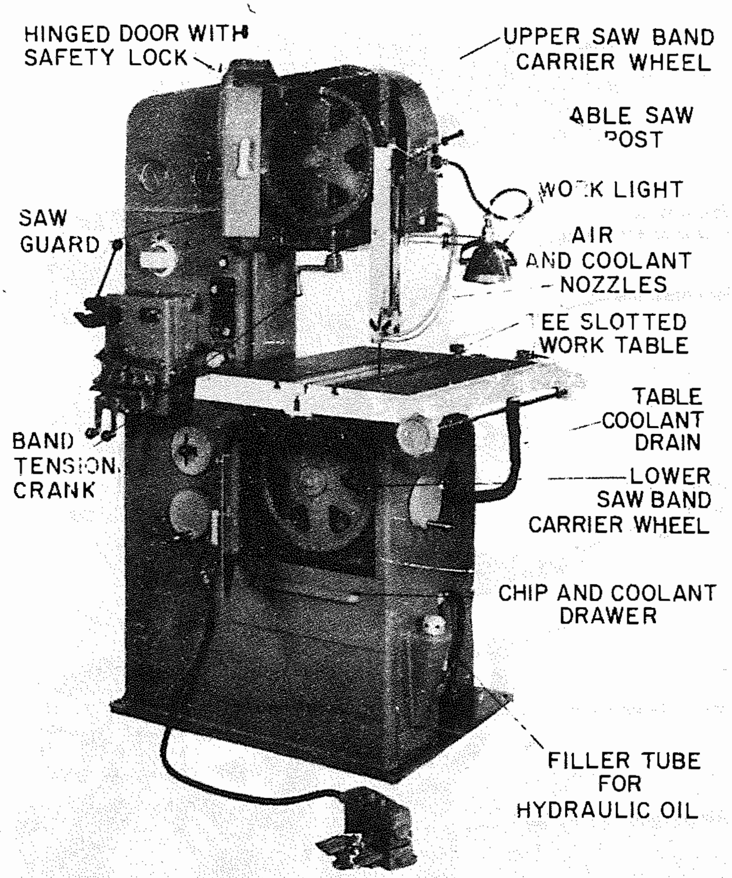


Fig. 12–14. Parts of the band saw exposed to show the upper and lower band-carrier wheels. (DoALL Co.)

15. *How are band saws driven?*
All manufacturers use a V belt to drive the lower band wheel, which drives the band saw blade.

The change of speed mechanism of the vertical band saw varies with each manufacturer. Band saws are made with one, four, or eight speeds with step pulleys, or with a combination of step pulleys and gears. Some models have a variable speed control made possible by using V belts in pulleys that have tapered flanged sides (see Fig. 12–15). The distance between the flanges can be altered. This alteration permits the belt to ride nearer the bottom or the top of the pulley, thus varying the speed. This type also has two-step and three-step gear changes. The last driven pulley drives the lower band wheel which drives the saw blade (Fig. 12–18, p. 286).

16. *How is the speed of the band saw measured?*
Band saw speed is measured by the number of linear feet of the saw blade that pass a given point in one minute. Band saw speed is specified in surface feet per minute (sfpm).

17. *How fast does the band saw travel?*
The speed at which the band saw travels will depend upon the size of the machine, the size and kind of material being cut, and the size and type of material of the saw blade. The light type of machine has a speed range from 35 to 6,000 sfpm. Heavy-duty machines with higher horsepower motors have speeds ranging from 40 to 10,800 sfpm. The position of belt, pulley, and gears must be changed to obtain the full range of speeds.

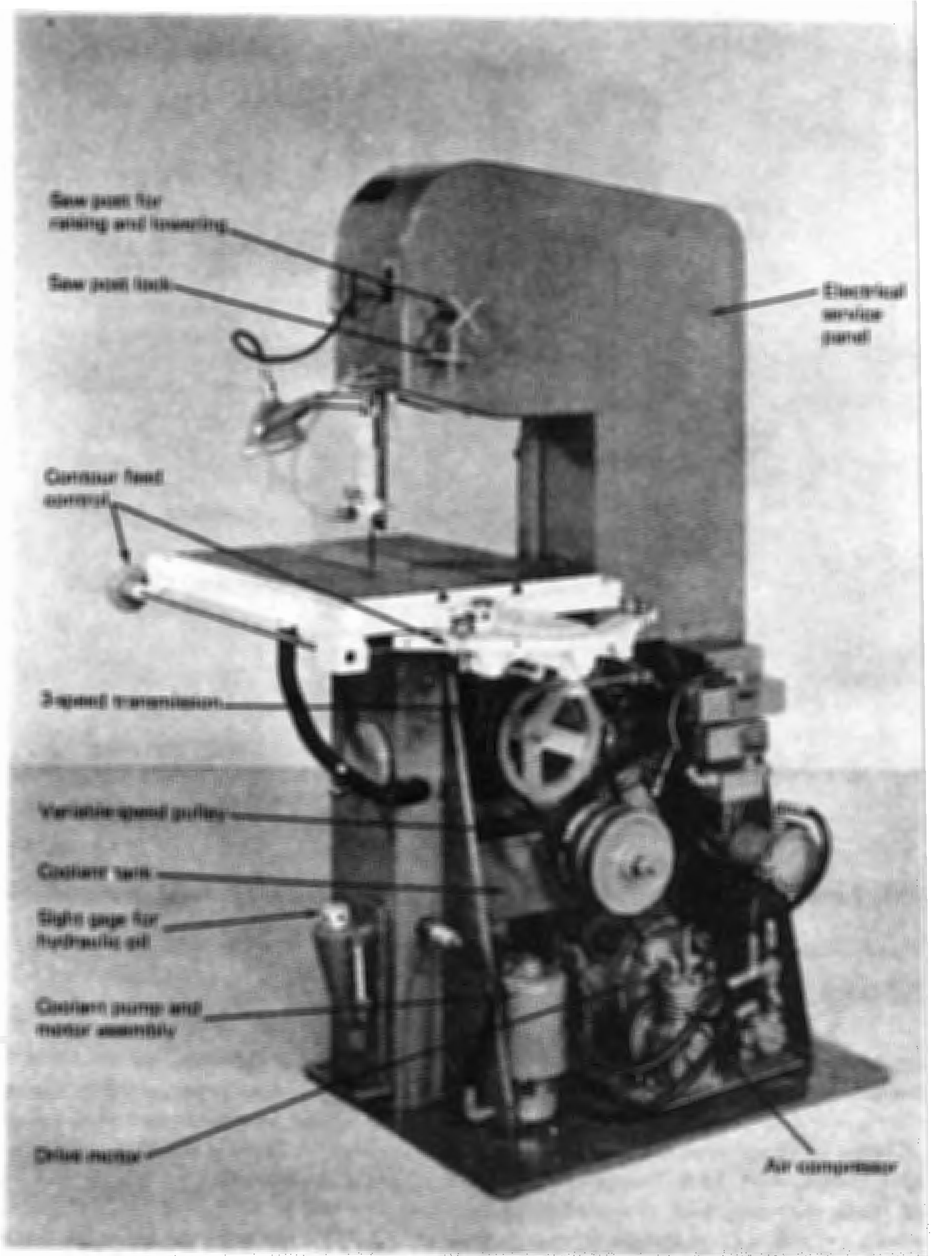


Fig. i2-15. Band machine opened to view the driving mechanism, variable-speed pulley, and hydraulic pump ind tank. (DoALL Co.)

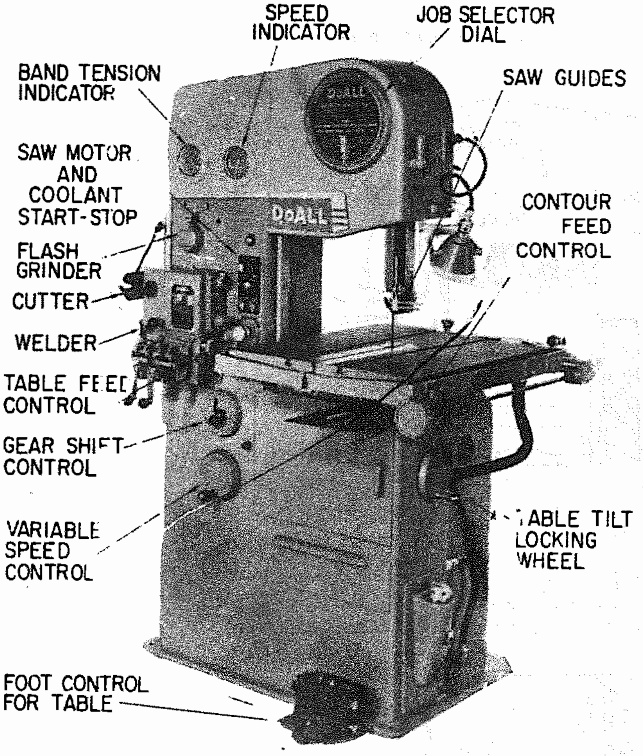


Fig. 12–16. The operating controls of the 16-in. power-table band saw. (DoALL Co.)

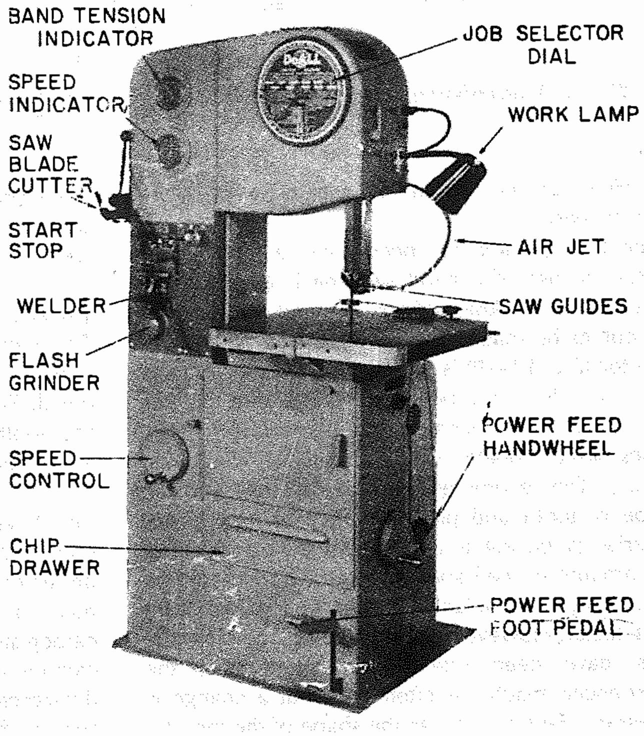


Fig. 12–17. Operating controls of fixed-table-model band saw. (DoALL Co.)

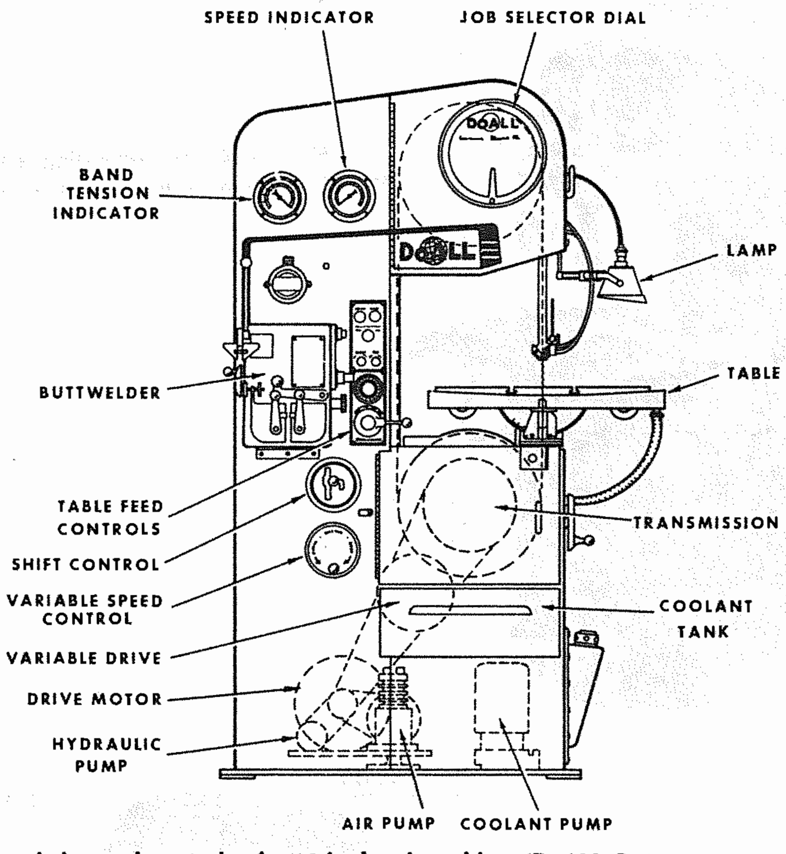


Fig. 12–18. Transmission and controls of a 16-in. band machine. (DoALL Co.)

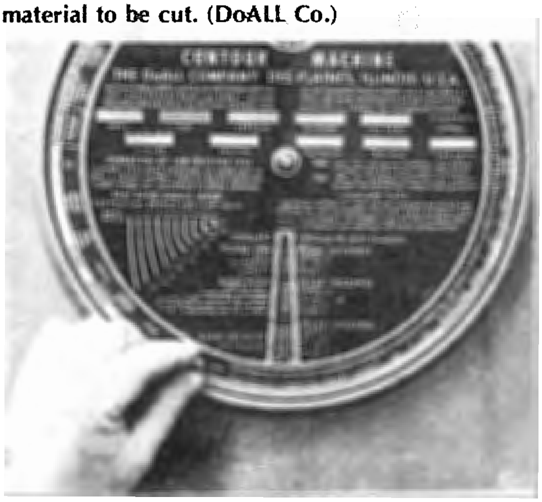
18. *How can the operator be sure of selecting the correct speed?*
Once the operator has been given a job that requires the use of a band saw, he is aware of the material, the thickness of the job, and the shape of the cut to be made. The movable dial on the job selector (Fig. 12–19) is turned until the name of the material to be cut is below the window in the dial (Fig. 12–20). The smallest radius required determines which blade width should be used (Fig. 12–21). The recommended type of blade and the shape of tooth and pitch for the thickness of the material to be cut is also shown on the selector. The amount of feed and the recommended method of applying the coolant can also be obtained from the selector. However, although these recommendations have been scientifically determined, the experienced machinist often sees that a change is necessary. Factors such as the shape of the job, the unevenness of thickness, the porosity of the metal, or hard spots could require changes in speed and feed.

19. *Are all saw blades identical?*
There are a great many varieties of band saw blades. One manufacturer makes 180 varieties for cutting metal. The blades differ in the shape and set of the saw tooth, the width and thickness, the pitch of the teeth, and the material from which they are made.

20. *What determines the selection of the saw blade?*
Many factors must be considered in order to decide on the correct saw blade. Saw blades are made from many different materials that vary in cost such as carbon steel, carbon alloy, high speed steel, tungsten carbide, and diamond edge. And within these groups differences in heat treatment add to the value and cost of the blade. Each blade has a specific char-

Fig. 12–19. Job selector. (DoALL Co.)

Fig. 12–20. Turning the job selector dial to the material to be cut. (DoALL Co.)



acteristic, which makes it suitable for a specific type of work. Thus for economical production, the blade must be matched to the work. The job may require high-speed cutting with a small amount of generated heat. Or the quality of the finished surface or the accuracy of the saw cut may be the important factor.

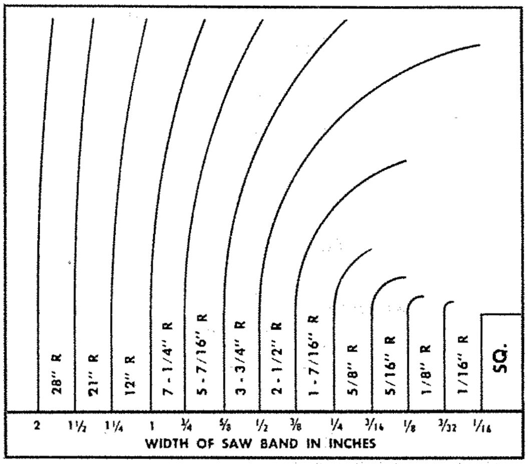


Fig. 12–21. The radius to be cut will be the decisive factor in choosing the width of the saw blade. (DoALL Co.)

21. *Are all saw teeth the same shape?*

No. Saw teeth are scientifically designed to fulfill a particular requirement. The depth of the gullet (Fig. 12–22), the spacing of the teeth, the clearance and rake angles of the teeth, each affects the saw's cutting characteristics. The thickness of the gage and the side clearance angles (Fig. 12–23) determine the width of the kerf, or saw cut (Fig. 12–24). Variations in the saw's set pattern give different re-

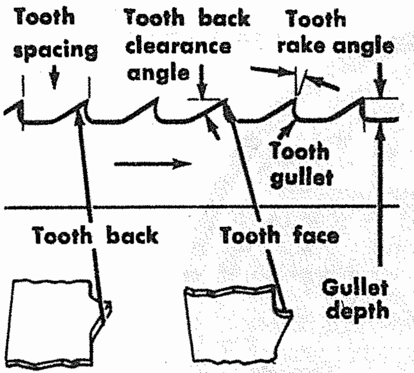
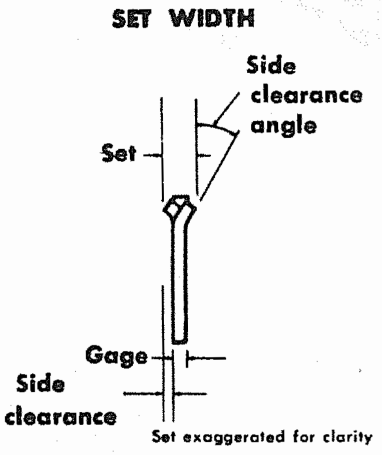


Fig. 12–22. Saw-blade nomenclature. (DoALL Co.)

Fig. 12–23. The set is the offset of the teeth measured at their widest point. (DoALL Co.)



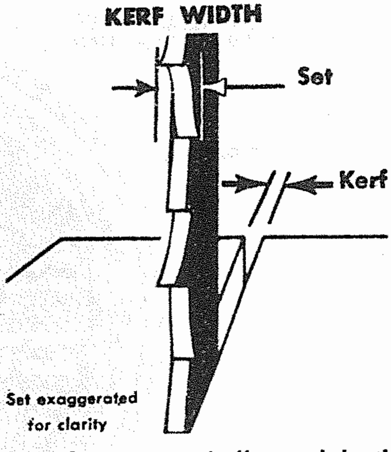
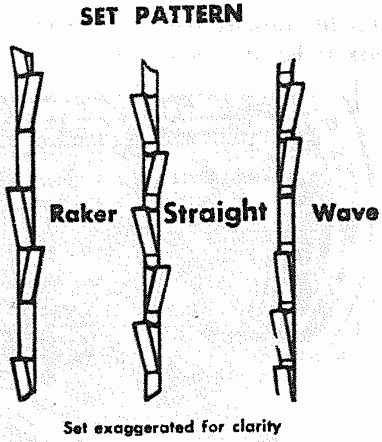


Fig. 12–24. The amount of offset and the thicknes of the gage will determine the width of the kerf (DoALL Co.)

Fig. 12–25. Variations in the set pattern affect the cutting efficiency for different thickness and kinds of metals. (DoALL Co.)



sults when cutting different metals or different thicknesses of metals (Fig. 12–25).

One manufacturer of band saws and band saw machines names each of the different tooth shapes (Fig. 12–26). They are explained as follows:

"The buttress tooth has a 0° rake angle and a shallow gullet. This permits a wider spacing between the teeth (pitch) on a narrow band resulting in an increase of the overall tensile strength.

The claw tooth has a positive rake angle that makes possible faster cutting rates, reduced feeding pressures, and longer tool life. The wide gullet has a special stress-proof design.

The precision shaped tooth is most commonly used. It has a deep gullet with a smooth radius at the bottom. The tooth rake angle is 0° with a back clearance angle of 30°

The tungsten carbide tooth has a positive rake angle and a deep gullet. The carbide insert at the face of the tooth is well reinforced by the long angle of the tooth back.".

22. *What is a spiral-toothed saw blade?*
The spiral-toothed, or spiral-edged, saw blade is unusual because it is a round saw. The tooth spirals

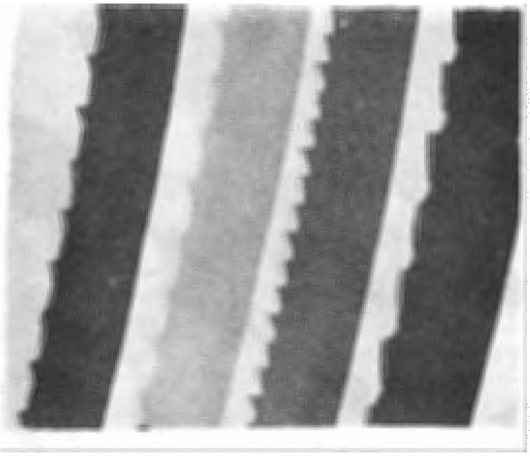


Fig. 12–26. The varying shapes of band saw teeth. From left to right: buttress, claw tooth, precision, tungsten carbide. (DoALL Co.)

around the body of the blade, which enables it to saw in any direction. This saw blade, which is sized according to its outside diameter, is available in four sizes: 0.020 in., 0.040 in., 0.050 in., and 0.074 in. diameters (Fig. 12–27). The 360° edge of the spiral-toothed saw blade enables it to saw in all directions. It is particularly adapted to the sawing of

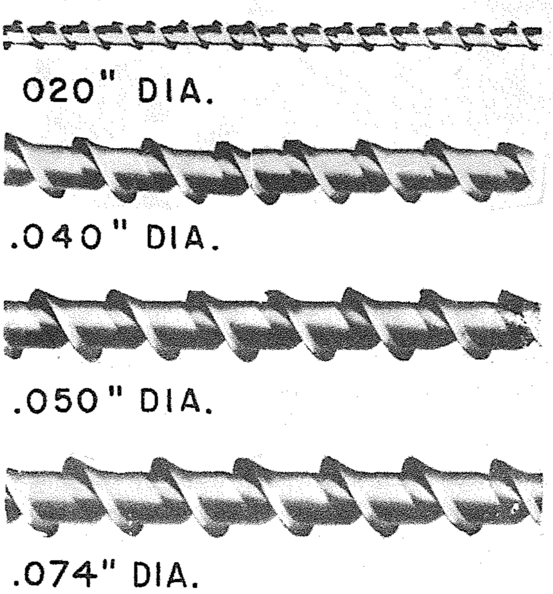


Fig. 12–27. The spiral-toothed saw blade is available in four diameters. (DoALL Co.)

unusual and intricate shapes in all materials including wood, plastic, brass, aluminum, and steel (Fig. 12–28).

The 0.020-in. diameter blade is capable of sawing a radius of 0.010-in., a facility often utilized where accuracy is of prime importance. Because of the greater area of the spiral cutting edge that is in contact with the material being cut, a spiral-toothed saw should run no faster than 2,000 fpm.

Fig. 12–28. The spiral-toothed saw blade can cut in all directions. (DoALL Co.)

23. *What is the pitch of a saw blade?*
Each of the different shapes of saw blade teeth can be obtained in several sizes. Saw blade teeth have a given size number (called the *pitch*), which represents the number of teeth in every inch of the blade (Fig. 12–29). The tooth is smaller or larger proportionately so that its cutting efficiency is unimpaired. The thickness of the metal to be cut is the principal factor in selecting the correct pitch. Because two teeth should be in contact with the metal being sawed, a fine tooth saw with more teeth per inch should be used on thin metal. Thick or heavy metal will permit the use of a coarser tooth with fewer

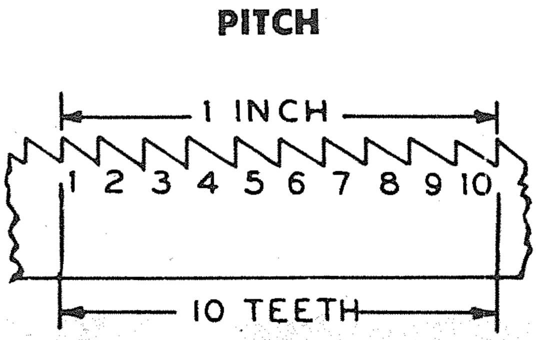


Fig. 12–29. The pitch of a saw blade is the number of teeth per inch. (DoALL Co.)

teeth per inch, and a lower numbered pitch. The thickness or gage of the saw blade has been standardized relative to the width of the blade. The ½-in. wide blade is 0.025-in. thick; ⅝-in. and ¾-in. wide blades are 0.032 in. thick; and 1-in. blades are 0.035 in. thick.

24. *What makes a metal-cutting vertical band saw a valuable machine shop tool?*
The vertical band saw can be used to make many different kinds of cuts, from cutting a curved line (Fig. 12–30) to sawing narrow slots in thin metal (Fig. 12–31). Other cutting operations are also possible such as angular cuts, ripping through long pieces, removing a section, beveling, recessing, sawing solid slabs to shapes, and making internal cuts.

25. *How is it possible to make internal cuts with a one-piece band saw?*
Making internal cuts is one of the most valuable uses of the band saw. The old method used to cut an internal shape from a solid block was by drilling a series of holes tangent to each other and just within the boundary lines of the shape to be cut. This is a long and tedious operation which must be followed by chipping and filing, or by shaping operations, to bring the shape to accurate and finished dimensions. The same results are obtained by the band saw by drilling one hole within the outline of the required shape, inserting a saw blade, and sawing accurately to shape and size.

26. *How is it possible to insert a band saw blade into a drilled hole and then saw to an inner line?*
The entire operation is made possible by the cutting-

Fig. 12–30. The results of band sawing: curved and straight lines on the same workpiece. (DoALL Co.)

Fig. 12–31. Slotting with a band saw. (DoALL Co.)

grinding-welding unit found on the column of the band saw machine (Fig. 12–32). The explanation of the procedure is as follows:

The saw blade is available in 100- and 500-ft rolls and in many widths and types of teeth. Find the correct width and type of blade by checking with the job selector dial on the machine. Then adjust the inserts that hold the blade in the clamping jaws of the butt welder to suit the width of the blade selected for the job. Manufacturers' charts give instructions on the setting of jaw pressure and jaw gap and the annealing setting for each width and type of blade. After adjusting the inserts to the correct setting, make sure that all parts of the welding unit are free from oil, dirt, chips, and scale. Get the correct length of blade from the information plate fastened to the machine. The exact length of blade can be cut off with the cut-off shears (Fig. 12–33) or tin snips, but if this method is used, special care must be taken to grind the ends square.

Next thread the blade through the hole drilled in the job as shown in Fig. 12–34. Then insert the ends into the clamps of the butt welder with the teeth of the blade away from the machine (Fig. 12–34). The ends are correctly aligned by pushing firmly against the aligning surface. The ends of the saw blade must be in the center of the space between the two clamping jaws and just touching. The two ends of the blade must meet squarely and never

Fig. 12–33. Using the cutoff shears to obtain the correct length of blade. (DoALL Co.)

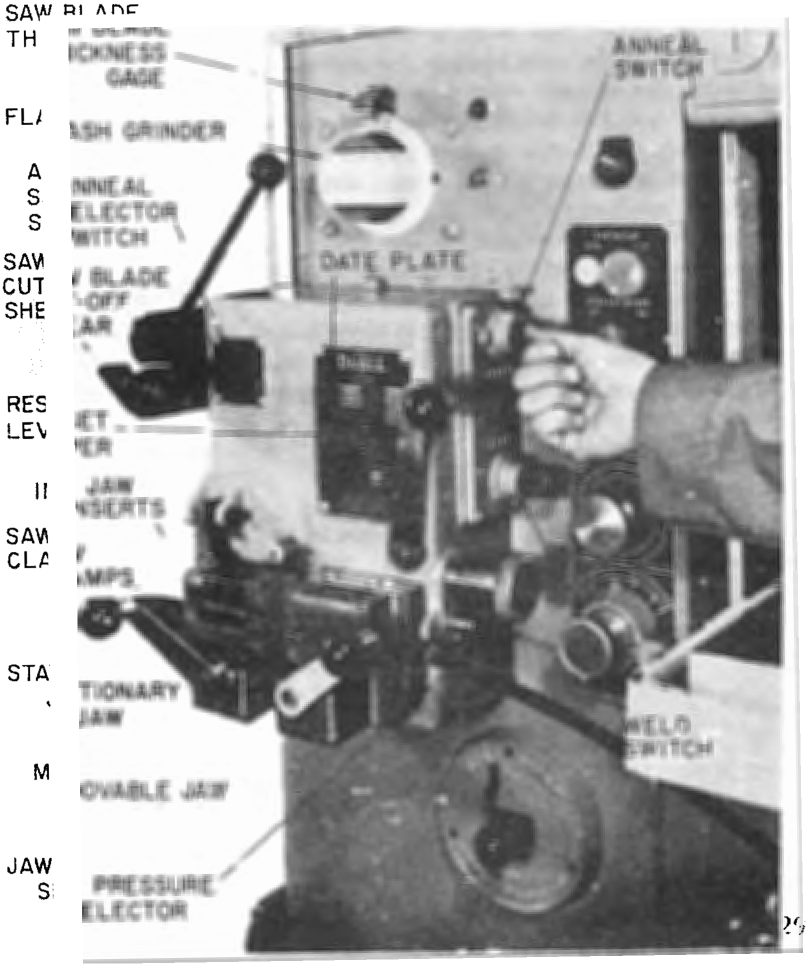


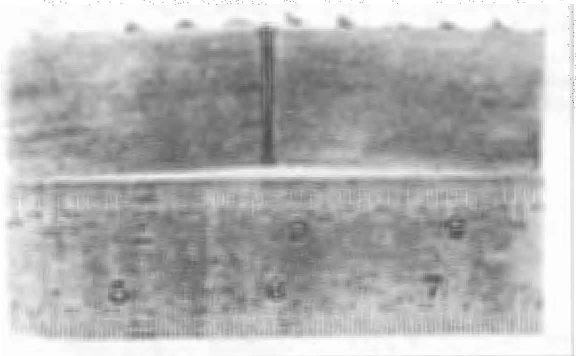
Fig. 12–32. The cutting-grinding-welding unit found on the column of a modern band-sawing machine. (DoALL Co.)

Fig. 12-34. Aligning the saw blade in the clamps of the butt welder. (DoALL Co.)

overlap. The blade is now ready for welding. Place the reset lever to the weld position. For protection from sparks, the operator must wear safety glasses and step to one side before pushing the welding switch button. The button must be pushed *all the way* in until it reaches a positive stop and then immediately released.

Release the clamps, remove the saw band, and examine the weld. Check the saw band for straightness. Grind off excess metal along the edges and test with a steel rule (Fig. 12-35). If the blade is not straight, break the weld, true-up the edges, and weld again. Always brush off the welding unit when finished; scrape off any metal adhesions from the clamping jaws and inserts.

Fig. 12-35. After welding, the blade should be checked for straightness.



The effect of the heat during the welding process and the effect of the cold air striking the heated blade cause the blade to become hardened. To anneal the blade in the vicinity of the weld, place the blade again in the clamping jaws with the teeth away from the operator and the weld in the center of the space between the jaws. Change the reset lever to the anneal position and set the selector switch for the temperature required for the particular blade. Allowance must be made for the expansion of the saw blade when it is heated; the allowance should be $\frac{1}{16}$ in.

Do not hold the annealing switch button in long; this will result in overheating and rehardening the band-saw blade. Press and release the annealing switch button until the blade turns to a *dull cherry red*. The saw blade should then cool off slowly. This can be achieved by pushing and releasing the annealing switch button a few times to slow down the cooling process.

The excess metal raised by the weld must be ground off until both sides are clean (Fig. 12-36) and there is no increase in size. The blade is held with the teeth toward the operator, using the top and bottom of the grinding wheel to remove the excess metal from both sides of the weld. The teeth

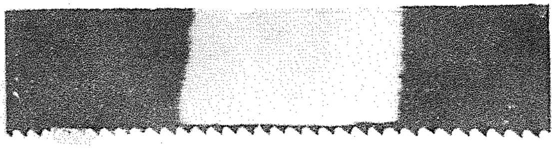


Fig. 12-36. The weld must be ground so that it is no thicker than the rest of the blade. (DoALL Co.)

of the saw must not come in contact with the wheel. Check often to make sure that too much metal is not ground away, making the blade too thin at the weld.

27. *How can the operator be sure that the welded section of the saw blade is exactly the same thickness?*

The thickness of the welded section of the blade can be checked in the saw blade gaging slots found above the grinding wheel (Fig. 12-37). The proper gage slot for each width of blade is given on a chart located on the machine or in the operator's manual.

Fig. 12–37. The welded section of the saw blade can be tested in the saw-blade thickness gage attached to the machine. (DoALL Co.)

28. *What is the purpose of the saw guides?*
In cutting metal of different sizes and shapes, the band saw meets with resistant pressures that tend to bend it to one side or the other. Saw guides support the blade and prevent it from bending. There are insert and roller saw guides. The insert style (Fig. 12–38) comes in three types: precision, for light duty and a maximum band speed of 2,000 fpm and for band sizes 1/16 in. and 1/2 in; heavy duty, for band sizes 5/8 in., 3/4 in., and 1 in; and high-speed band-saw guides for band speeds of 2,000 to 6,000 fpm and band sizes 1/16 to 1/2 in.

For continuous high band speeds of 2,000 to 6,000 fpm and higher, roller-style band-saw guides should be used (Fig. 12–39). The rolls revolve on antifriction ball bearings, thus reducing the frictional wear on both guides and blades. There are two types of roller style guides. Type one is for band sizes 1/4 in., 3/8 in., and 1/2 in. and for maximum speeds of 6,000 fpm. Type two has wider rollers and larger bearings, which permit speeds up to 10,000 fpm and band sizes of 1/4 to 1 in.

29. *Can the band saw blade become overheated when sawing tough metals?*
Yes. A coolant should be used to prevent losing the temper of the saw teeth because of overheating. The coolant can be a cutting fluid or soluble cutting oils applied to the saw blade and the job. Power-table band saws are supplied with twin flexible hoses, one for air, the other for coolant (Fig. 12–40).

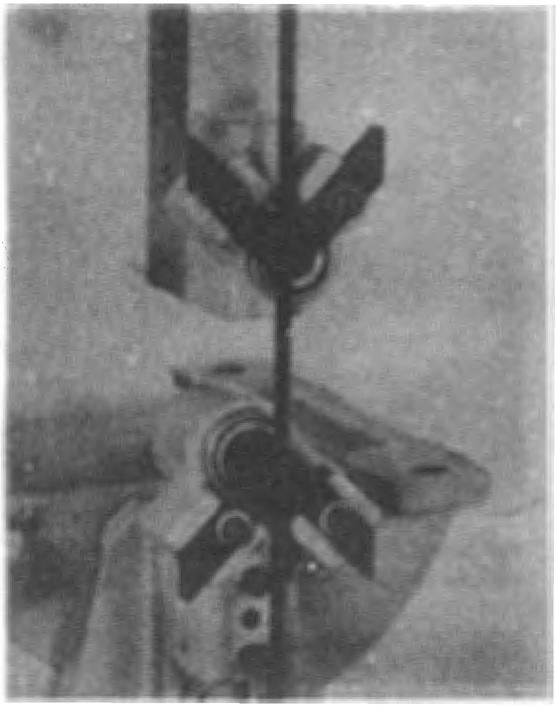
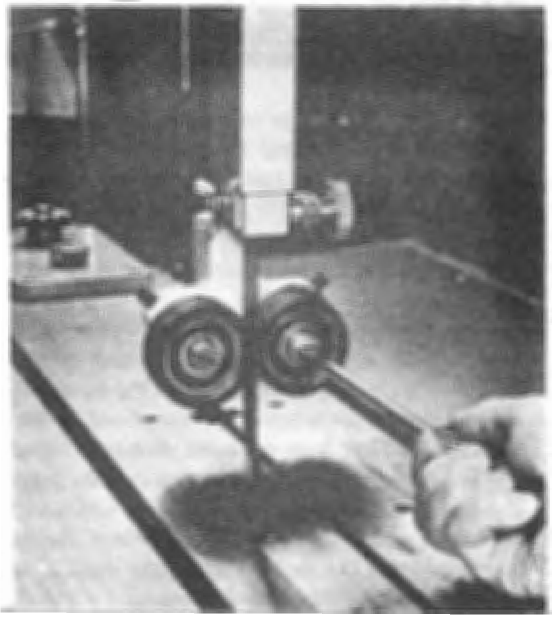


Fig. 12–38. The insert-style saw-blade guide. (DoALL Co.)

Fig. 12–39. Roller-style saw-band guides for continuous high band speeds. (DoALL Co.)



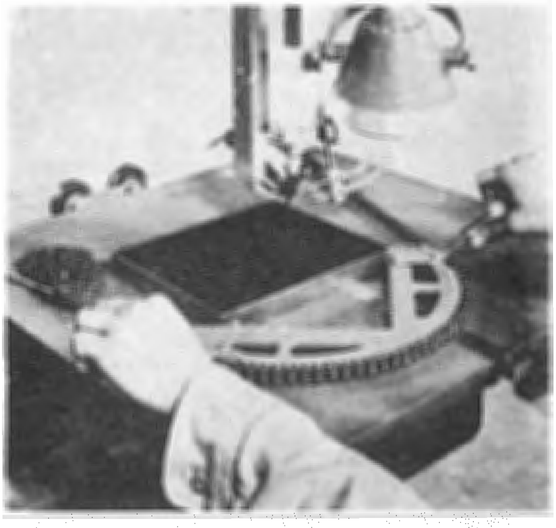


Fig. 12–40. The twin hoses carry air and coolant to the saw blade. (DoALL Co.)

The air hose outlet has two uses. It blows away the chips, and, in combination with the coolant hose outlet, it floods the saw blade and the job with a fine spray of coolant. The used coolant runs into the trough around the edge of the table, through a filter, and back to the coolant tank. Coolant can be fed to the saw blade of a fixed-table model by means of a gravity feed.

30. *Why are some band saws called band machines?*
Band sawing is not the only operation that can be performed by the band machines. With different bands, the machine can be used for filing and abrasive polishing.

31. *How can a file be made to curve over a round wheel?*
The file band is made up of small sections of files (Fig. 12–41). One end of each section is riveted to a flexible spring steel band. As the band travels around the carrier wheels, the loose end of the file section lifts away from the band, thus permitting the file to pass around the curve. Once past the curve of the wheel, the file returns to the band and is locked by means of a special interlocking device. The interlocking of the file sections forms the straight, even file necessary for the filing operation.

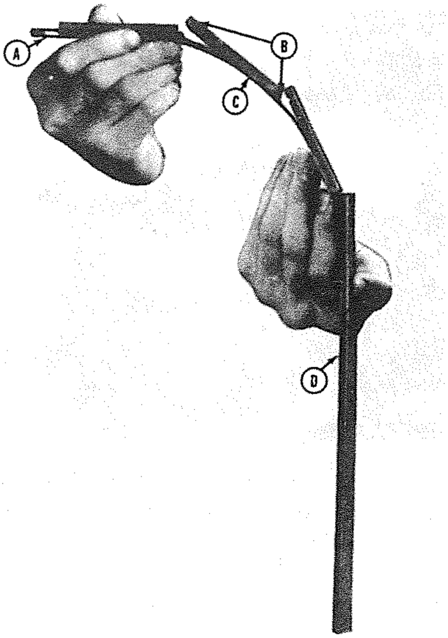


Fig. 12–41. The file band. (DoALL Co.)
A. A locking slot, which joins the ends of the band to form an endless loop.
B. Interlocking joint, which closes tight during contact with the work being filed.
C. A spacing strip, which gives an opening for chip clearance between the band and the file.
D. A flexible steel band to which the file segments are attached.

32. *What changes are necessary to convert the sawing machine into a filing machine?*
The plate inserted in the work table to permit the saw blade to pass through must be changed for a plate giving greater clearance for the file sections. Also, the guides for the saw blades must be replaced with heavier constructed file guides (Fig. 12–42). Care must be taken to give the correct amount of tension to the file band. Excessive tension will break the rivets that hold the file sections to the flexible band. A light tension gives best results.

33. *How fast can the file band travel?*
The best speed will depend upon the shape of the job, the material being filed, and the file band being used.

34. *What shapes and cuts of file sections are available?*

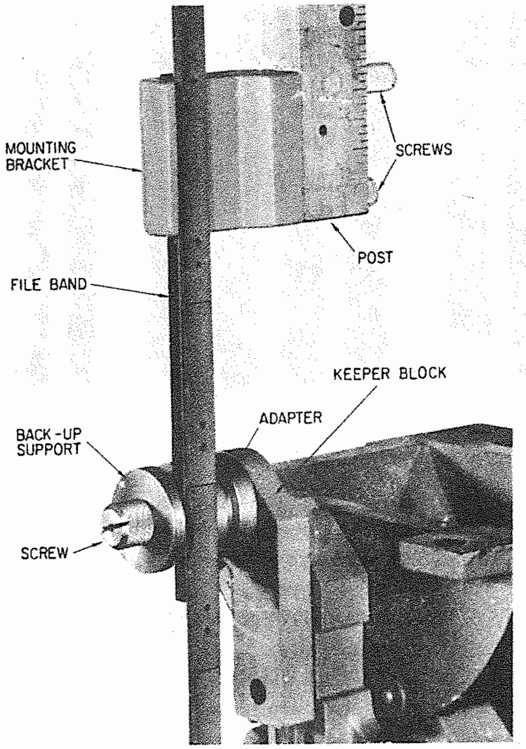


Fig. 12–42. Parts of the file-band guides. (DoALL Co.)

The files differ in shape, width, and cut. The shapes are oval, flat, and half round. The widths are ½, ⅜, and ¼ in. The cuts are coarse, medium coarse, and medium cut. The pitch of the teeth is given as the number of teeth per inch, 10, 12, 14, 16, 20, and 24 (Fig. 12–43). The type and shape of the job and the material from which it is made determine the right file for the job.

35. *What is a polishing band used for?*
Although filing can result in a smooth and properly shaped surface, the quality of its finish will not meet all requirements. An abrasive-coated band (Fig. 12–44) can improve the appearance and the efficiency of a job by giving a smooth and polished finish.

36. *How can a pliable abrasive band be held in a band machine?*
The abrasive band is mounted on the same wheels as the band saw but needs a back support to withstand the pressure of the workpiece. A special fixture used for this purpose is easily attached (Fig. 12–45).

37. *Is the polishing band available in various sizes?*
The length of the loop requires no variations. The width of all abrasive bands is 1 in. The band is coated with an aluminum oxide abrasive and comes in three grain sizes, 150 grit for high polish at speeds of 800 to 1,500 sfpm; 80 grit for rough polishing for general use at 1,000 sfpm maximum speed; and 50 grit for removing stock rather than for polishing. The 50-grit band is used at much slower speeds (Fig. 12–46).

38. *What is Electro-band machining?*
As its name implies, the Electro-band saws with the aid of electricity. The blade has a knife edge, not a saw edge. A low voltage, high amperage current is fed to the blade so that an arc is discharged from the edge of the blade into the job being cut (Fig. 12–47). In order to stop any damage to the material being cut, a stream of coolant is aimed where the arc meets the job.

39. *What is friction sawing?*
By running the saw at very high speeds, from 6,000 to 15,000 sfpm, enough frictional heat is generated by the teeth of the blade to soften the metal of the job being cut. The metal is reduced to a molten state and is easily removed by the teeth of the saw blade. Because of the heat that must be generated friction sawing gives best results with ferrous metals less than 1 in. thick. It is the fastest method of sawing thin metals (Fig. 12–48).

40. *What attachments can be used with the band machine?*
Many attachments are available. They simplify difficult operations and give greater accuracy. The work-squaring bar (Fig. 12–49) supports work when only straight line cutting is required. It can also be used to give accurate angular cuts up to 45°. The disc-cutting attachment (Fig. 12–50, p. 298) makes either external or internal circles from 2½ to 30 in. diameter; these can be cut to a precise size and smooth finish.

41. *Are all attachments hand controlled?*
Some attachments are operated by power and are also used in combination with the table power feed.

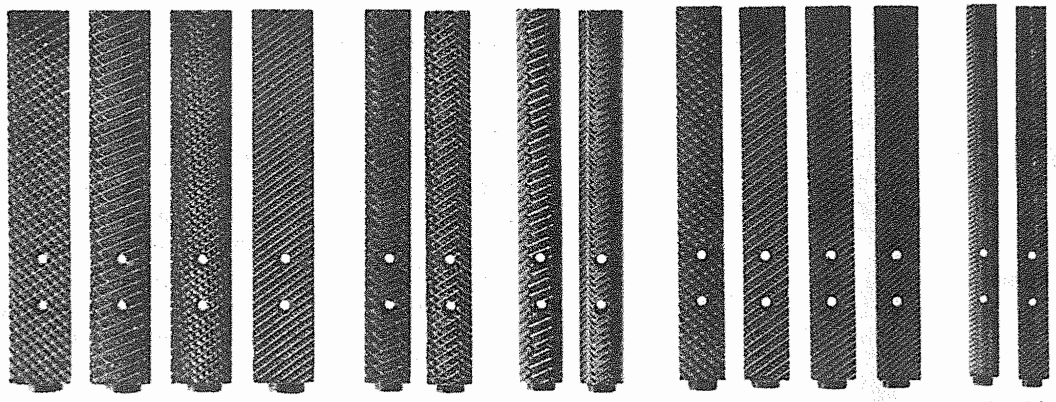


Fig. 12–43. Shapes, sizes, and types of file sections and uses for each. (DoALL Co.)

A. ½″ Flat, short angle, coarse cut, 10 teeth; for aluminum, brass, cast iron, copper, zinc.

B. ½″ Oval, short angle, coarse cut, 10 teeth; for aluminum, brass, cast iron, copper, zinc

C. ½″ Oval, bastard, medium coarse cut, 14 teeth; for general use on steel

D. ½″ Flat, bastard, medium coarse cut, 14 teeth; for general use on steel

E. ⅜″ Oval, short angle, coarse cut, 10 teeth; aluminum, brass, copper

F. ⅜″ Oval, bastard, medium coarse, 14 teeth; for general use on mild steel

G. ⅜″ Half round, short angle, coarse, 10 teeth; aluminum, brass, copper

H. ⅜″ Half round, bastard, medium coarse, 16 teeth; for general use on mild steel

I. ⅜″ Flat, short angle, coarse cut, 10 teeth; aluminum, brass, copper

J. ⅜″ Flat, bastard, coarse cut, 12 teeth; cast iron, nonferrous metals

K. ⅜″ Flat, bastard, medium coarse cut, 16 teeth; for general use on tool steel

L. ⅜″ Flat, bastard, medium cut, 20 teeth; medium finish tool steel

M. ¼″ Oval, bastard, medium cut, 24 teeth· for general use on tool steel

N. ¼″ Flat, bastard, medium cut, 20 teeth; for general use on tool steel

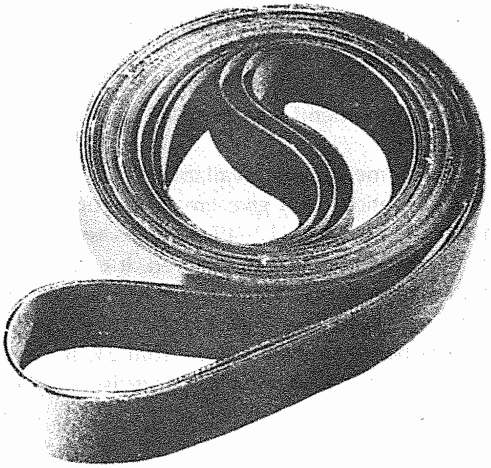


Fig. 12–44. An abrasive band used for polishing. (DoALL Co.)

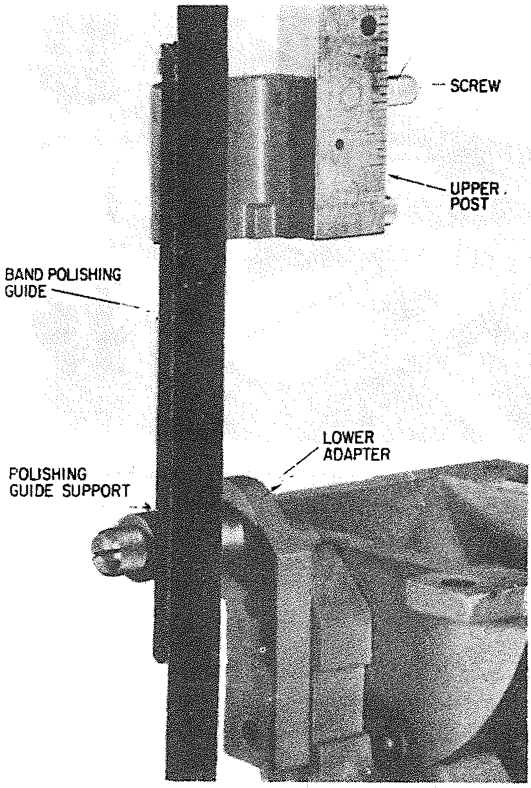
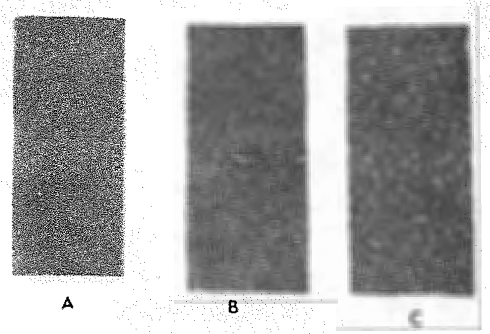


Fig. 12–45. Back support fixture for band polishing. (DoALL Co.)

Fig. 12–46. Abrasive bands are available in three grain sizes: (A) 150 grit, (B) 80 grit, (C) 50 grit. (DoALL Co.)



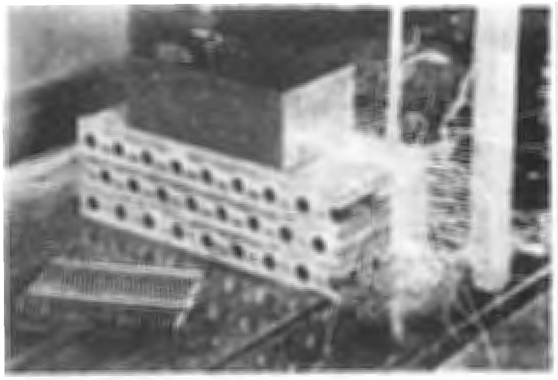
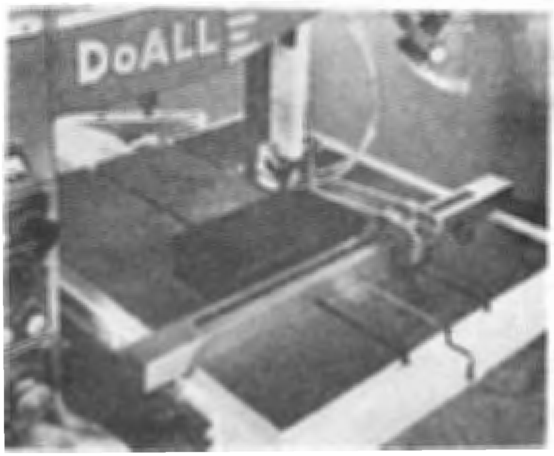


Fig. 12–47. Sawing through the core of an air conditioning unit by Electro-band machining. (DoALL Co.)

Fig. 12–48. Cutting thin material by friction-sawing method. (DoALL Co.)

Fig. 12–49. The work-squaring bar. (DoALL Co.)



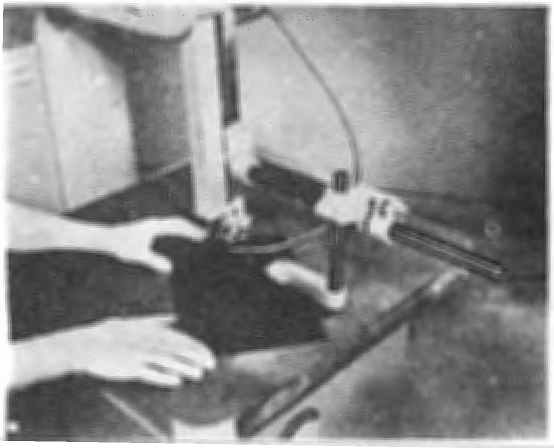


Fig. 12–50. The disc-cutting attachment. (DoALL Co.)

An example is the contour-cutting attachment (Fig. 12–51). This shows the table feed, controlled by the operator's left hand, moving the table forward while the rotary movement is being controlled by the operator's right hand.

42. *Can the contour-cutting attachment be used to cut an unbroken circle?*
Figure 12–52 shows the contour-cutting attachment being used in combination with the disc cutting attachment to remove a flange from a stainless steel ring. The cut was continuous and unbroken at the

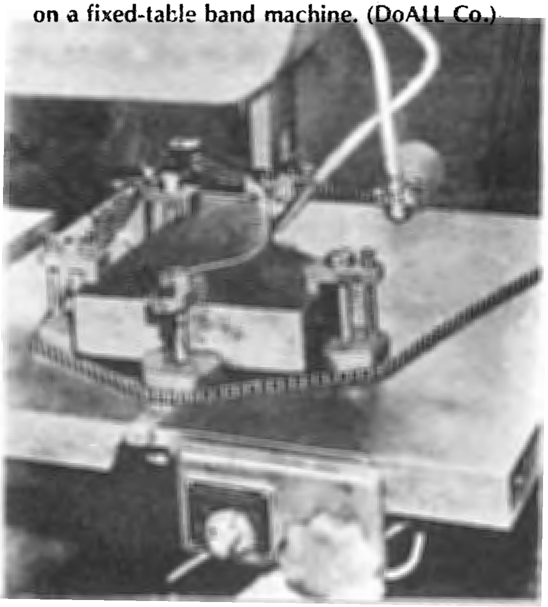
Fig. 12–51. The contour-cutting attachment being used in combination with the table power feed. (DoALL Co.)

Fig. 12–52. The contour-cutting attachment and the disc-cutting attachment combine to remove a flange from a steel ring. (DoALL Co.)

rate of over 2 inches per minute with a band speed of 200 sfpm.

43. *Is it possible to have a hydraulic power unit on a fixed table machine?*
Figure 12–53 shows a hydraulic controlled contour feed in operation on a fixed-table band machine. This unit comes as an attachment that can be located

Fig. 12–53. The hydraulic contour feed being used on a fixed-table band machine. (DoALL Co.)



adjacent to the machine. It can be easily attached to the machine. This unit provides power feeding for all types of contour sawing. It is controlled by a handwheel and control valve attached to the front part of the table.

44. *Are all band machine jobs held and controlled by attachments?*
The attachments to the band machine are each designed to simplify the machining of many jobs that have some factor common to them all. However, some jobs require the same operation to be made on many pieces. Production is often increased by devising a fixture that will fasten the job securely and quickly. One of the most common methods of holding work is the angle plate, which can be bolted to the machine table with the job clamped to its other face (Fig. 12–54).

45. *What type of fixture can be used on the band machine?*
All types of fixtures that will fasten the job securely and accurately can be used. Fixtures can be aligned accurately with the saw blade and the travel of the table and secured to the table with T bolts (Fig. 12–55). Designing fixtures for a specific job requires ingenuity and imagination. A properly designed fixture simplifies fastening and reduces setup time (Fig. 12–56).

Fig. 12–54. The angle plate is one of the most common methods of holding work. (DoALL Co.)

Fig. 12–55. A simple fixture made to hold work for a slotting operation. (DoALL Co.)

Fig. 12–56. Using an indexing fixture to cut 10 equally spaced slots in a pump rotor. (DoALL Co.)

46. *Can fixtures be designed for general use on a band machine?*

The type of operation will be the deciding factor in the designing of a fixture for band machining. Figure 12–56 illustrates a fixture that could be used for only one job. The number of pieces to be slotted justified the expense of making this single-purpose fixture. Figure 12–57 illustrates a fixture that can be used for angular cuts, both external and internal, of various lengths and thicknesses of stock.

Fig. 12–57. A special fixture for cutting short 45° angles. (DoALL Co.)

chapter 13

shaper and planer processes

THE SHAPER

The shaping machine, commonly called the *shaper*, is a basic machine tool used in both production and toolroom work. The shaper can machine a flat surface on a horizontal, vertical, or angular plane. Many types of work may be machined on a shaper, depending upon the tools used and the manner of adjusting the various parts of the machine. Figure 13–1 shows a shaper with an identification list of its parts.

1. *What are the five principal parts of a shaper?*
A shaper has many parts each important to the function of the whole. Five of its principal parts, which are shown in Fig. 13–1, are the table (2), the tool slide (10), the ram (12), the base (34), and the apron (35).

2. *What is the purpose of the base?*
The base is a hollow casting upon which the other parts of the shaper are mounted. It is also the reservoir for a supply of oil, which is circulated to the moving parts of the machine.

3. *What is the function of the apron?*
The apron supports the table on the crossrail and moves across it from left to right.

4. *What is the ram and how does it work?*
The ram is the main moving part of a shaper. It holds and drives a cutting tool back and forth across the work. It is attached to the rocker arm (Fig. 13–2), which is given an oscillating motion by the turning of a large driving gear. An adjustable pin attached to the driving gear acts as a crank (Fig. 13–2), which determines the length of the stroke of the ram.

5. *What is the purpose of the toolhead?*
The toolhead (Fig. 13–3) holds the cutting tools. Attached to the front of the ram, it may be swiveled to a required angle to the left or to the right and locked in place. It may also be adjusted vertically and locked in position. The tool post is fastened to a clapper block, which is hinged at the top to permit the tool to ride over the work on the return stroke.

6. *What is the purpose of the table?*
The table (Fig. 13–1) is a metal box attached to the frame of the shaper. It has T slots on the top and

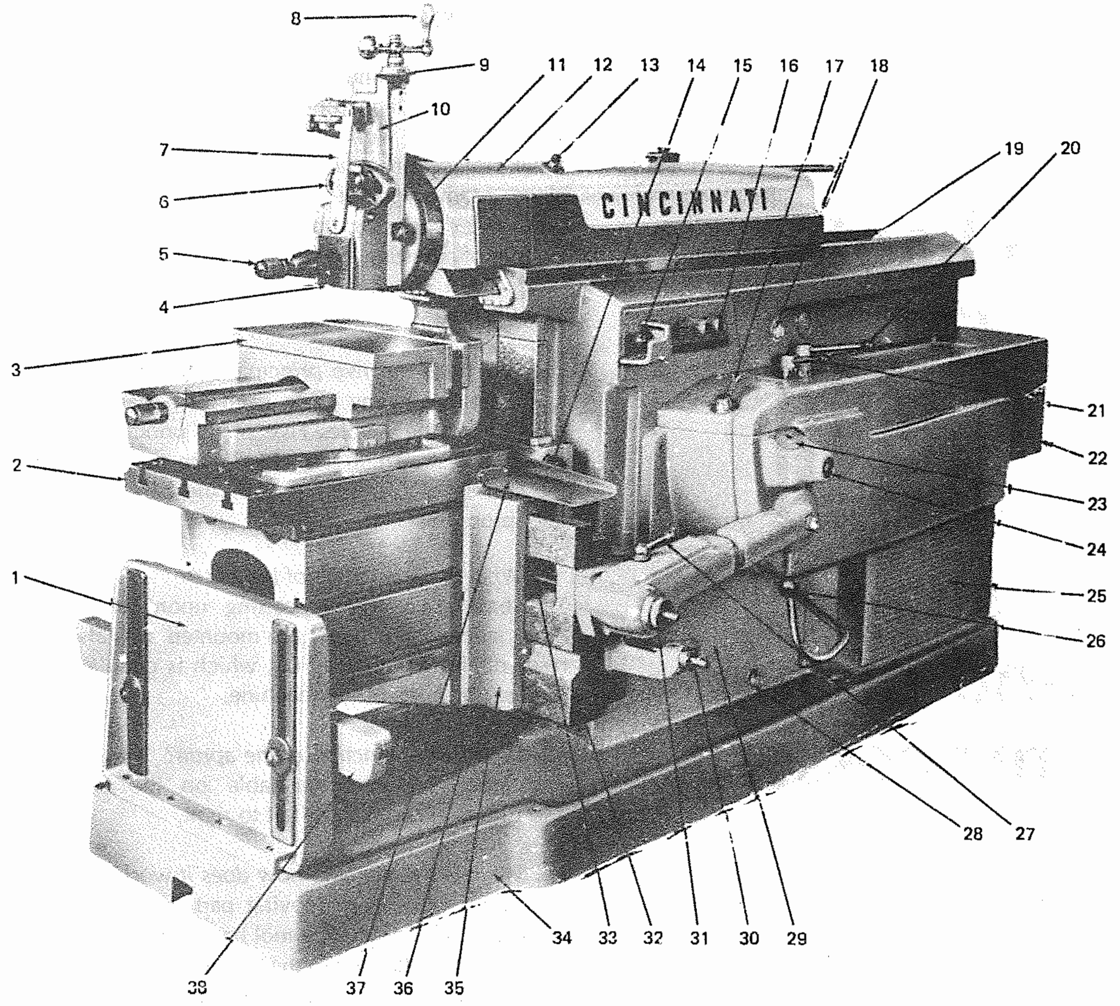


Fig. 13-1. Principal parts of the shaper. (The Cincinnati Shaper Co.)

1. Table support
2. Table
3. Vise
4. Clapper
5. Tool post
6. Clapper box
7. Tool lifter
8. Ball crank
9. Feed-screw dial
10. Tool slide
11. Graduated-head swivel
12. Ram
13. Ram positioning shaft
14. Rail clamp control
15. Electric clutch and brake lever
16. Start and stop buttons
17. Power cross-feed selector
18. Oil pressure gage
19. Ram guard
20. Gear shifter lever
21. Back gear selector lever
22. Motor starter
23. Stroke indicator dial
24. Stroke adjusting shaft
25. Drive motor
26. Power rapid-traverse lever
27. Cross-feed engagement lever
28. Oil sight gage
29. Column
30. Rail-elevating manual control
31. Cross-feed manual control
32. Crossrail
33. Cross-feed screw
34. Base
35. Apron
36. Elevating screw
37. Cross-rail chip guard
38. Table-support bearing

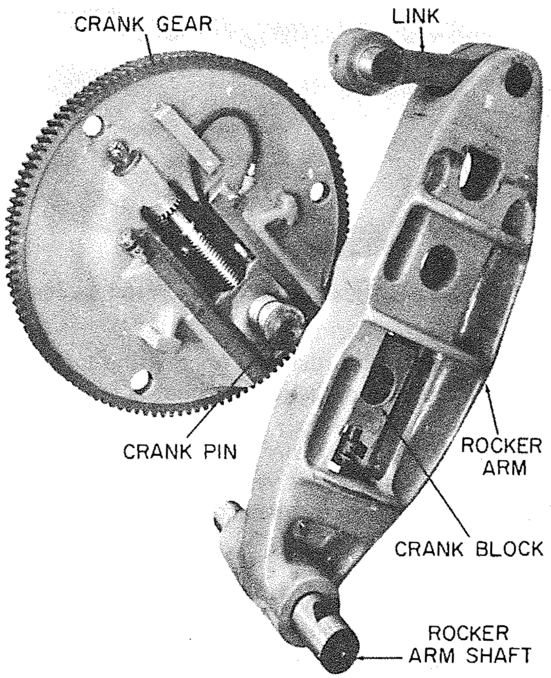


Fig. 13–2. Shaper driving mechanism. (The Cincinnati Shaper Co.)

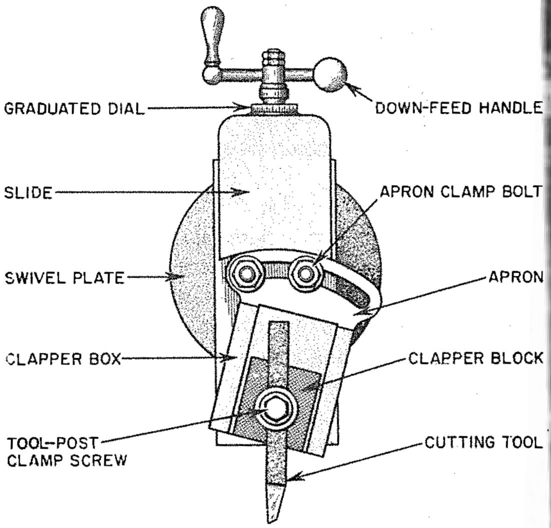


Fig. 13-3. The toolhead.

sides, which are used for clamping the work or a vise to the table. It may be adjusted vertically and locked in position. It is supported in front by a bracket attached to the base. The bolts connecting the bracket to the crossarm on which the table rests must be loosened while the vertical adjustment is being made.

7. *How is the horizontal adjustment of the table made?*
The table is moved horizontally by a hand crank or by power. Under power, the table may be moved a required distance, or it may be moved a definite amount during each return stroke of the ram. This is known as an *automatic power feed.*

8. *What is a universal table?*
A universal table (Fig. 13–4) can be operated in the same manner as a standard table or swiveled to the left or to the right and, if necessary, rotated a full circle. A dial plate, graduated in degrees, indicates the angular setting. The top surface may be tilted up to 15° forward or back. It too has graduations in degrees on its curved edge. All rotating and tilting movements are manually controlled. Examples of the use of the universal table are shown in Figs. 13–4 and 13–5.

Fig. 13–4. Universal table tilted for machining at a compound angle. (The Cincinnati Shaper Co.)

Fig. 13–5. Close-up of compound-angle setup with universal table. (The Cincinnati Shaper Co.)

Fig. 13–6. Safety glasses. (Willson Products, Inc.)

9. *How is the size of a shaper determined?*
The size of a shaper is determined by the length of the stroke of the ram.

10. *What safety rules apply to shaper work?*
(a) Always wear safety glasses (Fig. 13–6) to protect your eyes from flying particles of metal. (b) Do not pass your hands between the tool and the work while the machine is in operation. Use a brush to remove chips from the work. (c) Do not start the ram in motion until you are sure that the work is securely fastened to the vise or to the table, that the tool is secure in the tool post, and that the tool has been adjusted for height. (d) Keep tools away from the moving parts of the machine. (e) Do not wear long sleeves or neckties. (f) Make sure that you understand what you have to do regarding the operations to be performed, the dimensions, and the specifications. (g) Check the size of the rough stock. (h) Keep the machine well oiled. (i) Keep your mind on your work at all times.

11. *Explain how to set the stroke of the ram for length and position.*
To set the ram for the length of the stroke, bring the ram to the extreme back position and set for the length of work plus about ⅝ in., as shown on the graduated scale on the machine. This will allow for about ⅛-in. clearance in the front of the work and ½ in. in the back. For the position of the stroke, bring the ram to the extreme forward position and adjust it so that the front of the tool bit will clear the front of the job by about ⅛ in.

12. *What determines the speed of the shaper for the cutting of different metals?*
Three factors determine the cutting speed of the shaper:

A. The material being cut—for example, cast iron, machine steel, or aluminum.
B. The material from which the cutting tool is made—for example, high-speed steel, special alloys, or cemented carbide.
C. The depth of the cut. Roughing cuts will be slower than finishing cuts.

However, there is a basic cutting speed given to each metal by its manufacturer and reliable trade organizations interested in establishing dependable standards. Cutting speeds, available in standard trade handbooks, should be used in combination with experience and common sense.

13. *Is there a formula for the correct number of strokes per minute of the shaper ram?*
Formulas used to find the speed (rpm) of drill press, lathe, milling machine, and so forth are based on the continuous cutting action of either the tool or the job. The cutting action of the shaper is intermittent: The tool moves slowly on the cutting stroke (forward movement) and returns quickly. A careful study of Fig. 13–7 will show why. It must be remembered that the rpm of the crank gear is unchanging once it has been set. The ratio between the forward and the return strokes is approximately 1 to 1½ or 2 to 3, varying slightly with the length of the stroke. To obtain the correct number of strokes per minute, multiply the cutting speed by 7 and divide the product by the length of the stroke in inches.

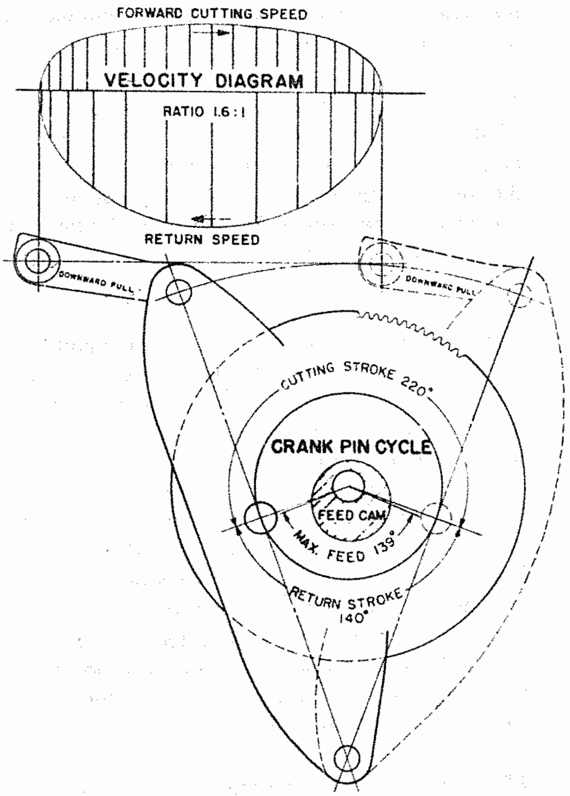


Fig. 13–7. Crank-pin cycle that gives fast return and slow forward cutting stroke. (The Cincinnati Shaper Co.)

Written as a formula this becomes

$$N = \frac{CS \times 7}{L}$$

Where

N = Number of strokes per minute
CS = Cutting speed of the metal
L = Length of the stroke in inches

example: When the cutting speed of the metal being shaped is 60 fpm and the length of the stroke is 10 in.,

$$N = \frac{CS \times 7}{L} = \frac{60 \times 7}{10}$$
$$= 42 \text{ strokes per minute}$$

The machine should be adjusted as near as possible to the speed of 42 strokes per minute. Figure 13–8 shows the allowable cutting speeds for shaping common metals.

14. *Which length is used in the shaper formula, the length of the stroke or the job?*
The distance traveled by the cutting tool, or the stroke of the ram, is the length used for shaper speed calculations.

Fig. 13–8. Cutting speeds for shaping using high-speed tools. (The Cincinnati Shaper Co.)

	cutting speeds in fpm	
material	*roughing*	*finishing*
Cast iron	**60**	**100**
0.10 to 0.20 Carbon	**80**	**120**
0.20 to 0.40 Carbon	**60**	**100**
Die steel	**40**	**40**
Hard bronze	**60**	**100**
Brass	**150**	**Max. speed**
Aluminum	**150**	**Max. speed**

15. *How can the cutting speed be determined if only the length of the stroke and number of strokes per minute is known?*
In order to find the cutting speed of a shaping job multiply the number of strokes per minute *(N)* by the length of stroke *(L)* and multiply the product by the constant 0.14.

Expressed as a formula this becomes

$$CS = N \times L \times 0.14$$

example: Strokes per minute = 45; length of stroke = 6 in.

$$CS = 45 \times 6 \times 0.14$$
$$= 37.8 \text{ fpm}$$

16. *How should the cutting tool be set in the tool post?*
The cutting point should be kept as close as is practical to the clamping bolt in the tool post.

17. *How much clearance should there be between the work in the vise and the ram?*
There should be about 2 in. clearance, or enough to clear one's hand (Fig. 13–9).

18. *What are the most common causes of chattering on a shaper?*
Chattering may result if (a) the tool is suspended too far from the toolholder, as in Fig. 13–10; (b)

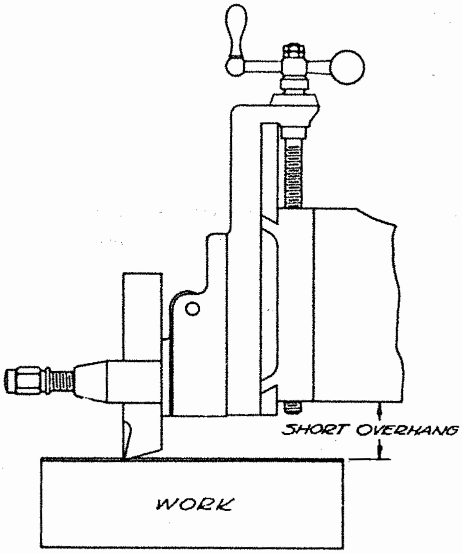
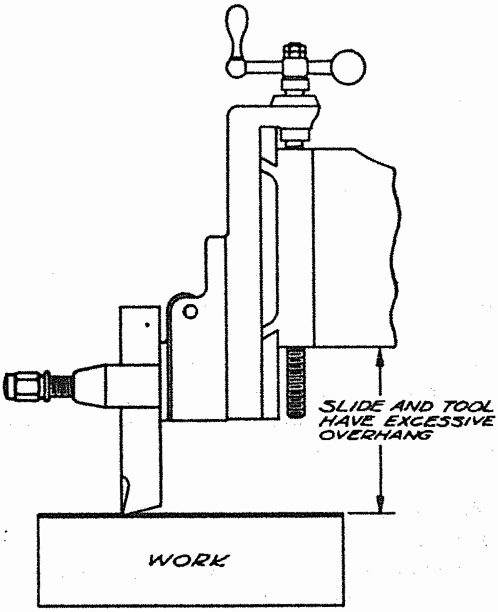


Fig. 13–9. Tool bit and tool post adjusted for mininum clearance. (The Cincinnati Shaper Co.)

Fig. 13–10. Tool bit and slide are too far from the work. This causes the tool to chatter.



the work is not being held rigidly in the vise; anc (c) the ram gibs are not in proper adjustment.

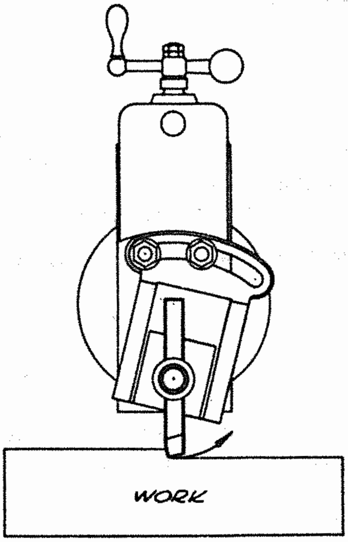
19. *How can chattering on a shaper be eliminated?* Chattering may be eliminated by (a) regrinding the cutting tool for less front clearance, (b) reducing the distance between the tool and the work, (c) retightening the work in the vise or on the table, and (d) adjusting the gibs of the ram for a minimum of clearance.

note: Do not use a hammer on the handle of a vise in an effort to tighten it. The vise handle is long enough so that when pressure is exerted on the end the leverage gained is sufficient to clamp the jaws tightly on the work.

20. *How should the toolhead and clapper block be set for shaping a horizontal surface?* The toolhead and cutting tool should be vertical and the clapper box should be turned away from the direction in which the tool is feeding, as in Fig. 13–11. With this position, the tool will not dig into the work and will swing away from the finished surface on the return stroke.

21. *How should the toolhead and clapper block be set for shaping an angular surface?*

Fig. 13–11. Setting of toolhead and clapper block for horizontal shaping. (The Cincinnati Shaper Co.)



The toolhead and the cutting tool should be adjusted to the same angle, and in the same direction, as the surface to be cut, as in Fig. 13–12. The clapper block should be turned away from the surface to be cut.

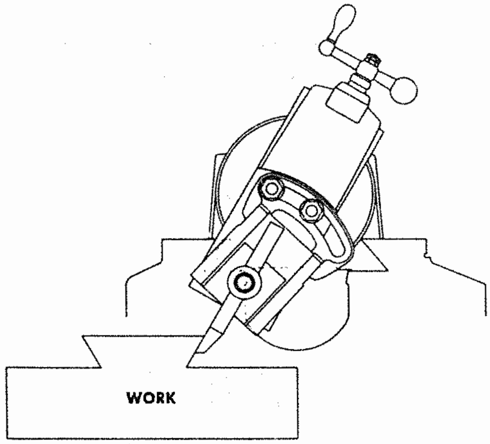


Fig. 13–12. Shaping dovetail with slide and clapper box set at the correct angle. *NOTE:* **Slide must be set at same angle as dovetail. (The Cincinnati Shaper Co.)**

22. *How should rectangular stock be held in a vise to machine it square and parallel?*
The material may be held in a vise without additional support if enough stock is above the vise jaws to make the required cut. Thin stock may be raised to a convenient height in the vise by placing a pair of parallels under the work. A round bar of soft metal, as in Fig. 13–13, or steel wedges, as in Fig. 13–14, are helpful in preventing wide pieces of material from being forced out of the vise.

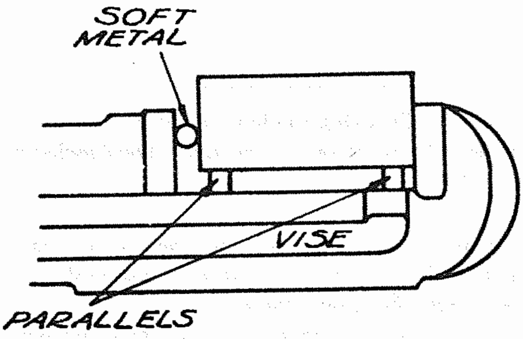


Fig. 13–13. A bar of soft metal helps to hold a wide piece of work for parallel shaping. (The Cincinnati Shaper Co.)

23. *How is work held on the table?*
Most jobs can be securely held by clamps, which are bolted to the table with T bolts, as in Fig. 13–15. A block of suitable height is placed under one end of the clamp to keep it level. Figure 13–16 shows a casting fastened to the shaper table with several clamps.

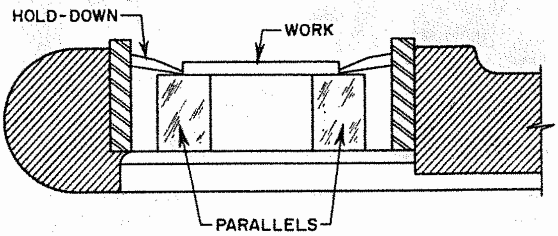
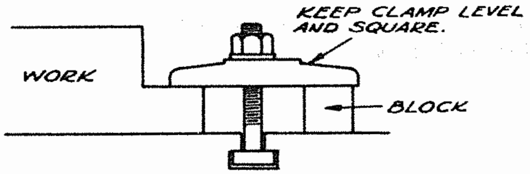


Fig. 13–14. Steel wedges help to hold down work held in a vise.

Fig. 13–15. Work held on table with clamp and T bolt. (The Cincinnati Shaper Co.)



24. *How may a thin piece of work be fastened to the table?*
A thin piece of work may be held with toe dogs, as in Fig. 13–17. The length of the material determines how many pairs of dogs should be used.

25. *How may the solid jaw of the vise be checked to make sure it is square with the stroke of the ram?*
Fasten the vise securely to the table with the solid jaw toward the ram. Place an indicator in the toolholder so that the point of the indicator touches the finished surface, as in Fig. 13–18. Note the movement of the indicator as the vise is moved back and forth with the aid of the crossfeed.

26. *How may the solid jaw of the vise be checked to make sure it is parallel with the stroke of the ram?*

Fig. 13–16. Some jobs require several clamps in order to hold them securely. (The Cincinnati Shaper Co.)

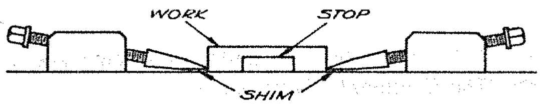


Fig. 13–17. Holding thin work with toe dogs. (The Cincinnati Shaper Co.)

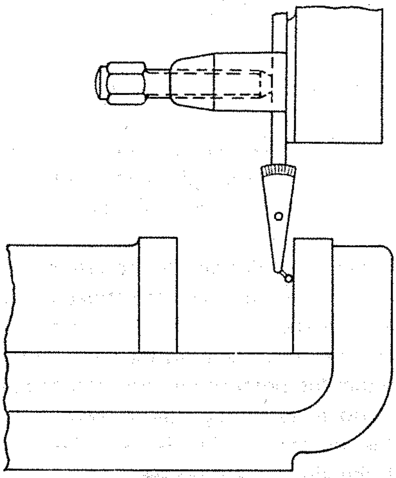


Fig. 13–18. Checking the jaw of a vise to see if it is square with the stroke of the ram. (The Cincinnati Shaper Co.)

Fasten the vise securely to the table with the edge of the solid jaw parallel to the ram. Place an indicator in the toolholder, with the point of the indicator touching the finished surface of the jaw, as in Fig. 13–19. Note the movement of the indicator as the ram is moved slowly back and forth.

27. *What should be done after a cut has been taken from each side of the work if the work is not parallel within reasonable limits?*
Inspect the vise thoroughly for dirt and chips and make sure that it is clean. If this does not correct the condition, check the vise jaw with an indicator.

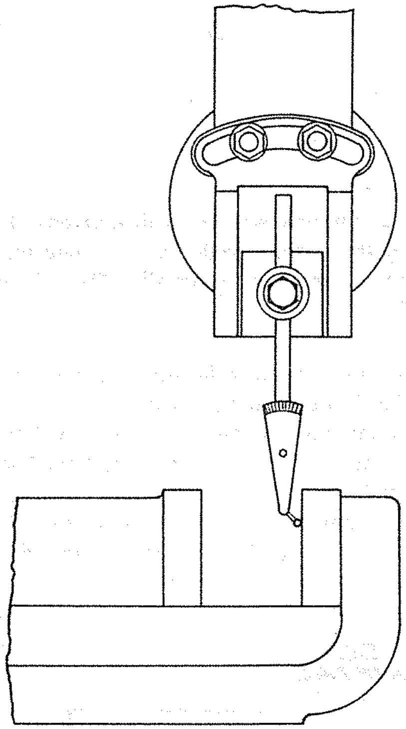


Fig. 13–19. Checking the jaw of a vise to see if it is parallel with the stroke of the ram. (The Cincinnati Shaper Co.)

28. *How may a workpiece be checked to make sure it is level with the surface of the table and parallel with the side of the table?*
For most jobs, the surfaces may be checked with a surface gage, as in Fig. 13–20, by sliding the surface gage along the table and noticing any variations. When a more accurate check is required, an

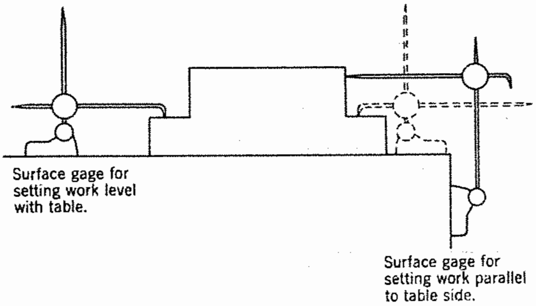


Fig. 13–20. Setting a job level and parallel with the table using a surface gage. (The Cincinnati Shaper Co.)

indicator may be fastened to the toolholder, as in Fig. 13–21, and moved across the surfaces with the aid of the crossfeed or the movement of the ram.

29. *How should the cutting tool be started when taking the first cut?*
When the length of the stroke of the ram has been adjusted, the machine is started and the tool is fed downward toward the work, while the table is moved crosswise by hand until the required depth of cut is started on the edge of the work. The automatic feed is then engaged.

30. *What is the purpose of layout lines on a job?*
Layout lines are generally used as a guide to show the amount of material to be machined. However, the job must be machined to the dimensions given on the blueprint. If the job is a casting on which the line has been scribed from the outline of a template,

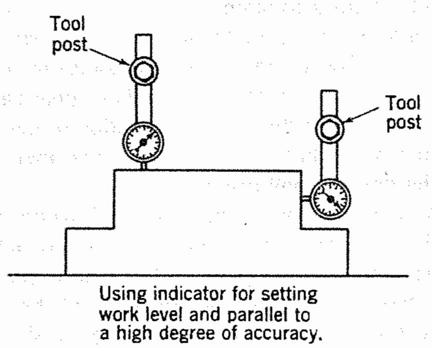
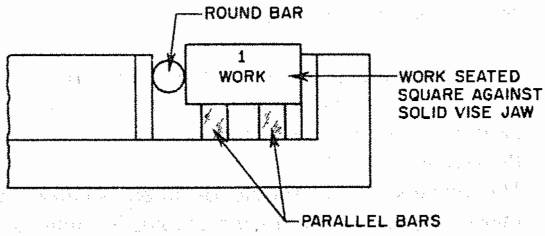


Fig. 13–21. To set a job level and parallel with the table to a high degree of accuracy, a dial indicator should be used. (The Cincinnati Shaper Co.)

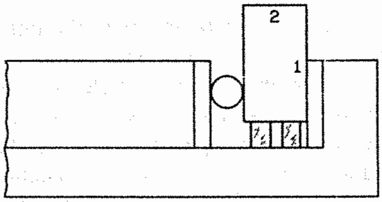
then, in machining it, the tool point must split the layout line. On a job of this type, consult your instructor or foreman.

31. *State the operations for shaping a rectangular job on the shaper, square and parallel.*
Four basic steps should be followed (Fig. 13–22).
Step 1. Set the work on parallels and use a round rod between the work and the movable jaw to seat the work square against the jaw. Proceed to shape surface No. 1.
Step 2. Remove the work from the vise. Remove all burrs and place surface No. 1 against the solid jaw, using the round rod to seat it square. Shape surface No. 2.
Step 3. Remove the work from the vise. Remove all burrs and place surface No. 1 on the parallel bars with surface No. 2 against the solid jaw. Use the round rod to hold surface No. 2 square against the jaw. Shape surface No. 3.
Step 4. Remove the work from the vise. Remove all burrs and place surface No. 3 against the solid jaw, making certain that surface No. 2 is seated firmly on the parallel bars. Use the round rod to hold surface No. 1 against the jaw. Then shape surface No. 4 to size. Measure each end to check for parallelism.

Fig. 13–22. Shaping a rectangle square and parallel.

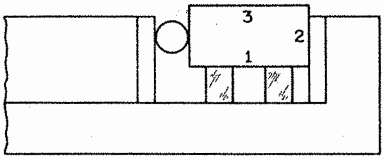


Step 1.

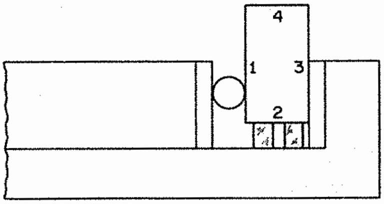


Step 2.

Fig. 13–22. (cont.).



Step 3.



Step 4.

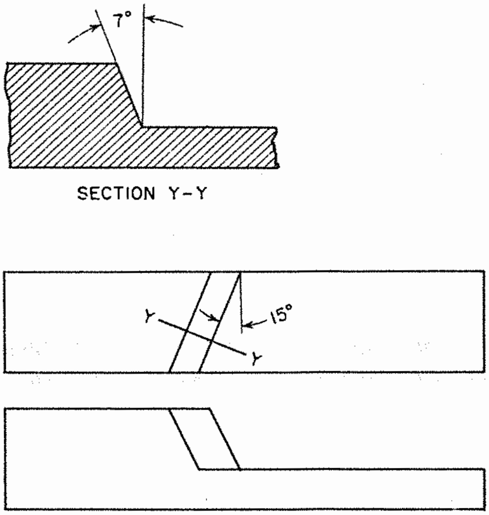


Fig. 13–23. Stock guide with compound angle to be shaped.

32. *How should a thin job be machined on a shaper to prevent the material from warping?*
First, a light cut should be taken off each side to relieve the internal strain of the metal. Then more light cuts should be taken off each side, alternately, until the correct thickness is obtained.

33. *Why should the speed of the shaper be increased when taking a finishing cut?*
Increasing the speed gives a smoother finish to the surface of the material and shortens the length of time required for machining.

34. *When cutting an angle on a large job, using a shaper that has a universal table, should the table be tilted, or should the toolhead be swung to the required angle?*
The universal table should be tilted because this makes it possible to use the automatic table feed. If the toolhead were set on the required angle and there were no automatic downfeed, it would be necessary to use the hand downfeed (see Fig. 13–4).

35. *How should a job similar to the one shown in the sketch of Fig. 13–23 be machined?*
First, machine the six sides, following the instructions given in question 31. Next, lay out the angle and the step according to the required dimensions. Place the work in the vise on parallels, swivel the vise to 15°, and rough out. Complete the machining by setting the toolhead at 7° and feeding the tool down to the layout on this angle until the operation is completed.

36. *Explain how a dovetail bearing may be cut on a shaper.*
The toolhead of the shaper should be set at the same angle as that of the dovetail to be cut. When dovetail bearings such as those shown in Fig. 13–24 are to be cut, the work should not be disturbed in shaping the angular and flat surfaces of the dovetail. The horizontal surfaces should be machined before completing the angular surfaces. A right-hand tool and a left-hand tool are used to machine the angular sides, one at a time, as shown in Fig. 13–25. Both a roughing and a finishing tool should be used if considerable stock is to be removed. In using two tools and moving the toolhead from one side of the center line to the other, great care must be exercised; if there is any variation in the angular setting of the head, a variation in the angular sides of the dovetail will result.

Another way of cutting a dovetail, when the sides of the work are parallel and the solid jaw of the vise is parallel with the stroke of the ram, requires only one tool. First, rough out the sides of the dovetail to within $1/64$ or $1/32$ of the finished size. Next, take a light cut on one side; then reverse the work in the vise but do not disturb the setting of the table, and take a light cut off the other side. Check

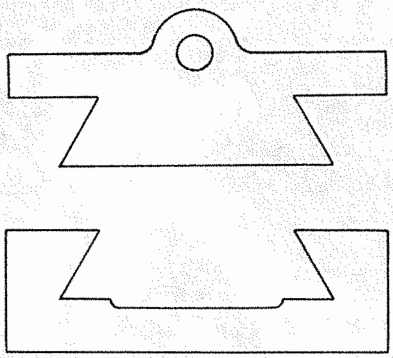
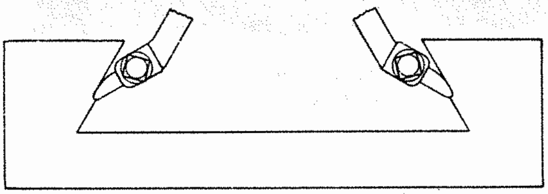


Fig. 13–24. Dovetail bearings.

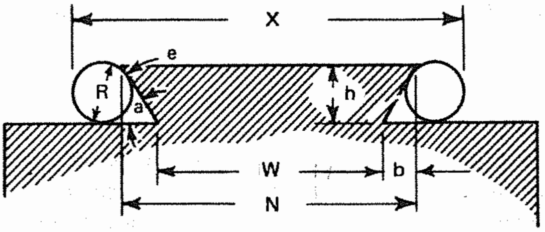
Fig. 13–25. Shaping a dovetail with a right-hand and a left-hand toolholder.



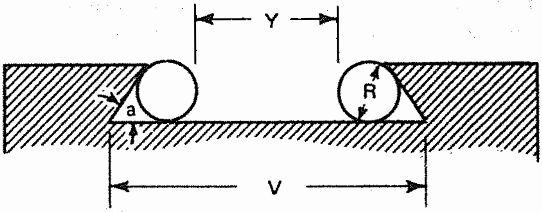
for size and repeat the process until the finished size is obtained. Using this method, the dovetail will be held central with the work and the angles will be the same.

In shaping dovetail bearings, it is very important to incline the clapper box in the proper direction so that the tool will swing away from the work on the return stroke of the ram, as in Fig. 13–12. The beginner should pay strict attention to this point because the setting may not be correct even though it may appear to be. Remember that the top of the clapper box must be set in a direction away from the surface being machined.

37. *What method is used to check the measurement of an external dovetail?*
Two cylindrical rods are placed against the dovetail as shown in Fig. 13–26A. The rods should be smaller than h and touch approximately at e. By measuring X across the rods with a vernier caliper, angle a



$X = R \times (1 + \cot \frac{1}{2}\, a) + W$ A



$Y = V - R \times (1 + \cot \frac{1}{2}\, a)$ B

Fig. 13–26. Measuring dovetails over rods.

and dimension W can be verified. The required value of X can be calculated as follows: Add 1 to the cotangent of ½ the dovetail angle a and multiply by the diameter of the cylindrical rods R. Then add the product to the dimension of W.

$$X = R \times (1 + \cot \tfrac{1}{2}\, a) + W$$

example: If $W = 4$ in., the angle $a = 60°$ and the diameter of the rods $R = ¾$ in., or 0.750 in.

$$X = 0.750 \times (1 + \cot 30°) + 4$$
$$X = 0.750 \times 2.732 + 4$$
$$X = 6.049 \text{ in.}$$

To obtain measurement b, multiply the vertical height h by the cotangent of a.

38. *How can an internal dovetail be checked?*
To verify the measurement of an internal dovetail (Fig. 13-26B) dimension Y is measured with an inside vernier caliper. A calculated value of Y is obtained as follows and the two figures compared: Add 1 to the cotangent of ½ the dovetail angle a. Multiply the result by the diameter of the rod R, and subtract the result from the dimension V.

$$Y = V - R \times (1 + \cot \tfrac{1}{2}\, a)$$

The sides of the dovetail should be finished with a smooth surface (Figs. 13–27 and 13–28).

39. *Explain the method used to shape a V or keyway centrally in a block.*
One method is to lay out the job and shape to scribed layout lines. A more accurate method of shaping a V is to set the vise jaws parallel to the stroke, set the toolhead at the required angle, and rough out to the layout lines. Next, take a cut from one side of the V, then reverse the job in the vise. With the table set in the same position, take a cut off the opposite side. Continue this until both sides of the V are machined and the proper depth has been obtained. The V will then be in the center of the block. The same procedure may be used in shaping a keyway.

40. *How may a keyway be cut on a shaper when the keyway does not extend the entire length of the shaft?*
Drill a hole slightly larger and deeper than the width and depth of the keyway at the place where the keyway ends. Set the position of the shaper stroke so that the tool will stop in the center of the drilled hole at the end of the forward stroke. Then cut the keyway in the usual manner. Lock the clapper box to prevent raising on the return stroke.

Fig. 13–27. Finishing the side of an internal dovetail to a smooth surface. (The Cincinnati Shaper Co.)

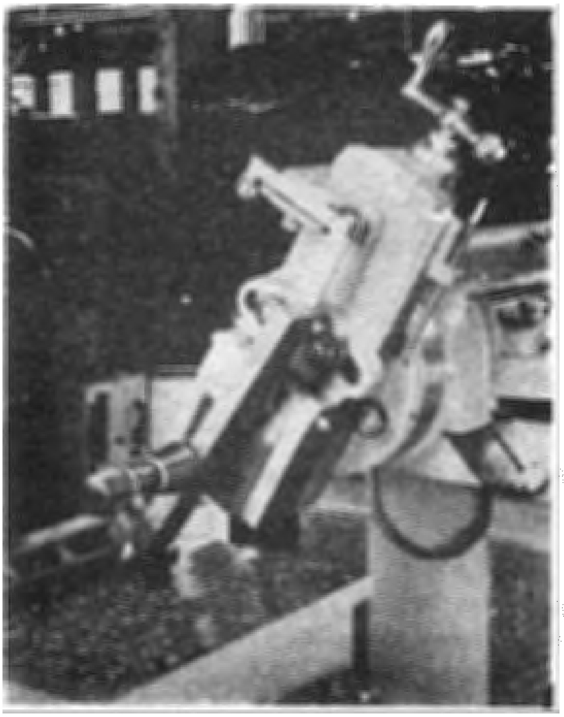


Fig. 13–28. Shaping the side of an external dovetail. (The Cincinnati Shaper Co.)

41. *Can the shaper be used for internal work?*
Yes. The shaper can be used to cut internal keyways (Fig. 13–29) as well as a variety of differently shaped holes. First, the holes must be bored. They must be of a sufficient size to permit the entry of the internal toolholder, which takes the place of the tool post. An example of this kind of work is shown in Fig. 13–29.

42. *What is the method of shaping an irregularly curved surface?*
The required shape is scribed on the surface of the material. After the work has been secured in position on the machine, the operator, by skillful manipulation of the vertical and horizontal feeds,

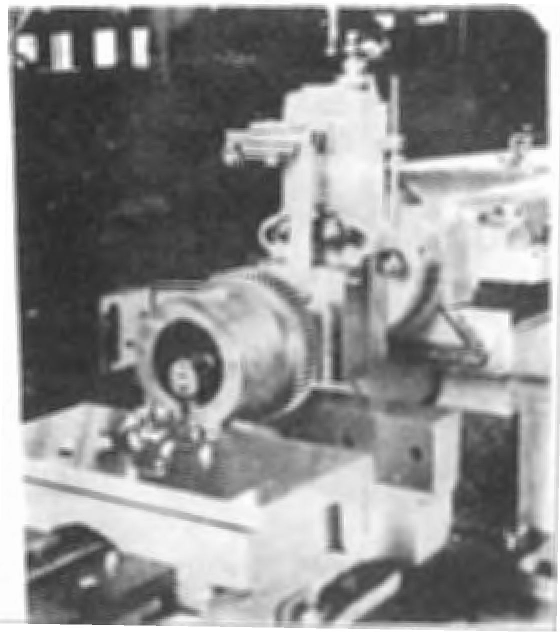


Fig. 13-31. Shaping work clamped directly to the shaper table. The machine is equipped with an auxiliary table top. (The Cincinnati Shaper Co.)

Fig. 13-29. Cutting an internal keyway cinnati Shaper Co.)

as in Fig. 13-30, guides the cutting tool so that it will follow the layout lines. This is known as *contour shaping.*

43. *Must all shaping jobs be held in a vise?*
The vise is a convenient method of holding many jobs for shaping. However, jobs can be clamped to the table of the machine. An auxiliary table top can also be utilized for large work (Fig. 13-31).

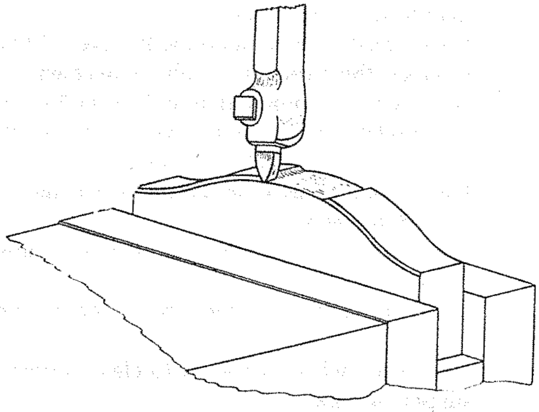


Fig. 13-30. Shaping an irregular surface.

44. *What other methods are used to hold jobs on the shaper?*
Special fixtures are often used when many pieces require the same shaping operation. Index centers are used when slots, splines, or teeth require accurate spacing (Fig. 13-32).

45. *Can shaper attachments be combined to machine unusual jobs?*
Yes. It is often necessary to utilize the advantages of a combination of accessories to machine jobs to unusual shapes and close tolerances (Fig. 13-33).

46. *How is a hydraulic shaping machine different from the more common crank-type shaper?*
In overall appearance there is very little difference between the hydraulic and the crank-type shapers. The ram of the crank-type shaper gets its movement from the rocker arm, which is caused to move by the crank pin attached to the bull gear.

The ram of the hydraulic shaper (Fig. 13-34) is moved by oil pressure, which is developed by a pump driven by an electric motor.

47. *How are the speeds and feeds of the hydraulic shaper controlled?*

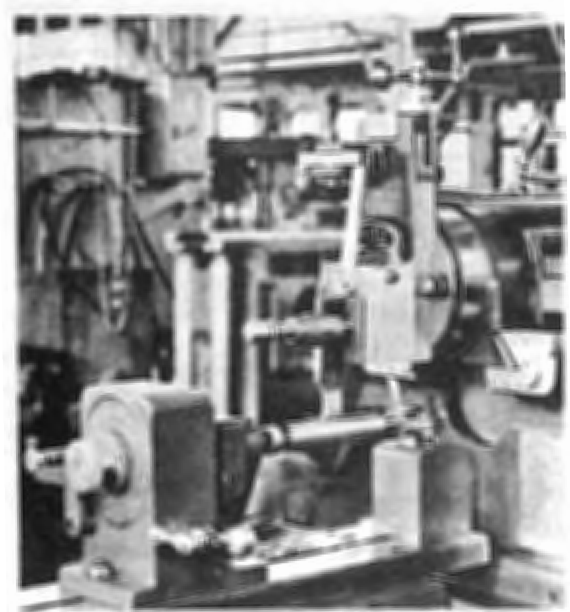


Fig. 13–32. Cutting splines in a shaft using shaper index centers. Splined shafts, gears, and ratchet teeth are made with this device. (The Cincinnati Shaper Co.)

Fig. 13–33. A compound angle being shaped on a forming die. The shaper is equipped with a universal table, auxiliary table top, and index centers. (The Cincinnati Shaper Co.)

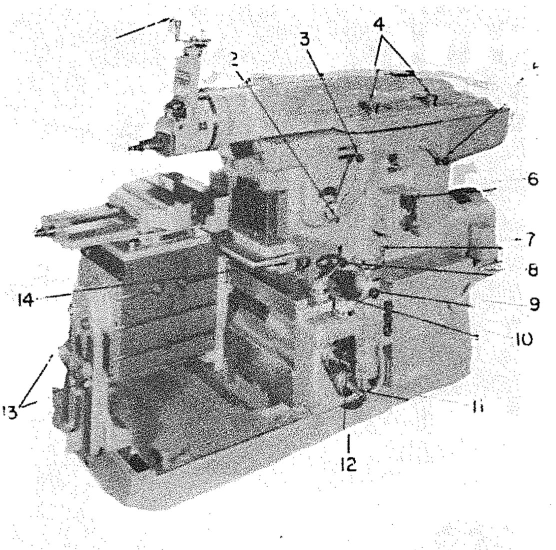


Fig. 13–34. The control levers and adjustments of a hydraulic shaper. (Rockford Machine Tool Co.)

1. Ball crank: used to move toolhead in vertical position.
2. Plunger knob: used to permit lever shift to high-speed range.
3. Lever: used to start and stop the machine and to select high or low range of speeds.
4. Knob: used to set the length of stroke and the position of the ram.
5. Lever: used to reverse the direction of stroke at any position, forward or return.
6. Lever: used to operate the valve that governs the ram speed.
7. Wheel: used to regulate the amount of vertical-feed or cross-feed.
8. Lever: used in conjunction with Lever 9, Lever 8 selects the direction of table movement.
9. Lever: used in conjunction with Lever 8 to control the table movement; Lever 9 selects either vertical or horizontal movement.
10. Plunger knob: used to permit lever shift for vertical travel of rail.
11. Safety crank: used on this shaft to raise or lower cross rail.
12. Screw: used to move the table along the cross rail.
13. Nuts: used when necessary to clamp outboard support to table.
14. Clamp plates: these should be tightened to provide greater rigidity to the work table.

The speeds of the shaper ram and the feeds of the table are controlled by the hydraulic mechanism. A lever (Fig. 13–34) operates a valve that varies the quantity of oil delivered to the ram cylinder and thereby governs the ram speed. The amount of cross or vertical feed of the table is regulated by a handwheel (Fig. 13–34), which affects the table feed cylinder. Figure 13–35 shows the hydraulic circuit of the shaper with its cylinders and valves.

48. *What advantages has the hydraulic shaper over the crank type?*
The cutting stroke of the ram of the hydraulic shaper is unchanging and uniform in its speed of travel. The return speed is constant for all lengths of stroke. The cutting speed remains unaltered when the length of the stroke is altered. The feeds are controlled independently of the ram drive and are unlimited in number.

49. *Is the hydraulic-controlled ram capable of taking deep and heavy cuts?*
Figure 13–36 shows deep and heavy cuts being taken on a casting held in a vise; the job is being machined on a hydraulic shaper.

50. *What accessories can be used on the hydraulic shaper?*
All the accessories used on a crank-type shaper can be used on the hydraulic shaper. The hydraulic shaper is fitted with a plain table on its standard

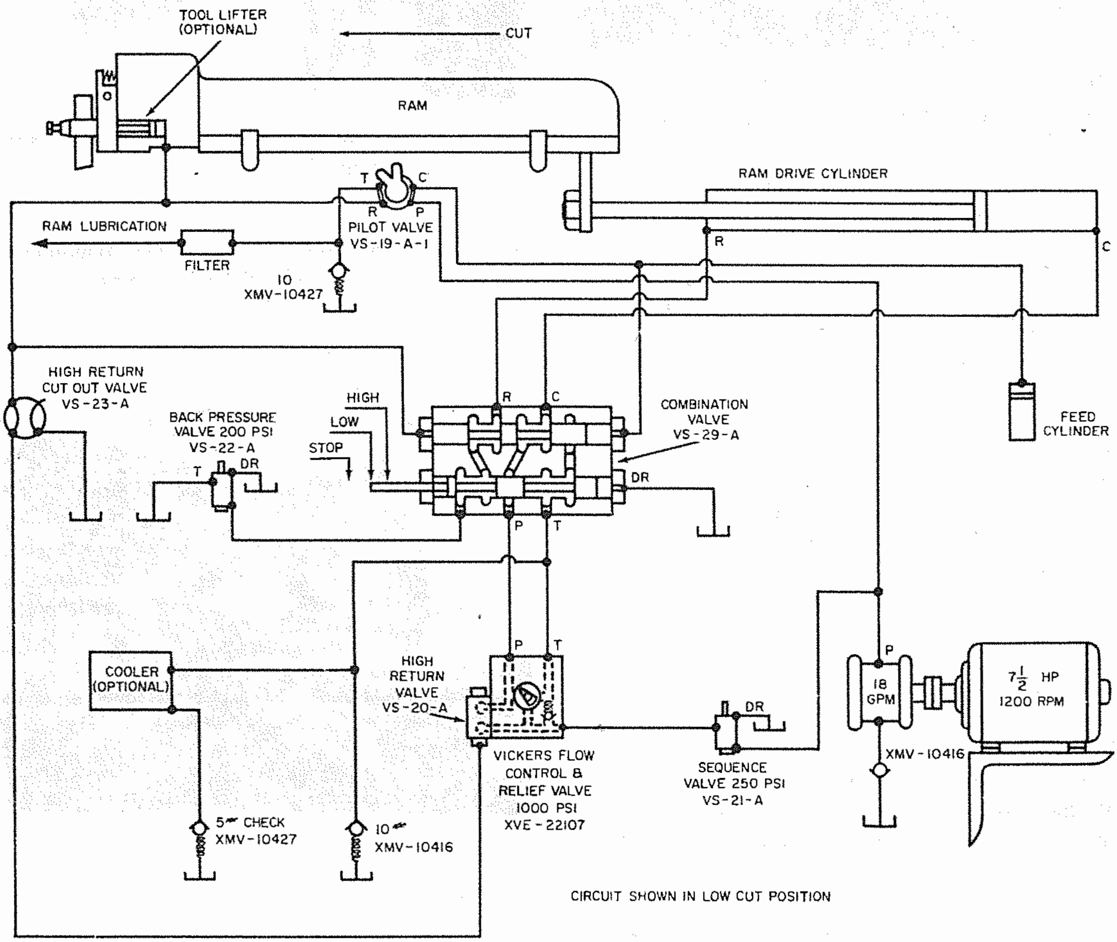


Fig. 13–35. The hydraulic circuit of the Rockford hydraulic shaper. (Rockford Machine Tool Co.)

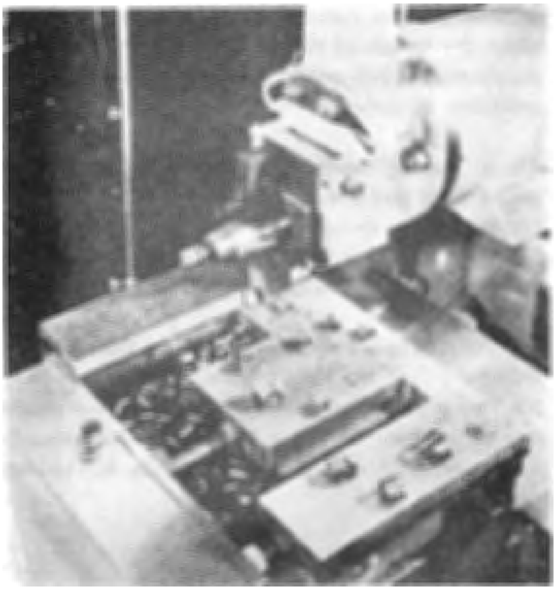


Fig. 13–36. Taking a deep and heavy cut across a casting being held in a vise on a hydraulic shaper. (Rockford Machine Tool Co.)

model but can also be equipped with the universal table (Fig. 13–37). The universal table has a top that is adjustable 15° in either direction. The table can also be revolved 360°. With a crank on the worm shaft, the table can be revolved and set at any angle. The degrees are graduated on a dial found at the front of the table.

51. *What is the toolhead power feed on a hydraulic shaper?*
Another alternate feature available on the hydraulic shaper is a power feed for the toolhead (Fig. 13–38). The direction of the feed, up or down, is selected by a lever (A). The amount of the feed is regulated by a screw with a knurled knob (B). The amount of the feed can be observed on a graduated collar at the top of the vertical feed screw.

52. *What types of cutting tools can be used on a hydraulic shaper?*
All the standard and conventional tools are suitable for use on the hydraulic shaper.

53. *What is a vertical shaper?*
A vertical shaper (Figs. 13–39 and 13–40), sometimes called a *slotter,* is similar to the more com-

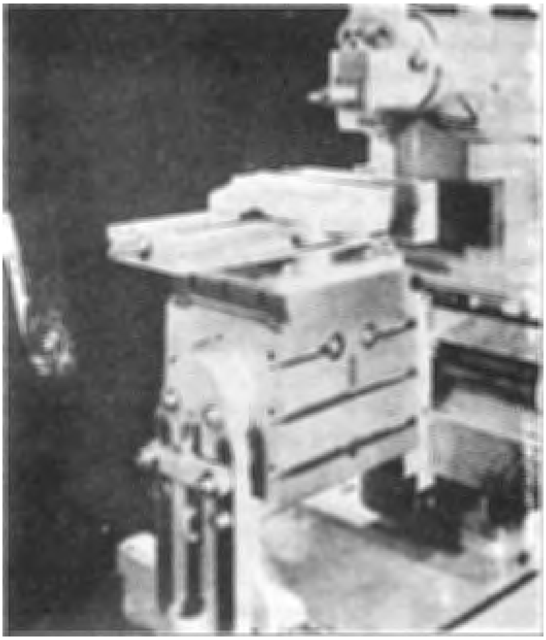
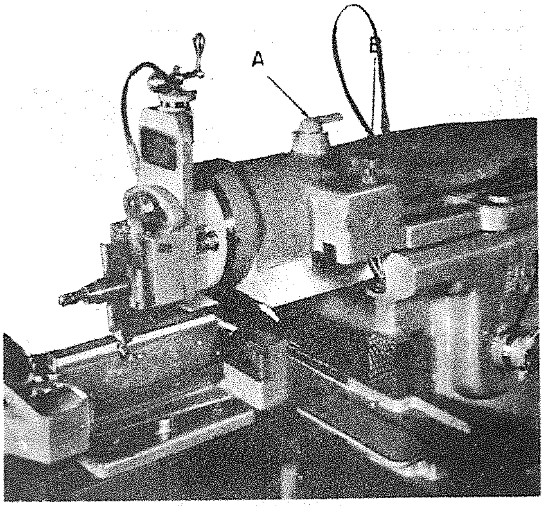


Fig. 13–37. A universal table of a hydraulic shaper. (Rockford Machine Tool Co.)

Fig. 13–38. The toolhead power feed available on the hydraulic shaper. (Rockford Machine Tool Co.)



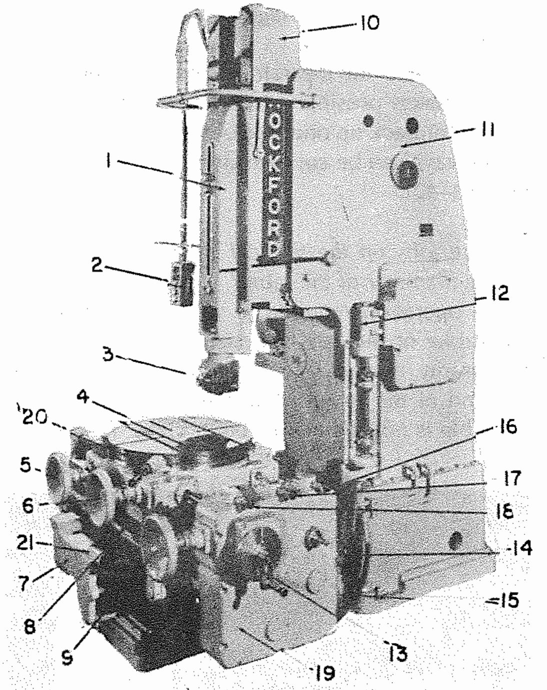


Fig. 13–39. Nomenclature of the vertical shaper—No. 1. (Rockford Machine Tool Co.)

1. Ram
2. Pendant station
3. Ram head
4. Rotary table
5. Cross-feed unit
6. Rotary-feed unit
7. Bed
8. Saddle
9. Longitudinal-feed unit
10. Ram slide
11. Column
12. Pilot valve
13. Dividing head
14. Feed cylinder
15. Traverse motor
16. Cross-feed
17. Longitudinal
18. Rotary
19. Gear box
20. 90° index plunge
21. Serial number

monly used shaper, the difference being that the ram is in a vertical position instead of being horizontal. Also, the table is mounted on a heavy base and provided with mechanisms that make possible forward-and-backward and side-to-side movement. It is also possible for the table to rotate and to be indexed. The ram may also be adjusted to an angular position (Fig. 13–41).

54. *How many different sizes of vertical shapers are available?*

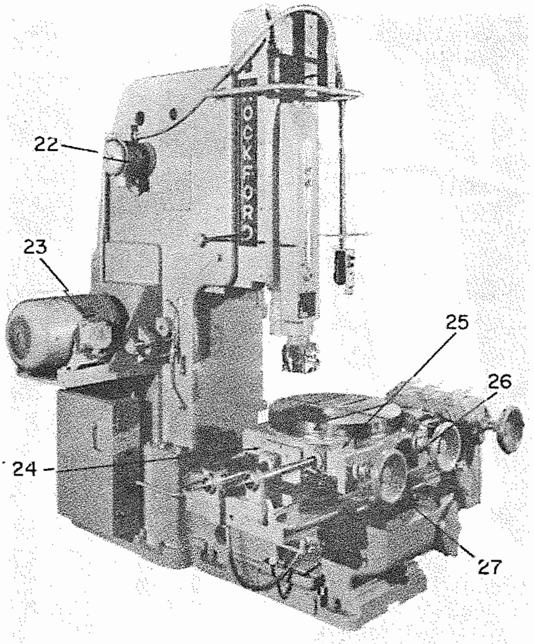


Fig. 13–40. Nomenclature of the vertical shaper—No. 2. (Rockford Machine Tool Co.)

22. Ram speed-change motor
23. Main drive motor
24. Cross slide
25. Table lock
26. Cross-slide lock
27. Saddle lock

There are many sizes of vertical shapers and slotters. The more commonly used sizes are 6, 12, and 20 in. The size of the machine refers to the length of the stroke. The stroke is adjustable from 0 to 6 in. on the small machine and from 3 to 22 in. on the large machine. Some vertical shapers are driven mechanically by pulleys and gears; others get their power hydraulically.

55. *What advantages are claimed for the vertical shaper?*

Setting up the job is more convenient because it is easier to see, align, measure, and clamp. The pressure generated by the cutting stroke is better supported by the table and the bed right below it (Fig. 13–42). There is less danger of the table springing. Circular shapes can be machined; gear teeth, splines, keyways, and so forth can be accurately spaced and indexed precisely.

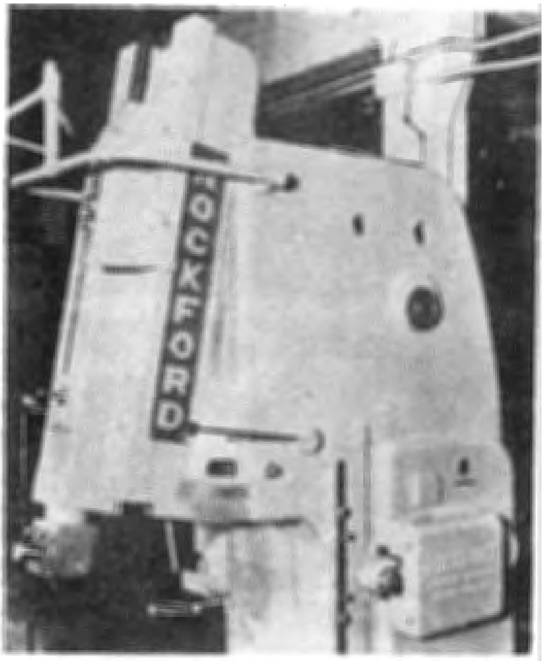
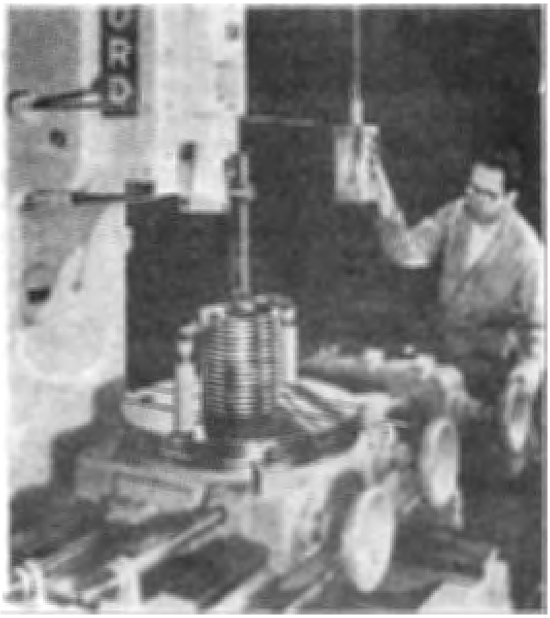


Fig. 13–41. The ram of the vertical shaper can be adjusted up to 10° from vertical. (Rockford Machine Tool Co.)

Fig. 13–42. Cutting a long keyway in a special pulley. (Rockford Machine Tool Co.)



56. *What is the advantage of being able to tilt the ram?*
Being able to tilt the ram at precisely measurable angles makes possible a tapered cut without having to shim or pack up one side of the job. Tapered slots or keyways can be cut with simple setup procedures (Fig. 13–42).

57. *Are jobs on the vertical shaper limited in size by the diameter of the table?*
If the operation required is within the capacity of the stroke of the ram, the size of the job does not necessarily matter. Care must be taken to support the end of the job so that it is perfectly level and the table is not strained or bound (Fig. 13–43).

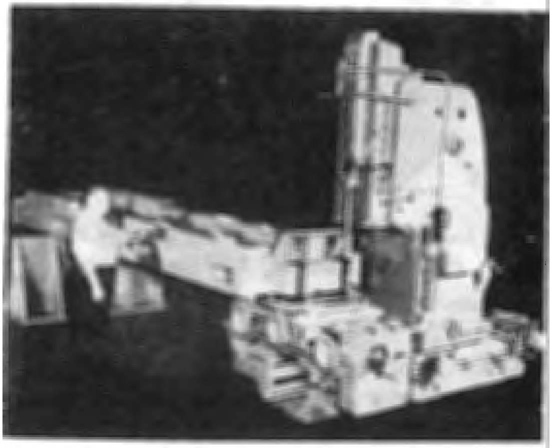


Fig. 13–43. Shaping at one end of a large job that is adequately supported at the other. (Rockford Machine Tool Co.)

THE PLANER

The planer is one of the basic machine tools of the machinist's trade. The invention of the planer has been claimed by several machine builders of the past; Robert Roberts of England is credited with inventing the planer with the reciprocating platen (or table) in 1817.

Until the more recent development of large milling and grinding machines, the machining of flat accurate surfaces was the work of the planer. Planing machines are made in a variety of sizes. The platen sizes range from 36 in. to 100 ft in length. Small work can be held in a vise and machined on a planer, but it is not usually economical to do so. The milling machine has taken over much of the small work previously machined on a planer. When the work is heavy, cumbersome, or of unusual shape, and an accurate flat surface must be machined, the planer is still the best machine to use.

The main skill of a planing machine operator lies in the manner in which he clamps the work to the platen without setting up undue strains, which cause shape distortion. The operator must be thoroughly skilled in the art of clamping, and he must have an expert's understanding of metals and how they react to the machining process. Jobs must be packed, shimmed, and clamped in such manner that no distortion will result. Most planing jobs are castings of various metals and alloys. Each job must be leveled with packing pieces, parallel strips, and/or jacks. The job must be held securely against the tremendous force exerted when the job meets the cutting tool. This requires ingenuity and good judgment developed from experience and study.

58. *What is a planer?*
A planer (Fig. 13–44) is a large machine designed for producing flat surfaces on a piece of work.

59. *In what way does a planer differ from a shaper?*
A planer is designed with a stationary housing for holding toolheads and a table with a reciprocating movement for holding the work; thus the work is moved against the cutting tool. With the shaper, the work is held stationary and the cutting tool is moved across the work.

60. *What type of work is done on a planer?*
Because of its large size the planer is capable of handling workpieces that would be too large or too awkward for a shaper to machine easily.

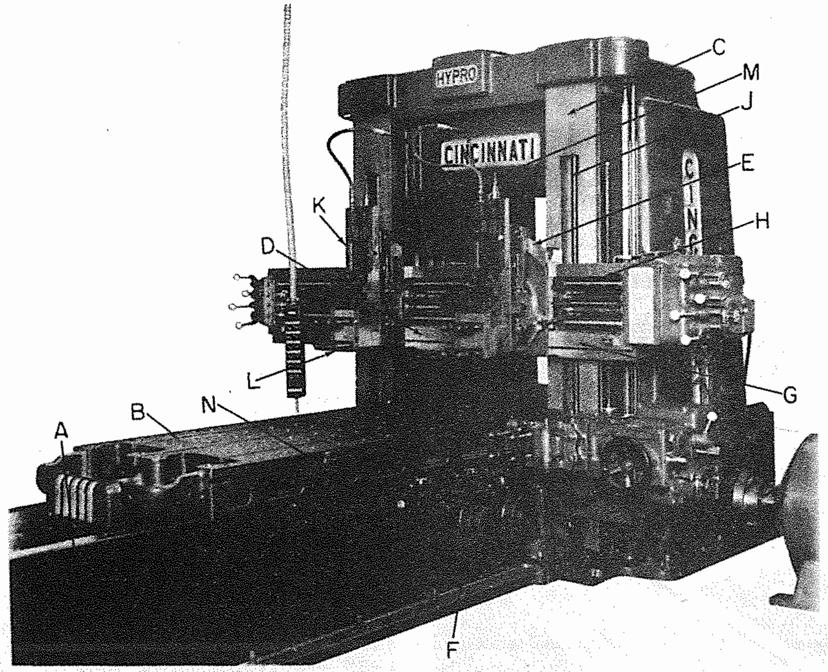


Fig. 13–44. Planer. (Cincinnati Planer Co.)
A. Bed
B. Table, or platen
C. Housing
D. Rail
E. Saddle
F. Toolhead
G. Rail screw – right-hand head
H. Rail screw – left-hand head
J. Elevating screw – right hand
K. Slide
L. Tool block
M. Downfeed-screw
N. Table dogs

61. *What are the principal parts of a planer?*
The principal parts of a planer are (a) the bed, (b) the table, (c) the housing, (d) the crossrail, (e) the saddle, and (f) the toolhead.

62. *What is the function of the planer bed?*
The planer bed, a large boxlike casting, acts as the foundation of the machine. The other parts are attached to, or supported by, the bed.

63. *What is the table, or platen, of a planer?*
The table, or platen, is a large, rectangular casting mounted on the top of the bed, on sliding V ways. It holds the work. The upper surface has T slots, which facilitate clamping the work, vises, or special fixtures with T bolts (Fig. 13–45).

64. *What is the housing of a planer?*
The housing is a large vertical casting, which straddles the table and bed of the planer and supports the mechanism for operating the toolheads.

65. *What is the crossrail of a planer?*
The crossrail is a unit mounted in a horizontal position on the vertical ways of the housing. It carries the vertical toolheads, which, by means of feed screws (one for each head), may be moved from left to right. The crossrail is moved up or down by means of elevating screws located within the ways of the housing (Fig. 13–46).

Fig. 13–45. The planer table, or platen. (Rockford Machine Tool Co.)

66. *What is the saddle of a planer?*
The saddle is a unit fitted to the ways of the crossrail. On its front surface are ways to which the toolhead is fitted, together with a vertical feed screw, which provides for a vertical movement of the toolhead. There are two saddles, one for the left toolhead, the other for the right toolhead. Each may be operated independently of the other.

67. *What is the toolhead of a planer?*
The toolhead, which is attached to the saddle, contains the tool post, which, in turn, holds the cutting tools. The tool post is hinged to the head so that on the return movement of the table the cutting tool will be raised and ride on the top of the work. This protects the cutting edge from being damaged and permits the automatic-traverse feed to operate without interference. There are three toolheads, two in a vertical position on the crossrail, the other in a horizontal position on the housing below the crossrail (Fig. 13–46).

68. *How is the size of a planer designated?*
The planer is given its size from the measurements of the largest job that can be fastened on its table and pass under and between housings. A 30-in. × 30-in. × 6-ft. planer would accommodate work that size and smaller.

Fig. 13–46. Toolheads on the crossrail. (Rockford Machine Tool Co.)

69. *Are all planers mechanically driven?*
Planers are driven by two different methods. Figure 13–47 shows the mechanically driven planer. The table of this machine is moved by gears and a gear rack attached to the underside of the table. The planer shown in Fig. 13–48 is driven hydraulically by a constant-speed, nonreversing motor, which drives a hydraulic pump. The oil used in this power unit is continuously filtered as it passes through the pipes to the hydraulic reservoir. The system is completely sealed to prevent dirt from entering, and only high-pressure hydraulic tubing and fittings are used to prevent oil leaks.

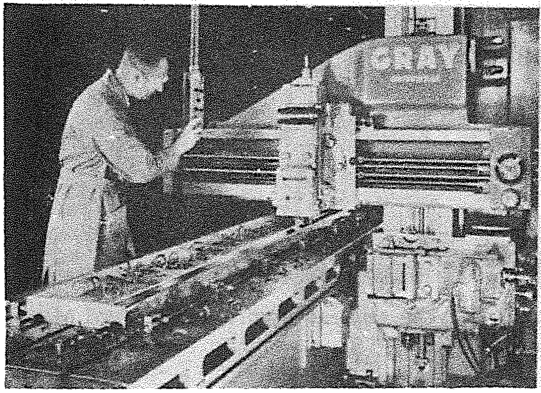


Fig. 13–47. A mechanically driven planer. (The G. A. Gray Co.)

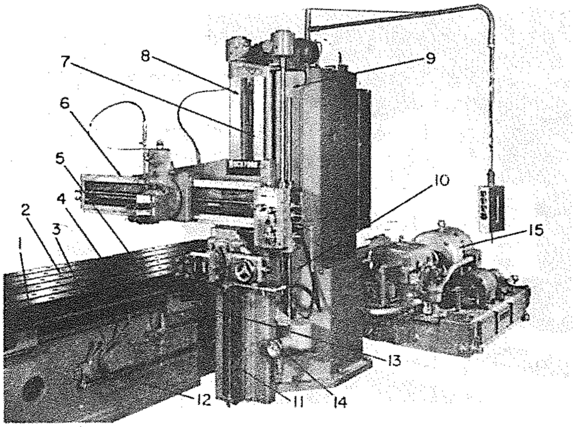
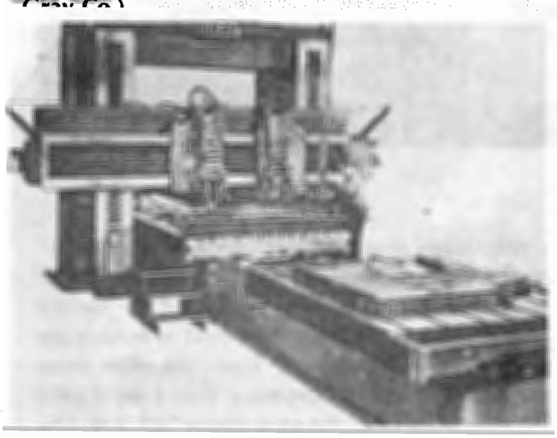


Fig. 13–48. Nomenclature of hydraulic planer. (Rockford Machine Tool Co.)

1. Reverse cam – front
2. Table
3. Range selector
4. Start and stop
5. Manual reverse lever
6. Crossrail
7. Counterweight chain
8. Column
9. Rapid traverse shaft
10. Feed shaft
11. Sidehead elevating screw
12. Bed
13. Reverse cam – rear
14. Feed adjusting handwheel
15. Unit power plant.

Fig. 13–49. The double housing planer. (The G. A. Gray Co.)



70. *Are all planers of the same type?*
There are two basic classes of planers. The double-housing type (Fig. 13–49), and the open-side type Fig. (13–50). The double-housing type is the older of the two. The table moves between the two housings, which support the crossrail and the toolhead. The open side makes it possible to plane work far wider than the table.

71. *Is it possible to take heavy cuts on the open side planer and avoid springing the crossrail?*
The crossrail of the open side is well supported by wide dovetailed guides fitted with gibs; it can take heavy cuts with accurate results (Fig. 13–51).

72. *How is the depth of cut and the feed of the cutting tools controlled?*
The feed box (Fig. 13–52), which is located on the operator's end of the crossrail, enables the operator to accurately control all the head movements and the selection of the feed. The sidehead is counterbalanced to permit easy vertical movement either by hand or by power. One railhead or the sidehead can be traversed while the other heads are being fed.

Fig. 13-50. The open side planer. (The G. A. Gray Co.)

Fig. 13-51. Open-side-type planer machining three accurate surfaces. (Rockford Machine Tool Co.)

73. *What types of cutting tools are used on a planer?*
Planer cutting tools may be solid. Figure 13-53 shows eight solid cutting tools shaped for various cutting situations. Small tool bits held in holders are also used, as in Fig. 13-54. These are often more convenient and more economical than a set of solid tools. Another type is the gang planer tool (Fig. 13-55). The head is solidly secured to the shank upon which it swivels to a limited degree by means of a deep and closely fitted tongue and socket. When set, its position is fixed by two steel collar screws. Two stop screws prevent slipping of the head. Because the head is graduated the tool can quickly and ac-

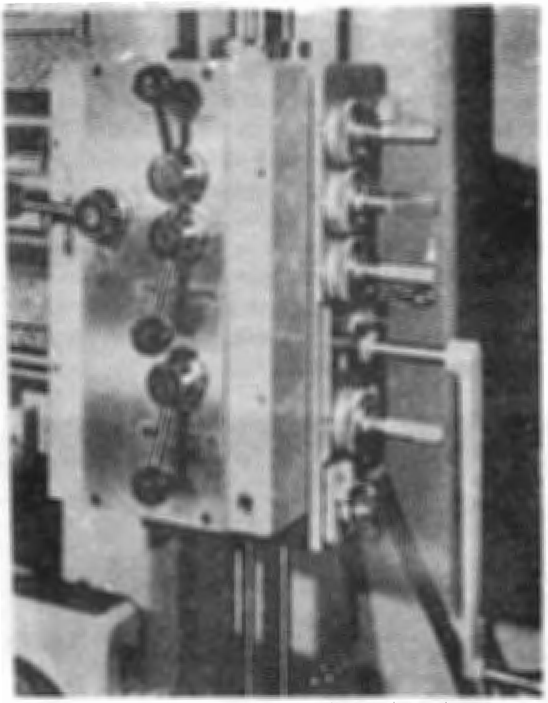


Fig. 13-52. The railhead controls. (Rockford Machine Tool Co.)

curately be set to any desired feed. Thus the tool always can be cutting at the greatest speed permitted by the hardness of the metal being cut. Because each chip is comparatively light, a gang planer will easily carry a feed and depth of cut much greater than is possible with a single-point cutting tool. There is less tendency for the gang planer tool to break off metal at the end of the cut.

74. *Can interchangeable single-point tooling systems be used in planer work?*
Yes. Interchangeable single-point tools for planer work were developed to permit changing the cutting tool for a different operation without having to tear down the complete tool setup. Figure 13-56 shows a 16-piece set of interchangeable tool bits, complete with toolholder, and a holder for grinding the tool bit. These tool bits are shankless and are commonly serrated on the bottom. These serrations fit into the toolholder serrations. The tool bits are held in place by a locking clamp. When loosened, the tool bit can be repositioned either to the right or left in increments of the serration spacing.

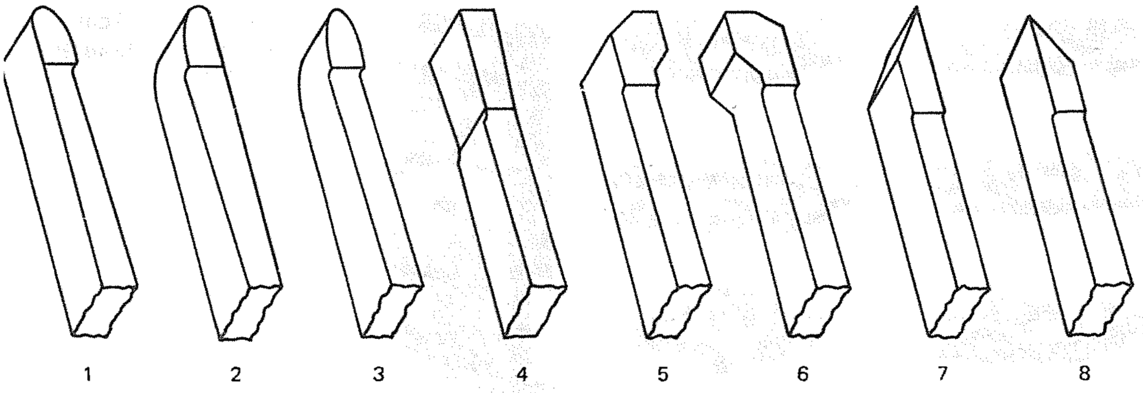


Fig. 13–53. Solid planer tools.

1. Right-hand roughing tool
2. Left-hand roughing tool
3. Round-nose roughing tool
4. Square-nose roughing tool
5. Right-hand side-cutting tool
6. Left-hand side-cutting tool
7. Right-hand dovetail tool
8. Left-hand dovetail tool

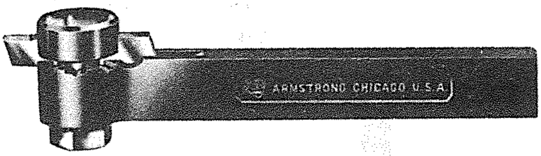


Fig. 13–54. Toolholder. (Armstrong Bros. Tool Co.)

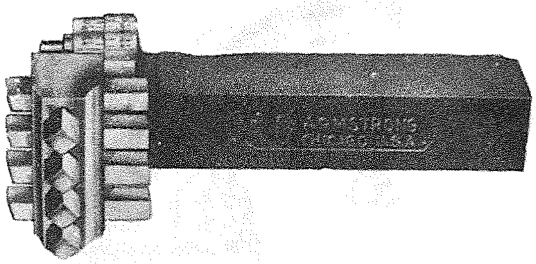


Fig. 13–55. Gang planer tool. (Armstrong Bros. Tool Co.)

Fig. 13–56. A set of interchangeable single-point tool bits for planing, complete with toolholder, grinding holder, and wrenches. (The O. K. Tool Co.)

75. *Are interchangeable tools made only in one size?*
Toolholders and tool bits are made in three sizes; E, G, and J. Size E is the smallest. Tool bits, which are made from several types of high-speed steel, are heat-treated for specified purposes. They can be obtained with carbide inserts or tips.

76. *How is work held on a planer?*
The work may be held in a vise fastened to the table, but usually jobs small enough to be so held are machined on a shaper. The most common way to hold work is to clamp it directly to the table of the planer. Many styles of clamps are available to suit particular situations. Several such clamps are shown in Fig. 13–57. One end of a clamp is set on the work, and the other end is supported by a step block (Fig. 13–58) or by an adjustable block (Fig. 13–59). Blocks such as these are preferred to odd pieces of wood or steel. Another type of clamp is the T-slot

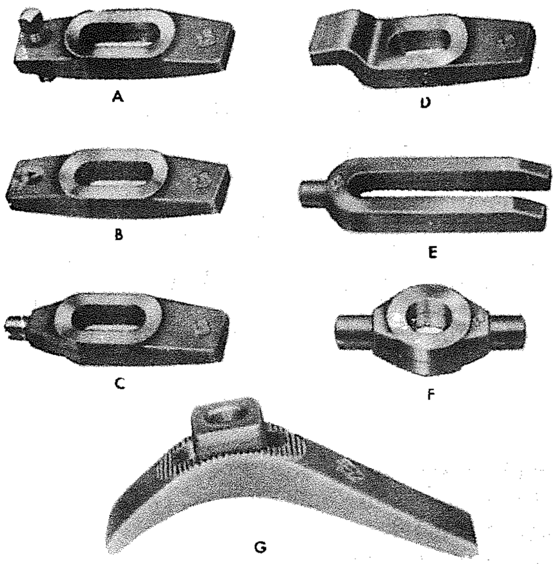


Fig. 13–57. Strap clamps. (A) Screw heel clamp. (B) Plain clamp. (C) Finger clamp. (D) Gooseneck clamp. (E) U clamp. (F) Double-finger clamp. (G) Universal adjustable clamp. (Armstrong Bros. Tool Co.)

Fig. 13–58. Step block.

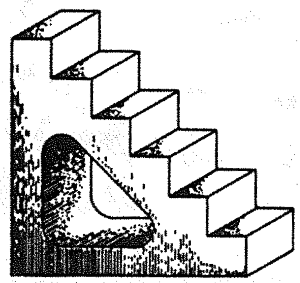
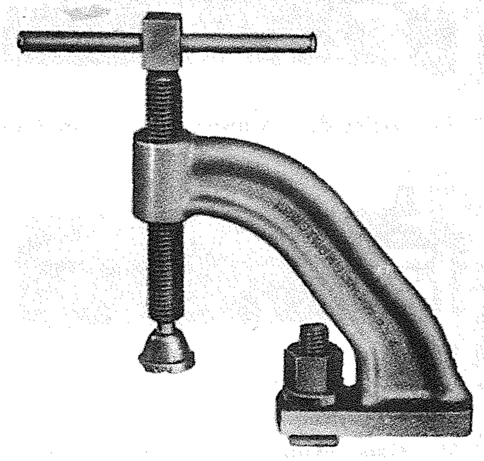


Fig. 13–59. Adjustable block. (Armstrong Bros. Tool Co.)

Fig. 13–60. T-slot clamp. (Armstrong Bros. Tool Co.)



clamp (Fig. 13–60). The base of this clamp is bolted securely to the table close to the work, and the vertical screw is tightened firmly on the surface of the work.

77. *What are some of the devices used to keep work level on the table?*
A setup wedge must be used sometimes under one or more corners of the work. A workpiece may need support at other points, as in Fig. 13–61. Note that the support is provided by vertical and bracing jacks (Figs. 13–62, 13–63, and 13–64). These jacks reduce the time required for preliminary arrangements, compared with looking for and adapting a haphazard group of blocks. The design of the bracing jack prevents creeping and permits setting the jack under a fillet or sloping surface without danger of sideslipping.

78. *What is a planer gage?*
A planer gage (Fig. 13–65) is a device designed for setting the cutting tool on a planer to a required

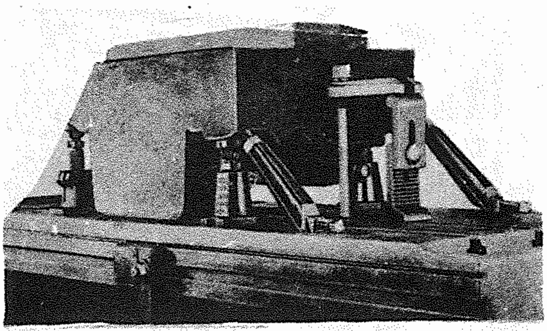
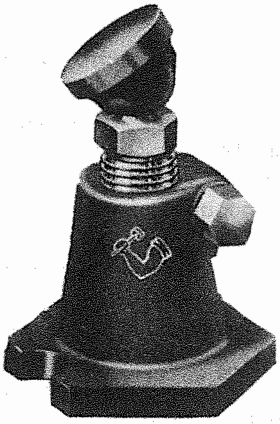


Fig. 13–61. A piece of work supported and levelled by jacks and clamps. (Armstrong Bros. Tool Co.)

Fig. 13–62. Standard planer jack. (Armstrong Bros. Tool Co.)



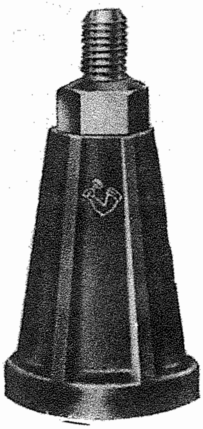


Fig. 13–63. Vertical jack. (Armstrong Bros. Tool Co.)

Fig. 13–64. Bracing jack. (Armstrong Bros. Tool Co.)

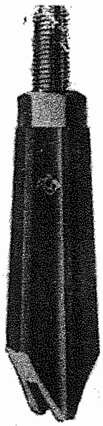
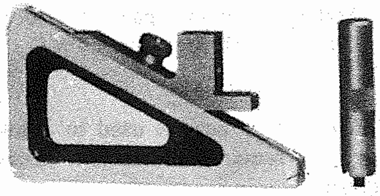


Fig. 13–65. Planer gage. (Brown & Sharpe Mfg. Co.)



distance from the table or a finished surface of the work. If the gage is set to a micrometer (Fig. 13–66) or to a surface gage or caliper and the planer tool is brought in contact with it, the first cut will give the desired dimension (Fig. 13–67). The slide of the gage is so designed that with one extension the operator can get a tool setting from ¼ to 8½ in. One feature of this slide is that the surfaces C and D (Fig. 13–68) are in the same plane and 1.000 in. from the plane of surface A, a combination that simplifies many settings, particularly for small measurements. Another feature is that the extension that screws into any of the three surfaces A, B, or C of the slide is 2.500 in. long, which further simplifies the making of accurate settings, particularly in the higher ranges.

79. *Describe a method of ascertaining if the crossrail is parallel to the table top.*
Clamp an indicator on the tool box, with its point touching the table top, and note if there is any variation in the indicator reading as the toolhead is moved across the length of the crossrail.

The indicator method is also used to test the crossrail for squareness (Fig. 13–69).

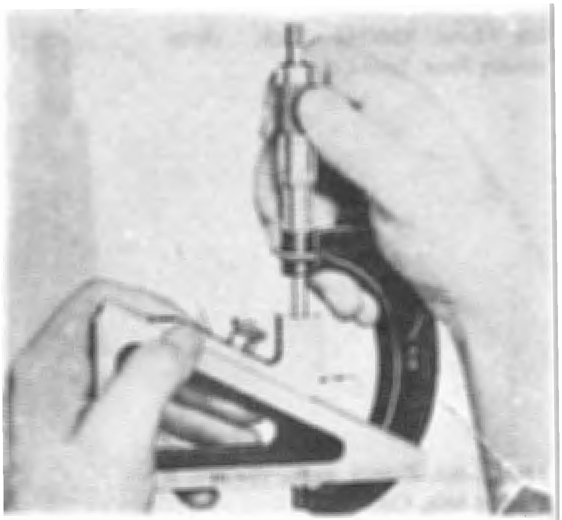
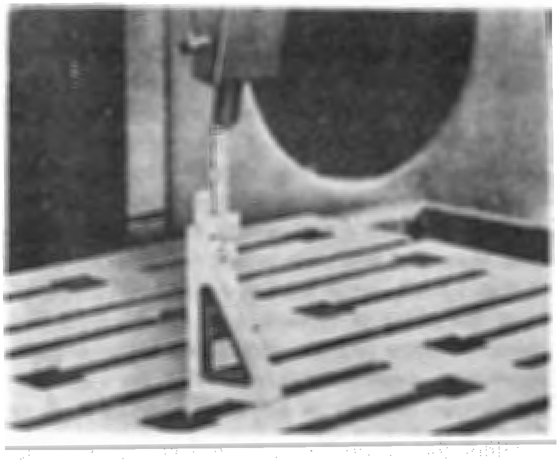


Fig. 13–66. Setting the planer gage to size with a micrometer. (Brown & Sharpe Mfg. Co.)

Fig. 13–67. The planer gage is used to adjust the cutting tool to a required dimension. (Brown & Sharpe Mfg. Co.)



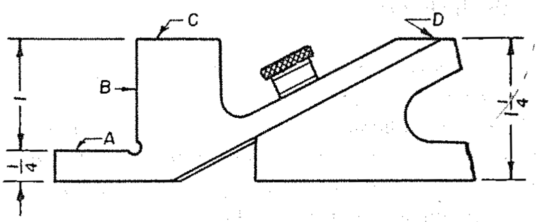


Fig. 13–68. Surfaces C and D of the slide are in the same horizontal plane.

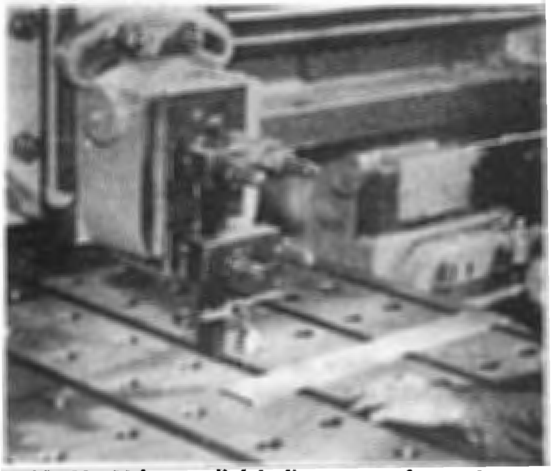


Fig. 13–69. Using a dial indicator on the toolbox to test the crossrail for parallelism and squareness to the table. (Rockford Machine Tool Co.)

80. *Give some hints on clamping work to the planer table.*

A. In clamping work on the planer table, the operator must take great care to see that the work is fastened securely by clamps, bolts, toe dogs, and so forth.
B. Clamps should not be placed on a finished part of the work unless the finished surface is protected by a piece of copper, brass, heavy paper, fiber, or similar soft material.
C. Flat, thin work is held down best by toe dogs.
D. See that the work does not spring when tightening clamps or toe dogs.
E. A washer must be used with every T bolt and nut. Select bolts of the proper length.
F. An open-end wrench of the correct size should be used on all square and hexagonal nuts. An adjustable wrench is not desirable.
G. When placing the work in position, see that it does not mar the finished surface of the planer table.
H. Allow enough clearance for the work to pass under the crossrail and between the housings.

Figures 13–70, 13–71, and 13–72 show some correct and incorrect methods of clamping work to the planer table.

81. *Can very large jobs be clamped to the table of the planer by these methods?*

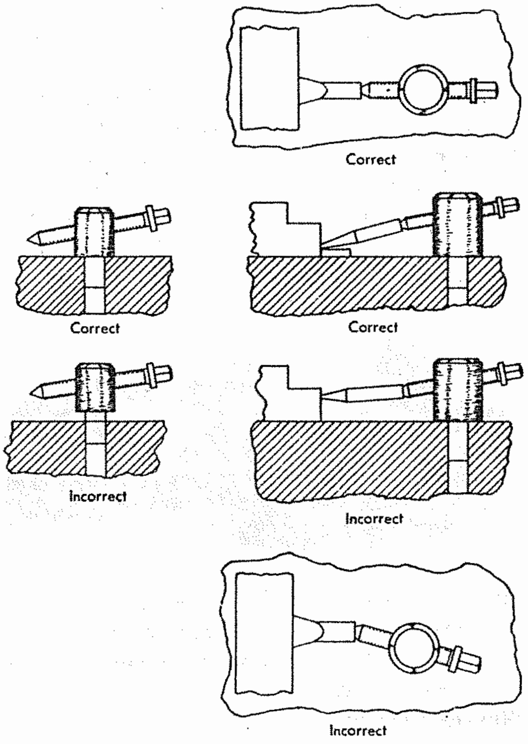


Fig. 13–70. Correct and incorrect use of toe dogs and poppets.

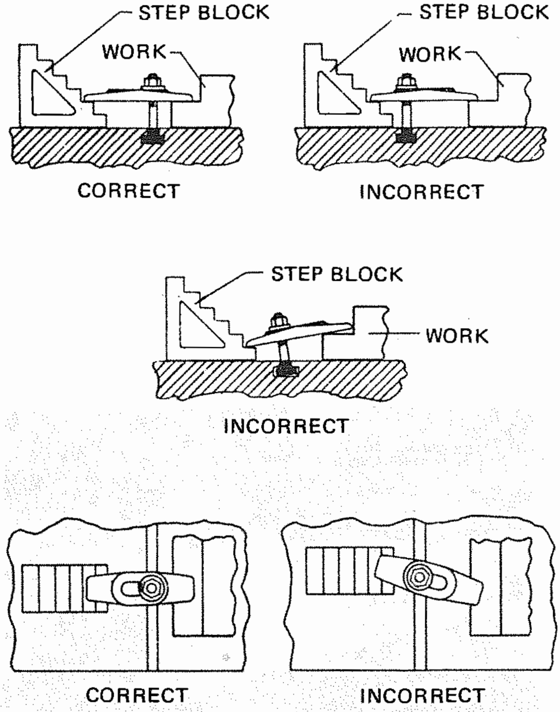
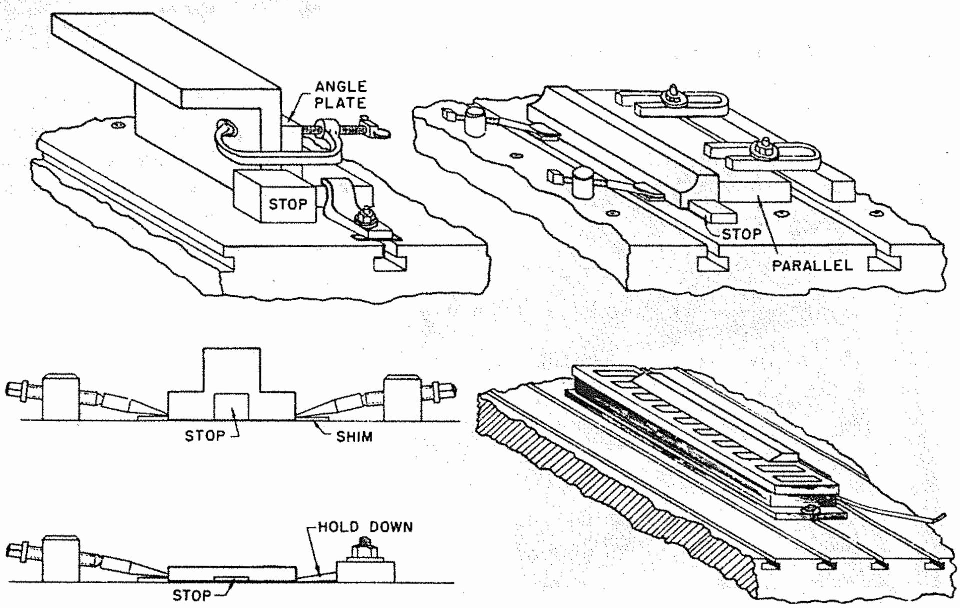


Fig. 13–71. Correct and incorrect methods of clamping.

Fig. 13–72. Planer setups.



The largest jobs can be clamped to the table with strap clamps and U clamps if the job is held securely between stops and bracing jacks (Fig. 13–73).

82. *Can the speed and feed of a planer be varied?* For many years, it made no difference whether the job was made of soft or hard metal: The planer could cut at only one speed. The return stroke was faster than the table's cutting stroke. Improvements in the driving units of the planer have made possible variations in the speed of both the cutting and returning strokes (Fig. 13–74).

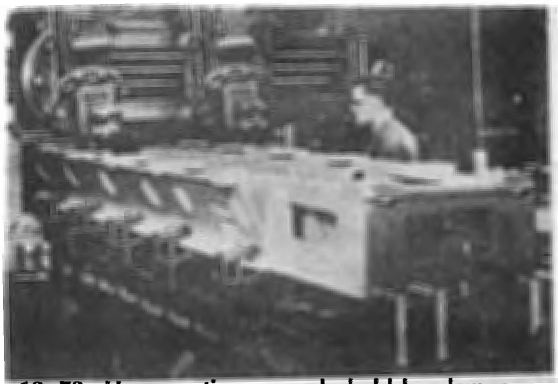


Fig. 13–73. Huge casting securely held by clamps, stops, and bracing jacks. (The G. A. Gray Co.)

Fig. 13–74. Phantom view of the space-saver drive on a 72-in. × 30-in. Gray planer. (The G. A. Gray Co.)

83. *What accessories are available for planer work?* The planer has the same accessories as the shaper. The vise is the most commonly used. Of heavy construction, it has two screws, which give greater holding power to the movable jaw (Fig. 13–75). Index centers are also available for planer work. Although much simpler in construction than the milling machine index centers, the planer-type index centers can divide the periphery of the job into accurately spaced divisions (Fig. 13–76).

Fig. 13–75. Double screw vise: Castings are semi-steel extra heavy. Jaws are faced with steel plates. Movable jaw floats for handling irregular or angular work. Base is graduated 90° each side of center. (Rockford Machine Tool Co.)

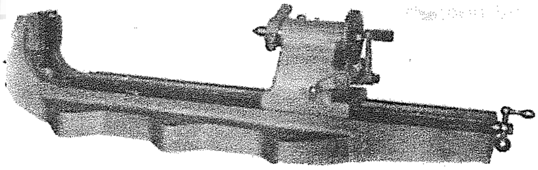


Fig. 13–76. Index centers: Accurate. Rigid. Adjustable index pin registers with two sets of accurately spaced holes in worm gear. Dead center is adjustable for taper work. Base can be bolted on table for straight work, or gripped in vise for adjustment to any horizontal angle. (Rockford Machine Tool Co.)

chapter 14 milling machine processes

The milling machine is one of the most versatile and widely used machine tools for both toolroom and production purposes. Its history dates back to about 1772, when metal was removed with a rotary cutting tool. In 1818, Eli Whitney invented the plain milling machine, one of the most important machine tools in that era. About 1850, the Lincoln miller was produced and widely used throughout the United States. In 1861, Joseph R. Brown, of the Brown & Sharpe Company, invented the prototype of the present universal milling machine; it was used primarily to make the tools used in the production of musket parts.

1. *What is meant by milling as it applies to machining?*
Milling is a process of removing material with a rotating multiple-tooth cutting tool called a *milling cutter.* In the usual operation, the workpiece is fed against the rotating cutter (Fig. 14-1).

2. *What kinds of jobs can be done on a milling machine?*
The milling machine is used to machine flat and angular surfaces, drill and bore holes, slot keyways, cut gear teeth, mill screw threads, cut irregular shapes, cut helical flutes in twist drills and milling cutters, and do specialty work for which it can be adapted.

3. *How many types of milling machines are used and how are they classified?*
There are three types of milling machines: (a) knee-and-column milling machines, (b) manufacturing milling machines, and (c) special milling machines.

4. *What type of milling machine is most often found in small, general machine shops?*

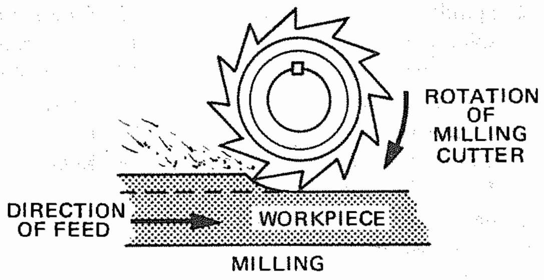


Fig. 14–1. Milling process.

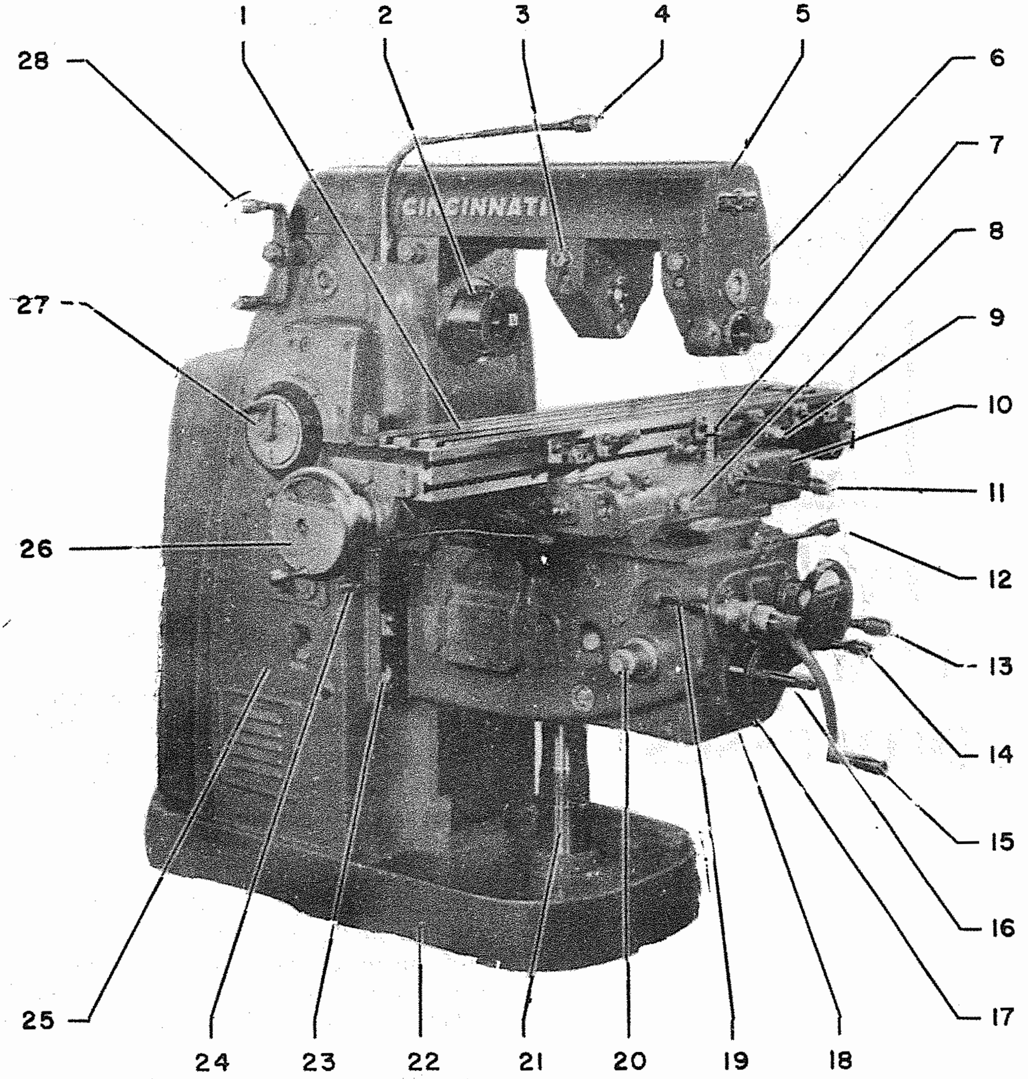


Fig. 14–2. Principal parts of plain knee-and-column milling machine, front view. (Cincinnati Milacron Co.)

1. Table
2. Spindle with Arbor-loc spindle nose
3. Inner arbor support
4. Start-stop lever
5. Overarm
6. Outer arbor support
7. Table trip plunger
8. Backlash eliminator knob
9. Table trip dogs
10. Saddle
11. Table-feed lever
12. Cross-feed lever
13. Rapid traverse lever
14. Cross-feed handwheel
15. Vertical-feed handcrank
16. Feed-change crank
17. Feed-change dial
18. Knee
19. Vertical-feed lever
20. Knee oil filter
21. Telescopic cutting-fluid return
22. Base
23. Vertical trip dogs
24. Knee clamp
25. Column
26. Table traverse handwheel
27. Speed-change dial and crank
28. Overarm positioning crank

The knee-and-column type. It is a general purpose machine with a full range of speeds and feeds, which are controlled either manually or automatically. There are three styles of knee-and-column milling machines: (a) plain, (b) universal, and (c) vertical.

5. *What are the principal parts of the plain knee-and-column milling machine?*
The column, the knee, the saddle, the table, the spindle, and the overarm. Each principal part, or assembly, consists of several other parts (Figs. 14–2 and 14–3). Each part has its own function in the overall operation of the machine.

6. *What is the function of the column?*
The column, including the base, is the main casting, which supports all the other parts of the machine. The front of the column, the column face, is machined to provide an accurate guide for the vertical travel of the knee.

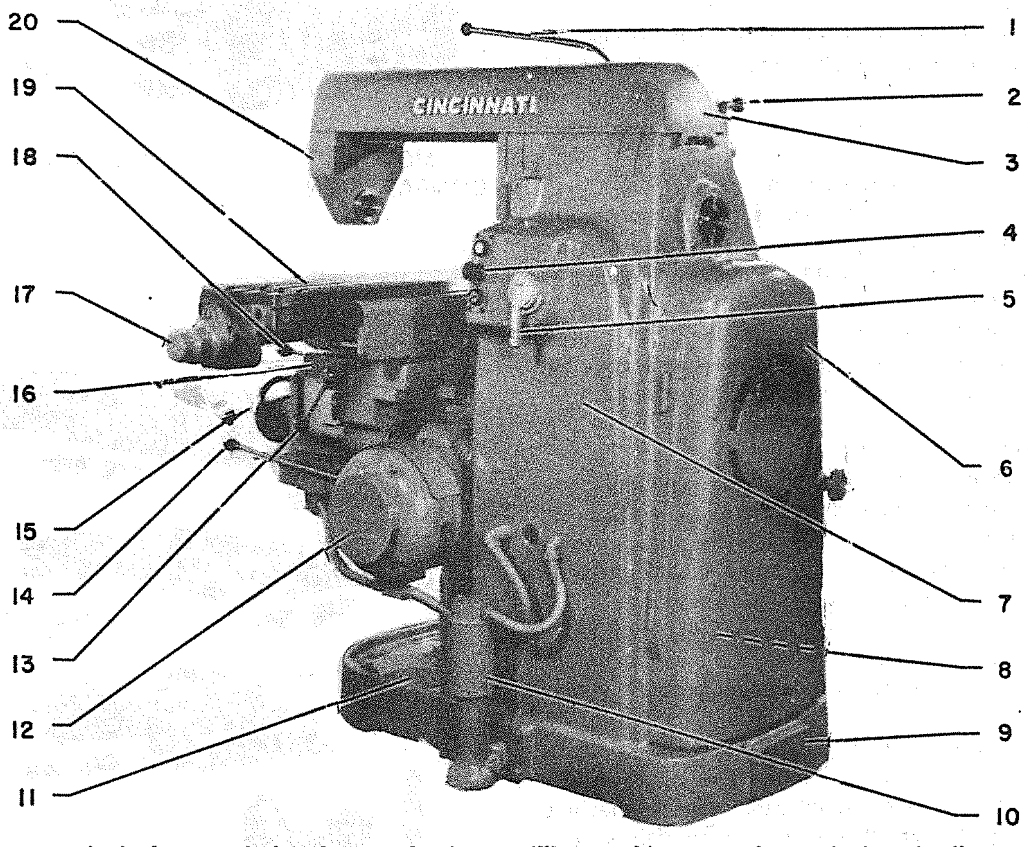


Fig. 14–3. Principal parts of plain knee-and-column milling machine, rear view. (Cincinnati Milacron Co.)

1. Start-stop lever
2. Overarm positioning crank
3. Overarm
4. Master push buttons
5. Master switch
6. Main drive cover
7. Enclosed electrical panel
8. Main drive motor (inside enclosure)
9. Coolant cleanout
10. Cutting-fluid pump
11. Cutting-fluid strainer
12. Feed-drive motor
13. Saddle clamp
14. Rapid traverse lever
15. Cross-feed handwheel
16. Saddle
17. Table power source
18. Cross-feed engaging lever
19. Table
20. Arbor support

7. *What is the function of the knee?*
The knee supports the saddle. The feed-change gearing is enclosed within the knee. The knee can be raised or lowered on the column face. It is supported and can be adjusted by the elevating screw.

8. *What is the function of the saddle?*
The saddle supports the table. It is supported and guided by the accurately machined surfaces of the knee.

9. *What is the purpose of the table?*
The table holds the workpiece. It rests on the dovetailed guides of the saddle. T slots are machined along the length of the top surface of the table. They are used to align the job or the fixture, which holds the job. Bolts fit loosely in the T slots and are used to clamp the job, vise, or fixture to the table.

10. *What is the purpose of the spindle?*
The spindle holds and drives the various cutting tools. It is a shaft mounted on bearings supported by the column. The spindle is driven by an electric motor through a train of gears all mounted within the column. The front end of the spindle has a tapered hole and driving keys for locating and driving various cutting tools, chucks, and arbors.

11. *What is the overarm?*
The overarm is mounted on the top of the column and is guided in perfect alignment by the machined dovetailed surfaces. It supports the arbor and is adjustable and can be tightened in any position. Some machines have two round overarms.

12. *What is the difference between the plain milling machine and the universal knee-and-column milling machine?*
The universal milling machine (Fig. 14–4) looks much like the plain milling machine, but its table is not supported by the saddle; the universal machine has a table housing that swivels on top of the saddle. This feature makes it possible to mill angular and helical slots (Fig. 14–5). This type of work requires an attachment called the *index head*. The universal milling machine is used to machine helical gears

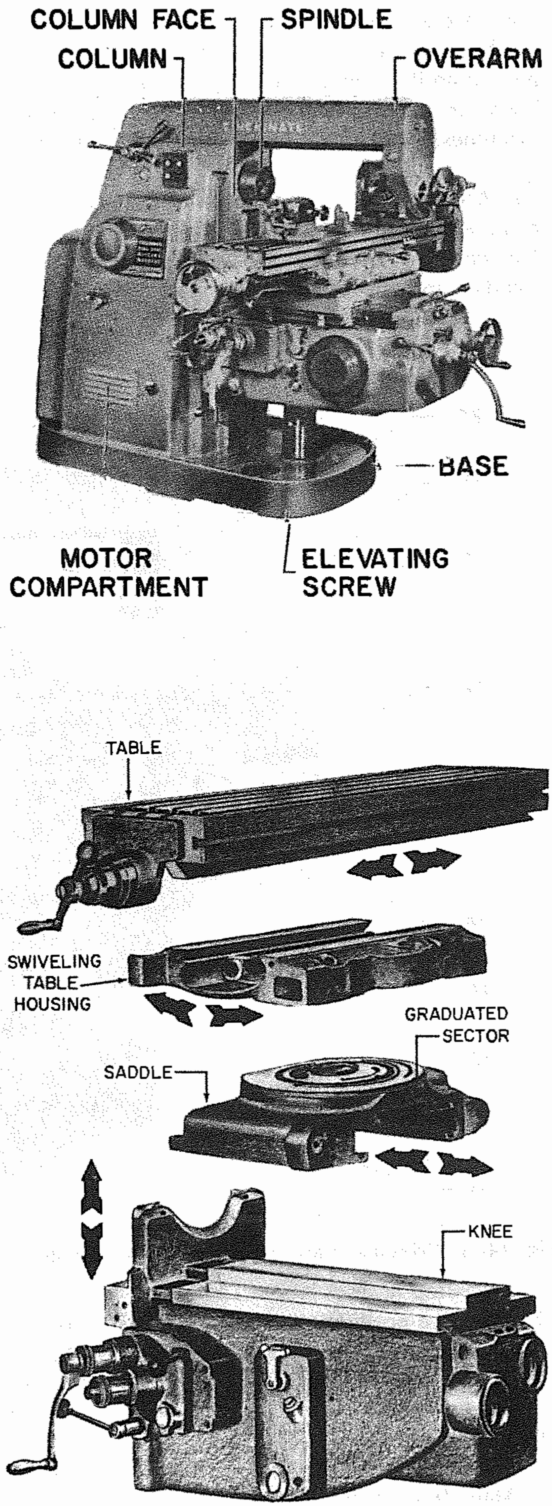


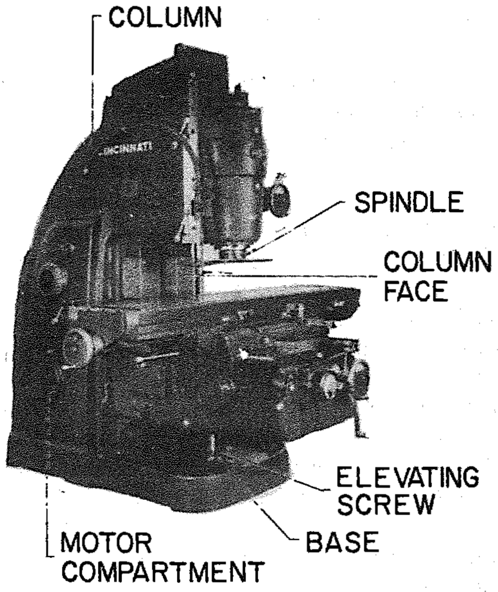
Fig. 14–4. Major parts of universal knee-and-column milling machine. (Cincinnati Milacron Co.)

Fig. 14–5. Cutting helical teeth on a cutter using a universal knee-and-column milling machine. (Cincinnati Milacron Co.)

and the helical flutes in twist drills, reamers, and milling cutters. It is one of the most important machines in a toolroom or instrument shop.

13. *What is a vertical knee-and-column milling machine?*
The vertical milling machine (Fig. 14–6) is so named because the spindle is located vertically and at a right angle to the surface of the table. The spindle has a vertical movement, and the table can be moved vertically, longitudinally, and transversely. Both the spindle and table movement can be controlled manually or by power. The vertical-spindle milling machine can be used for face milling, milling dies, and locating and boring holes. When used in conjunction with precision measuring instruments, this machine can be utilized as a very efficient jig borer.

14. *What is a manufacturing milling machine?*
The manufacturing milling machine is mainly used for quantity production of machine parts. These machines can be used for a variety of milling opera-



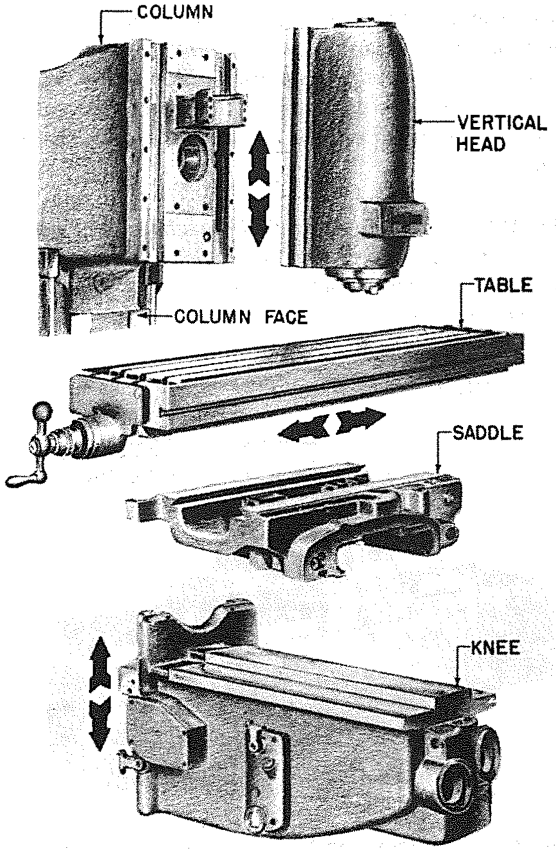


Fig. 14–6. Principal parts of a vertical knee-and-column milling machine. (Cincinnati Milacron Co.)

tions. With work-holding fixtures and special spindle heads, these machines can be used for face milling, end milling, and milling special shapes by means of a combination of arbor-mounted cutters. The spindle runs in bearings located in the spindle carrier, which can be moved vertically on the machined guideways of the headstock. The table rides in the machined ways of the bed. It moves longitudinally at right angles to the spindle. The top surface has a series of T slots, which are used to align and clamp the work. The table cannot be moved vertically (raised or lowered); thus the height of the work that can be milled is limited.

There are two styles of manufacturing milling machines. The plain manufacturing miller (Fig. 14–7) is equipped with one spindle and one headstock. The open front permits the convenient mounting and unmounting of jobs. It also enables the operator to observe the action of the cutter or cutters and the result.

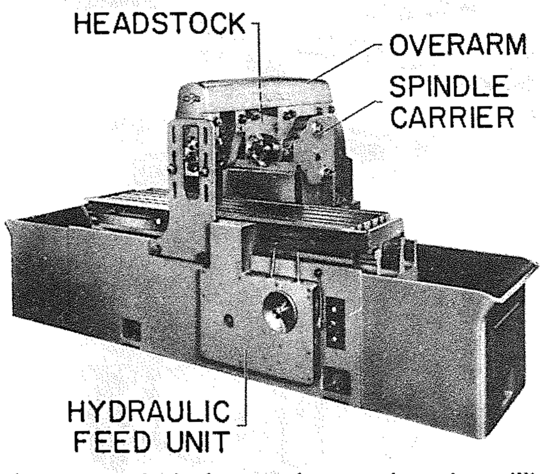
The duplex manufacturing milling machine (Fig. 14–8) is equipped with two horizontal spindles. The spindles are mounted on independently adjustable spindle carriers, which move on individual headstocks located on opposite sides of the bed. Two identical or two different milling operations can be performed on one or more jobs at the same time.

15. *What other types of milling machines are used in the manufacture of machine parts?*
There are small manufacturing milling machines, which look like plain knee-and-column machines. They are used in the quantity production of small or medium parts. The plain automatic milling machine (Fig. 14–9) is so named because the table is operated by power and controlled automatically by trip dogs mounted to the front side of the table. The Bridgeport machine is widely used for both production and toolroom work (Fig. 14–10).

16. *What is the planer milling machine?*
A planer milling machine is designed for large jobs requiring heavy cuts and powerful feed such as those found in heavy industry.

The work is clamped on a long table similar to that of the planing machine. The planer milling machine may be equipped with one or more cutting heads, which can be located and adjusted horizontally on the crossrail, or vertically on the housing uprights. Figure 14–11 shows a planer milling machine with double housings machining slots for a turbine-generator unit.

17. *What is a precision horizontal boring, drilling, and milling machine?*



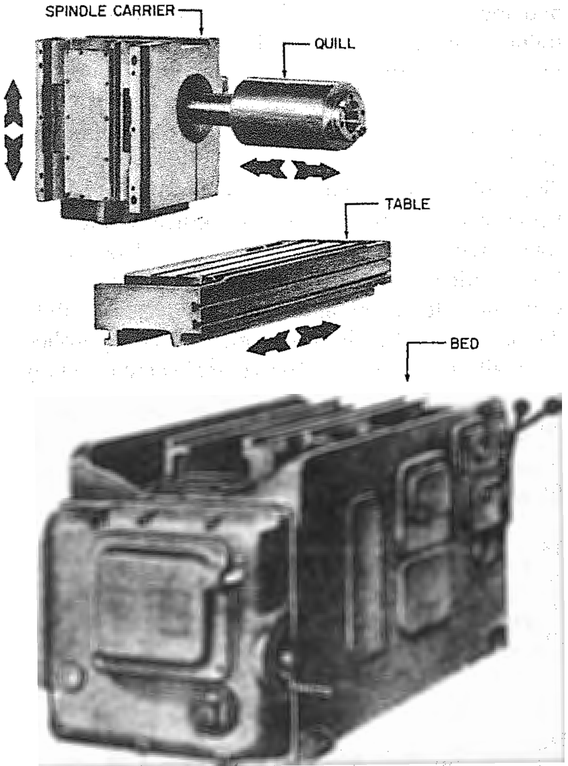


Fig. 14–7. Principal parts of a manufacturing milling machine. (Cincinnati Milacron Co.)

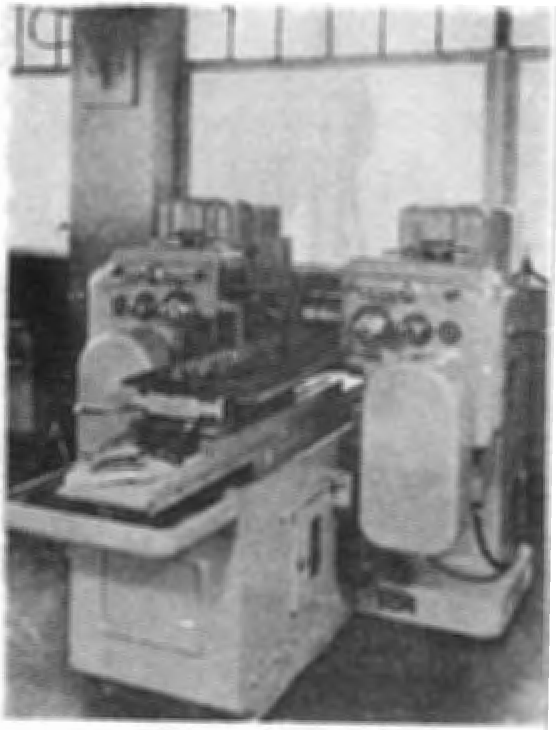


Fig. 14-8. A duplex manufacturing milling machine. (Cincinnati Milacron Co.)

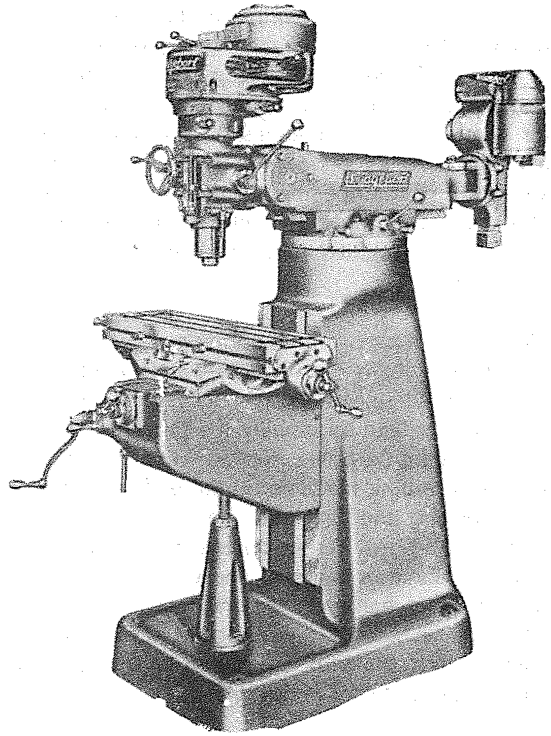


Fig. 14–10. Bridgeport vertical milling machine with a slotting attachment. (Bridgeport Machine Co.)

Fig. 14–9. Small, plain automatic knee-and-column milling machine. (Cincinnati Milacron Co.)

Fig. 14–11. This planer milling machine has an overall length of 102 feet and can machine work weighing 175 tons. (Allis-Chalmers Co.)

A precision horizontal boring, drilling, and milling machine (Fig. 14–12) is a large machine into which is built high precision and great strength. It is constructed to ensure accuracy as well as rigidity for heavy milling operations. It is a multipurpose machine used for performing, with one job setup, any or all of the operations indicated by its name. This saves setup time and ensures the accuracy of the various machined surfaces in relationship with each other.

18. *What is a precision jig-boring machine?*
A precision jig borer (Fig. 14–13) is a machine specifically designed to simplify boring holes to accurate size and to simplify the problems of precisely locating the holes. In many ways, it resembles a vertical milling machine; in the earliest stages of development, the machine looked like a single-spindle drill press. The jig borer's rigid construction prevents vibration and sag. The ways are made of steel and are hardened, ground, and lapped. The table can be set in either direction to an accuracy higher than 0.0001 in. Holes can be located to a tolerance of 0.00005 in.

19. *Why is this accuracy necessary?*
The precision jig borer is primarily a toolmaker's machine. The extreme accuracy required in machine building necessitates a very high degree of accuracy in the location of holes, contours and surfaces of the jigs, fixtures, and dies used in making parts (Fig. 14–14).

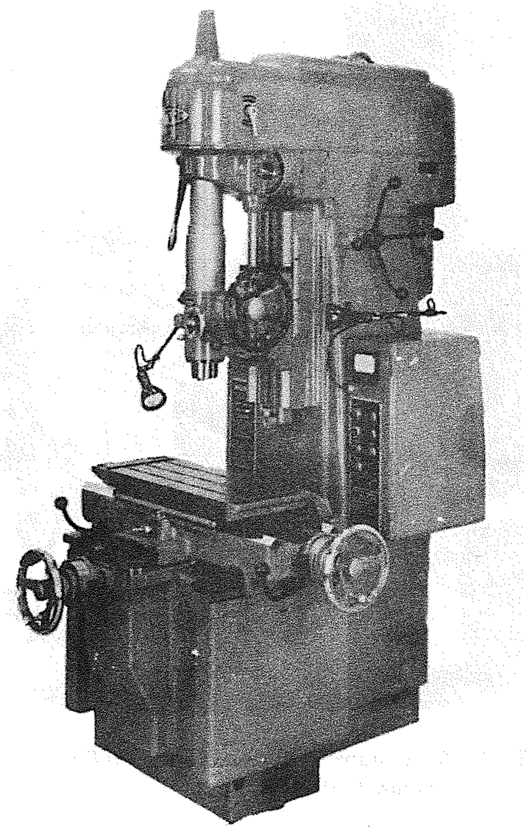


Fig. 14–13. Moore precision jig-boring machine. (Moore Special Tool Co.)

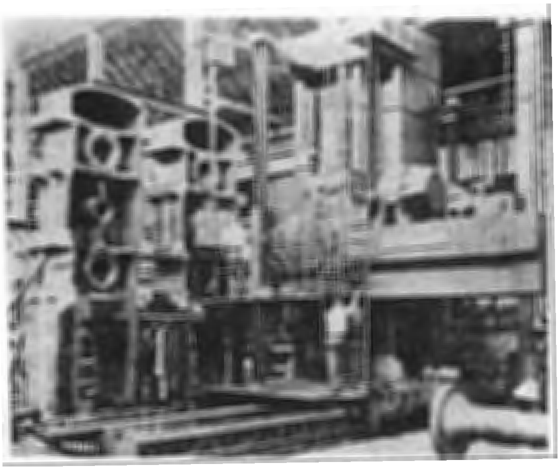


Fig. 14–12. Precision horizontal boring, drilling, and milling machine. (Giddings & Lewis Machine Tool Co.)

Fig. 14–14. Jig boring on the Moore precision jig-boring machine. (Moore Special Tool Co.)

20. *How is this high degree of accuracy made possible?*
The accurate movement of a machine table is made possible by the rotation of a thread within a nut. The lead screws of a jig-borer table must meet the most exacting standards of accuracy. The allowable tolerance in any inch of screw is 0.000030 (thirty millionths) of an inch. Table movement is controlled by an oversized handwheel dial with vernier graduations set with micrometer adjustment (Fig. 14–15).

21. *What is a tool and die milling machine?*
A tool and die milling machine (Fig. 14–16) is designed for the milling of curved or irregular surfaces and surfaces located between projections, shoulders, and bosses. By means of a tracer riding on a cam, the cutter automatically reproduces intricate shapes accurately. This machine also performs the usual milling machine operations.

22. *What is a milling machine attachment?*
Every machine used in machine shop work has one or more attachments. An attachment is designed to give the machine greater versatility, or work capability. The milling machine has many attachments, which add to its adaptability, efficiency, and convenience.

Fig. 14–15. Setting the cross-axis screw of a Moore precision jig-boring machine. (Moore Special Tool Co.)

23. *What is a vertical milling attachment?*
The vertical milling attachment (Fig. 14–17) can be mounted on the face of the column of a knee-and-column milling machine. Plain and universal milling machines can then perform the operations ordinarily done on a vertical milling machine. The spindle head can be swiveled accurately to any degree for angular milling.

24. *What are some of the advantages of the vertical milling attachment?*
The vertical milling attachment is used for vertical milling operations with large end mills, face mills, and single and double angle cutters.

25. *What is the universal milling attachment?*
A universal milling attachment (Fig. 14–18) makes a milling machine truly universal because its spindle may be set at any angle in both planes. This allows an end mill to do the work of an angular cutter (Fig. 14–19).

26. *What is a compound vertical milling attachment?*
A compound vertical milling attachment (Fig. 14–20)

Fig. 14–16. Tool and die milling machine. (Cincinnati Milacron Co.)

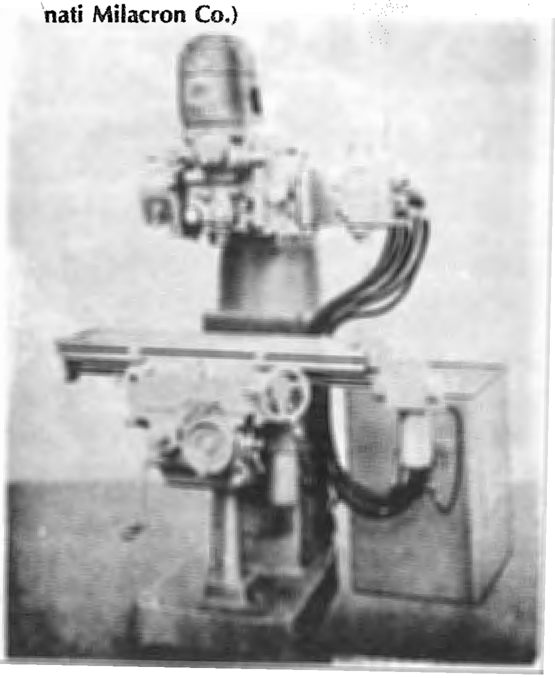
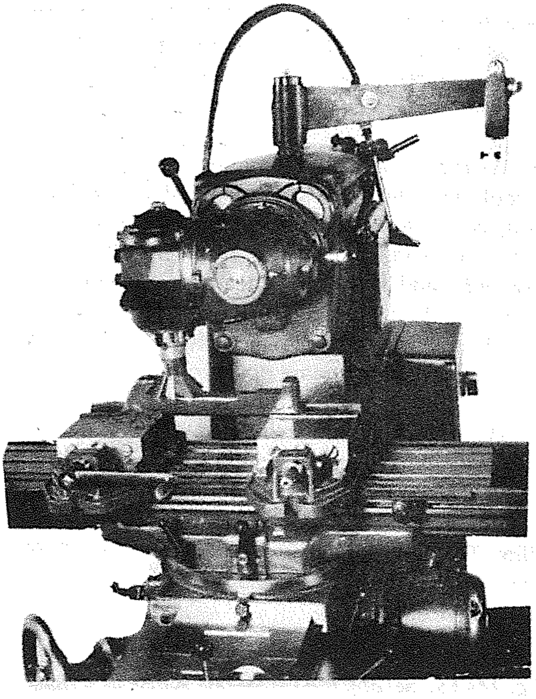


Fig. 14–17. Vertical milling attachment. (Brown & Sharp Mfg. Co.)

Fig. 14–19. Machining a dovetail with the universal attachment. (Brown & Sharpe Mfg. Co.)



has a spindle that can be set in two planes. With the spindle set at an angle to the table, as in milling beveled edges to long pieces, the full length of the table can be traveled, thus saving setup time.

27. *What is a high-speed universal milling attachment?*
When using a small-diameter milling cutter of the end mill type for milling slots, keyways, or splines, or for mold or die making, a high-speed universal milling attachment is used. By means of internal gearing, the speed of rotation is substantially increased, making possible a productive increase in feed (Fig. 14–21).

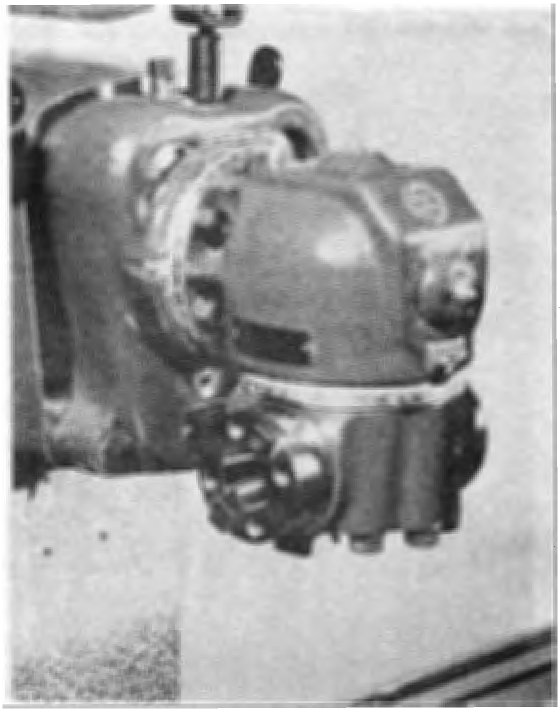


Fig. 14–18. Universal milling attachment. (Brown & Sharpe Mfg. Co.)

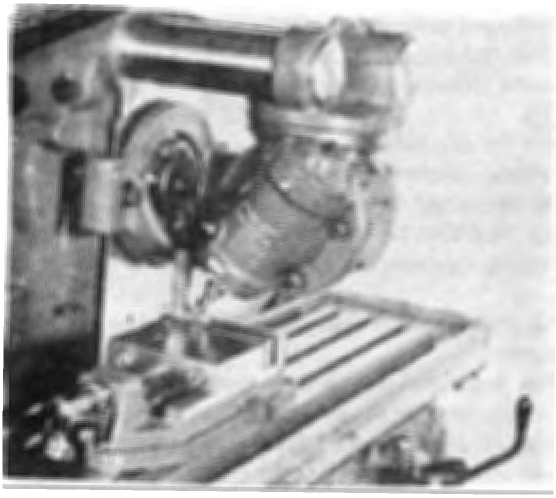
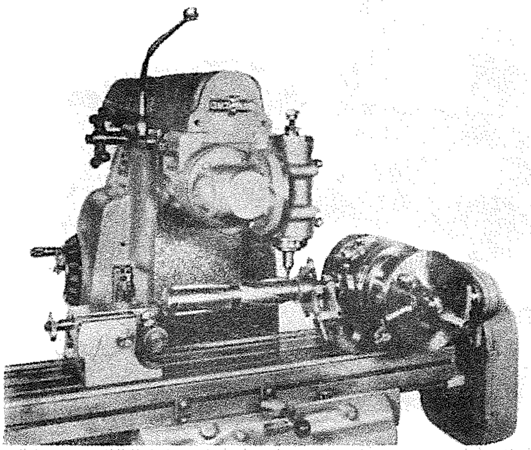


Fig. 14–20. **Compound vertical milling attachment. (Brown & Sharpe Mfg. Co.)**

Fig. 14–21. Milling splines with an end mill held in a high-speed universal milling attachment. (Cincinnati Milacron Co.)



28. *What is a rotary attachment?*
A rotary attachment (Fig. 14–22), sometimes referred to as a *circular milling attachment,* is bolted to the top of the table of a plain or universal milling machine. By using the table's longitudinal and cross-feeds in conjunction with the attachment's rotary movement, the operator can machine a wide variety of shapes such as circular T slots, various types of cams, and so forth. In addition to the hand-feed unit,

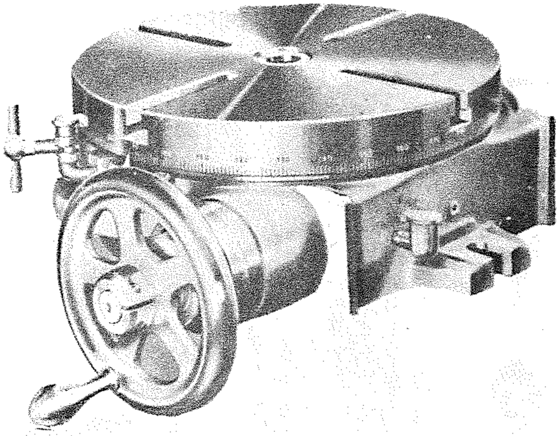


Fig. 14–22. A rotary attachment with hand feed. (Cincinnati Milacron Co.)

power-drive rotary attachments are also available. Both attachments are graduated in degrees or half-degrees on the table circumference.

29. *What is a slotting attachment?*
When mounted on the column face of a plain or universal milling machine, the slotting attachment (Fig. 14–23) converts the rotary motion of the spindle into the up and down motion of the tool slide. This is particularly valuable in a shop where keyways must be machined and no slotting machine is available. The tool slide of this attachment can be set at any angle between 0 and 90° on either side of the center line. The stroke can be set from 0 to 4 in.

30. *What is a rack milling attachment?*
A rack milling attachment (Fig. 14–24) is used to cut teeth, usually gear teeth, along a straight line. It can also be used in connection with the universal spiral index centers for cutting worms on universal milling machines. The cutter is mounted on the end of a spindle that extends through the attachment case parallel to the table T slots. This spindle is driven from the machine spindle by a train of hardened steel bevel and spur gears. A vise, which simplifies the holding of the rack, is furnished as a part of the attachment.

31. *What are the uses of a universal spiral milling attachment?*
When the universal spiral milling attachment is applied to a universal miller, it makes possible the

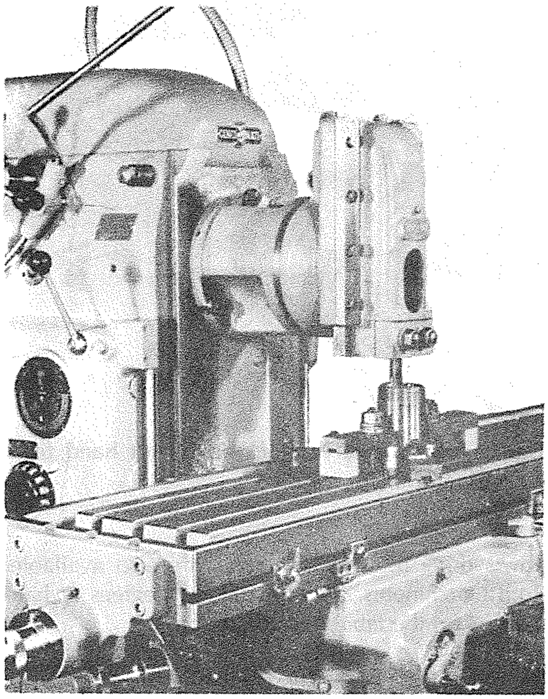


Fig. 14–23. Slotting a bushing using a slotting attachment. (Cincinnati Milacron Co.)

Fig. 14–24. Cutting teeth for a rack using rack attachment and rack vise. (Cincinnati Milacron Co.)

milling of helices with a helix angle greater than 45°. This attachment is used for milling gears, worms, screw threads, twist drills, and spiral milling cutters (Fig. 14–25). A universal spiral milling attachment can be mounted on a plain or universal knee-and-column machine. When used in conjunction with a dividing head, it increases the scope of a plain milling machine to approximate that of a universal milling machine.

32. *What types of vises are used for milling machine work?*
The shape and size of work to be milled will determine what type of vise must be used. The small vise (Fig. 14–26) is used for light milling operations. The bed slides are made of cast iron and the jaws are made of hardened and ground tool steel. The lever action permits quick clamping of the work, which enables speedier production. The vise is fastened to the table with T bolts, which pass through slotted holes at the ends of the vise. The plain vise is lower

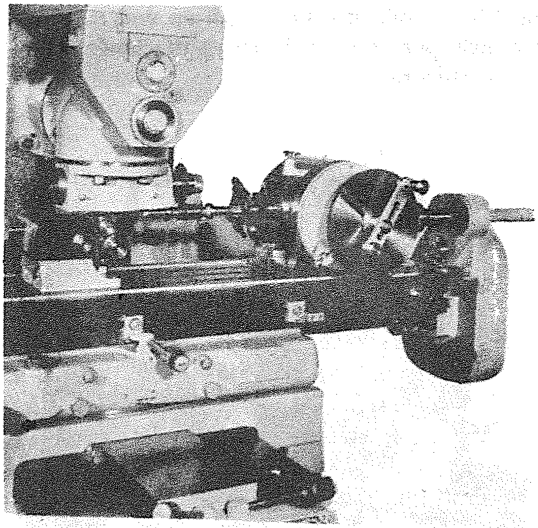
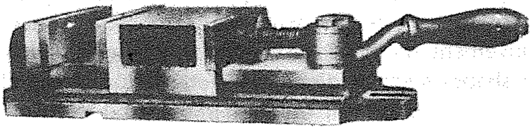


Fig. 14–25. Cutting a worm gear using the universal spiral milling attachment. (Cincinnati Milacron Co.)

Fig. 14–26. Plain vise. (Cincinnati Milacron Co.)



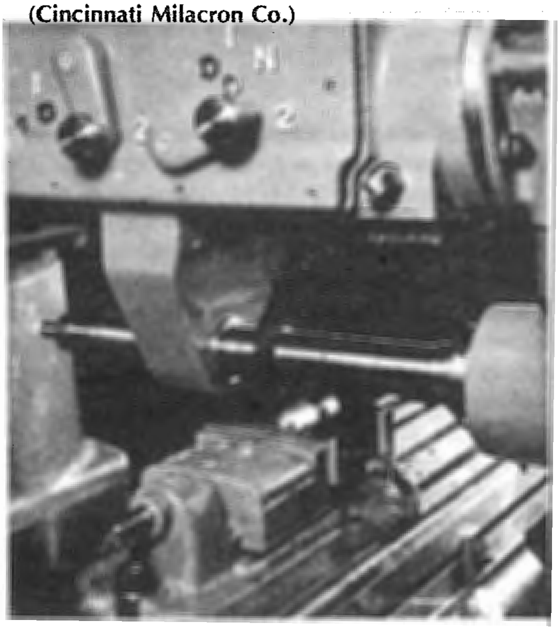
than other types of milling vises. The flanged vise, (Fig. 14–27) which holds work up to 7 in. wide, is the type used for plain milling operations. Its low height and broad base give it the rigidity needed for heavy cuts.

The swivel vise (Fig. 14–28) is made in two basic parts. The body is identical to the flanged vise, but it swivels on the base. The base is graduated in degrees. The body can be turned on the base and fastened at any angle.

The toolmakers' universal vise (Fig. 14–29) can be swiveled, like the swivel vise, on its base, 360° in a horizontal plane. It is hinged and can be adjusted, in a vertical plane, to any angle between 0 and 90°. A vise with a swivel jaw can hold irregular shapes of work (Fig. 14–30).

33. *How are vise bases aligned parallel with the edge of the milling machine table?*
Milling machine vises can be quickly aligned with the table by using square blocks fastened on the bottom face of the vise base plate. One half of the block's thickness fits into the slots, which are milled into the bottom face of the vise base plate. The other half of the block fits into the T slots of the table (Fig. 14–31). These locating blocks are also called *tongues* or *lugs*.

Fig. 14–27. Machining work held in a flanged vise. (Cincinnati Milacron Co.)



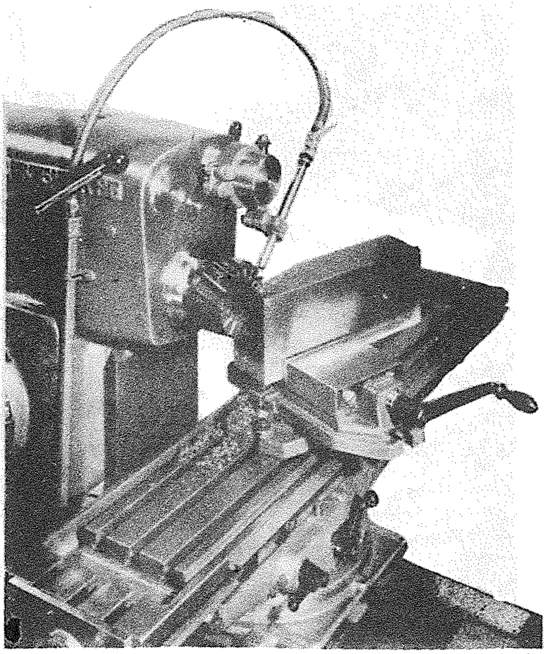
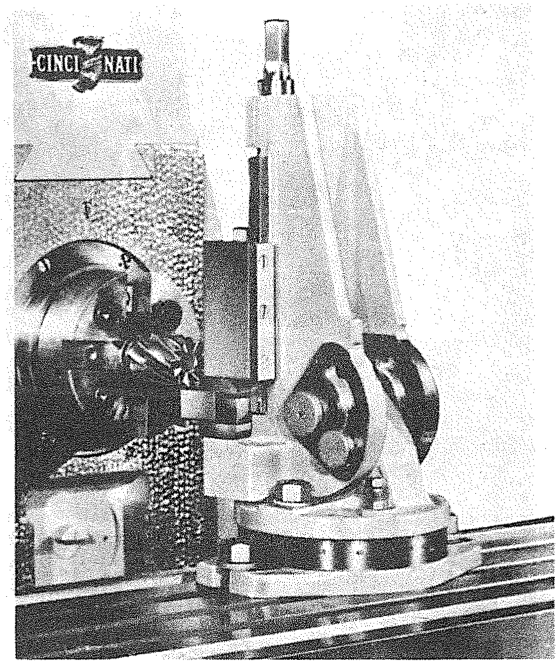


Fig. 14–28. Machining work held in a swivel vise. (Cincinnati Milacron Co.)

Fig. 14–29. A toolmakers' universal vise. (Cincinnati Milacron Co.)



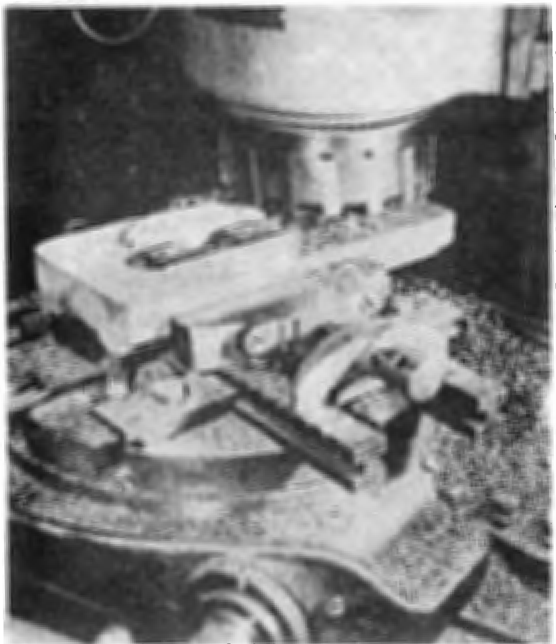
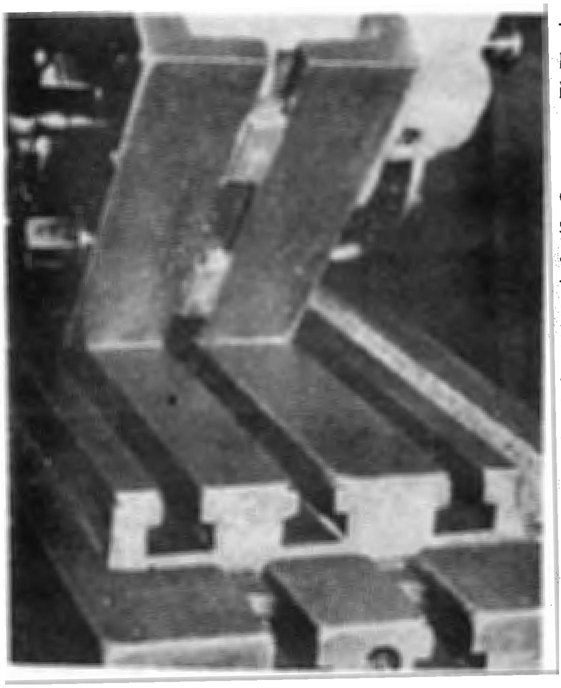


Fig. 14-30. A vise for holding irregularly shaped parts. (Cincinnati Milacron Co.)

Fig. 14-31. Blocks fitted to bottom align vises and other attachments.



34. *How are swivel vises, fixtures, and workpieces aligned accurately?*
All work and work-holding attachments must be aligned accurately before the work can be machined square and parallel. Swivel-type vises are easily and quickly aligned by using a dial indicator to test the accuracy of the solid jaw (Fig. 14-32). The movable jaw is not used for alignment. Similarly, fixtures, angle plates, and workpieces clamped directly to the table can be aligned accurately by using a dial indicator (Fig. 14-33).

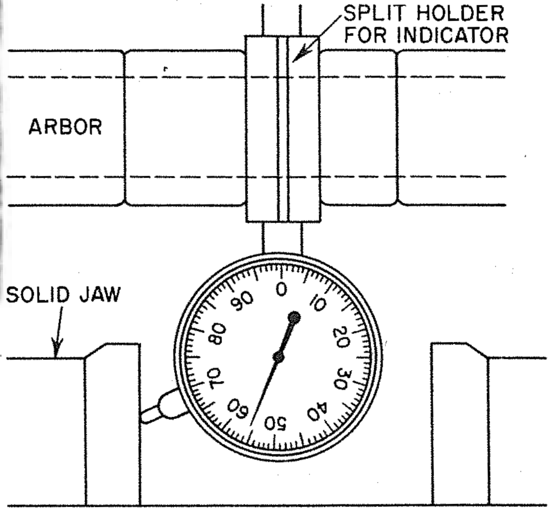


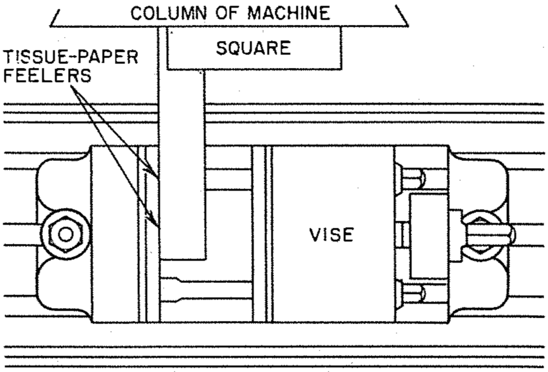
Fig. 14-32. Aligning the solid vise jaw using a dial indicator.

A precision steel square, held against the column, can be used to set and check the accuracy of the solid vise jaw (Fig. 14-34). Another method for aligning workpieces having a finish-machined surface, or an angle plate that is to hold a workpiece, is to fit a parallel bar into one of the table slots and locate the workpiece or angle plate against the parallel bar. Paper feelers are used to make sure the work or angle plate is making contact with the parallel bar (Fig. 14-35).

35. *What is a milling fixture?*
A milling fixture is a work-holding device that is clamped to the table for machining duplicate parts on a production basis (Fig. 14-36). Once the fixture is accurately aligned and set to the cutter, or cutters, and the first piece is machined and checked for accu-

Fig. 14–33. Aligning a milling fixture using a dial indicator. (Cincinnati Milacron Co.)

Fig. 14–34. A precision steel square can be used to align a vise.



racy, all of the following workpieces need only be clamped in the fixture and machined. When the table-feed is being used to feed the workpiece against the cutter, the vertical-feed and the cross-feed clamps must be tightened to provide a rigid setup and maintain the accuracy.

36. *What is a spring chuck?*
A spring chuck is an adapter that can be mounted in the spindle for holding and driving spring collets (Fig. 14–37). A typical set of collets includes sizes from ⅛ to 1 in. in diameter for holding drills, straight

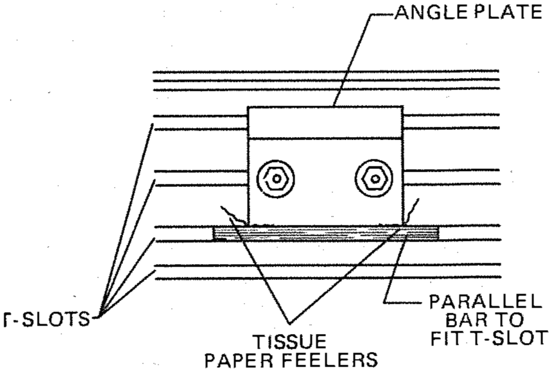
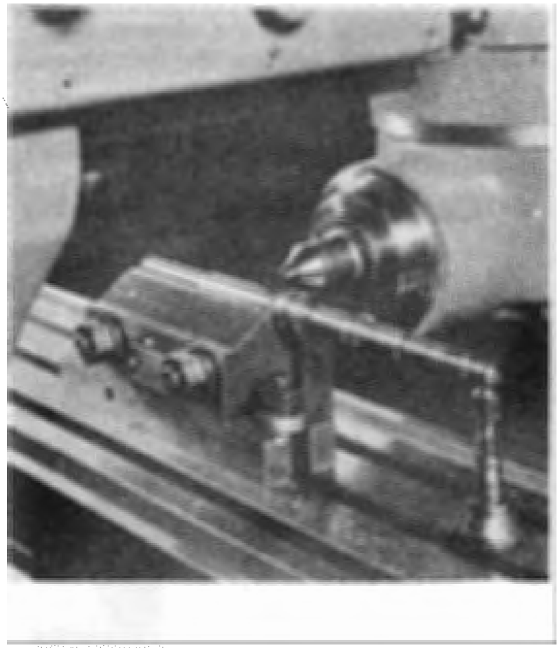


Fig. 14–35. Method of aligning work or fixture against a parallel bar fitted in the T slot.

Fig. 14–36. Milling a keyway with work held in a fixture. (Cincinnati Milacron Co.)



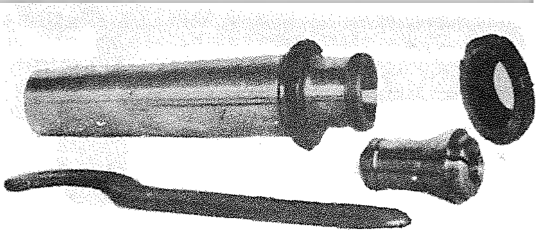
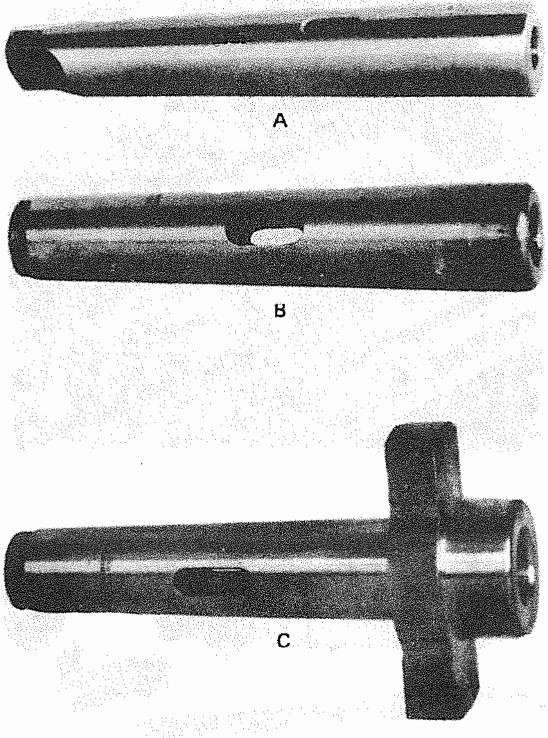


Fig. 14–37. A spring chuck attachment. (Brown & Sharpe Mfg. Co.)

shank cutters, and end mills. The collet holder has a ground taper shank to fit the spindle taper. Collets are held and located accurately in the holder by a cap nut, which forces the collet taper against the inside taper of the holder, clamping the collet tightly to the shank of the tool being held.

Other types of collets (Fig. 14–38) are used for holding cutters and tools, depending upon the nature of the work. Figure 14–38A is a collet with a tang; the inside is a No. 4 B & S taper, the outside a No. 7 B & S taper. Figure 14–38B shows a collet tapped on the small end to receive a drawbar, which holds it securely in place; it is available in many sizes and combinations of Brown & Sharpe tapers. Figure 14–38C is also a tapped collet; the inside is a No. 10 B & S taper, the outside a No. 12 B & S taper. Because it is used for large cutters this collet is provided with a tenon to help drive it. Taper collets are also called *sleeves*.

37. *What are milling arbors and adapters?*
Milling arbors and adapters are precision-made attachments designed to hold and drive many types of milling cutters. An arbor is a cutter-holding device with a taper shank to fit the spindle taper hole of the machine; the short or long shaft end is used to mount and drive one or more cutters having holes that fit on to the arbor. An adapter (Fig. 14–39) also has a taper shank to fit the spindle hole, but the opposite end has either a straight or taper hole for holding end mills, taper collets, spring collets, and small arbors.



A

B

C

Fig. 14–38. Milling machine collets. (Brown & Sharpe Mfg. Co.)

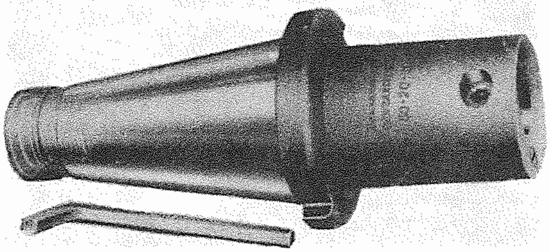


Fig. 14–39. A cutter adapter. (Brown & Sharpe Mfg. Co.)

38. *Describe the standard milling arbors.*
Standard milling arbors are made in three styles: A, B, and C. The Style A arbor (Fig. 14–40), often called a *short arbor,* has a pilot at the outer end, which is supported by a bronze split-bearing in the arbor support. This type of arbor is used in smaller milling machines. The Style B arbor (Fig. 14–40), often called a *long arbor,* is supported by one or more arbor supports having large-diameter bronze bearings into which a bearing collar mounted on the arbor fits. The bearing collars are larger than the spacing collars. The Style B arbor permits a more rigid setup because the bearing collars and arbor support can be mounted close to the cutters when heavy milling is to be done. A Style C arbor (Fig. 14–41) has a standard milling machine taper that fits into the machine spindle. The outer end has a short straight or taper diameter for mounting shell-end mills or small facing cutters. The outer end of the arbor is also provided with a screw for holding the cutters tightly against the shoulder of the arbor.

39. *How are arbors and adapters held in the spindle?*
The taper end of an arbor and the machine spindle have a standard milling machine taper of 3½ in. per ft. Because this taper was designed to be quick releasing it must be held in the taper spindle by an arbor draw-in bolt, or rod. The rod is threaded to fit

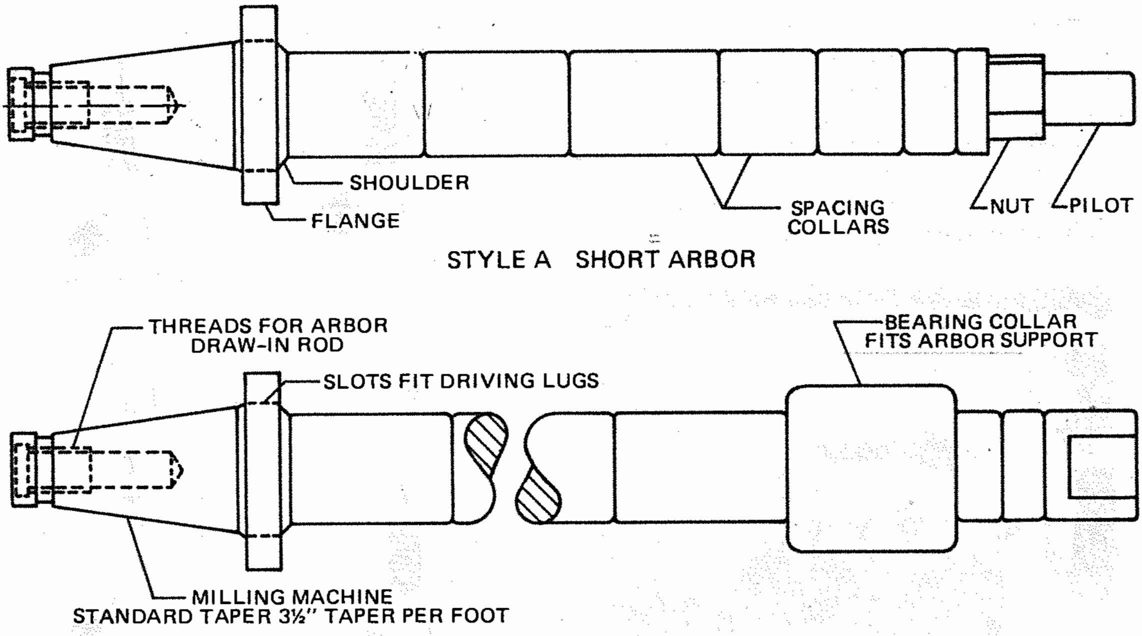
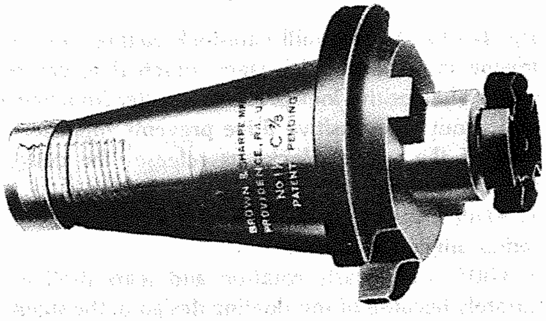


Fig. 14–40. Style A and B milling machine arbors.

Fig. 14–41. Style C arbor for holding shell end mills. (Brown & Sharpe Mfg. Co.)



the threaded hole in the arbor. To mount the arbor, it is first placed into the spindle; then the draw-in rod is turned by hand for a distance of several threads. The large nut on the draw-in bolt is then tightened firmly against the spindle end to hold the arbor securely.

40. *How is the arbor removed from the spindle?*
Quick-releasing arbors are easily removed from the spindle by first loosening the arbor nut while the arbor support is still in position. Next, loosen the arbor support and remove it, or move it out of the way of the arbor, depending upon the type of overarm. Remove the cutter from the arbor. At the rear of the machine, loosen the large nut on the draw-in bolt a turn or two. Tap the end of the draw-in bolt with a soft hammer to loosen the arbor. Hold the arbor with one hand so it will not drop, and unscrew the draw-in bolt until the arbor is free (Fig. 14–42).

41. *What is a quick-change spindle nose?*
A quick-change spindle nose is a specially designed attachment that can be clamped to the spindle nose for holding arbors and adapters. Various cutting tools

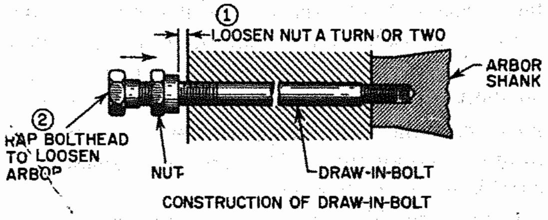


Fig. 14–42. Correct way to loosen a draw-in bolt.

needed to machine a job can be mounted in adapters or on an arbor and each used in sequence without changing the setup of the job (Fig. 14–43). A special clamping ring, threaded on the outside, is bolted to the spindle nose. The adapters and arbors are placed in this clamping ring and held in place by a ring nut. Because a draw-in bolt is not necessary much time can be saved when changing cutters.

Fig. 14–43. A quick-change spindle nose with cutters mounted in adapters and on arbors. (Cincinnati Milacron Co.)

42. *What is a cam lock?*

A cam lock is a device in cutter adapters; it is designed to give positive locking, drive, and quick release to end mills and to other adapters held in them. Figure 14–44 shows how this device works.

Many kinds of cutters are used on a milling machine. Most are considered standard and are available in many sizes. Cutters are also designed for a particular job. High-speed steel is the material most favored for cutters. They are also available with carbide tips or cutting edges.

Cutters should be kept sharp. The cutting edges are bound to become worn with use, so they should

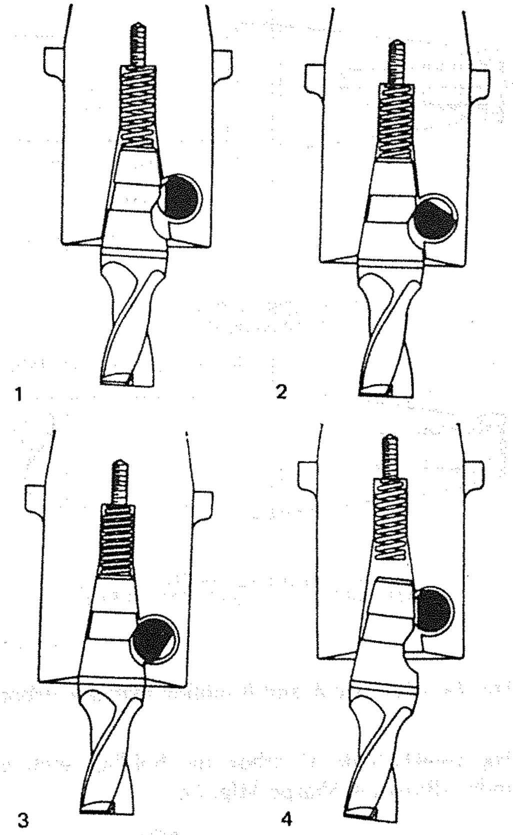


Fig. 14–44. An end-mill cam-lock adapter. By following these four quick steps, much time can be saved. The positive lock prevents a cutter from being pulled out. The positive drive prevents slippage. A turn of the wrench locks or releases the cutter. (Brown & Sharpe Mfg. Co.)

1. START: Insert end-mill shank into adapter, with radius aligned with cam.

2. GRIP: Cam starts rotation and seats itself accurately because of the floating design of the shank.

3. LOCK: End mill is securely locked in socket as the slight rise on cam grips the rounded slot on shank.

4. RELEASE: By turning cam backward with hex key, end mill is released.

always be inspected before starting a job. Cutters that are sharpened frequently usually last longer than those that are allowed to become quite dull.

43. *What are plain milling cutters?*
Plain milling cutters are made with cutting edges on the periphery of the cutter only (Fig. 14–45). They are used for cutting keyways and slots and for flat surfaces that are narrower than the width of the cutter. Plain milling cutters that are more than ¾ in. in width are usually made with spiral teeth. The helical plain cutter (Fig. 14–46) is especially desirable when an uneven surface, or one with holes in it, is to be milled.

44. *What are side milling cutters?*
Side milling cutters are cutters with teeth on both sides as well as on the periphery (Fig. 14–47). They are used for cutting slots that must be accurate in width. They are also used for straddle milling, in which case two cutters are mounted on an arbor with spacers between them, as when milling two sides of a casting or two sides of the head of a bolt (Fig. 14–48).

The staggered-tooth side milling cutter (Fig. 14–49) is used when deep cuts are required. With this type of cutter, it is possible to operate at a higher speed and feed than with an ordinary cutter. Cutters of various sizes are sometimes grouped together as in

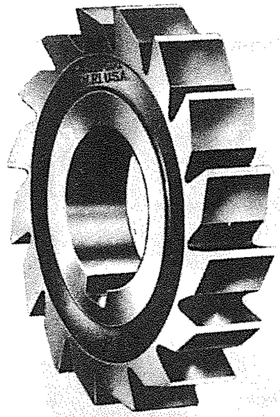


Fig. 14–45. Plain straight-tooth cutter. (Brown & Sharpe Mfg. Co.)

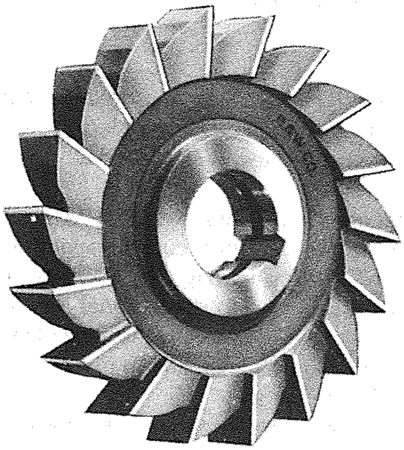


Fig. 14–47. Straight-tooth side milling cutter. (Pratt & Whitney Co.)

Fig. 14–46. Coarse-tooth helical cutter. (Morse Twist Drill & Machine Co.)

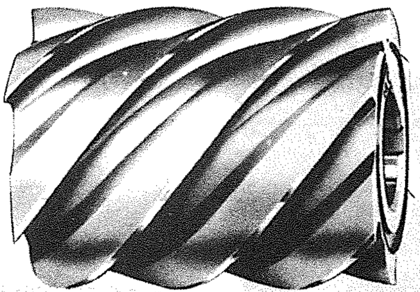
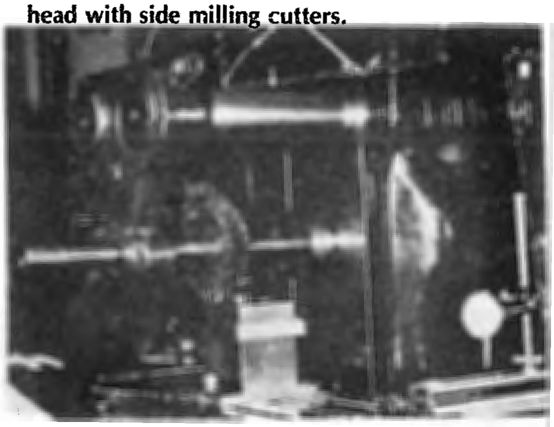


Fig. 14–48. Straddle-milling both sides of a bolt head with side milling cutters.



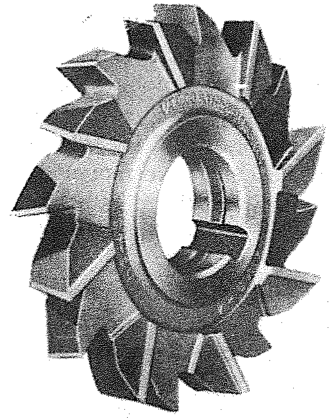


Fig. 14–49. Stagger-tooth side milling cutter. (Union Twist Drill Co.)

Fig. 14–51. Face-milling cutter with inserted teeth. (Brown & Sharpe Mfg. Co.)

Fig. 14–50. This is called *gang milling*. Large side milling cutters, 8 in. in diameter or larger, are usually made with inserted teeth (Fig. 14–51).

45. *What are slitting saws?*
Slitting saws are very thin cutters varying in thickness from 1/32 to 3/16 in. (Fig. 14–52). They are used to cut deep slots and to cut material into required lengths. The cutter is thinner at the center than at the edge, to provide clearance and to prevent the cutter from binding in the slot.

Another form of slitting saw is shown in Fig. 14–53. This style of cutter is preferred when deep

Fig. 14–52. Plain metal-slitting saws. (Pratt & Whitney Co.)

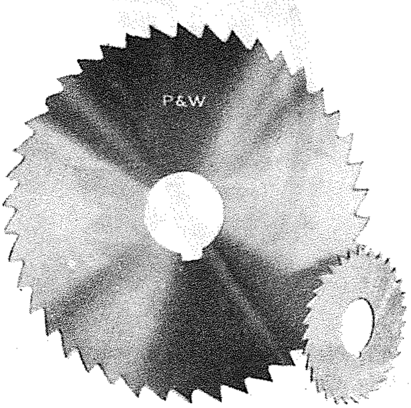


Fig. 14–50. Gang-milling a form using three interlocking cutters. (Brown & Sharpe Mfg. Co.)

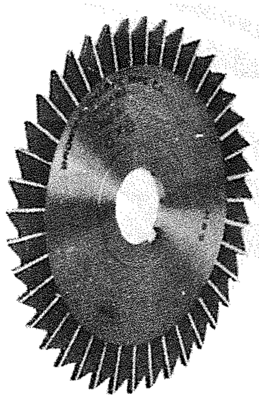


Fig. 14–53. Slitting saw with side chip clearance. (Brown & Sharpe Mfg. Co.)

slots must be cut at high speed. They are also used for cutting slots in the heads of screws.

46. *What are angular cutters?*
Angular cutters may be single, as in Fig. 14–54, or double, as in Fig. 14–55. They are used to cut teeth in flat and rotary cutters and to cut the flutes of drills and reamers.

47. *What are form cutters?*
Form cutters are designed to cut definite shapes. Examples of these are the convex cutter (Fig. 14–56), the concave cutter (Fig. 14–57), and corner-rounding cutters (Fig. 14–58). Another type of form cutter is shown in Fig. 14–59.

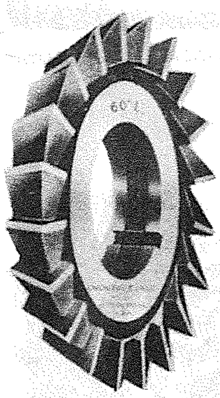
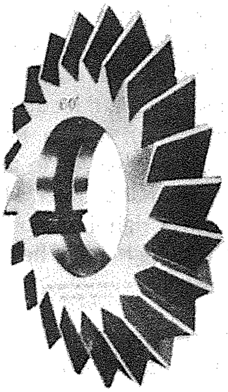


Fig. 14–54. Arbor-type single-angle cutter. (Union Twist Drill Co.)

Fig. 14–55. Double-angle cutter. (Union Twist Drill Co.)



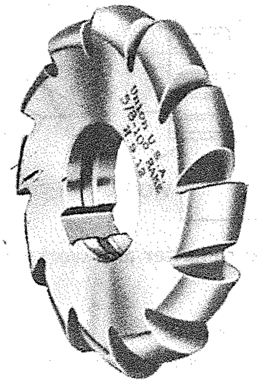
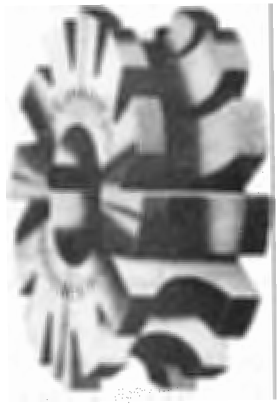


Fig. 14–56. Convex cutter. (Union Twist Drill Co.)

Fig. 14–57. Concave cutter. (Brown & Sharpe Mfg. Co.)



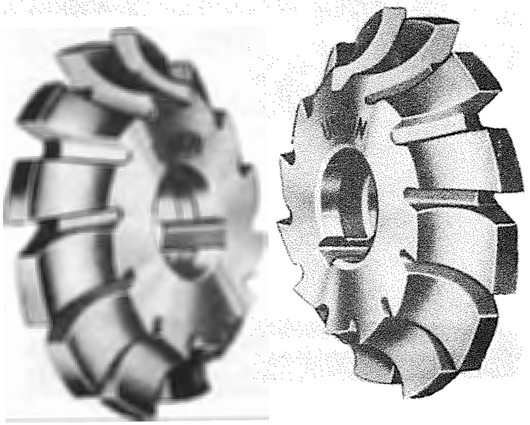


Fig. 14–58. Corner-rounding cutters. (Union Twist Drill Co.)

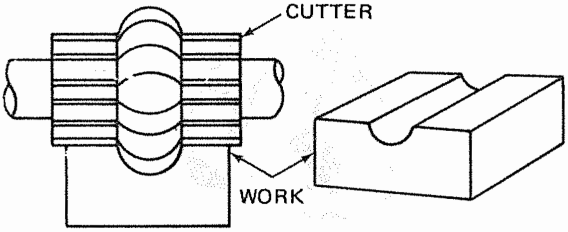


Fig. 14–59. Form cutter and workpiece.

48. *What are end mills?*
An end mill has cutting edges on its periphery and on the end. It is used for milling slots, flat surfaces, and profiles. It is available in many styles and in sizes from ⅛ to 2 in. in diameter. Figure 14–60 shows a spiral end mill with a straight shank. Figure 14–61 shows a spiral end mill with a milling machine standard tapered shank. Figure 14–62 shows a spiral end mill with a Brown & Sharpe tapered shank. Figure 14–63 shows a spiral double-end mill. Figure 14–64 shows a two-lipped end mill, and Fig. 14–65 shows a National Standard shell end mill.

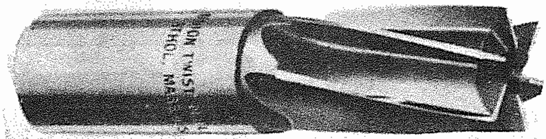
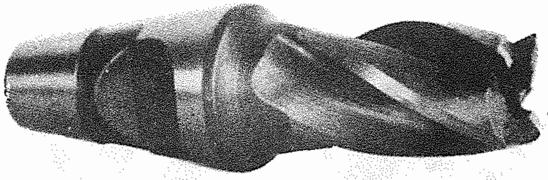


Fig. 14–60. Straight-shank multiple-flute end mill with right-hand helix. (Union Twist Drill Co.)

Fig. 14–61. Four-flute right-hand helix end mill with standard milling-machine taper-shank to fit cam-lock adapter. (Brown & Sharpe Mfg. Co.)



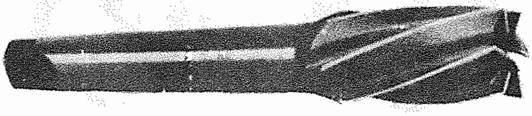


Fig. 14–62. Multiple-flute taper-shank end mill with left-hand helix. (Brown & Sharpe Mfg. Co.)

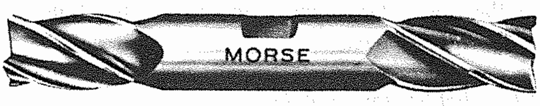


Fig. 14–63. Double end mill with right-hand helix. (Morse Twist Drill & Machine Co.)

Fig. 14–64. Two-flute end mill with taper shank. (Union Twist Drill Co.)

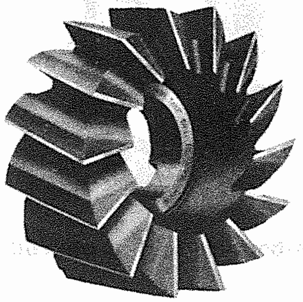


Fig. 14–65. Shell end mill. (Union Twist Drill Co.)

49. *How can a right-hand end mill be distinguished from one that is left-handed?*
To distinguish between right- and left-hand end mills, hold the shank of the cutter in the hand with the shank end toward you. If it cuts when it revolves to the right (clockwise), it is a right-hand cutter, and if it cuts when it revolves to the left (counter-clockwise), it is a left-hand cutter. Helical end mills may be made with a right-hand or left-hand helix, but most have the same hand of helix as the hand of cut (Fig. 14–66).

50. *What is a T-slot cutter?*
A T-slot cutter (Fig. 14–67) is used to cut T-shaped

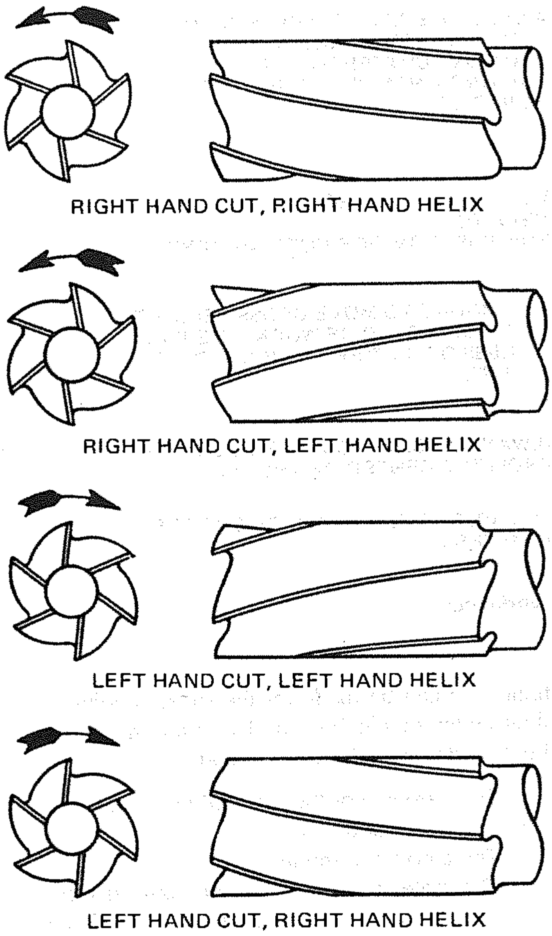


Fig. 14–66. How to tell the hand of cut, and the hand of helix for end mills.

Fig. 14–67. T-slot cutter. (Union Twist Drill Co.)

slots similar to those in the milling machine table. It is available in many sizes.

51. *What is a Woodruff keyway cutter?*
A Woodruff keyway cutter (Fig. 14–68) is similar in appearance to a T-slot cutter, but is designed spe-

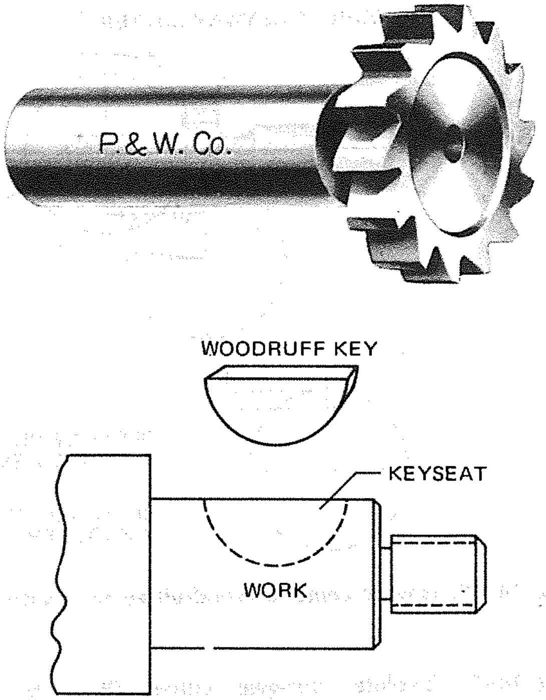


Fig. 14–68. Woodruff keyway cutter. (Pratt & Whitney Co.)

cifically to mill circular-shaped slots to fit standard Woodruff keys. They are available in many sizes.

52. *How should a Woodruff keyway cutter be set central with the work?*
A method for setting a Woodruff keyway cutter central with the work is shown and explained in Fig. 14–69.

53. *What is an involute spur-gear cutter?*
An involute spur-gear cutter (Fig. 14–70) is designed to cut teeth in gears and racks. It is available in many sizes to cut teeth from 1 to 48 diametral pitch. Each size of cutter is made in eight different forms, varying with the number of teeth in the required gear.

54. *Why are cutting oils or coolants used in the milling operation?*
Cutting oils or coolants are used principally to carry off heat from the cutter. If they are permitted to become overheated, the cutting edges of the milling cutter will lose their hardness and, as a result, become dull. The heat generated by the cutting action

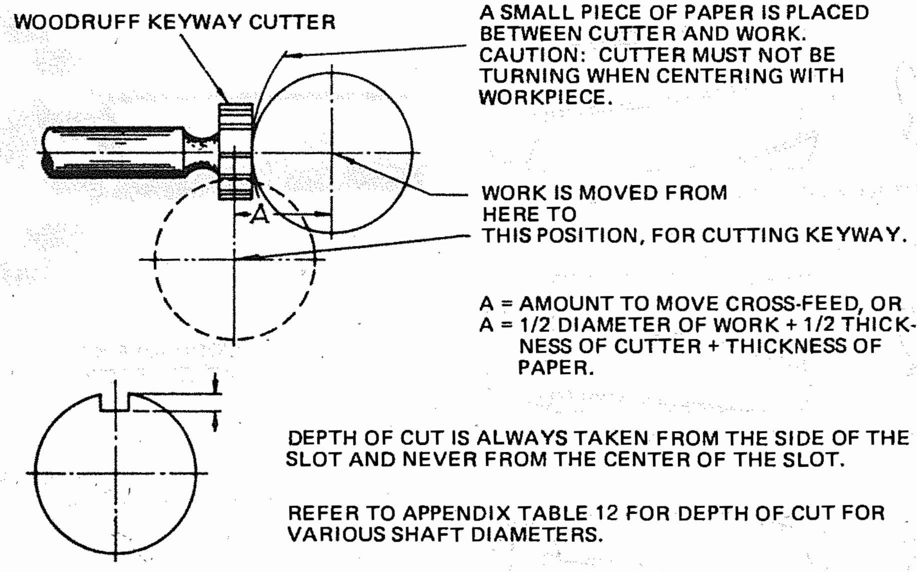
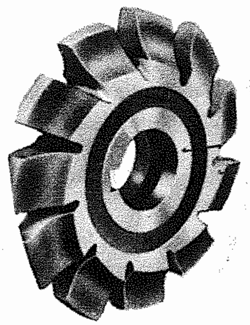


Fig. 14–69. How to center a Woodruff keyway cutter on workpiece.

Fig. 14–70. Involute spur-gear cutter. (Pratt & Whitney Co.)



must be carried away. This is accomplished by a heavy flow of a coolant or cutting oil suitable for the material being machined. Cutting oils also improve the quality of the finish.

Cast iron does not require the use of a coolant. When coolant is mixed with the chips of cast iron, an abrasive results, which dulls the edge of the cutter.

55. *What is meant by the cutting speed of a milling cutter?*

The cutting speed of a milling cutter is the speed at which the circumference of the cutter passes over the work. It is measured in feet per minute. No definite rule can be made for the speed at which a milling cutter should be run. Too many factors require consideration. Among these are:

A. The hardness of the material being cut
B. The depth of the cut
C. The amount of the feed
D. The material from which the cutter is made
E. The shape, size, and construction of the job being milled
F. The condition of the machine and the cutter
G. The quality of the finish specified
H. The use of a coolant, the type of coolant, and its efficiency

With the cutters made of high-speed steel or carbide tipped, the feet-per-minute speeds shown in Fig. 14–71 will act as a guide in selecting the proper cutting speed.

If this speed proves unsatisfactory and sets up excessive vibrations in the job, machine, or cutter or gives an unsatisfactory finish to the work, stop the machine and readjust the speed of the cutter. A cutter should never be run at a speed that would cause excessive heat, which would dull or burn the cutting edge. The following formulas can also be used to approximate a rotating speed (rpm) of a milling cutter.

material	high-speed steel rough	finish	carbide-tipped rough	finish
Aluminum	400	700	800	1,000
Brass	200–300	200–300	600–1,000	600–1,000
Bronze	100–150	150–180	600	1,000
Cast iron	50–60	80–110	180–200	350–400
Cast steel	45–60	70–90	150–180	200–250
Copper	100–150	150–200	600	1,000
Magnesium	600–800	1,000–1,500	1,000–1,500	1,000–1,500
Malleable iron	80–100	100–130	250–300	400–500
Steel, carbon 1020	60–120	60–120	300	300
Steel, nickel 2315	90–110	90–110	300	300
Steel, chrome-nickel 3150	50–60	70–90	200	200
Steel, chrome-nickel-molybdenum 4340	40–50	60–70	200	200
Steel, stainless	60–80	100–120	240–300	240–300

Fig. 14–71. Recommended cutting speeds for milling various metals using high-speed steel and carbide cutter. (From *New American Machinists Handbook*, LeGrand (ed.) Copyright 1955 by McGraw-Hill, Inc. used with permission of the McGraw-Hill Book Co.)

$$\text{rpm of cutter} = \frac{\text{cutting speed} \times 12}{3.1416 \times \text{diameter of cutter}}$$

example 1: To mill material having a cutting speed of 40 fpm, what should be the rpm of a 1¼-in.-diameter cutter?

$$\text{rpm} = \frac{\text{cutting speed} \times 12}{3.1416 \times \text{diameter of cutter}}$$
$$= \frac{40 \times 12}{3.1416 \times 1.25} = 122 \text{ rpm}$$

To find the cutting speed of the cutter when the rpm is known the following formula is used.

$$\text{Cutting speed} = \frac{3.1416 \times \text{diameter} \times \text{rpm of cutter}}{12}$$

example 2: Find the cutting speed of a 1½-in. end mill turning at 382 rpm.

$$\text{Cutting speed} = \frac{3.1416 \times 1.5 \times 382}{12} = 150 \text{ fpm}$$

The machinist in the shop seldom needs to find the *cutting speed* of the material on which he is working. This information is found in a cutting speed table (see Fig. 14–71). However, it is always necessary for him to decide the rpm setting of his machine. The following formula is the one used by the machinist in the shop. It is simple, and the answer given will be as accurate as the range of available speeds will allow.

$$\text{rpm} = \frac{\text{cutting speed} \times 4}{\text{diameter of cutter}}$$

example 3: Give the rpm of a 5-in. cutter. Material: cold-drawn steel having a cutting speed of 100 fpm.

$$\text{rpm} = \frac{\text{cutting speed} \times 4}{\text{diameter of cutter}} = \frac{100 \times 4}{5} = 80 \text{ rpm}$$

Figure 14–72 may be used to find the rpm of cutters of different diameters for the more common surface speeds. When it is not possible to set the machine speed for the exact number obtained, always choose the next lower number.

56. *What is meant by the feed of a milling machine cutter?*
The speed at which the work passes the cutter is called the rate of feed. The amount of feed can be expressed in three ways: (a) inches per minute, (b) thousandths of an inch, and (c) feed per tooth. Methods (a) and (b) are closely related because the thickness of the chip removed by each tooth, when multiplied by the number of teeth on the cutter, will give the amount of metal removed in one revolution of the cutter.

example 1: A high-speed heavy-duty plain milling cutter 4 in. in diameter with 12 teeth is to be used. Each tooth is expected to remove 0.006 in. What is the feed per revolution?

The feed per revolution equals 0.006 × 12, or 0.072 in. A plate on the machine will indicate the

cutter diameter (inches)	40	45	50	55	60	65	70	75	80	90	100	110	120	130	140	150
								cutting speed in rpm								
1/4	611	688	764	840	917	993	1,070	1,146	1,222	1,375	1,528	1,681	1,833	1,986	2,139	2,292
5/16	489	550	611	672	733	794	856	917	978	1,100	1,222	1,345	1,467	1,589	1,711	1,833
3/8	407	458	509	560	611	662	713	764	815	917	1,019	1,120	1,222	1,324	1,426	1,528
7/16	349	393	437	480	524	586	611	655	698	786	873	960	1,048	1,135	1,222	1,310
1/2	306	344	382	420	458	497	535	573	611	688	764	840	917	993	1,070	1,146
5/8	244	275	306	336	367	397	428	458	489	550	611	672	733	794	856	917
3/4	204	229	255	280	306	331	357	382	407	458	509	560	611	662	713	764
7/8	175	196	218	240	262	284	306	327	349	393	437	480	524	568	611	655
1	153	172	191	210	229	248	267	287	306	344	382	420	458	497	535	573
1 1/8	136	153	170	187	204	221	238	255	272	306	340	373	407	441	475	509
1 1/4	122	138	153	168	183	199	214	229	244	275	306	336	367	397	428	458
1 3/8	111	125	139	153	167	181	194	208	222	250	278	306	333	361	389	417
1 1/2	102	115	127	140	153	166	178	191	204	229	255	280	306	331	357	382
1 5/8	94.0	106	118	129	141	153	165	176	188	212	235	259	282	306	329	353
1 3/4	87.3	98.2	109	120	131	142	153	164	175	196	218	240	262	284	306	327
1 7/8	81.5	91.7	102	112	122	132	143	153	163	183	204	224	244	265	285	306
2	76.4	85.9	95.5	105	115	124	134	143	153	172	191	210	229	248	267	287
2 1/4	67.9	76.4	84.9	93.4	102	110	119	127	136	153	170	187	204	221	238	255
2 1/2	61.1	68.8	76.4	84.0	91.7	99.3	107	115	122	138	153	168	183	199	214	229
2 3/4	55.6	62.5	69.5	76.4	83.3	90.3	97.2	104	111	125	139	153	167	181	194	208
3	50.9	57.3	63.7	70.0	76.4	82.8	89.1	95.5	102	115	127	140	153	166	178	191
3 1/4	47.0	52.9	58.8	64.6	70.5	76.4	82.3	88.2	94.0	106	118	129	141	153	165	176
3 1/2	43.7	49.1	54.6	60.0	65.5	70.9	76.4	81.9	87.3	98.2	109	120	131	142	153	164
3 3/4	40.7	45.8	50.9	56.0	61.1	66.2	71.3	76.4	81.5	91.7	102	112	122	132	143	153
4	38.2	43.0	47.7	52.5	57.3	62.1	66.8	71.6	76.4	85.9	95.5	105	115	124	134	143
4 1/2	34.0	38.2	42.4	46.7	50.9	55.2	59.4	63.6	67.9	76.4	84.9	93.4	102	110	119	127
5	30.6	34.4	38.2	42.0	45.8	49.7	53.5	57.3	61.1	68.8	76.4	84.0	91.7	99.3	107	115
5 1/2	27.8	31.3	34.7	38.2	41.7	45.1	48.6	52.1	55.6	62.5	69.5	76.4	83.3	90.3	97.2	104
6	25.5	28.6	31.8	35.0	38.2	41.4	44.6	47.8	50.9	57.3	63.7	70.0	76.4	82.8	89.1	95.5

(Column headings 40–150: *cutting speed (fpm)*)

Fig. 14–72. Table for finding rpm when cutter diameter and cutting speed (fpm) are known.

setting nearest to this amount of table travel.

The feed in inches per minute will equal the feed per revolution times the rpm of the cutter.

Feed in inches per minute =
Feed per revolution × revolutions per minute

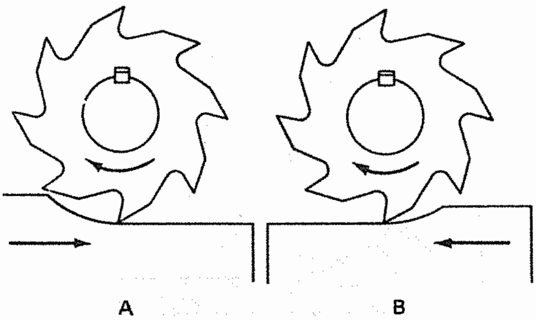
example 2: The feed per revolution is 0.072 in. and the machine is set for 120 rpm. Find the feed in inches per minute.

Substituting the data in the formula,

Feed = 0.072 × 120 = 8.64 inches per minute

57. *What determines the rate of the feed of the milling cutter?*
The same factors that determine the speed of the milling cutter determine the rate of the feed—that is, materials, finish, depth of cut, shape of job, condition of machine, and so forth. Remember, however, that the rate of feed will be the deciding factor in determining the time it takes to do the job, or the speed of production.

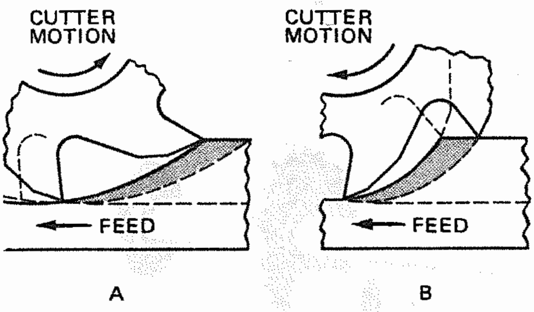
58. *What is meant by conventional and climb-cut milling?*
Conventional milling (also called *up milling*) and climb-cut milling (also called *down milling*) refer to the direction in which work is fed against the cutter (Fig. 14–73). As can be seen in Fig. 14–73B, in climb-cut milling the direction of feed can force the work into the cutter, and the result could be a broken cutter and damaged work. The table feed screws on milling machines built in the past were not designed to hold table or work back against the force of the cutter, so conventional, or up, milling was necessary. Because the work is fed against the rotation of the cutter in up milling there was no problem with backlash in the feed screw. Backlash means



ig. 14–73. (A) Conventional, or up, milling. (B) limb-cut, or down, milling. (Kearney & Trecker orp.)

ɔst motion or looseness, as when screw threads ecome worn. Machines equipped with a backlash- liminator device on the feed screw are capable of own milling safely (Fig. 14–74).

9. *What are some of the advantages of down ıilling?*
ʼown milling is more practical and efficient, and utters retain sharpness longer because cutting is :arted at the full thickness of the chip and comes out t zero thickness. In up milling, the cutter is forced ıto the metal at zero thickness and takes a pro-ressively bigger bite as the cut continues. Another dvantage of down milling is that simpler fixtures ıay be used because the downward forces against ıe workpiece make it easier to hold and prevent ıe workpiece from moving. In up milling, the forces ave a tendency to pull the work upward in a vise r fixture, which requires stronger clamping ıethods.



g. 14–74. Cutting action of cutter teeth (A) during ı milling and (B) during down milling.

60. *What are some basic principles required in setups for milling precision work?*
Precision milling begins with a clean table that must be free of chips, burrs, and dirt. This is the first and very important step in setting up work. Keeping the work, the table, the vise, and all other tools clean is a "must" all through the milling procedure. Before mounting cutters on an arbor, be sure to clean each of the arbor collars, the arbor itself, and the cutter that is to be clamped between the collars. The smallest chip wedged between the collars can give trouble when doing precision work. Before placing a vise, fixture, or attachment on the table, be sure to clean all contacting surfaces.

Workpieces held in a vise should always be seated on parallel bars when the thickness is less than the height of the vise jaws. Seating work properly on parallels requires tapping the work down, using a soft hammer or block (Fig. 14–75) and testing with the fingers to make sure the parallels are not loose at either end. If parallels are loose, the work is not seated properly.

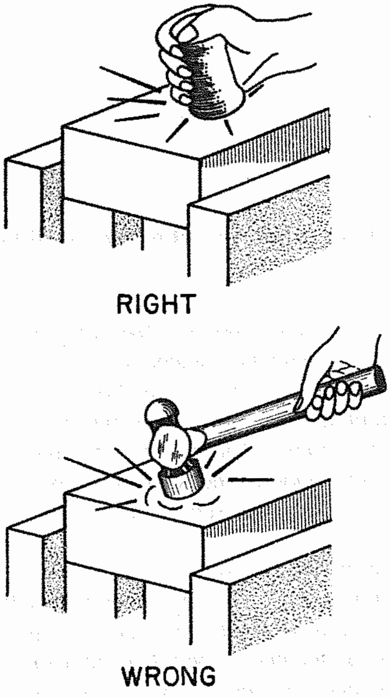


Fig. 14–75. When seating work on parallel bars, use a soft hammer or block. (Kearney & Trecker Corp.)

When selecting a cutter or cutters for a job, bear in mind that a milling tool's cut is not complete until it clears the end of the work. The center of the cutter must travel a certain distance beyond the end of the workpiece before the cut is finished (Fig. 14–76). To save milling time, select the smallest-diameter cutters that will do the job.

Before mounting cutters on the arbor, decide in which direction the spindle should rotate. Then mount the cutter to cut in that direction. After the cutter is mounted, check to see that the spindle is set to turn in the right direction. If fed against the workpiece, a cutter revolving in the wrong direction could ruin the cutting edges of the teeth (Fig. 14–77).

When mounting cutters on an arbor, be sure they fit freely. Cutters must never be forced on an arbor. An arbor that has been scored or burred should not be used until the burrs have been removed (Fig. 14–78).

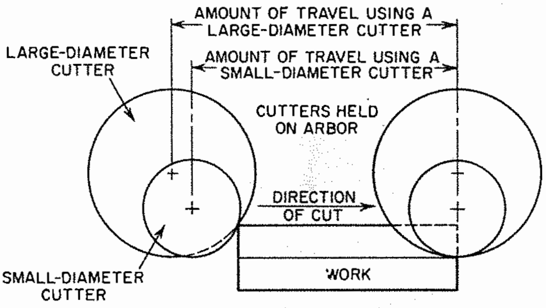


Fig. 14–76. Comparison of cutter size to distance traveled.

Good milling practice requires that both the work and the cutter should be located as close to the machine column as possible. A good rule for setting up milling work is to set up the work first, then move the table as close to the column as is convenient, and mount the cutters to be used. This provides a good, rigid setup (Fig. 14–79).

61. *What is a dividing head?*

A dividing head (Fig. 14–80), sometimes called an *index head,* is a mechanical device used to divide the circumference or periphery of a job into specified distances or angular separations. It also provides the means by which the job is securely held.

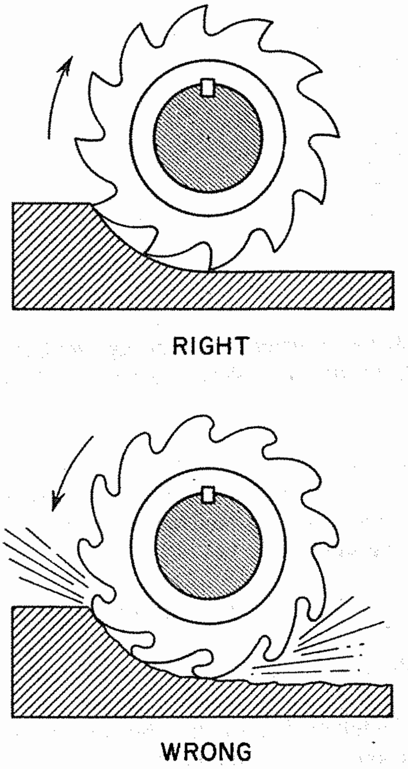
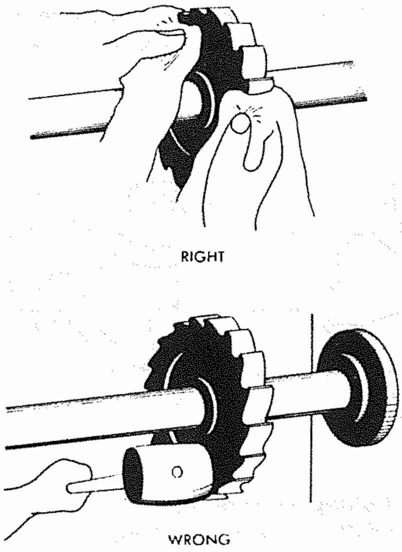


Fig. 14–77. Direction of cutter rotation must be correct. (Kearney & Trecker Corp.)

Fig. 14–78. Cutters must fit arbors without being forced. (Kearney & Trecker Corp.)



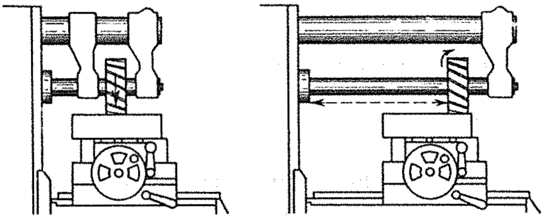
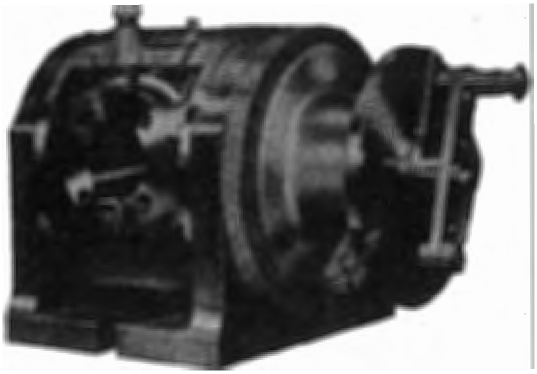


Fig. 14–79. Cutters and work should be as close as possible to the column for a rigid setup. (Kearney & Trecker Corp.)

Fig. 14–80. A dividing, or index, head. (Cincinnati Milacron Co.)



62. *How does the dividing head operate?*
The most important parts of the dividing head are held within the shell or casing. They consist of the worm and the worm wheel, index plates, sector arms, and change gears (Fig. 14–81). The worm wheel has 40 teeth, and the worm has a single thread. The worm wheel is fastened to the index head spindle and is meshed with a single-thread worm. Every turn of the index crank turns the worm one revolution, moving the worm wheel one tooth, or 1/40 of a revolution. Forty revolutions of the worm will turn the index head spindle (and the job) one complete revolution. Fractional parts of a turn are obtained by utilizing index plates, which are supplied with each head. The sector arms are used to mark off the number of holes on the index plate. This makes it possible to move the index crank the same number of holes without having to count the holes on each turn.

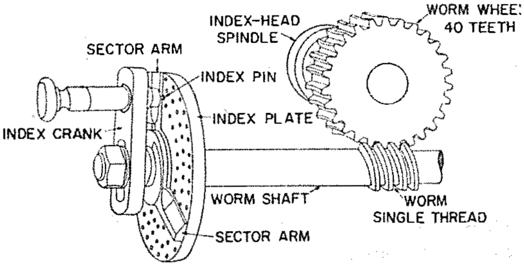


Fig. 14–81. Parts of a dividing-head mechanism.

63. *What is rapid indexing and how is it used?*
Rapid indexing, also known as *direct indexing,* is the simplest method of indexing. Figure 14–82 shows the front index plate attached to the work spindle. The front index plate usually has 24 equally spaced holes. These holes can be engaged by the front index pin, which is spring loaded and is moved in and out by means of a small lever. Rapid indexing requires that the worm and worm

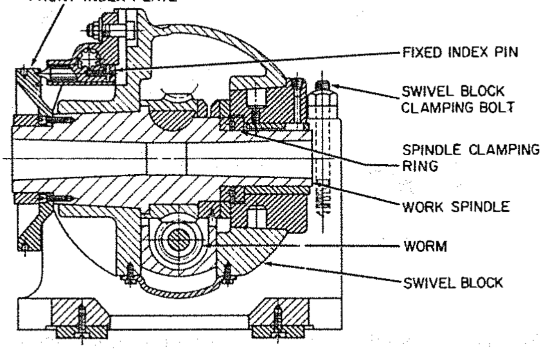


Fig. 14–82. Section through a universal dividing head showing front index plate and fixed index pin. (Cincinnati Milacron Co.)

wheel be disengaged so that the spindle can be moved by hand. Numbers that can be divided into 24 can be indexed. Rapid indexing is used when a large number of duplicate parts are to be milled.

The number of holes to move in the index plate can be found by dividing 24 by the number of divisions required.

$$\text{Number of holes to move} = \frac{24}{N}$$

where N = required number of divisions.

example: Indexing for a hexagon head screw. Because a hexagon head has six flats,

$$\frac{24}{N} = \frac{24}{6} = 4 \text{ holes}$$

caution: When the rapid indexing job has been completed, engage the worm and worm wheel in proper mesh. Leave the index head set up for plain indexing.

64. *What is plain indexing and how is it used?*
Plain indexing, or simple indexing, is used when a circle must be divided into more parts than is possible by rapid indexing. Simple indexing requires that the spindle be moved by turning an index crank, which turns the worm that is meshed with the worm wheel. The ratio between worm and worm wheel is 1 to 40, or 1:40 (Fig. 14–83). One

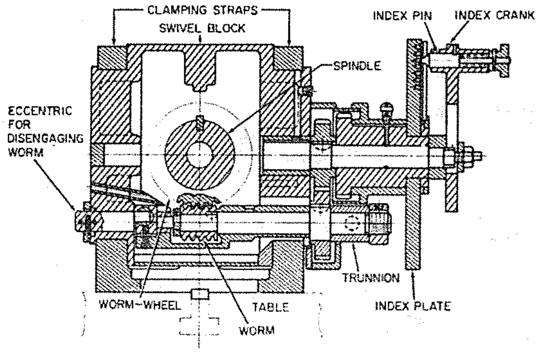


Fig. 14–83. Section through a dividing head showing worm, worm wheel, and worm shaft. (Cincinnati Milacron Co.)

turn of the index crank turns the index head spindle $\frac{1}{40}$ of a complete turn. Forty turns of the index crank will revolve the spindle, chuck, and job one complete revolution. The number of turns or fractional parts of a turn of the index crank necessary to cut any required number of divisions may be determined by the following rule.

To find the number of turns of the index crank divide 40 by the number of divisions required.

$$\text{No. of turns of index crank} = \frac{40}{N}$$

where N equals the number of divisions required.

example 1: Index for five divisions.

$$\frac{40}{N} = \frac{40}{5} = 8 \text{ turns}$$

There are eight turns of the crank for each division.

example 2: Index for eight divisions.

$$\frac{40}{N} = \frac{40}{8} = 5 \text{ turns}$$

example 3: Index for 10 divisions.

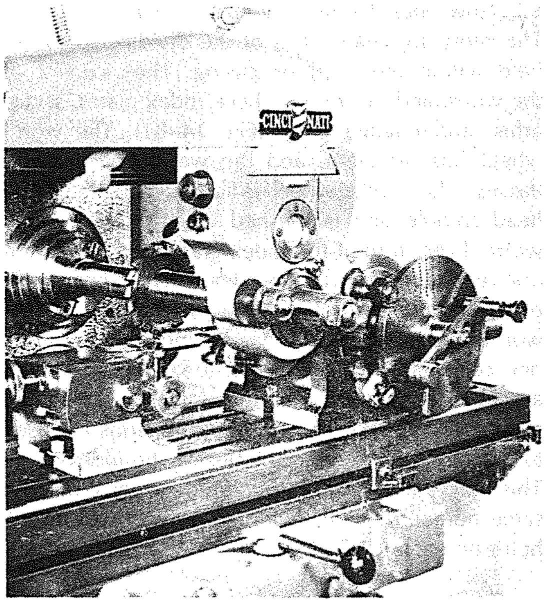
$$\frac{40}{N} = \frac{40}{10} = 4 \text{ turns}$$

Figure 14–84 shows an index head set up for a plain indexing job.

When the number of divisions required does not divide evenly into 40, the index crank must be moved a fractional part of a turn. This is done with index plates. A commonly used model of the Brown & Sharpe index head is furnished with three index plates (Fig. 14–85). Each plate has six circles of holes, as listed.

Plate one: 15-16-17-18-19-20
Plate two: 21-23-27-29-31-33
Plate three: 37-39-41-43-47-49

Fig. 14–84. Milling four flutes by plain indexing. (Cincinnati Milacron Co.)



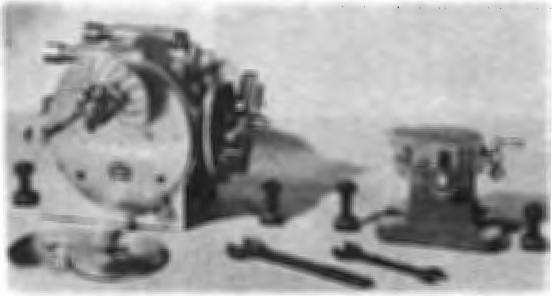


Fig. 14-85. Index head with index plates and foot stock. (Brown & Sharpe Mfg. Co.)

The previous examples of the use of the indexing formula 40/*N* gave results in complete turns of the index crank. This seldom happens on the typical indexing job. For example, indexing for 18 divisions.

$$\frac{40}{N}=\frac{40}{18}=2\frac{4}{18}\text{ turns}$$

The whole number indicates the complete turns of the index crank, the denominator represents the index circle, and the numerator represents the number of holes to use on that circle. Because there is an 18-hole index circle the mixed number $2\,^4/_{18}$ indicates that the index crank will be moved 2 full turns plus 4 holes on the 18-hole circle. The sector arms are positioned to include 4 holes *and* the hole that the index crank pin is in. The number of holes (4) represents the *movement* of the index crank; the hole that engages the index crank is not included.

When the denominator of the indexing fraction is smaller or larger than the number of holes contained in any of the index circles, change it to a number representing one of the circle of holes. Do this by multiplying or dividing the numerator and the denominator by the same number. For example, to index for the machining of a hexagon ($N = 6$),

$$\frac{40}{N}=\frac{40}{6}=6\frac{4}{6}\text{ turns}$$

In its simplest form, this is $6\,^2/_3$ turns. The denominator 3 will divide equally into the following circles of holes:

Plate one: 15 and 18
Plate two: 21 and 33
Plate three: 39

If plate 3 is conveniently on the index head, it should be used. The denominator 3 must be multiplied by 13 to equal 39. In order not to change the value of the original indexing fraction, both the numerator and the denominator must be multiplied by 13.

$$\frac{2}{3}\times\frac{13}{13}=\frac{26}{39}\qquad 6\frac{2}{3}=6\frac{26}{39}$$

Thus in order to mill each side of a hexagon, the index crank must be moved 6 full turns and 26 holes on a 39-hole circle.

When the number of divisions exceeds 40, both terms of the fraction may be divided by a common divisor to obtain an index circle that is available.

For example, if 160 divisions are required, $N=160$. The fraction to be used is:

$$\frac{40}{N}=\frac{40}{160}$$

Because there is no 160-hole circle this fraction must be reduced.

$$\frac{40/10}{160/10}=\frac{4}{16}$$

Turn 4 holes on the 16-hole circle.

It is usually more convenient to reduce the original fraction to its lowest terms and multiply both terms of the fraction by a factor that will give a number representing a circle of holes:

$$\frac{40/40}{160/40}=\frac{1}{4}$$

$$\frac{1}{4}\times\frac{4}{4}=\frac{4}{16}$$

The following examples will further clarify the use of this formula.

example 1: Index for 9 divisions.

$$\frac{40}{N}=\frac{40}{9}=4\frac{4}{9}$$

If an 18-hole circle is used, the fraction becomes

$$\frac{4}{9}\times\frac{2}{2}=\frac{8}{18}$$

For each division, turn the crank 4 turns and 8 holes on an 18-hole circle.

example 2: Index for 136 divisions.

$$\frac{40}{N}=\frac{40}{136}=\frac{5}{17}$$

There is a 17-hole circle, so for each division turn the crank 5 holes on a 17-hole circle.

caution: In setting the sector arms to space off the required number of holes on the index circle, *do not count the hole that the index crank pin is in.*

65. *What features are included in later-model Brown & Sharpe universal spiral index centers?*
Figure 14–86 shows a later-model Brown & Sharpe 10-in. universal spiral index headstock. It is of the trunnion type, of heavy construction with clamping around the entire circumference. It has wide bearings and is set low so that when clamped to the table it becomes as rigid as the machine itself.

66. *Do all index heads use the same index plates?*
Manufacturers provide different plates for indexing. Later-model Brown & Sharpe index heads use two index plates with the following circles of holes:

Plate one: 15-16-19-23-31-37-41-43-47
Plate two: 17-18-20-21-27-29-33-39-47

The standard index plate supplied with the Cincinnati index head is provided with 11 different circles of holes on each side.

Side one:24-25-28-30-34-37-38-39-41-42-43
Side two: 46-47-49-51-53-54-57-58-59-62-66

67. *What is differential indexing and how is it used?*
The differential method is used in indexing for numbers that are beyond the range of plain indexing. Differential indexing is made possible by using a gear train to connect the index plate to the headstock spindle. The index plate can be made to rotate in required relationship to the movement of the headstock spindle. By proper arrangement of the gearing, the index plate can be made to move either fast or slow, and in the same direction (positive) as, or in the opposite direction (negative) to, the index crank. This causes the movement of the index plate to be either faster or slower, traveling either more or less than the movement of the index crank. Before attempting to use differential indexing, it is necessary to understand gearing and how to obtain required gear ratios.

The standard change gears (12 gears) supplied with the Brown & Sharpe index head have the following number of teeth: 24 (two gears), 28, 32, 40, 44, 48, 56, 64, 72, 86, and 100.

Fig. 14–86. Principal parts of a late-model Brown & Sharpe universal spiral index head. (Brown & Sharpe Mfg. Co.)

When the required number of divisions cannot be indexed by plain indexing, an approximate number of divisions that can be indexed by plain indexing is selected. The difference between the movement of the spindle obtained by this approximate number and the required movement is corrected by using change gears. The proper ratio of gearing is found in the following manner.

Step 1. Select a number of divisions that can be indexed by plain indexing. It can be either greater or smaller than the required number. Determine the movement of the index crank for plain indexing by using the formula:

$$\text{Turns of index crank} = \frac{40}{A}$$

Step 2. Determine the gear ratio from the formula:

$$\text{Gear ratio} = (A - N) \times \frac{40}{A}$$

where A is the approximate number of divisions from Step 1, and N is the required number of divisions.

Step 3. Select suitable gears from the standard change gears with which the index head is equipped. The ratio of the gearing will determine whether a simple or compound train of gears is used.

The following examples show how standard gears are selected from given gear ratios.

example 1: A gear ratio of 3:8 has been computed for differential indexing. Select the gears for simple gearing.

Multiply each number of the ratio by a number that will make both the numerator and the denominator equal to the number of teeth in one of the standard change gears, as,

$$\frac{3}{8} \times \frac{8}{8} = \frac{24}{64}$$

Driving gear: 24 teeth
Driven gear: 64 teeth

example 2: A ratio of 16:33 has been calculated. Select the gears needed for compound gearing.

Factor each number of the ratio and then multiply the numerators and the denominators by factors so that the products will be equal to the number of teeth in standard change gears.

$$\frac{16}{33} = \frac{1}{3} \times \frac{16}{11}$$

$$\left(\frac{1}{3} \times \frac{24}{24}\right) \times \left(\frac{16}{11} \times \frac{4}{4}\right)$$

$$\frac{24}{72} \times \frac{64}{44} \begin{matrix}\text{Driving gears} \\ \text{Driven gears}\end{matrix}$$

In differential indexing the numerators of the fractions denote the driving gears and the denominators denote the driven gears. Idler gears control the direction of the rotation of the index plate and are arranged as follows:

Simple gearing. One idler for positive motion of the index plate. Two idlers for negative motion of the index plate.

Compound gearing. One idler for negative motion of the index plate. No idlers for the positive motion of the index plate.

Figure 14–87 illustrates, in three steps, how to determine the proper gears to use for the differential indexing of 57 divisions.

In Case 1 in Fig. 14–87, an approximate number greater than the required number was selected. Note that when the approximate number is greater than the required number, the index plate must turn in the *positive* direction. Using simple gearing, this requires one idler gear.

In Case 2 in Fig. 14–87, an approximate number smaller than the required number was used. Notice that when the approximate number is less than the required number, the index plate must turn in the *negative* direction. Using simple gearing, two idler gears are required.

In Case 3 Fig. 14–87, an approximate number smaller than the required number was used. Notice that, in this case, compound gearing is necessary. Because the approximate number is less than the required number, the index plate must turn in the negative direction. This requires one idler gear.

These examples show that the approximate number may be greater or less than the required number and that the movement of the index plate, both in speed and direction of rotation, can be controlled by the ratio of the gearing. The difference between the approximate number and the required number is limited only by the index plate circles of holes and the change gears available.

Figure 14–88 shows an index head geared for differential indexing with one idler. This is an example of simple gearing, as in Case 1.

Figure 14–89 shows an index head geared for differential indexing utilizing simple gearing with two idler gears, as in Case 2.

Figure 14–90 shows an index head geared for differential indexing making use of compound gearing with one idler, as in Case 3.

A chart similar to the one in Fig. 14–91 is usually available to machinists in machine shops and toolrooms. Although it provides a quick answer to the problems of index plates and sector arm settings, it is only a substitute for a true craftsman's knowledge.

68. *Describe the operation of graduating on a milling machine.*

Flat rules and verniers may be graduated (divided into regular intervals) on a milling machine by using a pointed tool and an index head. The tool is held stationary in a fly-cutter holder (Fig. 14–92). This is mounted in the spindle of the machine; or it

steps	*case 1*	*case 2*	*case 3*
	$A = 60$ $N = 57$	$A = 56$ $N = 57$	$A = 54$ $N = 57$
1. Plain indexing	$\frac{40}{A} = \frac{40}{60} = \frac{2}{3}$ $\frac{2}{3} \times \frac{7}{7} = \frac{14}{21}$ **14 holes,** **21-hole circle**	$\frac{40}{A} = \frac{40}{56} = \frac{5}{7}$ $\frac{5}{7} \times \frac{3}{3} = \frac{15}{21}$ **15 holes,** **21-hole circle**	$\frac{40}{A} = \frac{40}{54} = \frac{20}{27}$ **20 holes,** **27-hole circle**
2. Gear ratio	$(A - N) \times \frac{40}{A} =$ $(60 - 57) \times \frac{40}{60} =$ $3 \times \frac{2}{3} = \frac{2}{1}$	$(A - N) \times \frac{40}{A} =$ $(56 - 57) \times \frac{40}{56} =$ $-1 \times \frac{5}{7} = -\frac{5}{7}$	$(A - N) \times \frac{40}{A} =$ $(54 - 57) \times \frac{40}{54} =$ $= -3 \times \frac{20}{27} = -\frac{20}{9}$
3. Select gears	$\frac{2}{1} \times \frac{24}{24}$ **or** $\frac{\text{48 Driver}}{\text{24 Driven}}$ **1 idler**	$-\frac{5}{7} \times \frac{8}{8}$ **or** $\frac{\text{40 Driver}}{\text{56 Driven}}$ **2 idlers**	$-\frac{20}{9} = \frac{4}{3} \times \frac{5}{3}$ $= \left(\frac{4}{3} \times \frac{16}{16}\right) \times \left(\frac{5}{8} \times \frac{8}{8}\right)$ $\frac{64}{48} \times \frac{\text{40 Driving gears}}{\text{24 Driven gears}}$ **1 idler**

Fig. 14–87. Selection of gears for differential indexing of 57 divisions.

Fig. 14–88. An example of differential indexing with simple gearing and one idler gear. (Brown & Sharpe Mfg. Co.)

Fig. 14–89. An example of differential indexing with simple gearing and two idler gears. (Brown & Sharpe Mfg. Co.)

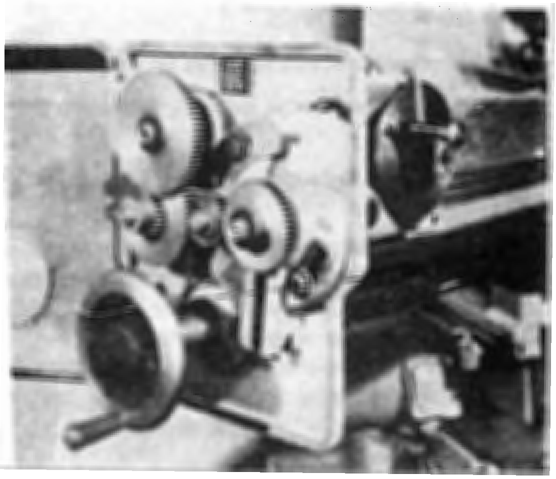


Fig. 14–90. An example of differential indexing with compound gearing and one idler gear. (Brown & Sharpe Mfg. Co.)

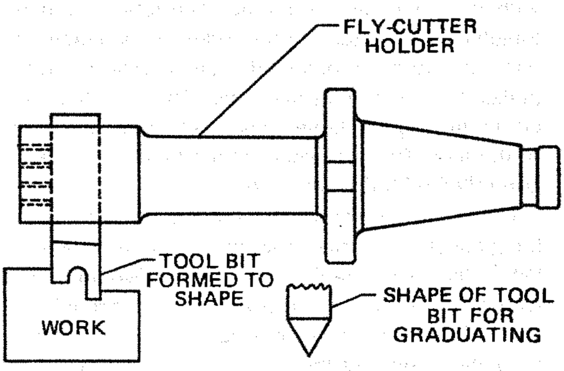
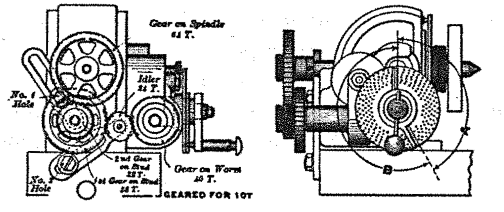


Fig. 14–92. A fly-cutter arbor holds single-point tool bits for forming or graduating work.

Fig. 14–91. Chart for plain and differential indexing.

PLAIN & DIFFERENTIAL INDEXING



Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Number of Divisions	Index Circle	No. of Turns of Index	Graduation
2	Any	20		13	39	$3\frac{3}{39}$	14	26	39	$1\frac{21}{39}$	106	40	Any	1	
3	39	$13\frac{13}{39}$	65	14	49	$2\frac{42}{49}$	169	27	27	$1\frac{13}{27}$	95	41	41	$\frac{40}{41}$	3*
	33	$13\frac{11}{33}$	65		21	$2\frac{18}{21}$	170	28	49	$1\frac{21}{49}$	83	42	21	$\frac{20}{21}$	9*
	18	$13\frac{6}{18}$	65	15	39	$2\frac{26}{39}$	132		21	$1\frac{9}{21}$	85	43	43	$\frac{40}{43}$	12*
4	Any	10			33	$2\frac{22}{33}$	132	29	29	$1\frac{11}{29}$	75	44	33	$\frac{30}{33}$	17*
5	Any	8			18	$2\frac{12}{18}$	132	30	39	$1\frac{13}{39}$	65	45	27	$\frac{24}{27}$	21*
6	39	$6\frac{26}{39}$	132	16	20	$2\frac{10}{20}$	98		33	$1\frac{11}{33}$	65		18	$\frac{16}{18}$	21*
	33	$6\frac{22}{33}$	132	17	17	$2\frac{6}{17}$	69		18	$1\frac{6}{18}$	65	46	23	$\frac{20}{23}$	172
	18	$6\frac{12}{18}$	132	18	27	$2\frac{6}{27}$	43	31	31	$1\frac{9}{31}$	56	47	47	$\frac{40}{47}$	168
7	49	$5\frac{35}{49}$	140		18	$2\frac{4}{18}$	43	32	20	$1\frac{5}{20}$	48	48	18	$\frac{15}{18}$	165
	21	$5\frac{15}{21}$	142	19	19	$2\frac{2}{19}$	19	33	33	$1\frac{7}{33}$	41	49	49	$\frac{40}{49}$	161
8	Any	5		20	Any	2		34	17	$1\frac{3}{17}$	33	50	20	$\frac{16}{20}$	158
9	27	$4\frac{12}{27}$	88	21	21	$1\frac{19}{21}$	18*	35	49	$1\frac{7}{49}$	26	GRADUATIONS IN TABLE INDICATE SETTING FOR ARMS OF SECTOR WHEN INDEX CRANK MOVES THROUGH ARC "A," EXCEPT CASES MARKED * WHEN THE INDEX CRANK MOVES THROUGH ARC "B."			
	18	$4\frac{8}{18}$	87	22	33	$1\frac{27}{33}$	161		21	$1\frac{3}{21}$	28				
10	Any	4		23	23	$1\frac{17}{23}$	147	36	27	$1\frac{3}{27}$	21				
11	33	$3\frac{21}{33}$	126	24	39	$1\frac{26}{39}$	132		18	$1\frac{2}{18}$	21				
12	39	$3\frac{13}{39}$	65		33	$1\frac{22}{33}$	132	37	37	$1\frac{3}{37}$	15				
	33	$3\frac{11}{33}$	65		18	$1\frac{12}{18}$	132	38	19	$1\frac{1}{19}$	9				
	18	$3\frac{6}{18}$	65	25	20	$1\frac{12}{20}$	118	39	39	$1\frac{1}{39}$	3				

Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole: 1st Gear on Stud	No. 1 Hole: 2nd Gear on Stud	Gear on Spindle	Idlers: No. 1 Hole	Idlers: No. 2 Hole	Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole: 1st Gear on Stud	No. 1 Hole: 2nd Gear on Stud	Gear on Spindle	Idlers: No. 1 Hole	Idlers: No. 2 Hole
51	17	$\frac{14}{17}$	33*	24			48	24	44	69	20	$\frac{12}{20}$	118	40			56	24	44
52	39	$\frac{30}{39}$	152							70	49	$\frac{28}{49}$	112						
53	49	$\frac{35}{49}$	140	56	40	24	72				21	$\frac{12}{21}$	113						
	21	$\frac{15}{21}$	142	56	40	24	72			71	27	$\frac{15}{27}$	110	72			40	24	
54	27	$\frac{20}{27}$	147								18	$\frac{10}{18}$	109	72			40	24	
55	33	$\frac{24}{33}$	144							72	27	$\frac{15}{27}$	110						
56	49	$\frac{35}{49}$	140								18	$\frac{10}{18}$	109						
	21	$\frac{15}{21}$	142							73	49	$\frac{28}{49}$	112	28			48	24	44
57	49	$\frac{35}{49}$	140	56			40	24	44		21	$\frac{12}{21}$	113	28			48	24	44
	21	$\frac{15}{21}$	142	56			40	24	44	74	37	$\frac{20}{37}$	107						
58	29	$\frac{20}{29}$	136							75	15	$\frac{8}{15}$	105						
59	39	$\frac{26}{39}$	132	48			32	44		76	19	$\frac{10}{19}$	103						
	33	$\frac{22}{33}$	132	48			32	44		77	20	$\frac{10}{20}$	98	32			48	44	
	18	$\frac{12}{18}$	132	48			32	44		78	39	$\frac{20}{39}$	101						
60	39	$\frac{26}{39}$	132							79	20	$\frac{10}{20}$	98	48			24	44	
	33	$\frac{22}{33}$	132							80	20	$\frac{10}{20}$	98						
	18	$\frac{12}{18}$	132							81	20	$\frac{10}{20}$	98	48			24	24	44
61	39	$\frac{26}{39}$	132	48			32	24	44	82	41	$\frac{20}{41}$	96						
	33	$\frac{22}{33}$	132	48			32	24	44	83	26	$\frac{10}{20}$	98	32			48	24	44
	18	$\frac{12}{18}$	132	48			32	24	44	84	21	$\frac{10}{21}$	94						
62	31	$\frac{20}{31}$	127							85	17	$\frac{8}{17}$	92						
63	39	$\frac{26}{39}$	132	24			48	24	44	86	43	$\frac{20}{43}$	91						
	33	$\frac{22}{33}$	132	24			48	24	44	87	15	$\frac{7}{15}$	92	40			24	24	44
	18	$\frac{12}{18}$	132	24			48	24	44	88	33	$\frac{15}{33}$	89						
64	16	$\frac{10}{16}$	123							89	27	$\frac{12}{27}$	88	72			32	44	
65	39	$\frac{24}{39}$	121								18	$\frac{8}{18}$	87	72			32	44	
66	33	$\frac{20}{33}$	120							90	27	$\frac{12}{27}$	88						
67	49	$\frac{28}{49}$	112	28			48	44			18	$\frac{8}{18}$	87						
	21	$\frac{12}{21}$	113	28			48	44		91	39	$\frac{18}{39}$	91	24			48	24	44
68	17	$\frac{10}{17}$	116							92	23	$\frac{10}{23}$	86						

may be fastened to the spindle of a vertical milling machine or rack-cutting attachment. The work is clamped to the table parallel to the T slots. The index head spindle is geared to the table-feed screw with gears having a 1:1 ratio. The table is moved longitudinally by turning the index crank. Fractional parts of a turn are obtained by means of the index plates, the same as in plain indexing. The lines are cut by moving the table transversely under the point of the tool. The movement of the table crosswise is controlled with the hand feed.

Figure 14–93 shows the milling machine setup for graduating. Notice how the gears are arranged. When the index crank is turned one revolution, the spindle turns 1/40 of a revolution, and through the 1:1 ratio causes the lead screw to move 1/40 of a revolution. Because the usual lead of the lead screw is 0.250 in., one turn of the index crank will move the table 1/40 of 0.250 in., which equals 0.00625 in.

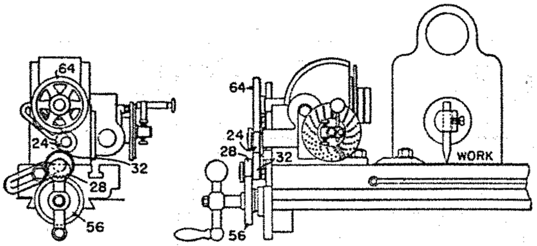


Fig. 14–93. Milling machine setup for graduating. The numbers indicate the number of teeth on each gear.

When the table is to be moved a required distance, divide the required distance by the actual distance the table is advanced in one turn of the index crank, namely, 0.00625 in., and the result will be the number of turns of the index crank that are necessary to move the table the required distance. This may be written as a formula, as follows:

$$T = \frac{W}{0.00625}$$

in which T equals the number of turns of the index crank, W equals the width of the required division, and 0.00625 equals the distance that the table moves in one turn of the index crank.

example 1: Determine the indexing for lines 1/32 (0.03125) in. apart.

$$T = \frac{W}{0.00625} = \frac{0.03125}{0.00625} = 5$$

Turn the index crank five full turns for each division.

example 2: Determine the indexing for lines 0.0481 in. apart.

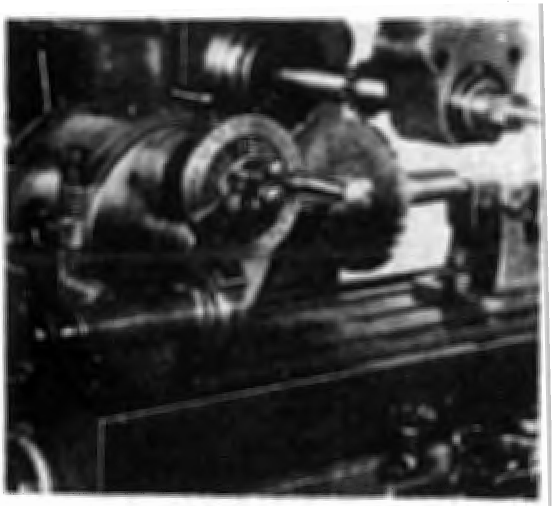
$$T = \frac{W}{0.00625} = \frac{0.04810}{0.00625} = 7\frac{435}{625}$$

By a method of calculation known as continued fractions, 435/625 may be reduced to a fraction suitable for indexing, and although not an equivalent fraction, the amount of error is small. For detailed instructions in combining fractions and continued fractions, see *Practical Shop Mathematics, Vol. II*, 4th ed., by J. H. Wolfe and E. R. Phelps (New York: McGraw-Hill Book Co., 1960).

69. *Describe the use of the index head for angular measurement.*

A simple method of indexing to accurate angular measurement is to use the angular index plate (Fig. 14–94). Whenever the job requires drilling or graduating at a fixed angular separation, the angular index plate saves time; it is simple to operate. The plate has two circles of holes. The inner circle has 18 holes; each hole represents one-half degree, or 30 minutes. The outer circle has 30 numbered holes; each hole represents 1 minute. The required angular movement can be obtained by combining the move-

Fig. 14–94. Cutting notches in a disc using an angular index plate. (Brown & Sharpe Mfg. Co.)



ment of the plate and the index crank. The plate can be rotated by withdrawing the back pin. The following information is important when indexing for angular measurement. It must be understood and remembered.

The symbol for degrees is °.
The symbol for minutes is ′.
The symbol for seconds is ″.
One circle equals 360°.
One right angle equals 90°.
One degree equals 60′.
One minute equals 60″.

To revolve the index spindle one complete revolution, or 360°, it is necessary for the index crank to make exactly 40 turns. Therefore, one turn of the index crank will rotate the spindle 1/40 of 360°, or 9°. The formula for finding the necessary indexing for angular measurement (in degrees) is:

$$\text{Turns of index crank} = \frac{\text{Required angle}}{9}$$

example 1: To index for 47°:

$$\frac{47}{9} = 5\frac{2}{9} \quad \left(\frac{2}{9} \times \frac{2}{2} = \frac{4}{18}\right)$$

$$= 5\frac{4}{18}$$

Answer: 5 turns and 4 holes of the 18-hole circle.

The following angular movements can be obtained by using the 18- and 27-hole circles on the Nos. 1 and 2 Brown & Sharpe plates:

2 holes in the 18-hole circle = 1°
2 holes in the 27-hole circle = 2/3°
1 hole in the 18-hole circle = 1/2°
1 hole in the 27-hole circle = 1/3°

In angles involving degrees and minutes, reduce the angles to minutes and divide by 540. In angles involving degrees, minutes, and seconds, reduce the angles to seconds and divide by 32,400. Carry the division to the fourth decimal place, and the result will be the number of turns of the index crank necessary to index the angle.

To find the index circle and the number of holes to move in that circle for the decimal part of a turn, look for the required decimal number or the nearest decimal number to it in Fig. 14–95. The index circle is listed under C and the number of holes to move in that circle is listed under *H*. The following examples show applications of the use of Fig. 14–95:

example 2: Angle $A = 24°\,45'$.

$$\begin{aligned} 24° &= 24 \times 60' = 1{,}440' \\ 45' &= \underline{\quad\quad 45'} \\ & \quad\quad\quad\;\; 1{,}485' \end{aligned}$$

$$1{,}485 \div 540 = 2.7500$$

In the angular-indexing table, opposite 0.7500, 12 is under *H* and 16 is under C. Total indexing equals 2 turns and 12 holes of the 16-hole circle.

example 3: Angle $A = 18°26'$

$$\begin{aligned} 18° &= 18 \times 60' = 1{,}080' \\ 26' &= \underline{\quad\quad 26'} \\ & \quad\quad\quad\;\; 1{,}106' \end{aligned}$$

$$1106 \div 540 = 2.0481$$

$$\begin{aligned} \text{Required decimal} &= 0.0481 \\ \text{Nearest decimal} &= \underline{0.0476} \\ & \;\;\; 0.0005 \end{aligned}$$

$$540 \times 0.0005 = 0.27'$$
$$0.27 \times 60'' = 16.2'' \text{ error}$$

In the angular-indexing table, opposite 0.0476, 1 is under *H* and 21 is under C. Total indexing equals 2 turns and 1 hole of the 21-hole circle.

example 4: Angle $A = 24°54'23''$.

$$\begin{aligned} 24° &= 24 \times 60' \times 60'' = 86{,}400'' \\ 54' &= 54 \times 60'' \quad\quad\quad 3{,}240'' \\ 23'' &= \underline{\quad\quad\quad\quad\quad\quad\quad\quad 23''} \\ & \quad\quad\quad\quad\quad\quad\quad\;\; 89{,}663'' \end{aligned}$$

$$89{,}663 \div 32{,}400 = 2.7674$$

In the angular-indexing table, opposite 0.7674, 22 is under *H* and 43 is under C. Total indexing equals 2 turns and 22 holes of the 43-hole circle.

example 5: Angle $A = 39°51'21''$.

$$\begin{aligned} 39° &= 39 \times 60' \times 60'' = 140{,}400'' \\ 51' &= 51 \times 60'' \quad\quad\quad 3{,}060'' \\ 21'' &= \underline{\quad\quad\quad\quad\quad\quad\quad\quad 21''} \\ & \quad\quad\quad\quad\quad\quad\quad\;\; 143{,}481'' \end{aligned}$$

$$143{,}481 \div 32{,}400 = 4.4284$$

$$\begin{aligned} \text{Nearest decimal} &= 0.4286 \\ \text{Required decimal} &= \underline{0.4284} \\ & \;\;\; 0.0002 \end{aligned}$$

$$32{,}400'' \times 0.0002 = 6.48'' \text{ error}$$

VALUE	H*	C†
0.0204	1	49
0.0213	1	47
0.0233	1	43
0.0244	1	41
0.0256	1	39
0.0270	1	37
0.0303	1	33
0.0323	1	31
0.0345	1	29
0.0370	1	27
0.0408	2	49
0.0426	2	47
0.0435	1	23
0.0465	2	43
0.0476	1	21
0.0488	2	41
0.0500	1	20
0.0513	2	39
0.0526	1	19
0.0541	2	37
0.0555	1	18
0.0588	1	17
0.0606	2	33
0.0612	3	49
0.0625	1	16
0.0638	3	47
0.0645	2	31
0.0666	1	15
0.0690	2	29
0.0698	3	43
0.0732	3	41
0.0741	2	27
0.0769	3	39
0.0811	3	37
0.0816	4	49
0.0851	4	47
0.0870	2	23
0.0909	3	33
0.0930	4	43
0.0952	2	21
0.0968	3	31
0.0976	4	41
0.1000	2	20
0.1020	5	49
0.1026	4	39
0.1034	3	29
0.1053	2	19
0.1064	5	47
0.1081	4	37
0.1111	2	18
0.1111	3	27
0.1163	5	43
0.1176	2	17
0.1212	4	33
0.1220	5	41
0.1224	6	49
0.1250	2	16
0.1277	6	47
0.1282	5	39
0.1290	4	31
0.1304	3	23
0.1333	2	15
0.1351	5	37
0.1379	4	29

VALUE	H	C
0.1395	6	43
0.1429	3	21
0.1429	7	49
0.1463	6	41
0.1481	4	27
0.1489	7	47
0.1500	3	20
0.1515	5	33
0.1538	6	39
0.1579	3	19
0.1613	5	31
0.1622	6	37
0.1628	7	43
0.1633	8	49
0.1666	3	18
0.1702	8	47
0.1707	7	41
0.1724	5	29
0.1739	4	23
0.1765	3	17
0.1795	7	39
0.1818	6	33
0.1837	9	49
0.1852	5	27
0.1860	8	43
0.1875	3	16
0.1892	7	37
0.1905	4	21
0.1915	9	47
0.1935	6	31
0.1951	8	41
0.2000	3	15
0.2000	4	20
0.2041	10	49
0.2051	8	39
0.2069	6	29
0.2093	9	43
0.2105	4	19
0.2121	7	33
0.2128	10	47
0.2162	8	37
0.2174	5	23
0.2195	9	41
0.2222	6	27
0.2222	4	18
0.2245	11	49
0.2258	7	31
0.2308	9	39
0.2326	10	43
0.2340	11	27
0.2353	4	17
0.2381	5	21
0.2414	7	29
0.2424	8	33
0.2432	9	37
0.2439	10	41
0.2439	12	49
0.2500	4	16
0.2500	5	20
0.2553	12	47
0.2558	11	43
0.2564	10	39
0.2581	8	31

VALUE	H	C
0.2593	7	27
0.2609	6	23
0.2632	5	19
0.2653	13	49
0.2667	4	15
0.2683	11	41
0.2703	10	37
0.2727	9	33
0.2759	8	29
0.2766	13	47
0.2777	5	18
0.2791	12	43
0.2821	11	39
0.2857	14	49
0.2857	6	21
0.2903	9	31
0.2927	12	41
0.2941	5	17
0.2963	8	27
0.2973	11	37
0.2979	14	47
0.3000	6	20
0.3023	13	43
0.3030	10	33
0.3043	7	23
0.3061	15	49
0.3077	12	39
0.3103	9	29
0.3125	5	16
0.3158	6	19
0.3171	13	41
0.3191	15	47
0.3226	10	31
0.3243	12	37
0.3256	14	43
0.3265	16	49
0.3333	5	15
0.3333	6	18
0.3333	7	21
0.3333	9	27
0.3333	11	33
0.3333	13	39
0.3404	16	47
0.3415	14	41
0.3448	10	29
0.3469	17	49
0.3478	8	23
0.3488	15	43
0.3500	7	20
0.3514	13	37
0.3529	6	17
0.3548	11	31
0.3590	14	39
0.3617	17	47
0.3636	12	33
0.3659	15	41
0.3673	18	49
0.3684	7	19
0.3704	10	27
0.3721	16	43
0.3750	6	16
0.3784	14	37
0.3793	11	29

VALUE	H	C
0.3810	8	21
0.3830	18	47
0.3846	15	39
0.3871	12	31
0.3878	19	49
0.3888	7	18
0.3902	16	41
0.3913	9	23
0.3939	13	33
0.3953	17	43
0.4000	6	15
0.4000	8	20
0.4043	19	47
0.4054	15	37
0.4074	11	27
0.4082	20	49
0.4103	16	39
0.4118	7	17
0.4138	12	29
0.4146	17	41
0.4186	18	43
0.4194	13	31
0.4211	8	19
0.4242	14	33
0.4255	20	47
0.4286	9	21
0.4286	21	49
0.4324	16	37
0.4348	10	23
0.4359	17	39
0.4375	7	16
0.4390	18	41
0.4419	19	43
0.4444	8	18
0.4444	12	27
0.4468	21	47
0.4483	13	29
0.4490	22	49
0.4500	9	20
0.4516	14	31
0.4545	15	33
0.4595	17	37
0.4615	18	39
0.4634	19	41
0.4651	20	43
0.4667	7	15
0.4681	22	47
0.4694	23	49
0.4706	8	17
0.4737	9	19
0.4762	10	21
0.4783	11	23
0.4815	13	27
0.4828	14	29
0.4839	15	31
0.4848	16	33
0.4865	18	37
0.4872	19	39
0.4878	20	41
0.4884	21	43
0.4894	23	47
0.4898	24	49
0.5000	8	16
0.5000	9	18

VALUE	H	C
0.5000	10	20
0.5102	25	49
0.5106	24	47
0.5116	22	43
0.5122	21	41
0.5128	20	39
0.5135	19	37
0.5151	17	33
0.5161	16	31
0.5172	15	29
0.5185	14	27
0.5217	12	23
0.5238	11	21
0.5263	10	19
0.5294	9	17
0.5306	26	49
0.5319	25	47
0.5333	8	15
0.5349	23	43
0.5366	22	41
0.5385	21	39
0.5405	20	37
0.5454	18	33
0.5484	17	31
0.5500	11	20
0.5510	27	49
0.5517	16	29
0.5532	26	47
0.5555	10	18
0.5555	15	27
0.5581	24	43
0.5610	23	41
0.5625	9	16
0.5641	22	39
0.5652	13	23
0.5676	21	37
0.5714	12	21
0.5714	28	49
0.5745	27	47
0.5757	19	33
0.5789	11	19
0.5806	18	31
0.5814	25	43
0.5854	24	41
0.5862	17	29
0.5882	10	17
0.5897	23	39
0.5918	29	49
0.5926	16	27
0.5946	22	37
0.5957	28	47
0.6000	9	15
0.6000	12	20
0.6047	26	43
0.6060	20	33
0.6087	14	23
0.6098	25	41
0.6111	11	18
0.6122	30	49
0.6129	19	31
0.6154	24	39
0.6170	29	47
0.6190	13	21

VALUE	H	C
0.6207	18	29
0.6216	23	37
0.6250	10	16
0.6279	27	43
0.6296	17	27
0.6316	12	19
0.6326	31	49
0.6341	26	41
0.6364	21	33
0.6383	30	47
0.6410	25	39
0.6452	20	31
0.6471	11	17
0.6486	24	37
0.6500	13	20
0.6512	28	43
0.6522	15	23
0.6531	32	49
0.6552	19	29
0.6585	27	41
0.6596	31	47
0.6666	10	15
0.6666	12	18
0.6666	14	21
0.6666	18	27
0.6666	22	33
0.6666	26	39
0.6735	33	49
0.6744	29	43
0.6757	25	37
0.6774	21	31
0.6809	32	47
0.6829	28	41
0.6842	13	19
0.6897	20	29
0.6923	27	39
0.6939	34	49
0.6957	16	23
0.6969	23	33
0.6977	30	43
0.7000	14	20
0.7021	33	47
0.7027	26	37
0.7037	19	27
0.7059	12	17
0.7073	29	41
0.7097	22	31
0.7143	15	21
0.7143	35	49
0.7179	28	39
0.7209	31	43
0.7222	13	18
0.7234	34	47
0.7241	21	29
0.7273	24	33
0.7297	27	37
0.7317	30	41
0.7333	11	15
0.7347	36	49
0.7368	14	19
0.7391	17	23
0.7407	20	27
0.7419	23	31

VALUE	H	C
0.7436	29	39
0.7442	32	43
0.7447	35	47
0.7500	12	16
0.7500	15	20
0.7551	37	49
0.7561	31	41
0.7568	28	37
0.7576	25	33
0.7586	22	29
0.7619	16	21
0.7647	13	17
0.7674	22	43
0.7692	30	39
0.7742	24	31
0.7755	38	49
0.7760	36	47
0.7777	21	27
0.7777	14	18
0.7805	32	41
0.7826	18	23
0.7838	29	37
0.7872	37	47
0.7879	26	33
0.7895	15	19
0.7907	34	43
0.7931	23	29
0.7949	31	39
0.7959	39	49
0.8000	12	15
0.8000	16	20
0.8049	33	41
0.8065	25	31
0.8085	38	47
0.8095	17	21
0.8108	30	37
0.8125	13	16
0.8140	35	43
0.8148	22	27
0.8163	40	49
0.8181	27	33
0.8205	32	39
0.8235	14	17
0.8261	19	23
0.8276	24	29
0.8293	34	41
0.8298	39	47
0.8333	15	18
0.8367	41	49
0.8372	36	43
0.8378	31	37
0.8387	26	31
0.8421	16	19
0.8462	33	39
0.8485	28	33
0.8500	17	20
0.8511	40	47
0.8519	23	27
0.8537	35	41
0.8571	18	21
0.8571	42	49
0.8605	37	43

VALUE	H	C
0.8621	25	29
0.8649	32	37
0.8666	13	15
0.8696	20	23
0.8710	27	31
0.8718	34	39
0.8723	41	47
0.8750	14	16
0.8776	43	49
0.8780	36	41
0.8788	29	33
0.8824	15	17
0.8837	38	43
0.8888	16	18
0.8888	24	27
0.8919	33	37
0.8936	42	47
0.8947	17	19
0.8966	26	29
0.8974	35	39
0.8980	44	49
0.9000	18	20
0.9024	37	41
0.9032	28	31
0.9048	19	21
0.9070	39	43
0.9090	30	33
0.9130	21	23
0.9149	43	47
0.9184	45	49
0.9189	34	37
0.9231	36	39
0.9259	25	27
0.9268	38	41
0.9302	40	43
0.9310	27	29
0.9333	14	15
0.9355	29	31
0.9362	44	47
0.9375	15	16
0.9388	46	49
0.9394	31	33
0.9412	16	17
0.9444	17	18
0.9459	35	37
0.9474	18	19
0.9487	37	39
0.9500	19	20
0.9512	39	41
0.9524	20	21
0.9535	41	43
0.9565	22	23
0.9574	45	47
0.9592	47	49
0.9630	26	27
0.9655	28	29
0.9677	30	31
0.9697	32	33
0.9730	36	37
0.9744	38	39
0.9756	40	41
0.9767	42	43
0.9787	46	47
0.9796	48	49

*H is the number of holes to move in the index circle.
†C is the index circle.

 Fig. 14–95. Angular indexing table.

In the angular-indexing table, opposite 0.4286, 9 is under H and 21 is under C. Total indexing equals 4 turns and 9 holes of the 21-hole circle.

70. *Is an angular-indexing table required in order to find the correct indexing?*
No. If an angular-indexing table is not available, the correct indexing may be determined as shown in Examples 1 and 2 that follow. If greater accuracy is required than can be obtained by the use of the angular-indexing table, the method for indexing shown in Example 3 may be followed.

example 1: Index for 25°. Use the formula:

$$T = \frac{N}{9}$$

where T equals turns of crank handle and N equals degrees in given angle.

$$T = \frac{25°}{9} = 2\frac{7}{9} \quad \left(\frac{7}{9} \times \frac{2}{2} = \frac{14}{18}T\right)$$

$$T = 2\frac{14}{18}$$

Index 2 turns and 14 holes in 18-hole circle.

example 2: Index for 12°12′. Use the formula:

$$T = \frac{N'}{540}$$

where T equals turns and N' equals angle in minutes.

$$\begin{aligned} 12° &= 12 \times 60' = 720' \\ 12' &= \underline{12'} \\ & 732' \end{aligned}$$

$$T = \frac{732}{540} = 1\frac{192}{540} = 1\frac{16}{45}$$

Differential indexing is required. Because $1\frac{192}{540}$ is approximately $1\frac{1}{3}$,

$$\frac{1}{3} \times \frac{5}{5} = \frac{5}{15}$$

$$T = 1\frac{5}{15}$$

Index 1 turn and 5 holes in 15-hole circle.
Gearing:

$$\frac{1}{3} = \frac{4}{3}$$

$$\frac{732}{540} \times \frac{3}{4} \times \frac{40}{1} = \frac{122}{3} = 40\frac{2}{3} \text{ turns}$$

$$40\frac{2}{3} - 40 = \frac{2}{3} \text{ gear ratio}$$

$$\frac{2}{3} \times \frac{24}{24} = \frac{48 \text{ Driving gears}}{72 \text{ Driven gears}} \text{ plus 1 idler}$$

example 3: Index for 29°25°16″. Use the formula:

$$T = \frac{N''}{32{,}400}$$

where T equals turns and N'' equals angle in seconds.

$$\begin{aligned} 29° &= 29 \times 60' \times 60'' = 104{,}400'' \\ 25' &= \phantom{29 \times{}} 25' \times 60'' = 1{,}500'' \\ 16'' &= \phantom{29 \times 60' \times 60'' = 104{,}4}\underline{16''} \\ & 105{,}916'' \end{aligned}$$

$$\frac{105{,}916}{32{,}400} = 3\frac{8{,}716}{32{,}400} = 3\frac{2{,}179}{8{,}100}$$

Differential gearing is required.

Using the method of continued fractions referred to in Question 68, Example 2, the required gearing is found.

$$\frac{45}{44} = \frac{9 \times 5}{4 \times 11} = \frac{72}{64} \times \frac{40 \text{ Driving gears}}{44 \text{ Driven gears}}$$

71. *Describe the process of helical and spiral milling.*
When the spindle of an index head is geared to the lead screw of a milling machine so that the work revolves on its axis as the table moves along the ways, a helical or spiral cut is produced. When the cut is made on cylindrical work, it is called a *helical cut*, and when made on a tapered piece, it is called a *spiral cut.* Helical milling cutters, helical gears, twist drills, counterbores, and similar work are produced in this way.

Before a helical cut can be made, the lead of the helix, the angle of the helix, and the diameter of the work must be known. The lead is equal to the distance the table advances when the work makes one revolution. Any change in the gearing connecting the index head spindle and the lead screw will change the lead of the helix. The helix angle is the angle the cut makes with the axis of the work, and changes with any change in the lead or in the diameter of the work. *The table must be set at the helix angle.*

The index head spindle is geared to the lead screw of the table by means of a train of change gears, as shown in Fig. 14–96. These gears are called *the gear on the screw (D), the first gear on the stud (C) the second gear on the stud (B), and the gear on the worm (A).* The gear on the screw and the first gear on the stud are the driving gears, and the second gear on the stud and the gear on the worm are the driven gears. This may be expressed as a ratio:

$$\frac{\text{Driven gear}}{\text{Driving gear}} = \frac{\text{gear on worm} \times \text{2d gear on stud}}{\text{1st gear on stud} \times \text{gear on screw}} = \frac{A \times B}{C \times D}$$

By using different combinations of change gears, the distance that the table moves while the spindle revolves once may be changed. In other words, the lead that is cut depends directly on the gears that are used. Usually (though not always) the gear ratio is such that the work is advanced more than 1 in. while it makes one revolution. Therefore, the lead is expressed in inches per revolution rather than in revolutions per inch, as in threads. For example, a helix is said to have an 8-in. lead rather than that its pitch is one-eighth turn per inch.

The table feed screw usually has four threads per inch and a lead of ¼ in. Motion is transferred from the lead screw to the spindle through the worm and worm wheel, which have a 40:1 ratio. When the spindle makes one revolution, the table moves 10 in. along the ways if even gearing (1:1 ratio) is used. One revolution of spindle times index head ratio times gear ratio times lead of lead screw equals lead of machine, or

$$\text{Lead of machine} = \text{index head ratio} \times \text{gear ratio} \times \text{lead of lead screw}$$

The standard lead of a milling machine is 10 in.,

$$\text{Lead of machine} = \frac{40}{1} \times \frac{1}{1} \times \frac{1}{4} = 10 \text{ in.}$$

and all change gears are figured on this basis. Any change in gear ratio makes a corresponding change in the lead.

example 1: Using 1:4 gear ratio:

$$\frac{40}{1} \times \frac{1}{4} \times \frac{1}{4} = \frac{5}{2} = 2.500 \text{ in. lead}$$

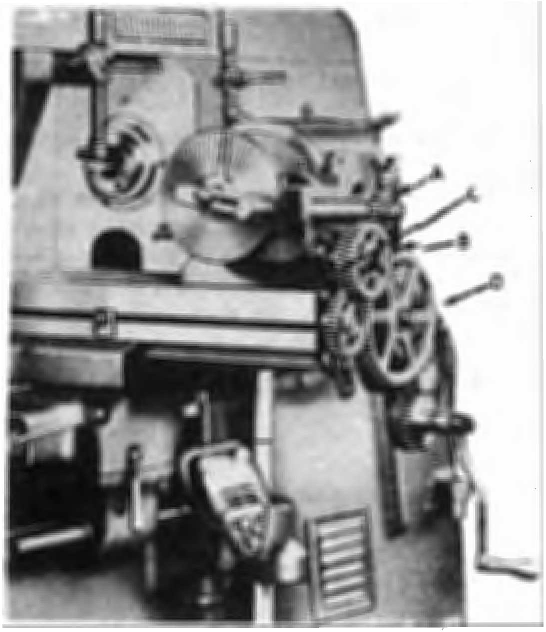


Fig. 14–96. Milling machine geared for helical milling. (Cincinnati Milacron Co.)

example 2: Using 2:1 ratio:

$$\frac{40}{1} \times \frac{2}{1} \times \frac{1}{4} = 20 \text{ in. lead}$$

The compound ratio of the driven to the driving gears equals the ratio of the lead of the required helix to the lead of the machine. Expressing this in fraction form,

$$\frac{\text{Driven gears}}{\text{Driving gears}} = \frac{\text{Lead of required helix}}{\text{Lead of machine}}$$

Or, because the product of each class of gears determines the ratio, and the lead of the machine is 10 in.,

$$\text{Compound ratio} = \frac{\text{Lead of required helix}}{10}$$

The compound ratio of the driven to the driving gears may always be represented by a fraction whose numerator is the lead to be cut, and whose denominator is 10. That is, if the required lead is 20, the ratio is 20:10. To express this in units instead of tens, divide both terms of the ratio by 10. This is often a convenient way to think of the ratio, a lead of 40 giving a ratio of 4:1, a lead of 25 a ratio of 2.5:1, and so forth.

To illustrate the usual calculations, assume that a helix of 12-in. lead is to be cut. The compound ratio of the driven to the driving gears equals the desired lead divided by 10, or it may be represented by the fraction 12/10. Resolving this into two factors to represent the two pairs of change gears,

$$\frac{12}{10}=\frac{3}{2}\times\frac{4}{5}$$

The numerator and denominator of the first fraction, three over two, are multiplied by a number (24 in this case) that will make the resulting numerator and denominator correspond with the number of teeth of two of the change gears furnished with the machine (such multiplications do not affect the value of a fraction).

$$\frac{3}{2}\times\frac{24}{24}=\frac{72}{48}$$

Treat the second fraction, 4/5, similarly, using the multiplier 8 in this case.

$$\frac{4}{5}\times\frac{8}{8}=\frac{32}{40}$$

Select 72, 32, 48, and 40 teeth gears:

$$\frac{12}{10}=\frac{72\times 32\ \text{Driven gears}}{48\times 40\ \text{Driving gears}}$$

The numerators of the fractions represent the driven gears, and the denominators the driving gears. The 72-tooth gear is the gear on the worm, the 40 is first on the stud, the 32 is second on the stud, and the 48 is the screw gear. The two driven gears or the two driving gears may be transposed without changing the helix. That is, the 72-tooth gear could be used as the second on the stud, or the 32-tooth gear could be used as the worm gear, if desired.

Determine the gears to be used in cutting a lead of 27 in.

$$\frac{27}{10}=\frac{3}{2}\times\frac{9}{5}$$

$$\left(\frac{3}{2}\times\frac{16}{16}\right)\times\left(\frac{9}{5}\times\frac{8}{8}\right)=\frac{48}{32}\times\frac{72\ \text{Driven gears}}{40\ \text{Driving gears}}$$

Reversing the procedure, determine the lead that would be cut by the gears, with 48, 72, 32, and 40 teeth, the first two being used as the driven gears.

$$\text{Helix to be cut} = 10\times\frac{48\times 72}{32\times 40}$$

$$= 27\ \text{in. to 1 revolution}$$

The milling machine table must always be set to the helix angle of the job (Fig. 14–97).

The angle of the helix depends upon the lead of the helix and the diameter to be milled. In Fig. 14–98, let A equal the circumference (circum) and C the lead of helix. The greater the lead of the helix for a given diameter, the smaller the helix angle, and the greater the diameter for a given lead, the greater the helix angle. Any change in the diameter of the work or in the lead will make a corresponding change in the helix angle.

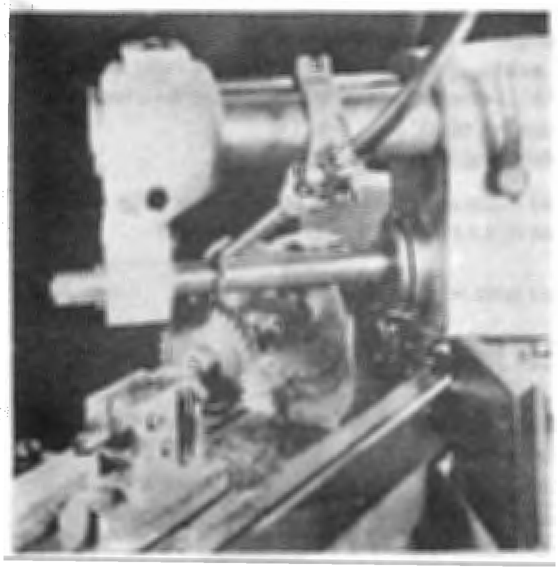
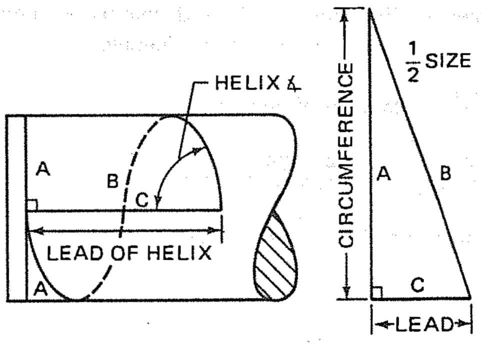


Fig. 14–97. Cutting teeth in a helical gear with the milling machine table set at the required helix angle. (Brown & Sharpe Mfg. Co.)

Fig. 14–98. Determining the relationship of the circumference and lead.



$$\frac{\text{Circum}}{\text{Lead}} = \frac{\text{side opposite helix angle}}{\text{side adjacent to helix angle}}$$

$$= \text{tangent of helix angle}$$

Lead = Circum × Cotangent of helix angle

$$\frac{\text{Lead}}{10} = \text{gear ratio}$$

Gear ratio × 10 in. = lead cut

Required lead minus lead that gears will cut equals the error in lead.

example 1: Find gearing required to mill the flutes on a 3-in.-diameter cutter when the helix angle is 35°8′. From a table of trigonometric functions, the cotangent of 35°8′ is 1.4211.

Referring to Fig. 14–99,

Lead = circum ($\pi \times D$) × cotangent of helix angle
Lead = 3.1416 × 3 × 1.4211 = 13.3935

$$\text{Gear ratio} = \frac{\text{lead}}{10} = \frac{13.3935}{10}$$

$$\frac{13.3935}{10} \times \frac{10{,}000}{10{,}000} \times \frac{133{,}935}{100{,}000}$$

using continued fractions an approximate fraction of 75/56 is found.

$$\frac{75}{56} = \frac{3 \times 25}{4 \times 14} \quad \text{or} \quad \frac{48}{64} \times \frac{100 \text{ Driven gears}}{56 \text{ Driving gears}}$$

$$\frac{75}{56} \times \frac{10}{1} = \frac{750}{56} = 13.3928 \text{ in. lead}$$

13.3935 required lead
13.3928 lead cut
0.0007 error in lead

Set table at the helix angle.

example 2: Find helix angle and gearing required for a lead of 3.140 in. on 1½ in. diameter.

$$\frac{\text{Circum}}{\text{Lead}} = \text{tangent of helix angle}$$

$$\frac{3.1416 \times 1.5}{3.140} = \frac{4.7124}{3.140} = 1.50076$$

The tangent of 56°19′24″ is 1.50076.

$$\text{Gear ratio} = \frac{\text{lead}}{10}$$

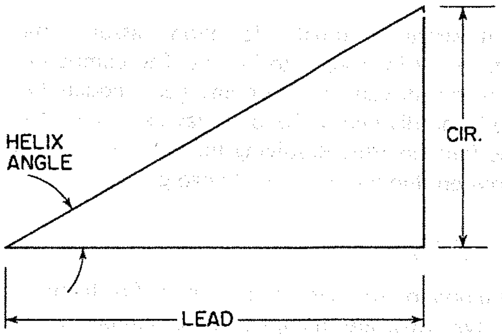


Fig. 14–99. Problem outline for calculating the helix angle.

$$\frac{3.140}{10} = \frac{314}{1000}$$

using continued fractions results in an approximate fraction of 27/86.

$$\frac{27}{86} = \frac{3 \times 9}{2 \times 43} \quad \text{or} \quad \frac{24}{64} \times \frac{72 \text{ Driven gears}}{86 \text{ Driving gears}}$$

$$\frac{27}{86} \times \frac{10}{1} = \frac{135}{43} = 3.13953 \text{ in. lead cut}$$

Required lead minus lead cut equals error.

3.140 − 3.13953 = 0.00007 in.

The helical-milling situation of Fig. 14–100 shows how the indexing head and the rack-cutting attachment are set up to mill a helical groove or thread in a worm. The worm shown has a triple thread, 2-in. pitch diameter, 0.500 pitch, 1.500 lead, and a helix angle of 76°34′30″. The gear ratio and the table setting for this worm are found as follows:

$$\frac{\text{Lead}}{10} = \text{gear ratio} = \frac{1.5}{10} \times \frac{10}{10} = \frac{15}{100}$$

$$\frac{15}{100} = \frac{3 \times 5}{4 \times 25} \quad \text{or} \quad \frac{24}{64} \times \frac{40 \text{ Driven gears}}{100 \text{ Driving gears}}$$

When using the rack-cutting attachment, the cutter is held at 90° angle with the work and the table is set at the complement of the helix angle.

$$\begin{aligned} 90° = {} & 89°59'60'' \\ & -76°34'30'' \\ \hline & 13°25'30'' \end{aligned}$$

72. *Describe the process of short-lead milling.*
When very small leads are required, the dividing head, worm, and worm wheel may be disengaged

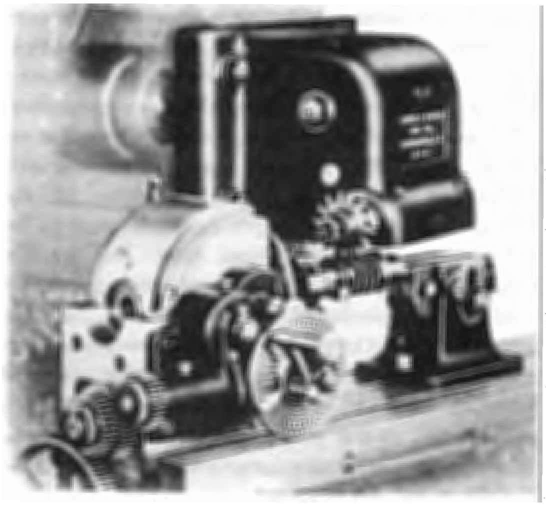


Fig. 14-100. Cutting a worm thread of short lead using a rack-cutting attachment. (Brown & Sharpe Mfg. Co.)

and the gearing connected directly from the dividing-head spindle to the table lead screw. With even gearing, when the dividing-head spindle revolves once, the lead screw (which has four threads per inch) makes one revolution, and the table is moved a distance equal to the lead, or 0.250 in. The rack-cutting attachment, shown cutting a worm in Fig. 14-100, is used with this method.

example: Find the gears to cut a lead of 0.3492 in.

$$\frac{\text{Lead}}{0.250} = \text{gear ratio} = \frac{0.3492}{0.250} \times \frac{10{,}000}{10{,}000} = \frac{3{,}492}{2{,}500}$$

The approximate fraction is $^{88}/_{63}$.

$$\frac{88}{63} = \frac{8 \times 11}{9 \times 7} \quad \text{or} \quad \frac{64}{72} \times \frac{44}{28}\ \begin{matrix}\text{Driven gears}\\ \text{Driving gears}\end{matrix}$$

$$\frac{88}{63} \times \frac{0.250}{1} = 0.349206 \text{ in. lead cut}$$

Required lead minus lead cut equals error.

$$0.349206 - 0.3492 = 0.000006 \text{ in. error}$$

The regular means of indexing cannot be used in short-lead milling. Make the number of teeth in the gear on the spindle some multiple of the number of divisions required. The gears may then be swung out of mesh and the gear on the spindle advanced the number of teeth necessary to index the work one division.

Sometimes it is necessary to mill a few teeth on a cylindrical shaft or plunger. If a rack-cutting attachment is not available, the work may be done as shown in Fig. 14-101. The shaft is supported on a parallel and clamped in a vise, and the teeth are indexed by means of the graduated dial on the cross-feed screw, the movement being equal to the linear pitch, or 3.1416 divided by the diametral pitch. Before indexing, care should be taken to remove backlash from the screw.

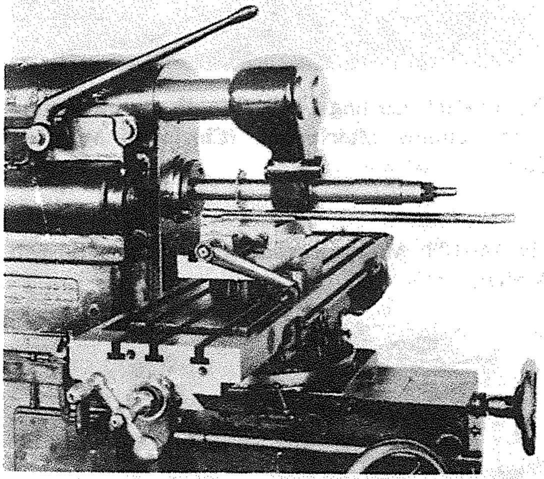


Fig. 14-101. Milling rack teeth in a round shaft. (Brown & Sharpe Mfg. Co.)

A rack-cutting attachment simplifies the job of milling the teeth of the helical rack (Fig. 14-102). Care must be taken to swivel the table to the required angle so that the rack teeth will be cut parallel to the cross-feed of the saddle, and also to the milling cutter mounted on the rack-cutting attachment. The linear movement of the table is indexed through a gear ratio between the lead screw of the milling machine table and the shaft of the rack-indexing attachment.

73. *Describe some of the methods of milling cams.* Figure 14-103 shows a cylindrical cam being milled with an end mill, producing a helical slot with parallel sides. The dividing-head centers are brought in line with the center of the machine spindle. The table is set at right angles to the spindle and the angle of the helix is obtained by the combination of change gears used. Either right-hand or left-hand

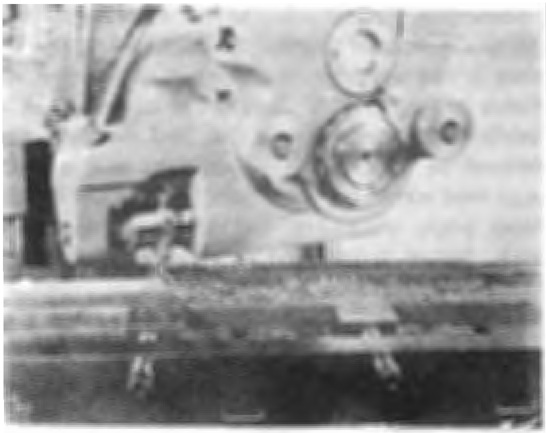
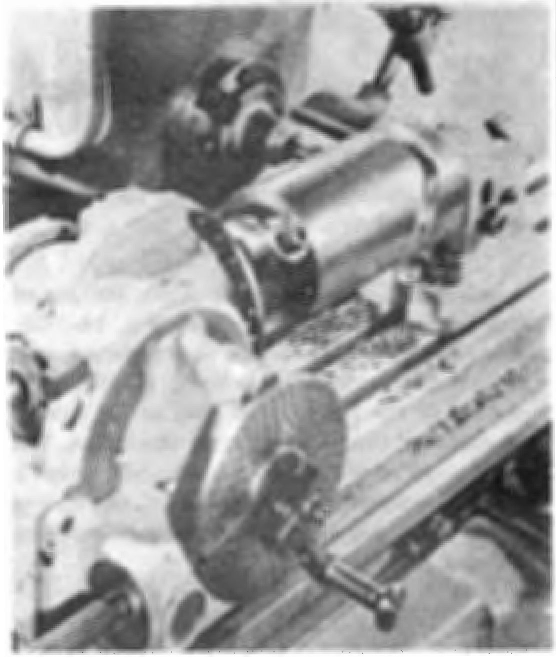


Fig. 14–102. Cutting a helical-tooth gear rack using a rack-cutting attachment. (Cincinnati Milacron Co.)

Fig. 14–103. Milling a cylindrical path cam. (Brown & Sharpe Mfg. Co.)



helices may be cut in this way by leaving out, or adding, an extra idler gear. When this method is used for cylindrical-cam milling, the gears are calculated and placed the same as for helical milling, as shown in Fig. 14–96.

The cam-cutting attachment in Fig. 14–104 is used for cutting face, peripheral, or cylindrical cams from a flat cam former. The cam former is made from a disk about ½ in. thick, on which the required outline is laid out. The disk is machined or filed to the required shape. The table of the machine remains clamped in one position during the cutting, and the necessary rotative and longitudinal movements are contained in the mechanism itself. The rotative movement is obtained by a worm driving a wheel fixed to the spindle of the attachment. The cam former is secured to the face of the worm wheel, and as the wheel revolves, the cam former depresses the sliding rack, which, in turn, drives a pinion geared to another rack in the sliding bed of the attachment. This gives the necessary longitudinal movement on the face of the worm wheel.

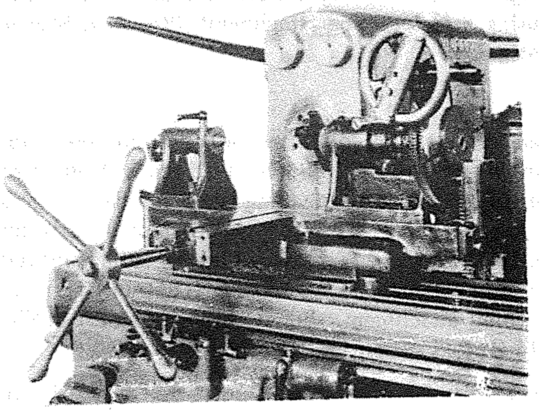


Fig. 14–104. Cam-cutting attachment. (Brown & Sharpe Mfg. Co.)

The path cam, illustrated in Fig. 14–105, is machined by another method. The work is held in the horizontal plane in the dividing head, and an end mill is used in the vertical spindle attachment.

In Fig. 14–105, we have a cam with two lobes (a lobe is a projecting part of a cam wheel), one (*A*) having a rise of 2.493 in. in 169°12′ and the other (*B*) having a rise of 2.442 in. in 104°24′.

The lead in 360° of lobe *A* equals

$$\frac{360^\circ}{169^\circ 12'} \times 2.493 \text{ in.} = 5.304 \text{ in.}$$

The lead in 360° of lobe *B* equals

$$\frac{360^\circ}{104^\circ 24'} \times 2.442 \text{ in.} = 8.421 \text{ in.}$$

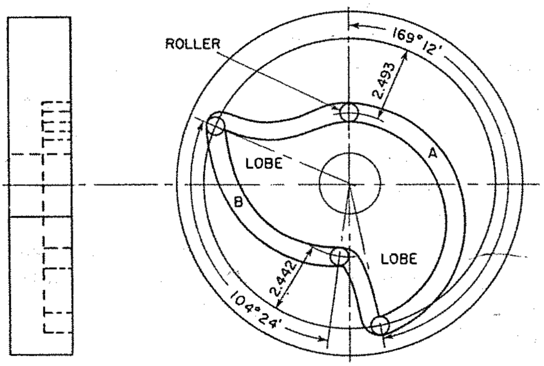


Fig. 14–105. A path cam.

To gear up the dividing head to cut lobe *A*:

$$\frac{\text{Lead of lobe}}{\text{Lead of machine}} = \frac{\text{driven}}{\text{drivers}} = \frac{\text{second} \times \text{worm}}{\text{first} \times \text{screw}}$$

$$= \frac{5.304}{10}$$

By continued fractions, we find this is approximately

$$\frac{35}{66} = \frac{7 \times 5}{11 \times 6} \quad \text{or} \quad \frac{28}{44} \times \frac{40}{48} \begin{array}{l}\text{Driven gears}\\ \text{Driving gears}\end{array}$$

To gear up the dividing head to cut lobe *B* (remember to use two idlers),

$$\frac{8.421}{10} \text{ is approximately } \frac{16}{19}$$

$$\frac{16}{19} \times \frac{4}{4} = \frac{64}{76} \begin{array}{l}\text{Driven gears}\\ \text{Driving gears}\end{array}$$

The path of the roller should first be rough-drilled. The parts of the cam, other than lobes *A* and *B*, can be scribed, drilled, and then milled to the scribed lines.

A method often followed in cutting peripheral cams, especially those for use on automatic screw machines, is that of using the dividing head and a vertical spindle milling attachment. This is illustrated in Fig. 14–106. The dividing head is geared to the table feed screw, the same as in cutting an ordinary helix, the cam blank is fastened to the spindle of the dividing head. An end mill is used in the vertical spindle milling attachment, which is set to mill the periphery of the cam at right angles to its sides. In other words, the axes of the dividing-head spindle and attachment spindle must always be parallel, in order to mill cams by this method. The cutting is done by the teeth on the periphery of the end mill.

Fig. 14–106. Milling a face cam. (Brown & Sharpe Mfg. Co.)

The principle of this method may be explained in the following way:

Suppose the dividing head is elevated to 90°, or at right angles to the surface of the table (Fig. 14–107), and is geared for a given lead. It is apparent that as the table advances and the blank is turned, the distance between the axes of the dividing-head spindle and the attachment spindle becomes less. In other words, the cut becomes deeper and the radius of the cam is shortened, producing a spiral

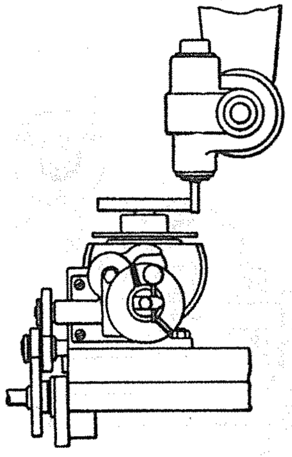


Fig. 14–107. Milling a cam in a horizontal position.

lobe with a lead that is the same as that for which the machine is geared.

Now suppose the same gearing is retained and the dividing head is set at 0°, or parallel to the surface of the table, as shown in Fig. 14–108. It is apparent, also, that the axes of the dividing head spindle and the attachment spindle are parallel to each other. Therefore, as the table advances and the blank is turned, the distance between the axes of the dividing-head spindle and the attachment spindle remains the same. As a result, the periphery of the blank, if milled, is concentric, or the lead is zero.

If, then, the dividing head is elevated to any angle between 0° and 90°, as shown in Fig. 14–109, the amount of lead given to the cam will be between that for which the machine is geared and zero.

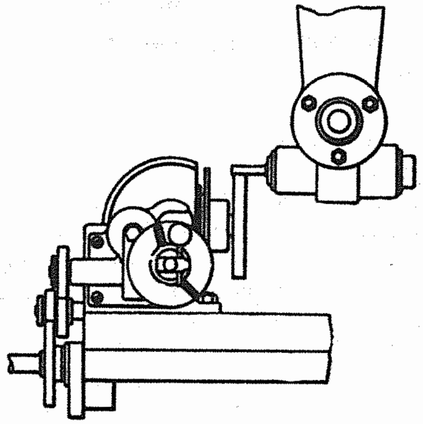


Fig. 14–108. Milling a cam in a vertical position.

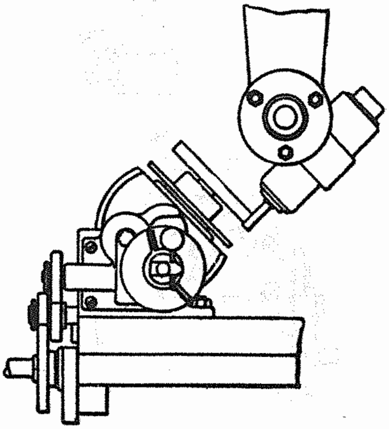


Fig. 14–109. Milling a cam in an angular position.

Hence it is clear that cams with a very large range of different leads can be obtained with one set of change gears, and the problem of milling the lobes of a cam is reduced to a question of finding the angle at which to set the dividing head to obtain any given lead.

To cut the smallest possible lead with the dividing head geared to the lead screw, place a 24-tooth gear on worm, an 86-tooth gear first on stud, a 24-tooth gear second on stud, and a 100-tooth gear on lead screw. Calculate the lead as follows:

$$\frac{24}{86} \times \frac{24}{100} \times \frac{40}{4} = 0.66976, \text{ or } 0.67$$

in which 40 equals the number of turns of the index crank to one spindle revolution and 4 equals the number of threads per inch on the lead screw.

example: To find the angle to set the dividing head and vertical spindle attachment, divide the lead of the cam by the lead of the machine. The lead of the machine must always be greater than the lead of the cam.

To find the lead of the cam, that is, the theoretical continuous rise in one complete revolution, if the rise in 27° is 0.127 in., calculate as follows: 360° divided by the angle in which the rise occurs times the rise. The answer is the rise in 360°.

$$\frac{360}{27} \times 0.127 = 1.693 \text{ rise in } 360° = \text{Lead of cam}$$

To calculate the leads, gears, and angles to incline the dividing head and vertical spindle attachment, for a cam having a 0.470 in. rise in 85°, 0.750 in. rise in 75°, and 0.358 in. rise in 58° (Fig. 14–110), proceed as follows:

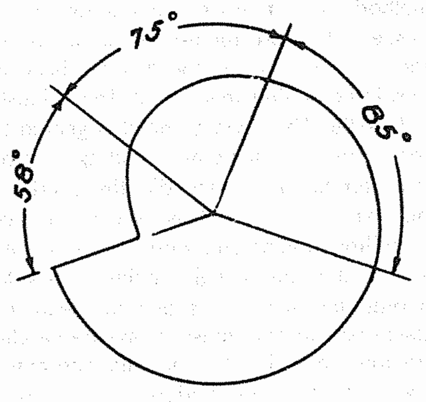


Fig. 14–110. A face cam.

$$0.470 \text{ in. rise in } 85° = \frac{360}{85} \times 0.470 = 1.990 \text{ lead}$$

$$0.750 \text{ in. rise in } 75° = \frac{360}{75} \times 0.750 = 3.600 \text{ lead}$$

$$0.358 \text{ in. rise in } 58° = \frac{360}{58} \times 0.358 = 2.222 \text{ lead}$$

The machine must be geared with a greater lead than that of the cam having the greatest lead. As an example, use as the lead 3.657 in. and gear the machine as follows:

$$\text{Gear ratio} = \frac{3.657}{10.000} \text{ which is approximately } \frac{64}{175}.$$

$$\frac{64}{175} = \frac{4 \times 16}{7 \times 25} \quad \text{or} \quad \frac{32}{56} \times \frac{64}{100}$$

Place the 32-tooth gear on the worm, the 56-tooth gear the first on the stud, the 64-tooth gear the second on the stud, and place the 100-tooth gear on the lead screw.

The sine of the angle at which to incline the dividing head is found by dividing the lead of the cam by the lead of the machine. The size of the angle can then be found in a table of sines.

$$\text{Lead of cam having } 0.470 \text{ in. rise in } 85° = \frac{1.990}{3.657} = 0.54416$$

This approximates sin 32°58′.

$$\text{Lead of cam having } 0.750 \text{ in. rise in } 75° = \frac{3.600}{3.657} = 0.98441$$

This approximates sin 79°52′.

$$\text{Lead of cam having } 0.358 \text{ in. rise in } 58° = \frac{2.222}{3.657} = 0.60760$$

This approximates sin 37°25′.

Note, in the above work, that the machine is geared the same for all leads and that the dividing head and vertical spindle attachment are inclined at different angles to mill the different leads.

A cylindrical cam is milled and the gears calculated in the same manner as a helical groove is milled, an end mill being used instead of a milling cutter.

All toolrooms have, or can obtain, a chart showing the many different leads and gears used to cut these leads.

It must be remembered that the cam rise can be so small that the required table lead may be out of the range of leads available with the standard driving mechanism. It will then be necessary to utilize a long and short lead attachment (Fig. 14–111).

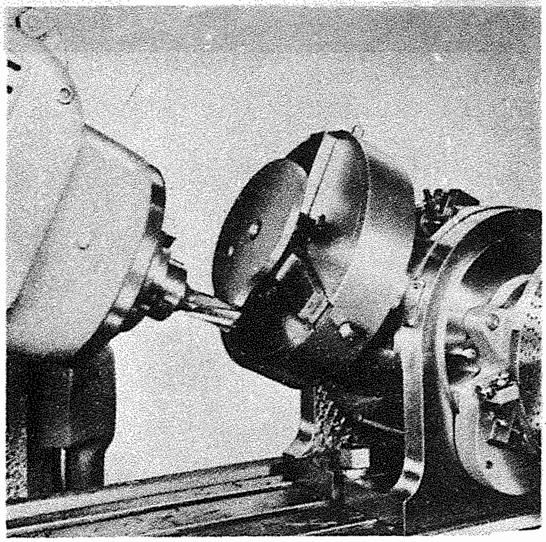
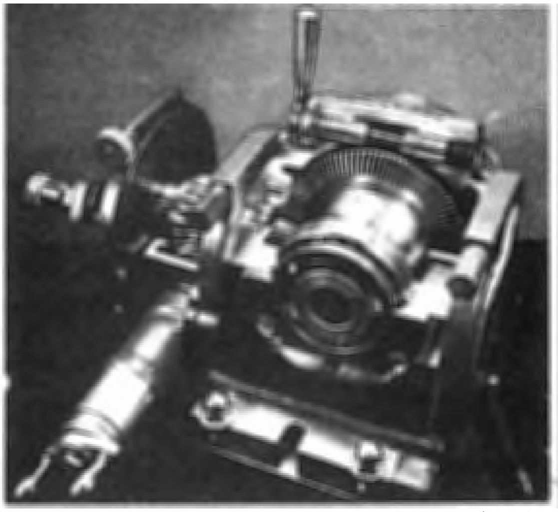


Fig. 14–111. Milling a uniform rise cam with vertical attachment and long- and short-lead attachment. (Cincinnati Milacron Co.)

74. *Are all makes of index heads standardized to a 40:1 ratio between spindle and index crank?*
Most index heads have a 40 to 1 ratio. One well-known exception has a 5 to 1 ratio (Fig. 14–112). This ratio is made possible by means of a 5 to 1 hypoid bevel gear ratio between the index crank and the dividing head spindle.

75. *What are the advantages of this ratio reduction?*
The faster movement of the spindle with one turn of the index crank permits speedier production. It is also an advantage when truing work or testing work for run out by means of a dial indicator.



76. *What are the disadvantages of the 5 to 1 ratio dividing head?*
Although made to a high standard of accuracy the 5 to 1 ratio dividing head does not permit as wide a selection of divisions by the simple indexing operation. Differential indexing can be utilized on the 5 to 1 ratio dividing head by means of a differential indexing attachment.

Fig. 14–112. Universal spiral dividing head with 5:1 ratio between spindle and index crank. (Kearney & Trecker Corp.)

chapter 15 grinding machine processes

To do a good job of grinding, one must be able not only to operate the machine but also to understand abrasives and grinding wheels. This chapter will begin with a description of natural and manufactured abrasives—the bonds and abrasives used in making grinding wheels, the different grades and shapes of grinding wheels, and the selection of the proper grinding wheel for different types of work.

1. *What is an abrasive?*
An abrasive is any material that can wear away a substance softer than itself. Sand and sandstone are perhaps the oldest abrasives known to mankind. Prehistoric man used sand and sandstone to form or shape edges of tools. As tools became more and more important for preservation of life, he became more dependent on natural abrasives for the maintenance of sharp tools.

2. *What are natural abrasives?*
Emery and *corundum* are two natural abrasives commonly used in industry to sharpen tool edges. They occur as a mineral deposit in the earth's crust. These abrasives, formed into wheels, are superior to the old sand grindstones. Although they can cut faster and be made coarse or fine, they cannot meet the demands of modern manufacturing because they contain impurities that are difficult to extract and because the percentage of the important cutting element, aluminum oxide, is not constant. The only other element known to be harder than emery or corundum is the diamond, but its cost was prohibitive for industrial usage.

3. *How were abrasives first manufactured?*
In 1891, Dr. Edward G. Acheson set to the task of trying to produce artificial diamonds by combining powdered coke and corundum clay at extremely high temperatures. He discovered that after the mass cooled it contained brightly colored crystals that could cut glass and had a slight cutting effect on diamonds. Dr. Acheson called the new substance *Carborundum* because it was formed from carbon and corundum. Subsequent research established that its components are silicon and carbon, so it was called *silicon carbide* (chemical symbol SiC).

Silicon carbide was considered the answer to the quest for a better abrasive, but cost and limited methods of manufacture kept it from being used except as a lapping compound for finishing precious jewels. With the development of hydroelectric generators and cheap electric power, the cost of production was cut to a point where all industries could afford to use it.

About the same time that Dr. Acheson was experimentally producing silicon carbide, Charles P. Jacobs, an engineer in Ampere, New Jersey, was attempting to produce a better grade of emery. He used a small electric furnace to extract the impurities of sand, iron, and titanium oxides from clay deposits rich in aluminum oxide. The result was a product that consisted of about 95 percent pure aluminum oxide (chemical symbol Al_2O_3).

4. *How do silicon carbide and aluminum oxide differ?*
Although these two excellent abrasives are similar in some respects, their significant properties differ widely. Silicon carbide is extremely hard; it is rated at 9.87 on the 10-point Mohs scale, which is based on the hardness of the diamond. It is easily fractured by impact, and its excellence depends upon the purity of the ingredients used in making it. Aluminum oxide is less hard (9.6 on the Mohs scale), but it is much tougher than silicon carbide.

5. *What is silicon carbide best suited for?*
Silicon carbide is best suited for grinding materials that have low tensile strength but are very hard, such as ceramics, pottery, and tungsten carbide.

6. *What is aluminum oxide best suited for?*
Because of its toughness aluminum oxide is resistant to shock and therefore suitable for grinding materials of high tensile strength such as tool steel and high-speed steel.

7. *Which type of abrasive is superior, natural or manufactured?*
Man-made abrasives have a distinct advantage over natural abrasives because purity and grain size can be readily controlled. Grain size is important because undersize grains cannot do their share of work, and oversize grains give work a poor finish.

8. *How are artificial abrasives manufactured?*
Electric furnaces are used to produce both types of abrasives. Silicon carbide is made in an open, troughlike furnace by fusing a mixture of coke, sawdust, sand, and salt. After the mass has cooled, the sides of the furnace are let down, exposing a big clinker. This clinker is broken with a drop weight, and the pieces are put through a crusher machi
As the abrasive particles leave the crusher, they
washed and magnetically cleaned. They then p
on to shaker screens, which have from 4 to 2
meshes to the lineal inch. By vibrating action
screens sort the grains according to size. If
abrasive passes through a screen with 30 meshes
the lineal inch, but is retained on a screen of
meshes, it is called a No. 30 abrasive. Abrasi
finer than 220 are graded for size by hydrau
or sedimentation methods. After the abrasive h
been graded to size, it is dried and placed in stora
bins or hoppers for future use. Figure 15–1 sho
various grain size classifications.

Fig. 15–1. Grain-size classification.

very coarse	*coarse*	*medium*	*fine*	*very fine*	*fl si.*
8	**12**	**30**	**70**	**150**	**2**
10	**14**	**36**	**80**	**180**	**3**
	16	**46**	**90**	**220**	**4**
	20	**60**	**100**	**240**	**5**
	24		**120**		**6**

9. *What is the hardest abrasive?*
Diamonds are the hardest known materials produc
by naturê. Chemists and laboratory technicia
tried for 125 years to develop the combination
elements that would produce a man-made diamon
In 1955, the General Electric Company announc
success in producing artificial diamonds suitab
for industrial use. The diamond abrasive whe
has become a necessary tool in all production sho
where cemented carbide cutting tools are used.

GRINDING WHEELS

10. *How is the hardness of a grinding whe determined?*
Grinding wheels are formed by using a suitab
material to cement, or bond, the abrasive grains t
gether in the desired shape (Fig. 15–2). The har
ness of the wheel is dependent upon the amou
and kind of bonding material used. Because th
hardness rating of the abrasive is constant, the bor
cannot have an effect on its rating. The hardne
of a wheel is always understood to mean th
strength of the bond.

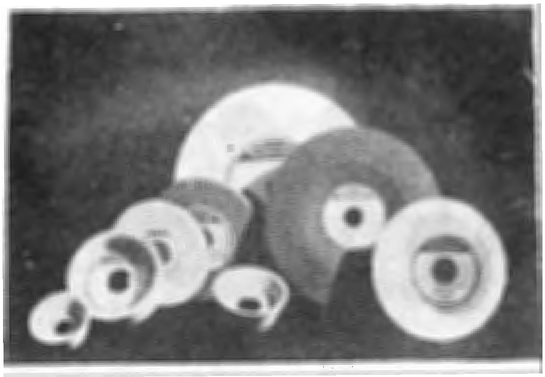


Fig. 15–2. Various shapes of grinding wheels. (Norton Co.)

11. *How many kinds of bonds are used to bond grinding wheels?*
There are many different kinds of bonds. Those most commonly used are vitrified, silicate, shellac, rubber, and resinoid. The vitrified and silicate are used more frequently than the others.

12. *What are the advantages of the vitrified bond?*
The vitrified bond has the strength and porosity to enable it to remove a considerable amount of stock from a job for each inch of wheel wear. It is not affected by water, acids, or ordinary temperature changes, and it is free from hard or soft spots. In the vitrified process, glass, feldspar, flint, or other ceramic substances are mixed with the abrasive and subjected to heat, which causes the bond to form a glasslike structure between each abrasive particle. The vitrified bond is used in 75 percent of all grinding wheels.

13. *What are the advantages of the silicate bond?*
The silicate bond is made from sodium silicate. The hardness of a silicate-bond wheel is governed by the amount of bond material used, and by the amount of tamping or pressing. This kind of bond produces a wheel that is milder acting than the vitrified wheel. Because the abrasive grains are released more readily they do not heat up so fast. Silicate wheels can be made in larger diameters than vitrified wheels. They are generally used for grinding edged tools such as drills, reamers, milling cutters, and so forth.

14. *Do rubber-bonded wheels have a special purpose?*
Rubber wheels (Fig. 15–3) are made of a mixture of abrasive, rubber, and sulphur. The mass is then pressed into shape and given a mild vulcanizing treatment. Wheels of this bond are used for high-speed grinding operations. Because of their high safety factor rubber-bonded wheels can be made very thin for use in cutting off steel stock (Fig. 15–4).

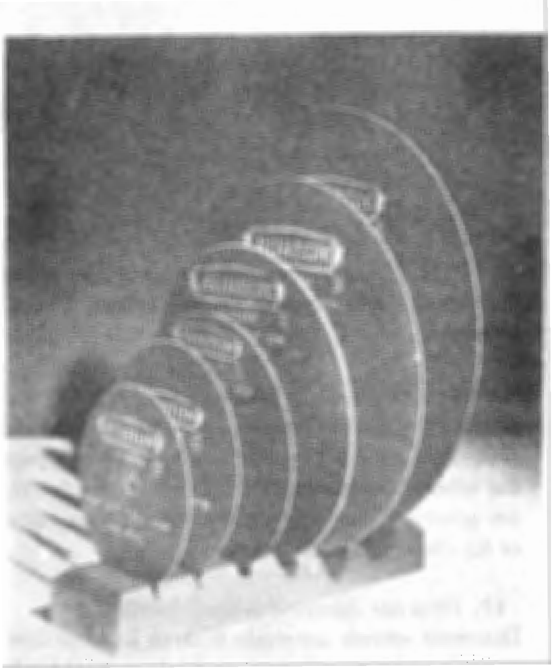


Fig. 15–3. Rubber-bonded grinding wheels. (Norton Co.)

15. *How are shellac-bonded wheels made?*
Shellac-bonded wheels are made by mixing the abrasive and the bond in a heated machine, which completely coats the abrasive with the bonding material. After the wheels are formed, they are placed in an oven, covered with sand, and baked for a short time at approximately 300°F. Wheels of this bond are used extensively for grinding mill rolls, and for jobs where a high-luster finish is required.

16. *Are resinoid wheels bonded by a different method?*
Resinoid-bonded wheels are made by mixing powdered resinoid with the abrasive particles and adding a plastic substance so that the wheels can be molded. The mold is then placed in an electric

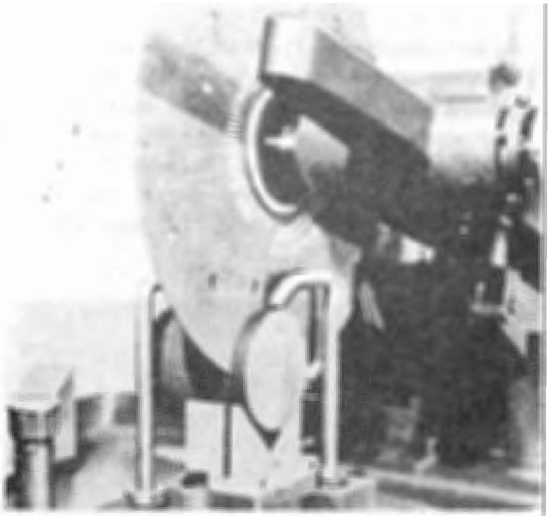
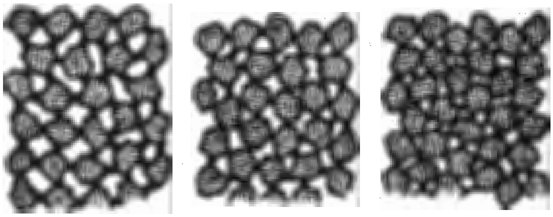


Fig. 15-4. A rubber-bonded wheel. Holes through the wheel carry coolant to aid cutting. (The Carborundum Co.)

Fig. 15-5. A variety of diamond wheels and dressing tools for diamond wheels. (The Carborundum Co.)

Fig. 15-6. Grain spacing in a grinding wheel. (A) Wide. (B) Medium. (C) Close.



A B C

oven and heated to approximately 300°F. for a period ranging from a few hours to three or four days, depending on the size of the wheel. Upon cooling, the wheel becomes very hard. Wheels of this bond are generally used in foundries for snagging castings or for cleaning up steel billets.

17. *How are diamond wheels bonded?*
Diamond wheels are made in three kinds of bonds: resinoid, metal, and vitrified. Each gives the wheel unique characteristics. The diamond wheel with the resinoid bond has a very cool and fast cutting action.

The metal-bonded wheel has unusual durability and a high resistance to grooving.

The vitrified-bonded diamond wheel has the fast cutting action of the resinoid-bonded wheel and the durability of the metal-bonded wheel (Fig. 15-5).

18. *What is meant by the term wheel structure?*
The term *wheel structure* refers to the spacing of the abrasive grains (Fig. 15-6). Two wheels of the same grade and grain size but of different grain spacing will have different cutting actions. Wheels with wide grain spacing should be used on soft materials or when stock is to be removed rapidly. Wheels with close spacing should be used on hard materials or when a fine finish is to be given to the work. Wheel life can often be increased without sacrificing grinding quality by using the same grain and grade of wheel but with a different structure, depending upon the job to be done.

Numbers are used to indicate wheel structure. The smaller the number, the closer the structure. In general, the ranges are 0 to 3 for close structure, 4 to 6 for medium structure, and 7 to 12 for coarse structure.

19. *What is meant by wheel grading?*
As noted previously, the amount of bond used in making a grinding wheel determines its hardness. Letters of the alphabet indicate the degree of hardness. Norton and several other companies use letters at the beginning of the alphabet to indicate soft wheels and letters at the end to indicate hard wheels. This lettering system for the grade of bond and the relationship to hardness is shown in Fig. 15-7. Figure 15-8 shows the grain sizes commonly used with various grades of bond. The Carborundum Company uses a letter system in the reverse order.

›ry soft	soft	medium	hard	very hard
E	H	L	P	T
F	I	M	Q	U
G	J	N	R	W
	K	O	S	Z

g. 15–7. Grade of bond according to hardness.

g. 15–8. Commonly used grades and grain sizes.

	surface	internal	external	cutter
rades	F G H I J K P	I J K L	J K L M P*	I J K L
rain sizes	36–46–60–80 120	34–46 60–120	46–60–80 120	36–46 60

for corners.

20. *How are wheels identified in the Norton* *›stem?*
the Norton system, a wheel marked 3860-K5BE ıs the following characteristics: 38 indicates e kind of abrasive, which in this case is alundum luminum oxide); 60 is the grain size, which is edium (see Fig. 15–1); K indicates the grade of e bond, which is soft (see Fig. 15–7); 5 indicates e wheel structure, which is medium; and BE dicates the kind of bond, which is vitrified. Other ›nd symbols are: S, silicate bond; T, resinoid bond; rubber bond; and I, shellac bond.

›1. *How is the correct wheel selected?*
›veral factors affect the selection of a grinding heel: (a) the kind of material to be ground, (b) e amount of stock to be removed, (c) the accuracy to size, (d) the kind of finish required, (e) the ea of contact between the wheel and the work, ıd (f) the kind of grinding machine to be used.
The nature of the material to be ground affects e selection of the wheel because, generally eaking, hard, dense materials require wheels ›ssessing a soft bond with silicon carbide abrasive; ft and tough materials require a hard bond ith aluminum oxide abrasive.
The amount of material to be removed is important selecting a grinding wheel because, when considerable amount of material is to be removed, e grains of a wide-spaced coarse-grain wheel ill take a bigger, deeper cut without heating the ›rk, but with a slight sacrifice as to surface finish. When the amount of stock to be removed is slight, a wheel of fine grain and narrow spacing will take a smaller bite and give a good finish.

Other factors affect the grinding operation—for example, the speed of the wheel, the speed of the work, the condition of the grinding machine, and the knowledge and skill of the machine operator.

22. *Is there a theory to grinding?*
Grinding is the act of dressing, shaping, or finishing surfaces with a rotating abrasive wheel (Fig. 15–9). In modern machine shop operation, grinding costs vary as much as 100 percent on the same work with the same kind of machine in the same factory. This is because some operators handle the machine more skillfully than others. A good machinist takes into consideration the factors involving the mounting, movement, size, and speed of the work and the mounting, movement, size, speed, and dressing, or truing, of the grinding wheel.

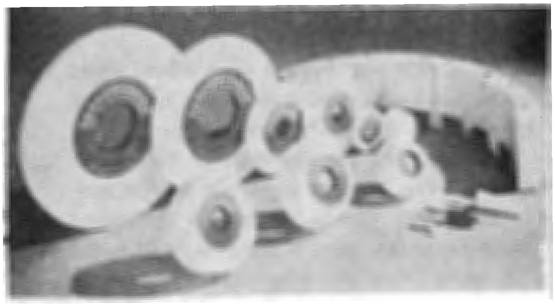


Fig. 15–9. A variety of toolroom grinding wheels, segments, and mounted points. (The Carborundum Co.)

For precision grinding, the work must be held rigidly to avoid vibration and to produce a good finish. If the work is held between centers, the center holes must be free from nicks, burrs, or dirt. The machine centers must be held securely and be free from nicks. If held in a chuck or fixture, the work must be solidly supported and clamped so as to put the least strain on it. After the work is correctly mounted, the work speed must be selected so that it will move at approximately the right number of surface feet per minute to prevent distortion and excessive wear of the wheel face, and, at the same time, the traverse movement must be at a constant speed to prevent high and low spots on the work. The mechanism for moving the wheel must work smoothly and freely, without play or bind, to ensure an accurate depth of cut.

The grinding wheel mounting is important because it must give steady and true motion to the wheel. After it is trued, the wheel

A. Will be free from vibration.
B. Will have steady cutting action.
C. Can be accurately dressed.
D. Will be able to produce a good surface finish.

23. *How is the grinding wheel speed determined?* In most modern grinding machines, the speed of the wheel is fixed and unchangeable. In others, the spindle speed can be altered by changing to different sized pulleys. More recent developments include the use of a variable-speed drive. Grinding wheel speeds should be held between 5,000 and 6,500 surface speed in feet per minute (sfpm). Some special-purpose grinding wheels operate at faster speeds. The safe operating speed is printed on the wheel.

If the surface feet per minute of a wheel must be determined, place a speed indicator in the center of the spindle and check the revolutions for one minute. Then multiply the diameter of the wheel in inches by 3.1416 in order to obtain the circumference of the wheel. The circumference multiplied by the revolutions per minute (rpm) will give the distance in inches that the wheel would travel in one minute if rolled on its periphery at the given rpm. This result divided by 12(12 in. = 1 ft) will give the surface speed in feet per minute.

example: Determine the sfpm of a 7-in.-diameter grinding wheel mounted on a surface grinder, with an rpm of 3,200. Multiply the diameter of the wheel by 3.1416 and by 3,200 and divided by 12.

$$\text{sfpm} = \frac{7 \times 3.1416 \times 3{,}200}{12}$$

$$= \frac{70371.84}{12} = 5864.32$$

Figure 15–10 shows the peripheral or surface speed of grinding wheels in relation to rpm of the wheels.

24. *What characteristics will be observed if the grinding machine is not operating properly?* By being a good observer, the operator can tell many things about the work and the machine. Poor or defective bearings in the wheel head will become evident while dressing the wheel. The diamond wheel dresser will not show a steady spark as it moves across the face of the wheel. This will result in a poor surface finish.

If the work vibrates, it will be shown by lines on the work parallel to the work axis. These are known as *chatter marks*. This condition can be remedied by (a) changing to a softer wheel, (b) tightening the spindle bearings, (c) checking and repairing poor belt connections, (d) reducing the size of the cut, or (e) cutting down on the work speed. If the surface of the work shows a mottled appearance, it is usually an indication of vibration set up by the irregular motion of the grinding wheel. Irregular motion will result if (a) the lead core in the wheel is improperly placed, (b) the wheel is waterlogged on one side, (c) the structure of the wheel is of uneven density, or (d) the face of the wheel is improperly trued.

25. *What causes the wheel to glaze?* Glazing is a condition in which the face or cutting edge takes on a glasslike appearance. This happens if the abrasive grains wear away faster than the bond that holds them together. As long as the bond is being worn away as fast as the abrasive particles of the wheel are being dulled, the wheel will continue to have good cutting action. To remedy glazing, use a wheel with a softer bond.

Frequently, the material being ground becomes embedded in the pores of the wheel. This condition, known as *loading* or *pinning,* is caused by too slow a work speed or by too hard a bond.

The continued use of the wheel after it becomes glazed or loaded puts an added strain on the work supports and on the wheel spindle bearings. It can also force the wheel out of true, and, if continued for long, will produce chatter marks on the surface of the work.

26. *Is dressing the wheel important?* The cutting face of a grinding wheel must be kept in a true, clean, sharp condition if the grinding operation is to be done efficiently. This requires frequent dressing and truing. Dressing is the operation of cleaning, or fracturing, the cutting surface of a wheel to expose new cutting particles. Truing is the operation of removing material from the cutting face so that the resulting surface runs concentric with the wheel-spindle axis.

ig. 15–10. **Grinding wheel speed in rpm — wheel size (in.) and peripheral speed (sfpm) known.**

liameter)f wheel (in.)	*peripheral speed (sfpm)*											
	4,000	*4,500*	*5,000*	*5,500*	*6,000*	*6,500*	*7,000*	*7,500*	*8,000*	*8,500*	*9,000*	*9,500*
1	**15,279**	**17,189**	**19,098**	**21,008**	**22,918**	**24,828**	**26,737**	**28,647**	**30,558**	**32,467**	**34,337**	**36,287**
2	**7,639**	**8,594**	**9,549**	**10,504**	**11,459**	**12,414**	**13,368**	**14,328**	**15,279**	**16,233**	**17,188**	**18,143**
3	**5,093**	**5,729**	**6,366**	**7,003**	**7,639**	**8,276**	**8,913**	**9,549**	**10,186**	**10,822**	**11,459**	**12,115**
4	**3,820**	**4,297**	**4,775**	**5,252**	**5,729**	**6,207**	**6,685**	**7,162**	**7,640**	**8,116**	**8,595**	**9,072**
5	**3,056**	**3,438**	**3,820**	**4,202**	**4,584**	**4,966**	**5,348**	**5,730**	**6,112**	**6,494**	**6,876**	**7,258**
6	**2,546**	**2,865**	**3,183**	**3,501**	**3,820**	**4,138**	**4,456**	**4,775**	**5,092**	**5,411**	**5,729**	**6,048**
7	**2,183**	**2,455**	**2,728**	**3,001**	**3,274**	**3,547**	**3,820**	**4,092**	**4,366**	**4,538**	**4,911**	**5,183**
8	**1,910**	**2,148**	**2,387**	**2,626**	**2,865**	**3,103**	**3,342**	**3,580**	**3,820**	**4,058**	**4,297**	**4,535**
10	**1,528**	**1,719**	**1,910**	**2,101**	**2,292**	**2,483**	**2,674**	**2,865**	**3,056**	**3,247**	**3,438**	**3,629**
12	**1,273**	**1,432**	**1,591**	**1,751**	**1,910**	**2,069**	**2,228**	**2,386**	**2,546**	**2,705**	**2,864**	**3,023**
14	**1,091**	**1,228**	**1,364**	**1,500**	**1,637**	**1,773**	**1,910**	**2,046**	**2,182**	**2,319**	**2,455**	**2,592**
16	**955**	**1,074**	**1,194**	**1,313**	**1,432**	**1,552**	**1,672**	**1,791**	**1,910**	**2,029**	**2,149**	**2,268**
18	**849**	**955**	**1,061**	**1,167**	**1,273**	**1,379**	**1,485**	**1,591**	**1,698**	**1,803**	**1,910**	**2,016**
20	**764**	**859**	**955**	**1,050**	**1,146**	**1,241**	**1,337**	**1,432**	**1,528**	**1,623**	**1,719**	**1,814**
22	**694**	**781**	**868**	**955**	**1,042**	**1,128**	**1,215**	**1,302**	**1,388**	**1,476**	**1,562**	**1,649**
24	**637**	**716**	**796**	**875**	**955**	**1,034**	**1,115**	**1,194**	**1,274**	**1,353**	**1,433**	**1,512**
26	**588**	**661**	**734**	**808**	**881**	**955**	**1,028**	**1,101**	**1,176**	**1,248**	**1,322**	**1,395**
28	**546**	**614**	**682**	**750**	**818**	**887**	**955**	**1,023**	**1,092**	**1,159**	**1,228**	**1,296**
30	**509**	**573**	**637**	**700**	**764**	**828**	**891**	**955**	**1,018**	**1,082**	**1,146**	**1,210**
32	**477**	**537**	**597**	**656**	**716**	**776**	**836**	**895**	**954**	**1,014**	**1,074**	**1,134**
34	**449**	**505**	**562**	**618**	**674**	**730**	**786**	**843**	**898**	**955**	**1,011**	**1,067**
36	**424**	**477**	**530**	**583**	**637**	**690**	**742**	**795**	**848**	**902**	**954**	**1,007**

Example: To find the rpm of an 18-in. grinding wheel having a peripheral speed of 6,000 sfpm, find 18-in. in the first column, refer across this row to the 6,000 column, and read the value 1,273 rpm.

27. *How is the wheel dressed?*
The operations of truing and dressing are usually accomplished by using one of the following implements: (a) a commercial diamond or a piece of tungsten carbide inserted in the conical point of a piece of cold-rolled steel; (b) a diamond dust impregnated cement formed into a stick and encased in metal tubing; or (c) a piece of silicon carbide mounted as a small wheel on an axle and placed in a cast iron base. In using any of these implements, the point of the dresser is brought into contact with the face of the wheel by means of a special holder, and then moved mechanically or by hand across the face of the wheel at a rate of speed that will produce the desired form or surface on the cutting edge.

28. *Is a coolant necessary on a grinding wheel?*
A clean, true wheel of the proper bond and abrasive size is a very efficient cutting tool, but it can cause the work to heat up rapidly. In the case of the lathe tool, there is only one cutting point acting on the work, but even so, it is a well-known fact that the cutting tool, work, and chips get quite hot. In the case of a grinding wheel, there are thousands of cutting points, each doing its share of the work but all acting at the same time. The action of a grinding wheel generates a much greater heat than a lathe. A flood of lubricant-coolant at the point of contact between the wheel and work is often necessary to carry off the heat and to keep the temperature of both the wheel and work as nearly constant as possible. This is true on rough- or finish grinding.

29. *What is the purpose of rough-grinding a job?* Roughing the job removes internal strains set up by heat treatment and removes the excess stock as rapidly as possible in preparation for finishing. Roughing is accomplished by using a slow work speed and a fast traverse. When finishing, use a high work speed and slow traverse. In both cases, use a flood of good coolant.

30. *Do grinding wheels require special care?* The following are suggestions originally made by well-known grinding wheel and machine manufacturers. If generally adopted, these procedures should do much to eliminate grinding accidents.

A. Handle all wheels with the greatest care in storing or delivery. Wheels are frequently cracked by rough usage long before they are ever placed on a grinding machine.
B. Wheels should be stored in a dry place.
C. Before a wheel is placed on the spindle, it should be sounded for cracks. When tapped by a nonmetallic object, a solid wheel gives off a dull ringing sound. A cracked wheel gives off a dull thudding sound.
D. Make sure that the grinding wheel is equipped with blotting-paper gaskets on each side.
E. Never crowd a wheel on the spindle; the hole in the wheel should be 0.003 to 0.005 in. oversize to permit it to slide easily on the spindle and squarely against the flange.
F. Never mount a wheel without flanges, which should be properly relieved and of suitable proportions.
G. Don't screw the wheel nut too tight. The nut should be set up only tight enough so that the flanges hold the wheel firmly.
H. Keep the wheel clean and true by frequent dressing, but don't remove any more stock than is necessary to put the wheel in proper condition.
I. If a wheel vibrates excessively after it has been properly trued, there is something wrong. Stop the machine and call an instructor.
J. Large wheels, that is, wheels over 12 in., require special balancing. Don't attempt to balance them yourself and do not use the wheel until it is balanced.

31. *What is a coated abrasive?*
A coated abrasive is made up of three parts:

A. A flexible backing material.
B. An adhesive, or bond.
C. Abrasive grains.

The abrasive grains are bonded to the backing sheet by means of the adhesive. The backing may be made of paper, cloth, vulcanized rubber, or a combination of materials. The bonds, or adhesives, used are glue, resin, and varnish. These are varied to suit the requirements of the finished product. The abrasive materials used in the manufacture of coated abrasives are flint, emery, crocus garnet, aluminum oxide, and silicon carbide.

32. *How do the abrasive materials vary?*
The flint, emery, garnet, aluminum oxide, and silicon carbide abrasives have different characteristics and are used for a variety of jobs. The abrasive is crushed and graded by screening and numbered according to the number of screen separations per inch.

33. *How are coated abrasives used in machine shop work?*
Abrasive cloth has been used for many years in machine shop work to improve the appearance of a job by polishing the surface, to remove sharp edges and burrs, or to obtain a specified size by removing a small amount of metal.

34. *What is the most common form of abrasive cloth used in machine shop work?*
Emery cloth is most often used for metal finishing. Although still called "emery cloth" by shop men the abrasives now used are the artificially produced aluminum oxide and silicon carbide. This form of coated abrasive comes in 9 in. × 11 in. sheets or in rolls of various widths.

35. *How are these abrasive cloths graded?*
Abrasive cloths come in a wide variety of grades, from fine to extra coarse. Emery cloth used for polishing comes in the following numbered sizes with equivalent mesh size beneath.

4/0 (0000)	3/0	2/0	0	1/2	IG	2	3
600	550	500	400	320	240	220	180

The aluminum oxide and silicon carbide varieties range in mesh size from 600 (a fine flour size) to 12 (a coarse grain size).

36. *By what other methods are coated abrasives used in machine shop work?*
The use of coated abrasives in machine shop work has increased tremendously due to developments in the use of abrasive belts (Fig. 15–11) and the abrasive disks (Fig. 15–12), both of which require the use of machines specially designed for this purpose.

Fig. 15–11. A well-enclosed and well-exhausted belt sander used to finish the surface of ornamental work. (Behr-Manning Division of Norton Co.)

37. *How are abrasive belts used?*
Abrasive belts are similar in basic construction to abrasive cloth. They require a flexible backing, an adhesive, or bonding, agent, and an abrasive material. Abrasive belts have the same variety of abrasive materials with the same wide range of mesh size as abrasive cloth. Machines are designed to use abrasive belts for many different kinds of grinding operations (Figs. 15–13 and 15–14). Abrasive belts are used for surface, cylindrical, and centerless grinding and can take heavy cuts and

Fig. 15–12. Grinding a die with a coated abrasive disk. (Behr-Manning Division of Norton Co.)

Fig. 15–13. Polishing a die-cast aluminum guard for a power saw using a 280-grit aluminum oxide belt. (Behr-Manning Division of Norton Co.)

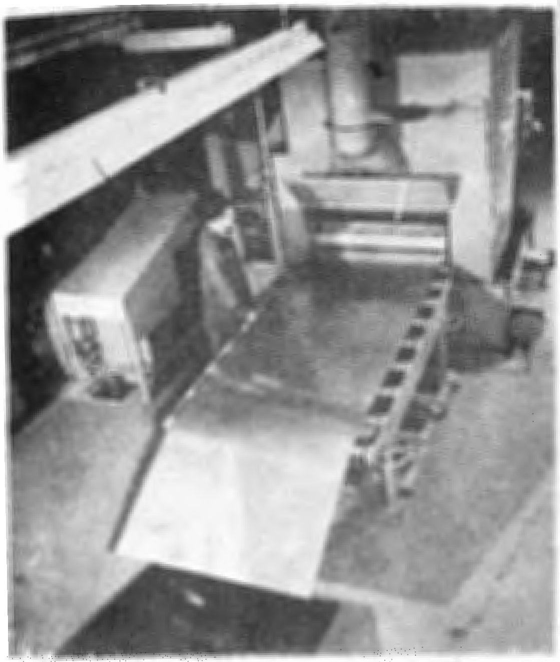


Fig. 15–14. Aluminum sheet is polished on a 150-hp grinder equiped with a 50-in. wide belt. (Behr-Manning Division of Norton Co.)

Fig. 15–15. Die-cast aluminum motor housings ground and polished by a 2-in. × 132-in. aluminum oxide cloth belt of [illegible] grit, operated at [illegible] surface feet per minute. (Behr-Manning Division of Norton Co.)

Fig. 15–16. Die-cast aluminum vacuum-cleaner part being cleaned and smoothed on the abrasive belt of a sander. (Behr-Manning Division of Norton Co.)

maintain close size tolerances. Some machines weigh 12 tons and use an abrasive belt 86 in. wide. Machines used for offhand grinding of rough castings (Fig. 15–15) or polishing metal ornaments consist of two pulleys connected by an abrasive belt (Fig. 15–16). These machines cost very little. Such offhand grinding machines are used to remove scale from castings and welds and also for deburring finished work.

Abrasive belts are used for cylindrical grinding and can remove metal with speedy efficiency. The centerless grinder using abrasive belts maintains close tolerances and can finish the surface of thin-walled tubing without any distortion of the tube due to excessive pressure or generated heat (Fig. 15–17).

Abrasive belts used for heavy stock removal have a grit or mesh size of 24 to 80. Abrasive belts are also used on an electrically driven portable machine utilized for finishing flat surfaces and small radii. Belts for average grinding use a finer grit size of 100 to 180. Grade range is unlimited. Belts can be made from any garnet, aluminum oxide, or silicon carbide cloth. Belts used for metalworking usually have a resin bond.

Fig. 15-17. **Duplex centerless grinding unit uses two belt stations for progressively finer finish. (Behr-Manning Division of Norton Co.)**

38. *Are coated abrasive disks used in machine shop work?*
Coated abrasive disks are used extensively in metalworking, and rank a very close second to abrasive belts. They are used on portable machines (Fig. 15–18) as well as stationary ones. Stationary machines use abrasive disks from 6 in. to 60 in. in diameter.

The abrasive disk is applied or attached to a backup pad of the same diameter. The disk is fastened to the pad by an adhesive, by a bolt at the center, or by clamps around the periphery. The pad backing up the disk can be made of rubber, metal, or a composition.

Fig. 15-18. A portable electrically driven disk grinder. (Behr-Manning Division of Norton Co.)

The most efficient speed for an abrasive disk at its cutting area ranges between 8,000 to 11,000 linear feet per minute. Coated abrasive disks are used to remove scale from welded parts, to remove rust and die marks, and to prepare surfaces for finish coatings (Fig. 15–19). The disks are given a very tough resistant backing and the abrasive is of the aluminum oxide variety. The sizes of the grit range from 16 to 180.

Fig. 15–19. Grinding off the excess weld on a stainless steel construction. (Behr-Manning Division of Norton Co.)

39. *Are all machines using the abrasive belt designed on the same mechanical principles?*
Many machines have been designed to utilize abrasive belts. There are five basic methods of supporting and applying the belts:

A. On a contact wheel.
B. As a free belt.
C. Over a platen.
D. On a drum.
E. In rolls.

40. *Is a coolant desirable when working with coated abrasives?*
Yes. Coolants will help to increase the rate of production, lengthen the life of the abrasive, and improve the quality of the finish.

41. *What fluids are used as coolants for coated abrasives?*
The following types of coolants are used for coated abrasives: (a) water solutions that contain rust inhibitors, wetting agents, and chemical additives; (b) soluble oils; (c) lard oil; (d) mineral oils, mineral lard oil; and (e) wax.

42. *What functions do these water, oil, and wax solutions perform?*
Each is used for either a special function or for a particular material. Their principal functions are:

A. Cool the job.
B. Wash away chips.
C. Reduce friction.
D. Improve the finish.
E. Protect the job from rust and corrosion.
F. Improve the life of the coated abrasive.
G. Prevent the surface of the coated abrasive from loading and glazing.

Ten Safety Suggestions for the Use of Machines Using Coated Abrasives

A. All drive belts should be covered.
B. Electrical equipment must be properly installed and grounded.
C. Abrasive belts must be entirely enclosed except at the working area.
D. All parts of the machine must be easily accessible for cleaning and lubrication.
E. The operator must have proper protection from dust by means of an adequate exhaust system.
F. The exhaust should be properly screened to prevent intake of pieces of the abrasive belt.
G. The work area must have sufficient guards to protect the machine operator and nearby workers.
H. The machine operator must wear safety glasses or a face shield.
I. The machine operator should wear a respirator mask and a protective apron.
J. The operator of a disk grinder should also be protected by gauntlet type gloves and wrist protectors.

ABRASIVE MACHINING

Until quite recently, abrasives in the form of grinding wheels had three uses:

A. Sharpening cutting tools.
B. Snagging—the process of removing burrs and the gates and risers left on castings after the molding process.
C. Finishing work to close size tolerances and to specified surface finish.

Grinding work to accurate dimensions has become increasingly important with the greater need for closer tolerances. Machines have been developed for grinding operations: surface grinding, cylindrical grinding, internal cylindrical grinding, thread grinding, gear tooth grinding, and other more specialized varieties. Before getting to the grinding operation the workpiece is machined by an engine lathe, a milling machine, a shaping machine, or a planing machine. The resulting job is machined to a specified size, which leaves an allowance of metal to be removed by the grinding process. The size allowance for the grinding operation seldom exceeds 0.015 in. This small amount is removed, usually in two cuts, to assure accurate size control and a high-quality surface finish.

In 1961, the Norton Company began research on using the grinding wheel to remove large amounts of stock with deep cuts and heavy feeds. The research, and subsequent testing on jobs, has proven the practicability of abrasive machining.

43. *What is abrasive machining?*
Abrasive machining is the removal of metal with an abrasive wheel to form a job to shape and size within the required size tolerances and surface finish requirements.

The process of shaping metal by means of an abrasive wheel, better known as *grinding*, is now considered a basic machining operation. Compared with turning, milling, and others, grinding is a relatively recent development; its potentialities have yet to be discovered. A full understanding of the basic machines and their operation will prepare the technician for the developments of the future.

A grinding machine employs a grinding wheel for producing cylindrical, conical, or plane surfaces accurately, economically, and efficiently. In order to bring the job to the required shape, size, and surface finish, the surplus stock is removed either by feeding the job against the revolving wheel or by forcing the revolving wheel against the job.

Of the many grinding machines, only those used in tool and die shops and in small jobbing shops will be discussed here. Those machines are the surface, cylindrical, centerless, internal, cutter, tool, and thread grinders. They are usually classified as to size by the largest piece of work they can completely machine—for example, 6″ × 18″ (6 in. diameter × 18 in. long)—or are specified by numbers, such as Brown & Sharpe Universal No. 2, No. 10N Cutter and Tool Grinding Machine, or No. 5 Surface Grinding Machine.

44. *Can abrasive machining do the work usually performed on the basic machine tools such as the lathe, miller, planer, and shaper?*
Large amounts of metal have been removed by grinding wheels on jobs usually machined on lathes and milling, planing, and shaping machines.

45. *Is it necessary to use special grinding wheels when removing large amounts of metal?*
No. Large amounts of metal can be removed by standard grinding wheels. The shape of the wheel, the type of abrasive, the grit size, the grade structure, and the bond must be considered and selected on the basis of the job, its shape, the metal being machined, the machining operation required, and the machine being used. Best results will be obtained from the use of grinding wheels and machines designed and constructed for abrasive machining.

46. *What advantages has abrasive machining over the conventional methods of machining?*
Tool changes for roughing and finishing cuts can be practically eliminated because the same wheel can do both. Also, because the grinding wheel is self-sharpening, shutdown time for tool replacement is unnecessary. The dressing of the wheel can be done in place. Less excess stock is required on castings because the grinding wheel can cut through scale and hard spots, which take the edge off a cutting tool. Less time is required for job and machine setup because in abrasive machining the cutting force is distributed over a larger area, thus reducing the need for elaborate fixtures or involved setup techniques. The magnetic chuck proves very efficient and is often used for grinding flat work (Fig. 15–20).

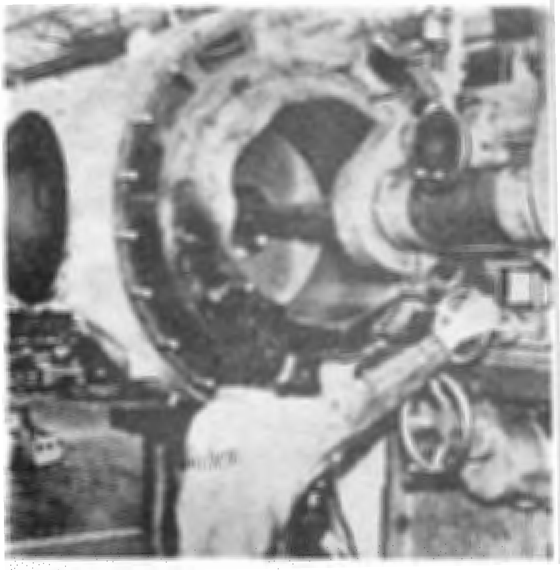
47. *Can all metal parts be finish machined by abrasive wheels?*
The shape of a part often prevents use of abrasive machining. Redesigning a part so that all areas are accessible to a grinding wheel makes possible tremendous savings of time. Parts can be designed with a reduction of the amount of excess metal to be removed. Chips produced by a grinding wheel are small (Fig. 15–21), which simplifies their removal.

48. *Can abrasive machining be adapted to a wide variety of work?*
Figure 15–22 shows the abrasive machining of a 24 in. ID cylinder, 24 in. in length. The job is being done on a planetary type internal grinder. The wheel measures 21 in. × 1¾ in. × 5 in. and is run at a

Fig. 15–20. Abrasive machining a motor-base casting. (Norton Co.)

Fig. 15–21. Magnified view of chips produced by abrasive machinińg. (Norton Co.)

Fig. 15–22. Abrasive machining a 24-in. diameter bore of a cast-iron cylinder. (Norton Co.)



speed of 4,000 sfpm. Size tolerance is ± 0.001 in. Surface finish is 20 to 25 microinches rms (root mean square).

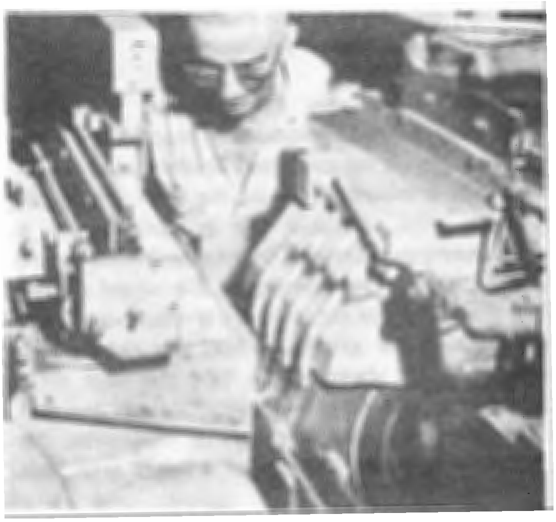
Figure 15–23 shows a worm being machined from a solid piece of metal. When finished, the job was well within the allowed tolerance and met all finish requirements with a substantial saving in production time.

Fig. 15–23. Worm machined from a solid piece by abrasive machining. (Norton Co.)

The centerless grinding operation is usually one in which very little stock is removed, yet Fig. 15–24 shows seamless tubing being abrasive machined from the rough tube to the highly polished finished products in a centerless grinding machine.

49. *Can abrasive machining be used on all metals?* According to the specialists of the Norton Company, who were the first to research abrasive

Fig. 15–24. Seamless tubing abrasive-machined on centerless grinder. (Norton Co.)



machining possibilities, "Abrasive machining can be done with any material . . . . by the proper selection of abrasive wheel specifications and machine operating conditions."

50. *What formula is used to find the correct speed and feed of the wheel in abrasive machining?*
There has been no rule developed to find the correct speed and feed when removing metal by abrasive machining. This is a new method of machining, which is still at the experimental stage. Absolute efficiency will not be achieved until new types of wheels have been developed and refinements have been made on the many types of grinding machines now used. However, improvements in economical production and work efficiency can be achieved by the use of abrasive machining on existing wheels and machines.

SURFACE GRINDING

51. *What is surface grinding?*
Surface grinding is the process of producing and finishing flat surfaces by means of a grinding machine employing a revolving abrasive wheel.

52. *How many types of surface-grinding machines are used in the machining industry?*
Surface-grinding machines are divided into two major groups according to the shape of the table and how it moves. They are the *planer type,* in which the table is rectangular and traverses under the wheel, and the *rotary type,* in which the table is circular and rotates under the wheel.

Planer Types

A. Horizontal spindle using the outside diameter (OD), or periphery of the wheel.
B. Horizontal spindle using the rim of a recessed or cupped wheel.
C. Vertical spindle using the rim of a recessed or cupped wheel.

Rotary Types

A. Horizontal spindle using the OD, or periphery of the wheel.
B. Vertical spindle using the rim of a recessed or cupped wheel.

Fundamentally, surface grinding machines consist of a spindle for mounting a grinding wheel and a table or magnetic chuck for holding the work. Each machine has its particular advantages, but, for the purpose of general toolroom work, this discussion deals principally with the horizontal planer-type surface grinder (Fig. 15–25), which uses the periphery of a disk wheel.

53. *What wheels are used on the surface grinder?*
Grinding wheels of various shapes are used on the horizontal surface grinder. Among the more common are the disk, gage, and thin rubber slotting wheels. The sizes of the wheels may vary from very small internal wheels used with a high-speed attachment, to wheels 10 in. in diameter with a 1-in. face. The wheels most commonly used on surface grinders are listed in Fig. 15–26.

54. *How should the wheels be mounted?*
The following items are to be considered in mounting a grinding wheel on the horizontal-planer surface grinder, from the time the wheel is received at the crib until the machine is running:

A. Sound the wheel for cracks. Hold the wheel by the bore and tap it with a nonmetallic object. If the wheel is not cracked, it will give off a dull, ringing sound. If the wheel is cracked, it will give a dull thud.
B. Make sure that the wheel has blotting-paper washers on both sides around the hole. (Most wheels arrive from the manufacturer with paper washers attached.)
C. Inspect the wheel flanges to make sure they are safety flanges and of the proper size.
D. Place the wheel on the spindle. The wheel should slide on the spindle, without either bind or too much play against the inner safety flange.
E. Put the outer safety flange on the spindle.
F. Put the spindle nut on securely.
G. Tighten wheel guards in place.
H. Turn the wheel over by hand to make sure that it clears the housing.
I. Start the machine and, as the starter button is pressed, step to one side, letting the machine run for at least one full minute before working with it.
J. True the wheel. Don't try to remove all of the runout with one pass of the diamond. Remove it a little at a time.

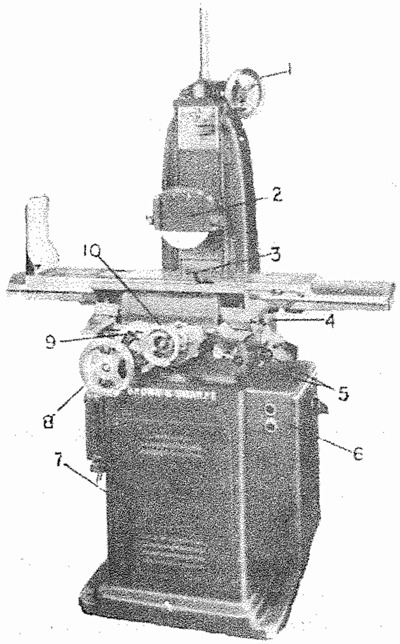


Fig. 15–25. Surface grinder operational controls. (Brown & Sharpe Mfg. Co.)

1. **Handwheel, graduated to half-thousandths of an inch, provides vertical adjustment of spindle head.**
2. **Removable unit spindle—plain-bearing, or antifriction-bearing spindle.**
3. **Table-reversing mechanism operated manually through lever shown, or automatically through second lever located on same shaft and tripped by adjustable table dogs.**
4. **Adjustable dogs permit stopping power movements automatically at any desired point in each direction of cross-feed.**
5. **Starting lever and trip lever start and stop both longitudinal and transverse power movements.**
6. **Start-stop push button switch and electrical control compartment.**
7. **Large base compartment for spindle and table driving motor.**
8. **Longitudinal table handwheel can be positively disengaged when power travel is used.**
9. **Adjustable stops provide for any cross-feed from 0.01 to 0.09 in. (or zero feed) at either end of table travel. Knob in center disengages cross-feed mechanism for manual operation.**
10. **Graduated handwheel for transverse adjustment.**

The wheel speed has been built into the machine by the manufacturer. For safety, don't try to increase it without getting competent advice.

From a safety standpoint, it is essential to sound the wheel for cracks because they may not be seen. If the wheel is cracked and placed on the machine, the centrifugal force of the machine when started up will cause the wheel to burst, thus endangering the operator or nearby fellow workers.

Blotting paper or rubber gaskets should be placed between the safety flanges and the wheel, to distribute evenly the pressures around the wheel when the nut is tightened.

55. *Are safety flanges necessary?*
Safety flanges are wheel flanges that act on the wheel

Fig. 15–26. Recommended abrasive wheels for use on surface grinders.

material	grain	grade	*abrasive**	process
Aluminum	30 to 46	H or I	C	Vitrified
Bronze	36 or 46	H	C	Vitrified
Cast iron	30 or 36	I or J	C	Vitrified
Copper	30 or 36	H or I	C	Vitrified
High-speed steel	46	G or H	A	Vitrified
Mild steel (including steel castings)	36 or 46	I, J, or K	A	Vitrified
Monel metal	46	G	A	Vitrified
Nitralloy (before nitriding)	36 or 36	J		Vitrified
Nitralloy (after nitriding)	60 to 100	H	A or C	Vitrified
Stainless steel (soft)	36	H	C	Vitrified
Tool steel	36 or 46	H	A	Vitrified
Tungsten carbide (roughing)	60 or 80	G or H	C	Vitrified
Tunsten carbide (finishing)	80 or 100	F or G	C	Vitrified

C—silicon carbide. A—aluminum oxide.

between the spindle and nut. They should be at least one-third the diameter of the wheel and relieved or undercut on the wheel side so that they bear on the wheel only at their outer edges. This bearing surface should be parallel with the opposite side so that when tightened, the nut will bear evenly against the flange, thus assuring equal pressure all around (Fig. 15–27).

Never force the wheel on the spindle. If it goes on snugly, the lead bushing should be scraped so as to be from 0.003 to 0.005 in. larger than the spindle, which enables the flanges to straighten the wheel without putting an internal strain on it.

The nut screws on to the spindle in a direction opposite to that in which the wheel rotates, so that the resistance offered by the work to the wheel tends to tighten the nut.

When starting the machine, especially after a new wheel has been mounted, or first thing in the morning after the machine has been standing all night, step to one side as the starting button is pressed, and let the machine run for at least one full minute. New wheels are apt to be out of balance due to being moisture-logged on one side, or the wheel spindle may have excessive end play in it, which upon starting would break the wheel. For that reason, be clear of it in case it does break.

56. *How should a grinding wheel be dressed?*
In the case of surface grinding where the work is ground dry, the wheel *must* be kept sharp and true if the grinding operation is to be done efficiently. The area of contact between the wheel and work is much greater than it is in cylindrical grinding, which means that a great many more cutting edges (abrasive elements in the wheel) are acting on the work at the same time. The heat generated by the added cutting edges may be kept at a minimum by keeping the wheel clean and sharp.

A dull or dirty wheel causes the work to burn or have a hard cutting action. Hard cutting action places more strain on the wheel and machine parts, causing them to overheat and operate inefficiently.

To dress a wheel, remove only sufficient material from the face of the wheel to sharpen it. Don't keep feeding the wheel down and hacking away at it with the diamond. Grinding wheels are costly tools and should be shown due consideration. Some grinding wheel manufacturers claim that about two-thirds of a grinding wheel is wasted due to improper dressing, truing, or handling.

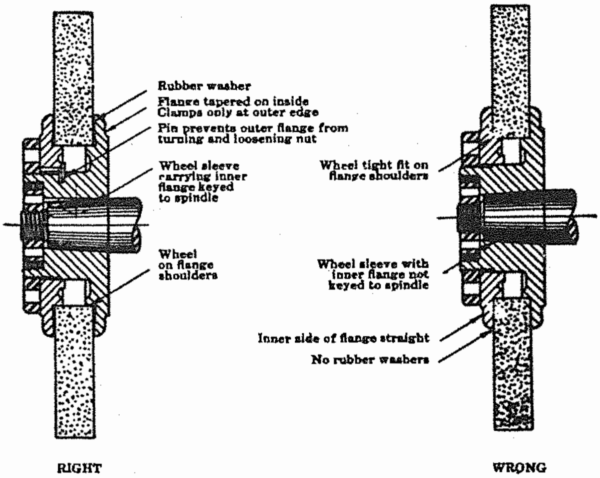


Fig. 15–27. Safety flanges for grinding wheels.

57. *How should the work be held for grinding?*
Most surface grinders use a magnetic chuck (Fig. 15–28) to hold the work in place on the machine, but the work may be held by clamping it directly to the table or by placing the work in a vise fastened to the table. Work may be held on the magnetic chuck in conjunction with a V block, angle plate, or sine bar, or with special fixtures.

The magnetic chuck holds the work in place by exerting a magnetic force on it. The magnetic poles of the chuck are placed close together so that it is possible to hold very small pieces of work. Frequently, however, the work is too small for the chuck to hold it. In this case, pieces of iron or steel, which are not as high as the work, are placed alongside to

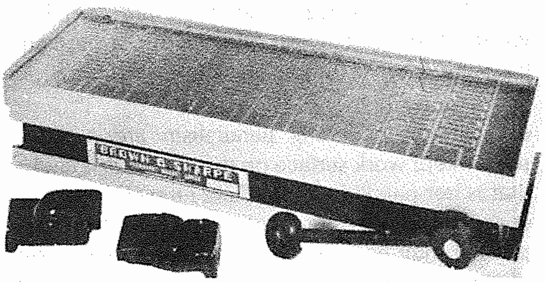


Fig. 15–28. Permanent magnetic chuck. (Brown & Sharpe Mfg. Co.)

act as blocks and retain the work on the chuck. Only magnetic materials such as iron or steel will adhere to the chuck. When grinding materials such as bronze, brass, fiber, or certain kinds of stainless steel, the pieces must be held in place on the chuck by bars of iron or steel.

The accuracy of the work—for example, parallelism and squareness—depends on the accuracy of the holding face of the magnetic chuck. For that reason, the holding surface of the chuck must be kept smooth and flat. As soon as the chuck shows nicks, scratches, or dents, or if the chuck has been removed for any purpose, it should be reground in place on the machine. Do this only on the advice of the instructor or foreman.

Sometimes the chuck is equipped with a back rail to support the work parallel to the table travel. This must be removed when the chuck is being reground; when the back rail is being replaced, it also must be ground in place to restore its accuracy.

Few toolroom jobs done on a surface grinder do not have to be kept parallel within reasonably close limits (Fig. 15–29). The most frequent causes of

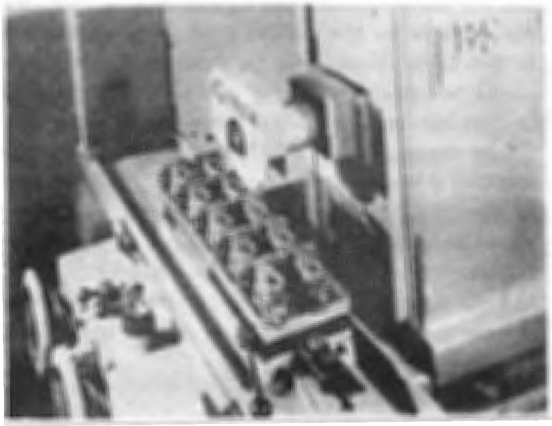


Fig. 15–29. A typical production job: grinding a group of parts to close limits, using a permanent magnetic chuck. (Brown & Sharpe Mfg. Co.)

difficulty in obtaining parallelism are a dirty or poorly kept work surface on the chuck, or a back rail that is not parallel with the table travel. Difficulty in keeping the opposite faces of thick pieces of work parallel may be overcome by reversing the position of the work on the chuck, putting it in nearly the same location, but without disturbing the wheel setting.

Thin work is especially hard to keep parallel because it warps so easily. The use of a free-cutting wheel and light cuts taken alternately from each side do much to eliminate the warping and hence make it easy to keep the work parallel within reasonable limits. Another method is to place a thin parallel under each end of the work, taking a light cut or series of light cuts alternately from each side. When this method is used, the work should be properly blocked on the table to keep it from sliding. Figures 15–30 and 15–31 illustrate the use of the magnetic chuck.

A magnetic V block (Fig. 15–32) is advantageous for holding iron or steel work of round or rectangular cross section and also for holding irregularly shaped pieces, which can be placed between, and in contact with, the V faces. It is suited for toolmaking, inspection, and hand operations as well as for light machine work and for wet or dry grinding. When the control is turned on, work is held firmly in the V and, if the V block rests on a magnetically conductive surface, the V block also is held firmly to this surface, as in Fig. 15–33. The V block can be used on its sides and end as well as on its base, but it is not held to a magnetically conductive surface when used on its sides. The holding power of the V block can be regulated by giving the control a part turn so that work can be moved or positioned in the V without fully releasing the V block from the conductive surface on which it is placed.

Magnetic-chuck parallels (Fig. 15–34) hold work with projecting surfaces, which cannot be held easily

Fig. 15–30. The use of a coolant does not affect the magnetic chuck. It permits heavy grinding cuts with a fine finish. (Brown & Sharpe Mfg. Co.)

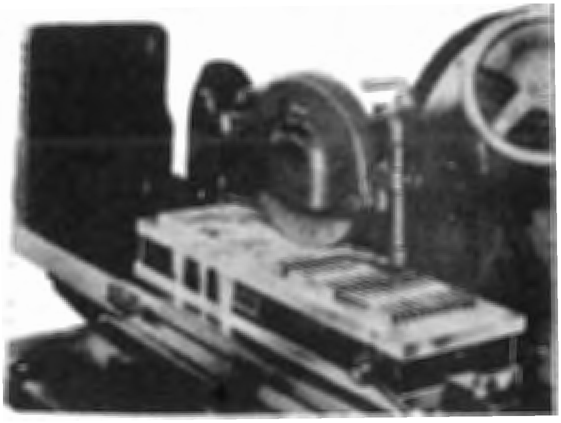


Fig. 15–31. Large jobs are securely held on the magnetic chuck. (Brown & Sharpe Mfg. Co.)

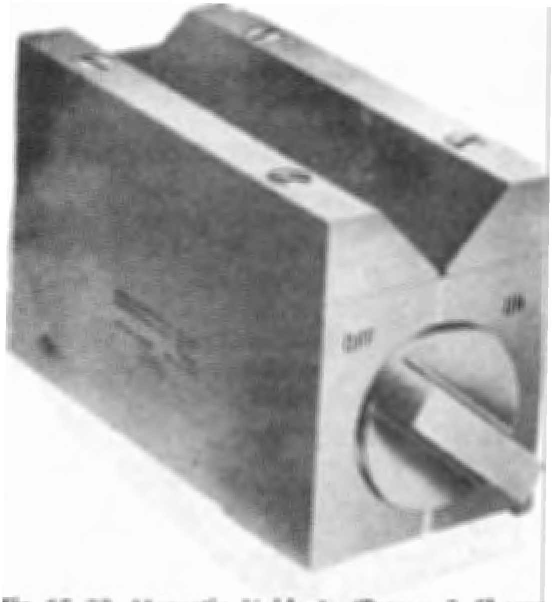


Fig. 15–32. Magnetic V block. (Brown & Sharpe Mfg. Co.)

Fig. 15–33. Magnetic V block is firmly held on the angle plate resting on a magnetic chuck.

Fig. 15–34. Magnetic chuck parallels. (Brown & Sharpe Mfg. Co.)

on the surface of a magnetic chuck. An example of work of this nature is shown in Fig. 15–35. The parallels are made of alternating steel and nonmagnetic bronze spacing strips. The magnetic flux passes from the magnetic chuck through the steel strips and the work, holding the work securely to the parallels and the parallels to the working surface of the chuck. Opposite sides are ground parallel and adjacent sides at right angles. Parallels can be used on all four sides, but not on their ends.

58. *What are witness marks, and how are they used?*

Occasionally the surface of a job must be ground to

Fig. 15-35. **Offset parts are held securely for grinding with magnetic chuck parallels. (Brown & Sharpe Mfg. Co.)**

cleanup. This means that the surface is to be ground so that a very small portion of the original surface can still be seen after the job is done. This is known as leaving *witness marks* on the work. The purpose of leaving these witness marks is to testify that only a small amount of stock was removed from the job. In some jobs, the wheel must be spotted on the work and then traversed over the entire surface to make sure that too much stock is not removed. If the surface is quite regular and has a good finish, it may be given a coat of blue vitriol or copper sulfate before grinding, to show that too much stock was not removed.

59. *Can angle plates be used on a grinding machine?*
Ninety-degree angle plates (Fig. 15-36) are used on the surface grinder for supporting the work, while two adjacent faces of the work are ground at 90° to each other.

Obviously, the accuracy of the work will depend on the accuracy of the plate. If the two adjacent faces of the plate are ground at exactly 90°, and if the edges of the plate are maintained parallel and at 90° to the adjacent faces, then it is possible to grind two sides of the work at 90° with a third side, thus cutting down on the work setup time.

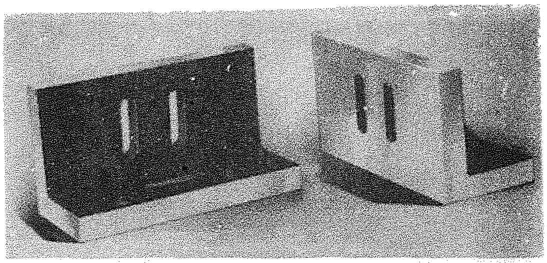
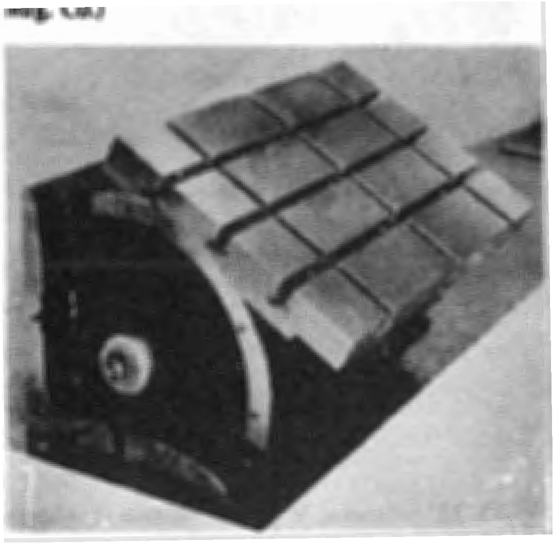


Fig. 15-36. Angle plates. (Taft-Peirce Mfg. Co.)

Precision-made adjustable angle plates (Fig. 15-37), known as *sine angle plates,* are available. Using these plates, work that has intricate angles can be ground. The end of the block is graduated in degrees. Some angle plates of this type, which can be set with a micrometer or precision gage blocks, are suitable for grinding angles that have exacting limits.

60. *What procedure is used to grind work square?*
To grind a piece of work square after two sides have been ground parallel, place the side to be ground down on the magnetic chuck. Place a thin parallel or rule alongside the work; then place the 90° angle plate, top edge down on the rule, bringing the outside face of the plate up against the finished side of the work (Fig. 15-38). Clamp the work and plate

Fig. 15-37. An adjustable angle plate. (Taft-Peirce Mfg. Co.)



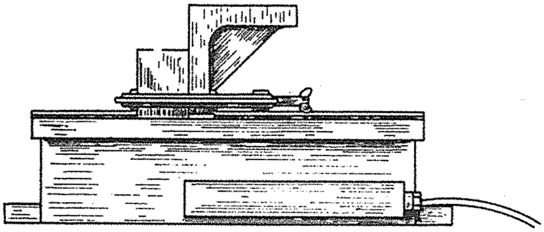


Fig. 15-38. **Angle plate resting on a parallel is clamped to the work.**

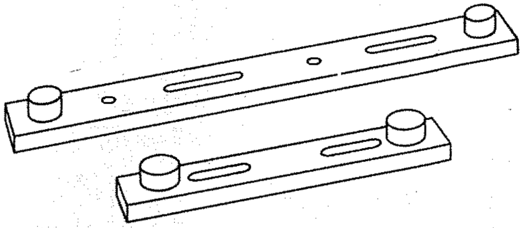


Fig. 15-40. **Sine bars.**

together in this position, so that when the angle plate is turned right side up on the magnetic chuck (Fig. 15-39), the work face to be ground will be exposed to the grinding wheel. Make sure that the clamp has been placed far enough below the face to be ground, and that the screw end is located inside the angle plate to reduce the overhang and not interfere with the grinding operation.

61. *Can angular surfaces be ground on a surface grinder?*

Angular surfaces can be readily ground on a surface grinder by dressing the wheel to produce the required angle, by using a sine bar (Figs. 15-40 and 15-41) or an adjustable angle plate and setting the work up to the required angle, or by using an adjustable magnetic chuck.

The grinding wheel should not be dressed at an angle except as a last resort because it decreases the wheel life. If the wheel must be dressed at an angle, make sure it is dressed correctly—that is, dress the wheel so that it will produce the angle required on the work and not the complement of it. For dressing the wheel at an angle, either a standard angle block or sine bar may be used to guide a sliding flanged block, which holds a diamond, as shown in Fig. 15-42. After the angle block or sine bar has been set up, it is located so that the point of the diamond is exactly on the vertical center line of the wheel spindle.

A grinding wheel may also be dressed with an angle-truing attachment (Fig. 15-43). The upper part

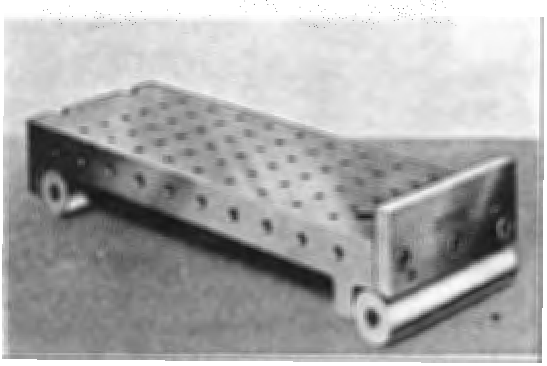


Fig. 15-41. **Sine block. (Taft-Peirce Mfg. Co.)**

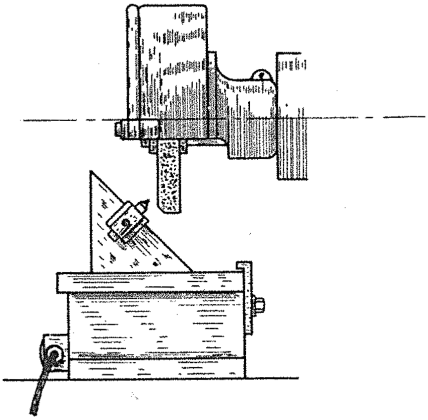


Fig. 15-42. **Dressing a grinding wheel to an angle by sliding a diamond tool along the edge of an angle plate.**

Fig. 15-39. **Surface of work to be ground is above the angle plate when inverted.**

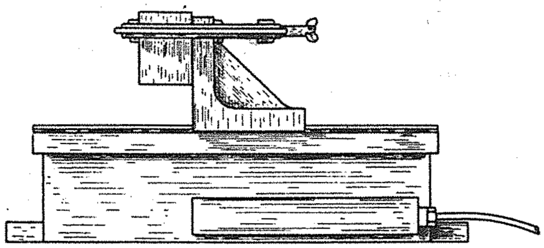


Fig. 15–43. Angle wheel truing attachment in position to dress a wheel to a required angle. (Brown & Sharpe Mfg. Co.)

is turned and clamped to the required angle using the graduations around the base. The diamond tool is brought close to the grinding wheel by the hand feed of the table, and the slide of the truing attachment is operated with the handwheel to move the diamond tool back and forth across the wheel.

When the work is to be set on an angle, the common practice is to use a standard angle block or sine bar (Fig. 15–44), in conjunction with a 90° angle plate. With some sine bars, it is necessary only to stack gage blocks or set a planer gage at five or ten times the sine of the angle, depending on the length of the sine bar, and then to place the work on the sine bar squarely against the 90° angle plate and clamp it in place. Other sine bars require that the addition of the radius of plugs, or the thickness of the base of the sine bar be added to five or ten times the sine of the angle.

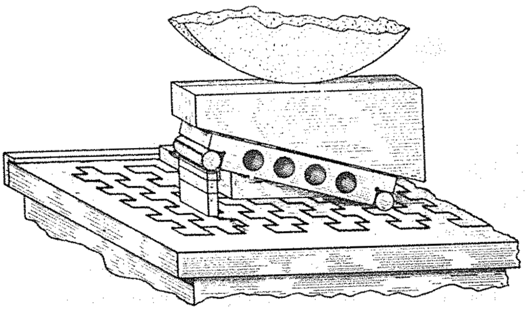


Fig. 15–44. Work is held level on a sine block, which is elevated the required distance by a combination of gage blocks.

Cylindrical workpieces may be held in V blocks while grinding flats, slots, radii, and so forth. The blocks are kept square, the sides parallel, the ends parallel, and the V maintained in the exact center of the block.

Job Analysis

The following outline is a typical analysis of the procedure for grinding two opposite flats central on the outside diameter (OD) of a shaft.

Type of job: Shaft as per sketch (Fig. 15–45)
Type of machine: Horizontal planer
Type of material: SAE 1095 steel
Heat treatment: Harden to Rockwell 52–64
Kind of grinding wheel: 60-K
Operations required: Grind flats to size and central with OD
Tools required: 4-in. V block, 10-in. height gage, 2-in. micrometer, dial indicator

Procedure

A. Check the flats for sufficient grind stock.
B. Place the job in a V block using a 10-in. height gage and dial indicator to make sure that the rough flats of the shaft are parallel with the sides of the V block.
C. Using the height gage and indicator, check to see that the cylindrical surface of the shaft that projects from the V block is centered. This is done by turning the block over on its side, taking a reading with the indicator, then turning the block on to its opposite side and observing whether the reading is the same on both sides of the shaft.
D. Check the unground flats to see that they are centered, observing which side is high and whether it is within the grind stock.

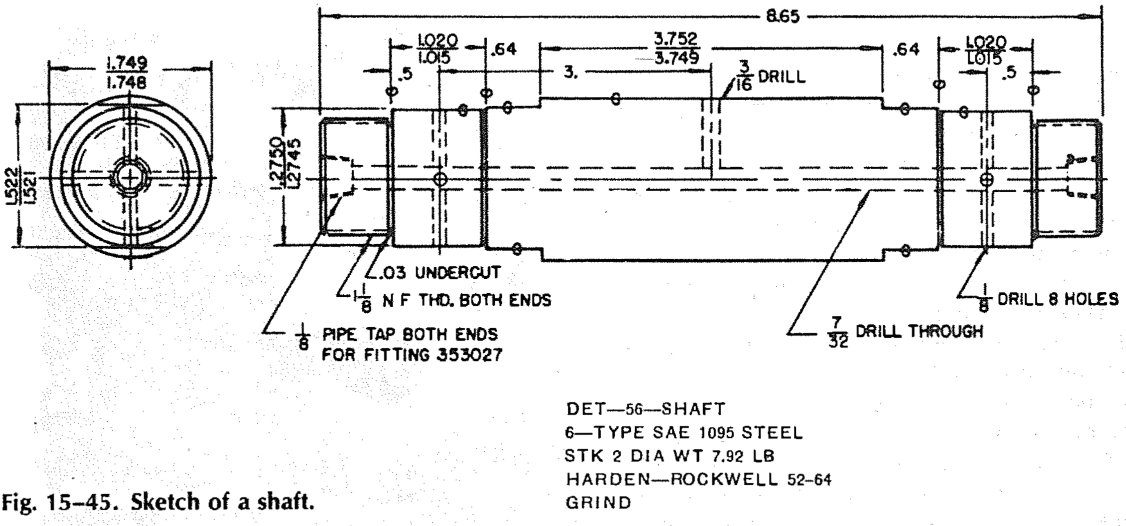


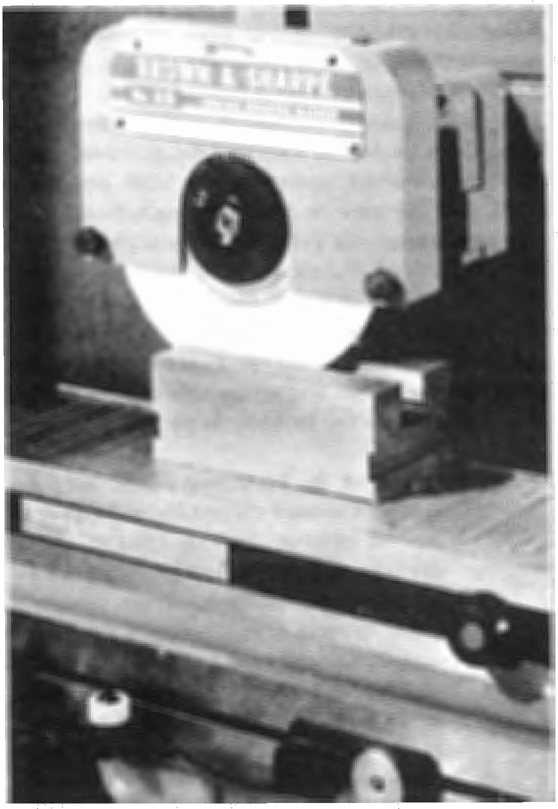
Fig. 15–45. Sketch of a shaft.

E. Place the job on the chuck with the low side up, and spot the wheel to clean up this side of the flat, leaving witness marks.
F. Reverse the V block to bring the unground side of the shaft up, and take the same cut from this face.
G. Check the job for size, noting by what amount it is oversize.
H. Feed the grinding wheel down an amount equal to one-half the remaining stock and grind both faces, reversing the V block as in step F. This should bring the job to the required size.
I. Check the flats for size and proper centering; then have it checked by the inspector.

62. *How can grooves and slots be ground?*
Certain classes of work on the surface grinder call for considerable skill and patience on the part of the operator. Some of the more common ones are groove or slot grinding and radius grinding, especially where they have to be maintained within accurate limits relative to another surface.

Probably the most important factor is selection of the proper wheel. Where the groove is wide enough, a gage wheel of medium-hard bond and from 46 to 60 grain size should be used for roughing. If a gage wheel cannot be secured, a disk wheel with the same characteristics can be used, but the sides must be undercut or relieved to avoid tapering on the top of the slot or groove (Fig. 15–46).

Fig. 15–46. Grinding a groove. Job aligned against the backrail of a magnetic chuck. (Brown & Sharpe Mfg. Co.)



Bellmouthing is a condition in which the ends of the slot or groove become gradually wider than the center. On the surface grinder, it is generally caused by spindle end play, or pressure on the wheel. The work forces the end play, or wheel, in one direction; then, as the wheel clears the slot, the work pressure decreases, permitting the spindle to occupy a normal running position. This condition can be overcome by doing most of the grinding in the central section of the groove or slot and only occasionally running the wheel off the ends.

To grind sharp corners on the bottom of the slot, a vitrified wheel of 80-O or 120-P should be used, after the slot has been ground to size.

Form grinding can be done on the surface grinder by dressing the wheel to the desired shape. In the case of convex or concave radii, a special diamond holder, known as a *radius wheel-truing attachment,* provides an efficient and accurate method of shaping a grinding wheel to a required radius (Fig. 15–47). The base of the attachment carries a swivel platen upon which is mounted a slide, which can be moved longitudinally by a handwheel. An upright, integral with the slide, holds the diamond tool and diamond-tool setting gage. The diamond may be set parallel to the slide or at right angles and clamped in position by a locking screw.

To form concave or convex outlines, the diamond point is located by means of the diamond-tool setting gage (turned upward 180° from position shown), and the slide is adjusted longitudinally to the desired radius, as indicated by a scale on the slide reading to 1 in. each side of zero by sixty-fourths. The slide is locked in position by a clamping screw, and the diamond is passed across the wheel by swiveling the attachment on its base to produce the desired form. A gib and adjusting screws provide means of compensating for wear in the slide.

caution: The table of the horizontal-planer surface grinder traverses very easily and may be pushed back or forth by leaning accidentally against the end of it. This is a desirable quality insofar as surface finish is concerned but is dangerous when removing work from the magnetic chuck. Many an operator has suffered an ugly hand wound on this type of machine because after he moved the table to the right of the wheel, he took hold of the work and gave it a pull in the direction of the wheel. If this is done, the operator's hand or arm is likely to come in contact with the revolving wheel; the result is a nasty burn and cut. To avoid such an accident, stop the wheel, move the worktable to the right of the wheel, turn off the magnetic chuck, and then remove the work from the chuck by pulling it in a direction perpendicular to the longitudinal travel of the table.

Fig. 15–47. Radius wheel-truing attachment in position to form radius on edge of wheel. (Brown & Sharpe Mfg. Co.)

63. *How does the horizontal rotary grinder operate?*

The horizontal rotary grinder (Fig. 15–48), commonly known as a *ring grinder,* consists of a horizontal wheel spindle having a reciprocating motion similar to that of the shaper ram, and a revolving magnetic chuck table supported by columns at the front of the machine. The worktable can be raised or lowered and tilted for concave or convex grind-

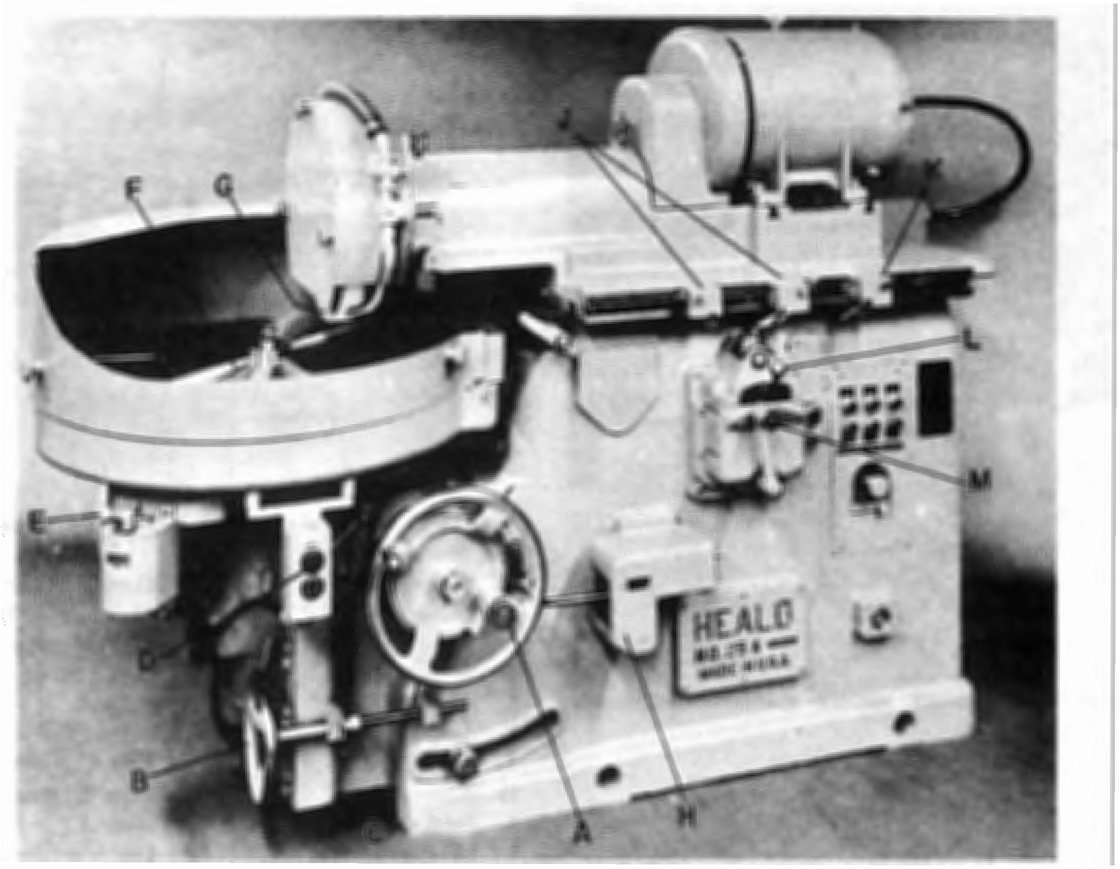


Fig. 15–48. Rotary surface grinder with reciprocating head. (Heald Machine Co.)

A. Knob for fine adjustment of work to wheel
B. Handwheel for adjusting chuck to give concave and convex surfaces
C. Handwheel for raising and lowering work chuck
D. Start-and-stop buttons for rotation of magnetic chuck
E. Off-and-on switch for magnetizing chuck
F. Magnetic chuck for holding work
G. Grinding wheel
H. Lever for adjusting speed of wheel slide
J. Dogs for adjusting length of stroke of wheel slide
K. Dog for quick return of wheel slide
L. Wheel-slide reverse lever
M. Lever for adjusting speed of wheel slide and wheel

ing. The machine is equipped with a coolant supply tank and pump for wet grinding, and because it uses the periphery of the wheel it can produce a good finish. This type of machine is used to reduce flat, concave, or convex surfaces, which makes it readily adaptable for either toolroom or multiple-production purposes.

Another type of horizontal rotary grinder is shown in Fig. 15–49.

64. *Is the vertical-spindle rotary grinder difficult to operate?*

The vertical-spindle rotary grinder (Fig. 15–50) consists of a cylindrical wheel mounted on a vertical spindle and supported on a vertical column. This vertical column provides a means of raising or lowering the wheel. The worktable consists of a revolving magnetic chuck supported on ways or slides, which provide a means of moving the work to and from the

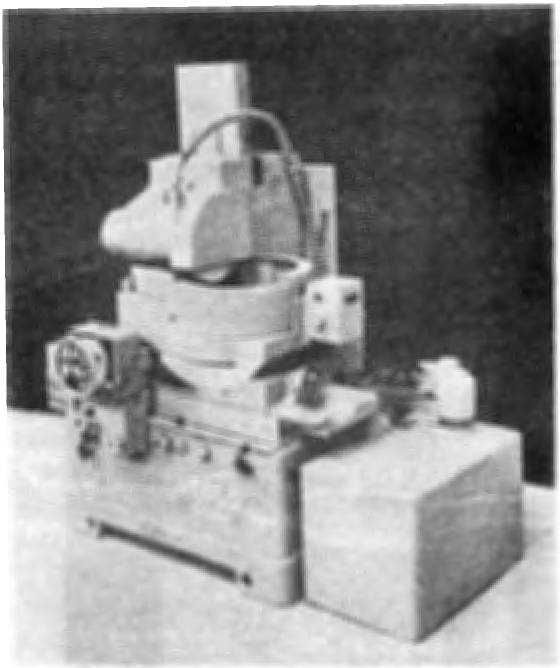


Fig. 15-49. Rotary surface grinder. (Heald Machine Co.)

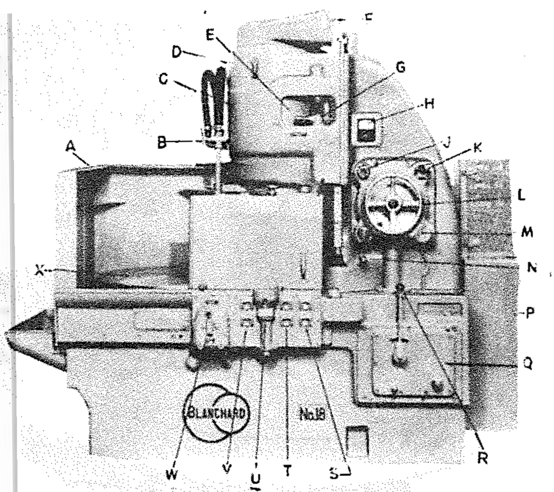


Fig. 15-50. Vertical-spindle rotary grinder. (Blanchard Machine Co.)

A. Steel guards
B. Water cocks
C. 25-hp induction motor
D. Wheel head
E. Air outlet
F. Air inlet
G. Wheel dresser
H. Ammeter
J. Feed variator
K. Oil-flow indicator
L. Feed dial and wheel
M. Oil filter
N. Feed and head-elevating lever
P. Control cabinet
Q. Chuck speed box with oil pump
R. Chuck speed control
S. Pump control
T. Wheel control
U. Table-traverse control
V. Chuck rotation control
W. Chuck switch
X. One-piece steel magnetic chuck

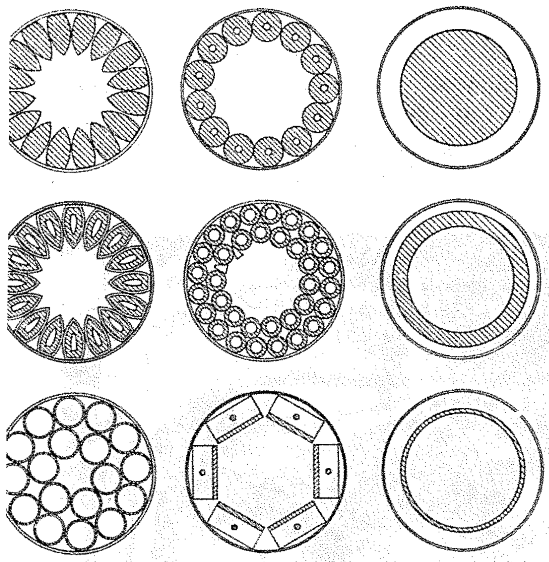
wheel. When the work and wheel are engaged, the magnetic chuck rotates in a clockwise direction, but the table is locked in place on the ways of the machine. This machine does not give as good a surface finish as the horizontal rotary grinder, but has a use in the toolroom as well as in production.

In using the vertical-spindle rotary grinder, the work is placed on the magnetic chuck in such a manner as to distribute the load equally, as shown in Fig. 15–51. The table is then moved in to bring the center of the chuck under the outer edge of the wheel where it is locked in place. The wheel head is then lowered very gradually until sparks indicate contact between the wheel and work. Then the power feed is engaged.

If one of the pieces of work has been previously ground to size at one spot and coated with blue vitriol, it may be placed on the chuck and used as a sizing block. The grinding wheel can then be fed into the work until light scratches appear on the vitriolized surface, indicating that the work is to size. When the correct size is obtained, the downfeed is stopped, the wheel head raised, the worktable moved out, and the job removed.

Essential points for the efficient operation of a vertical-spindle rotary grinder are given below. Each item requires special attention.

A. The selection of the proper grade and grain of wheel for the job.
B. The selection of the proper wheel feeds and chuck speeds to keep the wheel free-cutting and as nearly self-sharpening as possible.
C. The proper loading and blocking of the work on the chuck.
D. The condition of the working face of the chuck.
E. The condition of the working faces of the work to be ground.
F. The proper and judicious use of the wheel dresser, when required.



ig. 15–51. Methods of placing various types of work on the magnetic chuck of a vertical spindle grinding machine. (Blanchard Machine Co.)

65. *What type of grinding wheel is used for vertical surface grinding?*

There are several types of wheels for vertical surface grinding. Those most commonly used are the cylinder, the segment, and the sectored wheels. The advantages and disadvantages of each are detailed below:

The cylinder wheel (Fig. 15–52) is the most popular and generally the most satisfactory wheel for Blanchard grinding. The proper cylinder wheel will stay sharp with little or no dressing. Wear will be just sufficient to maintain this sharpness and no more. The grain size will be selected to provide clearance for chips, depending upon the nature of the material and the total area of the surface being ground, and to produce the desired finish. The maximum area of abrasive surface is in contact with the work continuously. The cylinder wheel should always be selected for fine finishes and where extreme flatness accuracy is required. Because of the broken contact surface, the segment and, to a lesser extent, the sectored wheel, will often cause scratches on a fine finish and a rounding off of the edges of the surfaces being ground. It takes less time for a trained operator to change a cylinder wheel than to install a new set of segments. With the cylinder wheel, there is only a wire band to be cut and removed.

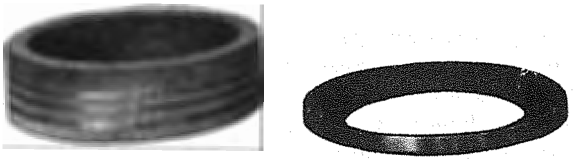


Fig. 15–52. Cylinder grinding wheel and ring adapter. (Blanchard Machine Co.)

The segment wheel (Fig. 15–53) is popular with many operators. It consists of several abrasive segments securely clamped into a segment chuck. There are several types of these chucks, and, in general, each type requires a special-shape segment. Blanchard manufactures segment chucks for segment wheels of the following diameters: 11, 18, 20, 27, 32, 36, and 42 in. The number of segments per set for each of these chucks, respectively, is 4, 6, 8, 8, 8, 10, and 10. Safety, balance, and ease of clamping are necessary for a satisfactory segment wheel. Segments are set out to compensate for wear but should never project more than 2 in. The segments are gripped so securely that only about 1 in. of the segment in the chuck is required for holding the last 2 in. However, many operators prefer to use backing blocks to prevent any possibility of a segment cocking. The spaces between the segments facilitate the clearance of chips and flow of coolant, which makes the segment wheel particularly suitable for grinding broad surfaces and rough castings. It is not suitable for grinding small pieces or narrow surfaces, especially where a fine finish and flatness accuracy are required. The interrupted grinding surface has a tendency to catch and tip small pieces and throw them from the chuck.

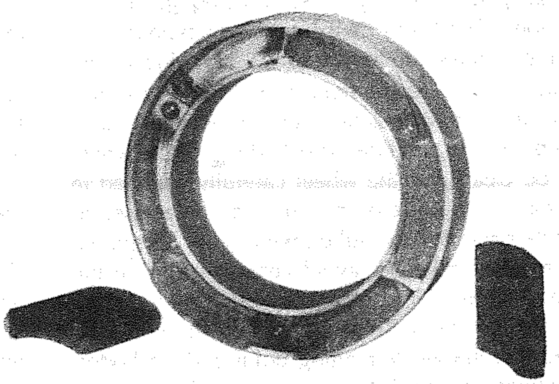


Fig. 15–53. Segment grinding wheel. (Blanchard Machine Co.)

The sectored wheel (Fig. 15–54) is essentially a cylinder wheel of increased rim thickness with V-shaped notches molded into the outer surface. The effect of these V-shaped notches is to give approximately the same number of linear inches of abrasive on any circumference. Thus, each abrasive grain does the same amount of work, and the grains are not overworked on one diameter and wasted on another. The sectored wheel is cool-cutting, free from vibration, and uniform in grade. As in the case of the segment wheel, it is particularly suitable for grinding broad surfaces. This wheel will often give the lowest wheel cost per cubic inch of material removed. It is recommended for all Blanchard grinding except where verv fine finishes are required.

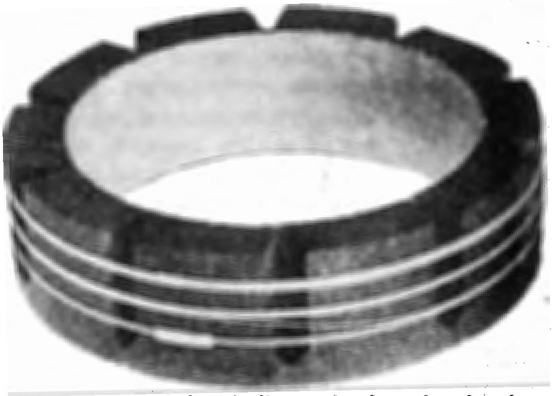


Fig. 15–54. Sectored grinding wheel. (Blanchard Machine Co.)

66. *How are the wheels mounted?*
Vertical-spindle rotary grinders come equipped with a number of cast iron rings into which cylinder and sectored wheels are mounted for fastening to the faceplate. The wheel is held in the ring with sulfur, which, in its molten state, is poured into the space between the ring and the wheel. The ring and wheel must be clean and the wheel carefully centered in the ring. The outside of the ring may be greased to facilitate removing any sulfur, which may be spilled. Care must be taken to avoid getting grease on the inside of the ring. To prevent noxious fumes and the possibility of the sulfur catching fire, it should be heated just above its melting point and no hotter. Sulfur becomes too thick to pour if overheated.

Wheels may also be mounted on the grinding machine with a solid wheel holder. This solid wheel holder (Fig. 15–55) eliminates the use of wheel rings and sulfur to mount cylinder wheels. The wheel holder provides the advantage of rapid wheel changes. It is especially useful when the grinder is employed on production work, or where the job requires frequent wheel changes.

Fig. 15–55. Solid wheelholder. (Blanchard Machine Co.)

67. *How should wheels be handled for storage?*
Because of its relatively thin section the cylinder wheel is more fragile than most other types of grinding wheels. Therefore, care must be taken in shipping, packing and unpacking, handling, and storage or breakage may be expected. Wheels should not be dropped or rolled along the floor. Racks should be provided for wheel storage. It is usually more convenient to rack them vertically, that is, with the axes horizontal. Proper labeling will facilitate finding a desired wheel if several different grits and grades are carried in stock. Wheels should not be stored in the open nor in damp cellars. They must be kept dry. Extreme temperature changes must be avoided.

68. *What is the best procedure to obtain a good finish when surface grinding?*
Good finishes can be obtained with medium-grain wheels by the following procedure. When final size is approached, continue grinding for several turns of the chuck without downfeed of the grinding wheel. This is sometimes referred to as *sparking out.* Raise the wheel by hand from 0.001 to 0.002 in. very slowly. This procedure will give a finish of from 15

to 20 microinches on hardened steel when a 24-grit wheel is used or on soft steel when a 46-grit wheel is used.

The same procedure should be followed when using fine-grit wheels for fine finishes. It is absolutely essential to use a free-cutting wheel because wheels as fine as 220 grit size are quite dense, and a wheel too hard for the job will tend to heat the work and will not produce the accuracy possible with the freer-cutting wheel. In using fine-grit wheels, 100 grit or finer, the regular wheel dresser can be used occasionally if necessary, but only light pressure should be used for this operation. To give best results, a silicon carbide dressing stick should be used, holding the stick against the face of the wheel as the wheel idles down to a stop. The inside and outside corners of the wheel should be rounded to about 1/16-in. radius in order to obtain the best finishes possible and eliminate occasional scratches.

Safety Rules for Surface Grinders

A. Test all wheels for cracks or defects before installing them on the spindle.

B. When starting a machine with a new wheel, stand a safe distance to one side until you are sure that the wheel is sound.

C. Whenever there is danger of injury in any way to yourself, in loading, unloading, or checking work on the chuck, *stop the machine*.

D. In removing work from the magnetic chuck, crank the table clear of the grinding wheel and then pull the stock *away* from the wheel.

E. Small, thin pieces of stock, extra long stock, or stock with small contact surfaces should be thoroughly blocked on the chuck.

F. Do not use an unguarded wheel at any time.

G. Always wear safety glasses when operating a surface grinder.

H. Do not wipe a chuck with a towel—use an oil brush.

I. Shut off the machine while checking or setting up a job.

J. Use properly undercut safety washers in mounting a wheel.

K. Exhaust hoods are supplied as a safeguard for the health of grinder operators. See that they are properly adjusted at all times and that they are not abused.

CYLINDRICAL GRINDING

69. *Is there more than one type of external cylindrical grinder?*
External grinders are divided into three general groups: plain cylindrical grinders, universal grinders, and special grinders such as the centerless and cam grinders.

70. *What is external cylindrical grinding?*
External grinding is commonly defined as the act of grinding the outside diameter of a piece of work while it is revolving on its axis, to reduce it to size, and leave a fine finish. However, external grinders are also used to produce external cams, eccentrics, and special forms on the outside diameter of work. These are done on machines that perform many of the operations done on a lathe, but more accurately than the lathe. A major advantage is that after a job has been heat-treated (hardened), a good surface finish and extreme size accuracy can be obtained. Where these two factors are important, the extra cost involved in grinding can be overlooked. If parts can be designed so that the amount of stock to be removed is within grinding limits, then grinding is much less costly than lathe turning.

71. *How does the plain cylindrical grinder operate?*
This grinder (Fig. 15–56) is used to produce external cylinders, tapers, fillets, undercuts, and shoulders. It may be used for form grinding by dressing the desired contour on the grinding wheel.

In any cylindrical grinder, three movements are very important: (a) rotation of the work on its axis, (b) movement of the work back and forth in front of the wheel, and (c) movement of the wheel into the work. Trouble in cylindrical grinding, with the exception of wheel content, or makeup, can be attributed to one of these movements.

Rotation of the work on its axis is important. If the centers in the work are bad or if the machine centers are of poor quality and loose, the work will be irregular in form. The movement of the work back and forth in front of the wheel must be steady and smooth to ensure both a good finish and accurate sizing. Movement of the wheel spindle in revolving the wheel

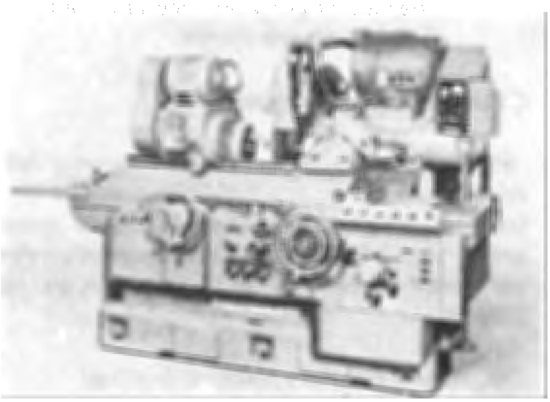


Fig. 15-56. **Plain hydraulic cylindrical grinder. (Cincinnati Milacron Co.)**

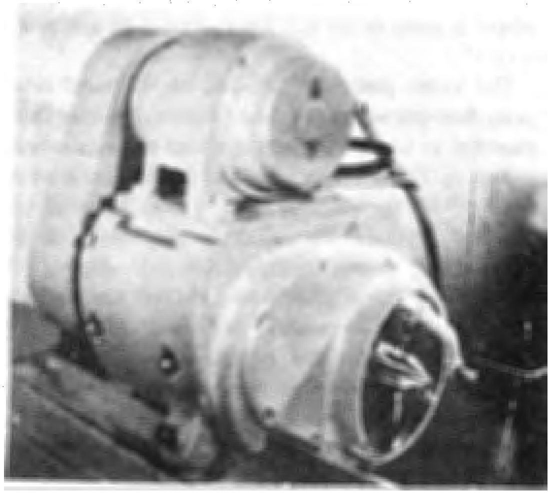


Fig. 15-58. Headstock, or workhead, of cylindrical grinder. (Cincinnati Milacron Co.)

must be true and smooth to prevent vibration and avoid chatter marks on the work. Movement of the wheel into the work must be without play or bind to ensure accurate depth of cut.

The work in external grinding usually revolves on two dead centers, one in the footstock (Fig. 15-57), and one in the headstock (Fig. 15-58). The work is given its rotary motion by a drive plate that revolves about the headstock center. The drive plate is driven by a motor, using pulleys and a belt. The drive plate contains an adjustable arm, which can be located at varying distances from the center and into which a drive pin is fitted. This drive pin engages the V slot of the grinder dog (Fig. 15-59), which is attached to the work, and hence the revolving motion of the plate is transmitted to the work.

Besides the rotary motion of the work, it is always necessary, except in the case of plunge-cut grinding, for the work to be traversed past the grinding wheel. The length of the table traverse should be set to permit the wheel to run off the end of the work about one-third of the wheel-face width. If the wheel is not permitted to overrun the end of the work, the job will be oversize at that point because the wheel will not have a chance to finish the cut. If the wheel is permitted to overrun the end of the work com-

Fig. 15-57. Footstock of cylindrical grinder. (Cincinnati Milacron Co.)

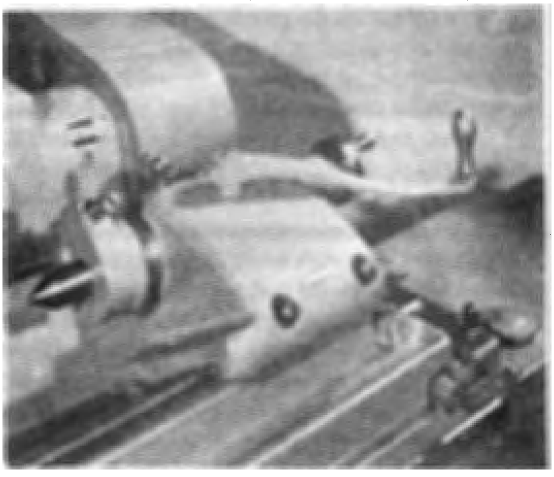
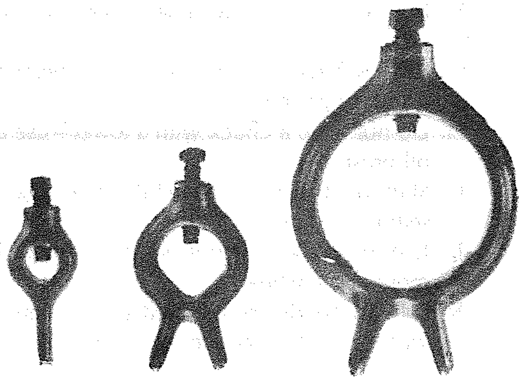


Fig. 15-59. Grinder dogs. (Brown & Sharpe Mfg Co.)

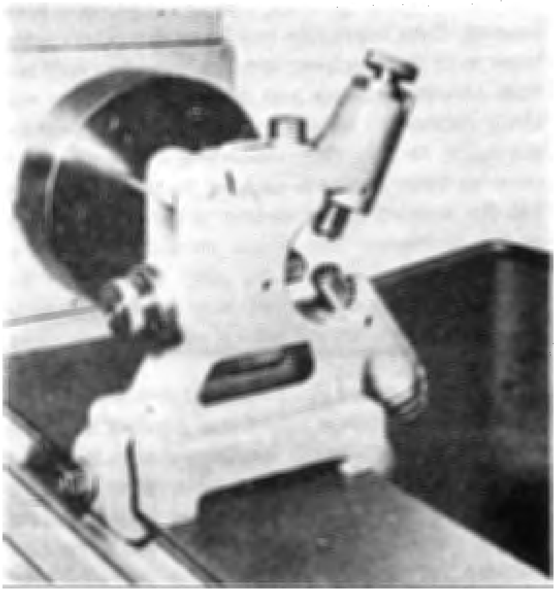


pletely, the job will be undersize because the pressure required between the wheel and the work is relaxed. This permits the work to spring toward the wheel, and so, at the beginning of the traverse, the wheel would cut undersize.

At the end of each traverse, the table stops momentarily to give the wheel a chance to grind the work to size, to permit the wheel to clear itself on the new cut, and to avoid the jarring motion which would be unavoidable with an immediate reversal of the table. If the traversing is not accomplished without jarring, or without a jerking movement, of the table, the work will show high and low spots due to the slight pause, or dwell, of the wheel on the work, which would take place at each jerk or jar of the table. The speed of the traverse depends on the width of the wheel face and the type of finish required on the work. It is generally such that the table will move two-thirds to three-fourths of the wheel face for each revolution of the work.

72. *Why is a steady rest used?*
Long, slender work, besides being supported by the centers at each end, should also be supported by steady rests near its center to avoid bowing the piece. Figure 15–60 shows a center steady rest. Figure 15–61 shows a back rest.

Fig. 15–60. Center steady rest. (Cincinnati Milacron Co.)



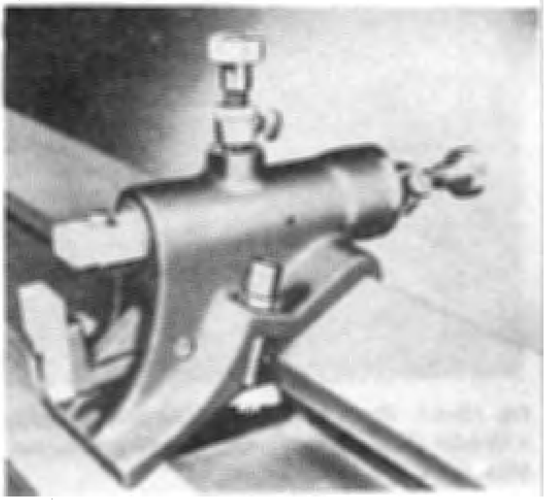


Fig. 15–61. Back rest. (Cincinnati Milacron Co.)

When using steady rests, as in Figs. 15–62 and 15–63, the jaws *must* be kept properly adjusted to the work; otherwise the work might get caught between the lower jaw and the grinding wheel and be thrown from the machine, or it might break the grinding wheel.

73. *What is a safe amount to feed the wheel?*
The grinding wheel can be fed to the work either by automatic feed or by hand feed, and feeds as small as 0.00005 in. are obtainable. It is not advisable to

Fig. 15–62. A center rest is placed in a central position to give support to the weakest section. (Cincinnati Milacron Co.)

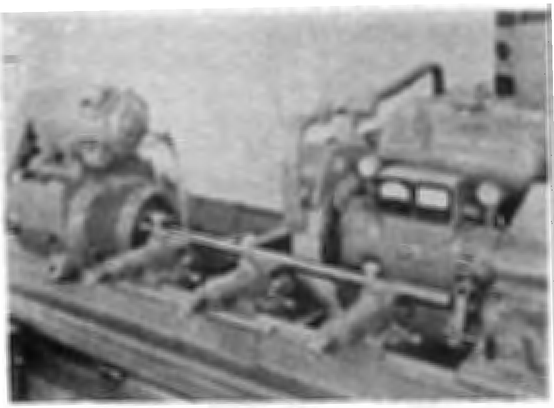


Fig. 15-63. Three back rests being used to support a slender shaft while traverse grinding. (Cincinnati Milacron Co.)

use the hand feed except to bring the wheel up to the work, to move it away from the work, or when taking very fine cuts. The automatic feed takes cuts from 0.00025 to 0.004 in. for each traverse of the table. Because cuts are more uniform, the automatic feed saves time and wear and tear and gives longer life to the grinding wheel. Generally speaking, roughing cuts may be from 0.001 to 0.004 in. at each reversal, depending on the rigidity of the machine, the work setup, and the amount of stock to be removed. It is common practice, when the work is not to be hardened, to leave from 0.006 to 0.010 in. grind stock, but work that is large, long, slender, or easily sprung may have an allowance of from 0.020 to 0.030 in. grind stock; in either case, however, heavy infeeds require good supports for the work. For roughing out the job, use a slow work speed, fast traverse, and heavy feed. For finish-grinding a job, use a high work speed, slow traverse, and a light feed.

The more common grades and grain sizes of aluminum oxide wheels used for external grinding are 46-J, 46-K, 60-K, 60-L, 80-0, 120-P.

74. *How fast should the work speed be?*
No set answer can be given. Jobs may or may not be of the same metal, same heat treatment, or same diameter. Each of these factors affects speed. Too fast a speed tends to wear away the wheel quickly, whereas too slow a speed causes the wheel to cut hard and become dull and glazed. If the wheel wears too fast, it requires more frequent dressing and truing and takes more time to do a given job. Extremely hard steels may have to be ground at 30 sfpm, whereas very soft steels may require up to 100 sfpm for finishing. Common work speeds are from 30 to 50 sfpm. If the wheel becomes dull or glazed, it will burn the work because of the added friction caused by forcing the wheel to cut. If the work speed is correct and the wheel still has a tendency to become glazed, it is an indication that the bond is too hard. This can be corrected by substituting a wheel of the same grain but softer bond.

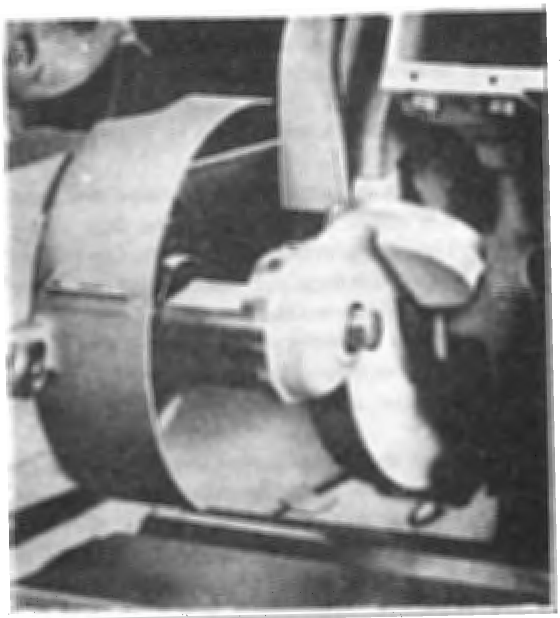
75. *How can operation errors be observed?*
When cracks, checks, or burns show up on the surface of the work, any one or any combination of the following conditions might be the cause: improper work speed, wheel too hard, or wheel glazed or loaded. If the wheel is glazed or loaded, it will cause the work to burn and crack even though there is a good supply of lubricant. Therefore, best results can be obtained by keeping the wheel sharp and clean at all times.

Perhaps the greatest obstacle the operator has to overcome in grinding a cylinder is taper developing in the work. Conditions contributing to it are poor machine or work centers, work improperly mounted, worktable out of adjustment, footstock out of line with headstock, or steady rests bearing too heavily or out of line with the work.

To correct tapering, first make sure that the centers of the work are clean and true, and of sufficient depth and clearance to give the machine centers a good bearing. Then inspect the machine centers for correct taper to fit the machine; see that they are clean and true. Mount the work and make sure that the machine centers are engaged properly, and inspect the worktable for side play, correcting it if necessary. If none of these factors is causing the taper, then adjust the knurled screw located at the footstock end of the worktable. The screw should be turned to move the small end of the work away from the wheel. Several adjustments may be necessary to get the work entirely cylindrical and free from taper.

76. *What is meant by plunge-cut grinding?*
Plunge-cut grinding is cylindrical grinding in which the width of the work is less than the width of the wheel face. Thus the wheel can be fed straight into the work and the cylinder can be completely ground without using the table traverse. With this technique, a square corner can be maintained between cylinder

and shoulder when a shouldered, or stepped, cylinder must be ground. Remember, a square corner is not necessarily a sharp corner. Figure 15–64 shows an example of plunge-cut grinding.



ˉig. 15–64. **Plunge-cut grinding. (Cincinnati Milıcron Co.)**

77. *What are the important steps in external ;rinding?*

ˉhe important steps in external grinding are as ollows:

A. Check the work for size to make sure grinding stock has been allowed, and at the same time note any tapering of the work.
B. Inspect the work centers to see that they are clean and true. Select machine centers of suitable diameters to fill the work's centers properly. The footstock center should be cut away enough to permit the grinding wheel to clear the end of the work; a center of this type is known as a one-half-full, or a three-quarters-full, center.
C. Attach the grinding dog on the end of the job, making sure that the dog does not damage such parts of the work as threads and keyways; then lubricate the machine centers.
D. Set the table traverse for the length of the work, allowing for overrun of the end and the space occupied by the grinder dog.
E. If necessary, mount the steady rests and adjust the shoes to the work.
F. Dress the grinding wheel, passing the diamond across the wheel-face quickly to make the wheel fast-cutting. Set the work speed at the correct surface speed in feet per minute.
G. Feed the wheel to the work by hand and take a light cut, noting that the wheel starts to cut approximately at the high point of the work, to conform to the check in step A.
H. Check the work for size and taper and make any table adjustments necessary to ensure that the work will be straight.
I. Rough-grind the job to the rough size. If several pieces are to be done, set the stop on the feed ratchet and proceed as before, roughing the balance of the pieces.
J. After the pieces have been roughed out, place the dog on the rough-ground end of the work and grind the unfinished end. If this end is shorter than the width of the wheel face, it may be plunge-cut ground. Make sure that the grinding wheel is kept sharp and clean by frequent dressing.
K. To finish-grind, set the machine for fast work speed and slow traverse, and dress the wheel by passing the diamond slowly across the wheel face.
L. Insert the piece to be finish-ground and take a light trial cut. Check it for size and make any corrections necessary for removal of taper. If steady rests are used, keep them adjusted to the work.
M. After the first piece has been ground to finished size, reset the stop on the feed ratchet so that the infeed will produce the required size and then set the shoes on the steady rests for the finished diameter.
N. Finish-grind the remaining pieces.

This outline pertains to grinding a plain cylinder. If the work to be ground has shoulders, keyways, or slots, some deviations from the outline must be made. If the work to be ground has a keyway, open at each end, or splines, and steady rests are to be used, the slot must be filled with key stock or other suitable material to prevent the steady-rest shoes from catching on the work.

Sometimes it is desirable to finish-grind a cylindrical piece of work of one diameter in one operation. To accomplish this, a small angle-iron bracket or other suitable projection may be sweated to the end of the work to act as a driver. Be sure when placing the driver that it will not interfere with the overrun of the grinding wheel or the work center. After the grinding is completed, the driver may be removed.

78. *How should a shoulder be ground?*
If the work must be ground to a shoulder, locate the grinding wheel up against the shoulder before starting to grind and then, by plunge-cut grinding, grind the surface to the required diameter. This method will leave the finished diameter with a fairly sharp and square corner at the shoulder. After the job has been ground to size at the shoulder, the balance of it may be ground by traversing the table.

Job Analysis

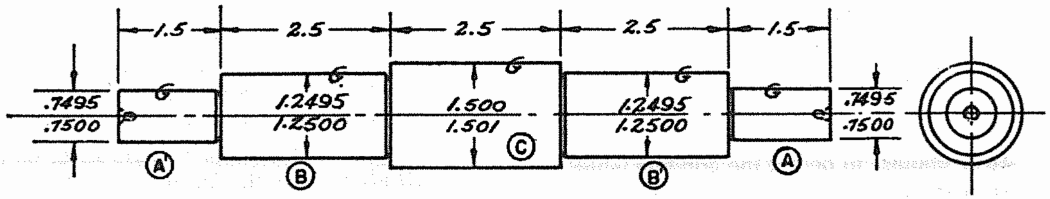
The following outline is a typical analysis of the procedures in external grinding with shoulder work.

Type of job: Shaft as per sketch (Fig. 15–65)
Type of machine: External grinder
Type of material: SAE 5132 steel
Heat treatment: Harden to Rockwell 33-35
Kind of grinding wheel: 60-L
Operations required: Rough- and finish-grind as per sketch

Procedure

A. Check all diameters for sufficient grind stock.
B. Check work centers to see that they are free from dirt and nicks.
C. Dress grinding wheel for roughing cut.
D. Mount a grinder dog of correct size on the work.
E. Set footstock to function for correct length of work.
F. Mount the work in the machine and properly adjust the drive pin to the dog.
G. Feed the grinding wheel to diameter A and take a cleanup cut, seeing that the wheel closely follows the work.
H. Check diameter A for straightness, make any necessary table adjustments, take a trial cut, and recheck the work for straightness.
I. With the wheel cutting straight, plunge-cut diameter A at the shoulder and rough-grind, leaving 0.003 to 0.005 in. for finishing. Repeat this operation on A′, B, B′, and C in the order stated, then have the job inspected.
J. Dress the grinding wheel for finishing and, with the machine cutting straight, finish-grind A, A′, B, B′, and C in that order.
K. Have all dimensions on work inspected.

79. *How is the work checked for size?*
Cylindrical work with dimensions that must be held to close tolerance requires the use of gages calibrated to a finer degree of accuracy than ordinary microme-



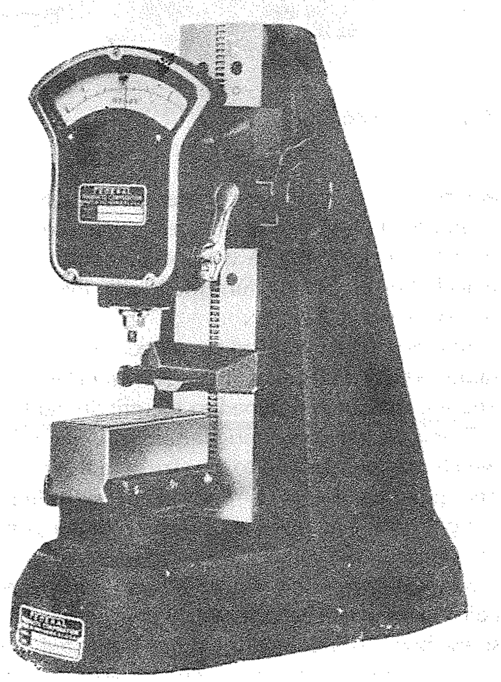
DET 1—SHAFT
1—TYPE SAE 5132 STEEL
STK 1¾ DIA WT 7½ LB
HARDEN—ROCKWELL 33–35
GRIND

 Fig. 15–65. Sketch of a shaft.

ters. For this purpose, a supersensitive comparator is used. There are several makes of comparators, one of which is shown in Fig. 15–66. The indicator is graduated in 0.00005-in. divisions so that very small variations in size may be easily detected. A common method of checking a piece of work is to place a combination of gage blocks equal to the required dimension on the comparator anvil, and to adjust the indicator to read zero. The gage blocks are then removed and the work is placed under the indicator with a sliding or rolling motion, depending on the shape of the work. Any variation between the size of the gage blocks and the size of the work is then noted on the indicator dial.

80. *Can taper work be ground on a cylindrical grinder?*
Accurate taper work can be produced on the cylindrical grinder by swiveling either the worktable or the headstock. For slight tapers, the table may be set with the swivel adjustments and table graduations, as in Fig. 15–67, but, because this can be only approximately accurate, a standard taper ring gage, female taper gage, or sine bar is necessary to check

Fig. 15–66. Supersensitive comparator. (Federal Products Corp.)



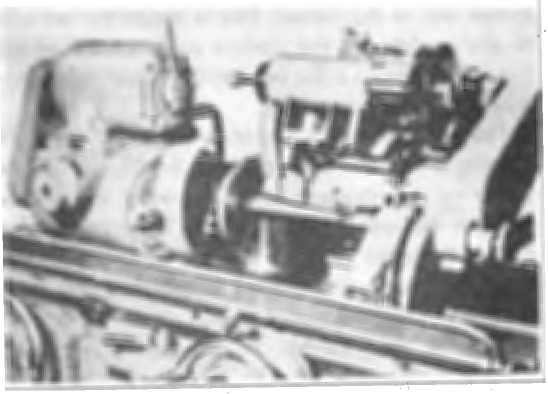


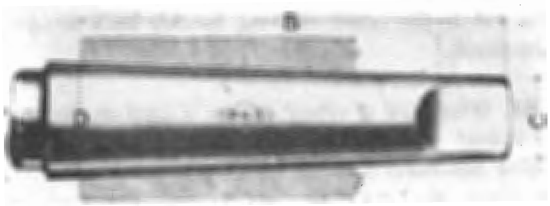
Fig. 15–67. Grinding a taper. (Cincinnati Milacron Co.)

the taper. Grinding tapers is very much the same as grinding a cylinder, except that the swivel table or wheel-stand slide is set to produce the correct taper angle. Generally, the graduation on the scale marked degrees is one-half of the whole taper angle, whereas taper per foot or percentage indicates the whole taper angle.

If a taper ring gage (Fig. 15–68) is used for checking the accuracy of the taper, the male section should be given three lengthwise stripes of prussian blue about 120° apart and then carefully inserted into the ring gage with a slight twisting motion. If the surface being checked does not conform to the surface of the gage, the irregularity rubs the blue off and leaves a bright metallic ring, indicating the high spot. If the gage bears only on one or two lines, it indicates that the piece being tested is out of round.

Steep tapers can be produced by swiveling the workhead or by dressing the wheel at an angle. If the wheel is to be dressed at an angle, it is absolutely necessary to have the diamond set on the exact

Fig. 15–68. Taper-ring gage and tapered shank. (Morse Twist Drill & Machine Co.)



center line of the wheel. This is necessary not only to ensure dressing the correct angle on the wheel, but also to obtain a flat face on the wheel rather than a concave or convex face.

The 60° point on a machine center is ground by placing it in the live spindle of the headstock and swiveling it through a 30° angle, using the graduations on the base of the headstock. These graduations cannot be relied upon for extreme accuracy of measurement. After a preliminary grinding, the work should be checked with a gage such as the flat style shown in Fig. 15–69, or the bell-center gage shown in Fig. 15–70. The necessary adjustments can then be made to the machine to ensure accurate results.

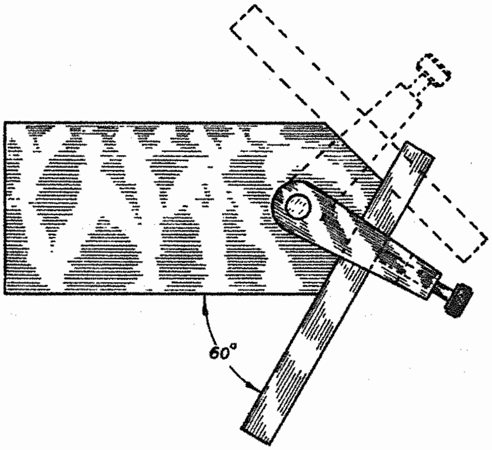


Fig. 15–69. Flat center gage.

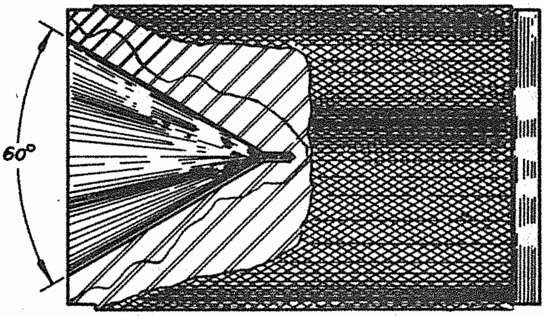
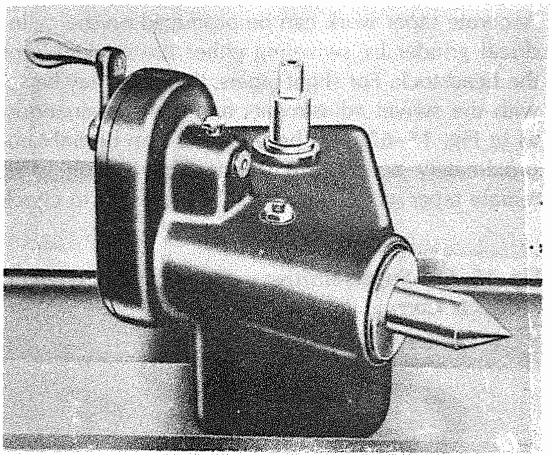


Fig. 15–70. Bell center gage.

Fig. 15–71. Center-grinding fixture. (Cincinnati Grinders, Inc.)



Another method for grinding centers is to use a center-grinding fixture (Fig. 15–71), which is designed to hold the center at the proper angle. A handle attached to a set of gears is used to revolve the center against the grinding wheel.

Machine centers must be ground very carefully. The steep taper changes the work speed, which may result in the point's being burned. This hazard may be overcome by using a slow work speed, a small infeed, and a flood of coolant and by starting the cut at the point, moving quickly back toward the shank.

81. *What type of wheel dresser is used on external grinders?*

Some provision is made on all external grinders for dressing the grinding wheel. The footstock is equipped with a suitable holder so arranged that it is adjustable and can be located on the center line of the wheel spindle. A type of diamond holder or wheel dresser usually furnished with the machine is shown in Fig. 15–72.

Another type of grinding wheel dresser is the radius wheel-truing attachment shown in Fig. 15–73. The attachment is fastened to the grinder table with a T bolt. A swiveling upright holds a diamond tool, which may be adjusted to the size of radius required. The grinding wheel is dressed by swiveling the upright back and forth against the rotating grinding wheel.

Some machines are equipped with a micrometer-adjustment wheel dresser, which consists of a hollow screw body surmounted by a dial graduated to read in thousandths of an inch, which passes through a

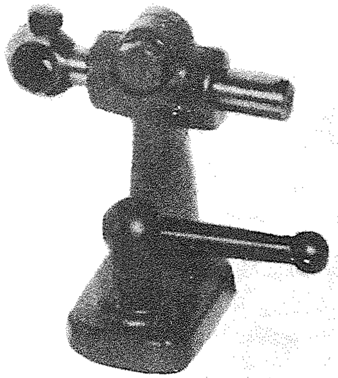
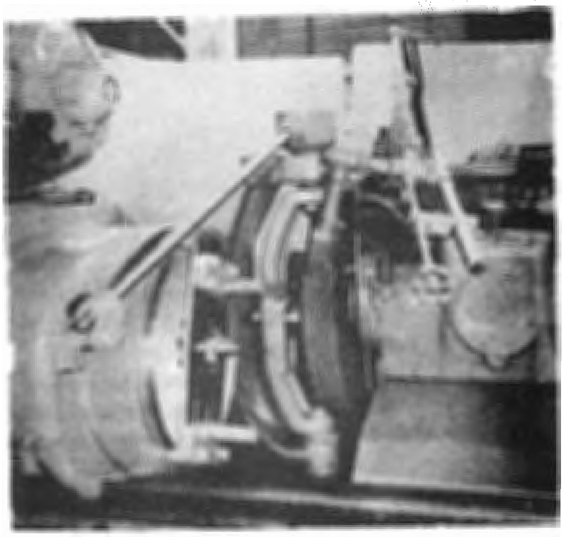


Fig. 15-72. Diamond-holder grinding-wheel dresser. (Brown & Sharpe Mfg. Co.)

Fig. 15-73. Radius wheel-truing attachment. (Cincinnati Milacron Co.)



threaded hole located on the axis of the footstock center. The diamond is inserted in the hollow screw and locked in place by a setscrew. This dresser is very efficient, especially when the job consists of a number of pieces of the same size. After the first piece has been reduced to size, the point of the diamond is spotted on the grinding wheel so that the distance from the axis of the footstock center to the tip of the diamond is equal to the radius of the work. The micrometer screw is then locked in place, ensuring the correct sizing ability of the wheel.

Safety Rules for External Grinders

A. Under no circumstances attempt to operate an external grinder unless the wheel is guarded adequately. Always wear safety glasses.
B. When a large external-grinding wheel must be replaced, ask the instructor about methods of proper mounting and testing.
C. Before starting the workhead, always test the work to see that it is between centers.
D. It is important to let the external grinder run for a few minutes to give it a chance to warm up.
E. During the warm-up time, let the coolant run on the wheel to balance it. Coolant drains overnight to the bottom of the wheel, causing it to be out of balance.
F. Check the stops, feed trips, and levers to make certain that the wheel does not run into the machine and damage it.
G. Poorly adjusted drivers, loose dogs, defective center holes in the work, and so forth are a constant danger on the external grinder. They cause the work to spin. Adjust the driver correctly and securely, fasten the drive dog tightly, and inspect the center holes in each piece of work before grinding it.
H. Keep a good stream of coolant running at the point of contact between the wheel and work; it helps dissipate the heat, tends to give the work a better finish, and keeps the wheel clean.
I. Keep your hands away from the moving wheel and the work.
J. If the work must be tested for size while it is between centers, be sure to allow ample clearance between your hands and the grinding wheel. Do not test for size while the wheel is running.
K. Be extremely careful in removing work from a collet head. Run the table back to a safety stop, which will give ample hand clearance between the wheel and work.
L. If the work is heavy, shut the machine down when placing the work between centers.
M. Avoid dressing the sides of a large grinding wheel, but if it is necessary for the job, ask the instructor to help. He will demon-

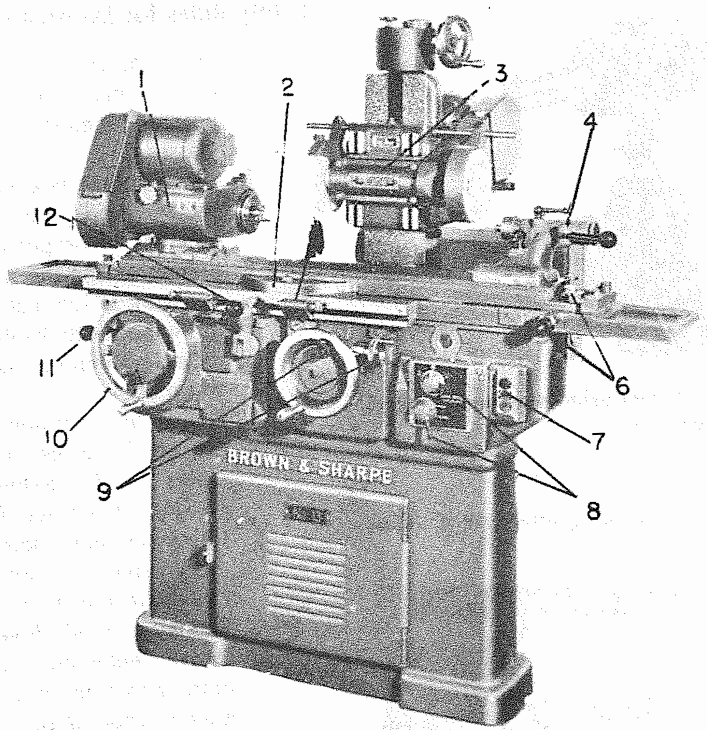


Fig. 15–74. Universal tool grinder. (Brown & Sharpe Mfg. Co.)

1. Motor-driven headstock has both dead-center and revolving-spindle drive. Swivels on graduated base. Knob at front releases belt tension and frees spindle for truing up work.
2. Swivel table turns on stud to 90° either side of zero. Double scale, graduated to degrees, indicates setting from either of two zero marks.
3. Double-ended wheel spindle carried in sturdy slide. Has vertical adjustment of 8⅜ in. Either plain-bearing or antifriction-bearing spindle available.
4. Footstock clamped in position by lever. Spindle operated by spring lever (pressure adjustable). Spindle hand clamp provided.
5. Table-reversing dogs quickly positioned along T slot and rack. Have fine thumb-screw adjustment.
6. Spring latch and knob for fine adjustments of swivel table. Latch engages knob.
7. Main start-stop push button conveniently located. Starts and stops wheel spindle and table motors and energizes line to headstock motor switch.
8. Levers provide six changes in rate of power table travel in two series: 7¾, 13, and 24 in. per min. and 32, 54, and 100 in. per min.
9. Fine cross-feed operated by small handwheel graduated to read to 0.0001 in. on work diameter; engaged by knob on cross-feed handwheel.
10. Handwheel for hand table travel. Convenient three-position lever (not visible in this view) at side of handwheel permits quick selection of two rates of hand travel or disengagement of handwheel. Knob on front of handwheel can be moved to give play between rim of handwheel and hub; this facilitates "bumping" when it is desired to move table only slightly.
11. Lever may be positioned to start and stop headstock motor or to start and stop headstock motor and power movement of table. Disengages table handwheel when set for power table travel.
12. Table-reversing lever; operated manually or by dogs. Has positive stop for grinding to shoulders.

strate how to dress the wheel and how cuts can be taken to preserve the corners of the wheel.

N. Do not put your hands on revolving material with any open work in it such as keyways, slots, and flutes.

O. Be careful when handling sharp tools such as drills, reamers, and cutters; otherwise severe lacerations may result.

P. If something goes wrong, stop the machine and call an instructor or foreman.

82. *How does the universal grinder operate?* Another type of grinder is rapidly being accepted as a utility machine: the universal tool grinder (Fig. 15–74). It can do the work of many other grinding machines, provided the necessary attachments are available. This machine is truly universal; the wheel-spindle unit is adjustable both horizontally and vertically and can be swiveled in a horizontal plane 110° either side of zero. The headstock has both dead-center and revolving-spindle drive, is adjustable along the table, and may be swiveled on its base 100° each side of zero. The table may be traversed by hand or by power with adjustable automatic reverse, and it may be swiveled 90° in either direction. Because of its adaptability, some shops use only universal grinders; other shops use them for work that might interfere with the continuous operation of specialized machines. Some operations performed on a universal tool-grinding machine are shown in Figs. 15–75 through 15–78.

Fig. 15–75. Face-grinding a job held in a magnetic chuck. (Cincinnati Milacron Co.)

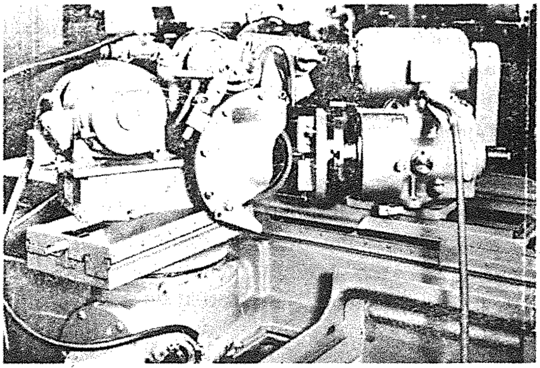


Fig. 15–76. Grinding a job held in a fixture. (Cincinnati Milacron Co.)

Fig. 15–77. Grinding a tapered machine part. (Cincinnati Milacron Co.)

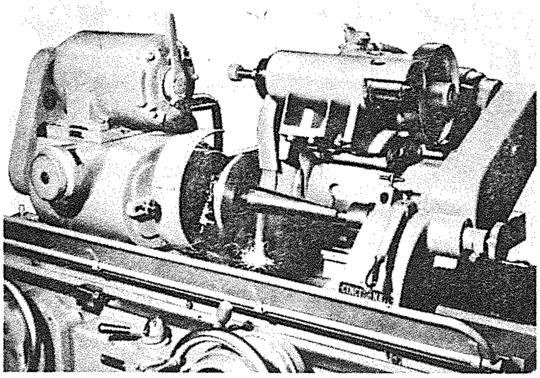
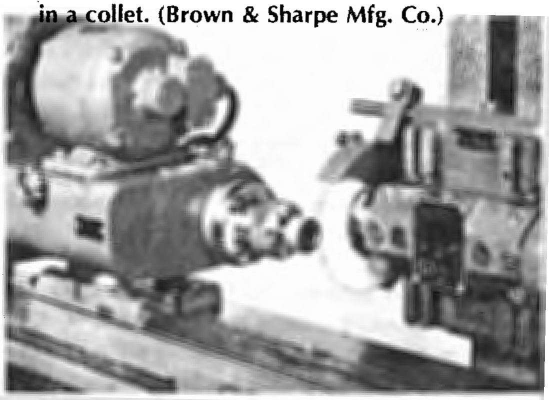


Fig. 15–78. Grinding the diameter at the end of a long part having no center holes. The work is held in a collet. (Brown & Sharpe Mfg. Co.)



83. *How does the centerless grinder operate?* The centerless grinder (Fig. 15–79) is a specialized machine, which was developed for the rapid production of cylindrical, external taper, or external profile work, examples of which are shown in Fig. 15–80.

In centerless grinding, two wheels are employed: One, the cutting or grinding wheel, is used to remove the excess stock; the other, a regulating wheel, is used to control the speed of rotation of the work and rate of feed. The work is supported on a work slide or rest.

Fig. 15–79. Centerless grinder. (Cincinnati Milacron Co.)

This machine has a distinct advantage over other grinders because the work does not have to be center-drilled, thereby saving the lathe time required for that operation. Because the work need not be mounted on centers, and because the grinding operation is almost continuous, loading and unloading time is saved. Furthermore, heavier cuts can be taken than with ordinary methods, and less material is left by the lathe operator to be removed, which saves more time and adds to the life of the grinding wheel. The operation of the machine does not require a skilled machinist. There are few moving parts, so upkeep cost is very low, while the output rate is very high.

Because the external centerless grinder was designed for grinding a large number of pieces of the same size many believe that it is not suited for toolroom use. Actually, because it is simple to set up,

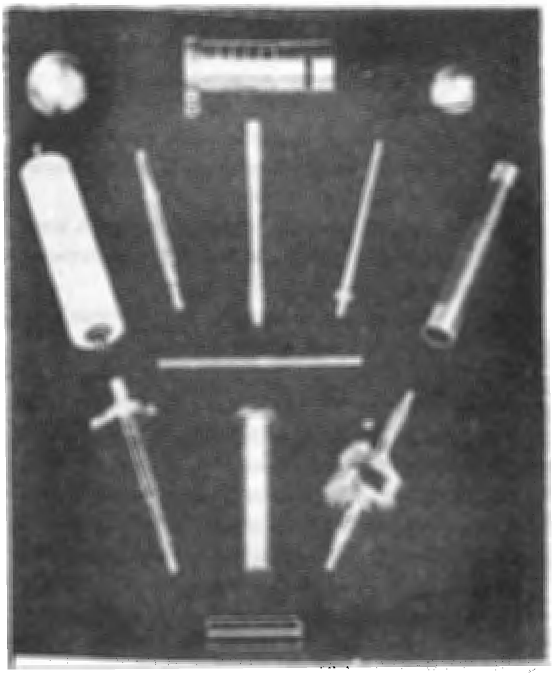


Fig. 15–80. Examples of the kinds of jobs that may be ground on the centerless grinder. (Cincinnati Milacron Co.)

much time and money can be saved when the job lot contains only a few pieces.

The actual grinding operation depends, for the most part, on the pressure exerted by the grinding wheel on the work and the operation of the work with respect to the wheel centers (Fig. 15–81). The pressure exerted by the grinding wheel forces the work against the work rest and regulating wheel. The regulating wheel revolves in the same direction as the grinding wheel and has a horizontal movement. It has a speed of 12 to 300 rpm, and at the same time feeds the work through the machine. The rounding of the work depends on how high the work rests are above the center lines of the wheels and the top angle of the work rest.

84. *How is the work fed to the centerless grinder?* Through-feeding and in-feeding are the common methods used to feed work to the centerless grinder. In the through-feed method, which is used for straight cylindrical work, the work goes in on one side of the machine and comes out on the other side. The work rest for through-feed grinding (Fig.

15–82) has adjustable guides on each end to steer the work between the grinding wheels. These guides must be carefully lined up with each other and with the face of the regulating wheel. The height of the rest blade must also be adjusted to fit the diameter of the work.

Because of a shoulder or some other obstruction some jobs can only enter the machine so far and must be withdrawn after the grinding is done. Infeed grinding is used for these jobs. The work rest for this operation does not have guides, but does have an adjustable stop on the far end (Fig. 15–83). The lever operates a plunger in the stop to eject the work.

The amount of material to be ground determines whether the work is passed through the grinding wheels more than once. If an average finish is required, up to 0.008 in. may be ground off during one pass through the machine. If a really fine finish is desired, it is best not to grind off more than 0.003 in. at the final pass.

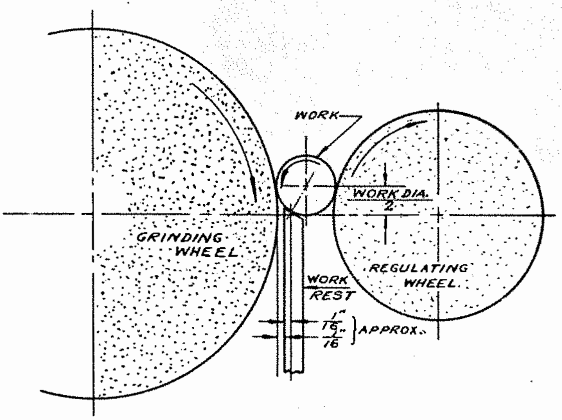


Fig. 15–81. Sketch showing the rotation of the grinding wheel, the regulating wheel, and the work.

85. *What kind of work can be done on an internal grinder?*
Internal grinding is the operation of grinding straight cylindrical, tapered, or formed holes to accurate size. The work is done on the plain internal grinder, the universal internal grinder, (Fig. 15–84), or other machines especially designed for that purpose.

Internal-grinding machines are divided into three groups, depending on the manner in which the work is held and the technique of operation. The two kinds already mentioned are known as the work-rotating type in which the work is held in place

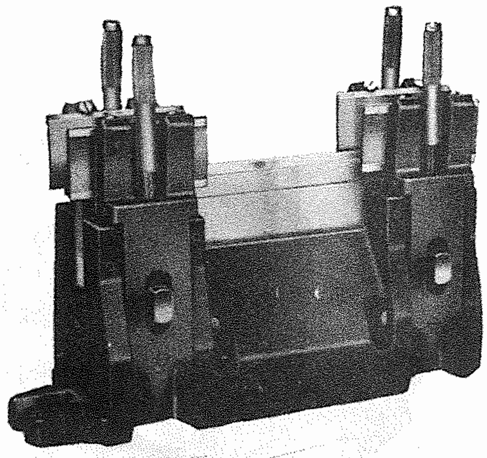
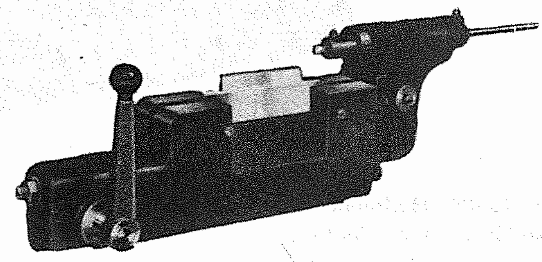


Fig. 15–82. Through-feed work-rest and guide for centerless grinder. (Cincinnati Milacron Co.)

Fig. 15–83. Work-rest with ejector for infeed centerless grinding. (Cincinnati Milacron Co.)



by a chuck, collet, faceplate, or special fixture. Another group of internal grinders is the centerless kind in which a set of rollers hold the work and give it a revolving motion. A third type is the cylinder grinder, which holds the work in a fixed, nonrotating position on a reciprocating table and depends on the amount of eccentric wheel-spindle travel to generate the correct size of the hole to be ground.

86. *How does the work-rotating-type internal grinder operate?*
The work-rotating type is the kind of internal grinder commonly used in tool and die rooms. The work head is mounted on the worktable, which in some cases moves back and forth. On most machines, the wheel head moves back and forth, with the worktable in a fixed position. A chuck, faceplate, or drive plate may be attached to the spindle nose.

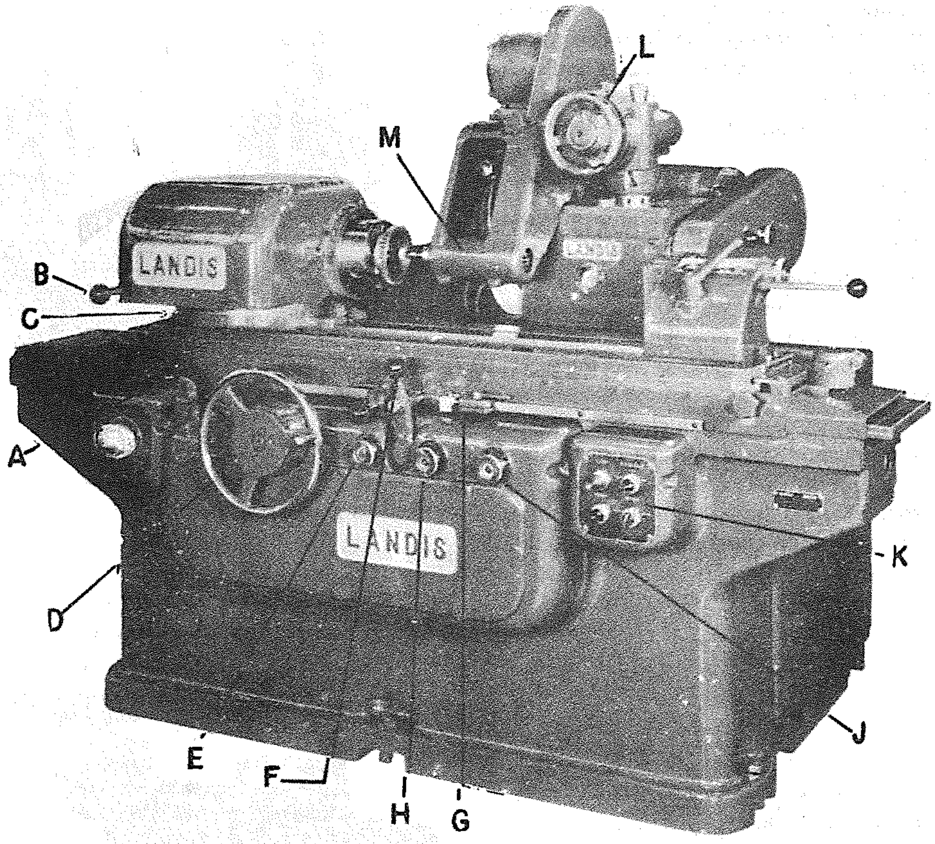
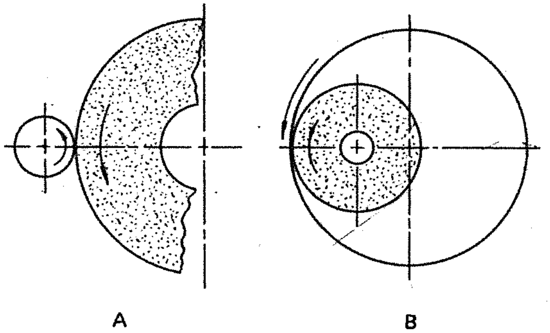


Fig. 15–84. Hydraulic universal internal grinding machine. (Landis Tool Co.)
A. On-and-off control lever
B. Lever to operate collet for holding work
C. Swivel base of work head
D. Hand-traverse wheel
E. Traverse speed-control valve
F. Traverse-reversing lever
G. Reversing dogs
H. Traverse-reversal tarry control
J. Automatic feed selector
K. Electrical controls
L. Cross-slide handwheel for feeding grinding wheel into work
M. Grinding wheel head

Because the work done on internal grinders in toolrooms is generally ground dry, these machines have to be built to much closer specifications than other grinders; it is harder to protect the vital parts from the ever-present abrasive dust, and the grinding wheel and work speeds are much faster than on other types of grinders. For the same reasons, internal grinders should be kept well lubricated.

The center line of the grinding wheel and that of the work on internal grinders are in the same horizontal plane, but because the grinding wheel is smaller than the hole to be ground, the two are not in the same vertical plane; for this reason, the grinding wheel must contact the work on the near, or far, side of the hole depending on the construction of the grinding machine. Figure 15–85 shows the relation of the internal-grinding wheel to the work.



ig. 15–85. Relation of grinding wheel to work urface. (A) External. (B) Internal.

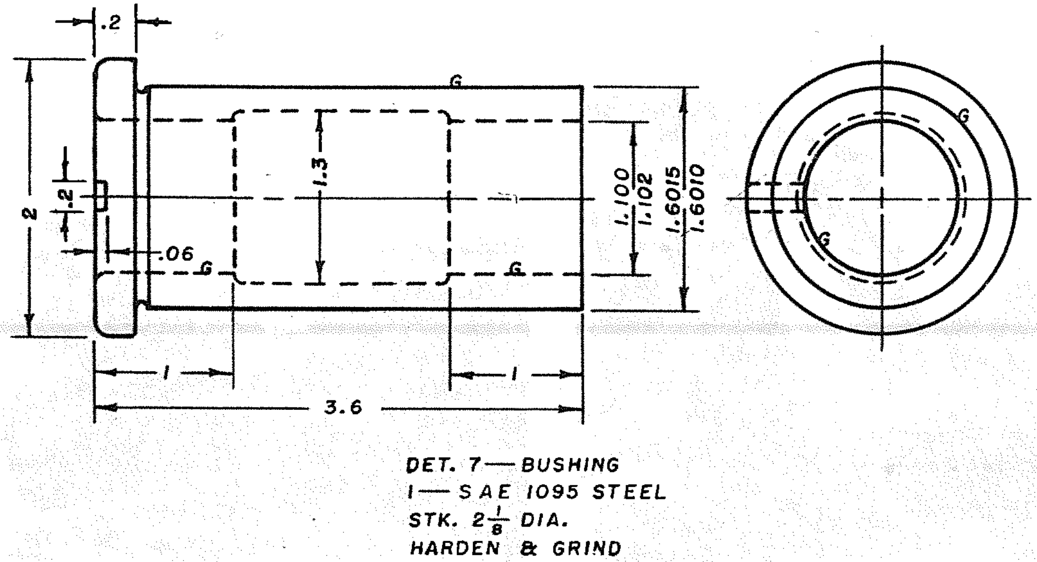
ob Analysis

'he following outline is a typical analysis of the rocedure in internal grinding.

Type of job: Bushing as per sketch (Fig. 15–86)
Type of machine: Internal grinder
Type of material: SAE 1095 steel
Heat treatment: Harden to Rockwell 52-64
Kind of grinding wheel: 60-K
Operations required: Rough-and finish-grind ID as per sketch
Method of holding: Four-jaw chuck

Procedure

A. Check ID for sufficient grind stock.
B. Mount a four-jaw chuck on the headstock and adjust the work in the chuck so that it runs true.
C. Select the proper quill (spindle) and grinding wheel, mount them on the wheel head, and dress the wheel. The proper quill to use is one that is as short and strong as possible, consistent with the length and diameter of the hole to be ground.
D. Adjust the machine for length of stroke, and set the table to grind straight, that is, without taper.
E. Take a trial cleanup cut, removing as little stock as possible.
F. Check the hole for straightness and make any necessary table adjustments.
G. With the wheel cutting straight, rough out the hole to within 0.001 or 0.002 in. of the required size.
H. Dress the grinding wheel for the finishing operation and finish-grind the hole to size.
I. Check the hole with the proper size of gage, noting any bellmouthing or out-of-roundness.
J. Have the first piece of work inspected.



ig. 15–86. Sketch of bushing.

87. *What methods are used to hold work on an internal grinder?*

A piece of work may be held in a required position on the work head of an internal grinder in many different ways, depending upon the size and shape of the work. The most common method is to hold the work in a four-jaw chuck, as in Fig. 15–87, which shows the grinding of an internal taper, and Fig. 15–88, which shows the grinding of an internal ring gear.

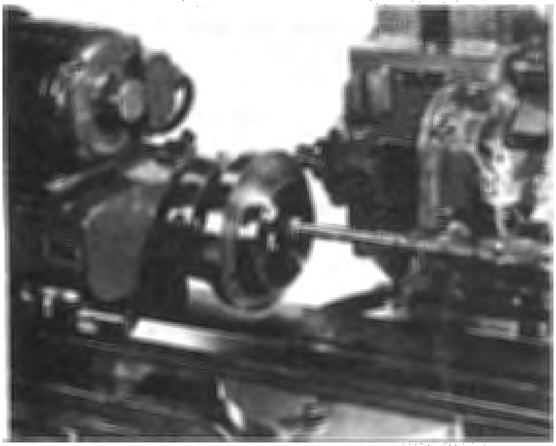
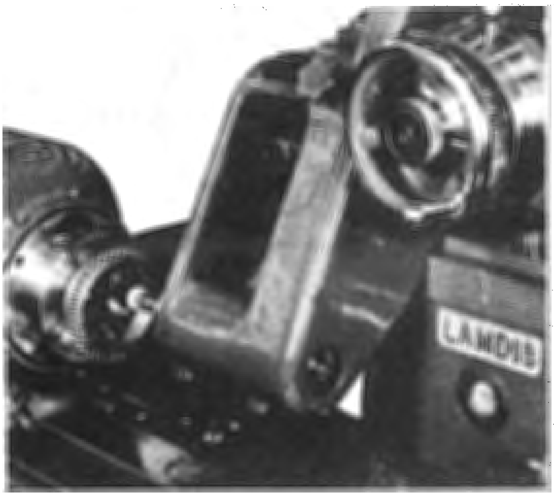


Fig. 15–87. Work held in a four-jaw chuck while grinding an internal taper. (Brown & Sharpe Mfg. Co.)

Fig. 15–88. Grinding the ID of a ring gear held in a four-jaw chuck. (Landis Tool Co.)



Another method is to use a magnetic chuck. Figure 15–89 shows a bushing held in this manner. Work may also be fastened to a faceplate with U clamps and T bolts in the same manner as one would fasten a piece of work to the table of a milling machine or a shaper. It is usually set directly on the faceplate. However, it is sometimes necessary, when grinding work of an uncommon shape, first to attach the job with C clamps to an angle plate, which is then fastened to the faceplate. Similarly, V blocks are sometimes used to hold a job in the required position, the V block being then fastened to the faceplate.

Long pieces of work are held in a chuck at one end and supported near the opposite end by a steady rest, or, as in Fig. 15–90, with a center rest. A long

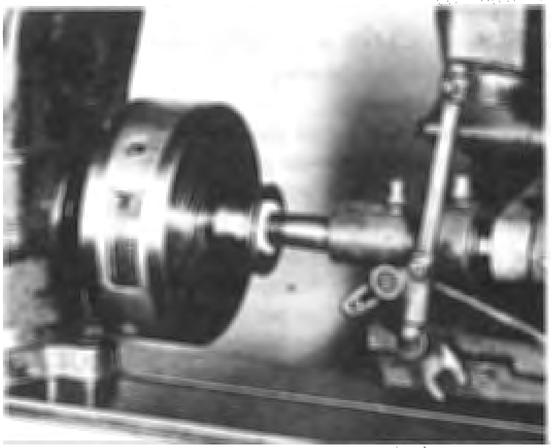
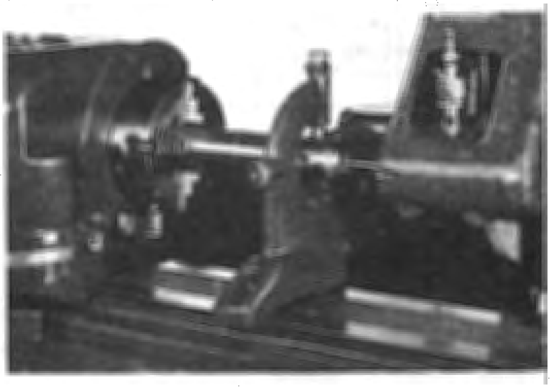


Fig. 15–89. Grinding the inside of a bushing held on a magnetic chuck. (Brown & Sharpe Mfg. Co.)

Fig. 15–90. The end of a long piece of work is supported by a center rest. (Landis Tool Co.)



piece of work that cannot be conveniently placed in a chuck may be held on a center and secured to a drive plate with straps of rawhide at one end and supported at the other end by a steady or center rest.

When a piece of work is placed in a four-jaw chuck, care must be exercised to get the work running true. Figure 15–91 shows a job in the chuck and the points at which it must be indicated to make sure that it is running true. The dial indicator is placed first at point A and the chuck jaws adjusted to give a minimum of runout to the work at that point; then the dial indicator is moved to point B. At this point, the work must be forced into line by tapping it with a mallet. This procedure should be repeated until the job runs true within the required limits at both ends.

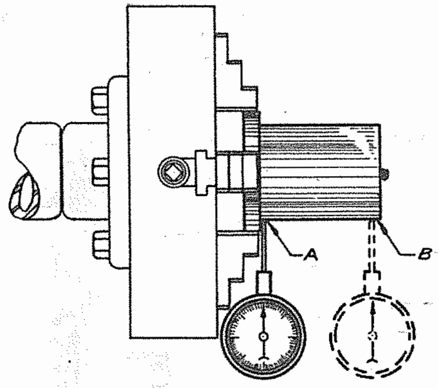


Fig. 15–91. Work must be adjusted in the chuck so that the indicator readings at A and B are the same.

When holding thin-walled bushings in a chuck, the jaws should be tightened only enough to hold the work; otherwise, the pressure exerted by the jaws will squeeze the bushing out of shape and so distort the hole. For similar reasons, when clamping work to a faceplate, be sure that the work is firmly seated, and that the pressure is evenly distributed and just sufficient to hold the work firmly.

Figure 15–92 shows a correct and an incorrect method of clamping work to the plate. On the right-hand side, note (a) that the clamp is not parallel with the faceplate because the rest block is too high, (b) that the bolt is too far away from the job, and (c) that the parallel, which is placed there to provide end clearance for the grinding wheel, is set too far toward center, and so will interfere with the grinding operation. The bolt, clamp, rest block, and parallel are shown in their correct position on the left-hand side.

Out-of-roundness may be due to improper support, overheating, loose work-head spindle, improper clamping, and so forth.

Generally speaking, the operator of an internal grinder is required to do either internal cylindrical grinding or internal taper grinding. Internal cylindrical grinding can be performed only if the wheel-heads and work heads are coordinated so that the axis of rotation of each are moved in parallel planes. This condition can be brought about by adjusting either the work head on its swiveled base or the worktable, so that the horizontal center line of the work will be parallel to the back and forth movement of the worktable or wheel head.

88. *How can an internal taper be ground?*
Internal tapers can be ground by swiveling the work head or by an adjustment to the table. Extreme taper is produced in the work by swiveling the work head to one-half the taper angle, according to the graduations on the circular base of the head. Slight tapers may be produced by adjusting the table to the correct taper per foot. These graduations are obviously not accurate enough for precision work, so a taper plug gage of the correct taper per foot is used for checking the work after a cleanup cut is taken. The plug gage is given a light coat of prussian blue and with a twisting motion is inserted in the hole to be checked. If

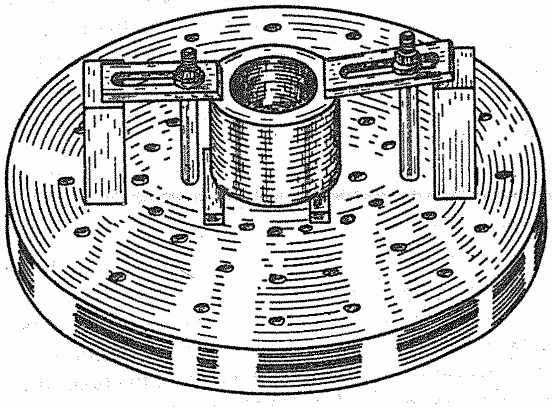


Fig. 15–92. Correct (left) and incorrect (right) methods of clamping work to a faceplate.

the two tapers are not identical, a bright metallic line, or surface, will show on the plug gage. This line, or surface, will indicate whether the taper is too much or not enough. If the head has been swiveled too much, the brightened surface will appear on the small end of the plug gage. If the head has not been swiveled enough, the brightened surface will appear on the large end of the plug gage.

When using plug gages for checking work, be careful that the plug does not freeze in the hole. *Freeze* is the term applied to a condition where the plug is held fast by the work and is brought about by the fact that the heat of grinding causes the work to expand; when a cold plug gage is inserted, the work contracts, thus locking or freezing the plug gage in the work.

When a number of pieces are being ground, this freezing may be prevented by keeping the plug and the work at the same approximate temperature. Leave the plug gage in the hole of the last piece ground until it is necessary to check the hole in the next piece. This keeps the plug gage warm and helps to prevent freezing.

89. *What determines the size of the grinding wheel?*
The diameter of the wheel for internal grinding is based on securing the stoutest-possible quill for maximum support consistent with the size of the hole to be ground. Generally speaking, the diameter of the grinding wheel should not exceed two-thirds of the diameter of the hole. It must be remembered that, as the size of the grinding wheel increases and the diameter of the hole remains constant, the greater the area of contact becomes between the grinding wheel and the hole, thus increasing the heating of the work and the probable distortion of the hole.

Manufacturers build the limits of grinding wheel speed into the machine; these limits are such that speeds from 4,000 to 6,500 sfpm can be obtained, depending on the size of the wheel.

Various kinds of diamond or tungsten carbide dressers are available for either mechanical or hand dressing. Occasionally, grinding wheels are dressed with a piece of silicon carbide, held in the operator's hand and passed along the wheel's periphery.

The amount of stock left in a hole, which must be removed by grinding to bring it to the required size, depends on the diameter and length of the hole; it is generally from 0.004 to 0.012 in. More grind stock than this means a longer grinding time.

Bellmouthing is a condition in which the ends of the hole flare out or are increasingly larger than the required diameter. It occurs if the grinding wheel overruns the ends of the hole, if the grinding wheel is too hard, if wheel pressure is excessive, or if the grinding wheels are too short. The first condition can be prevented by setting the length of stroke so that only one-quarter to one-half of the grinding wheel face will be uncovered by the work at the extremity of the wheel's travel.

The job should be checked for size and straightness after a cleanup cut has been taken, but be sure to move the work and grinding wheel far enough apart to enable the wheel guard (Fig. 15–93) to swing down and cover the wheel. Otherwise serious cuts and burns are apt to be received from the revolving grinding wheel.

Blind holes can be ground on the internal grinder, provided an undercut of sufficient width is made to

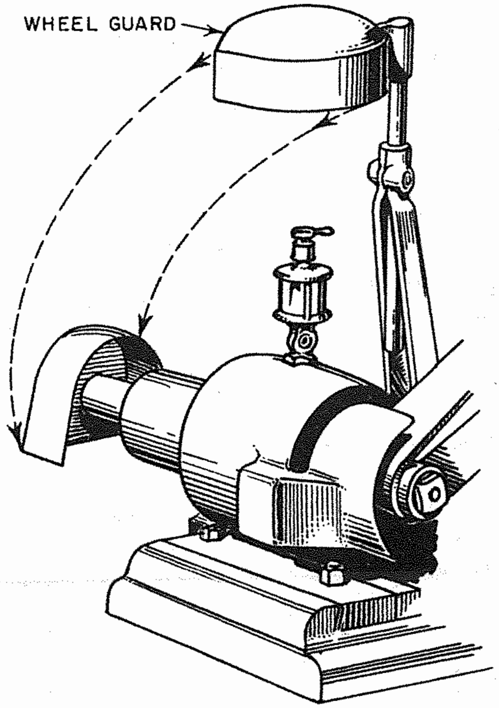


Fig. 15–93. Wheel guard for internal grinding wheel. The wheel guard swings downward to protect the operator but does not interfere with fixtures. It can be adjusted for all sizes of wheel heads.

wheel is mounted near the center of the shaft, which is supported by two bearings. The shaft is driven by a belt connecting it with a motor mounted in the base of the pedestal. The bearings are an integral part of the pedestal casting. The motor also drives a centrifugal pump which supplies a constant flow of coolant to the wheel and the tool being ground.

The bench grinders used for carbide tools are of sturdy construction and have a more precise tool rest or platform, which can be conveniently set and clamped at a specified angle. This makes possible the economical sharpening of carbide tools, with the least wear of the diamond wheels used for this purpose.

All bench and pedestal grinders should be equipped with adjustable eye shields made of safety glass and fitted with electrical lighting. The operator should continue wearing his safety glasses when using a grinder and consider the eye shield as an extra safety precaution.

Sometimes one wheel is removed from the bench grinder and replaced with a buffing wheel. Buffing improves the appearance of a job by giving it a high polish. The buffing wheel is made up of disks of cloth sewn together. A buffing compound, slightly abrasive, is used to coat the working surface of the wheel. When buffing, care must be taken to keep the job a little below the center of the wheel so that it is not pulled into the wheel. By following this procedure, one can avoid a serious accident.

94. *What is a cutter grinder?*

A cutter grinder holds the cutter while a rotating abrasive wheel is applied to the edges to sharpen it. These grinders vary in design from simple, limited-purpose machines to complex universal machines, which can be adapted to any cutter-grinding requirements.

Figure 15–98 is an illustration of a universal cutter grinder that is of particular value for grinding and resharpening all kinds of cutters held in spring chucks or collets. The work head, on the left, may be moved from left to right (longitudinally), and swiveled around through 235°. The wheel head, on the right, may be moved up or down, to left or right, or back and forth.

Another type of cutter grinder is shown in Fig. 15–99. This machine is designed to hold work in a chuck or collets and also between centers. The work head may be moved to a required position on the table and swiveled from side to side. The wheel

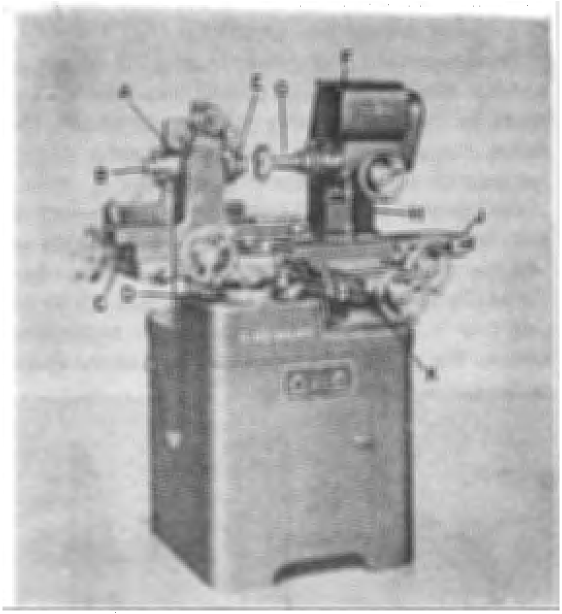
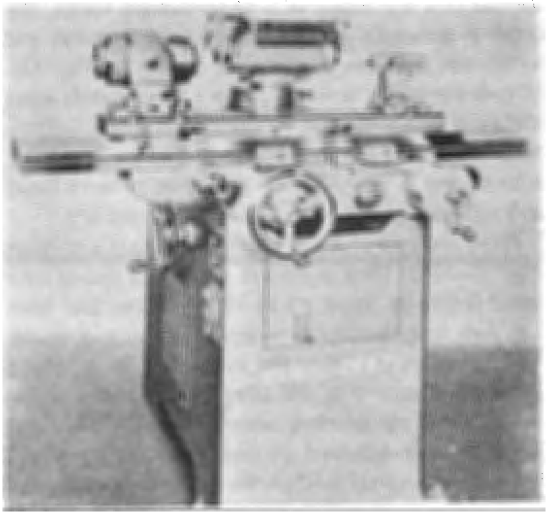


Fig. 15–98. Universal cutter and tool grinder. (Cincinnati Milacron Co.)

A. Work head	**F. Wheel head**
B. Work-head spindle	**G. Wheel-head spindle**
C. Longitudinal slide	**H. Vertical slide**
D. Turntable	**J. Longitudinal slide**
E. Indexing mechanism	**K. Transverse slide**

Fig. 15–99. Cutter and tool grinder. (Cincinnati Milacron Co.)



head may be moved up and down, back and forth, or swiveled around through 220°.

The universal cutter grinder can grind cutters of various shapes by using special attachments and specially formed grinding wheels. Generally the flaring cup, plain or disk, and dish or saucer wheels are used on cutter grinders (Fig. 15–100).

For general-purpose cutter grinding, select a soft, free-cutting wheel and take very light cuts so that the temper is not drawn from the cutting edge. Generally speaking, wheels of grain size 30 to 60 and J or K bond are best adapted for high-speed cutters. The shape of the wheel depends on the shape of the cutter to be sharpened.

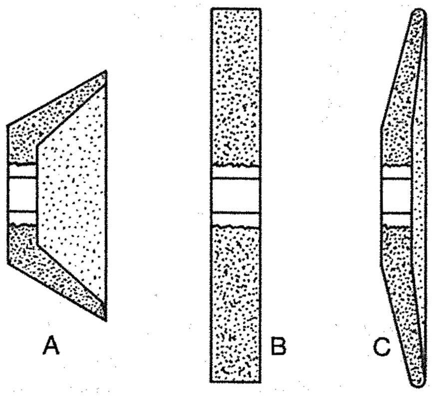


Fig. 15–100. Cutter grinding wheels. (A) Flaring cup wheel. (B) Plain, or disk, wheel. (C) Dish, or saucer, wheel.

95. *Is it difficult to sharpen a plain-milling cutter?* To sharpen the teeth of a plain-milling cutter, the cutter is generally mounted on a lathe mandrel and supported between centers, as shown in Fig. 15–101, or the cutter is mounted on a special stub arbor and held in a universal swivel fixture (Fig. 15–102). After the cutter has been mounted in the machine, a tooth rest is mounted on the table or work head and adjusted to the tooth to be sharpened first.

There are two kinds of tooth rests, plain and hook (Fig. 15–103). They consist of a piece of spring steel about 0.030 in. thick, ½ to 1½ in. wide, and from 1 to 3 in. long, brazed or riveted in a piece of round, cold-rolled steel. They are supported by a forged clamping fixture (Fig. 15–104), bolted either to the worktable or the grinding wheel head. The table and tooth rest are adjusted so that the grinding wheel follows the original land on the back of the tooth and gives the proper clearance. The cutter is then fed to the rotating grinding wheel until sparks indicate contact between it and the wheel; then the table is moved back and forth, traversing the cutter until the wheel has finished cutting. Next, the cutter is revolved backward 180° against the spring tension of the tooth rest and, without changing the depth of cut, a trial cut is taken on this opposite tooth to check for taper. If no taper is apparent, the cutter is revolved backward and the next tooth is sharpened. This process is repeated until all teeth have been sharpened and ground concentric.

Fig. 15–101. Sharpening a plain-milling cutter. (Cincinnati Milacron Co.)

Fig. 15–102. Universal head, or swivel fixture, and accessories. (Cincinnati Milacron Co.)

96. *Explain how to sharpen the teeth of a side-milling cutter.*

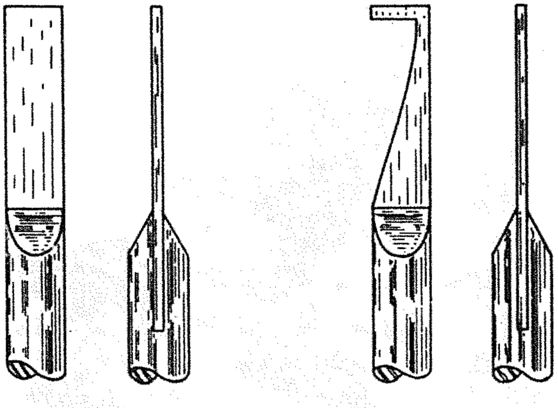
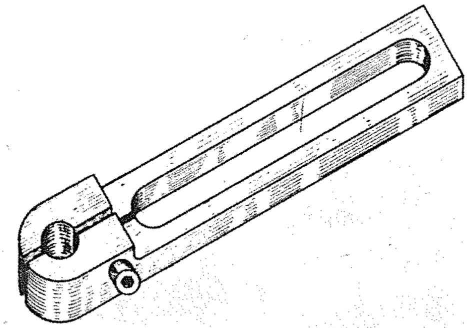


Fig. 15–103. Tooth rests. (A) Plain. (B) Hook.

Fig. 15–104. Clamp for tool rests.



The peripheral teeth of a side-milling cutter are sharpened the same way as those of a plain-milling cutter. To sharpen the side teeth, the cutter is generally mounted on a stub expansion arbor and placed in the universal swivel fixture (Fig. 15–105). The swivel fixture is then adjusted so that the side teeth will be ground about 1° out of parallel with the side of the cutter and have a side clearance of from 3° to 5°. The general practice is to give the teeth of roughing cutters a side clearance of 5° and finishing cutters, 3°. It is important in all cutter grinding to grind all teeth to the same height, so that each tooth will do its share of cutting. For that reason, after the teeth have all been sharpened, a very light cut is taken on each tooth to ensure uniform height.

97. *Are long slabbing cutters difficult to sharpen?*
These cutters, which are of considerable length relative to their diameters, are sharpened the same way as a plain-milling cutter, if they have straight teeth.

Fig. 15–105. Grinding side teeth of side-milling cutter. (Norton Co.)

98. *How can the curved tooth of a helical-toothed cutter be sharpened?*
These are ground and mounted the same as other cutters, but the tooth rest must be mounted in a fixed position relative to the grinding wheel. Generally, the tooth rest is mounted on the wheel head, as shown in Fig. 15–106.

This is done so that the cutter is forced to slide over the tooth rest, causing the cutter to turn in such a manner that the tooth being ground will have the same helical shape as when it was originally milled. When the cutter and tooth rest are properly mounted and the grinding ready to start, the tooth should be pressed lightly against the tooth rest and held there while the table is moved longitudinally. If this is not done, the tooth will leave the rest and the cutter will be damaged.

99. *What techniques must be followed to grind a formed cutter?*
This type of cutter is sharpened by grinding the face of the teeth radially—that is, by grinding the face of the teeth with a dish or saucer wheel so that the face of the tooth comes on the radius of the cutter.

The machine is set up for grinding the formed cutter by bringing the centers in line with the face

Fig. 15–106. Tooth rest mounted on wheel head when grinding a helical-tooth cutter. (Brown & Sharpe Mfg. Co.)

of the grinding wheel. If this is not done, the cutter will not have the correct shape.

The cutter, mounted on a mandrel, is placed between the centers and the face of the tooth brought against the grinding wheel. The tooth rest is then set against the back of the tooth. Move the table longitudinally, clear the wheel from the work, start the wheel, and take a trial cut. To adjust the work to the wheel while grinding, revolve the cutter by moving the tooth rest toward the grinding wheel. This practice keeps the faces of the teeth radial and maintains the correct shape of the tooth.

Various methods are used to control the proper spacing of the teeth. In Fig. 15–107, a master form with the same number of teeth as the gear cutter to be sharpened is placed securely on the end of the mandrel. The tooth rest is then placed in turn under each tooth of the master form.

100. *Are angular cutters difficult to sharpen?*
To sharpen an angular cutter, the cutter is mounted on a stub expansion arbor and placed in a swivel fixture (Fig. 15–108). The fixture is then swiveled to the desired clearance angle and the tooth rest set on the exact center line of the cutter. Adjust the grinding wheel to the cutter by raising or lowering the table so it will grind the tooth supported by the tooth rest and allow the tooth immediately above to clear the grinding wheel, as illustrated. If the tooth

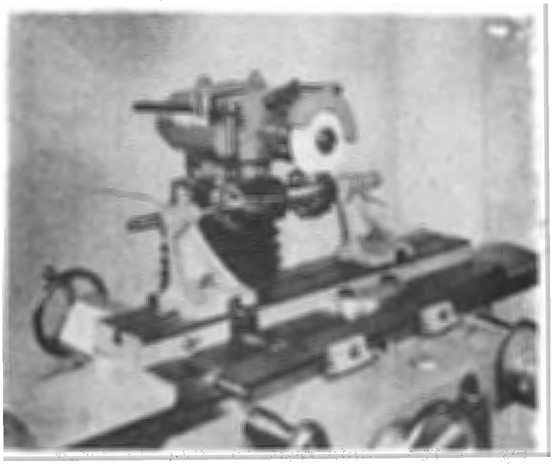
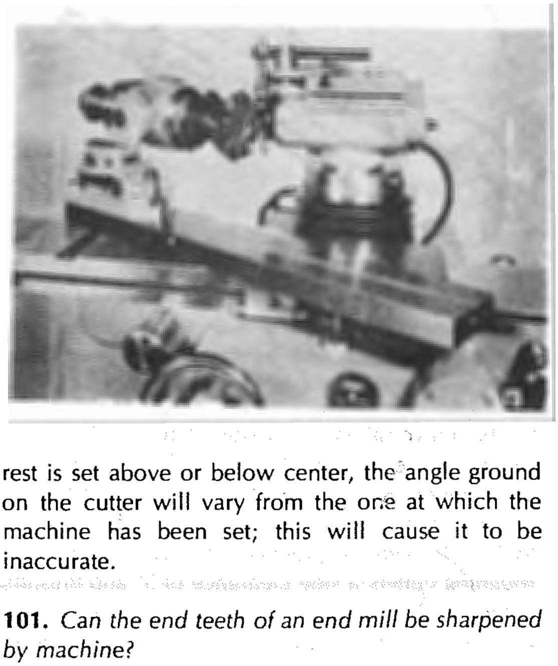


Fig. 15–107. Using a master form for spacing and supporting while sharpening a milling cutter. (Cincinnati Milacron Co.)

Fig. 15–108. Grinding an angular cutter. (Cincinnati Milacron Co.)



rest is set above or below center, the angle ground on the cutter will vary from the one at which the machine has been set; this will cause it to be inaccurate.

101. *Can the end teeth of an end mill be sharpened by machine?*
Whether the end mill is straight or helical, end teeth are ground the same way as the side teeth of a side-milling cutter. The end mill is held between centers. The tooth rest is set on the wheel-spindle slide (Fig. 15–109), or it may be held in the V block of the universal head, as in Fig. 15–110.

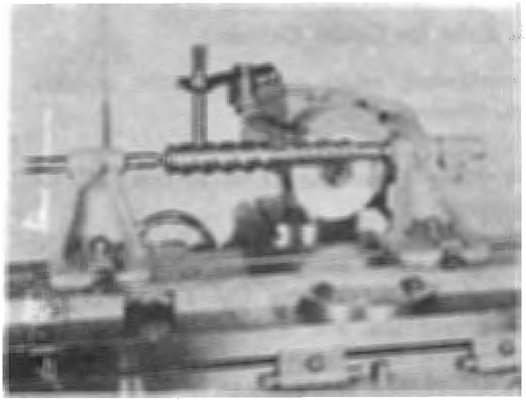
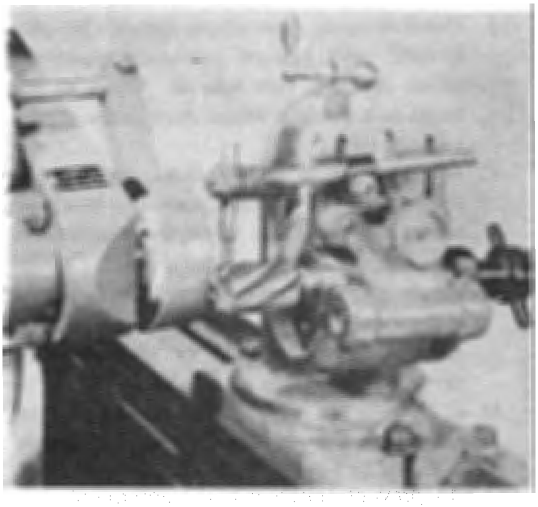


Fig. 15–109. Grinding a helical cutter between centers. (Cincinnati Milacron Co.)

Fig. 15–110. Grinding an end mill held in a V block of the universal head. (Brown & Sharpe Mfg. Co.)



102. *How are the teeth of a concave or convex cutter sharpened?*
This type may be sharpened with the aid of a radius-grinding attachment. The edge of the grinding wheel is first dressed to the radius of the cutter. As shown in Fig. 15–111, the wheel head is swiveled to bring the wheel in position to face the cutter. The cutter is held on a mandrel by the work holders. The work slide and the base are then adjusted so that as the swivel is turned the grinding wheel contacts the surface of the cutting edge of the cutter perfectly. Note the position of the tooth rest.

Fig. 15–111. Sharpening the edges of a concave cutter with a radius-grinding attachment. (Brown & Sharpe Mfg. Co.)

103. *What are the shapes of the wheels most commonly used to grind cutters?*
As noted previously, three wheel shapes are commonly used for cutter grinding: *disk, flaring-cup,* and *saucer* wheels. The saucer wheel is used to grind formed cutters; the disk wheel is used to grind the clearance on cutters with narrow lands on the teeth; the flaring-cup wheel is used to grind clearance on teeth with wide lands, and to gum out slitting saws and the spacing between the teeth of milling cutters.

In actual practice, the grinding wheel revolves downward toward the cutting edge, so that the action of the wheel forces the tooth against the tooth rest, as in Fig. 15–112. This results in a burr or wire edges being left on the tooth, which should be oil-stoned off.

A keener cutting edge, free from burr, is obtained if the cutter to be sharpened is reversed, as in Fig. 15–113. The disadvantage is that it is more difficult to maintain the tooth rest in position because the rotation of the grinding wheel tends to carry the cutter around.

Important Facts to Remember when Sharpening Cutters

A. Keep the cutter tooth firmly against the tooth rest.

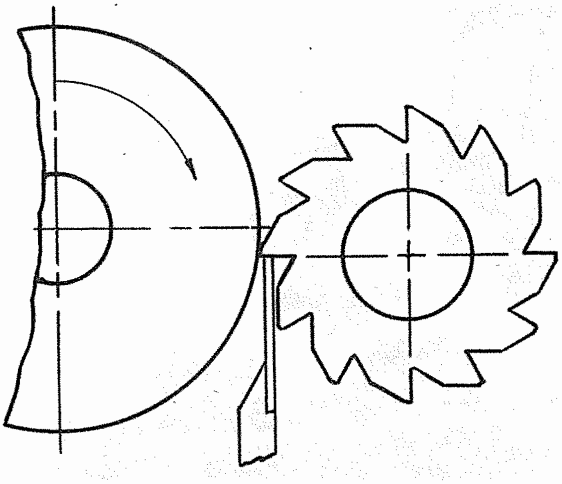
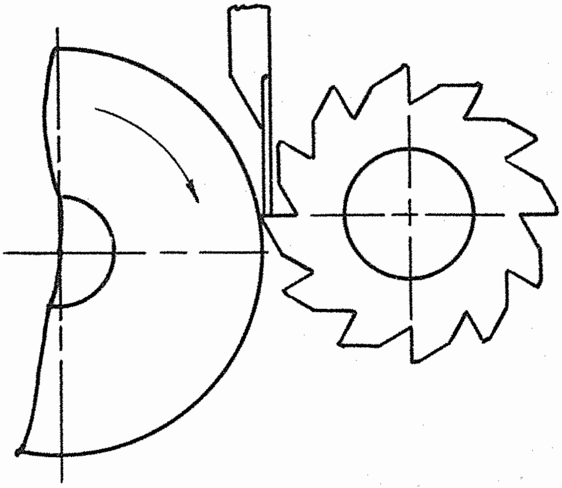


Fig. 15–112. In this arrangement the grinding wheel rotates off the cutting edge.

Fig. 15–113. In this arrangement the grinding wheel rotates on to the cutting edge.



B. Make sure the grinding wheel follows the original land on the tooth.
C. Mount the tooth rest correctly.
D. Keep the cutting surface of the grinding wheel clean.
E. Don't remove any more stock from the tooth than that required to sharpen it.
F. Be careful not to draw the temper of the tooth.

Safety Rules for Cutter Grinders

The following safety rules for cutter grinders must be observed at all times:

A. Always wear goggles on all cutter-grinder work.
B. Under no circumstances is the machine to be started unless the grinding wheel is adequately guarded. Use a guard of the proper size and adjust it closely to the wheel, allowing the minimum amount of wheel exposure with which to work.
C. In mounting wheels on cutter grinders, use standard wheel bushings and safety washers. Use paper washers on large wheels.
D. When hand-dressing wheels, be careful to allow ample hand clearance between the wheel and the table or other parts of the machine.
E. Hand-dressing operations should be performed with a light pressure, especially when dressing thin wheels. A slip of the hand or a broken wheel may cause severe lacerations.
F. Any changes of guards, dogs, centers, setup, tooth rests, or other parts of a machine are not to be made while the machine is running.
G. When grinding spot-facers, counterbores, and so forth in a draw collet, use a special, automatic safety guard, or shut the machine down to remove the work.
H. In backing off drills, spiral reamers, and so forth, see that the tooth rest is properly adjusted in relation to the wheel and work, to prevent slippage and consequent spinning of stock. Ask the instructor about this adjustment.
I. Care should be taken in handling sharp tools such as reamers, drills, cutters, and counterbores because severe lacerations may result from stock slipping through the hands.
J. Towels are not to be used to hold small tools such as spot-facers, counterbores, and similar tools, which become warm while grinding. Ask the instructor how to take care of work of this class.
K. Exhaust hoods are supplied as a safe-

guard for the health of grinder operators. See that they are properly adjusted at all times and that they are not abused.

THREAD GRINDING

104. *Is it possible to grind threads?*
Precision thread grinding has an extremely wide application in modern industry. Many manufacturers of precision-threaded parts depend upon thread grinding to obtain the extreme accuracy that the ever-rising standards of modern industry demand. Special machines have been designed for this purpose.

105. *Can several sizes of threads be ground on external thread grinders?*
An external-thread grinder for general-purpose work is shown in Fig. 15–114. On this type of machine, threads may be ground on work up to 6 in. in diameter and 18 in. long, held between centers. As shown in Fig. 15–115, many different types of threads may be ground, including American National form, 60° sharp V, 29° Acme, modified Buttress, Whitworth, and special thread forms. Threads may

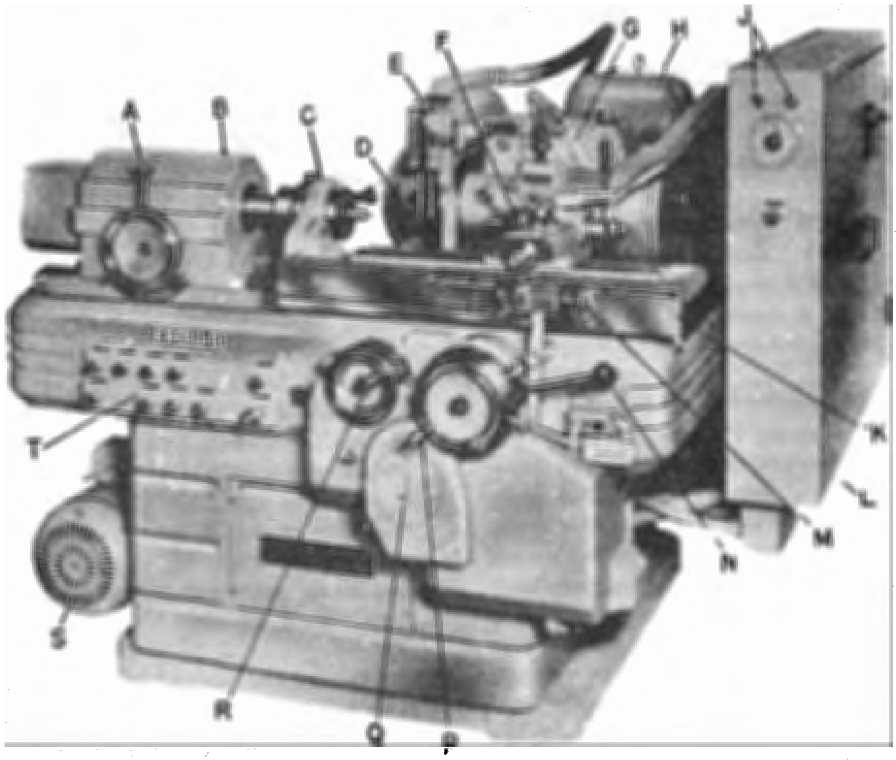


Fig. 15–114. External-thread grinder. (Ex-Cell-O Corp.)

A. Lead pickup
B. Work drive and lead-screw housing
C. Work head
D. Grinding wheel
E. Coolant valve
F. Tailstock
G. Helix-angle graduation
H. Wheel-spindle motor
J. Signal lights indicating dressing of wheel
K. Machine table slide
L. Electrical compartment
M. Table control dogs
N. Automatic cycle-starting lever
P. Size-setting handwheel
Q. Opening to adjust depth of initial grinding cut
R. Manual-dresser slide adjustment
S. Work-drive motor
T. Control panel

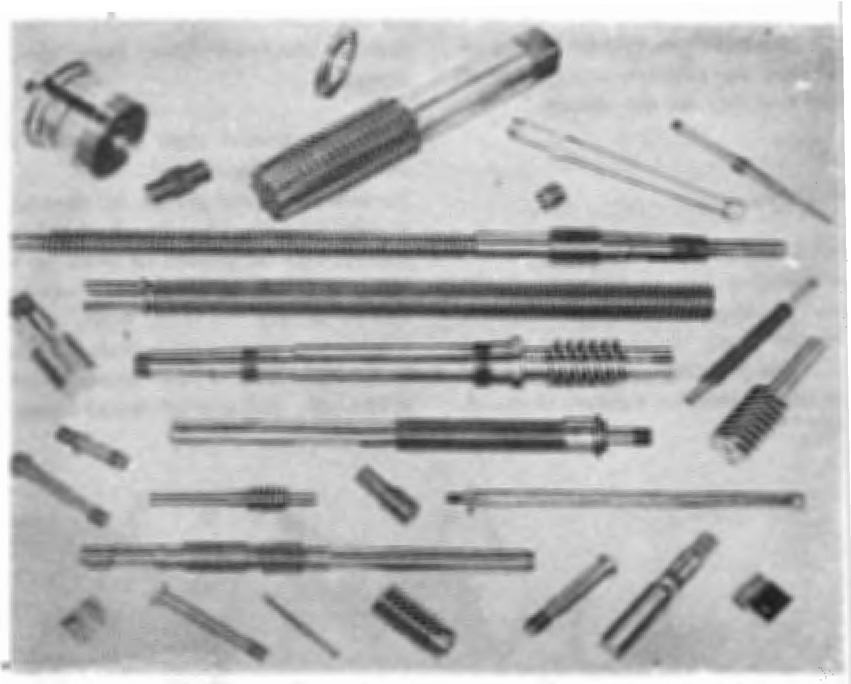


Fig. 15–115. Examples of external-thread grinding. (Ex-Cell-O Corp.)

be right- or left-handed, straight, tapered, or relieved; they also may be in single and multiple pitches from 1 to 80 threads per inch.

106. *Is it possible to grind internal threads?*
An internal-thread grinder is shown in Fig. 15–116. This type of machine is designed and built for grinding internally threaded parts on a production basis, with high finish and to close limits. Whether grinding fine threads from the solid, or coarse threads that have previously been roughed and then heat-treated, a tolerance on the pitch diameter of plus or minus 0.0002 in. can be held. Threads ranging from 1 in. to 9½ in. in diameter and up to 5 in. in length may be ground. Some examples of the type of work usually done on the internal-thread grinder are shown in Fig. 15–117. Some special adapters for holding unusual or awkward pieces of work are shown in Figs. 15–118 and 15–119.

A precision thread grinder for extra long work is shown in Fig. 15–120. This machine will grind an external thread 50 in. long, on work up to 68 in. in length, held between centers. Longer thread sections can be ground by turning the work end for end; the lead can be accurately picked up and the threads matched where the sections meet. Using a table extension, work up to 115 in. can be accommodated between centers. Threads up to 8 in. diameter may be ground when the grinding wheel is a full 18 in. in diameter, as in Fig. 15–121. With a grinding wheel 14 in. in diameter, threads up to 12 in. in diameter may be ground.

The thread shown in Fig. 15–121 is being ground with a narrow grinding wheel shaped to the required form of thread. It is known as a single-rib wheel (Fig. 15–122). An example of an internal thread being ground with a single-rib grinding wheel is shown in Fig. 15–123.

107. *How are the wheels shaped to grind threads?*
Thread-grinding wheels are also made with multiple ribs. Although the truing of single-rib grinding wheels is carried out principally by diamond wheel dressers, the truing of multiple-rib wheels is performed exclusively by rotating crushing rollers (Fig. 15–124). During the wheel-crushing operation, the crushing roller, which is mounted on a slide to permit rotation with axial play, is forced against the wheel by a threaded spindle and is driven by the grinding wheel. A wheel-crushing attachment is located behind the grinding wheel in Fig. 15–125. Figure 126 shows a multiple-rib grinding wheel.

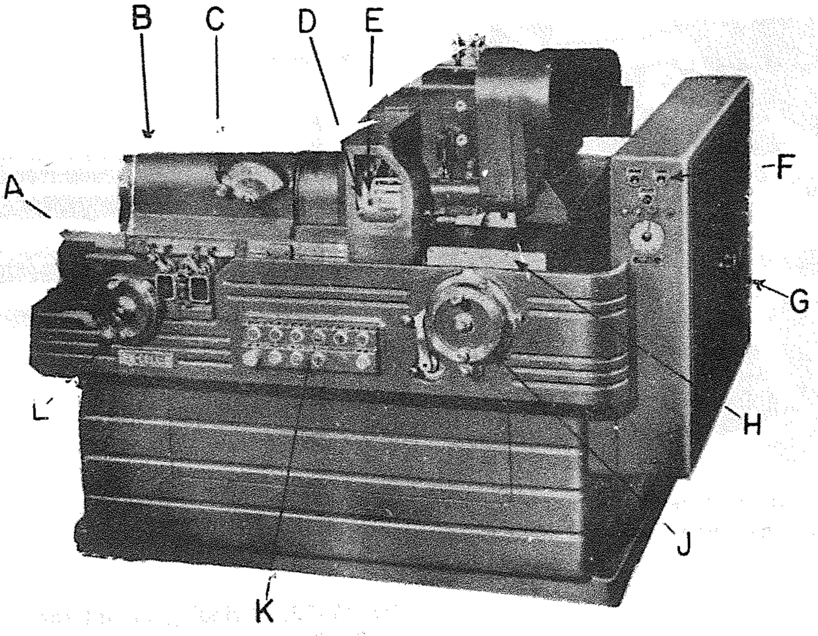


Fig. 15–116. Internal-thread grinder. (Ex-Cell-O Corp.)

A. Work drive and lead-screw housing
B. Work-head slide
C. Control for right- or left-hand thread and multiple index
D. Workpiece
E. Grinding wheel
F. Controls and indicating lights
G. Electrical compartment
H. Wheel slide
J. Size-control handwheel assembly
K. Operator's control panel
L. Lead pickup and automatic backlash-compensation control

Fig. 15–117. Examples of work done on internal-thread grinder. (Ex-Cell-O Corp.)

Fig. 15–118. A special adapter on the work spindle positions the propeller shaft so that the large projection can swing without interference while grinding internal threads. (Ex-Cell-O Corp.)

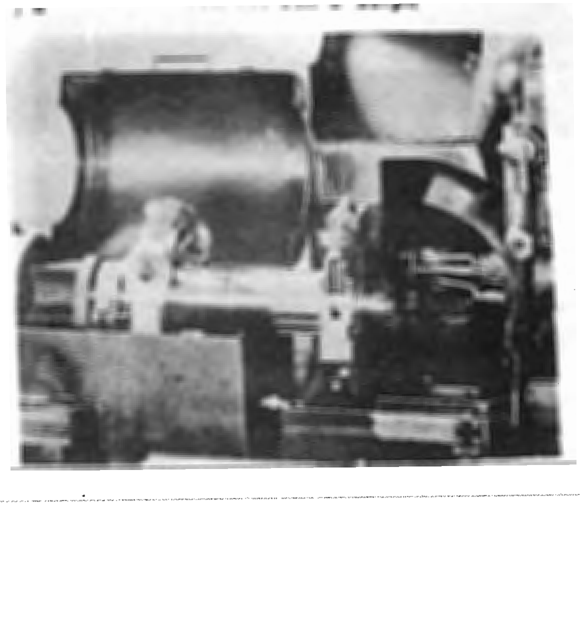


Fig. 15–119. The irregular part is held in a special chuck on an internal-thread grinder. (Ex-Cell-O Corp.)

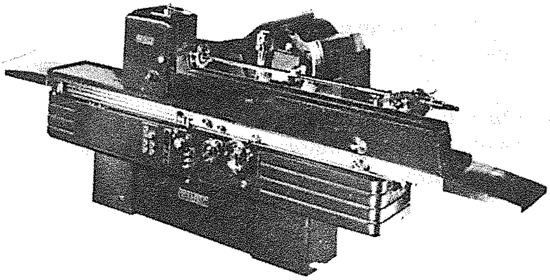


Fig. 15–120. An external-thread grinder designed for extra long work. (Ex-Cell-O Corp.)

Fig. 15–121. Grinding a ball-groove lead screw 7⅝-in. in diameter and 45 in. long, on an external grinder. (Ex-Cell-O Corp.)

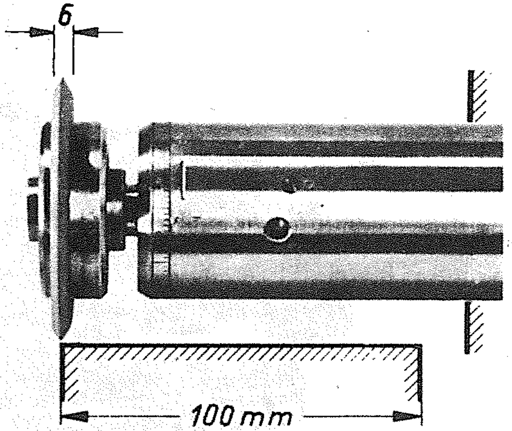
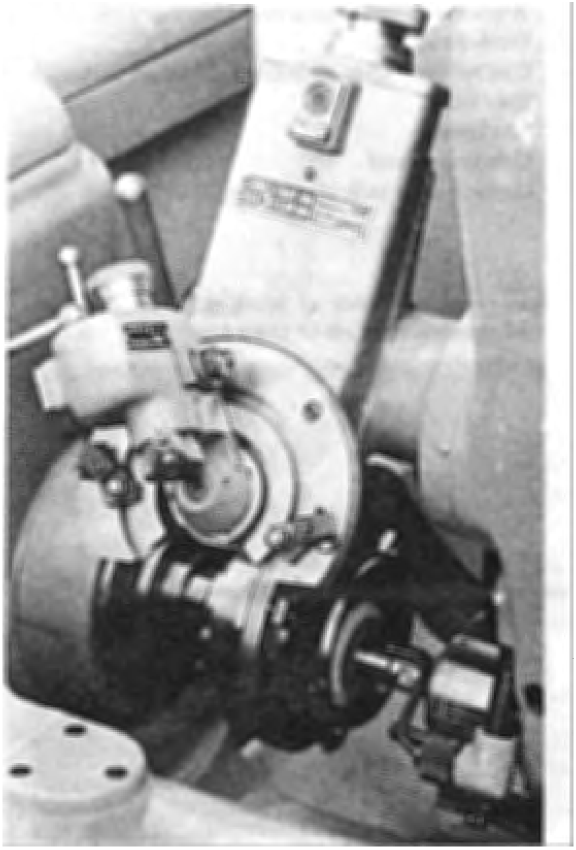
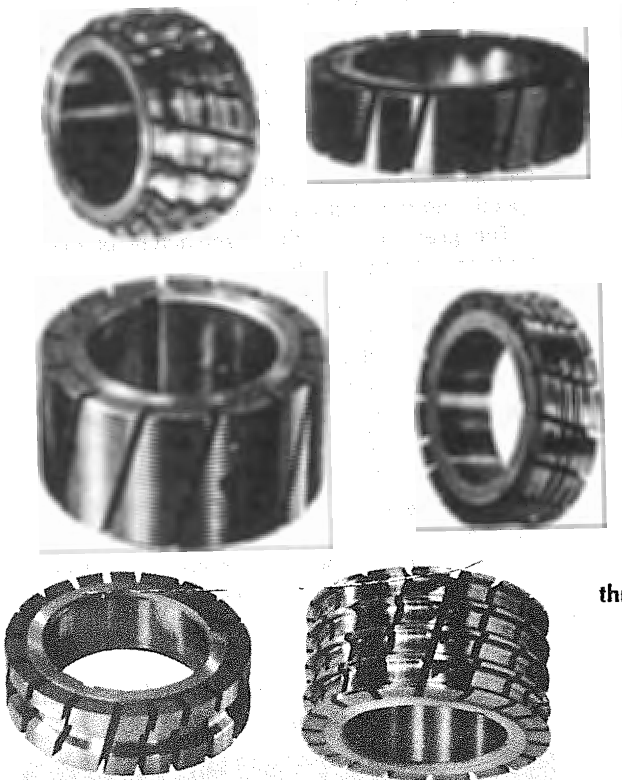


Fig. 15–122. Single-rib thread-grinding wheel. (Kurt Orban Co., Inc.)

Fig. 15–123. Grinding an internal thread with a single-rib grinding wheel. (Kurt Orban Co., Inc.)

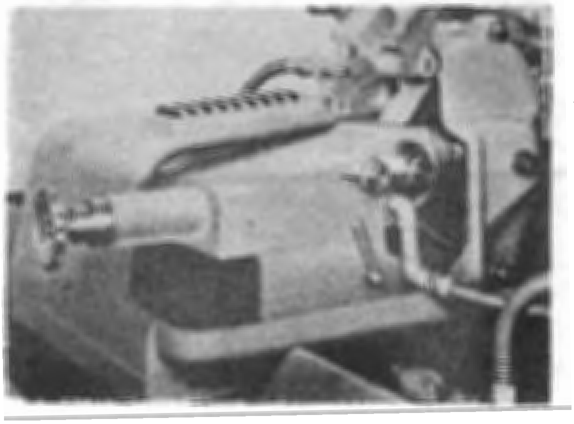




[illegible] a tap with a multiple-rib thread. (Ex-Cell-O Corp.)

Fig. 15–124. Crushing rollers for dressing multiple-rib grinding wheels. (Kurt Orban Co., Inc.)

Fig. 15–125. Attachment for holding crushing rollers on thread grinder. (Kurt Orban Co., Inc.)



chapter 16

gears and gearing

Many mechanical devices and practically every machine tool contains gears of one type or another. Gears are used in pairs or in combinations to transmit motion, change direction of motion, increase or decrease speed, and transmit power from one part of a machine to another part. The automobile transmission and differential are common examples of the use of gears to transmit the direction of motion, speed, and power from an engine to wheels.

The gears used in the manufacture of machine tools and other products are made in great quantities on gear-cutting machines especially designed for each type of gear (Fig. 16–1). These gear-cutting machines are set up and operated by highly skilled machinists, who are specialists in this type of work. However, an all-around machinist or toolmaker may be required to make special gears when a new product is being developed or machines for which replacement gears cannot be purchased must be repaired.

If two plain cylinders, or rollers, are placed in contact with one another and one is rotated, the other will rotate also, with the speed of the driven

Fig. 16–1. Machine for burring and chamfering spur-gear teeth. (Caterpillar Tractor Co.)

roller partly dependent upon the amount of slippage between the two rollers. This method of transmitting motion is called *friction drive* because it is the force of friction between the two cylinders that causes the driven cylinder to turn (Fig. 16–2). We say that this type of drive is not positive or exact because slippage may occur between the two rotating bodies.

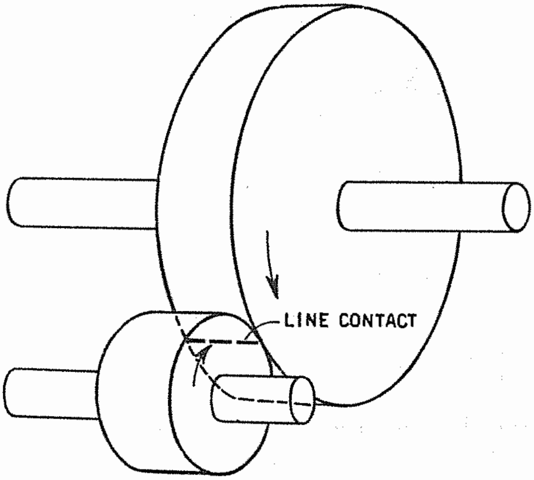


Fig. 16–2. Friction drive.

If teeth were cut on the circumference of each roller so that the teeth of one roller meshed precisely with the teeth of the other, there could be no slippage and we would have a positive transmission of motion. Gearing of all types provides just such a positive and exact transferal of motion from one shaft to another.

Precise meshing of gears requires the proper fitting of the teeth of one gear into the space between teeth of the other gear. Therefore, the machinist must have a good knowledge of gear ratios, the form and shape of gear teeth, the types and selection of gear cutters, the use of gear formulas, and the setting up of machine tools used to cut gears. He must also know how to space teeth accurately by using an index head, or dividing head, when cutting teeth on a milling machine.

SPUR GEARS

Of the several types of gears discussed in this chapter, the most common is the spur gear.

1. *What is a spur gear?*
A spur gear (Fig. 16–3) is a wheel or cylinder with teeth cut parallel with the axis of rotation.

2. *What are spur gears used for?*
Spur gears are the simplest and most widely used type of gear for transmitting motion between shafts that are parallel to each other.

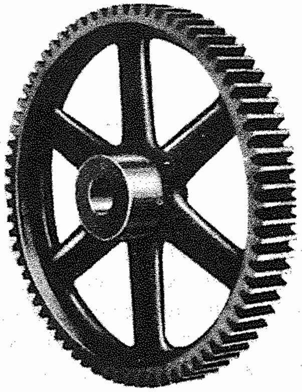


Fig. 16–3. Spur gear.

3. *What is meant by a gear and pinion?*
Two gears in mesh are called a *pair* of gears. The larger of the two is referred to as the *gear*, while the smaller one is called the *pinion*. Either could be a driver and the other the driven member (Fig. 16–4).

4. *What is meant by gear ratio and size?*
The gear ratio of a pair of meshing gears expresses a relationship between the number of teeth each gear contains. It is usually written as a fraction or ratio reduced to its lowest terms—for example: 3:1, 5:2, 22:1, and the like.

The size of a gear is given in terms of its pitch diameter. The ratio of pitch diameters of a pair of meshing gears is the same as the gear ratio. The gear or size ratio is used to determine the number of revolutions per minute (rpm) each meshing gear will make.

5. *What is speed ratio and how does it differ from gear or size ratio?*
The speed ratio of a pair of meshing gears expresses the relationship between the rpm of each gear. It is usually expressed as a fraction or ratio reduced to its lowest terms. Speed ratio is the inverse of gear

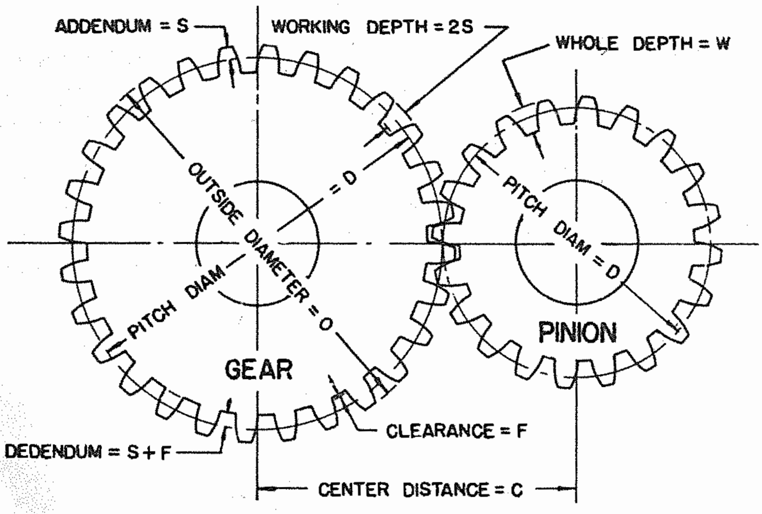


Fig. 16–4. Spur-gear and pinion dimensions and symbols.

ratio—that is, a speed ratio of 1:4 will be produced by two meshing gears with a gear or size ratio of 4:1. The smaller of the two gears will always rotate at a higher rpm than the larger gear. Speed ratios and gear ratios can be calculated from the number of teeth in each meshing gear (Fig. 16–5).

6. *How can the gear ratio of two meshing gears be calculated when the number of teeth in each is known?*
The gear ratio of two gears in mesh can be calculated from the number of teeth in each gear by writing the number of teeth as the numerator and denominator of a fraction and reducing the fraction to its lowest terms. For example, the gear ratio of a pair of gears with 24 and 48 teeth is found as follows:

$$\frac{48}{24} = \frac{2}{1}, \quad \text{or 2:1 gear ratio}$$

Note that the smaller number usually is used as the denominator when calculating gear ratios.

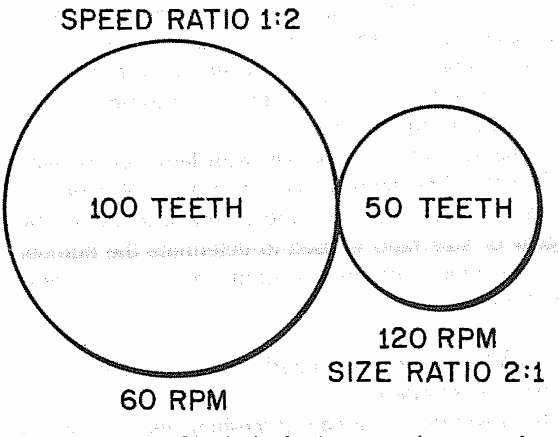


Fig. 16–5. Speed ratio is the inverse of gear or size ratio.

7. *How can the number of teeth in each of two gears be determined when a specific gear ratio is required?*
When the gear ratio of a pair of gears is specified, the number of teeth in each gear can be calculated by multiplying both terms of the ratio by the same number. This means that an unlimited number of teeth combinations is possible. For example, gear combinations of 48 and 24 teeth, 16 and 8, 50 and 25, and so forth all have a gear ratio of 2:1. For the first combination the common multiplier is 24:

$$\frac{2 \times 24}{1 \times 24} = \frac{48 \text{ Teeth}}{24 \text{ Teeth}}$$

In the second combination the multiplier is 8, and in the third the multiplier is 25. The physical requirements involved will usually determine the best combination to use.

If the gear ratio and the number of teeth in one of the gears is known, we can calculate the number of teeth in the other gear. Suppose we are told that the larger of two gears has 35 teeth and the gear ratio is 5:3. How many teeth does the smaller gear have? In this case we divide the number of teeth in the larger gear by the larger number in the ratio. This will give us the multiplier we need. Then the smaller number in the ratio is multiplied by this number to find the number of teeth in the smaller gear.

$$\frac{35 \text{ teeth in larger gear}}{5 \text{ (larger no. in gear ratio)}} = 7 \text{ (common multiplier)}$$

$$\begin{array}{l} \quad 3 \text{ (smaller number in gear ratio)} \\ \underline{\times 7 \text{ (common multiplier)}} \\ \quad 21 \text{ (teeth in smaller gear)} \end{array}$$

Check:

$$\frac{5 \times 7}{3 \times 7} = \frac{35 \text{ Teeth}}{21 \text{ Teeth}}$$

8. *What is a general rule relating speed (in rpm) and number of teeth in driver and driven gears?*
A general rule for calculating speed or number of teeth in driver or driven gears is: the product of speed and teeth of the driver gear is equal to the product of speed and teeth of the driven gear. This can be expressed as a formula, as follows:

Speed (in rpm) × Teeth of driver gear
= Speed (in rpm) × teeth of driven gear

If we know any three items, we can calculate the fourth with this formula. For example, how many rpm will a 20-tooth driven gear make when the driver gear has 40 teeth and rotates at 60 rpm? Using the general rule,

Product of driver gear data = product of driven gear data

$$40 \times 60 = 20 \times \text{speed of driven gear}$$

$$\frac{40 \times 60}{20} = \text{speed of driven gear} = 120 \text{ rpm}$$

9. *Name two types of gear trains.*
The simple gear train and the compound gear train.

10. *What is a simple gear train?*
A simple gear train consists of two or more gears mounted on separate shafts (see Fig. 16–6).

11. *Does the number of gears in a simple gear train affect the gear or speed ratios between the driver and driven gears?*
No. Regardless of the number of gears in a simple gear train, the gear and speed ratios of the driver and driven gears alone are the determining factors, and all gears in between, called *idler gears,* merely serve to fill up space and possibly change the direction of rotation of the driven gear. Figure 16–6 shows three examples of simple gear trains. An even number of gears in the train—for example, two, four, and so on—will cause the driven gear to rotate in a direction opposite to that of the driver gear (see Figs. 16–6A and 16–6C). An uneven number of gears in the train—for example three, five, and so on—will cause the driven gear to rotate in the same direction as the driver gear (see Fig. 16–6B).

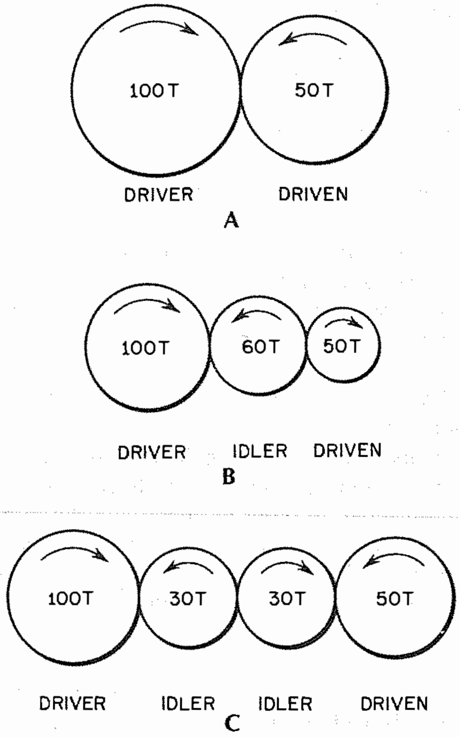


Fig. 16–6. Examples of simple-gear trains.

12. *What is a compound gear train?*
A compound gear train is a series of gears with two of the intermediate gears mounted on the same shaft and rotating at the same speed. A compound gear train requires at least four gears. Figure 16–7 shows a driver and a driven gear at each end of the train, with two intermediate gears mounted on the same shaft. The intermediate gears in this case are not idlers but rather driven and driver gears themselves. In some cases it may be necessary to add one or more idler gears either to fill up space or to change the direction of rotation of the driven gear.

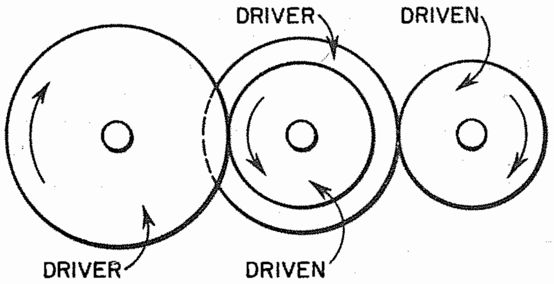


Fig. 16–7. Compound-gear train.

13. *What is the advantage of a compound gear train?*
Compound gearing permits a greater range of gear ratio combinations within a limited space than is possible for simple gear trains.

14. *What terms and symbols are used in the making of spur gears and pinions?*
The common terms and symbols used in spur gear and pinion making are given in Fig. 16–4.

15. *Why is it important to know the names of the various parts of a gear tooth?*
The proper meshing of a pair of gears depends on the dimensions of the gear teeth and the spaces between them. In order to understand the formulas used to solve gear problems, and machine the gears themselves, it is necessary to be able to identify the various parts of the gear tooth (Fig. 16–8).

16. *What is the pitch circle of a spur gear?*
The pitch circle of a spur gear is an imaginary circle passing through the points at which the teeth of the meshing gears contact each other. It is located about midway in the tooth's depth. The two contacting surfaces of the friction drive (see Fig. 16–2) are similar to the pitch circles of two gears in mesh.

17. *What is the pitch diameter of a spur gear?*
The pitch diameter of a spur gear is the diameter of the pitch circle.

18. *What is meant by the diametral pitch?*
The diametral pitch of a gear represents the number of teeth per inch of pitch diameter and thus gives some indication of the size of the gear teeth. Figure 16–9 shows relative sizes of gear teeth according to the diametral pitch. Note that a higher diametral

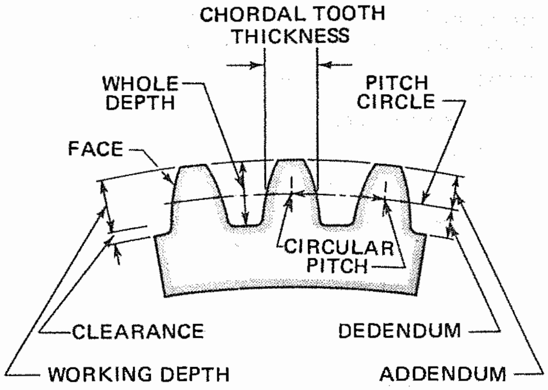


Fig. 16–8. Details of spur-gear tooth. (American Stock Gear Co.)

pitch number means a smaller tooth size. A gear tooth of 8 diametral pitch (also called 8-pitch) would be twice the size of a 16 diametral pitch tooth because there are only half as many teeth per inch of pitch diameter.

19. *What is the circular pitch of a spur gear?*
The circular pitch is the distance from the center of one tooth to the center of the next consecutive tooth measured on the pitch circle. It may also be defined as the distance between two corresponding points on adjacent teeth measured along the pitch circle.

20. *What is the addendum?*
The addendum is the portion of the tooth that projects above or outside of the pitch circle.

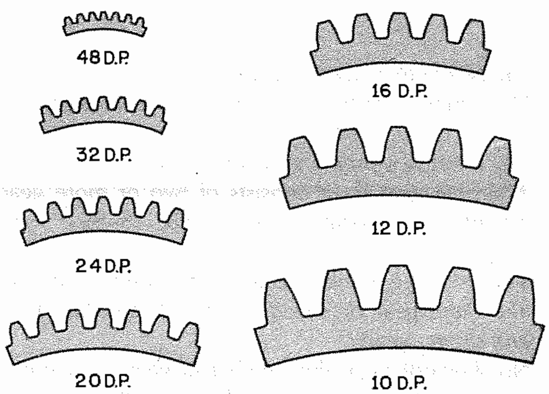


Fig. 16–9. Relative sizes of gear teeth. (American Stock Gear Co.)

21. *What is the outside diameter of a spur gear?*
The outside diameter of a spur gear is equal to the pitch diameter plus two times the addendum. It is also the major diameter at which the gear blank is turned before cutting the teeth.

22. *What is the dedendum of a gear tooth?*
The dedendum is the portion of the tooth space that is cut below the pitch circle and is equal to the addendum plus the clearance.

23. *What is the clearance of a gear tooth?*
Gear teeth are designed so that there will be a small space, or clearance, between the top of the tooth (the outside diameter) and the bottom of the tooth space (the root circle) of the meshing gear (see Fig. 16–8). The clearance is the difference between the whole depth and the working depth.

24. *Explain what is meant by the whole depth of a tooth.*
The whole depth of a tooth is the distance from the top of a tooth to the bottom. It is equal to the addendum plus the dedendum. The dedendum includes the clearance.

25. *What is the working depth of gear teeth?*
The working depth is the distance to which a tooth extends into the tooth space of the meshing gear. It is equal to twice the addendum.

26. *What is meant by the center-to-center distance between two gears in mesh?*
The center-to-center distance is the measurement from the center of one gear to the center of a meshing gear (see Fig. 16–4). It is equal to one-half of the pitch diameter of one gear plus one-half of the pitch diameter of the meshing gear. This permits the two gears to contact each other at their pitch circles and provides for the smooth and accurate operation of the gears.

27. *What is the form of the spur gear tooth?*
The common form of gear tooth is known as the *involute form.*

28. *Explain what is meant by the term involute.*
The term *involute* refers to the shape of the curve on the sides of a gear tooth. An involute can be drawn by unwinding a taut string from a cylinder as shown in Fig. 16–10.

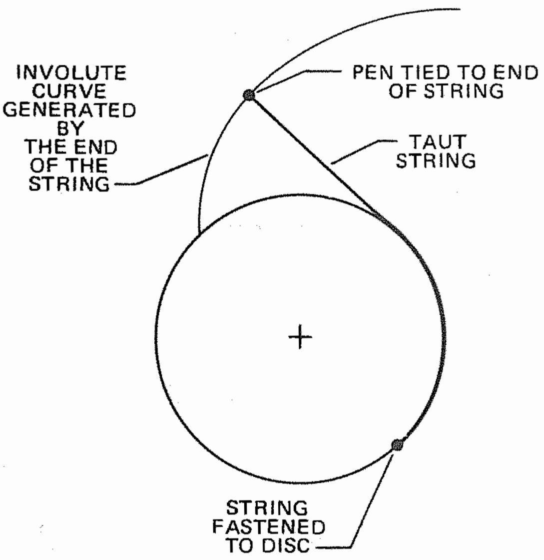


Fig. 16–10. An involute curve is formed by unwinding a taut string from a circular disk.

29. *What is the pressure angle of involute gear teeth?*
The pressure angle is the angle between the tangent to the pitch circles and the perpendicular line through the point of contact of the two meshing gears. A standard pressure angle is 14½° (Fig. 16–11).

30. *What is a stub tooth?*
A stub tooth is one that is thicker in proportion to its length than the involute tooth. It is not as smooth in operation as the involute but is preferred where strength is more important (Fig. 16–12).

31. *What are the proportions of a stub tooth?*
A stub tooth is designed by combining two sizes of

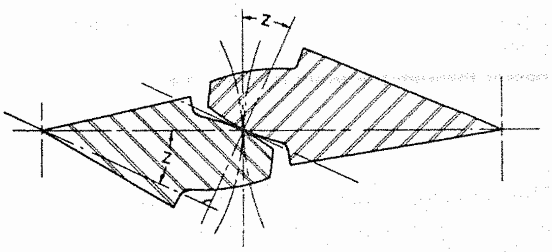


Fig. 16–11. Pressure angle (*Z*) of meshing gear teeth.

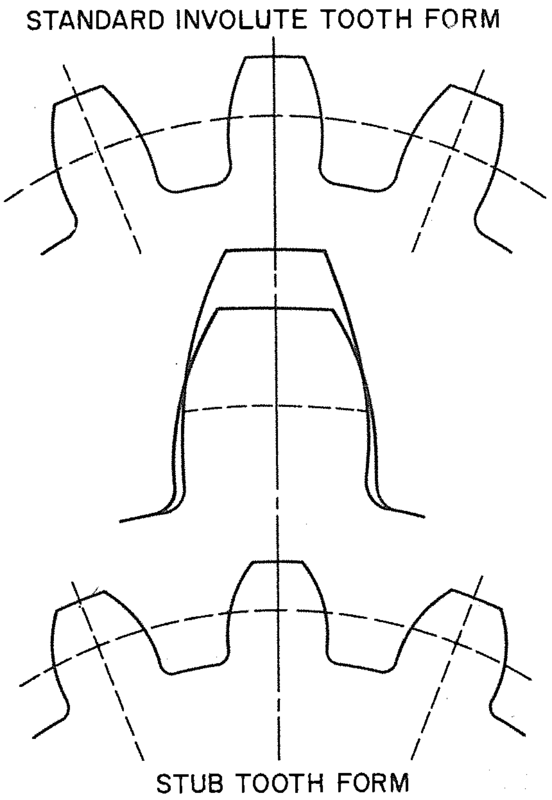


Fig. 16–12. Comparison of stub and involute gear teeth.

teeth, that is, two diametral pitch numbers. One size is used to determine the thickness of the tooth, the other the length of the tooth. For example, a 4/6-pitch tooth would have the thickness of 4-pitch teeth and the length of 6-pitch teeth. The pressure angle of stub gear teeth is 20°.

32. *What is the chordal thickness of a gear tooth?*
The chordal thickness of a gear tooth is the distance in a straight line (chord) from one side of a tooth to the other side at points where the pitch circle passes through the tooth (Fig. 16–13).

33. *What is the corrected addendum of a gear tooth?*
The corrected addendum of a gear tooth is the distance from the top of a tooth to the chord across the tooth at the pitch circle (see Fig. 16–13). As noted above, this is the point at which the chordal thickness is measured.

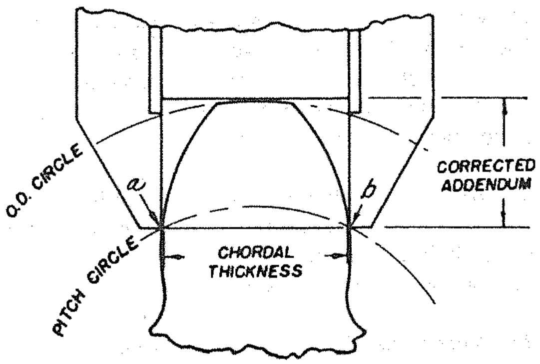
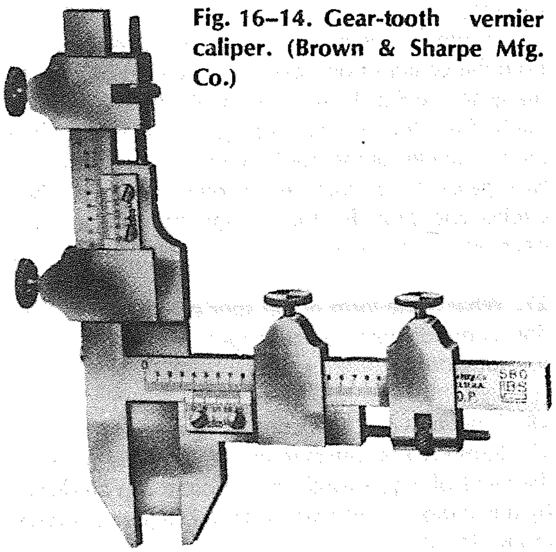


Fig. 16–13. Chordal thickness and corrected addendum of a gear tooth.

34. *For what purpose are the chordal thickness and corrected addendum dimensions used?*
The chordal thickness and corrected addendum dimensions are used to measure the size of gear teeth. The thickness of the tooth varies from the top to the bottom of the tooth. The thickness at the pitch line has been selected for measuring because the location and thickness may be accurately calculated and measured.

35. *How is the chordal thickness of a gear tooth measured?*
The chordal thickness is measured with a gear-tooth vernier caliper as shown in Fig.16–14. The vertical

Fig. 16–14. Gear-tooth vernier caliper. (Brown & Sharpe Mfg. Co.)



bar is adjusted to the corrected addendum measurement and then the caliper is placed on the tooth. The chordal thickness is measured with the horizontal bar of the caliper.

36. *How can the chordal thickness and corrected addendum dimensions be calculated?*
The dimensions may be calculated as shown in Fig. 16-15. However, these calculations have been made for a wide range of pitches and gear teeth and tabulated in convenient form. Thus it is simpler to use a table similar to Fig. 16-16 when available.

GENERAL

37. *What is a gear sector?*
A gear sector (Fig. 16-17) is a wheel that has teeth

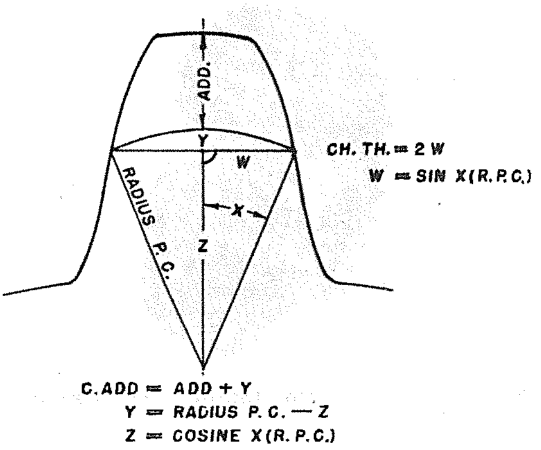


Fig. 16-15. Formulas for calculating chordal thickness.

Fig. 16-16. Dimensions for corrected addendum and chordal thickness.

pitch	*part of gear tooth to be measured*	*number of cutter and corresponding number of teeth in a gear*							
		No. 1 135 T	No. 2 55 T	No. 3 35 T	No. 4 26 T	No. 5 21 T	No. 6 17 T	No. 7 14 T	No. 8 12 T
1	**Corrected addendum**	**1.0047**	**1.0112**	**1.0176**	**1.0237**	**1.0294**	**1.0362**	**1.0440**	**1.0514**
	Chordal thickness	**1.5707**	**1.5706**	**1.5702**	**1.5698**	**1.5694**	**1.5686**	**1.5675**	**1.5663**
2	**Corrected addendum**	**0.5023**	**0.5056**	**0.5088**	**0.5118**	**0.5147**	**0.5181**	**0.5220**	**0.5257**
	Chordal thickness	**0.7853**	**0.7853**	**0.7851**	**0.7849**	**0.7847**	**0.7843**	**0.7837**	**0.7831**
3	**Corrected addendum**	**0.3349**	**0.3370**	**0.3392**	**0.3412**	**0.3431**	**0.3454**	**0.3480**	**0.3504**
	Chordal thickness	**0.5235**	**0.5235**	**0.5234**	**0.5232**	**0.5231**	**0.5228**	**0.5225**	**0.5221**
4	**Corrected addendum**	**0.2511**	**0.2528**	**0.2544**	**0.2559**	**0.2573**	**0.2590**	**0.2610**	**0.2628**
	Chordal thickness	**0.3926**	**0.3926**	**0.3926**	**0.3924**	**0.3923**	**0.3921**	**0.3919**	**0.3915**
5	**Corrected addendum**	**0.2009**	**0.2022**	**0.2035**	**0.2047**	**0.2058**	**0.2072**	**0.2088**	**0.2102**
	Chordal thickness	**0.3141**	**0.3141**	**0.3140**	**0.3139**	**0.3138**	**0.3137**	**0.3135**	**0.3132**
6	**Corrected addendum**	**0.1674**	**0.1685**	**0.1696**	**0.1706**	**0.1715**	**0.1727**	**0.1740**	**0.1752**
	Chordal thickness	**0.2618**	**0.2617**	**0.2617**	**0.2616**	**0.2615**	**0.2614**	**0.2612**	**0.2612**
7	**Corrected addendum**	**0.1435**	**0.1444**	**0.1453**	**0.1462**	**0.1470**	**0.1480**	**0.1491**	**0.1502**
	Chordal thickness	**0.2244**	**0.2243**	**0.2243**	**0.2242**	**0.2242**	**0.2240**	**0.2239**	**0.2237**
8	**Corrected addendum**	**0.1255**	**0.1264**	**0.1272**	**0.1279**	**0.1286**	**0.1295**	**0.1305**	**0.1314**
	Chordal thickness	**0.1963**	**0.1963**	**0.1962**	**0.1962**	**0.1961**	**0.1960**	**0.1959**	**0.1957**
10	**Corrected addendum**	**0.1004**	**0.1011**	**0.1017**	**0.1023**	**0.1029**	**0.1036**	**0.1044**	**0.1051**
	Chordal thickness	**0.1570**	**0.1570**	**0.1570**	**0.1569**	**0.1569**	**0.1568**	**0.1657**	**0.1566**
12	**Corrected addendum**	**0.0837**	**0.0842**	**0.0848**	**0.0853**	**0.0857**	**0.0863**	**0.0870**	**0.0876**
	Chordal thickness	**0.1309**	**0.1309**	**0.1308**	**0.1308**	**0.1308**	**0.1307**	**0.1306**	**0.1305**
14	**Corrected addendum**	**0.0717**	**0.0722**	**0.0726**	**0.0731**	**0.0735**	**0.0740**	**0.0745**	**0.0751**
	Chordal thickness	**0.1122**	**0.1122**	**0.1121**	**0.1121**	**0.1121**	**0.1120**	**0.1119**	**0.1118**
16	**Corrected addendum**	**0.0628**	**0.0632**	**0.0636**	**0.0639**	**0.0643**	**0.0647**	**0.0652**	**0.0657**
	Chordal thickness	**0.0981**	**0.0981**	**0.0981**	**0.0981**	**0.0980**	**0.0980**	**0.0979**	**0.0979**

Fig. 16–17. Gear sector. (Boston Gear Works.)

on a part of its periphery only. It is used to transmit power in an intermittent manner—that is, each time the sector revolves, it will cause the meshing gear to revolve only while the teeth of each one are in contact, and to remain idle until the sector teeth again come in contact with the gear. The sector illustrated has 20 out of a possible 40 teeth. If it is meshed with a gear having 60 teeth, the latter will be revolved only one-third of a revolution (after which it will be idle during a corresponding period of time) each time the sector makes one complete revolution. Intermittent straight-line motion may also be obtained by meshing a gear sector with a gear rack.

38. *Do gears that mesh together always have teeth identical in shape?*
No. Meshing gears always have teeth of the same size (pitch number), but the teeth are identical only when the meshing gears are the same size. Though the teeth may appear to be similar, the curved shape of the teeth varies according to the number of teeth in each gear.

39. *Why are not all gear teeth of a given size identical in shape?*
For efficient operation, the curvature on the side of a gear tooth is made in proportion to the curvature of the segment of the pitch circle containing one tooth. When only a few teeth are cut on a gear, the curvature of the segment is quite large compared to that of a gear with many teeth (Fig. 16–18).

40. *What abbreviations are used in spur gear formulas?*

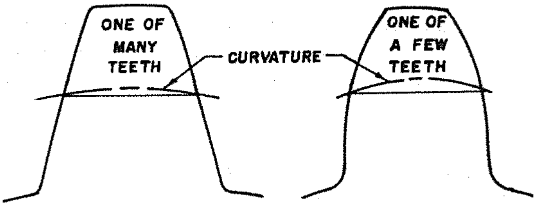


Fig. 16–18. Variations in curvature of gear teeth

The abbreviations used in this book are listed below. Although they differ from standard symbols adopted by the gear manufacturers and the ANSI, the beginner will find them easier to use and relate to the physical parts of the gear. Standard symbols may be found in the *New American Machinists Handbook* or can be obtained from the ANSI.

A = Addendum
$A + F$ = Dedendum
CD = Center Distance
DP = Diametral pitch
CP = Circular pitch
F = Clearance
N = Number of teeth
N_g = Number of teeth in gear
N_p = Number of teeth in pinion
OD = Outside diameter
PD = Pitch diameter
T = Thickness of tooth
W = Whole depth of tooth

41. *What formulas are commonly used in calculating the dimensions of spur gears?*
The formulas used for calculating spur gear dimensions are given in Fig. 16–19.

Fig. 16–19. Spur-gear formulas.

to find	*when we know*	*rule*	*formula*
Addendum	Circular pitch	Multiply the circular pitch by 0.3183	$A = CP \times 0.3183$
Addendum	Diametral pitch	Divide 1 by the diametral pitch	$A = \frac{1}{DP}$
Center-to-center distance	Number of teeth in gear and pinion and diametral pitch	Add the number of teeth in the gear to the number of teeth in the pinion and divide the sum by 2 times the diametral pitch	$C = \frac{N_g + N_p}{2DP}$
Center-to-center distance	Pitch diameter of gear and pinion	Add the pitch diameter of the gear to the pitch diameter of the pinion and divide the sum by 2	$C = \frac{PD_g + PD_p}{2}$
Circular pitch	Diametral pitch	Divide 3.1416 by the diametral pitch	$CP = \frac{3.1416}{DP}$
Circular pitch	Pitch diameter and number of teeth	Divide the pitch diameter by the product of 0.3183 and the number of teeth	$CP = \frac{PD}{0.3183 \times N}$
Clearance	Diametral pitch	Divide 0.157 by the diametral pitch	$F = \frac{0.157}{DP}$
Clearance	Thickness of tooth	Divide the thickness of the tooth at the pitch line by 10	$F = \frac{T}{10}$
Dedendum	Circular pitch	Multiply the circular pitch by 0.3683	$A + F = CP \times 0.3683$
Dedendum	Diametral pitch	Divide 1.157 by the diametral pitch	$A + F = \frac{1.157}{DP}$
Diametral pitch	Circular pitch	Divide 3.1416 by the circular pitch	$DP = \frac{3.1416}{CP}$
Diametral pitch	Outside diameter and number of teeth	Add 2 to the number of teeth and divide the sum by the outside diameter	$DP = \frac{N + 2}{OD}$
Diametral pitch	Pitch diameter and number of teeth	Divide the number of teeth by the pitch diameter	$DP = \frac{N}{PD}$
Number of teeth	Diametral pitch and outside diameter	Multiply the diametral pitch by the outside diameter and subtract 2 from the product	$N = (DP \times OD) - 2$
Number of teeth	Pitch diameter and circular pitch	Multiply the pitch diameter by 3.1416 and divide by the circular pitch	$N = \frac{PD \times 3.1416}{CP}$
Number of teeth	Pitch diameter and diametral pitch	Multiply the pitch diameter by the diametral pitch	$N = PD \times DP$
Outside diameter	Number of teeth and addendum	Add 2 to the number of teeth and multiply the sum by the addendum	$OD = A \times (N + 2)$
Outside diameter	Number of teeth and diametral pitch	Add 2 to the number of teeth and divide the sum by the diametral pitch	$OD = \frac{N + 2}{DP}$
Outside diameter	Pitch diameter and diametral pitch	Add the pitch diameter to the quotient of 2 divided by the diametral pitch	$OD = PD + \frac{2}{DP}$
Pitch diameter	Addendum and number of teeth	Multiply the number of teeth by the addendum	$PD = N \times A$

(cont.)

Fig. 16–19. **Spur-gear formulas** *(cont.)*

to find	*when we know*	*rule*	*formula*
Pitch diameter	**Number of teeth and diametral pitch**	**Divide the number of teeth by diametral pitch**	$PD = \frac{N}{DP}$
Pitch diameter	**Outside diameter and diametral pitch**	**Divide 2 by the diametral pitch and subtract the quotient from the outside diameter**	$PD = OD - \frac{2}{DP}$
Thickness of tooth	**Circular pitch**	**Divide the circular pitch by 2**	$T = \frac{CP}{2}$
Thickness of tooth	**Diametral pitch**	**Divide 1.5708 by the diametral pitch**	$T = \frac{1.5708}{DP}$
Whole depth	**Circular pitch**	**Multiply the circular pitch by 0.6866**	$W = CP \times 0.6866$
Whole depth	**Diametral pitch**	**Divide 2.157 by the diametral pitch**	$W = \frac{2.157}{DP}$

CUTTING GEAR TEETH

42. *Are differently shaped cutters used for cutting gear teeth of a given size?*
Yes. For example, when cutting gear teeth on a milling machine with an involute gear cutter (Fig. 16–20), any one of eight different cutters may be used for one size of teeth. The selection of a cutter depends on the number of teeth in the gear (Fig. 16–21) as well as the size of the gear tooth. Figure 16–22 shows the profile of each of the eight cutters, and, underneath each one, the shape of the corresponding tooth. When requisitioning an involute gear cutter from the tool crib, be sure to ask for the correct number of cutter as well as the correct size.

Fig. 16–20. Involute gear cutter.

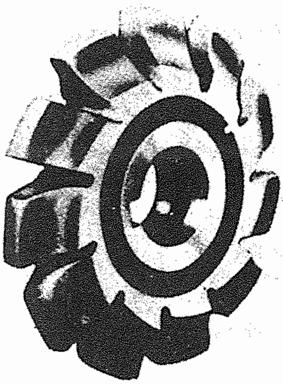


Fig. 16–21. Selection of cutter for gear teeth.

cutter no.	*no. of gear teeth*
1	**135 to a rack**
2	**55 to 134**
3	**35 to 54**
4	**26 to 34**
5	**21 to 25**
6	**17 to 20**
7	**14 to 16**
8	**12 to 13**

43. *What are some of the methods for cutting spur-gear teeth?*
Spur-gear teeth may be cut one tooth at a time on a milling machine (Fig. 16–23), using an involute gear cutter of the type shown in Fig. 16–20.

Another method is to cut the teeth with a multiple cutter called a *hob* (Fig. 16–24), which is used on a special gear-cutting machine known as a *gear hobber* (Fig. 16–25). The gear blanks are held on a vertical arbor, as in Fig. 16–40. A closeup view of a hob cutting several gears at one time is shown in Fig. 16–26.

A third method is to cut the teeth, one at a time, on a gear shaper (Fig. 16–27). This machine uses a cutter that looks like a gear (Fig. 16–28). The cutter is given a reciprocating motion similar to that of a planing or shaping tool. In Fig. 16–29, the cutter and work are shown rotating together in the direction of the arrows. The outlines show the various posi-

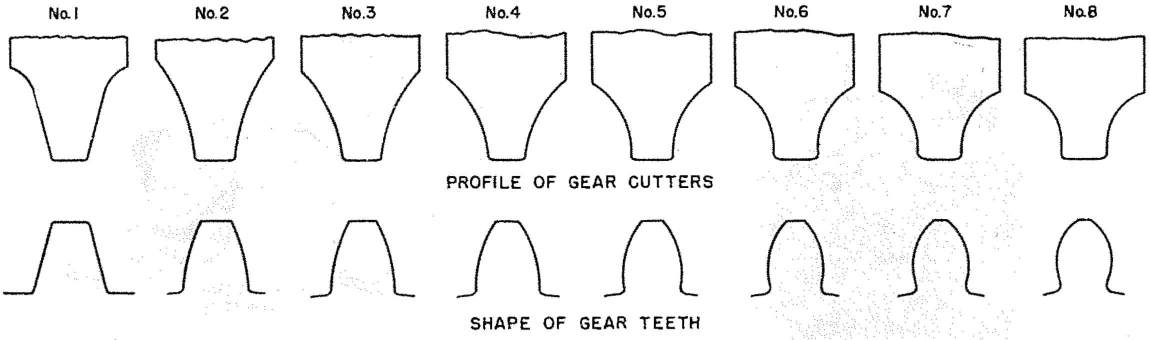
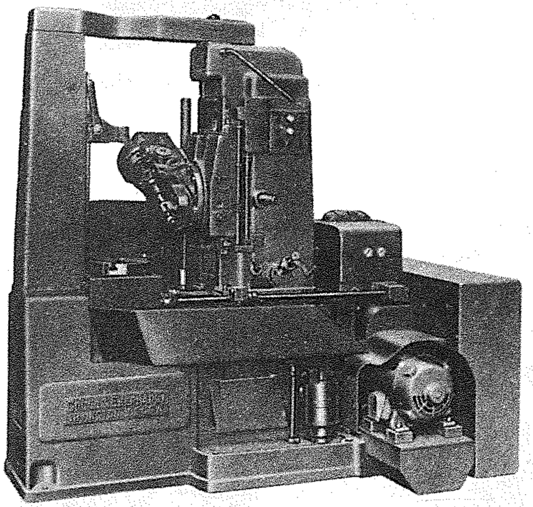


Fig. 16-22. Numbered gear cutters provide a choice of gear tooth shapes.

Fig. 16-23. Cutting spur-gear teeth on the milling machine. (Cincinnati Milacron Co.)

Fig. 16-25. Gear-hobbing machine. (Gould & Eberhardt, Inc.)



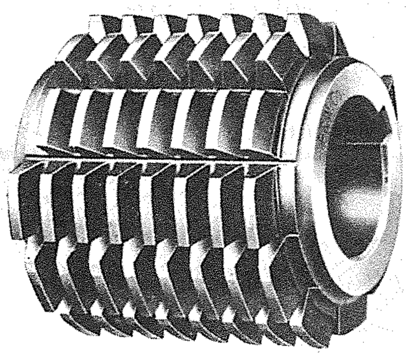


Fig. 16-24. Hob for cutting spur-gear teeth. (Pratt & Whitney Co.)

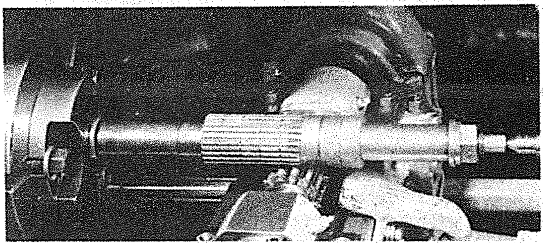


Fig. 16-26. Cutting teeth on eight spur gears at one time on a hobbing machine. (Gould & Eberhardt, Inc.)

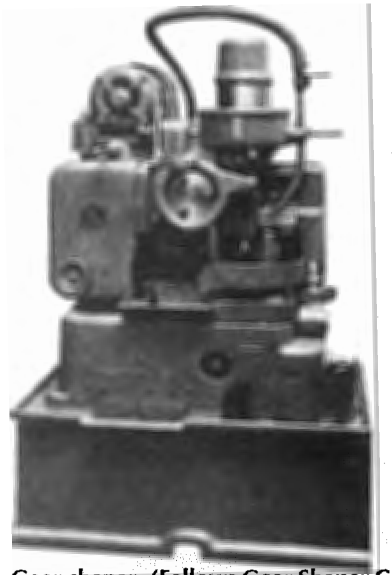
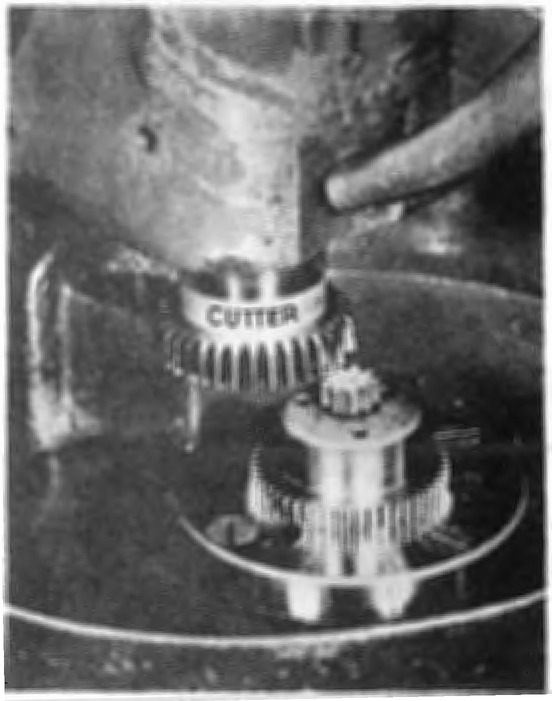


Fig. 16–27. Gear shaper. (Fellows Gear Shaper Co.)

Fig. 16–28. The gear shaper cutter looks like a gear. (Fellows Gear Shaper Co.)



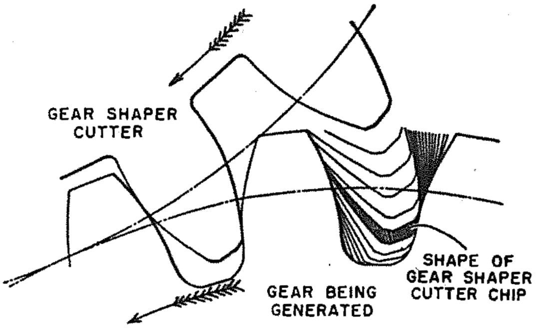


Fig. 16–29. Cutting action of a gear-shaping cutter. (Fellows Gear Shaper Co.)

tions the cutting edge will occupy for each successive stroke of the cutter. The distance between any two adjacent outlines at any point represents the thickness of the chip at that point.

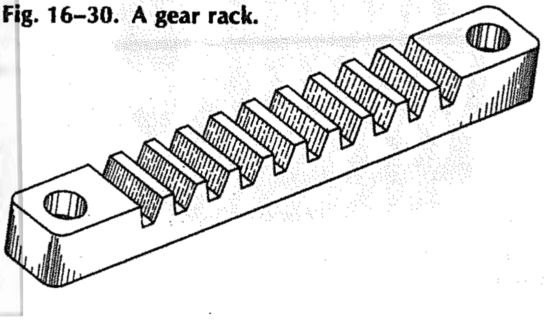
GEAR RACK

44. *What is a gear rack?*
A gear rack is a flat surface on which teeth have been cut (Fig. 16–30). Rectangular stock is commonly used, but square and round stock may be used, as on the side of a shaft.

45. *What is the purpose of a gear rack?*
A gear rack, when meshed with a gear, is used to change rotary motion to reciprocating motion.

46. *What terms and definitions used for spur gears are identical for gear racks?*
Diametral pitch, addendum, dedendum, whole depth, clearance, and pressure angle.

Fig. 16–30. A gear rack.



47. *What is the pitch line of a rack?*
The pitch line of a rack (Fig. 16–31) is an imaginary line, which passes through the teeth, separating the addendum from the dedendum. It corresponds tc the pitch circle of a gear.

48. *What is the linear pitch of a rack?*
The linear pitch of a rack is the distance from the center of one tooth to the center of the next tooth. It corresponds to the circular pitch of a gear.

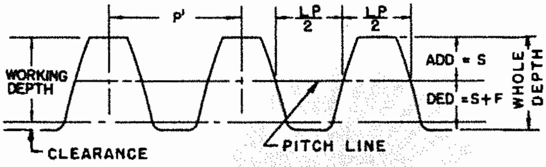


Fig. 16–31. Terms and abbreviations used with gear racks.

49. *What dimensions are used to measure the size of a rack tooth?*
The thickness of a tooth and the space between two teeth are equal on the pitch circle or pitch line. Because the pitch line is straight in the case of the gear rack, it is not necessary to calculate the length of a chord, but only to divide the linear pitch by two. The dimensions required to measure a rack tooth are addendum and one-half of the linear pitch. A gear-tooth vernier caliper is used for measuring rack teeth in the same manner as for measuring gear teeth.

50. *What formulas are used in calculating the dimensions of gear racks?*

Gear rack dimensions may be calculated using the following formulas:

Diametral pitch:

$$DP = \frac{3.1416}{LP}$$

Length of rack:

$$L = N \times LP$$

(N = number of teeth)

Linear pitch:

$$LP = \frac{3.1416}{DP}$$

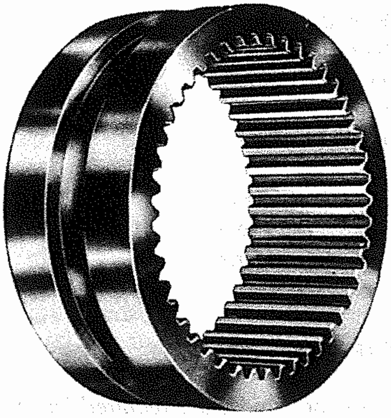


Fig. 16–32. An internal gear. (Philadelphia Gear Works.)

INTERNAL GEAR

51. *What is an internal gear?*
An internal gear (Fig. 16–32) is one in which teeth are cut on the inner surface of a ring, instead of being cut on the outside of a wheel.

52. *What is the inside diameter of an internal gear?*
The inside diameter of an internal gear is the size of the hole to be bored before the teeth are cut. It is equal to the pitch diameter minus two addendums.

53. *What formulas are used in calculating the dimensions of internal gears?*

The following formulas are used to calculate internal gear dimensions:

Center-to-center distance:

$$C = \frac{N_g - N_p}{2P}$$

Diametral pitch:

$$DP = \frac{N_g - N_p}{2C}$$

Inside diameter:

$$ID = \frac{N - 2}{DP}$$

where the symbols have the meaning as given in Question 40.

54. *What dimensions are necessary for drawing and machining spur gears?*

A. Pitch diameter.
B. Addendum.
C. Dedendum.
D. Diameter of hole.
E. Keyway.
F. Face.
G. Outside diameter.
H. Pitch.
I. Number of teeth.
J. Chordal thickness.
K. Corrected addendum.

SPUR GEAR PROBLEM

55. *Calculate the dimensions required for drawing and machining two meshing spur gears. The center-to-center distance is 3.9 in. The gear ratio is 2 : 1. The size of the hole, face, and pitch may be chosen.* The sum of the two pitch diameters is equal to twice the center distance, 3.9 times 2 equals 7.8. The pitch diameter of the large gear equals ⅔ of 7.8, or 15.6 divided by 3, which equals 5.2. The pitch diameter of the small gear or pinion equals ⅓ of 7.8, or 2.6.

The size of the tooth and pitch depends upon the pinion. In order to avoid having fractional parts of a tooth in a gear, the first choice of a pitch number is the denominator of the fraction in the pitch diameter; in this case it is 10.

Using the formulas, the addendum equals 1/10 or 0.100, the dedendum equals 1.157 divided by 10, or 0.1157.

After selecting the size of the hole, for instance, 1.250 for the gear and 0.750 for the pinion, the size of the keyways may be found in Appendix Table 12.

Meshing gears have the same face measurement. A reasonable size is 0.7 in.

The outside diameter and the number of teeth for each gear may be calculated from the formulas.

The chordal thickness and corrected addendum for each gear may be obtained from Fig. 16–16.

The complete list of dimensions is given in Fig. 16–33.

BEVEL GEARS

56. *What is a bevel gear?*
 A bevel gear (Fig. 16–34) is one in which the teeth are cut so that they radiate from the apex of a cone and lie on the conical surface.

gear		*pinion*
5.200	**Pitch diameter**	**2.600**
0.100	**Addendum**	**0.100**
0.1157	**Dedendum**	**0.1157**
1.250	**Diameter of hole**	**0.750**
5/16 x 5/32	**Keyway**	**3/16 x 3/32**
0.7	**Face**	**0.7**
5.400	**Outside diameter**	**2.800**
10	**Pitch**	**10**
0.1570	**Chordal thickness**	**0.1569**
0.1011	**Corrected addendum**	**0.1023**
52	**Number of teeth**	**26**

Fig. 16–33. Solution to spur gear problem (Question 55).

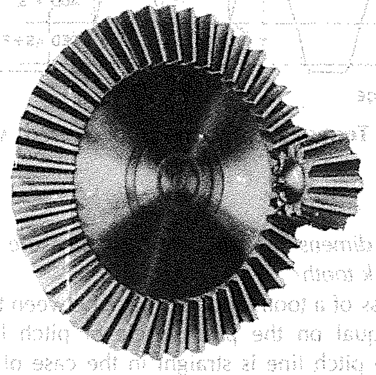


Fig. 16–34. Bevel gear and pinion. (Philadelphia Gear Works.)

57. *What are bevel gears used for?*
Bevel gears are used to transmit motion from one shaft to another shaft at an angle to the first.

The terms used for spur gears have the same meaning for bevel gears. However, some additional terms are peculiar to bevel gears (Fig. 16–35).

A set of bevel gears is developed on adjacent cones, which have a common vertex, as in Fig. 16–36. These are called *pitch cones.*

58. *What is the vertex distance of a bevel gear?*
The vertex distance of a bevel gear is equal to the altitude of the pitch cone.

59. *What is the cutting angle of a bevel gear?*
The cutting angle of a bevel gear is the angle at which

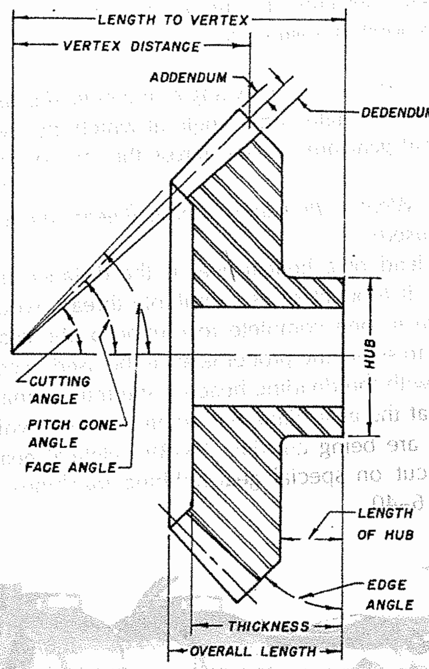


Fig. 16–35. Bevel-gear parts.

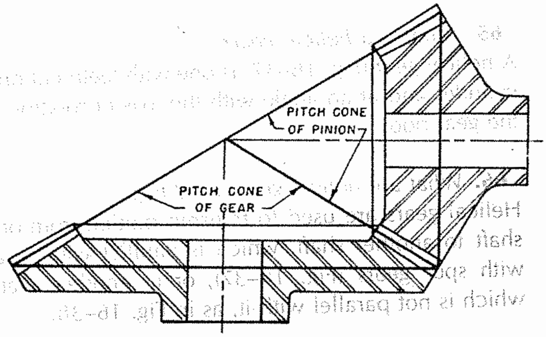


Fig. 16–36. Pitch cones of bevel gear and pinion.

the gear blank is held while cutting the teeth on a milling machine. Bevel gears are also cut on special machines.

60. *What is the pitch cone angle of a bevel gear?* The pitch cone angle is the angle between the conical surface of the pitch cone and the center line.

61. *What is the face angle of a bevel gear?* The face angle is the angle to which the gear blank is machined before cutting the teeth.

62. *What are miter gears?* *Miter gears* is the name given to mating bevel gears having the same number of teeth and pitch cone angles of 45°.

63. *What are the specific formulas used for calculating the dimensions of bevel gears whose shafts intersect at 90°?*

Vertex distance
= Pitch diameter (*PD*) of meshing gear ÷ 2
Pitch cone (*PC*) angle of gear
= Arc tan (*PD* of gear ÷ *PD* of pinion)
PC angle of pinion = 90° − *PC* angle of gear
Outside diameter (*OD*)
= *PD* + 2(cos *PC* angle) × Addendum
PC radius = (csc *PC* angle) × *PD* ÷ 2
Cutting angle = *PC* angle − (arc tan of *PC* radius)
Face angle = *PC* angle + (arc tan of *PC* radius)

64. *What dimensions are necessary for drawing and machining bevel gears?*

A. Pitch diameter.
B. Vertex distance.
C. Addendum.
D. Dedendum.
E. Pitch.
F. Number of teeth.
G. Chordal thickness.
H. Corrected addendum.
I. Pitch cone angle.
J. Pitch cone radius.
K. Cutting angle.
L. Face angle.
M. Outside diameter.
N. Diameter of hole.
O. Keyway.
P. Diameter of hub.
Q. Length of hub.
R. Face.
S. Length to vertex.
T. Thickness.
U. Edge angle.
V. Overall length.

HELICAL GEARS

65. *What is a helical gear?*
A helical gear (Fig. 16–37) is one with teeth cut on a cylinder and at an angle with the axis of rotation of the gear body.

66. *What are helical gears used for?*
Helical gears are used to transmit motion from one shaft to another shaft, which is parallel with it, as with spur gears (Fig. 16–37), or to another shaft, which is not parallel with it, as in Fig. 16–38.

Fig. 16–37. Helical gears on parallel shafts. (Boston Gear Works.)

Fig. 16–38. Helical gears on shafts at angles from each other. (Boston Gear Works.)

67. *What are the advantages of helical gears?*
Helical gears operate more quietly and smoothly because their teeth do not hit each other, as in spur gears, but slide one across the other. Also, when helical gears are meshed together, several teeth of each gear are in contact at one time and the load is spread, which results in greater strength than if only one tooth of each is in contact at a time.

68. *What is the undesirable factor of helical gears?*
Because of the sliding action of one tooth on another, the friction, and consequent heat and wear, is high. To offset this condition, helical gears are usually designed to run in an oil bath, as in an automobile transmission.

69. *What is the helix angle of a helical gear?*
The helix angle is the angle at which the teeth of a helical gear are slanted across the face of the gear.

70. *What is the lead of a helical gear, and for what is it used?*
The lead of a helical gear is the distance that the gear, if thought of as a multiple thread, would advance in one complete revolution of the gear. It is used to select the proper gears to be used in connection with the dividing head on the milling machine, so that the gear blank will rotate properly while the teeth are being cut (Fig. 16–39). Helical gears are also cut on special gear-hobbing machines, as in Fig. 16–40.

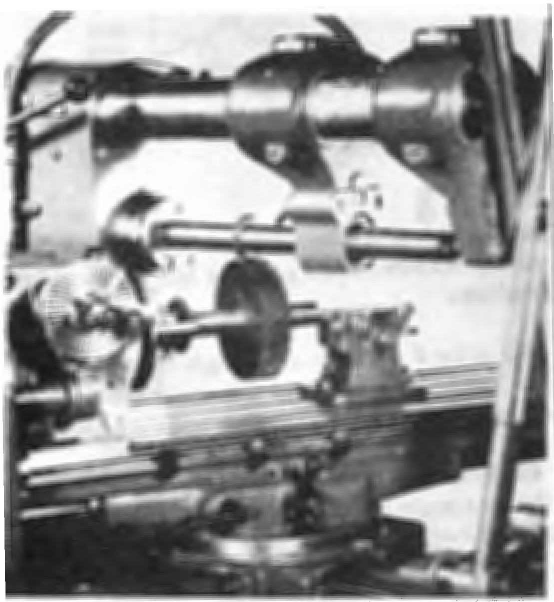


Fig. 16–39. Cutting a helical gear on a milling machine. (Brown & Sharpe Mfg. Co.)

71. *The spur gears in Question 55 are to be replaced with helical gears. The center distance of the shafts and the size of the teeth are not to be changed. Calculate the dimensions for the helical gears.*
The center distance and pitch remaining as before, several dimensions will be the same as in the original spur gears, namely, pitch diameter, addendum,

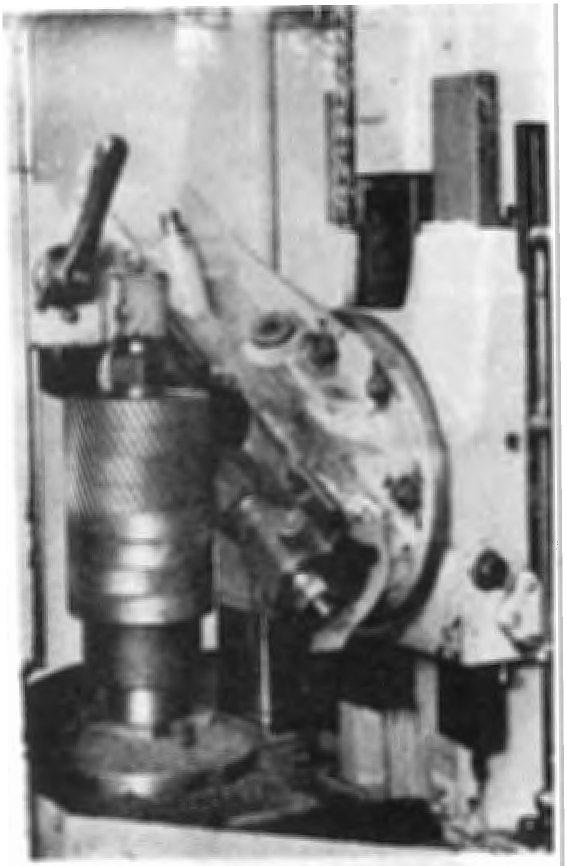


Fig. 16–40. Cutting helical gears on a gear hobber. (Gould and Eberhardt, Inc.)

dedendum, diameter of hole, keyway, face, outside diameter, pitch, chordal thickness, and corrected addendum.

When the teeth are slanted across the face of the gear, the distance between each one on the edge of the gear is greater than the circular pitch (Fig. 16–41). It is obvious, then, that the helical gears will have fewer teeth than the spur gears. In order to maintain the ratio between the gears, we may decide to use 50 teeth in the gear and 25 in the pinion. The helix angle may now be determined by using the formula

$$\text{Cosine of helix angle} = \frac{N \text{ of helical gear}}{N \text{ of spur gear}}$$

Where N = no. of teeth

$$\text{Cosine of helix angle} = \frac{50}{52} = 0.9615$$

$$\text{Therefore helix angle} = 15°56'$$

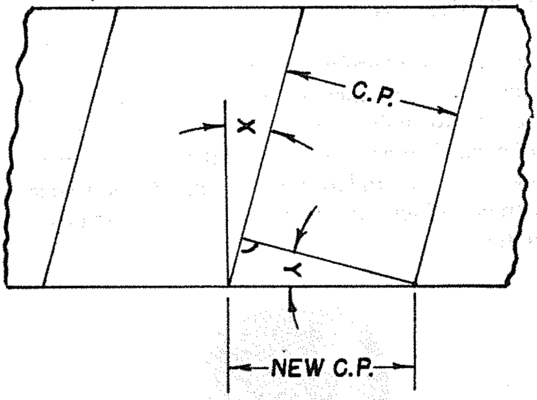


Fig. 16–41. Original and new circular pitch of a helical gear.

The lead of the gear is equal to the circumference of the pitch circle multiplied by the cotangent of the helix angle. The circumference of the pitch circle is equal to the pitch diameter multiplied by 3.1416.

$$\begin{aligned}\text{Lead of gear} &= PD \times 3.1416 \times \text{Cot (helix angle)}\\ &= 5.200 \times 3.1416 \times 3.50279\\ &= 57.222\end{aligned}$$

The pinion being one-half the size of the gear, the lead of the pinion will be one-half of the lead of the gear.

$$\begin{aligned}\text{Lead of pinion} &= \frac{\text{lead of gear}}{2} = \frac{57.222}{2}\\ &= 28.611\end{aligned}$$

The complete dimensions are given in Fig. 16–42.

Fig. 16–42. Solution to helical gear problem.

gear		*pinion*
5.200	**Pitch diameter**	**2.600**
0.100	**Addendum**	**0.100**
0.1157	**Dedendum**	**0.1157**
1.250	**Diameter of hole**	**0.750**
5/16 x 5/32	**Keyway**	**3/16 x 3/32**
0.7	**Face**	**0.7**
5.400	**Outside diameter**	**2.800**
10	**Pitch**	**10**
0.1570	**Chordal thickness**	**0.1569**
0.1011	**Corrected addendum**	**0.1023**
15°56'	**Helix angle**	**15°56'**
57.222	**Lead**	**28.611**
50	**Number of teeth**	**25**

note: When shafts are parallel, one gear is cut right-handed, the other one left-handed.

HERRINGBONE GEARS

72. *What is a herringbone gear?*
Originally, a herringbone gear (Fig. 16–43) consisted of two helical gears of equal size but of opposite hand joined together. Today, most herringbone gears are produced as a single unit on special machines which cut the teeth in two directions at one time.

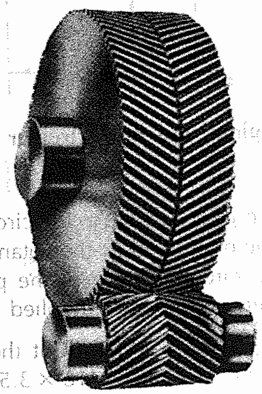


Fig. 16–43. Herringbone gears. (Philadelphia Gear Works.)

73. *What are some of the advantages of herringbone gears?*
(a) The sliding action of helical gear teeth exerts pressure of one gear toward the other, which must be compensated for by the use of thrust bearings. The thrust is equalized when herringbone gears are used. (b) Herringbone gears have a greater bearing surface than other gears of like size, which gives them exceptional tooth strength and heavy load-carrying capacity. (c) They are more satisfactory than other gears where a large ratio between gears is necessary. (d) They stand up under continuous high-speed operation better than other gears.

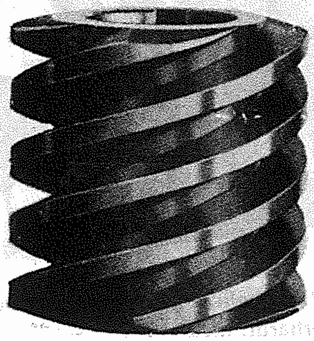
WORM AND WORM GEARS

74. *What is a worm gear?*
A worm gear (Fig. 16–44) is a wheel having teeth cut angular with the axis of rotation and radially in the gear face.

75. *What is a worm?*
A worm (Fig. 16–45) is a cylinder with teeth resembl-

Fig. 16–44. Worm gear. (Boston Gear Works.)

Fig. 16–45. Worm. (Boston Gear Works.)



ing those of an acme thread. The worm is mounted on a shaft, which is perpendicular to the shaft of the worm gear.

76. *What are worm gears used for?*
Worm gears are used for heavy-duty work where a large ratio of speed is required. They are used extensively in speed reducers.

77. *What terms are used in worm gearing that are not used for other types of gears?*
The terms throat, throat radius, and throat diameter are important in worm gearing (Fig. 16–46).

78. *What is the normal pitch of a worm?*
The normal pitch of a worm is the distance between the center of one tooth and the center of an adjacent tooth, measured perpendicular to the teeth.

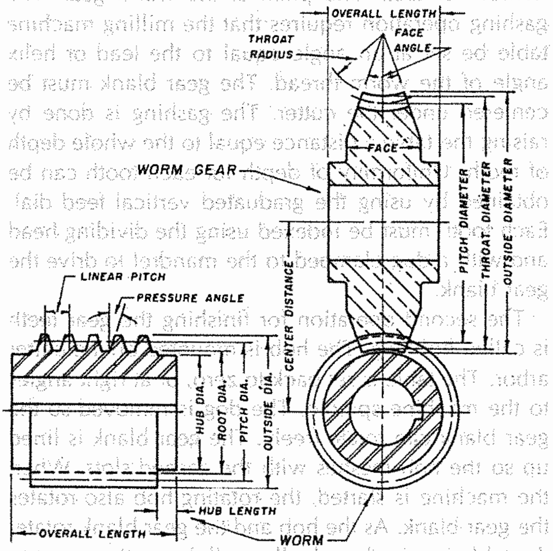


Fig. 16–46. Parts and terms for worms and worm gears.

79. *What is the throat of a worm gear?*
The throat of a worm gear is the concave surface of the gear tooth.

80. *What is the throat radius of a worm gear?*
The throat radius of a worm gear is the radius of the concave surface of the throat.

81. *What is the throat diameter of a worm gear?*
The throat diameter of a worm gear is the diameter of the gear, measured at the center of the throat.

82. *What is the face angle of a worm gear?*
The face angle of a worm gear is the angle to which the face of the gear is cut.

83. *What formulas are used for calculating worm gear dimensions?*

The following formulas are used for worm gears:

$$\text{Pitch diameter} = 0.3183 \times N \times CP$$

$$\text{Center distance} = \frac{PD \text{ of gear} + PD \text{ of worm}}{2}$$

$$\text{Addendum} = 0.3183 \times CP$$

$$\text{Dedendum} = 0.3677 \times CP$$

$$\text{Face} = 0.25 + (CP \times 2.38)$$

$$\text{Throat diameter} = PD + (2 \times \text{Addendum})$$

$$\text{Throat radius} = 0.55 + (CP \times 0.882)$$

Where the symbols are defined as in Question 55.

84. *What formulas are necessary for calculating worm dimensions?*

The following formulas are used to calculate worm dimensions:

$$\text{Pitch diameter} = 1.1 + (LP \times 2.4)$$

$$\text{Addendum} = 0.3183 \times LP$$

$$\text{Dedendum} = 0.3677 \times LP$$

$$\text{Root diameter} = PD - 2 \times \text{Dedendum}$$

$$\text{Outside diameter} = PD + 2 \times \text{Addendum}$$

$$\text{Lead} = LP \times \text{Number of threads}$$

$$\text{Helix angle} = PD \times 3.1416 \div \text{Lead}$$

$$\text{Normal pitch} = LP \times \text{Cosine of helix angle}$$

Dimensions for drawing and machining a worm and a worm gear are listed in Fig. 16–47

Fig. 16–47. Worm and worm-gear parts that need dimensioning.

worm	*worm gear*
Pitch diameter	**Pitch diameter**
Addendum	**Addendum**
Dedundum	**Dedendum**
Diameter of hub	**Diameter of hub**
Diameter of hole	**Diameter of hole**
Keyway	**Keyway**
Overall length	**Overall length**
Length of hub	**Face**
Linear pitch	**Circular pitch**
Pressure angle	**Pressure angle**
Outside diameter	**Outside diameter**
Root diameter	**Throat diameter**
Number of threads	**Number of teeth**
Lead	**Center distance**
Helix angle	**Helix angle**
Normal pitch	**Face angle**
	Throat radius

85. *How are worm gear teeth cut on a milling machine?*
The teeth on a worm gear may be cut on a milling machine, as shown in Fig. 16–48. Usually two operations are necessary. The first is called *gashing* the teeth. An involute spur-gear cutter of the correct

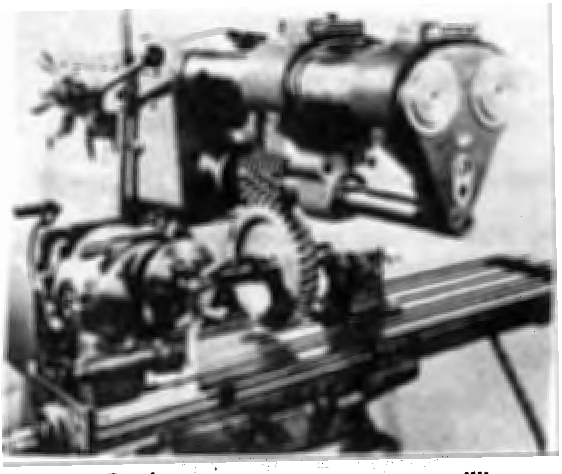


Fig. 16–48. Cutting a worm gear on a milling machine. (Brown & Sharpe Mfg. Co.)

pitch and number is selected according to the number of teeth and pitch of the worm gear. The gashing operation requires that the milling machine table be set at an angle equal to the lead or helix angle of the worm thread. The gear blank must be centered under the cutter. The gashing is done by raising the table a distance equal to the whole depth of tooth. Uniformity of depth for each tooth can be obtained by using the graduated vertical feed dial. Each tooth must be indexed using the dividing head and with a dog clamped to the mandrel to drive the gear blank.

The second operation for finishing the gear teeth is called *hobbing.* The hob is mounted on the cutter arbor. The table is set back to zero, or at right angles to the machine spindle. The dog is removed so the gear blank can rotate freely. The gear blank is lined up so the hob meshes with the gashed slots. When the machine is started, the rotating hob also rotates the gear blank. As the hob and the gear blank rotate, the table is raised gradually until the teeth are cut to the correct depth. The worm to be used with the worm gear can be used for obtaining the correct center-to-center distance before removing the worm gear from the milling machine.

chapter 17 fundamentals of numerical control

The development of technological progress by the human race can be traced through man's use of tools and of the machines that have resulted from this use.

It can be safely assumed that early man's use of the hammer, saw, and file made possible the moving of families from the dark and damp holes in the rocks to safer and more pleasant abodes on view-commanding hilltops.

The making of the wheel simplified transportation; from this came the development of the other basic mechanisms that contributed to man's comfort and security. Toothed wheels led to meshing gears, which, in turn, were applied to more advanced machinery. From advanced machinery came Watt's steam engine and Maudslay's screw-cutting lathe, each of which played their part in simplifying the problems of living for the family of man.

Each succeeding generation made its contribution to the easing of man's work load. Thomas Edison, Guglielmo Marconi, and Henry Ford brought benefits to industry and comfort and pleasure to the human race.

New methods of production brought increased benefits to the producers. The number of hours worked daily steadily decreased and the amount of weekly earnings increased. Mass production and interchangeable manufacture brought the purchasing price of unusual luxury items within the reach of the average family. Man's most arduous tasks have been lightened, lessened, and often eliminated by the broadening influence of machine tools.

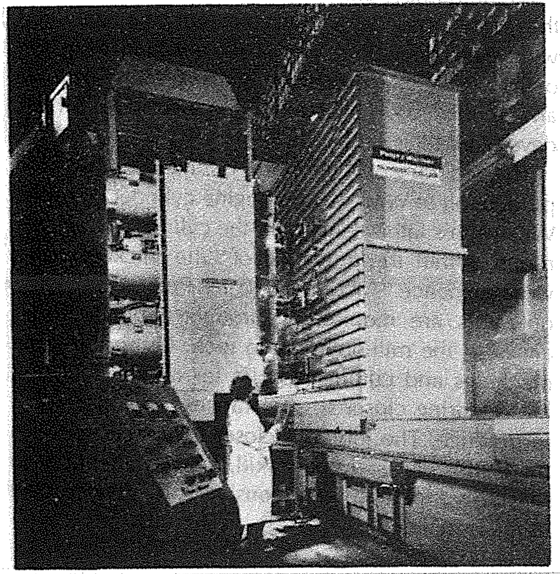
As the number and variety of machines increased, the closer man as a craftsman became identified with their operation. The work resulting from the operation of the machines became more delicate and refined as, necessarily, the operators further developed their skills.

The accuracy of Wilkinson's boring lathe made the production of Watt's steam engine cylinder possible. Wilkinson's lathe could bore the cylinder accurately round within the tolerance of "the thickness of a worn sixpence," about 0.040 in. Present-day lathe operators are required to produce work to tolerances in the millionths of an inch. Using the same machines and cutting tools as for rough work, the job requiring closer size tolerances takes more time to produce. The job with closer tolerances requires more of the operator's skill, closer attention to machining details, and considerably greater care in measurement.

The operator uses more time to make his machining decisions, more time to measure, more frequent measuring, and a far greater attention to the small details. Each of these details increases the possibility for error, and the amount of scrap multiplies. Each scrapped job carries with it a few minutes, or hours, of time worked by a machine and its operator. The correctly finished job must carry a price that will compensate the manufacturer for the parts that are spoiled or scrapped, all of which made precision machining a costly procedure—until the advent of numerical control.

Many meanings have been given to the term *numerical control;* some are very simple, others are difficult to understand. It could be simply described as the name given to a process that controls the function of a machine by the use of numbers. Such an explanation is hardly sufficient to describe the operation of a system that reduces the complexities of an engineer's blueprint to a series of holes in a length of tape that is placed in a roll beside a machine and, as it passes to a take-up roll, proceeds to guide a machine through its most complicated operations to infinitesimal tolerances. It is difficult to imagine that machines, when controlled by tape, make every diameter, length, depth, thread, radius, bore, and so forth to within specified tolerances with minimum spoilage, scrap, or loss of time. Because numerical control is another tool development that will bring many benefits to the human race, it deserves our study (Fig. 17–1).

Fig. 17–1. A numerically controlled milling machine with a continuous-path N/C system. This machine is designed for work that weighs over 20 tons. (Pratt & Whitney Co.)



1. *How was numerical control developed?* Controlling machines by means of holes punched in 1-in. wide tape can be considered an invention that followed in the wake of World War II. However, its beginnings can be traced to a much earlier period. The earliest known example of punched holes controlling the function of a machine is the Jacquard loom (Fig. 17–2), which still plays an important part in the production of textiles. The Jacquard principle is based on a mechanism that raises specified threads to leave a shed through which the shuttle travels, thus creating the pattern. The Jacquard harness is fastened above the loom and the thread selection is made through holes punched in heavy cardboard (Fig. 17–3). The cards are punched with the holes, which form the design, and are then joined together in a card lacer (Fig. 17–4).

Weaving was an ancient trade when Basile Bauchon, in 1725, substituted an endless band of

Fig. 17–2. Jacquard loom in operation. (Hamilton Web Co., and the Wilking Studio.)

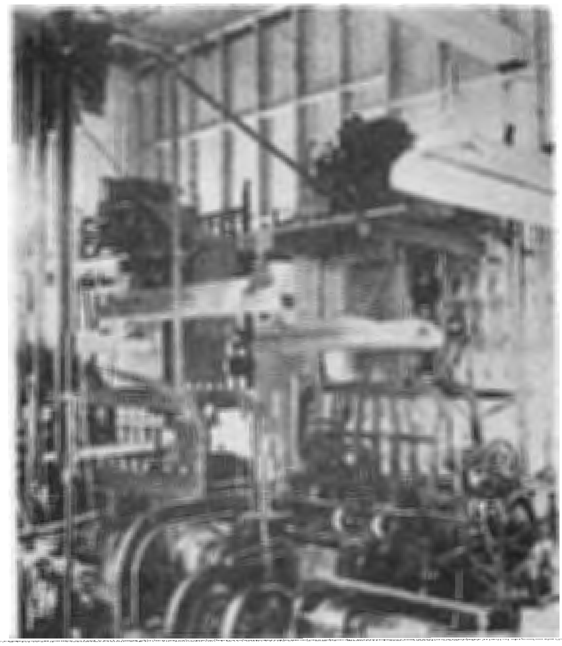
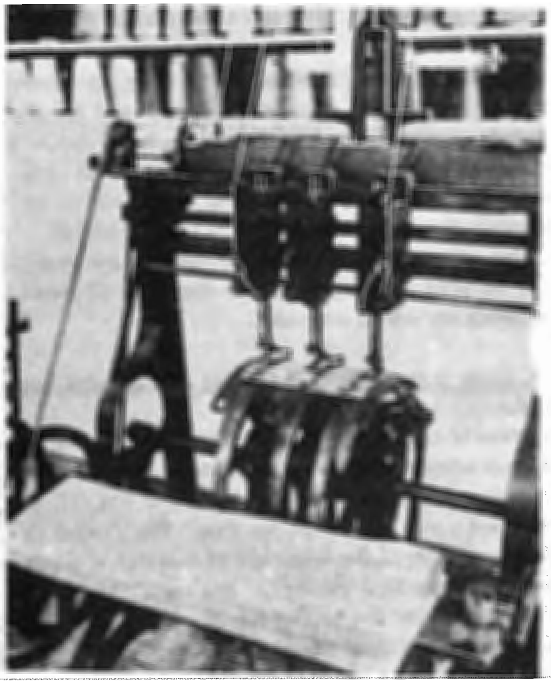


Fig. 17-3. Jacquard loom harness. (Hamilton Web Co., and The Wilking Studio.)

Fig. 17-4. Jacquard card lacer. (Hamilton Web Co., and The Wilking Studio.)



perforated paper for the looped cords or string that raised a section of the drawloom's harness.

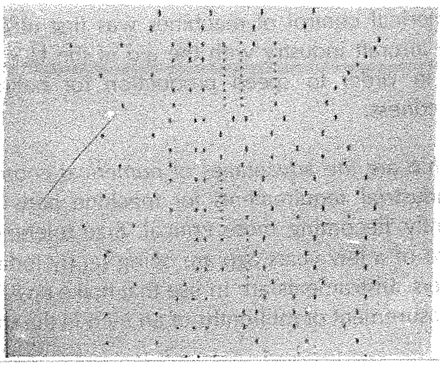
Later M. Falcon made a weaving machine that used perforated cards, but it needed an extra worker to operate the card mechanism. A further improvement was made in 1745, by Jacques de Vaucanson, who combined Bauchon's perforated paper with Falcon's mechanism.

Joseph-Marie Jacquard perfected and refined the power loom very much as it is today and demonstrated the result of his work in a Paris industrial exhibition in 1801. Jacquard was later honored by the Government of France and given a pension for his contribution to the economic welfare of his country. He is quite often given credit for having originated the use of perforations in paper or cardboard to control mechanical functions; but, as has been shown here, others predate his efforts and have prior claims for that honor.

More than a hundred years later, the perforated-paper technique was used in a device built into a piano for reproducing a pianist's playing. Paper rolls were perforated with holes arranged to produce any particular melody or pianoforte arrangement (Fig. 17–5). These rolls operated the piano as follows: Air passed through the hole in the paper roll and through the hole in a tracker bar. The tracker bar had 88 holes, one for each note (key) of the piano keyboard. When a hole in the piano roll became aligned with the hole in the tracker bar, the air passing through motivated valves that caused the correct note to play.

In the early 1950s, the Massachusetts Institute of Technology demonstrated the result of its experimentation with a numerically controlled milling

ig 17–5. Section from a player piano roll.



machine. Since that time, many engineering companies have made valuable contributions to the development of this technique, and there are now many different numerical control systems in productive use. Many of the basic steps in the various systems are the same or very similar. To date there is no international standard for numerical control systems. The tape with its arrangement of holes has been accepted as a standard. It is made and used in rolls, is 1 in. wide, and has eight tracks, or channels, of holes (Fig. 17–6).

Some systems use punched cards; others use a magnetic tape of various widths.

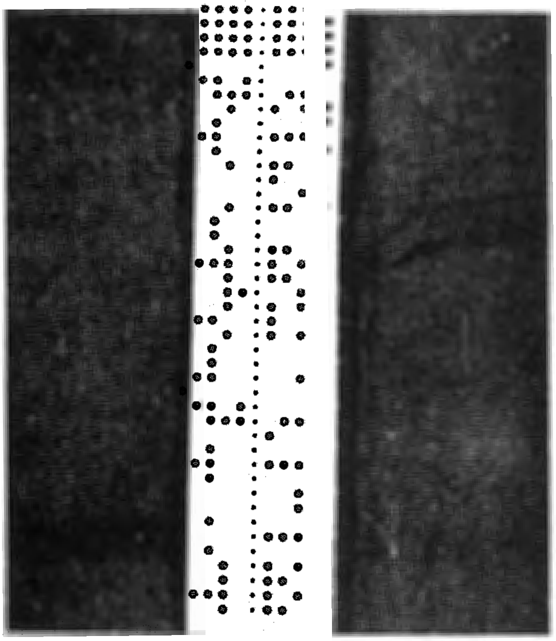


Fig. 17–6. A section of the tape used on an N/C milling machine. It is 1-in. wide and has 8 tracks of holes.

Numerical control of machines was first utilized by the aircraft industry with the aid of the U.S. Air Force in order to speed production for national preparedness.

2. *What are the advantages of numerical control?* The industrial requirements for machine parts are constantly becoming more critical. Size tolerances unheard of a few years ago are being set by today's engineers. Instruments are in use that make possible the measurement of millionths of an inch in the shop inspection department. Work finished to such a fine measurement requires extreme care by the machinist. Human judgment of size and distance is not consistently accurate. Numerical control, when correctly programmed, removes the possibility of human error (Fig. 17–7). Uniformity in duplication is assured. Each piece machined according to the specification of the same tape will be almost identical in size and shape. Properly chosen tool speeds and feeds remove the possibility of excessive pressures, which lead to tool breakage and undetected cracks in job materials.

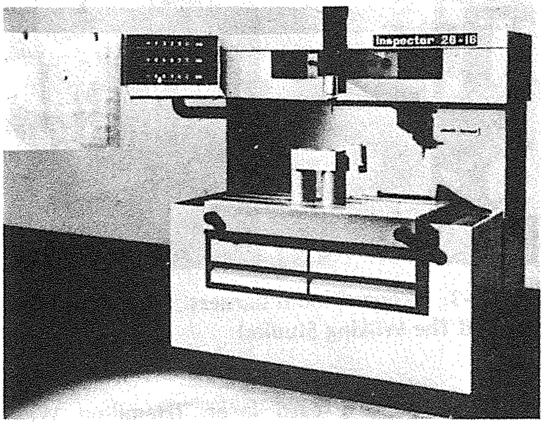


Fig. 17–7. A numerically controlled three-axes inspection machine. (Farrand Controls Inc.)

Numerical control removes the need for costly patterns, templates, jigs, and fixtures, and for the storage of such hardware. Tapes can be stored in a filing cabinet and reused whenever a repeat order is received. Scrap parts and the reworking of improperly finished parts will be all but eliminated.

The advantages of numerical control are many. The benefits vary according to the type of manufacturing for which it is used.

3. *How does numerical control operate machine tools?* Numerical control operates machine tools by means of instructions expressed in numerical code. This code is recorded on punched paper tape (Fig. 17–8), punched cards, or magnetic tape. The coded instructions control the sequence of machining operations; the machine positions; the speed, direction, and distance of the workpiece or cutting tool; the flow of coolant; and the setting of the cutting tools

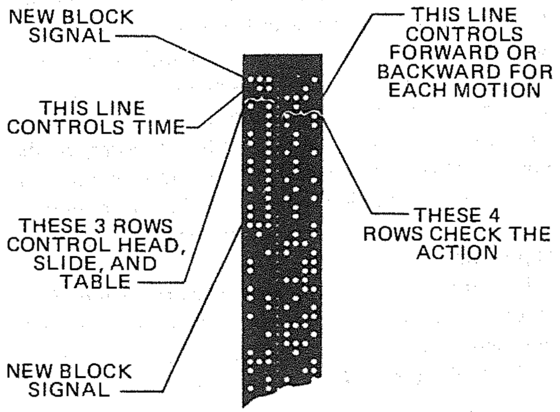


Fig. 17–8. Typical control-tape section. (*American Machinist*, McGraw-Hill, Inc.)

for each of the operations to be performed on the workpiece.

When the prepared instructions are placed in an electronically controlled device called a *tape reader* (Fig. 17–9), it can control the machine

Fig. 17–9. Tape reader for numerically controlled machine tool. (Fosdick Machine Tool Co.)

through the programmed movements and perform the necessary operations without any manual assistance (Fig. 17–10).

A typical numerical control system (Fig. 17–11) consists of the following basic equipment:

A. A tape-reader, which is a device that transmits coded information to the information-storage unit, using the principle of electrical contacts operated by the presence or absence of holes in the tape.
B. An information-storage unit (electronic director) (Fig. 17–12), which receives information from the tape-reader and translates it into the form of signals. The signals are then transmitted to the motors or actuating devices, which move the machine work-holding tables and spindles through the various positions.
C. A machine-actuation system, which consists of electric motor drives, hydraulic motor drives, or hydraulic cylinders (Fig. 17–13). Power-servo drives of various types are used for velocity changes and for reversing the direction of motion. Feed motion can be obtained from motor rotation through gearing, racks, or feed screws, as well as from the thrust of hydraulic cylinders.

4. *Explain the basic difference between manually operated and numerically controlled machine tools.*

Fig. 17–10. Interior view of tape reader. (Fosdick Machine Tool Co.)

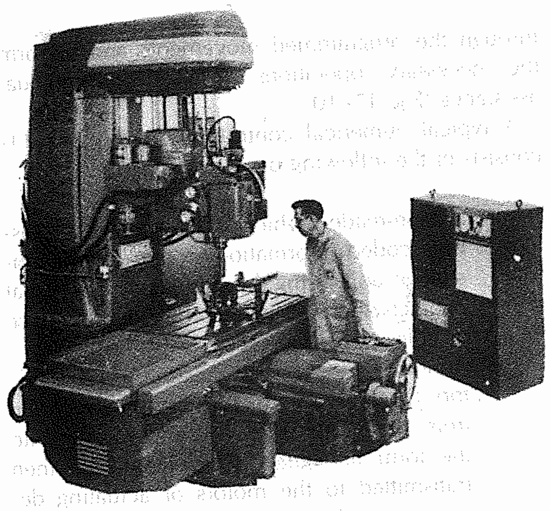


Fig. 17–11. Typical N/C system applied to precision jig-boring machine. (Fosdick Machine Tool Co.)

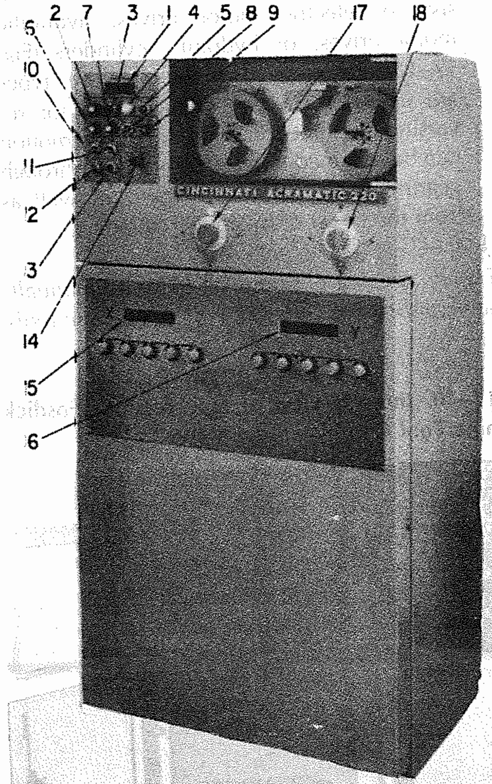


Fig. 17–12. Electronic information-storage console, showing operation indicators and manual controls. (Cincinnati Milacron Co.)

In the conventional method of operating machine tools, the machinist turns the controls, moves levers, and makes other adjustments by hand to set power feeds in motion. He also selects the proper speeds and feeds, whether it be for the spindle of the milling machine, drill press, boring mill, jig borer, or the engine lathe. The machinist does this in order to follow the instructions given on the job operation sheet or job blueprint, or simply on the basis of his experience.

In numerical control, a tape takes the place of the machinist and his experience. The tape controls the speed and feed of the cutting tool, the movement of the table, the flow of coolant, and the variety of other operations required to machine a particular job.

A machine directed by numerical control (Fig. 17–14) can machine workpieces to the highest degree of accuracy, within the accuracy of the machine tool itself. Each spindle, lead screw, cross-feed screw, and other machine tool member that moves is provided with its own motor-drive unit. Each movement to a spindle or lead screw, for example, comes from the motor attached for moving these members. Such motors are called *servomotors* or *servomechanisms*. A servomotor is an electric motor that rotates many revolutions, a single revolution, or an infinitesimal part of a revolution, in response to a command or signal from an electrical contact. The servomotor gets its command signal from the punched tape. The tape instructs the motor when to start, how many revolutions or parts of a

1. **Sequence number readout**
2. **Master start**
3. **Master stop**
4. **Acramatic ON light**
5. **In-cycle light**
6. **Cycle start**
7. **Cycle stop**
8. **Single continuous selector**
9. **Cycle selector switch**
10. **Manual tape selector**
11. **Loop-stop-reel switch**
12. **Search button**
13. **Parity light**
14. **Table feed (in./min.) selector**
15. **Position readouts (optional)**
16. **Position readouts (optional)**
17. **Zero shift adjustment**
18. **Cycle start adjustment**

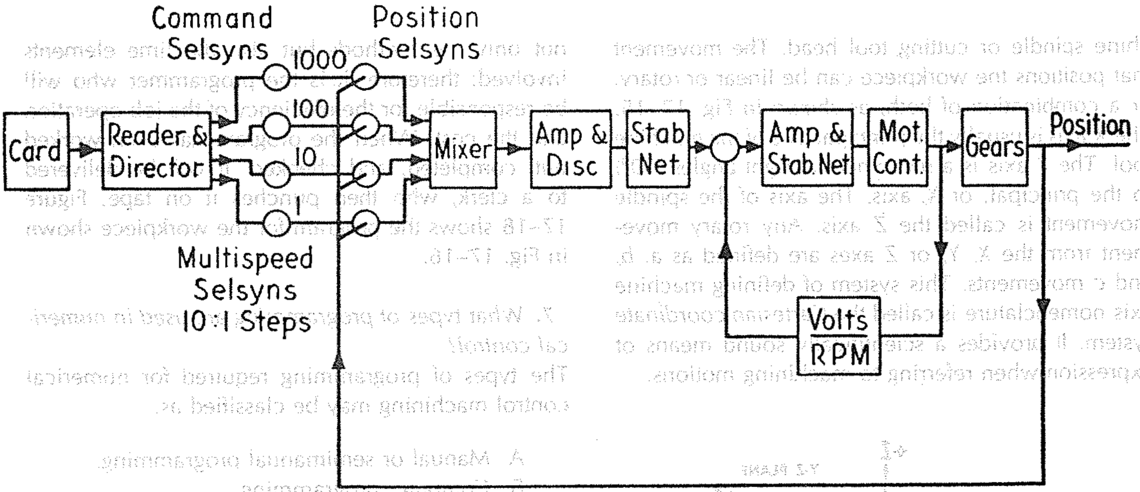
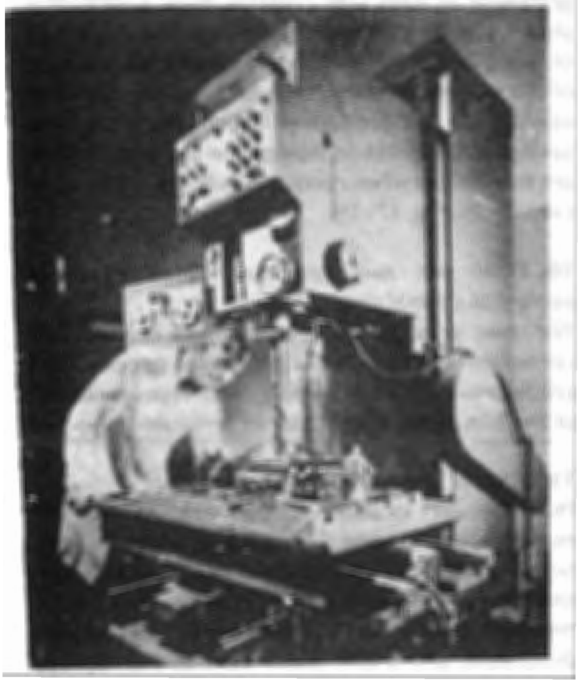


Fig. 17–13. Diagram of machine-actuation system for numerical control. A multispeed selsyn position-indicating system coupled with a servomechanism to position machine elements makes up the numerical control system. Selsyn (or synchro) generators of the machine position-indicating units make up the follow-up. Selsyn control transformers of the card reader direct the machine elements. Signals of corresponding connected-pair selsyns are compared by the electrical circuits, which then operate the drive motor to bring each selsyn generator of the director to the angular position corresponding to instructed position. (*American Machinist*, McGraw-Hill, Inc.)

Fig. 17–14. A numerically controlled drilling machine. (Pratt & Whitney Co.)



revolution to turn, and when and where to stop. This is done by the on-and-off switching of electrical current to the servomotors.

Just as the holes in the paper roll of the player piano permit air to pass through and actuate the valves for the required musical note, so the holes in the punched tape permit contact to be made with the on-and-off switches that control the servomotors. The punched tape is placed in a control unit, called a *tape-reader*, which interprets the code of the tape from the placement of the holes. The tape passes below mechanical fingers; whenever a hole appears, one of the fingers makes a contact, which completes an electrical circuit, which, in turn, will set up electrical contact giving a pulse movement to the servomotor. Combinations of lead-screw pitch and servomotors can vary in the distance traveled in response to a single pulse. The distance traveled usually ranges from 0.0001 to 0.0002 in. Finer variations can be obtained.

5. *Explain briefly the nomenclature of the machine axes.*

The principal function of a numerical control system is to position the workpiece precisely under a machine spindle or cutting tool head. The movement that positions the workpiece can be linear or rotary, or a combination of both, as shown in Fig. 17-15. The *X* axis is usually the principal axis of the machine tool. The *Y* axis is a movement at right angles (90°) to the principal, or *X*, axis. The axis of the spindle movement is called the *Z* axis. Any rotary movement from the *X*, *Y*, or *Z* axes are defined as *a*, *b*, and c movements. This system of defining machine axis nomenclature is called the *Cartesian coordinate* system. It provides a scientifically sound means of expression when referring to machining motions.

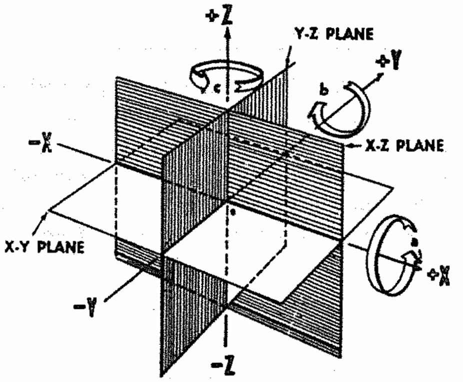


Fig. 17-15. Nomenclature of machine-axes–Cartesian-coordinates system. (*American Machinist*, McGraw-Hill, Inc.)

6. *What is meant by programming?*
The work of the programmer is most important to the success of the job. The programmer need not have a college degree in engineering. The individual who has a broad background in shopwork and is still willing to learn new techniques can be a successful programmer. The programmer reads the engineer's drawing (Fig. 17-16) and translates it into a program for a numerically controlled machine (Fig. 17-17). He will list the required movements of table, cutting tool, and job. He will determine the operations to be performed and the order of performance of those operations. He will decide how the job will be held on the machine table and how to hold it so that the cutting tool can perform all operations without changing the original setup. The programmer will decide on the changing and regular replacement of tools and provide instructions to do so for the machine operator to follow. He determines not only the methods but also the time elements involved; therefore, it is the programmer who will be responsible for the efficiency of the job operation and the cost. When the program has been worked out, completed, and checked, it will be delivered to a clerk, who then punches it on tape. Figure 17-18 shows the program for the workpiece shown in Fig. 17-16.

7. *What types of programming are used in numerical control?*
The types of programming required for numerical control machining may be classified as:

A. Manual or semimanual programming.
B. Computer programming.

8. *What is meant by manual programming?*
Manual programming takes into consideration the details and variations from conventional processes without the use of computers. It has been defined as "preparing a detailed sequence of operating instructions for a particular problem."

9. *To what extent are computers used in programming for numerical control?*
Computers are finding wide acceptance in the programming of parts with complex three-dimensional shapes and for jobs with many holes. The advantage of using computers lies in the speed and accuracy of storing great amounts of data, handling repetitive operations, and producing logical decisions. The savings of time and cost through the use of computers are tremendous when compared with the use of other calculators (Fig. 17-19).

10. *What are two principal classifications of numerical control programming?*
The two principal classifications of numerically controlled machine tools are point-to-point and continuous-path programming. Both types make use of the 1-in. wide, eight-channel perforated tape.

11. *What is point-to-point programming?*
Point-to-point location is the simplest type of numerical control and the easiest to program. Positioning controls on the point-to-point location system are used to locate a point or series of points by moving the table in two independently controlled dimensions (the *X* axis and *Y* axis) to the required point. The route, or path, of the movement is not

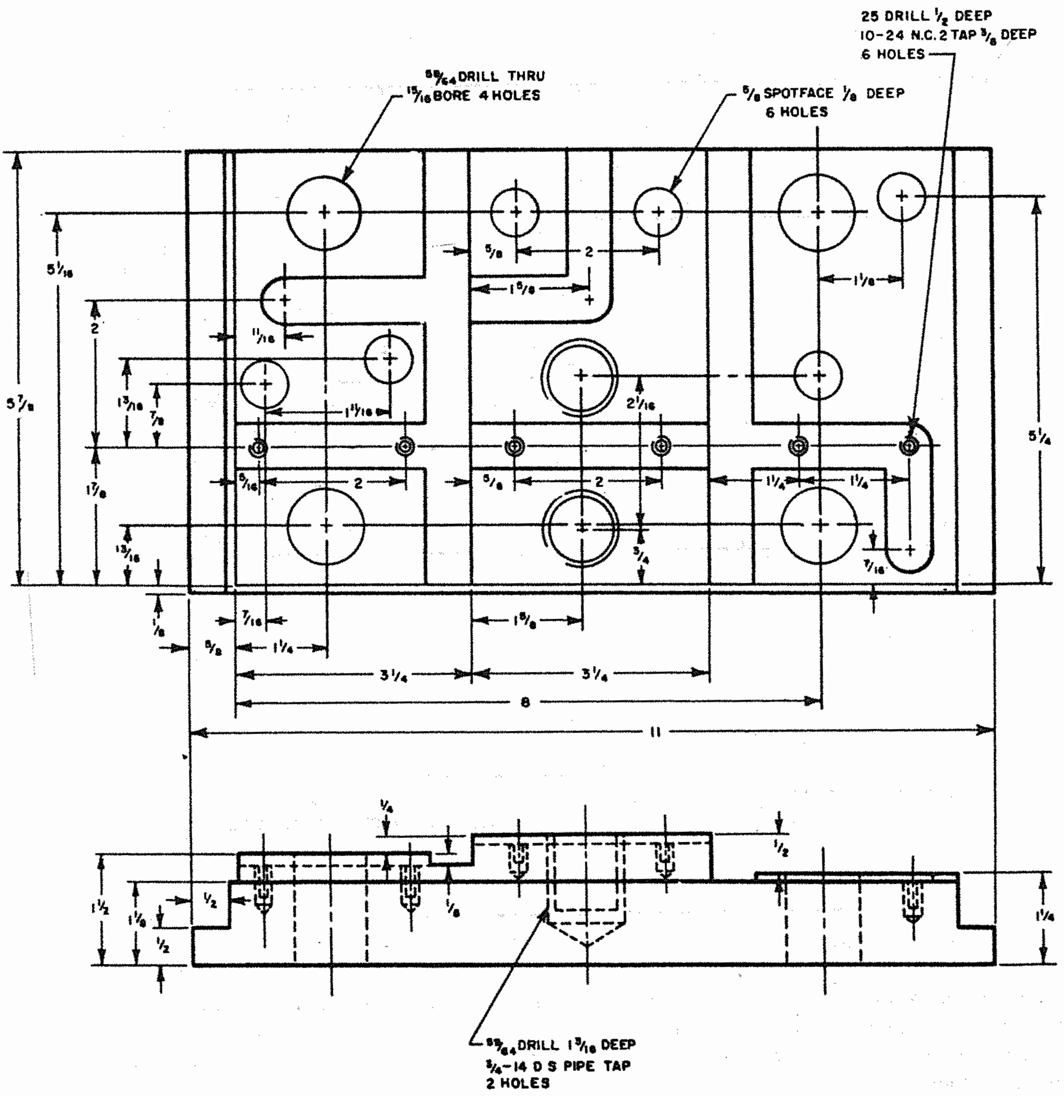


Fig. 17–16. Conventional dimensioned drawing for test block. (Cincinnati Milacron Co.)

necessarily controlled as it travels from point to point. When that point is reached, a third movement may begin its operation to a predetermined depth on the Z axis. The most common example of the point-to-point locating system would be a drill press operation; drilling a series of holes equally spaced on a specified center distance (Fig. 17–20). Other machines using point-to-point positioning are turret drills, boring mills, turret lathes, and jig borers (Fig. 17–21).

12. *What is continuous-path programming?* Although point-to-point programming is the simpler of the two systems, continuous-path programming was the first developed. This came about as a result of a U.S. Air Force request for tape-controlled machinery to reduce production cost.

Continuous-path programming offers the greater challenge to the designer, engineer, and programmer. It calls for the control of tool and job on two, three, and sometimes more numerically defined

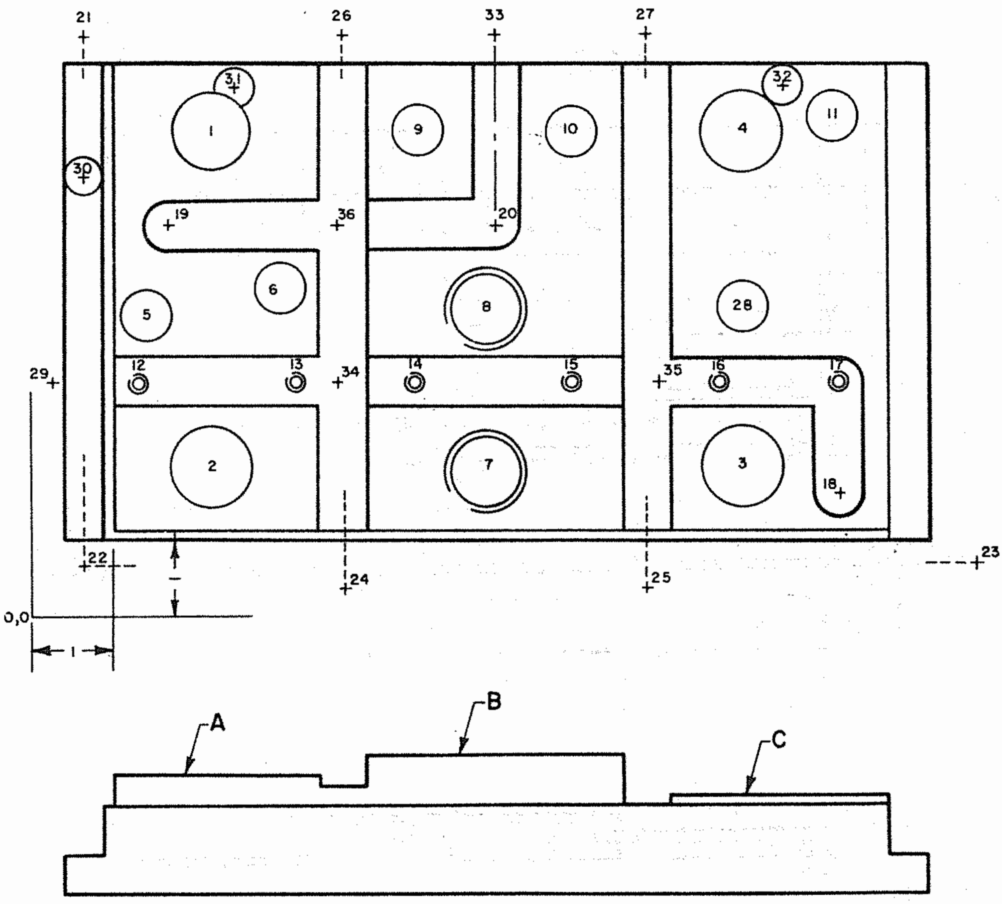


Fig. 17–17. Numerical drawing for test block. (Cincinnati Milacron Co.)

dimensions. It can result in the production of difficult and unusual shapes, contours, and complex curves, which would be extremely difficult to machine by any other process. The cutting tool is still required to move in a straight line, but the curves are machined by breaking down the travel distance of the cutter into many short straight line units. Herein lies the important difference between point-to-point locating and the continuous-path system; the path of the cutting tool is important. The movement along the three axes (*X*, *Y*, and *Z*) must be accurately synchronized both in dimension and time. The number of straight line units will depend upon the amount of allowable tolerance between the required curve and the chord formed by the straight lines left by the path of the cutting tool (Fig. 17–22). Many jobs require short line units no longer than 0.0005 in. or the chord of a 1° arc.

13. *How is a numerical control tape prepared?* The techniques used to translate a blueprint or designer's drawing to a punched tape will vary from one system to another and (even within the same system) will vary from one job to another, depending upon the equipment to be used, the size and tolerance requirements, and the shape of the part to be made. The step-by-step procedure for preparing a numerical control tape is as follows (Fig. 17–23):

A. The engineer or designer produces a drawing or sketch of the part that is to be manufactured.
B. The sketch is redrawn and redimensioned for this new production technique. Measurements are located from one reference point, usually the bottom left, right angle corner of the job. The reference point can also be out-

CINCINNATI
ACRAMATIC POSITIONING
NUMERICAL CONTROL SYSTEM

#3 CINTIMATIC TEST BLOCK | C.I. | 706620
POSITION #50; X = 00.625, Y = 05.500; POSITION #51; X = 02.500, Y = 06.625; POSITION #52; X = 05.500 Y= 06.625. USE 1/2" PIN AS SHOWN ON COORD. DWG. 706620. | 6/15/63 | 1 - 3
A. FRANCIS

SEQ NO	PREP FUNCT	X POSITION	Y POSITION	X Y FEED	Z FEED POSITION	Z FEED	Z RAPID POSITION	ROTARY TABLE POSITION	SPINDLE SPEED	TOOL FUNCTION	MISC FUNCT	POS NO	FEED IN REV	SPEED RPM	DEPTH OF CUT	TOOL REMARKS	LENGTH OF CUT	STANDARD
N001	080	X00587	Y07625								M51	21	.006	750	.375	5/8 DIA. E.M.(SET Z		
N002	079											21				DEPTH FROM SURFACE A)		
N003			Y00587									22				USE TURRET STOP #1 FOR		
N004		X12125										2[illegible]				CAMS M51 - M55		
N005	081											23						
N006	078	X07812	Y00250								M52	25			.125	SET Z DEPTH FROM		
N007	079		Y07625									27				SURFACE C. (CLAMP QUILL)		
N008	078											27				UNCLAMP QUILL - RETRACT		
N009	080	X03937	Y07625								M53	26			.125	SET Z DEPTH FROM		
N010	079											26				SURFACE A.		
N011			Y00250									24						
N012	081											24						
N013	080	X10250	Y01437								M52	18						
N014	079											18						
N015			[illegible]									17						
[illegible]												35						
			[illegible]									35						
N055		X10250														[illegible] Z DEPTH FROM		
N056	081	X09000	Y01812															
N057			Y06062								M00	4				INDEX - #2 TURRET [illegible]		
N058	081	X05875	Y03937								M57	8						
N059			Y01750								M00	7				INDEX - #3 TURRET STOP		
N060	081	X02250	Y01812								M57	2						
N061			Y06062								M06	1						
N062	085	X02250	Y06062								M58	1	.004	690	1.500	3/4 DIA. BORING BAR		
N063			Y01812								M00	2				INDEX - #1 TURRET STOP		
N064	085	X09000	Y01812								M58	3						
N065			Y06062								M06	4						
N066	084	X05875	Y03937								M59	8	.072	800	0.7500	1/2 - 14 DS PIPE TAP		
N067			Y01750									7						
N068	080	X01000	Y01000								M02					UNLOAD POSITION		

Fig. 17–18. Complete program manuscript for test block. (Cincinnati Milacron Co.)

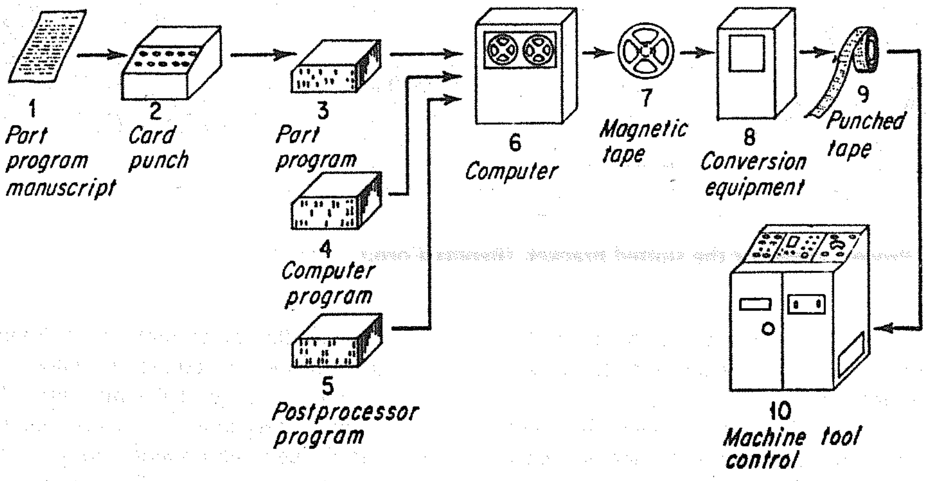


Fig. 17–19. Steps in computer programming for N/C. (*American Machinist*, McGraw-Hill, Inc.)

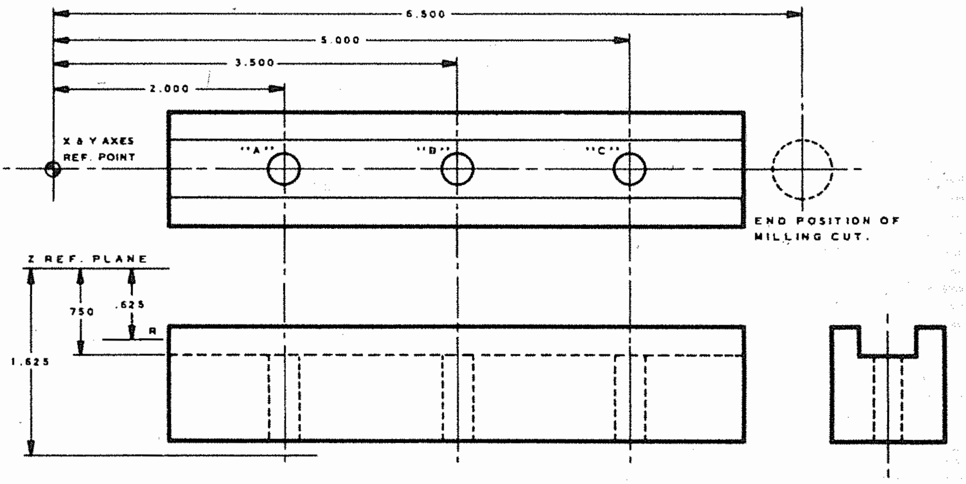


Fig. 17–20. This slotted bracket is a typical job for point-to-point programming. (Bendix Corp.)

Bendix PROCESS SHEET
DYNAPOINT 40

PART NO. DLP-31702 | TAPE NO. 7221 W | DATE 3-1-64

PART NAME SLOTTED BRACKET | MACHINE NO. SMALL NC DRILL | PLANNER D.P. FORTY

BLK.	SEQ. NO. (n)	PREP. FUNC. (g)	X AXIS POSITION (x)	Y AXIS POSITION (y)	Z AXIS FINAL DEPTH (z)	SECONDARY FEED PT. (q)	FEED ENGAGE POINT (r)	FEED RATE (f)	SPIND. SPEED (s)	TOOL (t)	MISC. FUNC. (m)	REMARKS
1	n001										SC	REWIND STOP CODE
2	n002	g89			z-750		r-625	f14	s78	t01	m03	POSITION FOR MILLING
3	n003		x+6500								m08	MILL SLOT
4	n004	g81	x+5000		z-875			f06	s38	t02		CENTER DRILL HOLE "C"
5	n005		x+3500									CENTER DRILL HOLE "B"
6	n006		x+2000									CENTER DRILL HOLE "A"
7	n007				z-1625			f10	s60	t03		DRILL HOLE "A" THRU
8	n008		x+3500									DRILL HOLE "B" THRU
9	n009		x+5000									DRILL HOLE "C" THRU
10	n010	g90			z+000		r+000				m09	RETURN Z TO ZERO
11	n011	g91	x+0000								m05	RETURN X-Y TO ZERO
12	n012										m30	REWIND TAPE

Fig. 17–21. Process sheet for the slotted bracket. (Bendix Corp.)

side of the job or it may be the geometric center of the part. Convenience usually determines this.

C. A programmer then breaks down the entire job into single operations; he numbers each operation in its proper operational sequence and pinpoints its location in inches and thousandths of an inch (or millionths of an inch if the job requires it) within the limits of the accuracy of the machine. The numbered operations, location measurements, sizes, feeds and speeds, tools, instructions to the operator regarding tool changes and coolants, and so forth are then written on a

Fig. 17–22. An example of continuous-path machining. (Ex-Cell-O Corp.)

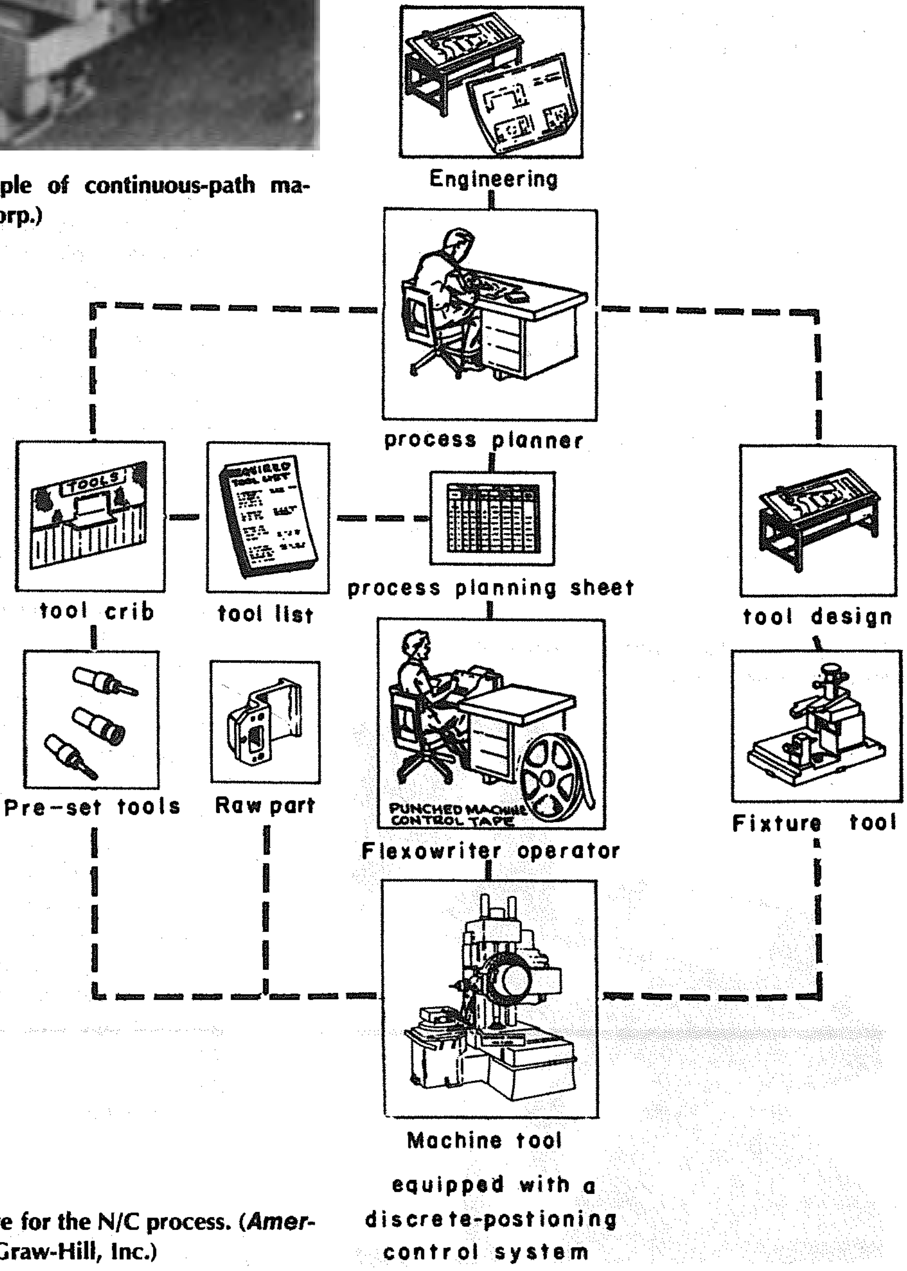


Fig. 17–23. Procedure for the N/C process. (*American Machinist*, McGraw-Hill, Inc.)

planning sheet, sometimes called a process sheet, operation sheet, or program manuscript.

D. The planning sheet is given to a typist who copies the information on a tape-punching typewriter. The typewriting machine resembles an ordinary electric typewriter (Fig. 17–24) and operates in the same way. There is an important added feature, a tape punch in a box at one side of the typewriter. When the typist types digits, letters, or symbols on the keyboard, two things occur. First, a printed copy of the information is made, which is called the *printout*. Second, the information typed is translated by the attachment at the side of the typewriter (Fig. 17–25) into binary coded language (binary coded decimal form). This language appears as a series of holes punched into a standard 1-in.-wide tape. The tape can be made from paper or plastic; the thickness of the tape must not exceed 0.0043 in.

The standard code is one character per row, punched perpendicular to the longitudinal axis of the tape with a maximum of eight holes. The location and the number of holes signify the alphabetical or numerical character.

Fig. 17–24. A tape-punching typewriter. (Friden, Inc., and Fosdick Machine Tool Co.)

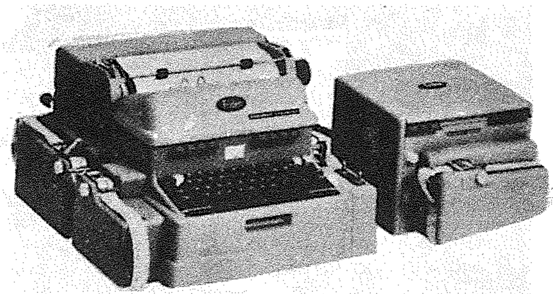


Fig. 17–25. Tape-punching typewriter with Verifier attachment. (Friden, Inc.)

E. The tape is then inserted in a separate tape reader attached to the tape-punching typewriter and is played back for verification and checking. Once more it must be stated that the method of operation differs with each make of tape typewriter. A widely used tape typewriter is shown in Fig. 17–25. The operator of this machine types the information that the programmer has prepared, simultaneously producing a typewritten document and a standard eight-channel control tape. To verify the accuracy of the tape the typist places it into an attachment called the *Verifier* and retypes the information on the same machine, which produces a new tape. As each character is retyped, the Verifier compares the retyping with the first typing. If the two tapes are not identical, the keyboard of the typewriter locks automatically. The operator then locates the error, unlocks the keyboard by pressing a button, and types the correction.

When not used for preparing numerical control tapes, this machine can automatically perform many routine office chores such as purchase order writing, sales order and invoice writing, inventory reports, and so forth. It creates documents under control of punched tape and, at the same time, produces a by-product tape for subsequent data processing, including direct input to electronic computers.

14. *How many axes can be numerically controlled on one tape?*

From two to five axes, depending upon the type of machine and the job to be machined. The axes most often used on a machine are X and Y for the positioning of a workpiece or job mounted on the machine table. The vertical movement of the tool brings the Z axis controls into play. These are the primary axes, which control the three basic dimensions: length, width, and height (or depth). The tape may need to control rotary direction around each of those axes (Fig. 17–15). It is possible to have machines with four, five, and six axes where movement is controlled on the tilt and indexing of the table and/or the tilt and swivel of the head.

15. *What is binary arithmetic?*
The binary system of numbers is an arithmetic based on the use of two digits. It is used in digital computers and other electronic devices. It is the system of arithmetic that makes numerical control possible. The decimal numbering system with which we are all familiar makes use of ten digits, 0 through 9; this would prove too complex for electronic interpretation in a numerical control system. The two digits of the binary system, 0 and 1, are used because electrical circuits are firmly established on two conditions, either on or off—that is, a positive or negative condition. As used in numerical control, a tape would either have a hole or it wouldn't have a hole. Binary numbers can be added, subtracted, multiplied, or divided, but these processes are somewhat different from the methods with which we are familiar. We know that in any number system the value of a number depends upon the placement of the digits that make up that number and the number base. For example, in decimal number 31, the digit 1 represents one solitary, individual unit, but in the number 12,987, the digit 1 represents 10,000 units, demonstrating that the position of a digit in a number really represents a multiplier of that digit. Because 10 is the base of decimal numbers, we can further analyze the number 12,987 as follows:

$$
\begin{aligned}
10{,}000 &= 1 \times 10^4\\
2{,}000 &= 2 \times 10^3\\
900 &= 9 \times 10^2\\
80 &= 8 \times 10^1\\
\underline{\quad 7} &= 7 \times 10^0\\
12{,}987 &
\end{aligned}
$$

Notice that the position multiplier increases by a factor of 10 as we move to the left.

In the binary system, 2 rather than 10 is used as the base number. Figure 17–26 shows several common numbers in both binary and decimal forms.

	decimal value of binary digit					
decimal numbers	2^5 *(32)*	2^4 *(16)*	2^3 *(8)*	2^2 *(4)*	2^1 *(2)*	2^0 *(1)*
0	**0**	**0**	**0**	**0**	**0**	**0**
1	**0**	**0**	**0**	**0**	**0**	**1**
2	**0**	**0**	**0**	**0**	**1**	**0**
3	**0**	**0**	**0**	**0**	**1**	**1**
4	**0**	**0**	**0**	**1**	**0**	**0**
5	**0**	**0**	**0**	**1**	**0**	**1**
6	**0**	**0**	**0**	**1**	**1**	**0**
7	**0**	**0**	**0**	**1**	**1**	**1**
8	**0**	**0**	**1**	**0**	**0**	**0**
9	**0**	**0**	**1**	**0**	**0**	**1**
10	**0**	**0**	**1**	**0**	**1**	**0**
20	**0**	**1**	**0**	**1**	**0**	**0**
30	**0**	**1**	**1**	**1**	**1**	**0**
40	**1**	**0**	**1**	**0**	**0**	**0**
45	**1**	**0**	**1**	**1**	**0**	**1**
50	**1**	**1**	**0**	**0**	**1**	**0**
57	**1**	**1**	**1**	**0**	**0**	**1**

Fig. 17–26. Binary-decimal conversion table. Each decimal number can be represented by the six-digit binary number to its right. The initial zeros are used only for uniformity and are usually omitted in writing binary numbers.

Figure 17–27 gives the decimal values for powers of 2.

For example, in the binary system, the number 1111 represents

$$
\begin{aligned}
1000 &= 1 \times 2^3\\
100 &= 1 \times 2^2\\
10 &= 1 \times 2^1\\
\underline{\quad 1} &= 1 \times 2^0\\
1111 &
\end{aligned}
$$

Using the information given in Figs. 17–26 and 17–27, we find

$$8 + 4 + 2 + 1 = 15$$

Binary 1111 equals decimal 15. Another example could be 10111011101. By checking the position of these numbers and using the powers of 2 listed in Fig. 17–26, the number can be converted to decimal notation:

$$1024 + 0 + 256 + 128 + 64 + 0 + 16 + 8 + 4 + 0 + 1 = 1501$$

The binary number 10111011101 equals the decimal number 1501.

Power Value	2^{14}	2^{13}	2^{12}	2^{11}	2^{10}	2^{9}	2^{8}	2^{7}	2^{6}	2^{5}	2^{4}	2^{3}	2^{2}	2^{1}	2^{0}
Decimal Value	16384	8192	4096	2048	1024	512	256	128	64	32	16	8	4	2	1

Fig. 17–27. Equivalent decimal values of each binary digit position.

Addition of Binary Numbers

The rules for adding binary numbers may be a little difficult to understand at the beginning. However, after you solve a few examples, the process becomes quite clear. The four rules for addition are:

$$0+0=0$$
$$0+1=1$$
$$1+0=1$$
$$1+1=10$$

The last addition means 0 with 1 to carry over into the next column. For example:

$$\begin{array}{rcr} \text{Binary} & & \text{Decimal} \\ 1101 & = & 13 \\ \underline{+1111} & = & \underline{+15} \\ 11100 & & 28 \end{array}$$

Beginning with the extreme right binary column,

Step 1: $1+1=10=$ Put down 0 and carry 1

$$\begin{array}{r} 1 \\ 1101 \\ \underline{1111} \\ 0 \end{array}$$

Step 2: $0+1+1$ (carried over) $=10=0$ carry 1

$$\begin{array}{r} 11 \\ 1101 \\ \underline{1111} \\ 00 \end{array}$$

Step 3: $1+1+1$ (carried over) $=11=1$ carry 1

$$\begin{array}{r} 11 \\ 1101 \\ \underline{1111} \\ 100 \end{array}$$

Step 4: $1+1+1$ (carried over) $=11=$ Put down 11

$$\begin{array}{r} 1 \\ 1101 \\ \underline{1111} \\ 11100 \end{array}$$

Answer = 11100.

When the position of these digits is compared with the chart in Fig. 17–27, the following number will result:

$$16+8+4=28$$

Subtraction of Binary Numbers

Subtraction of numbers of the binary system is similar to subtraction in the decimal system. The rules are:

$$0-0=0$$
$$1-1=0$$
$$1-0=1$$
$$10-1=1$$

example:

$$\begin{array}{rr} \text{Binary} & \text{Decimal} \\ 1011 \text{ (minuend)} & 11 \\ \underline{-\ 101} \text{ (subtrahend)} & \underline{-\ 5} \\ 110 \text{ (remainder)} & 6 \end{array}$$

Begin with the column at the extreme right:

Step 1: $1-1=0$ Put down 0

$$\begin{array}{r} 1011 \\ \underline{-\ 101} \\ 0 \end{array}$$

Step 2: $1-0=1$ Put down 1

$$\begin{array}{r} 1011 \\ \underline{-\ 101} \\ 10 \end{array}$$

Step 3: $0-1=?$ Not possible in binary subtraction unless you regroup as in Step 4.

$$\begin{array}{r} 1011 \\ \underline{-\ 101} \\ 10 \end{array}$$

Step 4: $10-1=1$

$$\begin{array}{r} 1011 \\ \underline{-\ 101} \\ 110 \end{array}$$

It is good practice to check the answer as you would a decimal subtraction by adding the subtrahend and the remainder.

Binary	Decimal
101	5
+110	+6
1011	11

Multiplication of Binary Numbers

The rules of multiplication are:

$0 \times 0 = 0$
$0 \times 1 = 0$
$1 \times 0 = 0$
$1 \times 1 = 1$

Addition usually plays a part in multiplication problems, and the rules for addition of binary numbers must be remembered.

example 1:

Binary	Decimal
1011	11
× 10	×2
0000	22
1011	
10110 = 22	

example 2:

111011	59
× 101	×5
111011	295
000000	
111011	
100100111 = 295	

Division of Binary Numbers

The rules for division of binary numbers are as follows:

$0 \div 0$ is impossible
$0 \div 1 = 0$
$1 \div 1 = 1$
$1 \div 0$ is impossible

Subtraction plays its part in problems of division, and the subtraction rules must be remembered.

example:

Binary division:

```
    111
10)1110
   10
    11
    10
     10
     10
```

Decimal division:

```
  7
2)14
  14
```

proof:

Binary	Decimal
111	7
× 10	×2
1110	14

Binary arithmetic has very little value for solving the usual problems that arise in machine shop work, but in the making of punched tapes for the numerical control of machines it is a vital necessity. In order to gain proficiency in binary arithmetic, use Fig. 17–27 to translate decimal numbers into binary form. Then complete the computation and proof as binary arithmetic, and convert the binary answer to decimal form.

16. *What is feedback?*
There are electric or hydraulic devices built into numerical control systems that receive signals indicating whether positions have been reached and operations have been completed as programmed. This information is fed back to the controlling, or directing unit, indicating that the operation has been carried out in accordance with the signals and that the numerical values are correct. If the values are incorrect, the feedback will indicate the extent of the error.

The type and the extent of the feedback coverage differ in the many numerical control systems. One type of feedback indicates whether the numerical commands have been carried out; another compensates for the errors made. A third type of feedback keeps pace with the progress of the cutting tool. When a discrepancy exists, the machine stops. Such feedback devices are quick to signal any defect that develops in the cutting tool, whether it be wear, loss of cutting edge, change in size, or breakage.

Usually a change in cutting tools can be made and the cut continued from the stopping point or from any point prior to that position.

17. *What is meant by the zero reference point?*
The zero reference point is a point from which all measurements and movements of the machine members are made (Fig. 17–20). For linear motions it is a point at the extreme end of travel, from which workpieces are located on the machine with respect to their reference points. The first command on the control tape specifies the distance the machine table will move from its zero position. Therefore, the machine operator must have a means of locating the workpieces to maintain the zero position for all duplicate workpieces. In some numerical control systems, the zero reference point can be selected at any convenient point on or off the part.

18. *How are workpieces located relative to the zero point?*
Jigs and fixtures have largely been eliminated as holding devices on numerical control machines. However, workpieces must be located and held securely in place. Parts may be located against parallels and stops utilizing the table T slots and then held by means of clamps. A subplate equipped with pin locators and suitable clamps is another device often used for certain types of workpieces (Fig. 17–28).

Fig. 17–28. Positioning on this numerical control jig-boring machine requires careful location and secure clamping of workpieces. (Pratt & Whitney Co.)

19. *Can toolmaking be done by numerically controlled machine tools?*
Yes. Parts for such tools as jigs, fixtures, and dies can be produced by numerically controlled machine tools just as easily as can parts for other products. Tool parts with complex shapes can be produced through the use of computer calculations and programmed instructions, and, in some instances, without the need or use of the usual tool drawing. As can be seen, toolmaking by numerical control eliminates time-consuming layout, template making, and other operations performed by the highly skilled tool and die maker.

20. *Explain the difference between digital and analog signals.*
As applied to numerical control, two basic types of electrical systems may be defined in terms of the signals for transmitting information. These electrical signals are information carriers, which make up both the quantity and kind of operations that can be performed. The electrical systems referred to are known as *digital* and *analog*. A digital signal is a single, sharp, discrete signal of definite duration—usually a pulse. A simple doorbell push-button switch gives out digital signals. An analog signal is continuous—that is, it gives a continuous representation of some quantity or process (Fig. 17–29). An example of an analog signal could be an automobile speedometer. It should be noted that many *N/C* systems handle both digital and analog signals. The input to the system may be a digital signal which is converted to an analog signal for use by the machine-tool components.

21. *Do all numerically controlled machine tools use punched tape?*
The majority of numerically controlled machine tools use punched tape, but not all. The number codes, which control a machine, can be incorporated on a punched tape, on a magnetic tape, or on punched cards. Magnetic tape is similar to the tape used on a tape recorder. It is coated with small pieces of ferrous oxide, which, when magnetized, will give electrical impulses as the tape passes over the tape-reading unit. The pulses are converted by a transducer into rotary motion, which turns the various machine screws, which move the machine tool members.

Punched cards are widely used by many business firms such as banks, publishers, and government

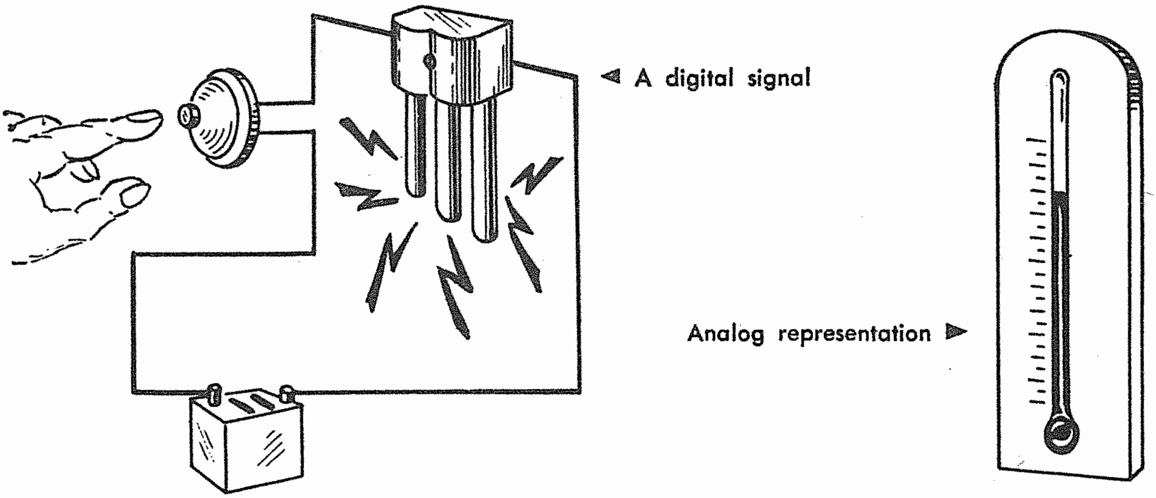


Fig. 17–29. Comparison between digital and analog signals. (*American Machinist*, McGraw-Hill, Inc.)

agencies to provide information and computations quickly. Punched-card systems are also readily adaptable for the control of machine tools. Figure 17–30 shows a punched-card control system used by one machine tool manufacturer.

22. *Is a computer a necessary part of a numerical control system?*
Computers are necessary for continuous-path programming. There is a definite place for computers in preparing point-to-point programs also. Measurement and mathematics are a part of every machine shop layout and machining job. The mathematical computation necessary to prepare a control tape for a point-to-point positioning system can usually be solved by the programmer. Some jobs are made easier by the use of a desk calculator.

However, continuous-path programming for contour control requires considerable use of mathematics. Thousands of points on a required curve must be provided in order to stay within the allowed tolerances. This requires solving thousands of mathematical problems, which would take an individual programmer weeks and perhaps months to solve. This would greatly increase the preparation time for every job that required a continuous-path program and thus make the cost exorbitant. Geometric problems often arise in the location of the intersections of two connected arcs or in moving the tool from one size radius to the machining of an altogether different radius (Fig. 17–31). A computer can solve problems such as these in a very short time. A computer can solve a thousand problems while a programmer is working to solve just one problem. There will be a far greater probability of error in the programmer's solution than in the answer supplied by the computer.

Computers are used to solve mathematical problems that confront the programmer of a numerical control system. In this way, computers reduce the cost of every machined part.

23. *Do computers really think?*
Present computers are not creative. They are not capable of original thought but must follow predetermined routines. Everything the computer does must first be built into the machine and directed by a computer program.

24. *Do all computers have the same storage and processing capacity?*
No. The capacity of a computer is selected according to the job it has to do and the cost requirements. Some have from 6,000 to 50,000 cores, where units of information are stored; others have hundreds of thousands of storage units (Fig. 17–32).

25. *Does each N/C machine need its own computer?*
No. Some machines have their own computers; others are in a group controlled by a single computer.

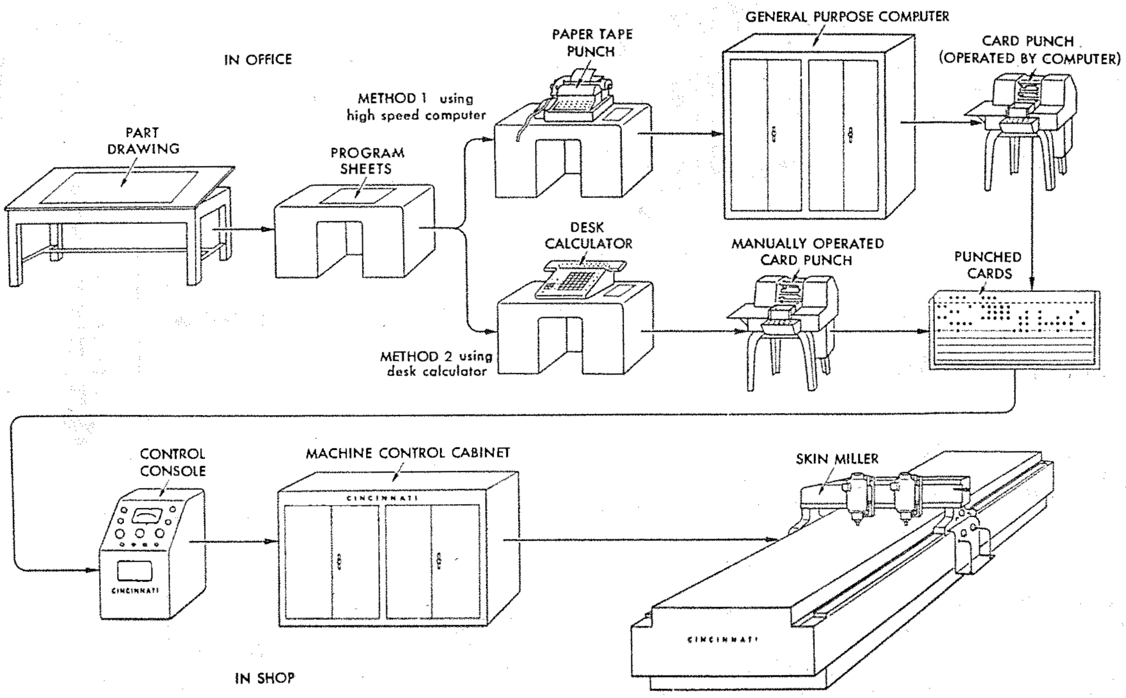


Fig. 17–30. Numerical control system for continuous-path control of a miller. This system uses punched cards for machine input. Depending upon available facilities and job requirements, either a general-purpose digital computer or a manually operated card punch can be used for informational processing. This system provides either discrete positioning or contouring, positive feedback at all times, cutter wear or size compensation at the machine, and parabolic interpolation to minimize the number of points plotted. The system is absolute, with all dimensions taken from a reference line in direct reading numbers. Machine can be operated as a standard miller with manual feed, power feed, and rapid reverse—with or without numerical control. (Cincinnati Milacron Co.)

Fig. 17–31. Profiling a titanium helicopter rotor by N/C. (Cincinnati Milacron Co.)

Fig. 17–32. A small N/C machining center. (Cincinnati Milacron Co.)

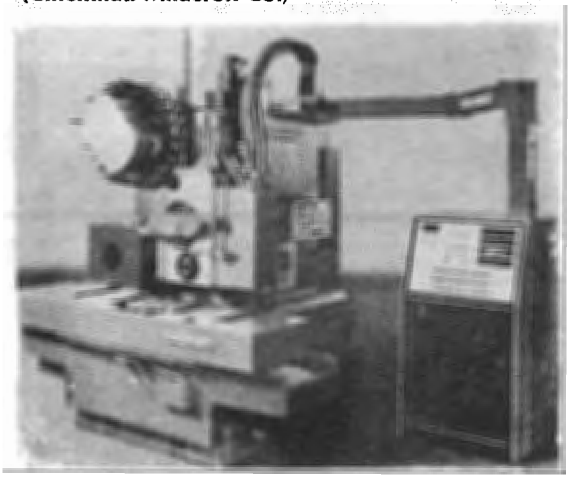
26. *The most up-to-date utilization of numerical control is known as direct numerical control (DNC). How does that function?*
In DNC a central bank of complete machining data is stored in a computer. The computer is connected directly to the machine tool and directs the operations and movement of the tools without the intermediate step of programming a punched tape. The computer may serve a single machine, or typically, a bank of machines each operating independently.

27. *Must the DNC machine tools be of the same type, size, and make and must they perform the same operations?*
No. The machine tool equipment need not be the same because the operating instructions are fed individually and independently to them from the computer.

28. *How can a machine perform different operations without stopping to have its cutting tools changed?*
Most N/C machines are equipped with multiple toolholders, which are positioned or changed automatically with each of the different operations.

29. *How many operations are these machines capable of performing?*
A typical machining center (Fig. 17–33) can automatically mill, drill, tap, bore, and ream the various faces of a workpiece, often with a single setup. The tool drum of this machine holds 24 tools (Fig. 17–34), which are selected, mounted, and changed automatically. Figures 17–35 through 17–41 show the sequence of movements that remove a tap from the tool drum and exchange it with a drill. All movements of job and tools are programmed for numerical control on X, Y, and Z axes, rotary table, and tool drum.

Fig. 17–33. Cim-Xchanger N/C Machining Center. (Cincinnati Milacron Co.)



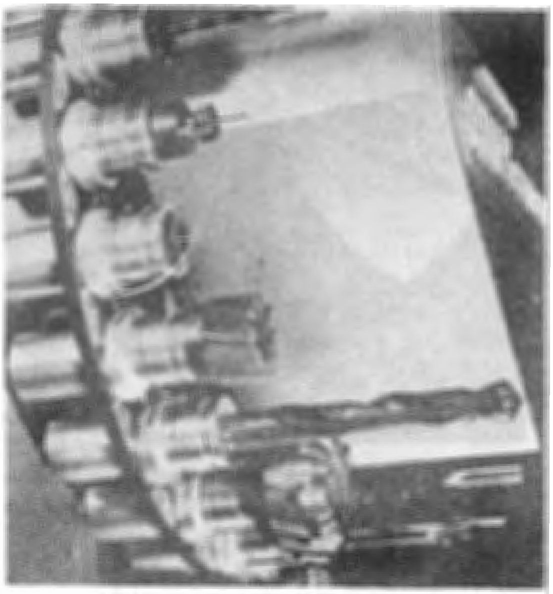


Fig. 17–34. Close-up of tool drum with tools. (Cincinnati Milacron Co.)

30. *How accurately can the rotary table be positioned on this type of a machine?*
The rotary table can be automatically indexed to any of 72 positions at random, programmed in 5° increments. Accurate positioning and repeatability is possible to within ±0.0005 in. (Fig. 17–42).

31. *How much time does it take to change tools?*
It takes about 2½ seconds to change tools. The total time from the moment one tool stops cutting and the next tool begins cutting is about 7 seconds. These times may be slightly more on the heavier machining centers where tool sizes are much bigger.

32. *Must the tools be positioned in the tool drum in the order in which they will be used?*
No. Tools can be programmed for random selection

Fig. 17–35. Tool drum rotates until tap (position 19) is opposite drum arm. (Cincinnati Milacron Co.)

Fig. 17–36. Drum arm grasps tap and removes it from drum position 19. (Cincinnati Milacron Co.)

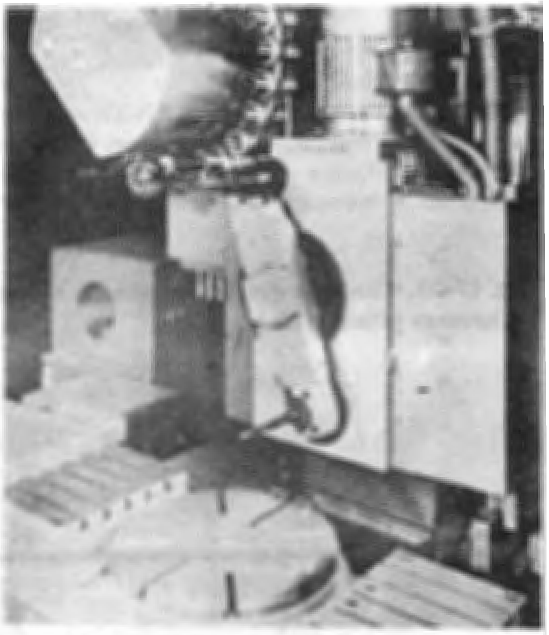
from any position on the tool drum. In practice, many tools are used several times at different points in the machining sequence.

33. *Can a wide variety of operations be performed on a machining center?*
Most machining centers can handle a wide variety of machining operations both in size and number of operations.

34. *Is there a limit to the number of machines that can be directly controlled from a single computer?*
It has been demonstrated that DNC can run a pro-

Fig. 17–37. Drum arm inserts tap in standby position. Empty drum arm retracts to drum. (Cincinnati Milacron Co.)

Fig. 17–38. Rotating arm swings around and grasps both tap in standby position and drill in headstock. (Cincinnati Milacron Co.)



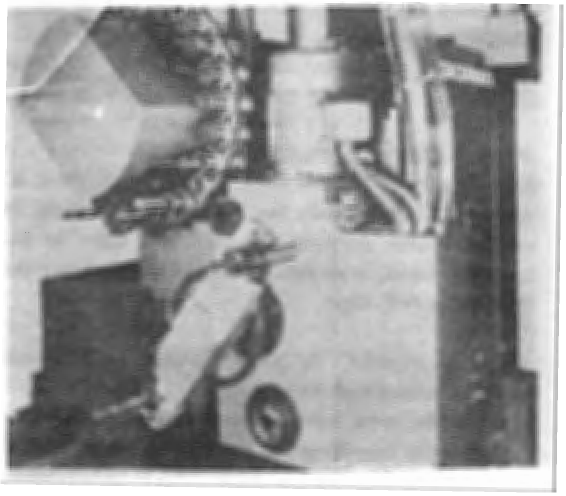


Fig. 17–39. With tap and drill firmly grasped, rotating arm swings clockwise. (Cincinnati Milacron Co.)

Fig. 17–40. Rotating arm has rotated 180° and drill is now at standby position while tap is at headstock. (Cincinnati Milacron Co.)

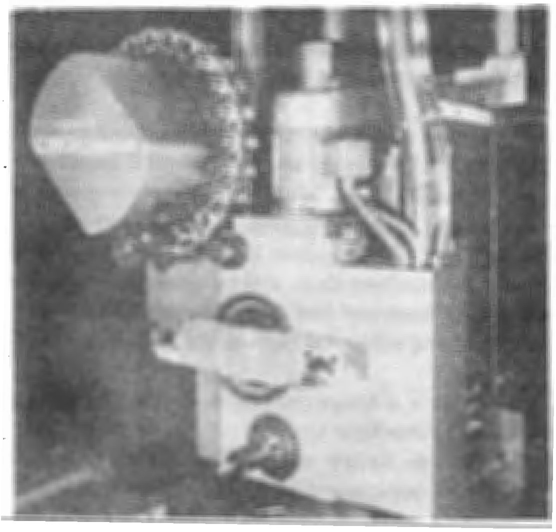


Fig. 17–41. With tools in place, rotating arm releases grasp and swings to neutral position. Tool drum will rotate until drill position is reached; drum arm will come out, grasp drill, and return it to its proper position in drum. (Cincinnati Milacron Co.)

Fig. 17–42. Indexing a job on the rotary table. (Cincinnati Milacron Co.)

duction line, controlling not only the operations of the machine tools but also the movement of the workpieces from one machine to another.

35. *Is direct computer control being used to manufacture machine parts on a commercial basis?*
An Ingersoll-Rand plant manufactures parts for pneumatic tools using DNC on a production schedule. It is the first system to use a computer to run both the machine tools and to move the parts automatically from one tool to another without an operator touching either the tools or the parts (Fig. 17–43).

36. *What is a future possibility for direct numerical control of machine tools?*
Nobody can foresee precisely all of the applications for DNC, but present plans call for its use to completely automate a manufacturing plant. The only functions of human operators in such a plant would be to monitor and adjust the automatic equipment.

37. *Can an individual machine be run with the use of its own computer?*
Until recently this was not practicable because of the high cost and large size of the computers. A new type of minicomputer has been developed with adequate power to control individual machine tools for all of their operations. Economies in production have made it possible to use the minicomputers individually in machine tools.

Fig. 17–43. Moving parts down the Sundstrand-built machining line at Ingersoll-Rand's Roanoke (Va.) plant. (Sundstrand Machine Tool Corp.)

38. *What name has been given to this system of machine control?*
It is called *computer numerical control,* or simply CNC.

39. *What are the advantages of CNC?*
Each machine has its own computer. If there is a computer failure, only the machine is affected. The minicomputer controls the machine from its own memory bank, and this control is more direct than the use of N/C tape.

40. *Can mistakes in programming be corrected when a minicomputer is used?*
One of the most valuable advantages of the minicomputer is that errors in programming can be corrected directly at the machine. This is very economical compared with the time needed to correct an N/C paper-taped program.

41. *Can an N/C unit be attached to an old machine?*
Yes; this is possible providing that the degree of precision required in the result is not excessive. The process of adding N/C to an existing machine is called *retrofitting.* Numerically controlled machines must have positive movement on every axis. There can be no allowance made for lost motion or backlash in the feed screw and feed screw nut. Machines designed for numerical control operation are equipped with a ball-nut engaging the thread of each lead and feed screw. The ball-nut is split and preloaded to eliminate the possibility of backlash and to reduce friction. Each machine slide is required to move with a smooth action free from erratic or jerky motion. Machines equipped with a solid threaded nut and screw cannot be converted for numerical control operation unless a control system is used that automatically takes up backlash by always approaching the machining points from the *same* direction.

Attachments and accessories controlled by tape can be fitted to standard machines provided that there is not an excessive amount of backlash caused by wear in either the lead or cross-feed screws.

Where a lead screw has been badly worn in a small area, it would be necessary to replace the worn lead screw and nut.

The movement or *indexing* of the lead and cross-feed screws is then made possible by the addition of a specially made motor attached to each spindle and controlled by tape from a console (Fig. 17–44).

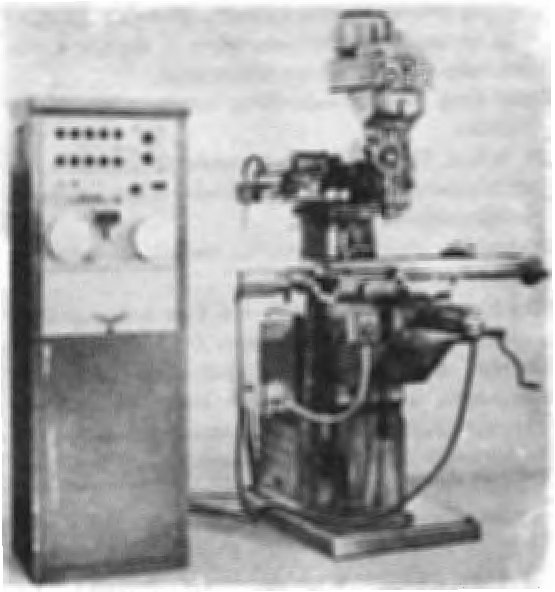


Fig. 17–44. The SLO-SYN control system installed on a vertical milling machine. (The Superior Electric Co.)

Included in the console are a tape reader, a power supply, control circuits, and the control panel.

42. *How is the indexing of the lead screw and feed screw accomplished?*
A specially constructed indexing motor is fitted to the end of the lead screw and to the cross-feed screw. This permits positioning of the table along two axes *X* and *Y*. The motor can be controlled to move in steps or increments of 1.8°. A complete revolution of the lead screw is made in 200 steps. Each motor step will move the table 0.001 in. when coupled to a 5-pitch lead screw or 0.0005 in. when coupled to a 10-pitch lead screw.

43. *How fast can such table movements be made?*
The SLO-SYN tape controlled indexer when positioning jobs for drilling can move at 1,000 motor steps per second. This speed of 1,000 steps per second will drive the table 60 in. per minute on a machine that has a 5-pitch lead screw. Slower speeds can be obtained where a smoother action is required, as in milling.

44. *Can numerical control be added to a standard machine, removing and replacing it as required?*
A numerically controlled table can be installed on an existing standard machine, which will give a two-axis automatic-positioning system (Fig. 17–45). The SLO-SYN positioning table can be installed and moved from machine to machine. The positioning of the table is controlled by tape through the SLO-SYN motors and ball-nut lead screws, which achieve low friction, negligible backlash, and a high degree of accuracy.

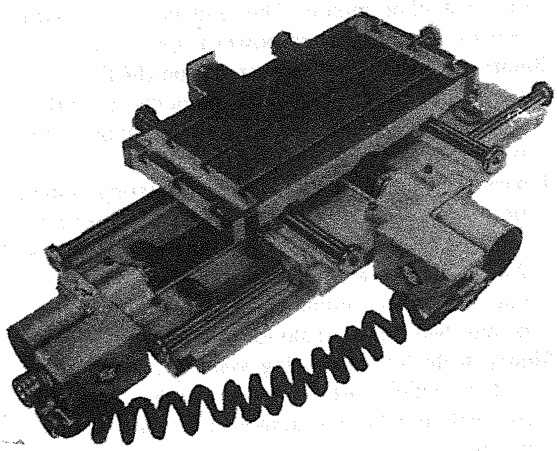


Fig. 17–45. The SLO-SYN positioning table. (The Superior Electric Co.)

GLOSSARY OF NUMERICAL CONTROL TERMS

The growth of numerical control created a need for new terminology. For a better understanding of numerical control, the student will find it essential to know and understand the meaning of the terms listed in the glossary that follows (adapted from *The American Machinist*).

Address. A label that identifies, for the computer, a specific location in its memory where certain information is stored. Serves the computer in much the same way that index tabs on your filing system serve you.

Analog computer. A computer using a physical or electrical model representing the mathematical problem to be solved.

Assemble. To integrate subroutines and routines into a main program.

Attenuation. A decrease in signal strength. Opposite of gain (see gain).

Automatic programming. A term for all techniques designed to simplify the writing and execution of programs. Assembly programs, which usually translate from the programmer's symbolic language to machine language, assign absolute addresses to instruction and data words, and integrate subroutines into the main routine, are examples of automatic programming aids.

Backlash. Total play in the feed system in terms of linear slide motion. The tendency for a feed to reverse direction when power is removed.

Binary-coded-decimal representation (BCD). A system of representing decimal numbers. Each decimal digit is represented by a combination of four binary digits.

Binary digit (Bit). In the binary numbering system, only two marks (0 and 1) are used. Each of these marks is called a binary digit. The decimal number 296 is the binary number 100101000; we say that the binary number has nine binary digits, or bits. See Binary scale (or numbering system).

Binary scale (or numbering system). A numbering system widely used for computers; where the decimal numbering system uses ten symbols (0 through 9), thus having a radix (or base) of 10, the binary system uses only two symbols (0 and 1), thus having a base of 2.

Block. A group of words considered as a unit.

Closed loop. A sequence of automatic control units linked together with a process to form an endless chain. The effects of control action are constantly monitored so that if the process deviates from the preset limits, the control units make adjustments to bring it back into line.

Code. A system of characters and rules for representing information in a language that can be understood and handled by the control.

Command. A group of signals, or pulses, initiating one step in the execution of a program.

Computer. Any device capable of performing calculations—that is, carrying out transformations of information.

Control means. The part of an automatic control device that makes the corrective action.

Control point. The value you actually get as the result of some control action.

Cycling. A rhythmic change of the factor under control at or near the desired value.

Damping. A characteristic built into control systems, which diminishes the system's tendency for making excessive corrections when it detects a momentary deviation from the normal.

Dead time. Any definite delay between two related actions.

Deviation. The difference between the actual value of a condition and the one at which it is supposed to be controlled.

Diagnostic check. A specific routine designed to locate a malfunction.

Digital computer. A computer that uses numbers rather than physical quantities.

Discrete units. Distinct or individual units. For example, automobile crank shafts or bathtubs would be discrete units as contrasted to petroleum or orange juice, which is produced in one continuous flow.

Dynamic behavior. Describes how a control system or an individual unit carries on with respect to time.

Error. The margin by which an automatic control missed its target value.

External memory. A storage unit such as punched or magnetic tape, which is external to the computer.

Feedback. Part of a closed-loop system, which brings back information about the condition under control for comparison to the target value.

Final control element. Unit of a control system (such as a value), which directly changes the amount of energy to the process.

Flip-flop. A device or circuit with two stable states. The circuit remains in either state until the application of a signal causes it to change.

Frequency response. Frequency at which output ceases to follow input accurately when feedback loop is closed and input (for measuring) is a sine wave or sine function.

Gain. Amount of increase in a signal (or measurement) as it passes through a control system or a specific control element. If a signal gets smaller, it is said to be *attenuated.* Gain can also mean the sensitivity of a device to changes.

Gate. A logic circuit with one output and many inputs, designed so that the output is energized only when certain input conditions are met. They include *And Gates* and *Or Gates* and others.

An *And Gate* is one whose output is energized only when all of the inputs are energized.

An *Or Gate* is one whose output is energized when one or more of the inputs are energized.

-lunting. Even control or measuring instruments sometimes have trouble finding the target. When an instrument wanders around the target without success, engineers appropriately claim it is "hunting."

-lysteresis. The difference between the response of a unit or system to an increasing signal and the response to a decreasing signal.

nstruction. A word or part of a word that tells the director to perform some operation.

nstruction code. An artificial language for expressing or describing the instructions that can be carried out by the computer.

nput. Transfer of external information into the control system.

ntegrator. A device that continuously adds up a quantity being measured over a period of time. Similar in use to your electric meter at home.

nternal arithmetic. Any computations performed by the arithmetic unit of a computer, as distinguished from those performed by the peripheral equipment.

nternally stored program. A sequence of instructions (program) stored inside the computer or control system, as opposed to being stored externally on punched paper tape, pin boards, and so forth.

ogical operations. Nonarithmetical operations such as selecting, searching, sorting, matching, comparing, and so forth.

lachine language. The set of symbols, characters, or signs, and the rules for combining them, which conveys to a computer instructions or information to be processed. This language is unintelligible to the people unless the symbols and the rules for their use are understood. Special equipment is usually needed to convert this language from the form in which it is stored in the computer to a form perceptible to human beings.

lagnetic tape. Tape made of metal or plastic, coated with a magnetic material, which can store information.

lanipulated variable. A quantity, or a condition, which is altered by the automatic units to set off a change in the value of the chief condition under regulation.

latrix. An arrangement of circuit elements such as wires, relays, diodes, and so forth, which can transform a digital code from one type to another.

lemory. A general term for the equipment that holds information in machine language in electrical or magnetic form. This equipment also receives information for storage and gives out the stored information for later use. The word *memory* usually means storage inside the computer, whereas *storage* refers to magnetic drums, discs, cores, tapes, punched cards, and so forth outside of the control system.

Mnemonic code. Instructions for a computer written in a form that is easy for the programmer to remember, but which must later be converted into machine language.

Neutral zone. An automatic control engineer's version of No Man's Land—a range of values in which no control action occurs.

Nixie light. A glow tube device, which converts a combination of electrical impulses into a visual number.

Noise. Similar to radio static. Meaningless stray signals in a control system, which do not require correction, but can cause confusion.

Off-line operation. The computer operates independently of the time base of the actual inputs—that is, considerable time may elapse between an input to the computer and the resulting output. Can also mean operation of peripheral equipment independent of the central processor of a computer system.

On-line operation. Operation where input data are fed directly from measuring devices into the computer. Results are obtained in real time—that is, computations are based on current values of operating data, and answers are obtained in time to permit effective control action.

Can also mean the operation of peripheral equipment in conjunction with the central processor of a computer system.

Open loop. A control system in which there is no self-correcting action for misses of the target value, as there is in a closed loop system. Might be likened to a hunter firing a rifle at a deer; the bullet goes where aimed; if it misses, no deer!

Optimization. A method by which a process is continually adjusted to the best obtainable set of operating conditions.

Oscillograph recorder. A device capable of charting high speed variations in measured quantities such as temperature or pressure, as found in aircraft testing, for example.

Output. Information sent from the director.

Overshoot. Occurs when the motion exceeds the target value.

Patch. A section of coding inserted into a routine to correct a mistake or alter the routine.

Phase shift. A time difference between the input and output signal of a control unit or system.

Play. Looseness between lead screw and nut, end-looseness of screw, backlash in other gear meshes, and cocking of some machine members.

Potentiometer. Probably the most versatile of all measuring instruments. It can measure a wide range of processes by comparing the difference between known and unknown electrical voltages.

Program. *Verb:* To prepare a program. *Noun:* A sequence of steps to be executed by the computer or control to solve a given problem.

Programmed check. A check consisting of tests inserted into the programmed instructions, and performed by the control equipment.

Programmer. A person who prepares the planned sequence of events the control must follow to solve a problem, but who need not necessarily convert them into detailed instructions (coding).

Proportional control. Control action related to the extent a condition being regulated is off-the-beam.

Random access. Equal access time to all memory locations, independent of the location of the previous memory reference.

Read. To gain information, usually from some form of storage.

Readout. The manner in which a control displays the processed information. May be digital visual display, punched tape, punched cards, automatic typewriter, and so forth.

Reproducibility. The exactness with which measurement of a given value can be duplicated.

Reset rate. The number of corrections per minute made by the control system. Usually expressed as a specific number of repeats per minute.

Routine. A set of instructions arranged in the correct sequence to direct the control-computer to perform a common operation or series of operations. For example, "get two numbers—add them together—store the answer."

Sensitivity. A measure of the system's ability to react to changes in the system.

Serial operation. Type of information transfer within a digital computer whereby all digits of a word are handled sequentially rather than simultaneously.

Servomechanism. A closed-loop control system in which physical position is the controlled variable.

Signal. Information relayed from one point in the control system to another.

Static behavior. Describes how a control system, or an individual unit, carries on under fixed conditions (as contrasted to dynamic behavior, which refers to behavior under changing conditions).

Storage capacity. The amount of data that can be retained in the storage or memory unit of a computer or control; often expressed as the number of words that can be retained.

Subroutine. A section of a computer program which is stored once in the memory and can be used over and over again to accomplish a certain operation; *sine, log, square root, cube root* for example.

System engineering. An approach to problem solving, which takes into consideration all of the elements involved in a particular problem down to the smallest item and the process itself. The system itself can vary according to the definition being used. Thus an automobile engine is the *power system* and all parts of the engine belong to the system. The engine belongs to a larger system consisting of all parts making up the *automotive system.*

Tachometer. A measuring instrument used to determine rotational speed, usually in revolutions per minute (rpm).

Total lost motion. Twice the windup plus the backlash.

Transducer. A device that converts one form of energy into another form of energy—for example, a phonograph cartridge converts mechanical energy into electrical energy, and a thermocouple converts heat energy into electrical energy.

Transistor. Tiny solid-state element in an electronic circuit, which does much the same job as a three-element vacuum tube. It is small, requires little energy to operate, and is rugged. There are no filaments to burn out as in vacuum tubes.

Variable. A factor or condition that can be measured, altered, or controlled—for example, temperature, pressure, flow, liquid level, humidity, weight, chemical composition, color, and so forth.

Windup. The twist (as the twist in a lead screw) necessary to overcome *friction,* in terms of linear slide motion.

Word. A group of characters occupying one storage location. This unit of information is treated and transported by the computer circuits as an entity; it is treated by the control unit as an instruction, and by the arithmetic unit as a quantity.

Write. To impart or introduce information, usually into some form of storage device.

chapter 18 special machining processes

For many years, industry manufactured its products from a relatively small group of metals. Engineers made extensive use of cast iron, brass, bronze, soft steels, cast steel, and carbon and high-speed steel. Aluminum and its many alloys came in later, the result of many years of laboratory experimentation. Other metals were being developed in the laboratories but because there was no immediate need for them in industry little was heard of them. Modern living, however, increased the demands for more and better products. The automobile, radio and television, jet planes, and most recently space travel have made tremendous demands on our technology. Metals that for decades had been satisfactory for most uses were found inadequate to meet the challenge of these new developing products. Metals were required to be both light and strong; they had to resist the widest ranges of temperatures, from subzero to thousands of degrees, without failing. The metallurgists in the laboratories developed metals to meet these unusual demands. Metals that had been considered exotic were now required for a practical industrial use. New methods had to be developed, which would easily and quickly change these new metals into precision machine and instrument components. Intricately shaped miniature parts requiring the most delicate handling had to be machined, measured, and assembled. With the new materials came the need for new methods of cutting and removing metal, new machinery, new machining techniques, and the refinement of old methods to suit the new requirements.

BROACHING

One of the fastest methods of removing metal is by broaching. It is particularly useful in the mass production of intricate internal and external shapes.

1. *What is a broach?*
A broach is a cutting tool made up of a series of cutting edges, which start with the shape of the existing hole and gradually increase in size until the desired shape and size is reached (Fig. 18–1).

2. *Is the beginning hole drilled?*
The beginning hole can be drilled or cored in a casting, and the finished hole can be round, square, rectangular, or irregular in shape. Broaching is

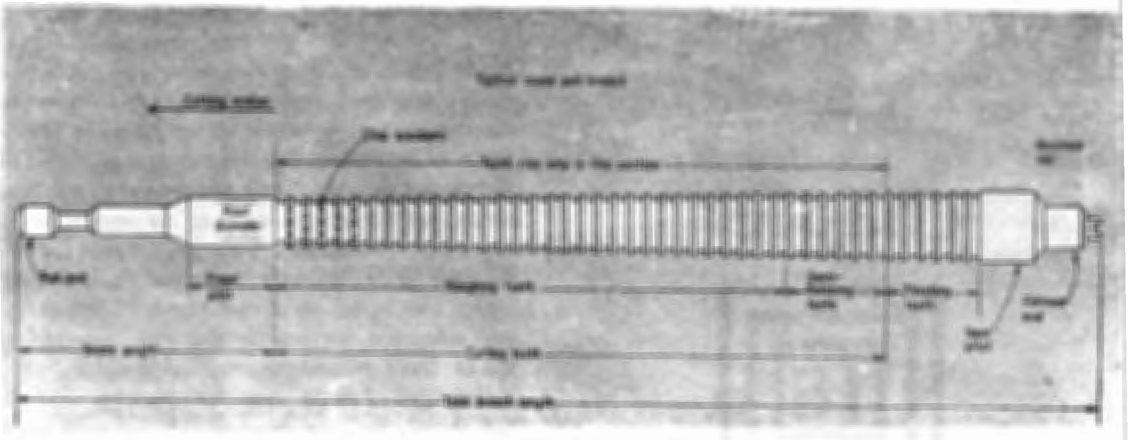


Fig. 18–1. Basic shape and nomenclature for a conventional internal broach. Note chipbreakers in the first few roughing teeth. If broach is to be used for heavy cuts or on material difficult to machine, more teeth may have chipbreakers. Note extra finishing teeth. (Detroit Broach & Machine Co.)

used to cut single or multiple keyways in pulleys and gears, splines in hubs, and teeth in internal gears and ratchets (Fig. 18–2).

3. *How was the broaching operation first developed?*
Broaching was first developed when tapered drift punches were driven by hammer through a piece of metal to form a larger or different shaped tool. Later a device similar to a rack and gear arbor press was used to replace the hammer. Teeth were cut on the sides of the tapered drift to remove metal with a cutting action in order to form the hole to the shape required. Modern methods have made it possible for the broach to be either pushed or pulled over or through the workpiece. Figure 18–3 shows a broach being pulled through a workpiece.

4. *Can the broaching operation be used on all types of jobs?*
Broaching is used on a full range of work-sized jobs, from the very small parts of a delicate instrument to the large castings of the engine block of a heavy truck.

5. *What are the different types of broaching machines?*
There are three types: vertical, horizontal, and continuous-chain broaching machines.

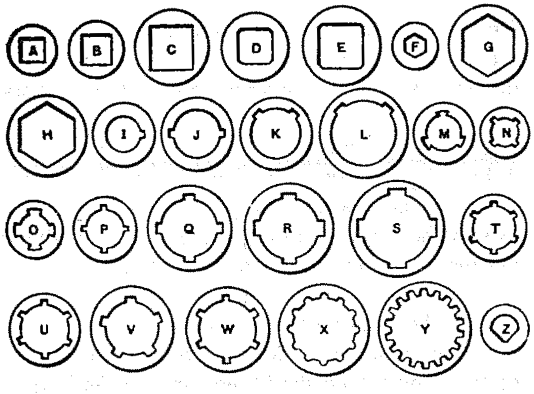


Fig. 18–2. Examples of internal broaching.

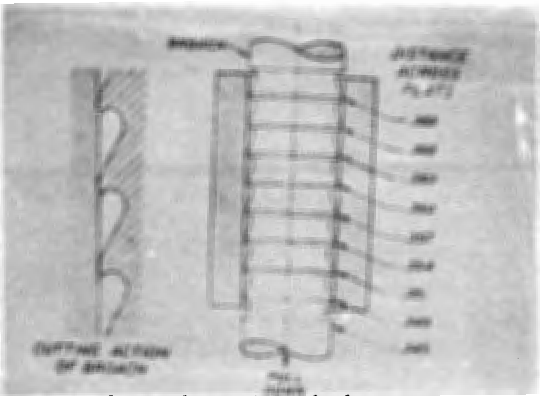


Fig. 18–3. The cutting action of a broach.

6. *What determines the type of machine to be used?*
A job on which a long broach must be used will require a horizontal stroke because of the space requirements. A vertical machine conserves floor space, is more accurate, and allows less deflection of the material surrounding the broached hole. The continuous-chain machine can be either vertical or horizontal; it is used mainly for mass production operations. The work is held in special fixtures designed for it and which carry it across the cutting edges of the broach (Fig. 18–4).

Fig. 18–4. A continuous horizontal surface broaching machine. (Detroit Broach & Machine Co.)

7. *How are broaching machines driven?*
They can be driven either hydraulically or by electric motors.

8. *In what direction does the cutting action of the broaching tool take place?*
The action of the broach can be pull-up, pull-down, press, or push depending on the kind of work, the size of the job, and the degree of accuracy and smoothness of the finish required (Fig. 18–5). The appropriate broach must be used in each case.

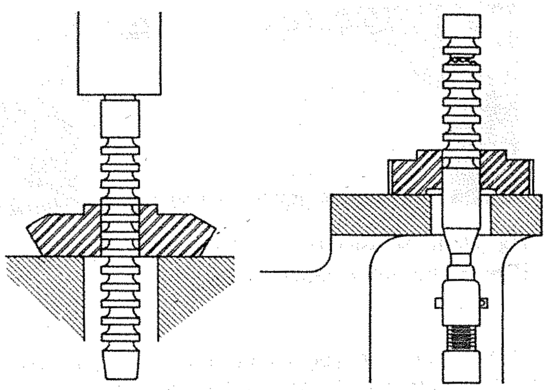


Fig. 18–5. (A) Push and (B) pull broaching actions.

9. *What factors determine the length of the broaching tool?*
The length of the broaching tool is determined by the amount of metal that must be removed, the length of the machine stroke, the required accuracy, and the degree of finish.

10. *What limitations are recommended for the length of a broach?*
The length of a push-type broaching tool should not exceed 25 times the diameter of the finishing teeth. A pull-type broach should not exceed 75 times the diameter of its finishing teeth.

11. *What are the sizes of broaching tools?*
The sizes range from 0.050 to 20 in. in diameter.

12. *Are all teeth on the broach identical in shape?*
There are three types of teeth on the typical broach: roughing, semifinishing, and finishing. The first roughing tooth is proportionately the smallest tooth on the broach. The teeth progressively increase in diameter up to and including the first finishing tooth. All finishing teeth are the same size. Individual teeth have a land, cutting edge, hook or face angle, gullet, and pitch (Fig. 18–6).

13. *What determines the distance between the teeth?*
The distance between teeth, called the *pitch*, is determined by the length of the cut, the material being cut, and the size of the tooth gullet.

14. *What determines the size of the tooth gullet?*
The size of the tooth gullet is related to the material

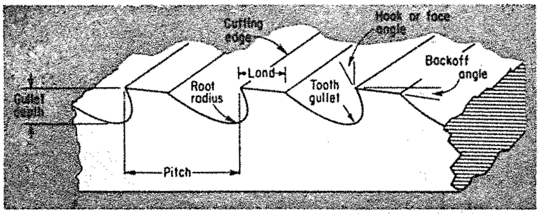


Fig. 18–6. Nomenclature of broaching tool teeth. (Detroit Broach & Machine Co.)

to be cut and the type of chips produced. The radius of the tooth root is designed so that chips can be carried away from the cutting edge (Fig. 18–7).

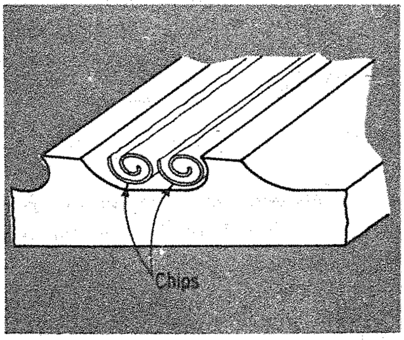
15. *Why are the teeth of some broaches shear-angled?*
A broach with shear-angled teeth gives a better surface finish and will reduce tool chatter (Fig. 18–8).

16. *What provision is made to break up the chips during the cutting operation?*
Notches, called *chip breakers,* are ground into the roughing and semifinishing teeth to eliminate chip packing and allow for chip removal (Fig. 18–9).

17. *Of what material are broaches made?*
Most broaches are made of high-speed steel. Others have inserted carbide cutting edges brazed onto the body of the broaching tool.

18. *Are cutting fluids used in the broaching operation?*

Fig. 18–7. A flat-bottomed gullet allows space for more chips between teeth. (Detroit Broach & Machine Co.)



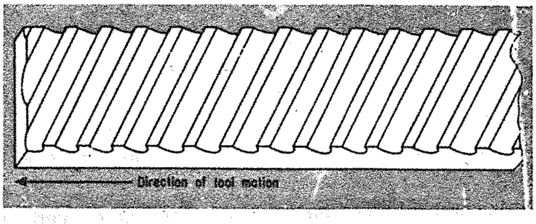
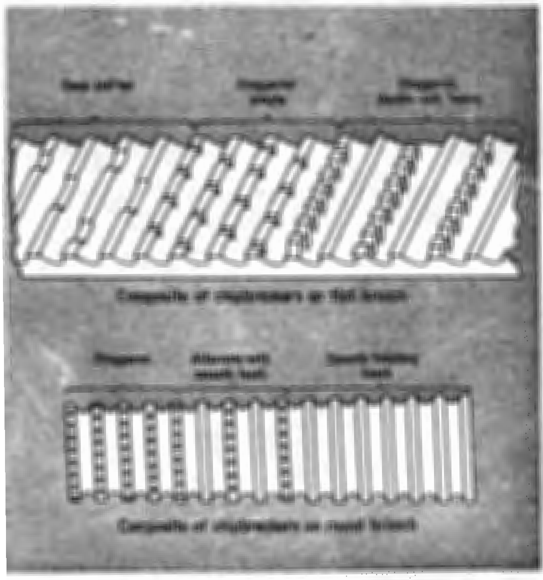


Fig. 18–8. Shear-angled teeth give a better surface finish. (Detroit Broach & Machine Co.)

Fig. 18–9. Chipbreakers relieve the total load on the broaching machine by splitting the heavy chips. (Detroit Broach & Machine Co.)



Cutting fluids are used to reduce cutting temperature, lubricate the cutting tool, improve surface finish, increase tool life, and remove chips.

HONING

Because of the high speeds of rotating machine parts, designing engineers must consider the bearing surfaces and their problems. The surface smoothness of the contacting parts of journal and bearing have long been a problem to those who design and manufacture machinery. Often, more time was spent in scraping a bearing than had already been taken to machine it. Measurement of size and surface quality were part of the problem. Coupled with the need for a much smoother surface was the equally important need for more accurate measurement.

The grinding machine brought changes, and as the bond of the grinding wheel improved, the results of the grinding operation became more reliable. Although improvement was noted, the quality of the surface finish could not be measured. Surfaces could not be gaged to the requirements of the job.

In 1936, E. J. Abbott developed the profilometer, an instrument that measures the smoothness of a surface in microinches (millionths of an inch). It was then possible to observe that grinding the bore of a bearing leaves a pattern of ridges, which not only have depth but also a threadlike pitch. These surface imperfections are the result of several factors, including the mechanical inaccuracies of the grinder, the violence with which the metal is removed, and the heat generated during the operation. To remove these surface irregularities and to make possible more accurate dimensioning a process called *honing* was developed.

19. *What is honing?*
Honing, a machining process similar to grinding, is mainly used to finish bore surfaces.

20. *How does honing differ from grinding?*
Grinding machines are run at high speeds and high wheel pressure. This results in high temperatures. Honing requires the use of slow speed and low pressure, which keeps the surface temperature relatively low.

21. *In what other way does honing differ from grinding?*
The abrasive stones used in the honing machine have a relatively large area of abrasive in contact with the job. Because surface temperature is low, surface damage is kept to a minimum.

22. *Is honing a manual or power operation?*
In machine honing, the abrasive-carrying mandrel is power driven. The workpiece is held in a clamping work-holder and moved back and forth along the mandrel, which can be gradually expanded until the desired size is obtained (Fig. 18–10). The job movement can be manual or power stroked; the machines are different. The bore capacity ranges up to 3⅞ in., and the stroking length is infinitely variable from ¼ in. to 6 in. The speed of the power stroke can vary from 80 to 300 strokes per minute (Fig. 18–11).

Fig. 18–10. The workpiece is held in a clamping device and moved back and forth manually along the mandrel. (SUNNEN Products Co.)

23. *How accurately does the honing process finish a hole?*
Dimensional accuracy to 0.0001 in. is common. Tolerances to 0.000025 in. are easily obtainable. Surface finish to 2 microinches can be expected.

24. *What kinds of material can be worked by this process?*
Almost every material can be efficiently honed: Steels of all varieties, cast iron, aluminum, magnesium, brass, bronze, glass, ceramics, hard rubber, graphite, and silver are a few examples.

25. *Will the honing tool correct an out-of-round bore?*
By means of two unevenly spaced metal guide shoes, which are a part of the honing tool, the abrasive stone will gradually improve the bore until roundness is achieved.

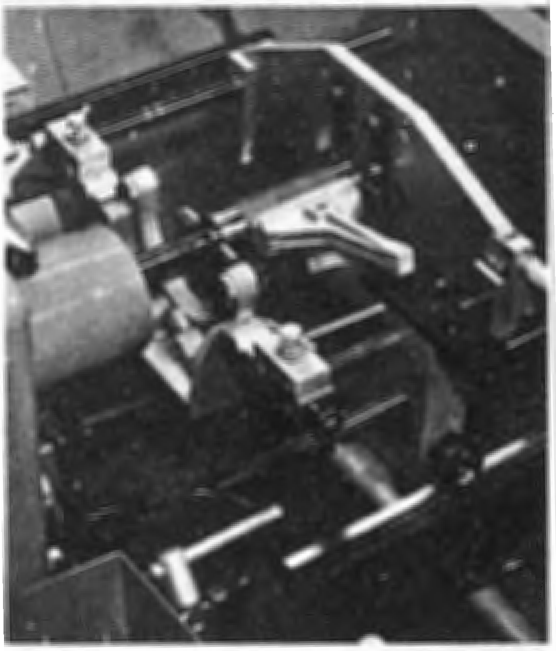


Fig. 18–11. Workpiece positioned in fixture for power stroked honing. Machine is capable of repetitive accuracy to 0.0005 in. for roundness. (SUNNEN Products Co.)

26. *Can other bore imperfections be corrected by this process?*
Holes that are tapered, barrelled, or bellmouthed can be made straight and parallel. The two metal guide shoes will not follow the shape of an imperfect hole or bore, and thus keep the abrasive stone cutting straight and true (Fig. 18–12).

27. *What other hole defects can be corrected by the honing technique?*
Honing corrects the problems left by other operations that result in holes that are misaligned, undersized, or have marks left by reamers and boring tools.

28. *Is it possible to hone workpieces of a wide range of shapes and sizes?*
Honing machines are made in different sizes and can handle many different types of work. Heavier machines are made for vertical honing (Fig. 18–13).

29. *How are the workpiece and the abrasive kept cool and clean?*

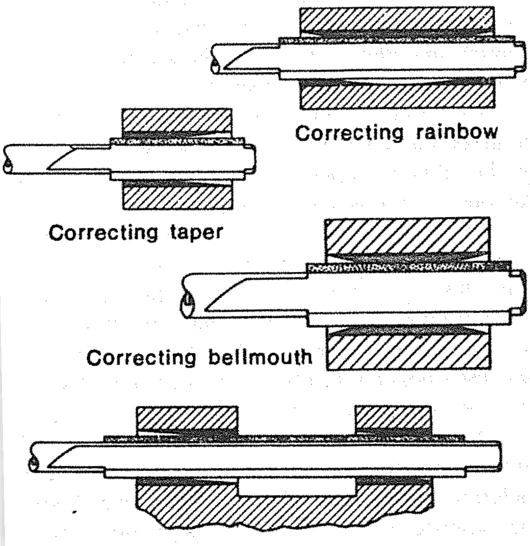


Fig. 18–12. Correcting hole variations. Permanent metal guide shoes keep the grinding stones cutting straight and true. (SUNNEN Products Co.)

Fig. 18–13. Honing a valve on vertical machine. (SUNNEN Products Co.)

A reservoir tank, which is a part of the machine, holds many gallons of industrial oil, which is pumped from the tank and can be directed on job and mandrel (Fig. 18–14). The oil is then automatically filtered and recirculated.

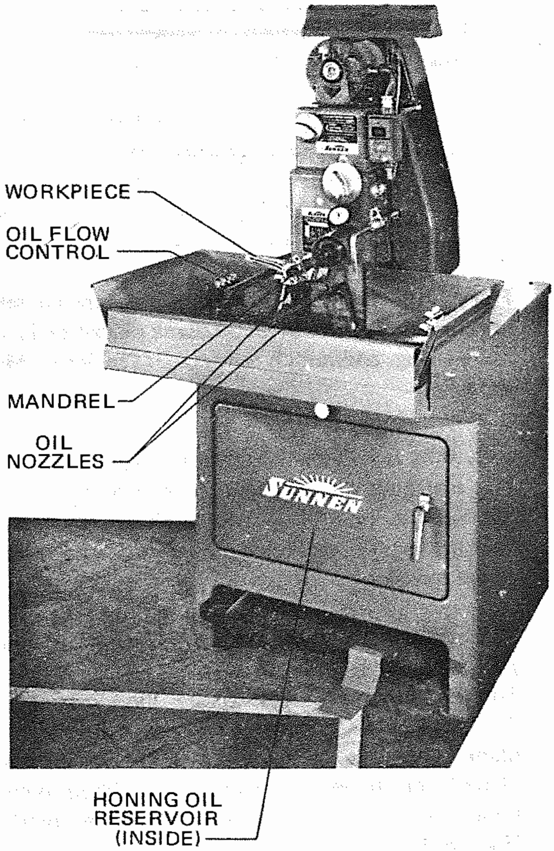


Fig. 18–14. Circulating oil keeps the workpiece and abrasive cool and clean. (SUNNEN Products Co.)

METAL DISINTEGRATOR

Metal disintegration is a process for making holes without cutting or shearing the workpiece and without producing chips. Because it does not rely on the action of a cutting edge against metal it can be used on materials not otherwise easily drilled or bored.

30. *How does the disintegration process work?* Metal disintegration is an electrical process that will produce a desired hole in any material that will act as a conductor to electrical current. Metal removal results from making and breaking a low-voltage arc between an electrode (called a *disintrode*) of proper size and shape and the workpiece (Fig. 18–15).

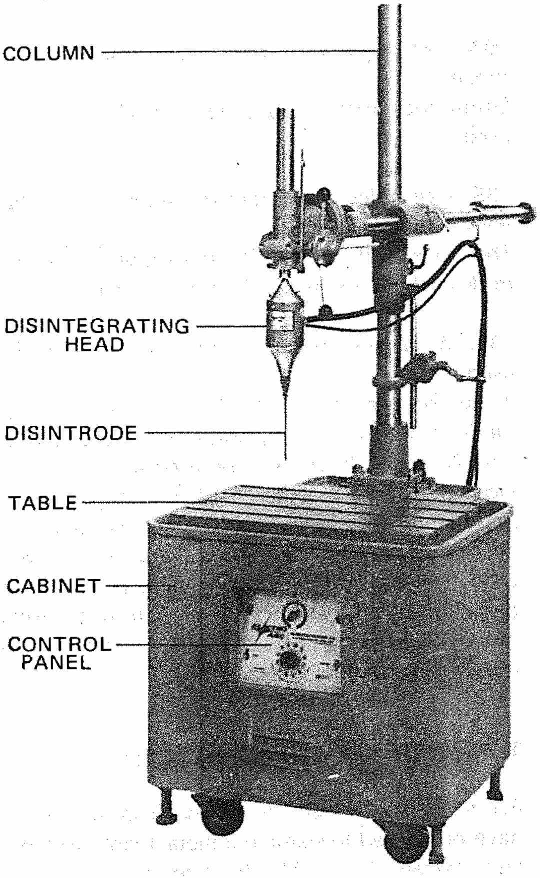


Fig. 18–15. The metal disintegrator. (Electro Arc Manufacturing Co.)

31. *What results from the removal of metal at the arc?*
A correctly sized hole will be made in the workpiece as a result of the intense heat at the arc.

32. *What is the temperature at the end of the disintrode?*
A temperature of 5000°C. occurs at the tip. At the

same time a coolant, under pressure of 90 psi, passes through the hollow core of the disintrode, rapidly cooling the workpiece. The thermal shock thus created reduces the metal at the arc to powder, which is washed away by the coolant.

33. *Does the intense heat affect the material around the hole?*
No, because of the rapid action of the coolant.

34. *Can holes of various sizes result from this process?*
Disintrodes from 0.030 in. to over 0.750 in. can be used.

35. *Can holes of different shape be made in hardened materials?*
The holes will conform to the shape of the disintrodes, which are available in many shapes.

36. *What type of job is the metal disintegrator used for?*
It can be used to drill bolt holes, coolant holes, lubricant holes—in fact, holes of any shape in any kind of metal. It can also be used to cut dovetails, elongate holes, recenter hardened shafts, and cut or enlarge keyways in milling cutters, gears, and hardened bushings. Metal disintegration can be used to remove broken tools such as taps, drills, and reamers in workpieces by permitting the drilling of small extracting holes in the tool without damaging the surrounding workpiece.

THE HYDROFORMING PROCESS

For many years mechanical and hydraulic presses have been used to stamp out metal blanks to special and intricate shapes. This has been done by squeezing the metal blank between dies until it conforms to the required shape, which is outlined by the dies. The presses that perform this operation are heavy and powerful. The matching dies, both upper and lower, must conform to accurate size and shape.

37. *How does the hydroform process differ from the mechanical type of press forming technique?*
Hydroforming requires the use of one accurately shaped die. Tools do not require intricate installation and alignment. Pressure is exerted by a fluid contained in the forming chamber (Fig. 18–16).

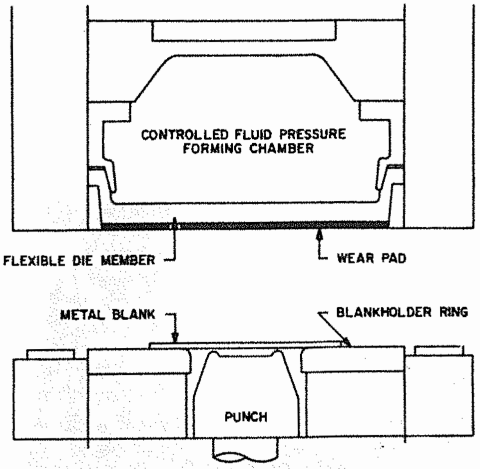


Fig. 18–16. The hydroform press. Forming chamber in raised position with metal blank placed on blankholder ring, and punch retracted. (Cincinnati Milacron Co.)

38. *Why is only one shaped die necessary?*
The matching die is a flexible pad forced against the blank. A fluid-filled cavity holds this die in place and makes the workpiece conform to the shape of the master die.

39. *What is the main advantage of the hydroform process?*
The fluid-forming process applies the forces around the blank with uniform pressure and wraps the blank around the shaping die. This enables the metal blank to be shaped in a single pass without putting undue or excessive strains on the finished product (Fig. 18–17).

40. *What other advantages are there in this method?*
Only a single die is required instead of a costly matching pair, less storage room is required, fewer dies are necessary, and the smooth wrap-around method of forming puts less strain on the metal and leaves a smooth surface, which requires no further finishing (Fig. 18–18).

41. *Does this method require larger sized blanks?*
The hydroform method does not need a mechanical device to hold the blank. Less than a normal amount of material is required to form the holding flange; therefore, the blank is smaller and costs less.

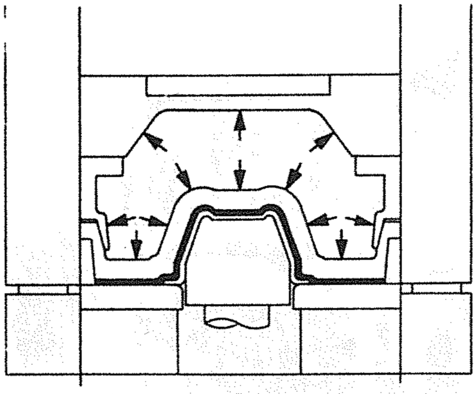


Fig. 18–17. Forming chamber of the hydroform press is lowered and initial pressure is applied.

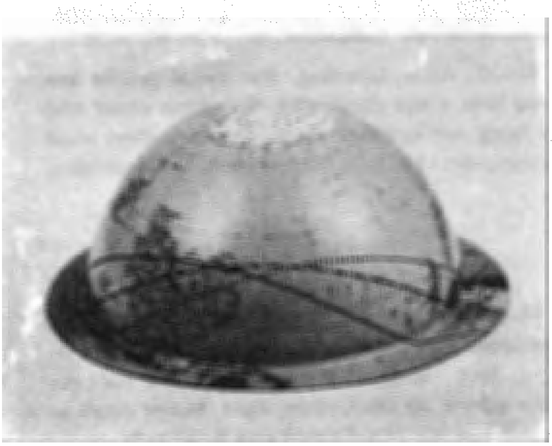


Fig. 18–18. Example of work done on hydroform press. This hemisphere is 8" in diameter and 3½" deep; machine cycle was 3 sec. The workpiece blank was lithographed steel, 12" in diameter and 0.018" thick. The hydroforming operation took one draw with a pressure of 6,000 psi. (Cincinnati Milacron Co.)

42. *What are the maximum pressures that can be applied by a hydroform machine?*
The forming pressure can be developed to 15,000 psi, and the maximum punch force 630 tons.

43. *Is the hydroform machine limited to a specific shaped job?*
Both simple and intricate shapes can be formed by this method in a short space of time and with a minimum of power and labor (Fig. 18–19).

Fig. 18–19. Hydroform machine showing blank and finished product. (Cincinnati Milacron Co.)

CHEMICAL MACHINING

44. *Is chemical machining an entirely new process?*
Removing metal by a chemical process is not new. For many years it has been used by photoengravers to prepare plates for printing and engraving. It has been used in the etching of metals for decorative purposes and also in the manufacture of etched printed circuits for radio and television receivers.

45. *Why was the development of chemical machining found to be necessary?*
Very little was done to expand the use of chemical machining until it was found that the conventional method of removing metal was falling short of industrial requirements. As more and tougher metals

and alloys were being utilized for the manufacturing process, the conventional methods were found to be inadequate. The removal of areas of metal was found to be superior to machining by the cutting tool method.

46. *How is chemical machining used?*
There are two categories of chemical removal of metal: nonselective and selective.

47. *What is the difference between the two?*
When metal is to be removed from all parts of the surface, the process is considered to be nonselective; in the selective process, parts of the workpiece are protected from the chemical action by a chemical-resistant coating.

48. *Where is the selective method used?*
It is used to reduce the weight of a workpiece in specified areas but not in others so that functional strength can be maintained. The selective method is also used in etching decorative work, nameplates, and printed circuits.

49. *What are the steps in the chemical machining process?*
There are four basic steps in chemical machining:

A. Artwork and negative preparation (Fig. 18–20).
B. Metal preparation (Fig. 18–21).
C. Image printing and developing (Fig. 18–22).
D. Etching and resist removal (Fig. 18–23).

Fig. 18–21. After cleaning, the metal panels are dipped into a vat containing the photo resist and then hung vertically to drain. This operation must be done under controlled temperature and humidity.

Fig. 18–22. To get the images on the metal, the photo-sensitized panel is placed in a negative envelope. This "sandwich" is placed in a vacuum printer where an ultra-violet light source exposes both sides of the metal panel simultaneously.

Fig. 18–20. Photographing the artwork.

The requirements of these operations will vary depending on the metal being used and the end result desired.

50. *Are there advantages to the chemical-machining process?*
The important advantages of chemical machining include:

Fig. 18–23. In the etcher, osciliating nozzles uniformly spray both sides of the metal. Areas of the metal not protected by the photo resist are dissolved, leaving only the finished parts.

A. The cost involved with the setup for this procedure is minimal.
B. Jobs can be produced in a minimum of time after the design has been selected.
C. Changes in design can be made with little cost.
D. Removal of burrs is unnecessary because none are formed in the process.
E. Extremely thin metals can be worked without distortion.

51. *Does this process have disadvantages?*
The disadvantages of chemical machining include:

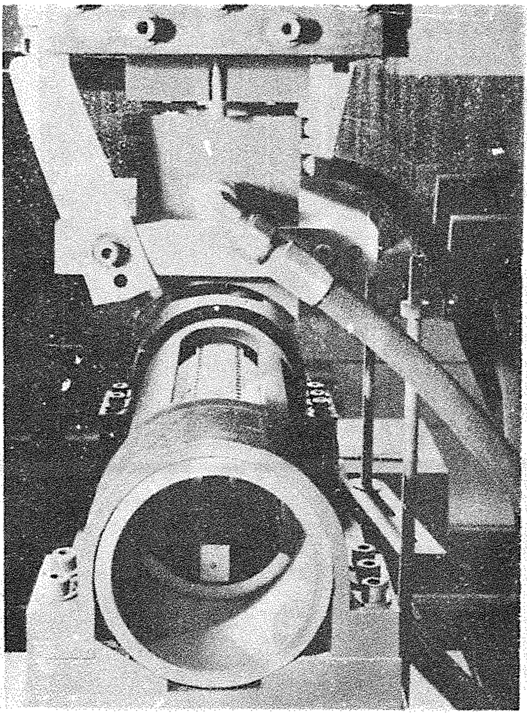
A. The equipment must be carefully protected from corrosion.
B. A highly skilled operator is essential.
C. Only thin metals can be worked. Practical limits in thickness for production pieces is approximately 0.0625 in.
D. Certain types of work require excellent photographic facilities.

ELECTROCHEMICAL MACHINING

52. *Why was electrochemical machining developed?*
The metals used in modern manufacturing, especially in the aerospace and aeronautics industries, were difficult to machine. The conventional methods of metal cutting were found to be inadequate. Electrochemical machining was found to have a high rate of metal removal and could overcome the problem of machining difficult-to-machine metals (Fig. 18–24).

53. *How does this method of metal removal work?*
Electrochemical machining takes place when an electrical current passes through an electrolyte in the space or gap between the workpiece and a specially shaped tool. The workpiece metal is dissolved and carried away by the electrolytic solution. The tool represents the cathode (−) and the job the anode (+). The cavity left in the workpiece follows the shape of the tool.

Fig. 18–24. A typical application of ECM. The trepanning of a heat-exchanger part from stainless steel. (Cincinnati Milacron Co.)



54. *What shape is the tool?*
The tool is shaped to the requirements of the job. It can be round, square, octagonal, or irregular. It can be irregularly shaped on the face that meets the surface of the job. This type of tool would be used where the bottom of a blind hole was of irregular shape (Fig. 18–25).

55. *Is the tool made of a special metal?*
The tool, which acts as the electrode, must be a good conductor of electricity; it should be noncorrosive; it must be machinable; and it should be inflexible. Tools for this operation are generally made of copper, brass, or stainless steel, depending upon the type of job, the depth and size of the cavity to be made, and the number of pieces to be machined.

56. *Does the tool require frequent replacement because of wear?*
The tool does not make actual contact with the job. A space or gap of 0.001 in. or 0.002 in. normally exists between tool and workpiece. The sides of the tool are insulated to prevent them from setting up a cutting action. The electrolyte is fed into the cutting area through the center of the tool while the electric current is concentrated on the parts of the workpiece where metal has to be removed (Fig. 18–26).

57. *How much metal can be removed in a given length of time?*
Several factors influence the rate at which metal is removed. The distance between tool and job, the size and shape of the tool, and the voltage applied across the electrodes all have a direct bearing on this rate. The intensity of the current will be greatest at the closest point between tool and job. If the face of the tool is irregular in shape, more metal will be dissolved away as the shape of the job begins to conform to the shape of the tool. Rates vary from 0.020 to 1.000 in. per minute.

58. *What is the composition of the electrolyte?*
The basic electrolyte is a water solution of 10 percent sodium chloride (salt) by weight. Increased electrical

Fig. 18–25. The fast and economical machining of spherical ball seats was done with a single ECM setup. (Cincinnati Milacron Co.)

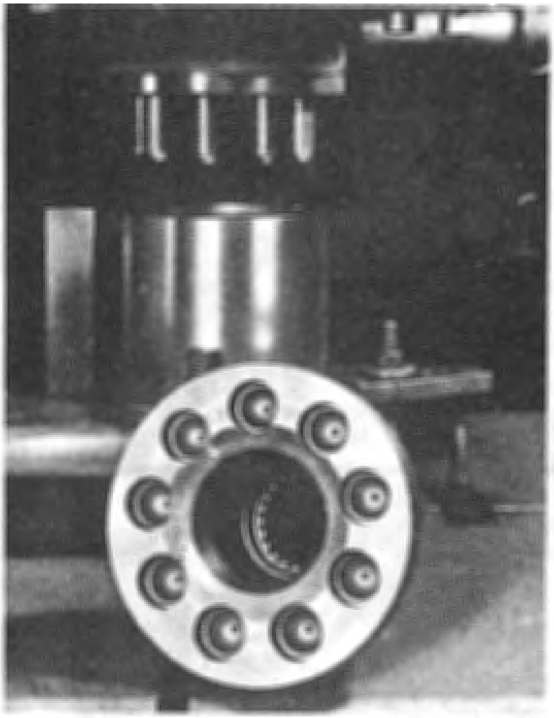
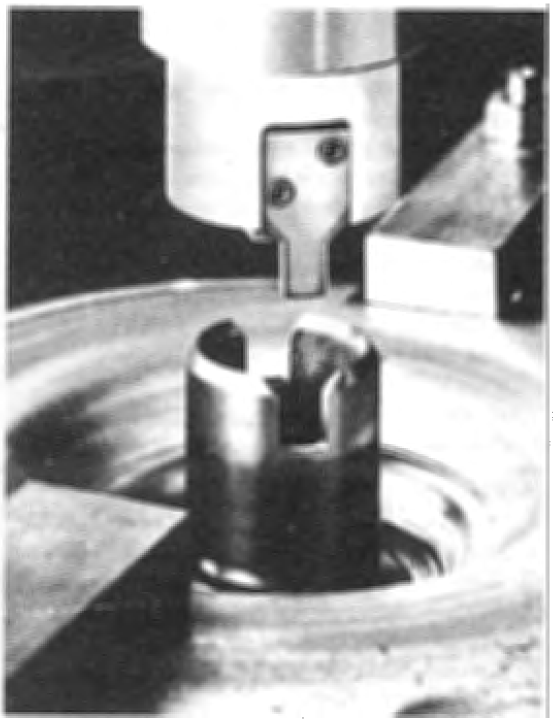


Fig. 18–26. Deburring an automotive torque converter drive section using ECM. (Cincinnati Milacron Co.)



conductivity is obtained by adding other ingredients such as caustic soda, mineral acid, or caustic potash. A weak solution will restrict the amount of metal removed, and the cooling effects of the fluid solution will be weakened.

59. *Is electrochemical machining (ECM) used only for making holes?*
No. Electrochemical machining is used to form intricate shapes, which might ordinarily be done by drilling, turning, sawing, milling, and grinding operations (Fig. 18–27).

60. *What are the main advantages of ECM?*
The main advantages of ECM are:

A. It can be used on the hardest metals. It can be used effectively on metals that have been hardened and tempered.
B. Because the tool does not touch the job there is very little wear on the tool.
C. This method can be used on thin and delicate work without the job becoming out of shape.
D. Because there is very little heat generated the completed job shows almost no distortion.
E. The completed job does not have to be deburred because none are formed by this process.
F. It satisfies the most severe surface finish requirements.

Fig. 18–27. This ECM machine has a 12-in. quill stroke and a fully enclosed 24" × 24" movable work table. (Cincinnati Milacron Co.)

61. *What are the disadvantages of ECM?*
Disadvantages of ECM include:

A. The equipment is very expensive.
B. The electrolyte may attack or corrode some metals.

ELECTROLYTIC GRINDING

62. *What is the purpose of electrolytic grinding?*
Electrolytic grinding, also called ELG, removes metal by electrochemical decomposition combined with the abrasive cutting action of a grinding wheel, which serves as an electrode.

63. *What is the theory of the ELG process?*
Basically, ELG resembles the electroplating process, which dissolves material from the positive electrode (anode) and deposits it on the negative electrode (cathode) (Fig. 18–28).

64. *How is the process used in electrolytic grinding?*
In ELG the grinding wheel is used as the cathode. The workpiece is electrically connected to the plus terminal of a dc power source and thus becomes the anode. The electrolyte is injected into the space, or gap, between the wheel and the job. The circuit is completed and the electrical current flows from the workpiece to the wheel, through the electrolyte,

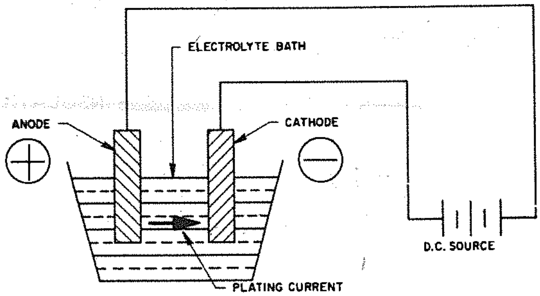


Fig. 18–28. The electroplating process. (Cincinnati Milacron Co.)

electrochemically dissolving the surface of the workpiece (Fig. 18–29).

65. *What percent of the metal removal is attributable to the abrasive action of the grinding wheel?*
Only 10 percent. Ninety percent is removed by electrochemical action.

66. *What are the most important elements affecting electrolytic grinding?*
The four most important elements are (Fig. 18–30) (a) the electrolytic wheel, (b) the electrolyte, (c) the power source, and (d) the table and feeds.

67. *Describe the electrolytic wheel.*
It is a conductive-bonded abrasive-type wheel, mounted on a spindle, which is electrically connected to a dc power source. The abrasive must protrude from the bond of the wheel, thus forming the gap through which the electrolyte is applied; the gap is approximately 0.001 in.; and the wheel must run true to 0.0005 in. to achieve maximum effectiveness.

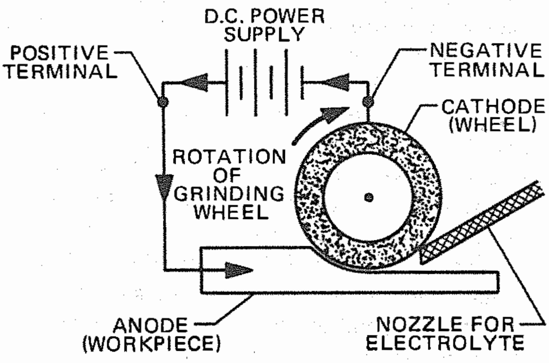


Fig. 18–29. Electrolytic grinding. (Cincinnati Milacron Co.)

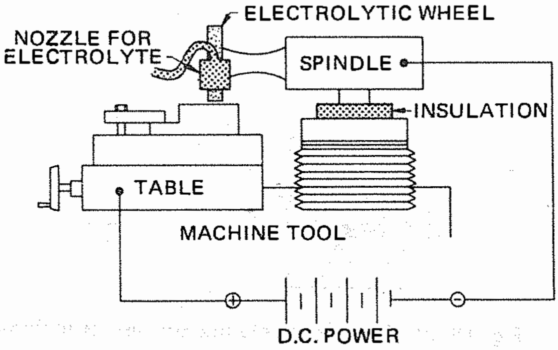


Fig. 18–30. Basic ELG machine setup.

68. *What abrasives are bonded to the electrolytic wheel?*
The two abrasives most commonly used are diamond and aluminum oxide. Diamond wheels are used for machining tungsten carbide; aluminum oxide is used for machining other materials.

69. *What is the function of the electrolyte?*
It has two functions: (a) to pass high current from the workpiece to the wheel and (b) to combine chemically with the material of the workpiece. It is necessary to distribute an even and continuous flow of fresh filtered electrolyte over the cutting area (Fig. 18–31).

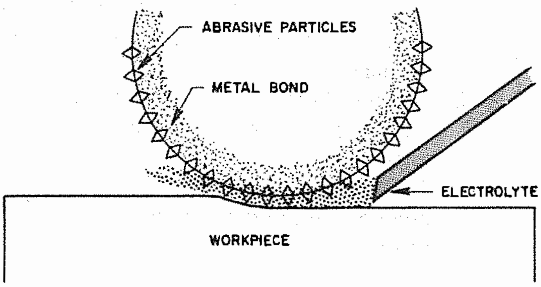


Fig. 18–31. Application of the electrolyte.

70. *What are the characteristics of the power source?*
The power source can range from 50 to 3,000 amp dc. The voltage can be varied to handle a wide variety of jobs. It can maintain a constant voltage to meet changing load conditions.

71. *How should an electrolytic grinding machine be selected?*
It should be selected to suit the type of work it will be required to perform; it should have a variety of speeds and feeds; it should be easy to operate, have a good electrolyte system, and be properly and adequately protected from corrosion.

72. *Are there advantages to electrolytic grinding?*
There is a saving in wheel costs compared with regular abrasive grinding mainly because 90 percent

of the metal removal is accomplished by the electrochemical action, which results in less wear on the wheel. Because there is less wear on the wheel it will not be necessary to true the wheel as often. This means that there will be less downtime for the truing operation. Hard and tough alloyed materials can be machined at maximum rate without fear of overheating or tool breakdown. Because of the cold machining characteristic of electrolytic grinding there is less chance of job distortion.

73. *Does this method of grinding leave difficult-to-remove burrs?*
Electrolytic grinding is a burr-free operation. This makes deburring unnecessary. Parts such as thin wall tubing, hypodermic needles, and laminated materials can be ground without burring, burning, smear, or layover.

74. *At what rate can the metal be removed?*
The electrolytic decomposition of metal occurs in proportion to the amount of current that flows between the work and the wheel. As a general rule of thumb, stock can be removed at the rate of 0.010 cu. in. per min for each 100 amp of electrolytic grinding current used in a cut. Job setup is of prime importance and it should be made so that the maximum work surface is in contact with the wheel. In some cases this must be sacrificed in order to reduce handling and increase production rates.

75. *Is it possible to estimate the time required to machine a job by this method?*
The following steps should be taken to estimate ELG machining time: (a) Determine the best setup; (b) determine the area of contact; (c) determine the current density for a metal removal rate of 0.010 cu. in. per min per 100 amp; and (d) determine the total work-handling time—loading and unloading.

76. *What quality of surface finish results from the ELG process?*
Finishes obtained on steels and various alloys will vary from 15 to 30 microinches; the higher the alloy, the better the finish. Finishes obtained from ELG have a dull appearance. If shine or gloss is required, a conventional light machining pass will satisfactorily shine the surface.

77. *Where is electrolytic grinding used?*
Electrolytic grinding applications fall into two general categories: toolroom applications and production applications.

78. *What kind of cutters are ground by the ELG process?*
Milling cutters (both end and face mills), single-point lathe tools, small cutting tool tips, which can be held in a fixture, counterbores, and step tools (Fig. 18–32).

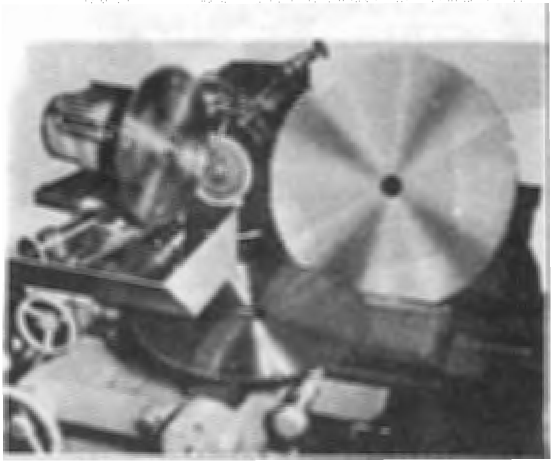


Fig. 18–32. Grinding carbide-tipped saws on an ELG machine. (Cincinnati Milacron Co.)

79. *Is ELG done manually or automatically?*
This will depend on the type of machine available. The single-purpose machine is usually controlled manually. Where a great variety of tools and cutters are to be ground a multipurpose machine is more practical (Fig. 18–33).

80. *How is ELG used for production applications?*
It is replacing many conventional grinding, turning, milling, and broaching operations on exotic alloys, hardened steels, and conventional metals.

81. *Can all operations be performed by one machine?*
Because most production applications require efficiency rather than versatility, electrolytic grinders are designed to perform single-purpose operations such as surface, plunge, rotary, straddle and other methods of grinding. Due to its many advantages, especially burr-free machining, the use of electrolytic grinding in production is steadily increasing. When properly applied, it can result in substantial savings for the user.

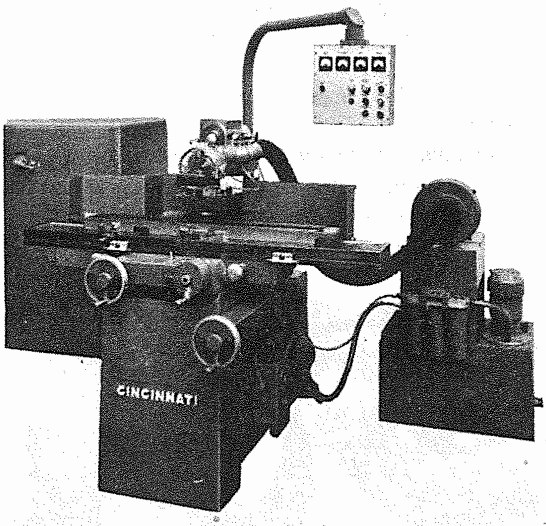


Fig. 18–33. A multipurpose electrolytic grinding machine. (Cincinnati Milacron Co.)

ELECTRICAL DISCHARGE MACHINING

82. *What is electrical discharge machining?*
Electrical discharge machining, also known as EDM, is a process that removes metal by utilizing an accurately controlled electrical spark, or discharge. These discharges are repeated many thousands of times per second in the selected area of the workpiece (Fig. 18–34).

83. *How is it possible to machine a job to accurate size and shape by this method?*
By controlling voltage, amperage, capacitance, and frequency, the shape of an electrode tool can be imparted to the job. This can be done either as a through hole or as a cavity impression. Both roughing and finishing cuts can be made by this process.

84. *What procedure is followed for roughing cuts?*
Roughing cuts are made at low voltage and frequency, with high amperage and capacitance.

85. *How are finishing cuts made?*
Finishing cuts require high voltage and frequency with low amperage and capacitance.

86. *Can this process be used on hardened materials?*

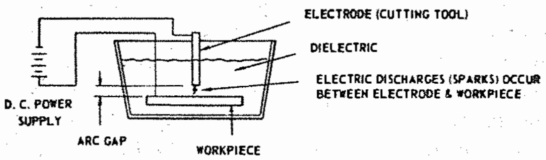


Fig. 18–34. Basic EDM circuit. (Elex Corp.)

The EDM process is unaffected by the hardness of the material being machined.

87. *Is this process limited to the machining of simple shapes?*
No. A wide range of radii and shapes can be machined. The electrode is shaped to give the required shape of the job.

88. *What are the components and functions of a typical EDM system?*
The following descriptions are extracted from *Fundamentals of EDM,* published by the Edoc Corporation, a leading manufacturer of EDM equipment.

Power supply. An electronic unit generating and controling the electrical discharges, or sparks.
Machine tool. The overall structure, which holds the workpiece and guides the electrode.
Electrode. A terminal of the electric circuit; it might be called a *cutting tool* in conventional machining. The shape of the electrode is reproduced in the workpiece.
Amperes. A measurement of cutting current and the basis for rating power-supply capacity and metal-removal rate.
Overcut (or spark length or spark gap). The distance between the electrode and the workpiece across which the spark travels.
Dielectric. The nonconducting oil covering the workpiece during machining.

89. *How does the amperage affect the process?*
As the amperage is increased for a particular discharge frequency, more metal is removed from the job. Figure 18–35 shows three similar machining conditions. In each example the material of the workpiece and the material of the electrode remain the same. Only one spark is used in each example. This shows that as the amperage is doubled, twice the volume of the workpiece is removed.

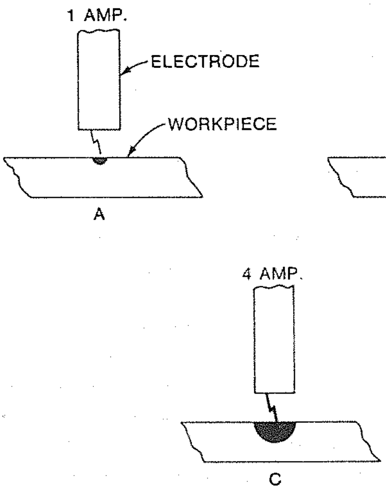


Fig. 18–35. The effect of amperage on metal removal. (Elex Corp.)

90. *Can the quality of surface finish be controlled in electrical discharge machining?*
The quality of surface finish is controlled by the machine's power supply unit (Fig. 18–36), which has a surface finish selector (frequency control) built in. This control makes it possible to vary the number of sparks per second between the electrode and the workpiece. Surface finishes of 2 and 4 microinches can be produced.

91. *How does frequency control affect the surface finish?*
Surface finish improves as the spark frequency increases, due to the reduction of energy per spark. In this way the quality of the finish can be improved without sacrificing the rate of metal removal.

92. *How accurately can the EDM process machine parts?*
This depends on the machine tool and the job setup. Tolerances of 0.0001 in. are quite common. The EDM process has been found particularly useful in the production of dies and molds.

93. *What are the most important applications of EDM?*
The EDM process is used in both small and large manufacturing industries. Its use for machining various types of dies has resulted in considerable

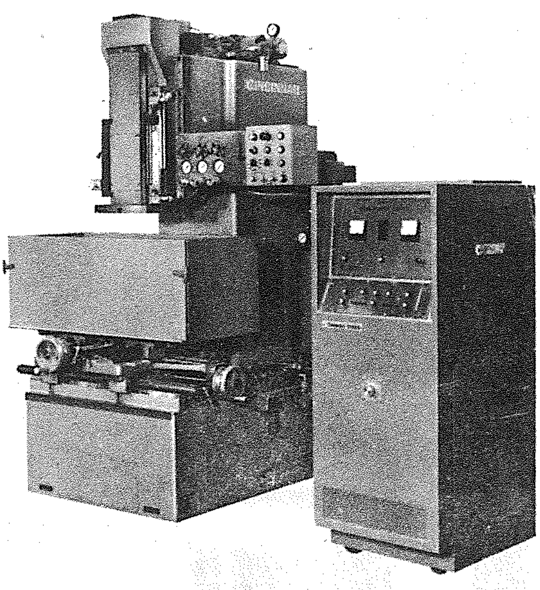


Fig. 18–36. An ADM machine and its power supply unit. (Cincinnati Milacron Co.)

savings in time and money in their manufacture. The process is particularly useful in the machining of odd or unsymmetrical shapes and designs requiring close tolerances.

94. *What types of dies are machined by the EDM process?*
A wide range of dies are prepared by EDM, including cold-heading dies, extrusion dies, plastic mold dies, and multipunch dies (Fig. 18–37).

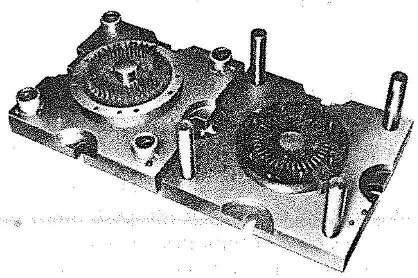


Fig. 18–37. An example of a multipunch die (for multislot laminations) produced by EDM. The steel punch of the set (left) was used as the electrode in the process. Extremely close tolerances were required in order to produce burr-free edges on the finished laminations. (Cincinnati Milacron Co.)

95. *Can large work be machined by the EDM process?*
The large dies used in the automotive and transportation manufacturing industries are produced in special machines capable of handling this type of work (Fig. 18–38).

Fig. 18–38. A four-poster EDM. Machine can handle workpieces up to 50 tons and electrodes up to 25 tons. (Cincinnati Milacron Co.)

THE LASER IN INDUSTRY

The laser is a relatively new tool in the metalworking industries. Although its potential applications in many fields are still being developed, many applications have become commonplace and are no longer merely of interest in the laboratory. Everyday use of the laser is being made in medicine (delicate eye surgery, for example), communications, photography, metrology (the accurate measurement and alignment of points on a building construction site, for example), and the machining of metals, which is of particular interest here.

96. *How did the laser get its name?*
The name is derived from the first letters of the words describing what the laser does: *L*ight *A*mplification by *S*timulated *E*mission of *R*adiation.

97. *What is a laser?*
The laser is a device that can concentrate a light beam in a very narrow path. This gives the light beam tremendous power and enables it to do many things previously thought to be impossible.

98. *How is the laser beam generated?*
One version of the laser uses a ruby crystal rod, the ends flat and partially silvered. A flash lamp or tube is helically wrapped around the rod and connected to a powerful source of electrical energy. The ruby rod absorbs the energy from the flashtube and in an infinitesimal fraction of a second reemits it, intensifying its heat and light energy. A fraction of the light energy produced by the ruby crystal is in the form of a red beam of light that is reflected back and forth between the mirrored ends of the crystal. As it travels through the ruby crystal, the light picks up more energy from it, increasing its strength each time it passes through. One end of the ruby crystal is only partially silvered, thus permitting a fraction of the light to pass through. This energized light beam is called a *laser beam* (Fig. 18–39).

99. *How powerful is the laser beam?*
The laser produces light beams millions of times more intense than those reflected from the surface of the sun. The quality of the light is more pure than any previously known. Light from a ruby laser has been reflected from the surface of the moon, where it illuminated a 2-mile-wide circle, back to earth, a distance of 250,000 miles, in 2.5 seconds. This

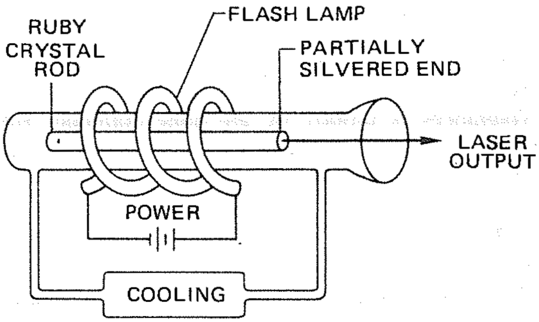


Fig. 18–39. A ruby laser system.

proved that the light of a laser beam is not dissipated; nor does it spread out over long distances. The light is not visible to the naked eye; it is infrared and invisible.

100. *Who developed the first laser and when?*
Dr. Theodore H. Maiman demonstrated the first ruby laser in the Hughes Research Laboratories in Malibu, California, in July 1960. The scientists in the Bell Laboratories developed the first gas laser using a mixture of helium and neon energized by a radio frequency generator in 1961 (Fig. 18–40).

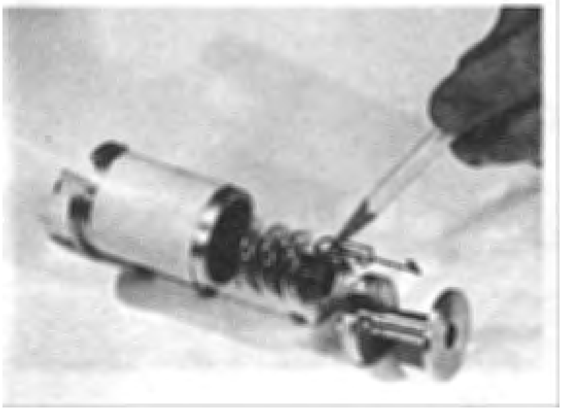


Fig. 18–40. Dr. Maiman's first laser. Output was 10,000 watts.

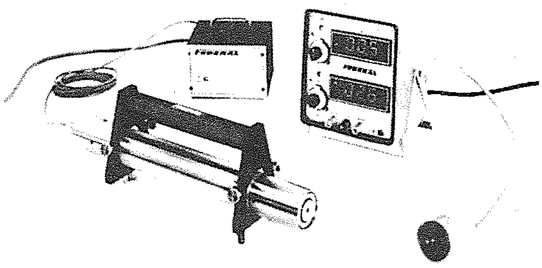
101. *How many types of lasers are in use?*
The three types of lasers are the ruby laser, the gas laser, and the injection laser.

102. *What are some of the areas in which the laser is used?*
Lasers are used in cinematography, communications, computers, holography, medicine, surgery, distance measurement, interferometers in the machine tool industry, machining, welding, drilling holes in diamonds to form wire-drawing dies, drilling holes through rock formations, and many others. Every day brings new applications for the laser.

103. *How is the laser used in the metalworking industry?*
The helium-neon laser has many applications in the machine trades. A typical use is in the laser interferometer, which in conjunction with an optical system can make measurements to millionths of an inch (Fig. 18–41). Because of its stability and time-space coherence the laser makes possible the measurement, inspection, and checking of critical machine parts such as the lead screws and worms of the most accurate machines as well as the surface flatness of newly installed heavy machinery (Fig. 18–42).

Fig. 18–41. Operators making a preliminary optical alignment before making final measurements with a laser interferometer. (Cincinnati Milacron Co.)

Fig. 18–42. An alignment laser. This unit has an accuracy of 0.0001 in. per ft and an operating range up to 300 ft; measurements are read on a digital readout in two axes. (Federal Products Corp.)



104. *What other industrial uses has the laser?*
It is used in many ultraprecision operations such as making thousands of tiny holes, all within a tolerance of ±0.0005 in. Tiny parts of electronic equipment are welded by the laser beam using wire

0.001 in. in diameter; each weld is made in one millionth of a second. Laser interferometers are being fitted into N/C machining systems so that the parts being machined can be continuously measured. The adjustments necessary to compensate for the wearing of the cutting tool are controlled by the laser. The laser beam can burn an accurate hole through a diamond in two minutes. Other methods of doing this take a skilled technician two or three days. Industry is continually finding new uses for the laser beam, particularly in penetrating through some materials that resist conventional machining (Fig. 18-43).

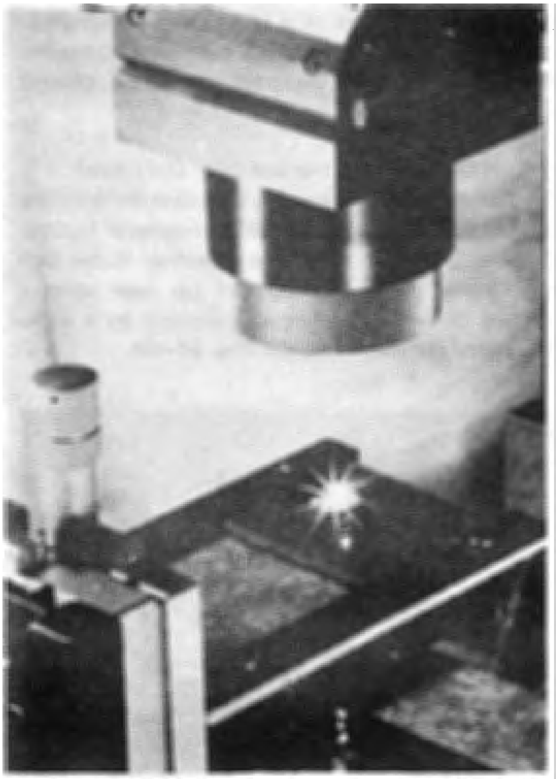


Fig. 18-43. Laser beam accurately cutting a very small hole in a tough metal. (Perkins-Elmer.)

chapter 19

surface finish and surface measurement

The smoothness of a machined surface has always been of concern to the machinist, the technician, and the engineer. Serious consideration was given to surface smoothness wherever two machined surfaces came in contact with each other—for example, in a bearing and a journal.

Prior to the development of a means to measure surface roughness accurately, machined surfaces in contact with each other had to be broken in before they could operate at full efficiency. When observed through a microscope, a seemingly smooth machined surface showed a series of hills and valleys. When two such surfaces operated together (e.g., a shaft and a bearing) they were fitted to a close tolerance. After a short period of running time, the hills wore off of each surface resulting in excess clearance. The machinery had to be stopped so the bearing could be adjusted to compensate for the wearing in of the hills. Most bearings were made in two pieces so shim stock could be placed between the two halves and removed after the wearing-in period.

Developments in machining operations brought smoother finished surfaces but did not eliminate the problem. The automobile industry financed extensive research to discover methods for achieving smoother surface finish. Machining techniques were developed to reduce the breaking-in time of the new automobile engine. Owners were advised to drive new automobiles only at slow speeds for the first 500 miles so that the bore of the engine's cylinders could be worn to a smooth finish. Engines and bearings had to be overhauled or replaced after a few thousand miles because of reduced efficiency. The only method of determining the quality of a finished surface was to note the amount of resistance given by the ridges when a thumbnail edge was scraped across a machined section. Machine operator and engineer alike used this "method." Great strides had been made in developing accuracy in measurement, but nothing had been done in the field of measuring surface roughness.

The SKF Ball Bearing Company engaged the services of E. J. Abbott, who in 1936 perfected an instrument that could accurately measure the irregularities on a machined surface. He called it the *profilometer,* which soon was available to all who needed it. Abbott's contribution led to continuous improvement in the methods and techniques of obtaining surfaces that are almost free of any irregularities. Since that time other instruments have been developed to measure surface roughness. Among these is the Brush Surface Analyzer.

1. *What is meant by surface finish?*
Every machining process leaves its evidence on the machined surface: finely spaced irregularities left by the cutting tool. Each kind of cutting tool leaves its own individual pattern, which easily can be identified by the experienced technician. This pattern is known as *surface finish* or *surface roughness*. Every machined surface is composed of tiny hills and valleys (or bumps and dents). Whether the surface is the result of turning, milling, shaping, grinding, honing, or polishing can be determined by close investigation. The characteristics of the surface of a workpiece can make it unsuitable for some kinds of work.

2. *What causes the irregularities in the surface of a machined job?*
Surface irregularities are related to the efficiency of the machining operation. It is well known that this efficiency depends, in large measure, upon the correct grinding of the cutting tool—correct clearance, rake, and cutting angle. Surface irregularities are also caused as the chip is forced from the work by the cleaving action of the cutting tool. The shape of the job can also have a contributing effect for the vibrations of both job and cutting tool leave their mark on the finished surface. Even the wear on improperly machined ways can be observed in the finish of the job. An efficient grinding job depends largely upon the selection of the correct wheel for the metal being ground and the proper dressing of the wheel. The quality of the surface finish is affected by the same factors of proper selection and wheel condition.

3. *What factors contribute to the quality of a surface finish?*
The most important factors include:

A. The keenness of the tool's cutting edge.
B. The uniformity of that cutting edge.
C. The smoothness of the tool surfaces that come in contact with the job, or the chip during the machining operations.
D. The feed given by the machine to the cutting tool as it traverses the job.
E. The condition of the machine ways that guide the cutting tool along its path.

4. *What characteristics of surface roughness are measured to obtain an evaluation of the surface?*
Several characteristics contribute to the evaluation of surface quality. These have been defined by the American National Standards Institute (ANSI) which decided to focus on the height, width, and direction of surface irregularities.

5. *What are the most important characteristics of a surface as defined by ANSI?*
Surface characteristics as defined by ANSI are shown in Fig. 19–1. The standard states that these terms and ratings "relate to surfaces produced by such means as machining, abrading, extruding, casting, molding, forging, rolling, coating, plating, blasting, or burnishing, etc."*

Surface texture. Repetitive or random deviations from the nominal surface, which form the pattern of the surface. Surface texture includes roughness, waviness, lay, and flaws.

Surface. The surface of an object is the boundary that separates that object from another object, substance, or space.

Nominal surface. Nominal surface is the intended surface contour, the shape and extent of which is usually shown and dimensioned on a drawing or descriptive specification.

Measured surface. The measured surface is a representation of the surface obtained by instrumentation or other means.

Profile. The profile is the contour of a surface in a plane perpendicular to the surface, unless some other angle is specified.

Nominal Profile. The nominal profile is the profile disregarding surface texture.

Measured Profile. The measured profile is a representation of the profile obtained by instrumental or other means.

Center line. The center line is the line about which roughness is measured; it is a line parallel to the general direction of the profile within the limits of the roughness-width cutoff, such that the sums of the areas contained between the center line and those parts of the profile that lie on either side of it are equal.

Microinch. A microinch is one millionth of an inch

*Extracted from *Surface Texture* ANSI Standard B46. 1-1962 (R1971) with the permission of the publisher, the American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, N. Y., 10017.

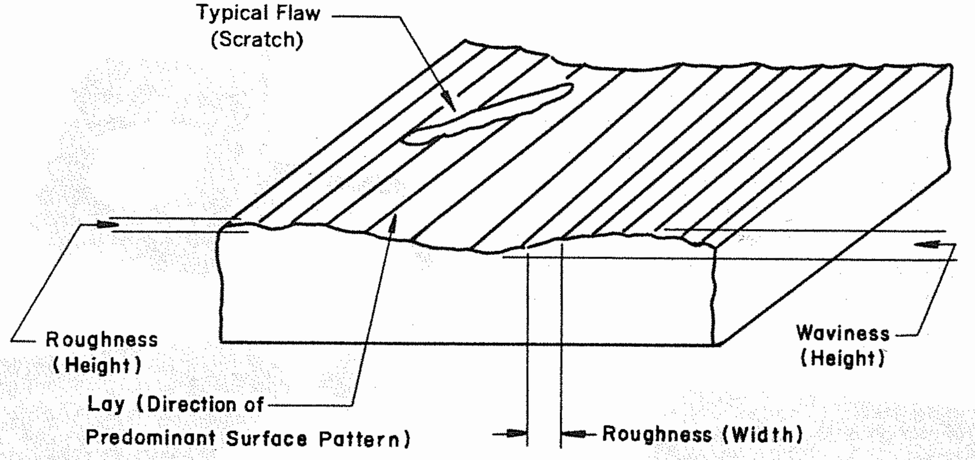


Fig. 19–1. The characteristics of surface finish.

(0.000001 in.). Microinches may be abbreviated as μin.

Roughness. Roughness consists of the finer irregularities in the surface texture, usually including irregularities that result from the inherent action of the production process. These are considered to include traverse feed marks and other irregularities within the limits of the roughness-width cutoff.

Roughness height. For the purpose of this standard, roughness height is rated as the arithmetical average deviation expressed in microinches measured normal to the center line.

Roughness width. Roughness width is the distance parallel to the nominal surface between successive peaks or ridges, which constitute the predominate pattern of the roughness. Roughness width is rated in inches.

Roughness-width cutoff. The greatest spacing of repetitive surface irregularities to be included in the measurement of average roughness height. Roughness-width cutoff is rated in inches. Roughness-width cutoff must always be greater than the roughness width in order to obtain the total roughness height rating.

Waviness. Waviness is the usually widely spaced component of surface texture and is generally of wider spacing than the roughness-width cutoff. Waviness may result from such factors as machine or work deflections, vibration, chatter, heat treatment, or warping strains. Roughness may be considered as superimposed on a "wavy" surface.

Waviness height. Waviness height is rated in inches as the peak to valley distance.

Waviness width. Waviness width is rated in inches as the spacing of successive wave peaks or successive wave valleys. When specified, the values shall be maximum.

Lay. The direction of the predominant surface pattern ordinarily determined by the production method used.

Flaws. Flaws are irregularities which occur at one place or at relatively infrequent or widely varying intervals in a surface. Flaws include such defects as cracks, blow holes, checks, ridges, scratches, etc. Unless otherwise specified, the effects of flaws shall not be included in the roughness-height measurement.

6. *How is the degree of surface roughness measured?*

There are occasions when visual comparison with the naked eye will disclose that one surface is rougher than another. This method is possible only in instances of wide difference, which could not be misinterpreted by individual reaction. The methods of evaluating surface roughness used most often are as follows:

A. Inspection by touch comparison. A fingernail is moved along the surface of the job and a mental note taken of the amount of resistance and the depth of irregularities. The fingernail is then moved across a series of master roughness scales which have numbers corresponding to their measurement in microinches (Fig. 19–2). The machining finish must compare satisfactorily with the correct master. This form of testing is used mainly by machinists.

Fig. 19–2. Finger comparison scales.

B. A visual comparison inspection can be made with the aid of illuminated magnifiers (Fig. 19–3).

C. The interference microscope (Fig. 19–4) makes use of a microscope in conjunction with an optical flat plate and a monochromatic light. The height of the surface irregularity is observed in light reflected between the microscope objective and the surface of the job. The interference fringes indicate the intersection of the wave fronts reflected between the job and the front surface of the microscope objective. The distance between the fringes represents 11 microinches. The use of the interference microscope for the measurement of surface finish is a laboratory procedure; it seldom is done in the shop.

D. The most commonly used instrument for

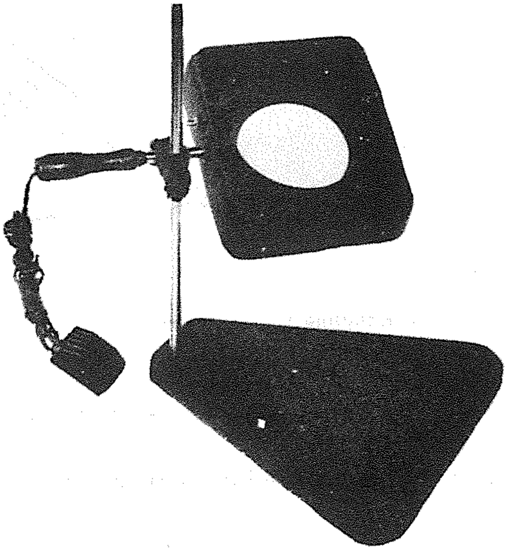
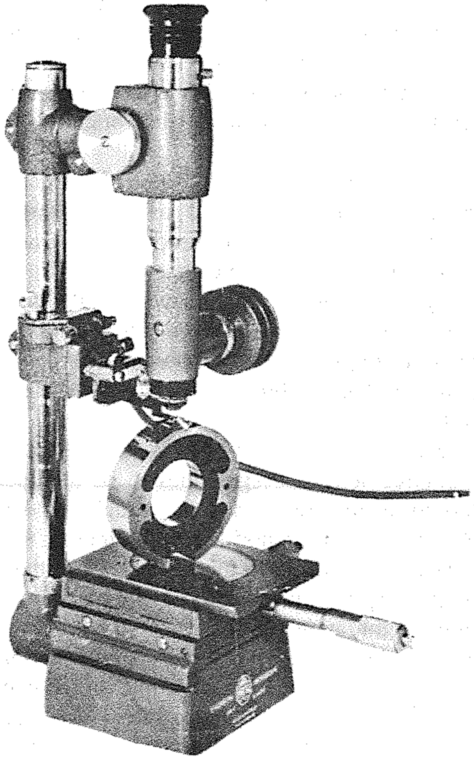


Fig. 19–3. Magnifier with illuminator for surface inspection. (Scherr-Tumico, Inc.)

Fig. 19–4. The interference (surface-finish) microscope. (Engis Equipment Co.)



finding the degree of surface roughness is the profilometer (Fig. 19–5). It is one of the instruments that utilizes the tracer method and actually measures the differences in the depth of the surface irregularity. The profilometer is a mechanical-electronic instrument, which can be used for both shop and laboratory purposes.

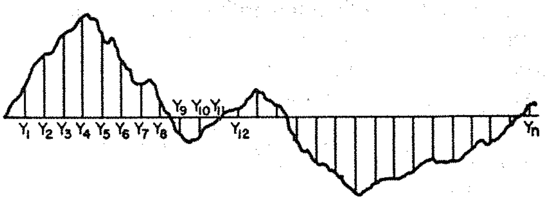
7. *How does the profilometer operate?*
The two main units of the profilometer are the tracer and amplimeter. Tracers are made in several designs to measure a variety of shapes. The tracer has a stylus with a very small radius at its tip. As the tracer is moved across the surface being measured, the stylus follows the contours of the irregularities left by the machine tool. These up and down movements of the tracer stylus are converted into a small fluctuating voltage. The voltage is fed into the amplimeter where it is amplified to actuate the microinch meter on the front panel. The meter shows the variations in the average roughness height in microinches. There is a motor-driven unit, the motorace, shown in Fig. 19–5, which permits the mechanical movement of the tracer and its stylus when manual operation is not possible or not practical.

8. *How large is the tip of the stylus that measures the surface roughness?*
The radius of the stylus used on the surface-roughness measuring instruments must conform to the standard: 0.000500 ± 0.000150 in.

9. *How is the full depth or height of the 'up and downs' of a surface measured when the stylus tip cannot reach the full depth?*
As the tracer moves along the surface of the job, the profilometer automatically places a center line through the roughness profile of the surface, inverts the portion of the profile below the center line, remembers the last couple of hundred irregularities that the tracer passed over, computes the average height of these irregularities, and shows this average-height figure on the meter in microinches. In this way the profilometer shows the variations in average roughness height that occur on most surfaces.

10. *How are the readings of the profilometer curve translated into a measurement?*
Figure 19–6 represents a magnified roughness profile of a short portion of a surface. A center line is established from which the average-height measurement of this curve can be measured. The area above this center line is equal to the area below the

Fig. 19–6. Representative portion of a surface profile. (Micrometrical Manufacturing Co.)



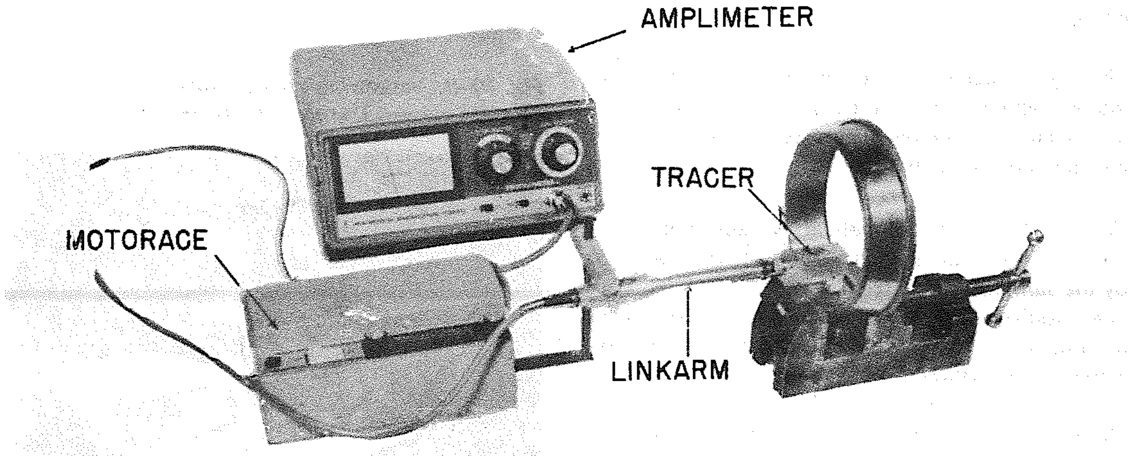


Fig. 19–5. The profilometer measuring the surface roughness of an internal diameter. (Micrometrical Manufacturing Co.)

line. The equally spaced vertical lines, Y_1, Y_2, Y_3, etc. (shown in Fig. 19–6) show the deviations of the surface from the center line. In order to determine the average, the parts below the line are treated exactly the same as the parts above the line. The measurement of the height of surface roughness is determined by the average deviation from the center line.

11. *What methods are used to find the average deviation from the center line?*
The two methods of obtaining the average deviation are:

A. The arithmetical average height.
B. The root-mean-square (rms) average height. The formula for the arithmetical average height of the surface profile shown in Fig. 19–6 follows.

$$\underset{\text{(arithmetic)}}{\text{Average height}} = \frac{Y_1 + Y_2 + Y_3 + Y_4 + \cdots Y_n}{n}$$

where n is the total number of vertical measurements.
Root-mean-square (rms) average height is about 11 percent higher than the arithmetical average; this difference is of little importance in most cases. The formula for the rms average height of the profile shown in Fig. 19–6 follows.

$$\underset{\text{(rms)}}{\text{Average height}} = \sqrt{\frac{Y_1^2 + Y_2^2 + Y_3^2 + Y_4^2 + \cdots Y_n^2}{n}}$$

where n is the total number of vertical measurements.

The rms average was more commonly used when the tracer method of measuring surface roughness was in its infancy; arithmetical average is now considered the standard rating throughout the world.

12. *Can both the arithmetical average height and the root-mean-square average height be measured by the same instrument?*
The profilometer can measure average roughness in arithmetical average or rms standards by moving a switch (Fig. 19–7).

13. *How is it possible to measure the surface finish at the machine where the workpiece is being machined?*
No technical knowledge or special skill is needed

Fig. 19–7. The profilometer amplimeter control panel. (Micrometrical Manufacturing Co.)

to operate the instruments designed for this purpose. A machinist can learn to do this in a few minutes. The instrument can be set up on a bench or cabinet beside the production machine and the workpiece can be checked at the bench (Fig. 19–8), or the tracer can be used manually on the job while it is in the machine (Fig. 19–9). Work can also be checked at on-the-floor inspection units (Fig. 19–10).

Fig. 19–8. Measuring surface finish during production. (Micrometrical Manufacturing Co.)

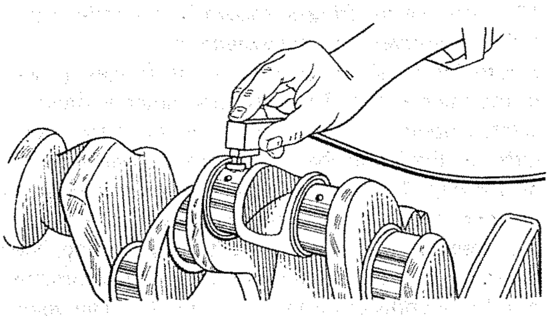
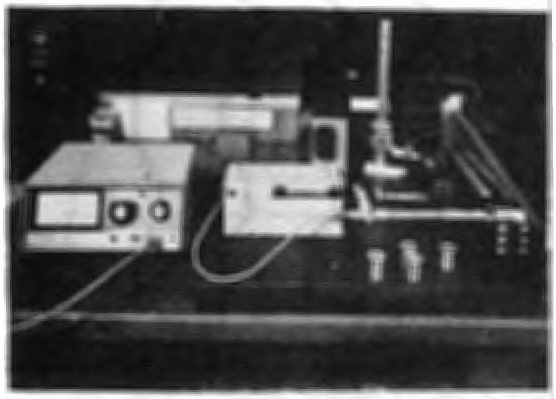


Fig. 19–9. Checking surface finish on the machine. (Micrometrical Manufacturing Co.)

Fig. 19–10. On-the-floor inspection of surface finish. (Micrometrical Manufacturing Co.)



14. *Why are jobs checked for the quality of surface finish during production?*
The machinist is always interested in the quality of the finish that his cutting tool has given to the surface of the machined job. The smoothness and regularity of the finished surface will indicate:

A. Efficiency of the cutting tool and whether the tool is correctly ground.
B. The approaching breakdown of the cutting edge (or the dulling, loading, and glazing of the grinding wheel).
C. The variation in size caused by a change in surface roughness.
D. The need for or the extravagance of additional machining.

By availing himself of a quick, reliable method of checking surface roughness the machinist saves time and effort.

15. *Is the profilometer the only instrument used for checking surface finish?*
Several instruments are used for checking the quality of surface finish. The Brush Surfindicator is well known as a practical shop instrument designed for the accurate measurement of surface finish roughness. Like the profilometer, the Brush Surfindicator (Fig. 19–11) measures the irregularities of the surface finish and records them in microinches. This is done by means of a tracer stylus, which registers the rise and fall of the peaks and valleys on the finished surface. These variations are amplified and indicated on an electrical meter, which is calibrated to read in microinches. The Surfindicator can be calibrated to read directly in arithmetical average or root-mean-square average and can be fitted with various accessories for use in specialized areas.

16. *Can the quality of the finished surface be observed and measured by optical instruments?*
A machined surface can be observed by means of a microscope, but since surface roughness must be measured in millionths of an inch a special microscope technique is necessary for the measurement

Fig. 19–11. The Brush Surfindicator. (Brush Electronics Co.)

of surface roughness. The Hilgar and Watts Surface Finish Microscope (see Fig. 19–4) uses interference fringes, which make possible the measurement of surface finish by utilizing the wavelength of light. The microscope magnifies the surface under examination 125 times to 170 times, depending on the manufacturer's plans. The illumination (Fig. 19–12) is provided by a high-intensity mercury lamp (A), which is housed in a small tube branching out of the side of the main microscope. The lamp is connected with a capacitor switch, which plugs directly into the main supply at either 210–240V or 100–110V. The light passes through a green filter (B) and illuminates an adjustable iris diaphragm (C), which is focused by means of a lens system (D) after reflection at a semireflecting mirror (E) onto the back focal plane of the objective (F), which is especially designed to work with parallel light. Below the objective is a comparator plate (G), which is an optical flat coated with a hard semireflecting oxide film, contacting the work surface and inclined to it at a very small angle so as to enclose a wedge-shaped air space between the flat and the work, which must itself be the reflector. Multiple reflection of the light takes place between the two surfaces enclosing this wedge of air. The work, together with the superimposed fringes so produced, is viewed through the eyepiece.

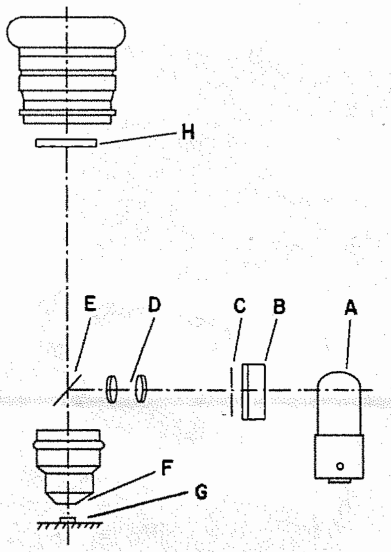


Fig. 19–12. Diagram of the optical system of a surface-finish microscope. (Farrand Optical Co., Inc.)

17. *How are the fringes, shown by the reflection of light, interpreted into measurement?*

Figure 19–13 shows a view of the fringes as seen in the microscope. The V-shaped notches denote a scratch upon the surface of the work. If the irregularity in the fringe pattern is exactly one fringe in height (Fig. 19–14), the scratch is ten millionths of an inch deep (microscope magnification 125×). If the irregularity is seen to be 6 fringes deep, then the depth of the scratch is $6 \times 10 = 60$ microinches, or 60 millionths of an inch (Fig. 19–15). The degree of magnification affects the height of the fringe.

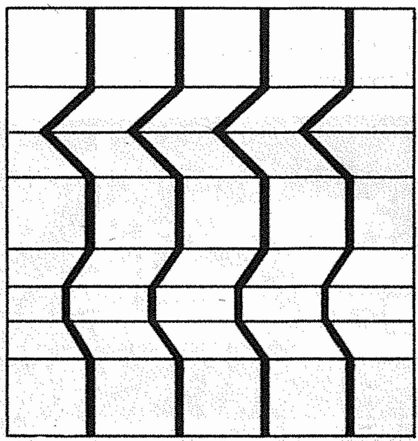
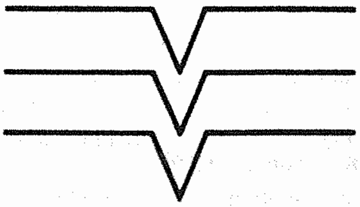


Fig. 19–13. Diagrammatic view of the fringes as seen in the microscope. (Hilgar & Watts, Ltd.)

Fig. 19–14. The fringe pattern of a scratch, one fringe in height. (Farrand Optical Co., Inc.)



A 35-mm camera can be fitted to the microscope in order to obtain a record of the interferogram. This picture can be used by the mechanic as a comparative measure or, through enlargement, to make more accurate measurements.

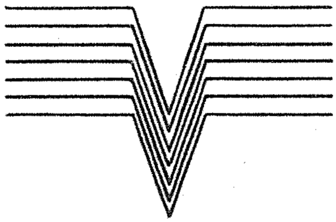


Fig. 19–15. The fringe pattern of a scratch, six fringes in height. (Farrand Optical Co., Inc.)

18. *What is the simplest method of judging the roughness of a surface?*

The simplest method of judging the roughness of a surface has always been the fingernail test. The human fingernail is very sensitive and will detect the result of a tearing cut, as well as the hills and valleys that contribute to the roughness of the finished surface. In order to give the machinist some kind of a reference surface with which he could compare his work, surface roughness scales were developed (Fig. 19–16). By using touch and sight to compare the surface of the job with the matching part of the scale, the machinist can determine whether he is conforming to the requirements of the job specifications. The scales are made to duplicate machined surface standards in appearance, pattern, and roughness value. The scales are made of flat steel and are pocket size. To identify its correct degree of surface roughness each pattern is engraved with a number representing the arithmetic average deviation from the mean surface in microinches—that is, 8 represents 8 microinches roughness. A curved set of reference scales simplifies the measurement of cylindrical surfaces, both internal and external (Fig. 19–17). A further development of this method of measuring surface roughness is shown in Fig. 19–18. Each pattern of the reference scale is marked with a number representing the

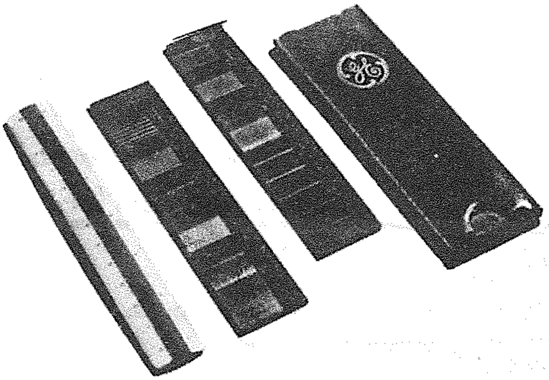
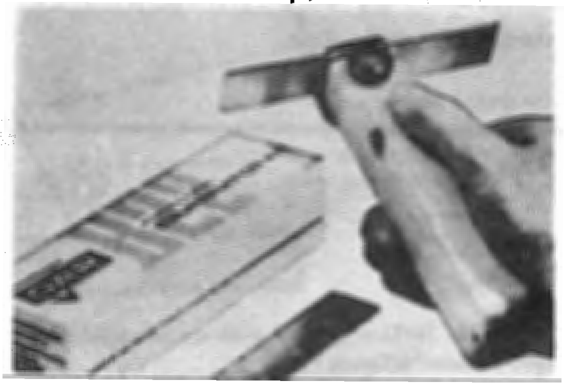


Fig. 19–16. General Electric roughness scales. View of case and two scales, showing relative size compared to a 6-in. rule. (General Electric Co.)

Fig. 19–17. Cylindrical roughness scales. (General Electric Co.)

Fig. 19–18. Surface-finish comparator kit, which allows comparison of surface roughness either by touch or by optical enlargement. (Gar Precision Division of Heli-Coil Corp.)



surface roughness in microinches and a code letter indicating the machining process; for example, 63M denotes 63 microinches, milled. The reference scale can be used by sight or touch, but as an added advantage the manufacturer supplies a 10× hand magnifier with built-in illumination. This complete kit consists of 2 scales on which are represented 22 specimens of a variety of finishes, the 10× optical magnifier, and a carrying case.

19. *How are the characteristics of a surface specified on a machine drawing?*

The American National Standard, as developed by ANSI, stipulates that "the symbol used to designate surface irregularities is the check mark with horizontal extension"* as shown in Fig. 19–19.

The recommended proportions of the surface symbol is shown in Fig. 19–20. "The point of the symbol shall be on the line indicating the surface, on the extension line or on a leader pointing to the surface. The long leg and extension shall be to the right as the drawing is read. Where roughness height only is indicated it shall be permissible to omit the horizontal extension."

*All quoted materials have been extracted from *Surface Texture* ANSI Standard B46.1–1962 (R1971) with the permission of the publisher, the American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, N. Y., 10017.

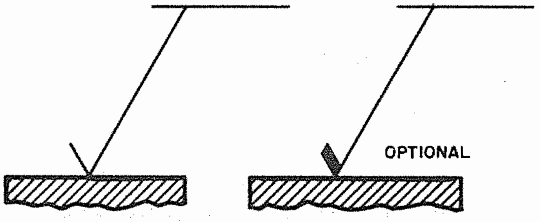


Fig. 19–19. The surface symbol. (Micrometrical Manufacturing Co.)

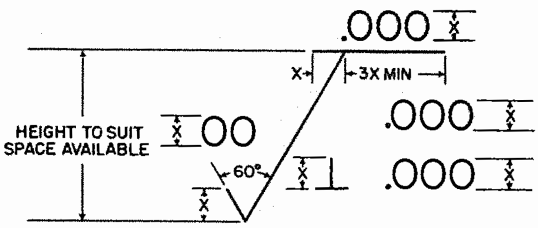


Fig. 19–20. Recommended proportions for surface symbol. (Micrometrical Manufacturing Co.)

Figure 19–21 shows a surface symbol, which includes specifications for all of the surface characteristics covered by the ANSI standard. The ANSI standard says, "Only those ratings required to specify adequately the desired surface shall be shown in the symbol. Roughness height rating is placed at the left of the long leg. The specification of only one rating shall indicate the maximum average and any lesser average shall be acceptable.

"The specification of maximum average and minimum average roughness height ratings indicates permissible range of average rating."

Figure 19–22 shows typical examples of the ways to apply the surface symbol on a drawing. Figure 19–23 shows a convenient method of specifying roughness for several operations on the same surface.

The study of surface roughness is still in a state of development; it is expected that the future will bring many refinements in machining processes and in the measurement of surface finish.

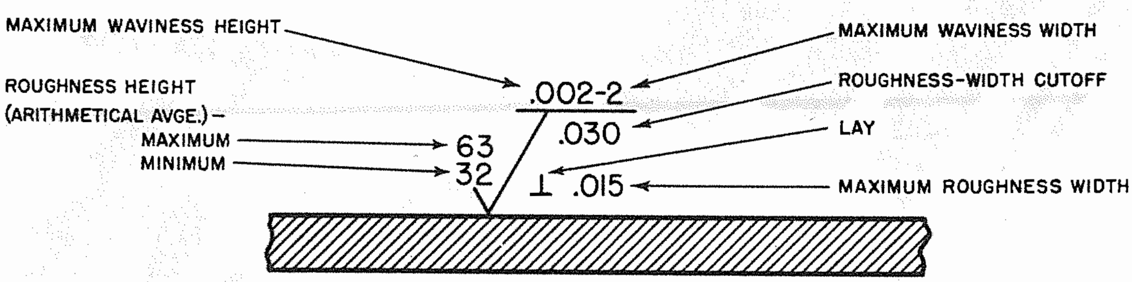


Fig. 19–21. Surface symbol with specifications for all the characteristics covered by the standard. (Micrometical Manufacturing Co.)

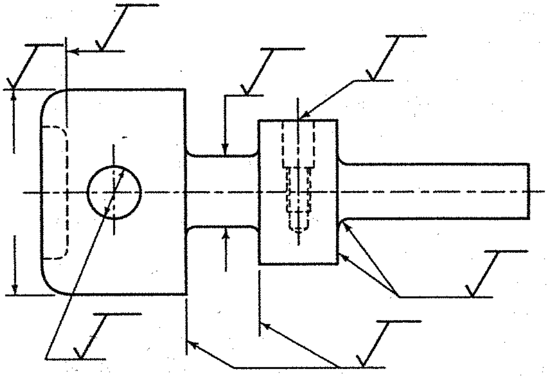


Fig. 19–22. Typical applications of the surface symbol on a drawing. (Micrometrical Manufacturing Co.)

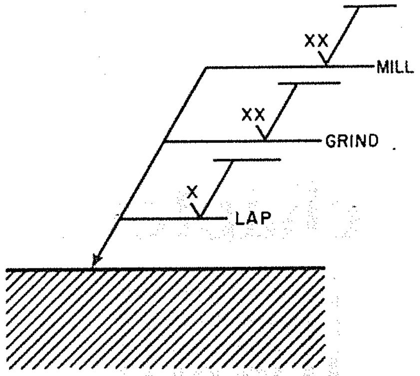


Fig. 19–23. Convenient method of specifying roughness for several operations on the same surface. (Micrometrical Manufacturing Co.)

chapter 20

heat treatment and testing of metals

Heat treatment is a term used in industry to describe a process whereby the physical properties of a metal may be changed by subjecting it to heat. In some instances the procedure is a simple one; in others it is quite complicated, involving the use of scientific knowledge and equipment. In this book, the discussion of heat treatment will be limited to the heat treatment of steel.

There are two principal reasons for heat-treating steel: one is to harden it, the other is to anneal (soften) it.

Before any heat-treating process is described, it is well to become acquainted with the material being treated. To some people, steel is simply a hard metal. To persons in industry, however, the word *steel* brings to mind not just one kind of material, but a great number, which may all be classified as steel but which differ from one another in both their chemical analysis and their physical properties.

1. *What is steel?*
Steel is an alloy of iron and carbon. In addition, there are minute percentages of other elements present, including silicon, phosphorus, sulfur, and manganese.

2. *How may steels be classified?*
Steels may be roughly classified as straight-carbon steels and alloy steels. A straight-carbon steel is one that owes its particular properties chiefly to the presence of certain percentages of carbon without substantial amounts of other alloying elements. Straight-carbon steels may be classified into three groups, low carbon, medium carbon, and high carbon. An alloy steel is one in which some element other than carbon has been added to improve or change the physical properties.

3. *Of what importance is the element carbon in straight-carbon steel?*
Carbon is the element that makes possible the hardening of straight-carbon steel.

4. *How much carbon must be present in steel before it can be hardened noticeably?*
Steel must contain at least 0.20 percent of carbon before it can be hardened sufficiently for commercial use.

5. *What is a low-carbon steel?*
A low-carbon steel is one that does not contain

enough carbon to cause it to harden when heated to a high temperature and quenched in oil, water, or brine. The amount of carbon in low-carbon steel may vary from 0.05 to 0.20 percent. Some of the low-carbon steels are machine steel and cold-rolled steel, which are also identified as SAE 1015 steel. Typical of the articles made from low-carbon steel are bolts, nuts, clamps, washers, pressure pads, stripper plates, and similar items where the surface is not subjected to continuous wear. When a hard-wearing surface and a soft core are required, low-carbon steel may be case-hardened by a special process.

6. *What is a medium-carbon steel?*
A medium-carbon steel is one that contains from 0.20 to 0.60 percent carbon. Medium-carbon steels are used for a wide variety of work including nuts, bolts, stock guides, flask pins, crankshafts, crane shafts, and so forth. Medium-carbon steels are also used extensively in production manufacturing. A medium degree of hardness (Rockwell 38–46) may be obtained by heat treatment.

7. *What are high-carbon steels?*
High-carbon steels are those that usually contain from about 0.60 to 1.30 percent of carbon. Tool steel (SAE 1095) is a high-carbon steel. It may be heat-treated, hardened, and tempered. The degree of hardness is high: between 52 and 64, Rockwell. Many of the tools and working parts of machines, guide pins, rest buttons, locating pins, dies, punches, gages, bushings, centers, and the like (all of which are required to withstand a great deal of wear) are made from tool steel.

8. *What are alloy steels?*
Alloy steels are those that contain, in addition to carbon and iron, alloying elements such as chromium, vanadium, nickel, molybdenum, tungsten, or manganese. These alloying elements give some peculiar characteristics not possessed by ordinary steel. The alloys can be used in combination in order to make a steel to meet specific requirements. Alloys are put into steels for many reasons, including (a) to secure greater hardness; (b) to secure greater toughness or strength; (c) to enable the steel to hold its size and shape during hardening; and (d) to enable the steel to retain its hardness at high temperatures.

Chromium is added to steel to increase the depth to which the steel may be hardened. The amount used is from 0.40 to 1.5 percent. Larger amounts, 12 to 25 percent, are used in stainless steels.

Vanadium is added to steel in small quantities, 0.12 to 0.20 percent; it retards internal stress in the steel even when subjected to high temperatures.

Nickel will increase the toughness and strength of steel, but will not increase its capacity for being hardened. The amount added varies from 0.30 to 3.75 percent. For stainless steel, as much as 20 percent is used.

Molybdenum increases greatly the depth of hardness and makes steel tough. It also helps it to remain hard at high temperatures. It is added in small amounts of from 0.10 to 2.00 percent.

Tungsten is used in tool steel to make a fine grain alloy, which tends to maintain a sharp cutting edge on tools. The amount used is 0.50 to 1.50 percent. For high-speed steel, 6 to 18 percent tungsten is added. High-speed steel is used for high-grade cutting tools, milling machine cutters, drills, reamers, broaches, and many other tools that are required to stay sharp under conditions that would ruin the cutting edge of tools made of ordinary tool steel.

Manganese is present in nearly all steels. It counteracts the undesirable effects of sulfur and is known as a deoxidizer and a desulfurizer. The amount of manganese in steel for this purpose is seldom more than 1 percent. Manganese steel contains 12 to 14 percent manganese and 1 percent carbon. It is a difficult metal to machine because the more this metal is worked the harder it becomes.

9. *What are some of the operations involved in the heat treatment of steel?*
Normalizing, annealing, quenching, tempering or strain drawing, cyaniding, carburizing, and nitriding are some of the operations involved.

10. *What is the process of normalizing steel?*
Normalizing is the uniform heating of steel above the usual hardening temperatures, followed by cooling freely in air. This treatment is used to put steel back in a normal condition after forging or after an improper heat treatment.

11. *What is the process of annealing?*
Annealing is accomplished by heating the steel slowly above the usual hardening temperature, keeping it at the heat for ½ to 2 hours, then cooling slowly, preferably in a furnace. This operation softens a piece of work that is too hard to machine

or requires machining after it has been hardened. Annealing is also done to relieve internal strains set up in a piece of steel by extensive machining.

12. *What is the process of quenching?*
Quenching is the operation of cooling a heated piece of work rapidly, by dipping it in water, brine, or oil (Fig. 20–1).

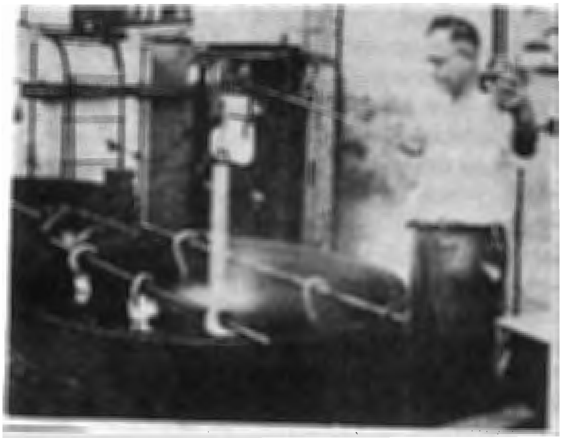


Fig. 20–1. Quenching parts in oil.

13. *What is the process of tempering steel?*
Tempering, also known as strain drawing (drawing the temper or strain from the steel), is a process whereby a certain degree of hardness is sacrificed in order to reduce brittleness and increase the toughness of a steel tool. This can be done in several ways. One process is to reheat the tool to a low temperature ranging from 300° to 1300°F. and then to cool it. The lower the temperature used for tempering, the harder the piece will be. The higher the tempering temperature, the softer the piece.

14. *Why are different methods used to temper steel?*
The method used to temper steel will depend upon the kind of steel being used, its size, its shape, and what it is to be used for.

15. *What methods are used to temper steel?*
There are many methods, some of them highly specialized. The most common include:

A. Brine or Salt Bath. Temperature 300° to 1200°F., depending upon the type of salt used. There are different salts for different purposes. The bath must be clean and free from grease.
B. Oil Bath. Temperature from 300° to 400°F., although with special oils a higher temperature can be attained. Lubricating oil is not suitable for tempering. Best results are obtained when the oil is circulated and passed through a cooling agency.
C. Lead Bath. Temperature 700° to 1200°F. The particular alloy being tempered will determine the most effective temperature of the bath.
D. Water Bath. The water must be clean and free from grease or soap. The shape of the job and the type of alloy will determine the most effective water temperature.
E. Muffle Furnace. A job can be tempered in a muffle furnace if the air blast can be controlled.

16. *How can a tool be hardened and tempered with one heating?*
The cutting end of the tool is heated, about 1½ in. from the edge. The cutting edge is quenched (½ in. to ¾ in.). The tool must be kept moving, slightly up and down and in large circles, to be kept in contact with cool water. The tool is removed from the quenching bath with the heat still retained in the remainder of the tool. The hardener watches the colors pass to the cutting edge and immediately quenches the tool when the color representing the desired hardness reaches the cutting edge. This method is often used by the machinist to harden and temper cutting tools, (e.g., cold chisels, special shape machine cutting tools, punches, and so forth).

17. *How can the hardness of steel be judged by a color?*
The color of the cooling steel represents the temperature and the degree of hardness (Fig. 20–2).

18. *Can more than one tool be tempered at a time?*
Modern production requires that machine parts and tools be hardened in batches. When more than one tool is being tempered, it is more practical to reheat the parts or tools in a bath of oil or nitrate, in a pyrometer-controlled heating pot, as shown in Fig. 20–3.

This type of furnace is designed especially for heat-treating operations that require a liquid heating

temper colors	temperature (F°)	tools
Pale yellow	**375° to 400°**	**Punches** **Scrapers** **Centers**
Light straw	**430°**	**Hammers** **Machine cutting tools**
Medium straw	**460°**	**Dies** **Drills** **Screwdrivers**
Dark straw	**490°**	**Chisels** **Center punches**
Light purple	**520°**	**Axes** **Needles**

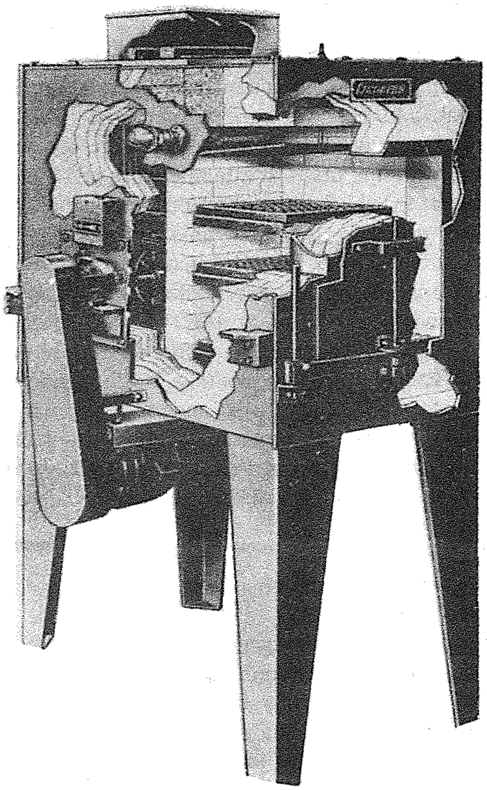
Fig. 20–2. Temper colors for steel.

medium. Reheating for tempering purposes can also be accomplished in an electrically heated box-type furnace (Fig. 20–4A). This furnace is refractory lined to withstand a temperature of 1250°F. The furnace is heated by the forced circulation of large volumes of accurately heated air, which is constantly recirculated through the work chamber under pressure. Figure 20–4B shows the adjustable and removable shelves and the insulating walls of this type of furnace.

Fig. 20–3. A gas-fired pot furnace. (Lindberg Engineering Co.)

Fig. 20–4(A). A toolroom tempering furnace. (Lindberg Engineering Co.)

Fig. 20–4(B). Cut-away drawing of toolroom tempering furnace showing insulating walls and removable shelves. (Lindberg Engineering Co.)



Tools made of high-speed steel are tempered by reheating to much higher temperatures than those specified for ordinary tool steel. These temperatures vary from 1000° to 1200°F.

19. *What is the process of cyaniding steel?*
Low-carbon steels do not become hard when heated above their critical points and quenched. However, the surface of the steel may be hardened by cyaniding. This is done by immersing the piece of steel in a molten bath of sodium cyanide from 5 to 30 min, depending on the size of the piece of work and the depth of penetration desired. It is then quenched in water, brine, or oil; a very hard skin or casing, 0.010 to 0.015 in. thick, is formed. This is also called case *hardening.*

20. *Is it customary to grind a piece of work made of low-carbon steel that has been case hardened by cyaniding?*
No. The hardened case of the steel is only about 0.015 in. thick, and this amount is usually removed during the grinding operation.

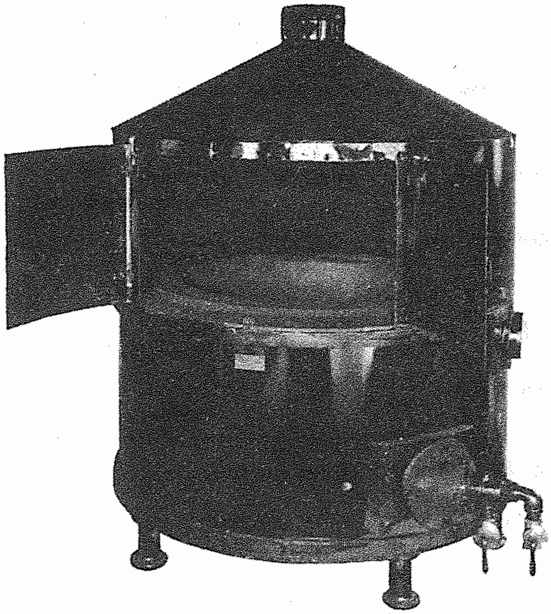


Fig. 20–5. Lead pot. (Bellevue Industrial Furnace Co.)

21. *What is the process of carburizing steel?*
Carburizing is another method of giving a hardened case to a piece of steel. The piece of work is placed in a metal box containing a mixture of bone, leather, charcoal, and other carburizing materials. The lid is sealed with fire clay and the box is placed in a furnace for some hours at a temperature of 1700°F. The depth to which the carbon penetrates the steel depends upon the length of time the work is left in the furnace. After the steel is removed from the furnace and cooled to room temperature, it can be normalized by reheating at 1560° to 1650°F. and cooling in air. It can then be hardened by inserting it into a furnace or a lead pot (Fig. 20–5), heating it to the required temperature, and quenching it in the same manner as other high-carbon steel, but only the part that absorbed the carbon will become hard. The inside, which did not absorb the carbon, will remain soft.

22. *For what type of job is a carburized piece of steel recommended?*
Carburized steel is recommended for work requiring a hard surface and a tough core. The hard surface can be made sufficiently deep so that it may be ground without removing all of the hardened surface. An example of this kind is the wrist pin of an automobile engine. It must have a hard surface to resist wear and a tough core to absorb the shock incident to its use. Many jobs made in the toolroom require this form of heat treatment.

Carburizing may also be used for special jobs requiring partial hardening, as in the nut shown in Fig. 20–6. In this case, the outside diameter must be hard and the threads are to be kept soft. The operations are as follows: Finish the outside diameter and the thickness of the nut to the required size, leaving a flange on each side 1/8 in. greater than the major diameter of the thread and extending 1/8 in. on each side. Bore the hole for the thread 1/4 in. smaller than the minor diameter of the thread. Mill the slots. Carburize the nut. After carburizing, bore the hole to within 1/16 in. of the required size and face off the flanges. Heat-treat to the required hardness. The threads may now be cut. Inasmuch as the carbon did not penetrate the part of the steel in which the threads are to be cut, the heat treatment did not harden it.

23. *What is the process of nitriding steel?*
Nitriding is a method of putting an extremely hard surface on a piece of steel. The process consists

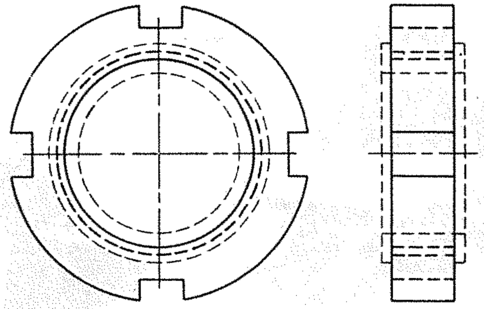


Fig. 20–6. Nut prepared for case-hardening.

of exposing the steel to hot ammonia gas for some hours. The ammonia breaks down into nitrogen and hydrogen because of the heat, and the nitrogen reacts with the steel to form a nitride case around the steel.

24. *What operations are involved in hardening steel?*
Hardening involves both heating and cooling operations. Heating is the bringing of the steel to the desired temperature above the critical range in order to get the grain structure in the steel into the proper state for hardening. Cooling is the quenching of the steel in some medium such as water, brine, caustic solution, or oil in order to preserve the structure obtained in heating. The quenching medium must have an even temperature.

25. *What is meant by the critical point when heating steel?*
The critical point, or critical temperature, is that at which some definite change takes place in the physical properties of the steel. This point is important because a piece of steel must be heated to a temperature just above its own particular critical point. The critical point varies according to the type of steel being heat-treated. For instance, tool steel and high-speed steel must be heated to 1400° but not more than 1450°F., whereas die steel is heated to between 1550° and 1600°F.

26. *How is the exact temperature of a furnace controlled?*
The heat of the furnace can be controlled or regulated by a pyrometer. Figure 20–7 shows a type of pyrometer used on an electric furnace. Not so many years ago, it was the custom for a hardener of steel to determine its temperature by watching the color of the work in the furnace. There was a big element of chance in this procedure, and the U. S. Bureau of Standards has demonstrated conclusively that at temperatures around 2000°F. the old-timers who depended on their eyes were off as much as 200° in judging furnace temperature. Nowadays, scientific instruments such as the pyrometer are in common use for the accurate control and monitoring of furnace temperatures.

Fig. 20–7. Pyrometer. (Minneapolis-Honeywell Regulator Co.)

27. *What are some of the types of furnaces used in heat-treating metals?*
Gas, oil, and electric furnaces are most commonly used. The heat can be easily controlled in these furnaces, which is an important factor. Some steels are heated in open furnaces, others are heated in pot furnaces. If the pot contains molten lead, it is called a *lead pot,* if it contains molten cyanide, it is called a *cyanide pot.* The pot furnace can also be used for tinning, for melting low-fusion metals, and for other heating purposes. Tools such as dies, punches, springs, and other small steel parts may be hardened uniformly in this type of furnace without danger of oxidizing the steel. The lead pot is especially adapted for jobs where only a portion of the tool is to be hardened. Only the portion of the tool to be hardened is immersed in the lead. The pot furnace is rapid, convenient, and satisfactory.

An automatic heat-treating furnace (Fig. 20–8) is heated by radiant-heating tubes, which are designed

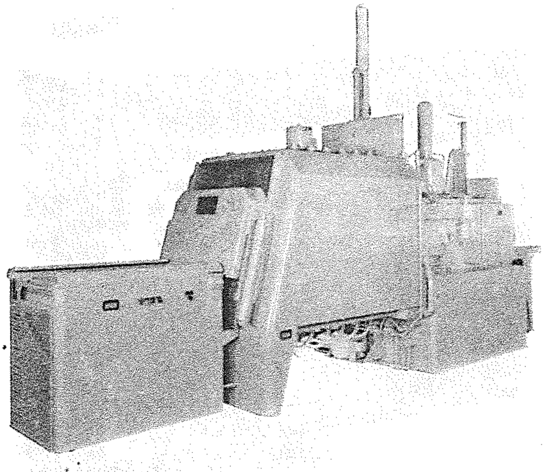


Fig. 20–8. Automatic heat-treating furnace. (Ipsen Industries, Inc.)

Fig. 20–9. Furnace for tempering and controlled oxide coating of steel, with control panel. (Ipsen Industries, Inc.)

for either gas-fired or electric heating elements. The unit operates at temperatures up to 2000°F. and has completely automatic straight-through operation, from heating of the parts through cooling or oil quench. The unit is sealed to provide absolute atmosphere control during the entire heat-and-quench cycle, assuring bright, scale-free work on all types of heat-treating processes such as hardening, carburizing, nitriding, and normalizing. The work is loaded directly into the heating zone, and after the proper time at heat, the work tray is automatically transferred onto a quenching rack, which holds the load for atmospheric cooling, or lowers it for oil quench, whichever has been preselected on the cycle-control panel. As soon as the tray is on the rack, a new load can be put into the heating zone.

A furnace for the bright-tempering of steel is shown in Fig. 20–9. During the entire cycle of operation, this unit is supplied with a protective atmosphere. After sufficient time at the required temperature, the load is cooled in the furnace until it reaches approximately 400°F. The bright, scale-free work is then cool enough to be removed from the furnace without danger of oxidation.

This type of furnace also produces a controlled oxide coating, which is often desired to reduce corrosion or wear, and to produce an attractive blue-gray or blue-black appearance.

28. *Why is charcoal kept on top of the lead in a lead pot?*

Charcoal is kept on top of the molten lead in a lead pot to burn up the oxygen in the air, to prevent oxidation, and to keep the job clean. This prevents surface or skin softness and helps eliminate scale on the steel.

29. *Is it possible to harden one part of a piece of work without hardening it all over?*

Yes. One way is to cover a part of the work with fire clay, which insulates the material covered from the full heat of the furnace. Another method, when the shape of the work permits, is to heat the work in a pot of lead or cyanide, immersing only the part of the work that is to be hardened. A third way is to heat the part to be hardened with the flame of an oxy-acetylene torch. The flame can be directed to the desired part without heating the remainder of the work sufficiently to affect it.

The process of hardening steel in this manner is known as *flame-hardening*. It has been developed extensively in the last few years, to the point where special machines have been designed for the purpose. Figure 20–10 shows a machine designed for the express purpose of flame-hardening gears. Multiple nozzles grouped in a flame head on each side of the machine direct heat onto the gear (Fig. 20–11). The temperatures for heating and quenching are maintained and controlled with an accuracy of ±5°F. by means of electronic equipment. Another example of a flame-hardening machine is shown in Fig. 20–12. This machine is used to harden the ways of a lathe. A separate flame head with multiple

Fig. 20–10. Special Flamatic machine, flame hardening a loom camshaft gear, 17⅜" diameter × 2" face. Teeth are hardened to below the pitch diameter. Material is high-test alloy gray iron. (Cincinnati Milacron Co.)

Fig. 20–12. Special flame-hardening machine holds cast-iron lathe bedways within limits of 0.004 in. per ft. Flame heads, with water-spray quench, remain stationary while work travels. (Cincinnati Milacron Co.)

Fig. 20–11. Multiple nozzles pour streams of heat onto the gear. (Cincinnati Milacron Co.)

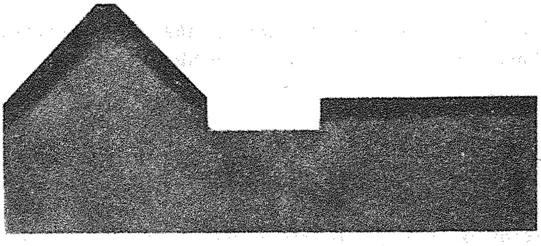


Fig. 20–13. Cross section of the ways of a lathe after flame hardening. Note the difference in grain structure of the hardened area. (Cincinnati Milacron Co.)

nozzles is used for each side of the lathe bed. Figure 20–13 shows a cross section of the ways of a lathe that have been heat-treated by the flame-hardening process.

30. *What are some of the advantages of flame-heating?*

A. Because it heats quickly, flame-heating is convenient when hardness is required only for a limited depth of the material, the remainder retaining its original toughness and ductility.

B. Flame-heating makes it possible and practical to harden a part or all of a piece of work that is too large or too inconvenient to place in a furnace.

C. The amount of time required for heating is less with flame-heating than with a furnace, and there is no need to wait until a furnace is available.

A close-up view of the lathe bedways hardening machine (Fig. 20–14) shows the twin flame heads, which remain stationary over the bed. The lathe

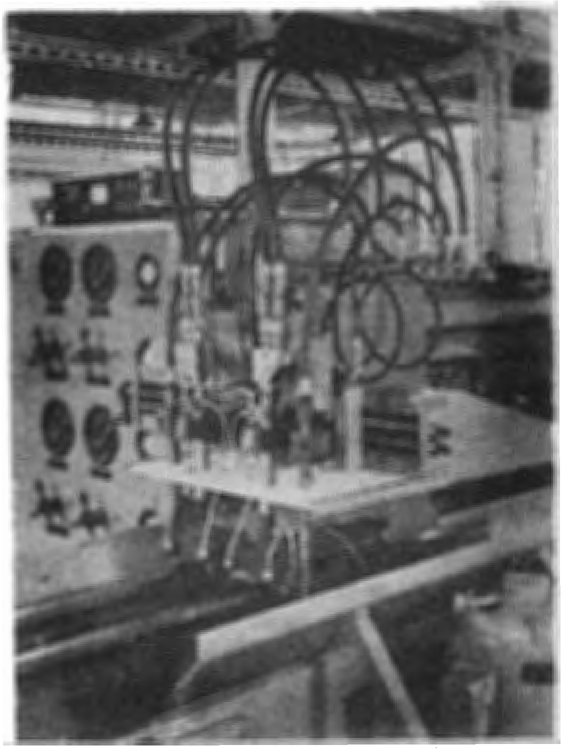


Fig. 20–14. A close-up view of the lathe bedways hardening machine. (Cincinnati Milacron Co.)

bed is guided by the track and moves along under the flame heads and the water heads, which are an integral part of the flame head. The water heads spray quench the heated bedways, thus hardening them as fast as they are heated. The depth of the hardened surface is controlled by the speed of the table, which carries the lathe bed past the flame heads.

31. *How are different types of steel designated?* Standards for the identification of carbon and alloy steels have been set up by two recognized authorities, the SAE (Society of Automotive Engineers) and the AISI (American Iron and Steel Institute). These systems are similar. The SAE uses numbers to identify the types of steel and their composition. Each number consists of four or sometimes five digits. The first digit at the left indicates the general group. The second digit indicates the approximate percentage of the principal alloying element (other than carbon), and the last two or three digits give the approximate amount of carbon, in points. A point equals 0.01 percent. The general groups represented by the first digit are:

1. Carbon steel.
2. Nickel steel.
3. Nickel chromium steel.
4. Molybdenum steel.
5. Chromium steel.
6. Chromium vanadium steel.
7. Tungsten steel.
8. Silicon steel.

Some examples of this numbering system are: Type SAE 1020 steel is a carbon steel containing 0.20 percent carbon. Type SAE 2317 steel is a nickel-steel alloy containing 3 percent nickel and 0.17 percent carbon. Type SAE 5130 steel is a chromium-steel alloy containing 1 percent chromium and 0.30 percent carbon.

32. *Do all manufacturers use the SAE system of identifying different grades of steel?*
No. Some companies have developed systems of their own, using numbers or letters.

33. *How are steels designated by the AISI system?*
The AISI uses a letter preceding the number. The letter indicates the process by which the steel is made. The number is read the same as the number in the SAE system. Steels made by different processes may have slight but important differences in their properties. The AISI letter prefixes and their meanings are as follows:

A. Open hearth alloy steels.
B. Acid Bessemer carbon steel.
C. Basic open hearth carbon steel.
D. Acid open hearth carbon steel.
E. Electric furnace steel.

For example, AISI C1095 designates that it is a basic open hearth carbon steel having approximately 0.95 percent carbon.

34. *What is the steel color code?*
The ends of steel bars are sometimes painted in various colors and color combinations as a means of identifying different grades of steel. Bars of straight carbon steel are painted with a solid color to identify the carbon content. For instance, SAE 1010 is painted yellow; SAE 1020, dark blue; and SAE 1040, dark red.

Bars of alloy steels are painted a solid color but also have a colored stripe. The solid color identifies the alloy and the stripe identifies the carbon content. For example, SAE 2320 is painted solid red to denote that it is a nickel steel, with a blue stripe to identify its 0.20 percent carbon content; SAE 2340 is painted red with a white stripe. Chrome nickel steels are printed white. Molybdenum steels are painted green. Chromium vanadium steels are painted dark blue.

35. *What is the spark-test method for identifying different kinds of steel?*
Steels that are not marked may be identified within certain limits by the type of sparks given off when they are held against a revolving grinding wheel. This is known as the *spark-test* method. When testing a piece of steel in this manner, use only enough pressure to maintain a steady contact between the work and the grinding wheel. A satisfactory speed for the grinding wheel is about 8,000 surface feet per minute. The type of sparks from a piece of hardened steel is practically the same as from a piece of the same grade of unhardened steel. The sparks are seen most easily in diffused daylight.

In general, the presence of various elements in steel have the following effects upon the sparks: Carbon causes the sparks to burst. Manganese tends to brighten the spark and increase the spray around the periphery of the grinding wheel. Chromium darkens the color of the sparks, suppresses the stream and bursts, and causes fine carrier lines. Nickel suppresses the stream slightly and causes forked tongues. Tungsten suppresses the stream and bursts, and causes fine red carrier lines. Molybdenum causes a detached spearhead at the end of the ray. Figure 20–15 illustrates the meaning of the terms used in spark testing.

The chart of Fig. 20–16 shows sketches of sparks from some of the most commonly used steels. Of necessity very general, they may be used to point out certain characteristics. For example, the difference in the carbon content of steel is indicated by the difference in the number of sparks, as shown in the first three sketches. If a piece of machine steel and a piece of high-speed steel were sparked, the difference between them could be easily discerned. However, proficiency in identifying all steels can be gained only by practice and experience. The spark test does not analyze a piece of steel, but simply guides in identifying it.

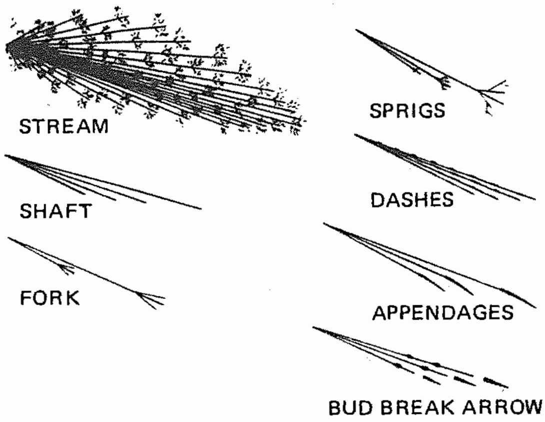


Fig. 20–15. Meaning of terms used in spark testing. (Linde Div., Union Carbide)

36. *Why are steels tested for hardness?*
Steels are tested to obtain proof of their suitability for specific jobs. Many characteristics must be tested—for example, tension, stress, compression, bending, shear, impact, and hardness.

A hardness test can indicate the suitability of the metal for a specific job and its resistance to wear and abrasion. It will also disclose the effect of heat treatment to which the metal has been subjected.

The hardness of steel may be determined by a file test and also by the more reliable scientific tests by means of the Brinell, the Rockwell, or the Shore scleroscope hardness-testing machines.

37. *What is a file test?*
A file test is a method of determining the hardness of a piece of material by trying to cut into it with the corner of a file. The hardness is indicated by the bite that the file will take. This is the oldest and one of the simplest methods of checking hardness. Although this test will not give very definite results—a new file will cut better than an old file—it will give results ranging from quite soft to glass hardness. The principal objection to the use of the file test is that no accurate record of results can be maintained.

38. *What is the Brinell system for testing the hardness of steel?*
In the Brinell test, the hardness of the material tested is indicated by a number, which is determined by the resistance the material offers to the penetration of a steel ball under pressure. The standard ball

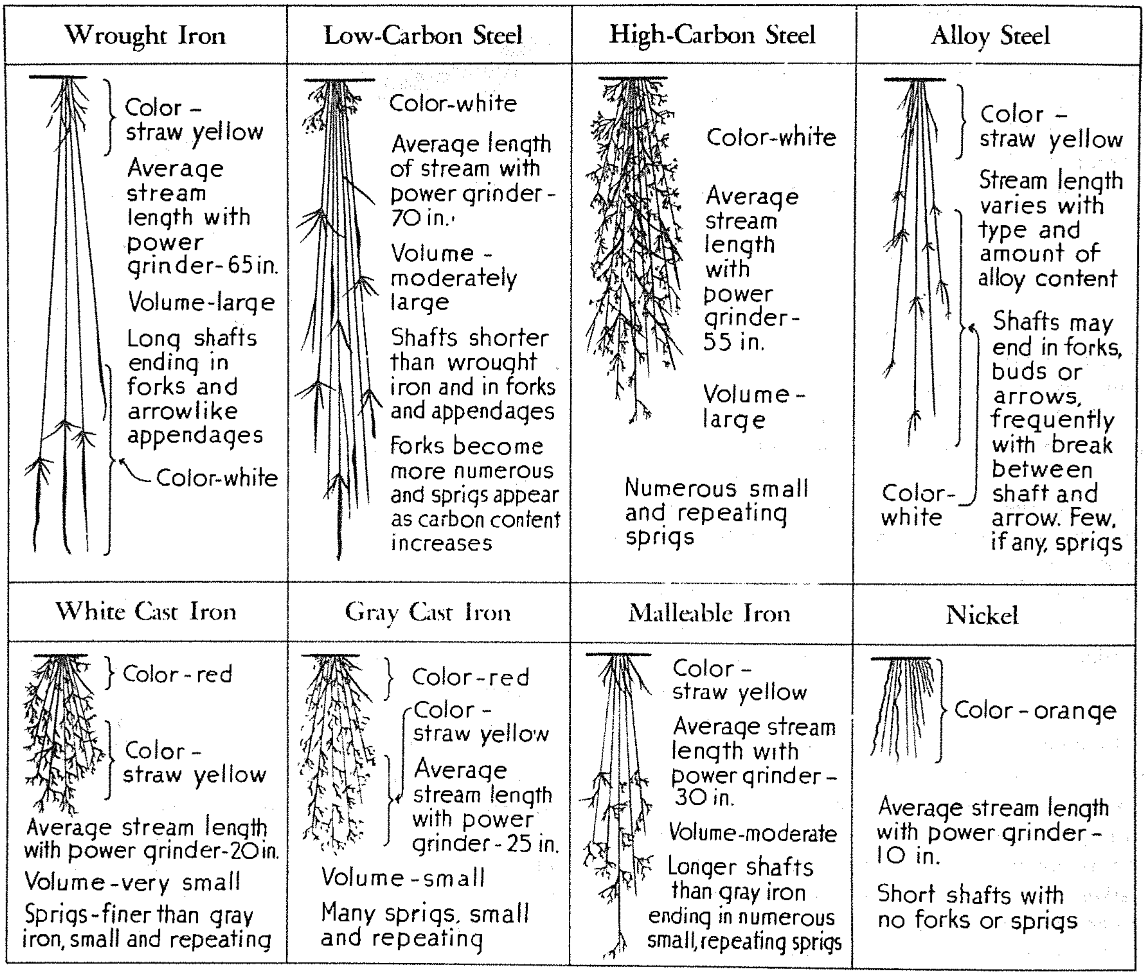


Fig. 20–16. Identification of sparks from the various types of metals. (Linde Div., Union Carbide)

diameter is 10 ± 0.01 mm. To test the hardness of the material, a known load is applied to the surface of the specimen through the hardened steel or tungsten carbide ball of known diameter for a given length of time. The diameter of the indentation permanently impressed on the specimen is measured and converted to a Brinell hardness number by the use of standard tables.

There are three types of Brinell hardness-testing machines in general use: the hydraulic, the dead-weight lever loading, and the air operated (Fig. 20–17).

To ensure exact measurement of the indentation diameter, a microscope designed for this purpose is generally used. The thickness of the material being tested should not be less than ten times the depth of the impression. The Brinell tester is most useful in testing large parts of low or medium hardness.

39. *What is the Rockwell system for testing the hardness of a metal?*

In the Rockwell hardness test, a 120° diamond cone for hard metals, or a 1/16-in. steel ball for the softer materials, is impressed into the surface to be tested by a dead weight acting through a series of levers. The depth of penetration is then measured. The softer the piece of metal, the deeper will be the impression under a given load. The average depth of penetration on the softest steel is only about

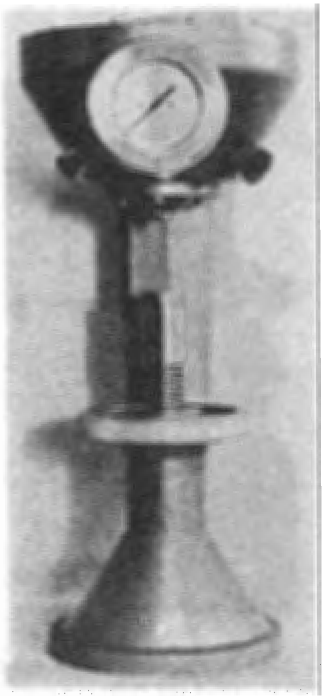


Fig. 20–17. Air-O-Brinell Metal Hardness Tester. A hardness tester using the Brinell principle, completely operated by air. (Tinius Olsen Testing Machine Co.)

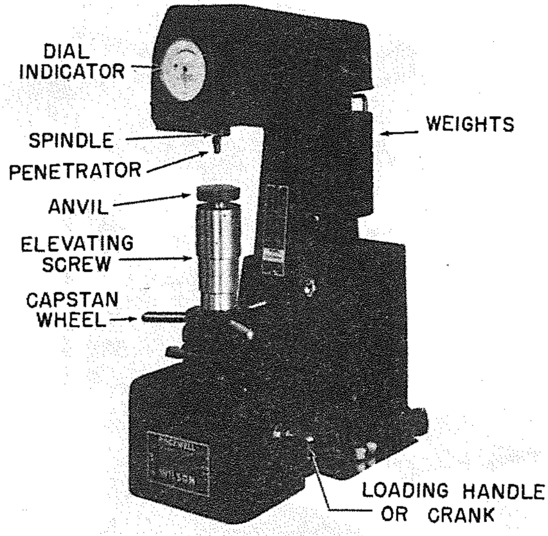


Fig. 20–18. The Rockwell Hardness Tester. (Wilson Mechanical Instrument Division, American Chain and Cable Co., Inc.)

0.008 in. The hardness is indicated on a dial gage graduated in the Rockwell B and C hardness scales. The harder the piece of steel, the higher the Rockwell number will be. For example, to be machinable, steel should not show a reading of more than 35 on the Rockwell C scale, whereas a cutter made of hardened high-speed steel would show a reading of from 63 to 65. When testing hard steels, the diamond point should be used and the hardness number read on the C scale. For nonferrous metals, the steel ball should be used and the hardness number read on the B scale. Figure 20–18 shows the Rockwell tester, and Figs. 20–19 to 20–22 the directions for using it. Some special equipment for use with this machine is shown in Fig. 20–23.

40. *Is the Rockwell Hardness Tester suitable for testing the hardness of all kinds of workpieces?*
There are several models of Rockwell hardness testers, each being suited for specified work. Figure 20–18 shows the standard Rockwell Hardness Tester,

Fig. 20–19. Step 1: Place the part to be tested on the anvil of the tester. (Wilson Mechanical Instrument Division, American Chain and Cable Co., Inc.)

Fig. 20–20. Step 2: By turning the handle gently, raise the workpiece until it makes contact with the penetrating point. Continue turning until the small pointer on the dial is nearly vertical, slightly to the right of the dot. Raise the workpiece until the long pointer is approximately upright. The minor load, 100 kg, has been applied; set the dial to zero. (Wilson Mechanical Instrument Division, American Chain and Cable Co., Inc.)

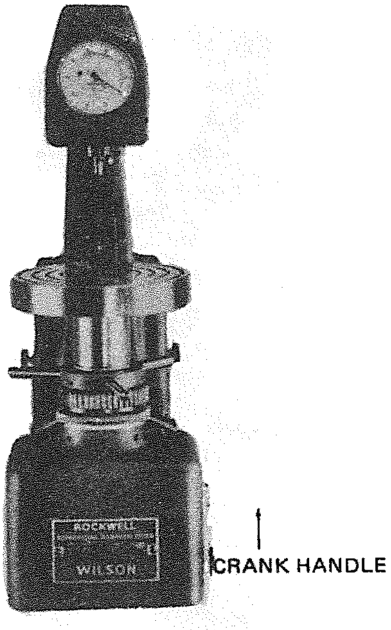


Fig. 20–21. Step 3: Trip the major load by pulling the crank handle forward, lifting the major load but leaving the minor load still applied. (Wilson Mechanical Instrument Division, American Chain and Cable Co., Inc.)

developed in 1921 to measure the hardness of metals and alloys, hard or soft, and of all shapes.

Figure 20–21 shows the Superficial Hardness Tester, introduced in 1930 to test thin sheet steel and small nitrided or carburized parts. It utilizes lighter loads and a more sensitive depth measuring system for shallow indentations.

Figure 20–24 shows the Tukon Microhardness Tester introduced in 1941 to test carbide tips of cutting tools, watch springs, and instrument pivots. Rapid measurement of the indentation is made possible by direct reading in micrometers from the microscope.

Figure 20–22 shows the Zerominder device dial for rapid testing, which enables the operator to save time by using a short-cut method in obtaining the final dial reading. This method is not used where accuracy is important.

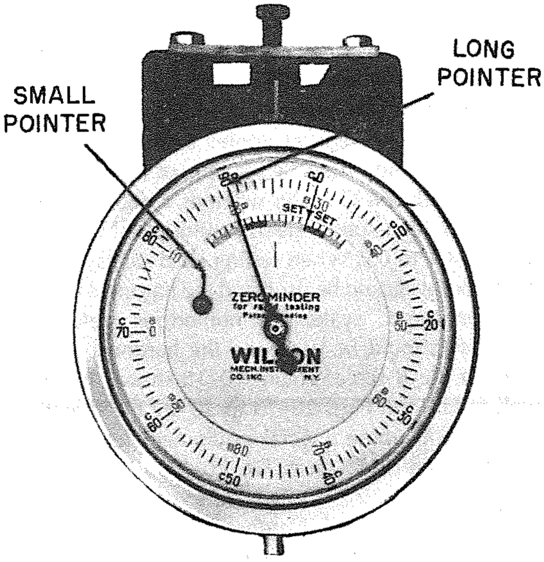


Fig. 20–22. Step 4: Read the hardness number on the dial. (Wilson Mechanical Instrument Division, American Chain and Cable Co., Inc.)

Fig. 20–23. Equipment for Rockwell Hardness Tester. (Wilson Mechanical Instrument Division, American Chain and Cable Co., Inc.)

A. Cylindron Jr., consisting of hardened parallel twin cylinders for supporting round work ¼″ diameter to 3″ diameter.
B. Plane anvil, a flat surface for testing flat-bottom pieces of heavy section.
C. Shallow V anvil to test round pieces ¼″ diameter and smaller.
D. Spot anvil for small pieces, thin pieces, or pieces having bottoms not truly flat.
E. Eyeball anvil for testing shear blades, chisels, knives, and screwdriver blades.
F. Diamond spot anvil for testing and supporting thin, soft sheet metal.
G. Cylindron anvil for cylindrical pieces from 2″ to 8″ diameter.
H. Test block for checking the accuracy of tester.
I. Testing table, a work support for large pieces. It is 8″ diameter and fits on the elevating screw.

Fig. 20–24. The Rockwell Tukon Hardness Tester, for microhardness testing. (Wilson Mechanical Instrument Division, American Chain and Cable Co., Inc.)

41. *What is the Shore scleroscope system for testing the hardness of a metal?*
In the Shore scleroscope hardness test, the piece of work to be tested is placed on the clamping stand of the unit and the large handwheel on the left side of the clamp is revolved to bring the instrument barrel firmly in contact with the test specimen. As pressure is being maintained on the handwheel, the diamond hammer, which is located in the upper end of the glass tube, is released from its elevated position by squeezing the rubber bulb. The height to which the hammer rebounds on its first bounce indicates the hardness of the specimen. The hammer is then raised preparatory to the next test by again squeezing and releasing the bulb. The operator should focus his eyes several points below the general area of the first rebound and take two or three more tests. The top of the hammer, not its bottom, should be observed. The average of several tests is the correct hardness of the specimen. Tests should not be made more than once in the same spot, as the impact of the diamond hammer cold-works that spot, causing subsequent tests on that spot to be high. A direct-reading scleroscope is shown in Fig. 20–25.

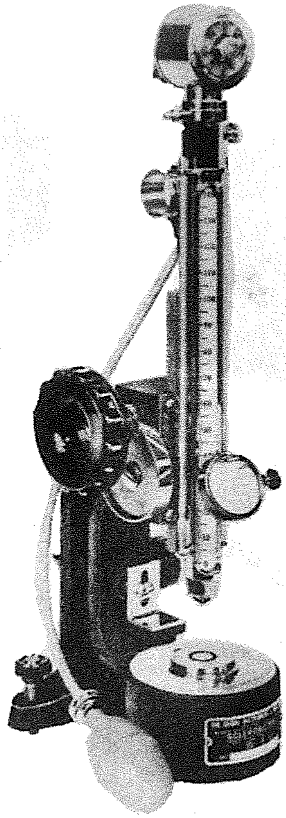


Fig. 20–25. Shore Vertical Scale Scleroscope Hardness Tester on clamping stand. (Shore Instrument & Manufacturing Co.)

In testing various small parts up to 3 in. high, the instrument is mounted, as shown, on the clamping stand. It may also be mounted on a swing arm and post, illustrated in Fig. 20–26, for testing large, unwieldy parts. Very heavy objects and structures that cannot be conveniently moved may be tested by holding the scleroscope freehand.

A dial-recording scleroscope is shown in Fig. 20–27. This instrument operates on the same general

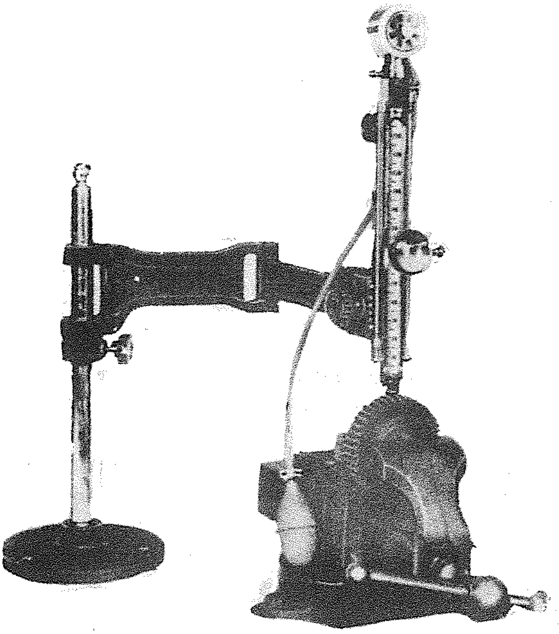
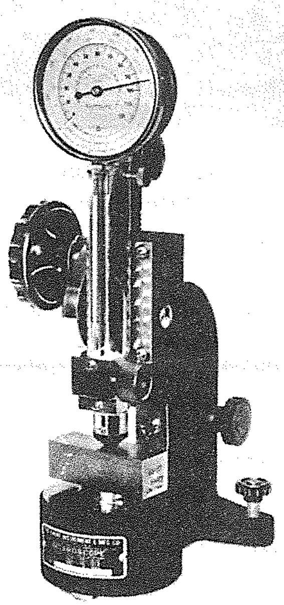


Fig. 20–26. Shore Vertical Scale Scleroscope on swing arm and post. (Shore Instrument & Manufacturing Co.)

Fig. 20–27. Shore Dial-recording Scleroscope on clamping stand. (Shore Instrument and Manufacturing Co.)



principle as the other kind, but by an ingenious arrangement of a ball-and-hollow-cone clutch, the degree of hardness is recorded on a dial. The dial hand remains fixed until the knob is turned for another test. It may be used freehand, or in a swing arm and post in the same manner as the regular scleroscope.

A comparison of Brinell, Rockwell, and Shore hardness numbers is given in Fig. 20–28.

Fig. 20–28. Hardness conversion chart. (Values are approximate.)

Brinell		*Rockwell*		*Shore*
diameter of indentation (mm) 3,000 kg, 10-mm ball	*hardness no.*	*C scale 150 kg, 120° cone*	*B scale 100 kg, $\frac{1}{16}$-in. ball*	
		very hard		
2.20	780	68		96
2.25	745	67		94
2.30	712	65		92
2.35	682	63		89
2.40	653	62		86
2.45	627	60		84
		hard		
2.50	601	58		81
2 55	578	56		78
2.60	555	55		76
2.65	534	53		73
2.70	514	51		71
2.75	495	50		68
2.80	477	48		66
2.85	461	47		64
2.90	444	46		62
2.95	429	44		60
3.00	415	43		58
3.05	401	42		56
		medium hard		
3.10	388	41		54
3.15	375	39		52
3.20	363	38		51
3.25	352	37		49
3.30	341	36		48
3.35	331	35		46
3.40	321	35		46
3.40	321	34		45

Fig. 20–28. *(cont.)*

Brinell		*Rockwell*		*Shore*
		tough but can be machined		
3.45	**311**	**32**		**43**
3.50	**302**	**31**		**42**
3.55	**293**	**30**		**41**
3.60	**285**	**29**		**40**
3.65	**277**	**28**		**38**
3.70	**269**	**27**		**37**
3.75	**262**	**26**		**36**
3.80	**255**	**25**		**35**
3.85	**248**	**24**	**100**	**34**
3.90	**241**	**23**	**99**	**33**
		soft		
4.00	**229**	**21**	**98**	**32**
4.10	**217**	**18**	**96**	**30**
4.20	**207**	**16**	**95**	**29**
4.30	**197**	**14**	**93**	**28**
4.40	**187**	**12**	**91**	**27**
4.50	**179**	**10**	**89**	**25**
4.60	**170**	**8**	**87**	**24**
4.70	**163**	**6**	**85**	**23**
4.80	**156**	**4**	**83**	**23**
4.90	**149**	**2**	**81**	**22**

42. *How may fractures be prevented when heat-treating an article with sharp edges or one with adjacent thick and thin sections?*
Fractures may be prevented in cases of this kind by applying fire clay to the thin parts, to permit uniform heating.

43. *How long should a piece of steel be left in a furnace when heating?*
Steel should be heated long enough to ensure a good, even heat throughout. The practical rule is to keep, or "soak," the part in the furnace one hour for each square inch of cross-sectional area.

44. *How may warping be avoided when quenching a long, slender piece of work?*
Warping may be avoided by holding the part vertically over the quenching bath and plunging it straight down.

45. *Can a hardened piece of work that has become warped in the process of heat-treating be salvaged?*
Yes. A warped piece of work may be straightened under pressure in a straightening press after heating it with an oxy-acetylene torch. The work is held between centers and moved back and forth as required to bring the distorted section under the pressure unit. The work is checked for accuracy after each adjustment, with a dial-indicator test gage.

46. *During the heat-treating process, scale often forms on the surface of the metal, and dirt may be baked on it. This should be removed before the work is sent to the inspector or to the grinding department. What are some of the ways of cleaning heat-treated parts?*
A stiff wire brush and a scraper are helpful when parts have to be cleaned once in a while, but a more efficient job may be done by sandblasting Figure 20–29 shows aircraft components being sandblasted prior to further machining and installation. The sandblasting is carried out in a special room designed for this purpose. The operator is safely protected by high gauntlet—an air-supplied hood.

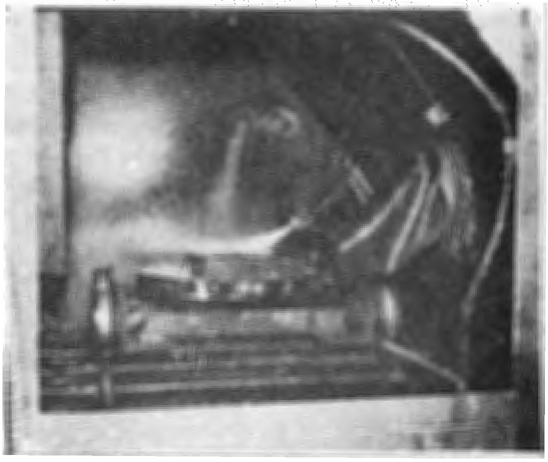
Fig. 20–29. An operator in an air-blast room blasting aircraft components. (The Wheelabrator Corp.)

Another type of metal cleaner is the wet blast (Fig. 20–30). This machine uses a liquid abrasive, which is directed toward the surface to be cleaned by the operator. Figure 20–31 shows the interior of a wet blast, with the operator aiming the blasting gun toward the work.

Metal cleaning is also done by a machine that does not use air or liquid. A machine of this type is the table-style Wheelabrator, shown in Fig. 20–32. Abrasives, in the form of shot or grit of various

Fig. 20-30. Wet blast machine. (The Wheelabrator Corp.)

Fig. 20-31. Interior of a wet blast machine. (The Wheelabrator Corporation).



grades, are hurled upon the work. The driving unit is shown in Fig. 20–33. It can throw 300 lb of abrasive per minute. This type of cleaning is considered the most efficient in shops where a large amount of work is cleaned daily.

The driving unit may also be used in a tumbling machine (Fig. 20–34), which is preferred for the speedy cleaning of castings and similar parts that can withstand being tumbled around. A phantom

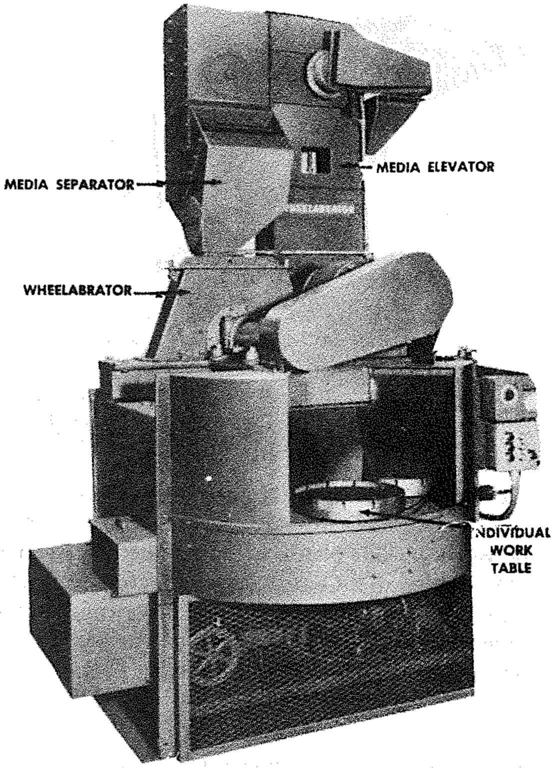


Fig. 20–32. Table-style Wheelabrator blast-cleaning machine and its component parts. (The Wheelabrator Corp.)

view of the Tumblast showing how the abrasive is driven against the parts to be cleaned, and the manner of elevating the abrasive to be used again, is shown in Fig. 20–35.

Metal parts are also cleaned by wire-wheel brushes mounted on a general-purpose grinding machine (Fig. 20–36) or held in an electric drill. Brushes of this kind are shown in Fig. 20–37.

47. *What are some of the safety rules that should be observed in the heat-treating department?*

A. Goggles must be worn when working on a lead, cyanide, or nitrate pot.
B. Cyanide is a deadly poison. Do not leave any of it around. Keep it under lock and key. Do not breathe fumes. Area should be ventilated with an exhaust hood.
C. Do not put anything damp or wet into a heating pot, or an explosion will occur.

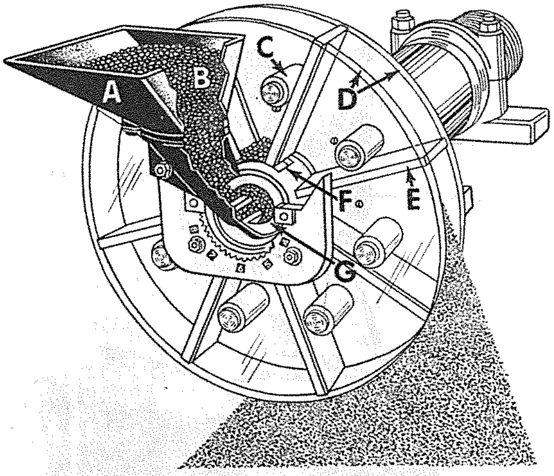


Fig. 20–33. Driving unit of Wheelabrator: (A) Abrasive funnel. (B) Abrasive shot. (C) Spacers between the side plates. (D) Side plates. (E) Removable blades. (F) Control cage. (G) Impeller. The impeller carries the abrasive to the opening in the control cage where it discharges to the bladed section of the wheel. (The Wheelabrator Corp.)

Fig. 20–34. Tumbling style of metal cleaner removing sand from gray iron casting. (The Wheelabrator Corp.)

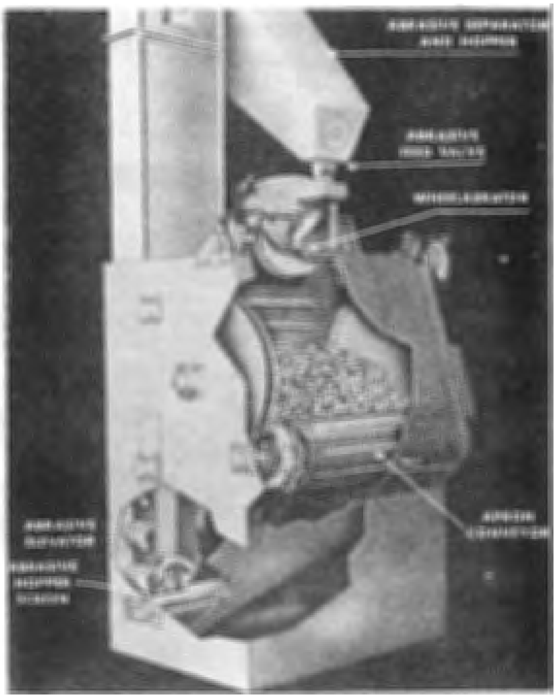


Fig. 20–35. A cut-away view of the Tumblast showing the manner of operation. (The Wheelabrator Corp.

D. Do not leave hot tongs where other persons may accidentally be burned by them.
E. Do not pick up a piece of work with the bare hands unless you are sure that it is not hot.
F. Rubber gloves must be worn while sand-blasting or wet-blasting.

Examples of typical heat treatment for various types of steel are listed below:

Commercial Annealing

1. Heat to 1500° to 1550°F.
2. Cool in mica.
3. To eliminate scale, pack in charcoal.

Commercial Normalizing

1. Heat to 1425°F.
2. Cool in air.

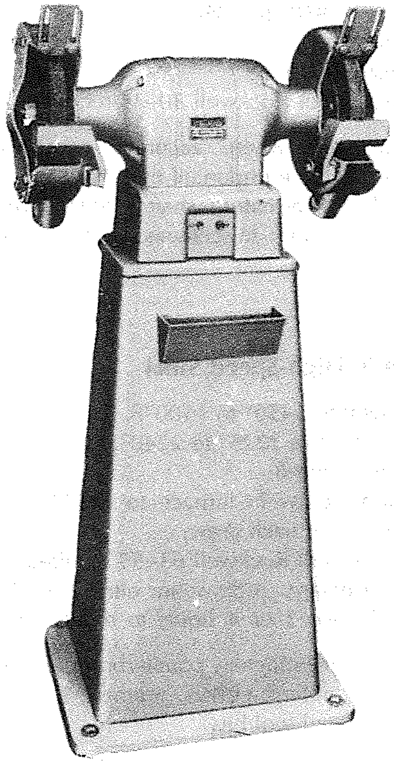


Fig. 20–36. General-purpose grinding machine. (Black & Decker Manufacturing Co.)

Fig. 20–37. Wire brushes for use on grinding machine or electric drill. (Black & Decker Manufacturing Co.)

Cyaniding of Low-Carbon Steel

1. Heat in cyanide 1500° to 1560°F. Soak 10 min.
2. Quench in brine; quench small parts in oil.
3. Test for hardness with a file.

Use for a hard surface not subject to continuous wear.

Do not grind.

Suitable for clamps, locating gages, pressure and stripper pads, stock guides, bolts, nuts, and washers.

Carburizing of Low-Carbon Steel

1. Carburize at 1700°F.
2. Cool in carburizing box.
3. Reheat to 1650°F.
4. Cool in air.
5. Reheat to 1425°F.
6. Quench in brine.
7. Strain-draw in oil at 350° to 375°F.
8. Hardness of Rockwell 62–64 required.

Because of soft core, this method should be used for parts difficult to straighten. This heat treatment may also be used for selective hardening where it is necessary to machine after hardening, in which case:

A. Leave stock.
B. Carburize.
C. Remove surplus stock.
D. Harden.
E. Machine.

SAE 1075 Spring Steel

1. Heat to 1450°F.
2. Quench in oil.
3. Draw temper at 750°F.
4. Hardness of Rockwell 41–44 required.

Use for all types of steel springs.

SAE 1095 Tool Steel

1. Heat to 1400° to 1450°F.

2. Quench in brine.
3. Strain-draw in oil at 350° to 375°F.
4. Draw temper if specified.
5. Hardness of Rockwell 52–64 required.

Suitable for arbors, ball races, bushings, cams, chuck jaws, gages, locators, V blocks, and so forth.

Use when the maximum hardness is desired.

For small parts, quench in oil if the required degree of hardness can be obtained.

SAE 3150 Die Steel

1. Heat to 1620°F.
2. Cool in air (fan blast).
3. Draw to 1050° to 1075°F.
4. Hardness of Rockwell 42–46 required.

Suitable for hammer-die inserts, hot-heading dies.

SAE 5132 Steel

1. Rough machine.
2. Heat to 1560°F.
3. Quench in brine or caustic solution.
4. Draw to 950° to 1050°F.
5. Cool in air.
6. Finish machine.
7. Hardness of Rockwell 30–34 required.

To be used where accuracy combined with toughness is more important than hardness.

Suitable for armature shafts, large boring bars, large gears, and miscellaneous heavy machine parts.

SAE 6470 High-Speed Steel

1. Preheat to 1450° to 1500°F.
2. Superheat to 2225° to 2240°F.
3. Quench in oil.
4. Double draw in furnace to 1050°F., allowing 3 hours for each draw.
5. Hardness of Rockwell 63–65 required.
6. If necessary, redraw in nitrate at 700° to 800°F. for 3 or 4 hours to reduce brittleness.

Suitable for broaches, counterbores, cut-off tools, form tools, milling cutters, reamers, special drills, spot-facers, and tool bits.

appendix

Useful Data and Tables

Table 1. Abbreviations and Symbols Commonly Used in Industry

Addendum	ADD.
Adjust	ADJ
Altitude	ALT
And	&
Approximate	APPROX
Brown & Sharpe	B&S
Cast iron	CI
Center to center	C to C
Center line	CL or ℄
Centigrade	C
Circular pitch	CP
Circumference	CIRCUM
Cold-rolled steel	CRS
Cotangent	COT
Counterbore	CBORE
Countersink	CSK
Cylinder	CYL
Dedendum	DED
Degree	DEG or °
Detail	DET
Diameter	DIA
Dimension	DIM.
Drill rod	DR
Fahrenheit	F
Fillister head	FIL HD
Finish	FIN. or *f*
Flat head	FH
Foot	FT or ′
Gage	GA
Grind	G or GRD
Hexagon	HEX
Hypotenuse	HYP
Inch	IN. or ″
Inside diameter	ID
Left hand	LH
Linear pitch	LP
Machine	MACH
Machine steel	MS
Maximum	MAX
Millimeter	MM
Minimum	MIN
National Coarse*	NC
National Fine*	NF
National Special*	NS
Number	NO. or #
Outside diameter	OD
Pattern	PATT
Pitch	P or *p*
Pitch diameter	PD
Pound	LB
Radius	R
Right hand	RH
Round head	RD HD
Screw	SCR
Society of Automotive Engineers	SAE
Socket head	SOC HD
Spot-faced	SF
Square	SQ
Standard	STD
Stock	STK
Tangent	TAN
Thread	THD
Unified National Coarse*	UNC
Unified National Fine*	UNF
Unified National Special*	UNS
Weight	WT

*On Nov. 18, 1948, the United Kingdom, Canada, and the United States agreed on certain National standards and renamed them Unified National Coarse, Unified National Fine, and Unified National Special accordingly. Those National standards not agreed on are still known as National Coarse, National Fine, and National Special. Sometimes those National standards that were agreed on are still referred to in the trade literature by their old designation of National Coarse, National Fine, or National Special.

Table 2. Decimal Equivalents of Fractions of an Inch

fractions	*64ths*	*32ds*	*16ths*	*8ths*	*4ths*	*decimal equivalents*	*fractions*	*64ths*	*32ds*	*16ths*	*8ths*	*4ths*	*decimal equivalents*
1/64	1	.....	.....	.....	.....	0.015625	33/64	33	.....	.....	.....	.....	0.515625
1/32	2	1	.....	.....	.....	0.03125	17/32	34	17	.....	.....	.....	0.53125
3/64	3	.....	.....	.....	.....	0.046875	35/64	35	.....	.....	.....	.....	0.546875
1/16	4	2	1	.....	.....	0.0625	9/16	36	18	9	.....	.....	0.5625
5/64	5	.....	.....	.....	.....	0.078125	37/64	37	.....	.....	.....	.....	0.578125
3/32	6	3	.....	.....	.....	0.09375	19/32	38	19	.....	.....	.....	0.59375
7/64	7	.....	.....	.....	.....	0.109375	39/64	39	.....	.....	.....	.....	0.609375
1/8	8	4	2	1	.....	0.125	5/8	40	20	10	5	.....	0.625
9/64	9	.....	.....	.....	.....	0.140625	41/64	41	.....	.....	.....	.....	0.640625
5/32	10	5	.....	.....	.....	0.15625	21/32	42	21	.....	.....	.....	0.65625
11/64	11	.....	.....	.....	.....	0.171875	43/64	43	.....	.....	.....	.....	0.671875
3/16	12	6	3	.....	.....	0.1875	11/16	44	22	11	.....	.....	0.6875
13/64	13	.....	.....	.....	.....	0.203125	45/64	45	.....	.....	.....	.....	0.703125
7/32	14	7	.....	.....	.....	0.21875	23/32	46	23	.....	.....	.....	0.71875
15/64	15	.....	.....	.....	.....	0.234375	47/64	47	.....	.....	.....	.....	0.734375
1/4	16	8	4	2	1	0.250	3/4	48	24	12	6	3	0.750
17/64	17	.....	.....	.....	.....	0.265625	49/64	49	.....	.....	.....	.....	0.765625
9/32	18	9	.....	.....	.....	0.28125	25/32	50	25	.....	.....	.....	0.78125
19/64	19	.....	.....	.....	.....	0.296875	51/64	51	.....	.....	.....	.....	0.796875
5/16	20	10	5	.....	.....	0.3125	13/16	52	26	13	.....	.....	0.8125
21/64	21	.....	.....	.....	.....	0.328125	53/64	53	.....	.....	.....	.....	0.828125
11/32	22	11	.....	.....	.....	0.34375	27/32	54	27	.....	.....	.....	0.84375
23/64	23	.....	.....	.....	.....	0.359375	55/64	55	.....	.....	.....	.....	0.859375
3/8	24	12	6	3	.....	0.375	7/8	56	28	14	7	.....	0.875
25/64	25	.....	.....	.....	.....	0.390625	57/64	57	.....	.....	.....	.....	0.890625
13/32	26	13	.....	.....	.....	0.40625	29/32	58	29	.....	.....	.....	0.90625
27/64	27	.....	.....	.....	.....	0.421875	59/64	59	.....	.....	.....	.....	0.921875
7/16	28	14	7	.....	.....	0.4375	15/16	60	30	15	.....	.....	0.9375
29/64	29	.....	.....	.....	.....	0.453125	61/64	61	.....	.....	.....	.....	0.953125
15/32	30	15	.....	.....	.....	0.46875	31/32	62	31	.....	.....	.....	0.96875
31/64	31	.....	.....	.....	.....	0.484375	63/64	63	.....	.....	.....	.....	0.984375
1/2	32	16	8	4	2	0.500	1 inch	64	32	16	8	4	1.000

Table 3. Decimal Inch Equivalents of Millimeters

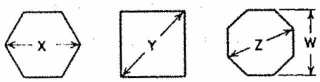
mm	inches	mm	inches	mm	inches	mm	inches	mm	inches
0.1	0.00394	3.5	0.13779	6.9	0.27165	10.3	0.40551	13.8	0.54330
0.2	0.00787	3.6	0.14173	7.0	0.27559	10.4	0.40944	13.9	0.54724
0.3	0.01181	3.7	0.14566	7.1	0.27952	10.5	0.41388	14.0	0.55118
0.4	0.01575	3.8	0.14960	7.2	0.28346	10.6	0.41732	14.1	0.55511
0.5	0.01968	3.9	0.15354	7.3	0.28740	10.7	0.42125	14.2	0.55905
0.6	0.02362	4.0	0.15748	7.4	0.29133	10.8	0.42519	14.3	0.56299
0.7	0.02756	4.1	0.16141	7.5	0.29527	10.9	0.42913	14.4	0.56692
0.8	0.03149	4.2	0.16535	7.6	0.29921	11.0	0.43307	14.5	0.57086
0.9	0.03543	4.3	0.16929	7.7	0.30314	11.1	0.43700	14.6	0.57480
1.0	0.03937	4.4	0.17322	7.8	0.30708	11.2	0.44094	14.7	0.57873
1.1	0.04330	4.5	0.17716	7.9	0.31102	11.3	0.44488	14.8	0.58267
1.2	0.04724	4.6	0.18110	8.0	0.31496	11.4	0.44881	14.9	0.58661
1.3	0.05118	4.7	0.18503	8.1	0.31889	11.5	0.45275	15.0	0.59055
1.4	0.05512	4.8	0.18897	8.2	0.32283	11.6	0.45669	15.5	0.61023
1.5	0.05905	4.9	0.19291	8.3	0.32677	11.7	0.46062	16.0	0.62992
1.6	0.06299	5.0	0.19685	8.4	0.33070	11.8	0.46456	16.5	0.64960
1.7	0.06692	5.1	0.20078	8.5	0.33464	11.9	0.46850	17.0	0.66929
1.8	0.07086	5.2	0.20472	8.6	0.33858	12.0	0.47244	17.5	0.68897
1.9	0.07480	5.3	0.20866	8.7	0.34251	12.1	0.47637	18.0	0.70866
2.0	0.07874	5.4	0.21259	8.8	0.34645	12.2	0.48031	18.5	0.72834
2.1	0.08267	5.5	0.21653	8.9	0.35039	12.3	0.48425	19.0	0.74803
2.2	0.08661	5.6	0.22047	9.0	0.35433	12.4	0.48818	19.5	0.76771
2.3	0.09055	5.7	0.22440	9.1	0.35826	12.5	0.49212	20.0	0.78740
2.4	0.09448	5.8	0.22834	9.2	0.36220	12.6	0.49606	20.5	0.80708
2.5	0.09842	5.9	0.23228	9.3	0.36614	12.7	0.49999	21.0	0.82677
2.6	0.10236	6.0	0.23622	9.4	0.37007	12.8	0.50393	21.5	0.84645
2.7	0.10629	6.1	0.24015	9.5	0.37401	12.9	0.50787	22.0	0.86614
2.8	0.11023	6.2	0.24409	9.6	0.37795	13.0	0.51181	22.5	0.88582
2.9	0.11417	6.3	0.24803	9.7	0.38188	13.1	0.51574	23.0	0.90551
3.0	0.11811	6.4	0.25196	9.8	0.38582	13.2	0.51968	23.5	0.92519
3.1	0.12204	6.5	0.25590	9.9	0.38976	13.3	0.52362	24.0	0.94488
3.2	0.12598	6.6	0.25984	10.0	0.39370	13.4	0.52755	24.5	0.96456
						13.5	0.53149	25.0	0.98425
3.3	0.12992	6.7	0.26377	10.1	0.39763	13.6	0.53543	25.5	1.00393
3.4	0.13385	6.8	0.26771	10.2	0.40157	13.7	0.53936	26.0	1.02362

Table 4. Dividing the Circumference of a Circle into Equal Parts

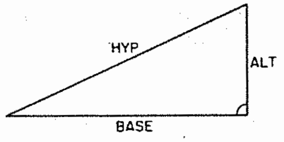
To find the length of the chord required to divide the circumference of a given circle into a certain number of equal parts, multiply the factor given in the table by the diameter of the circle.

number of spaces	*length of chord*	*number of spaces*	*length of chord*	*number of spaces*	*length of chord*
3	0.866	21	0.149	39	0.0805
4	0.7071	22	0.1423	40	0.0785
5	0.5878	23	0.1362	41	0.0765
6	0.5	24	0.1305	42	0.0747
7	0.4339	25	0.1253	43	0.073
8	0.3827	26	0.1205	44	0.0713
9	0.342	27	0.1161	45	0.0698
10	0.309	28	0.112	46	0.0682
11	0.2818	29	0.1081	47	0.0668
12	0.2584	30	0.1045	48	0.0654
13	0.2393	31	0.1012	49	0.0641
14	0.2224	32	0.098	50	0.0628
15	0.2079	33	0.0951	51	0.0616
16	0.1951	34	0.0932	52	0.0604
17	0.1837	35	0.0896	53	0.0592
18	0.1736	36	0.0872	54	0.0581
19	0.1645	37	0.0848	55	0.0571
20	0.1564	38	0.0826		

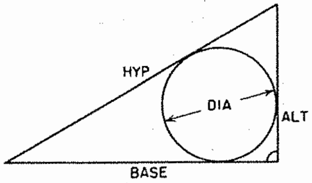
Table 5. Formulas for Length, Area, and Volume



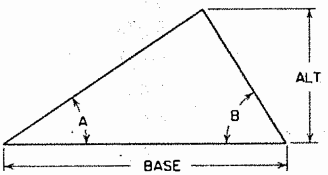
W = WIDTH
$X = 1.1547\ W$
$Y = 1.4142\ W$
$Z = 1.0824\ W$



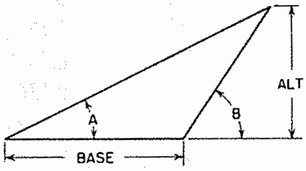
$HYP = \sqrt{BASE^2 + ALT^2}$
$BASE = \sqrt{HYP^2 - ALT^2}$
$ALT = \sqrt{HYP^2 - BASE^2}$



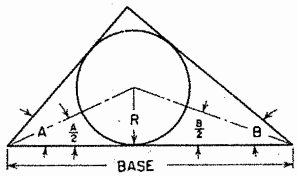
$DIA = BASE + ALT - HYP$



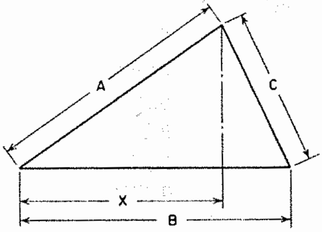
$$ALT = \frac{BASE}{\cot A + \cot B}$$

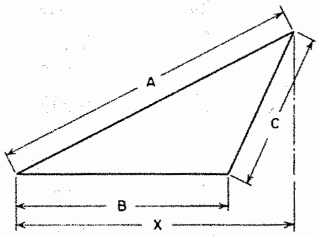


$$ALT = \frac{BASE}{\cot A - \cot B}$$

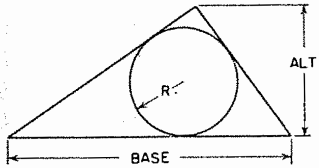


$$RAD = \frac{BASE}{\cot \frac{A}{2} + \cot \frac{B}{2}}$$



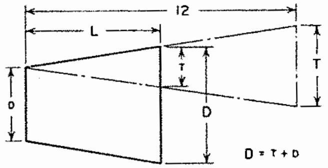


$$X = \frac{A^2 + B^2 - C^2}{2B}$$



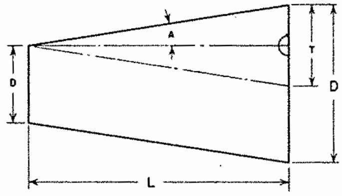
PERIMETER : BASE : : ALT : R

$$R = \frac{BASE \times ALT}{PERIMETER}$$



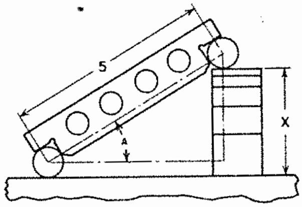
$D = T + d$
$d = D - T$
$T = D - d$

$\frac{L}{12} = \frac{t}{T}$ OR $L : 12 : : t : T$

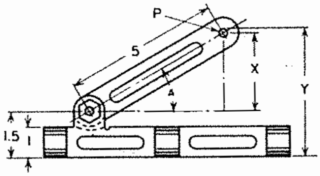


$T = D - d$

$TAN \angle A = T \div 2L$

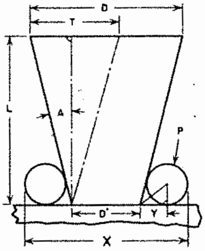


$X = 5 \times$ SINE OF $\angle A$

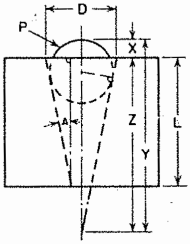


A = INCLUDED $\angle$
$X = 5 \times$ SIN INC $\angle$

P = PLUG SIZE
$Y = X + 1.5 + \frac{P}{2}$



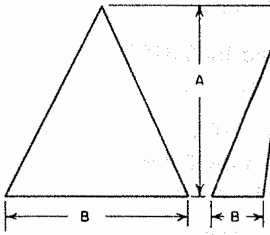
P = PLUG SIZE
T = TAPER PER FT
$\frac{T}{24} = TAN \angle A$
$T = 2(L \times TAN \angle A)$
$D' = D - T$
$Y = \frac{P}{2} \times COT \frac{90° - A}{2}$
$X = D' + 2Y + P$



$TAN \angle A = \frac{T}{24}$
$Y = \left(\frac{P}{2} CSC \angle A\right) + \frac{P}{2}$
$Z = \frac{D}{2} COT \angle A$
$X = Y - Z$

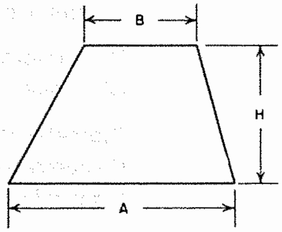
Table 5. Formulas for Length, Area, and Volume (continued)

TRIANGLE



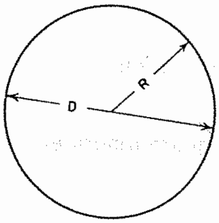
$\text{AREA} = \frac{1}{2}\, B \times A$

TRAPEZOID



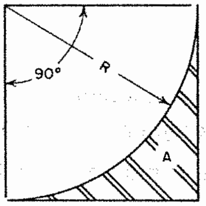
$\text{AREA} = \frac{1}{2}\,(A+B)H$

CIRCLE



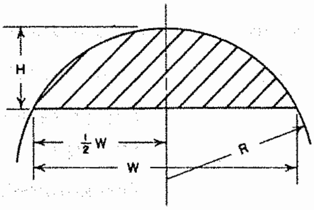
$\text{AREA} = 3.1416\, R^2$

FILLET



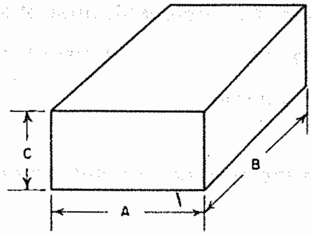
$A = R^2 - \frac{3.1416\, R^2}{4}$

SEGMENT



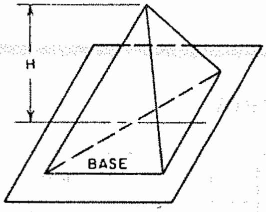
$R = \frac{(\frac{1}{2}W)^2 + H^2}{2H}$

RECTANGULAR PRISM



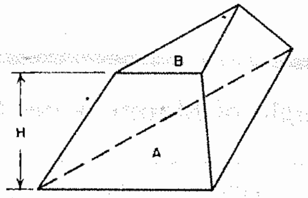
$\text{VOLUME} = ABC$

TRIANGULAR PYRAMID



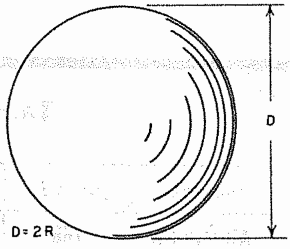
$\text{VOLUME} = \frac{\text{AREA OF BASE} \times H}{3}$

FRUSTUM OF PYRAMID



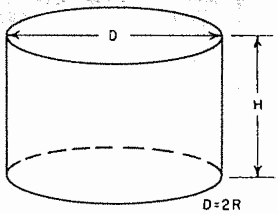
$\text{VOLUME} = \frac{H(A+B+\sqrt{AB})}{3}$

SPHERE



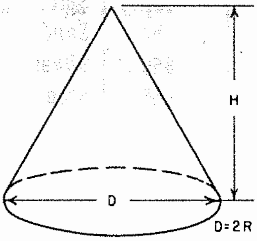
$\text{VOLUME} = \frac{4 \times 3.1416\, R^3}{3}$

CYLINDER



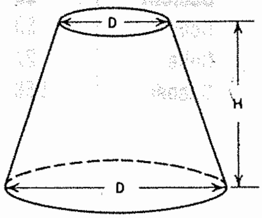
$\text{VOLUME} = 3.1416\, R^2 \times H$

CONE



$\text{VOLUME} = \frac{3.1416\, R^2 \times H}{3}$

FRUSTUM OF CONE



$\text{VOL} = 0.2618\, H\,(D^2 + {}_{0}^{2} + D_{0})$

Table 6. Circle Formulas

Circumference of a circle	Diameter multiplied by 3.1416 Diameter divided by 0.3183
Diameter of a circle	Circumference multiplied by 0.3183 Circumference divided by 3.1416
Side of a square inscribed in a given circle	Diameter multiplied by 0.7071 Circumference multiplied by 0.2251 Circumference divided by 4.4428
Side of a square with area of a given circle	Diameter multiplied by 0.8862 Diameter divided by 1.1284 Circumference multiplied by 0.2821 Circumference divided by 3.545
Diameter of a circle with area of a given square	Side multiplied by 1.128
Diameter of a circle circumscribing a given square	Side multiplied by 1.4142
Area of a circle	The square of the diameter multiplied by 0.7854 The square of the radius multiplied by 3.1416
Area of the surface of a sphere or globe	The square of the diameter multiplied by 3.1416

Table 7. Weight of Materials per Cubic Foot

material	*pounds*	*material*	*pounds*	*material*	*pounds*	*material*	*pounds*
Aluminum	**168**	**Gold**	**1,203**	**Oak, white**	**52**	**Sulfur**	**125**
Brass	**525**	**Gravel**	**90**	**Petroleum**	**55**	**Tin**	**456**
Brick	**125**	**Ice**	**59**	**Pine, white**	**25**	**Tungsten**	**1,203**
Bronze	**550**	**Iron**	**490**	**Pine, yellow**	**34**	**Vanadium**	**372**
Cement	**90**	**Lead**	**707**	**Salt**	**45**	**Water**	**62.4**
Coal	**50**	**Maple**	**50**	**Sand**	**95**	**Zinc**	**445**
Coke	**27**	**Mercury**	**850**	**Silver**	**655**		
Copper	**556**	**Nickel**	**555**	**Steel**	**480**		

Table 8. Equivalent Units of Weight, Volume, and Temperature

AVOIRDUPOIS WEIGHT

16 drams or 437.5 grains = 1 ounce
16 ounces or 7,000 grains = 1 pound
2,000 pounds = 1 net or short ton
2,240 pounds = 1 gross or long ton
2,204.6 pounds = 1 metric ton

BOARD MEASURE

One foot board measure is a piece of wood 12 inches square by 1 inch thick, or 144 cubic inches. A piece of wood 2 by 4, 12 feet long contains 8 feet board measure.

DRY MEASURE

2 pints = 1 quart
8 quarts = 1 peck
4 pecks = 1 bushel
1 standard U.S. bushel = 1.2445 cubic feet
1 British imperial bushel = 1.2837 cubic feet

LIQUID MEASURE

4 gills = 1 pint
2 pints = 1 quart
4 quarts = 1 gallon
1 U.S. gallon = 231 cubic inches
1 British imperial gallon = 1.2 U.S. gallons
7.48 U.S. gallons = 1 cubic foot

LONG MEASURE

12 inches = 1 foot
3 feet = 1 yard
1,760 yards = 1 mile
5,280 feet = 1 mile
16.5 feet = 1 rod

PAPER MEASURE

24 sheets = 1 quire
20 quires = 1 ream
2 reams = 1 bundle
5 bundles = 1 bale

SHIPPING MEASURE

1 U.S. shipping ton = 40 cubic feet
1 U.S. shipping ton = 32.143 U.S. bushels
1 U.S. shipping ton = 31.16 imperial bushels
1 British shipping ton = 42 cubic feet
1 British shipping ton = 33.75 U.S. bushels
1 British shipping ton = 32.718 imperial bushels
1 register ton* = 100 cubic feet

*Register ton is used to measure the internal capacity of a ship.

SQUARE MEASURE

144 square inches = 1 square foot
9 square feet = 1 square yard
30.25 square yards = 1 square rod
160 square rods = 1 acre
640 acres = 1 square mile

TEMPERATURE

Freezing, Fahrenheit scale = 32 degrees
Freezing, centigrade scale = 0 degrees
Boiling, Fahrenheit scale = 212 degrees
Boiling, centigrade scale = 100 degrees

If any degree on the centigrade scale, either above or below zero, be multiplied by 1.8, the result will, in either case, be the number of degrees above or below 32 degrees Fahrenheit.

TROY WEIGHT

24 grains = 1 pennyweight
20 pennyweights = 1 ounce
12 ounces = 1 pound

WEIGHT OF WATER

1 cubic centimeter = 1 gram or 0.035 ounce
1 cubic inch = 0.5787 ounce
1 cubic foot = 62.48 pounds
1 U.S. gallon = 8.355 pounds
1 British imperial gallon = 10 pounds
32 cubic feet = 1 net ton (2,000 pounds)
35.84 cubic feet = 1 long ton (2,240 pounds)
1 net ton = 240 U.S. gallons
1 long ton = 268 U.S. gallons

ENGLISH-METRIC EQUIVALENTS

1 inch = 2.54 centimeters
1 centimeter = 0.3937 inch
1 meter = 39.37 inches
1 kilometer = 0.62 mile
1 quart = 0.946 liter
1 U.S. gallon = 3.785 liters
1 British gallon = 4.543 liters
1 liter = 1.06 quarts
1 pound = 0.454 kilogram
1 kilogram = 2.205 pounds
1 watt = 44.24 foot-pounds per minute
1 horsepower = 33,000 foot-pounds per minute
1 kilowatt = 1.34 horsepower

Table 9. Wire Gage Standards

wire gage no.	American or Brown & Sharpe	Birmingham or Stubs wire	Washburn & Moen on steel wire gage	American S. & W. Co.'s music wire	Imperial wire gage	Stubs steel wire	U.S. Standard for plate
	decimal parts of an inch						
18	0.040303	0.049	0.0475	0.041	0.048	0.168	0.050
19	0.03589	0.042	0.0410	0.043	0.040	0.164	0.04375
20	0.031961	0.035	0.0348	0.045	0.036	0.161	0.0375
21	0.028462	0.032	0.0317	0.047	0.032	0.157	0.034375
22	0.025347	0.028	0.0286	0.049	0.028	0.155	0.03125
23	0.022571	0.025	0.0258	0.051	0.024	0.153	0.028125
24	0.0201	0.022	0.0230	0.055	0.022	0.151	0.025
25	0.0179	0.020	0.0204	0.059	0.020	0.148	0.021875
26	0.01594	0.018	0.0181	0.063	0.018	0.146	0.01875
27	0.014195	0.016	0.0173	0.067	0.0164	0.143	0.0171875
28	0.012641	0.014	0.0162	0.071	0.0149	0.139	0.015625
29	0.011257	0.013	0.0150	0.075	0.0136	0.134	0.0140625
30	0.010025	0.012	0.0140	0.080	0.0124	0.127	0.0125
31	0.008928	0.010	0.0132	0.085	0.0116	0.120	0.0109375
32	0.00795	0.009	0.0128	0.090	0.0108	0.115	0.01015625
33	0.00708	0.008	0.0118	0.095	0.0100	0.112	0.009375
34	0.006304	0.007	0.0104	....	0.0092	0.110	0.00859375
35	0.005614	0.005	0.0095	....	0.0084	0.108	0.0078125
36	0.005	0.004	0.0090	....	0.0076	0.106	0.00703125
37	0.004453	....	0.0085	....	0.0068	0.103	0.006640625
38	0.003965	....	0.0080	....	0.0060	0.101	0.00625
39	0.003531	....	0.0075	....	0.0052	0.099	
40	0.003144	....	0.0070	....	0.0048	0.097	

Table 9. Wire Gage Standards (continued)

wire gage no.	American or Brown & Sharpe	Birmingham or Stubs wire	Washburn & Moen on steel wire gage	American S. & W. Co.'s music wire	Imperial wire gage	Stubs steel wire	U.S. Standard for plate
	decimal parts of an inch						
18	0.040303	0.049	0.0475	0.041	0.048	0.168	0.050
19	0.03589	0.042	0.0410	0.043	0.040	0.164	0.04375
20	0.031961	0.035	0.0348	0.045	0.036	0.161	0.0375
21	0.028462	0.032	0.0317	0.047	0.032	0.157	0.034375
22	0.025347	0.028	0.0286	0.049	0.028	0.155	0.03125
23	0.022571	0.025	0.0258	0.051	0.024	0.153	0.028125
24	0.0201	0.022	0.0230	0.055	0.022	0.151	0.025
25	0.0179	0.020	0.0204	0.059	0.020	0.148	0.021875
26	0.01594	0.018	0.0181	0.063	0.018	0.146	0.01875
27	0.014195	0.016	0.0173	0.067	0.0164	0.143	0.0171875
28	0.012641	0.014	0.0162	0.071	0.0149	0.139	0.015625
29	0.011257	0.013	0.0150	0.075	0.0136	0.134	0.0140625
30	0.010025	0.012	0.0140	0.080	0.0124	0.127	0.0125
31	0.008928	0.010	0.0132	0.085	0.0116	0.120	0.0109375
32	0.00795	0.009	0.0128	0.090	0.0108	0.115	0.01015625
33	0.00708	0.008	0.0118	0.095	0.0100	0.112	0.009375
34	0.006304	0.007	0.0104	....	0.0092	0.110	0.00859375
35	0.005614	0.005	0.0095	....	0.0084	0.108	0.0078125
36	0.005	0.004	0.0090	....	0.0076	0.106	0.00703125
37	0.004453	....	0.0085	....	0.0068	0.103	0.006640625
38	0.003965	....	0.0080	....	0.0060	0.101	0.00625
39	0.003531	....	0.0075	....	0.0052	0.099	
40	0.003144	....	0.0070	....	0.0048	0.097	

Table 10. Basic Screw Thread Dimensions and Tap Drill Sizes in the American National Series

screw size	threads per inch: NC coarse thread series	threads per inch: NF fine thread series	basic dimensions, in.: major diameter	basic dimensions, in.: pitch diameter	basic dimensions, in.: single depth of thread	basic dimensions, in.: minor or root diameter	commercial tap drill to produce approx. 75% full thread: tap drill	commercial tap drill to produce approx. 75% full thread: decimal equiv.	body drill	decimal equiv.
0	....	80	0.060	0.0519	0.00812	0.0438	3/64	0.0469	52	0.0635
1	64	....	0.073	0.0629	0.01015	0.0527	53	0.0595	47	0.0785
1	....	72	0.073	0.0640	0.00902	0.0550	53	0.0595	47	0.0785
2	56	....	0.086	0.0744	0.01160	0.0628	50	0.0700	42	0.0935
2	....	64	0.086	0.0759	0.01015	0.0657	50	0.0700	42	0.0935
3	48	....	0.099	0.0855	0.01353	0.0719	47	0.0785	37	0.1040
3	....	56	0.099	0.0874	0.01160	0.0758	45	0.0820	37	0.1040
4	40	....	0.112	0.0958	0.01624	0.0795	43	0.0890	31	0.1200
4	....	48	0.112	0.0985	0.01353	0.0849	42	0.0935	31	0.1200
5	40	....	0.125	0.1088	0.01624	0.0925	38	0.1015	29	0.1360
5	....	44	0.125	0.1102	0.01476	0.0955	37	0.1040	29	0.1360
6	32	....	0.138	0.1177	0.02030	0.0974	36	0.1065	27	0.1440
6	....	40	0.138	0.1218	0.01624	0.1055	33	0.1130	27	0.1440
8	32	....	0.164	0.1437	0.02030	0.1234	29	0.1360	18	0.1695
8	....	36	0.164	0.1460	0.01804	0.1279	29	0.1360	18	0.1695
10	24	....	0.190	0.1629	0.02706	0.1359	25	0.1495	9	0.1960
10	....	32	0.190	0.1697	0.02030	0.1494	21	0.1590	9	0.1960
12	24	....	0.216	0.1889	0.02706	0.1619	16	0.1770	2	0.2210
12	....	28	0.216	0.1928	0.02320	0.1696	14	0.1820	2	0.2210
1/4	20	....	0.2500	0.2175	0.03248	0.1850	7	0.2010		
1/4	....	28	0.2500	0.2268	0.02320	0.2036	3	0.2130		
5/16	18	....	0.3125	0.2764	0.03608	0.2403	F	0.2570		
5/16	....	24	0.3125	0.2854	0.02706	0.2584	I	0.2720		
3/8	16	....	0.3750	0.3344	0.04059	0.2938	5/16	0.3125		
3/8	....	24	0.3750	0.3479	0.02706	0.3209	Q	0.3320		

(continued)

Table 10. Basic Screw Thread Dimensions and Tap Drill Sizes in the American National Series (continued)

screw size	threads per inch		basic dimensions, in.				commercial tap drill to produce approx. 75% full thread		body drill	decimal equiv.
	NC coarse thread series	NF fine thread series	major diameter	pitch diameter	single depth of thread	minor or root diameter	tap drill	decimal equiv.		
7/16	14	....	0.4375	0.3911	0.04639	0.3447	U	0.3680		
7/16	....	20	0.4375	0.4050	0.03248	0.3725	25/64	0.3906		
1/2	13	....	0.5000	0.4500	0.04996	0.4001	27/64	0.4219		
1/2	....	20	0.5000	0.4675	0.03248	0.4350	29/64	0.4531		
9/16	12	....	0.5625	0.5084	0.05413	0.4542	31/64	0.4844		
9/16	....	18	0.5625	0.5264	0.03608	0.4903	33/64	0.5156		
5/8	11	....	0.6250	0.5660	0.05905	0.5069	17/32	0.5313		
5/8	....	18	0.6250	0.5889	0.03608	0.5528	37/64	0.5781		
3/4	10	....	0.7500	0.6850	0.06495	0.6201	21/32	0.6562		
3/4	....	16	0.7500	0.7094	0.04059	0.6688	11/16	0.6875		
7/8	9	....	0.8750	0.8028	0.07217	0.7307	49/64	0.7656		
7/8	....	14	0.8750	0.8286	0.04639	0.7822	13/16	0.8125		
1	8	....	1.0000	0.9188	0.08119	0.8376	7/8	0.8750		
1	....	14	1.0000	0.9536	0.04639	0.9072	15/16	0.9375		
1 1/8	7	....	1.1250	1.0322	0.09279	0.9394	63/64	0.9844		
1 1/8	....	12	1.1250	1.0709	0.05413	1.0167	1 3/64	1.0469		
1 1/4	7	....	1.2500	1.1572	0.09279	1.0644	1 7/64	1.1094		
1 1/4	....	12	1.2500	1.1959	0.05413	1.1417	1 11/64	1.1719		
1 3/8	6	....	1.3750	1.2667	0.10825	1.1585	1 7/32	1.2188		
1 3/8	....	12	1.3750	1.3209	0.05413	1.2667	1 19/64	1.2969		
1 1/2	6	....	1.5000	1.3917	0.10825	1.2835	1 11/32	1.3438		
1 1/2	....	12	1.5000	1.4459	0.05413	1.3917	1 27/64	1.4219		
1 3/4	5	....	1.7500	1.6201	0.12990	1.4902	1 9/16	1.5625		
2	4 1/2	....	2.0000	1.8557	0.14434	1.7113	1 25/32	1.7813		

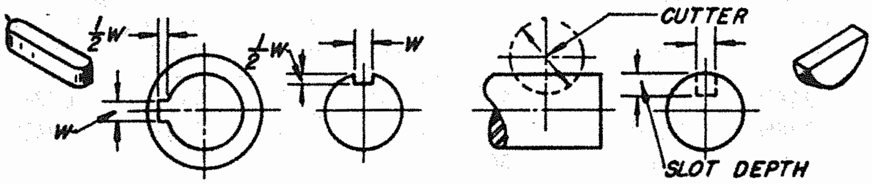
Table 11. Percentage of Full Thread Produced in Tapped Holes

tap	tap drill	decimal equiv. of tap drill	probable hole size	percentage of thread
0-80	56	0.0465	0.0480	74
	¾	0.0469	0.0484	71
1-64	54	0.0550	0.0565	81
	53	0.0595	0.0610	59
1-72	53	0.0595	0.0610	67
	1/16	0.0625	0.0640	50
2-56	51	0.0670	0.0687	74
	50	0.0700	0.0717	62
	49	0.0730	0.0747	49
2-64	50	0.0700	0.0717	70
	49	0.0730	0.0747	56
3-48	48	0.0760	0.0779	78
	5/64	0.0781	0.0800	70
	47	0.0785	0.0804	69
	46	0.0810	0.0829	60
	45	0.0820	0.0839	56
3-56	46	0.0810	0.0829	69
	45	0.0820	0.0839	65
	44	0.0860	0.0879	48
4-40	44	0.0860	0.0880	74
	43	0.0890	0.0910	65
	42	0.0935	0.0955	51
	3/32	0.0938	0.0958	50
4-48	42	0.0935	0.0955	61
	3/32	0.0938	0.0958	60
	41	0.0960	0.0980	52
5-40	40	0.0980	0.1003	76
	39	0.0995	0.1018	71
	38	0.1015	0.1038	65
	37	0.1040	0.1063	58
5-44	38	0.1015	0.1038	72
	37	0.1040	0.1063	63
	36	0.1065	0.1088	55
6-32	37	0.1040	0.1063	78
	36	0.1065	0.1091	71
	7/64	0.1094	0.1120	64
	35	0.1100	0.1126	63
	34	0.1110	0.1136	60
	33	0.1130	0.1156	55
6-40	34	0.1110	0.1136	75
	33	0.1130	0.1156	69
	32	0.1160	0.1186	60
8-32	29	0.1360	0.1389	62
	28	0.1405	0.1434	51
8-36	29	0.1360	0.1389	70
	28	0.1405	0.1434	57
	9/64	0.1406	0.1435	57
10-24	27	0.1440	0.1472	79
	26	0.1470	0.1502	74
	25	0.1495	0.1527	69
	24	0.1520	0.1552	64
	23	0.1540	0.1572	61
	5/32	0.1563	0.1595	56
	22	0.1570	0.1602	55
10-32	5/32	0.1563	0.1595	75
	22	0.1570	0.1602	73
	21	0.1590	0.1622	68
	20	0.1610	0.1642	64
	19	0.1660	0.1692	51
12-24	11/64	0.1719	0.1754	75
	17	0.1730	0.1765	73
	16	0.1770	0.1805	66
	15	0.1800	0.1835	60
	14	0.1820	0.1855	56
12-28	16	0.1770	0.1805	77
	15	0.1800	0.1835	70

Table 11. Percentage of Full Thread Produced in Tapped Holes (continued)

tap	tap drill	decimal equiv. of tap drill	probable hole size	percentage of thread
12-28	14	0.1820	0.1855	66
	13	0.1850	0.1885	59
	3/16	0.1875	0.1910	54
1/4-20	9	0.1960	0.1998	77
	8	0.1990	0.2028	73
	7	0.2010	0.2048	70
	13/64	0.2031	0.2069	66
	6	0.2040	0.2078	65
	5	0.2055	0.2093	63
	4	0.2090	0.2128	57
1/4-28	3	0.2130	0.2168	72
	7/32	0.2188	0.2226	59
	2	0.2210	0.2248	55
5/16-18	F	0.2570	0.2608	72
	G	0.2610	0.2651	66
	17/64	0.2656	0.2697	59
	H	0.2660	0.2701	59
5/16-24	H	0.2660	0.2701	78
	I	0.2720	0.2761	67
	J	0.2770	0.2811	58
3/8-16	5/16	0.3125	0.3169	72
	O	0.3160	0.3204	68
	P	0.3230	0.3274	59
3/8-24	21/64	0.3281	0.3325	79
	Q	0.3320	0.3364	71
	R	0.3390	0.3434	58
7/16-14	T	0.3580	0.3626	81
	23/64	0.3594	0.3640	79
	U	0.3680	0.3726	70
	3/8	0.3750	0.3796	62
	V	0.3770	0.3816	60
7/16-20	W	0.3860	0.3906	72
	25/64	0.3906	0.3952	65
	X	0.3970	0.4016	55
1/2-13	27/64	0.4219	0.4266	73
	7/16	0.4375	0.4422	58
1/2-20	29/64	0.4531	0.4578	65
9/16-12	15/32	0.4688	0.4736	82
	31/64	0.4844	0.4892	68
9/16-18	1/2	0.5000	0.5048	80
	33/64	0.5156	0.5204	58
5/8-11	17/32	0.5313	0.5362	75
	35/64	0.5469	0.5518	62
5/8-18	9/16	0.5625	0.5674	80
	37/64	0.5781	0.5831	58
3/4-10	41/64	0.6406	0.6456	80
	21/32	0.6563	0.6613	68
3/4-16	11/16	0.6875	0.6925	71
7/8-9	49/64	0.7656	0.7708	72
	25/32	0.7812	0.7864	61
7/8-14	51/64	0.7969	0.8021	79
	13/16	0.8125	0.8177	62
1-8	55/64	0.8594	0.8653	83
	7/8	0.8750	0.8809	73
	57/64	0.8906	0.8965	64
	29/32	0.9063	0.9122	54
1-12	29/32	0.9063	0.9123	81
	59/64	0.9219	0.9279	67
	15/16	0.9375	0.9435	52
1-14	59/64	0.9219	0.9279	78
	15/16	0.9375	0.9435	61

Table 12. Keyway Dimensions



shaft dia	square keyways	Woodruff keyways*			
		key no.	thickness	cutter dia	slot depth
0.500	⅛ × 1/16	404	0.1250	0.500	0.1405
0.562	⅛ × 1/16	404	0.1250	0.500	0.1405
0.625	5/32 × 5/64	505	0.1562	0.625	0.1669
0.688	3/16 × 3/32	606	0.1875	0.750	0.2193
0.750	3/16 × 3/32	606	0.1875	0.750	0.2193
0.812	3/16 × 3/32	606	0.1875	0.750	0.2193
0.875	7/32 × 7/64	607	0.1875	0.875	0.2763
0.938	¼ × ⅛	807	0.2500	0.875	0.2500
1.000	¼ × ⅛	808	0.2500	1.000	0.3130
1.125	5/16 × 5/32	1009	0.3125	1.125	0.3228
1.250	5/16 × 5/32	1010	0.3125	1.250	0.3858
1.375	⅜ × 3/16	1210	0.3750	1.250	0.3595
1.500	⅜ × 3/16	1212	0.3750	1.500	0.4535
1.625	⅜ × 3/16	1212	0.3750	1.500	0.4535
1.750	7/16 × 7/32				
1.875	½ × ¼				
2.000	½ × ¼				
2.250	⅝ × 5/16				
2.500	⅝ × 5/16				
2.750	¾ × ⅜				
3.000	¾ × ⅜				
3.250	¾ × ⅜				
3.500	⅞ × 7/16				
4.000	1 × ½				

*The depth of a Woodruff keyway is measured from the edge of the slot.

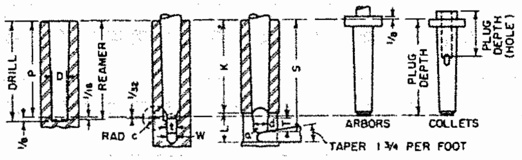
Table 13. Tapers per Foot and Corresponding Angles

taper per foot	included angle deg	included angle min	included angle sec	angle with center line deg	angle with center line min	angle with center line sec
1/64	0	4	28	0	2	14
1/32	0	8	58	0	4	29
1/16	0	17	54	0	8	57
3/32	0	26	52	0	13	26
1/8	0	35	48	0	17	54
5/32	0	44	44	0	22	22
3/16	0	53	44	0	26	52
7/32	1	2	34	0	31	17
1/4	1	11	36	0	35	48
9/32	1	20	30	0	40	15
5/16	1	29	30	0	44	45
11/32	1	38	22	0	49	11
3/8	1	47	24	0	53	42
13/32	1	56	24	0	58	12
7/16	2	5	18	1	2	39
15/32	2	14	16	1	7	8
1/2	2	23	10	1	11	35
17/32	2	32	4	1	16	2
9/16	2	41	4	1	20	32
19/32	2	50	2	1	25	1
5/8	2	59	2	1	29	31
21/32	3	7	56	1	33	58
11/16	3	16	54	1	38	27
23/32	3	25	50	1	42	55
3/4	3	34	44	1	47	22
25/32	3	43	44	1	51	52
13/16	3	52	38	1	56	19
27/32	4	1	36	2	0	48
7/8	4	10	32	2	5	16
29/32	4	19	34	2	9	47
15/16	4	28	24	2	14	12

taper per foot	included angle deg	included angle min	included angle sec	angle with center line deg	angle with center line min	angle with center line sec
31/32	4	37	20	2	18	40
1	4	46	18	2	23	9
1 1/16	5	4	12	2	32	6
1 1/8	5	21	44	2	40	52
1 3/16	5	39	54	2	49	57
1 1/4	5	57	48	2	58	54
1 5/16	6	15	38	3	7	49
1 3/8	6	33	26	3	16	43
1 7/16	6	51	20	3	25	40
1 1/2	7	9	10	3	34	35
1 9/16	7	26	58	3	43	29
1 5/8	7	44	48	3	52	24
1 11/16	8	2	38	4	1	19
1 3/4	8	20	26	4	10	13
1 13/16	8	38	16	4	19	8
1 7/8	8	56	2	4	28	1
1 15/16	9	13	50	4	36	55
2	9	31	36	4	45	48
2 1/8	10	7	10	5	3	35
2 1/4	10	42	42	5	21	21
2 3/8	11	18	10	5	39	5
2 1/2	11	53	36	5	56	48
2 5/8	12	29	2	6	14	31
2 3/4	13	4	24	6	32	12
2 7/8	13	39	42	6	49	51
3	14	15	0	7	7	30
3 1/8	14	50	14	7	25	7
3 1/4	15	25	24	7	42	42
3 3/8	16	0	34	8	0	17
3 1/2	16	35	40	8	17	50
3 5/8	17	10	40	8	35	20

taper per foot	included angle deg	included angle min	included angle sec	angle with center line deg	angle with center line min	angle with center line sec
3 3/4	17	45	40	8	52	50
3 7/8	18	20	34	9	10	17
4	18	55	28	9	27	44
4 1/8	19	30	18	9	45	9
4 1/4	20	5	2	10	2	31
4 3/8	20	39	44	10	19	52
4 1/2	21	14	2	10	37	1
4 5/8	21	48	54	10	54	27
4 3/4	22	23	22	11	11	41
4 7/8	22	57	48	11	28	54
5	23	32	12	11	46	6
5 1/8	24	6	28	12	3	14
5 1/4	24	40	42	12	20	21
5 3/8	25	14	48	12	37	24
5 1/2	25	48	48	12	54	24
5 5/8	26	22	52	13	11	26
5 3/4	26	56	46	13	28	23
5 7/8	27	30	34	13	45	17
6	28	4	2	14	2	1
6 1/8	28	37	58	14	18	59
6 1/4	29	11	34	14	35	47
6 3/8	29	45	18	14	52	39
6 1/2	30	18	26	15	9	13
6 5/8	30	51	48	15	25	54
6 3/4	31	25	2	15	42	31
6 7/8	31	58	10	15	59	5
7	32	31	12	16	15	36
7 1/8	33	4	8	16	32	4
7 1/4	33	36	40	16	48	20
7 3/8	34	9	50	17	4	55

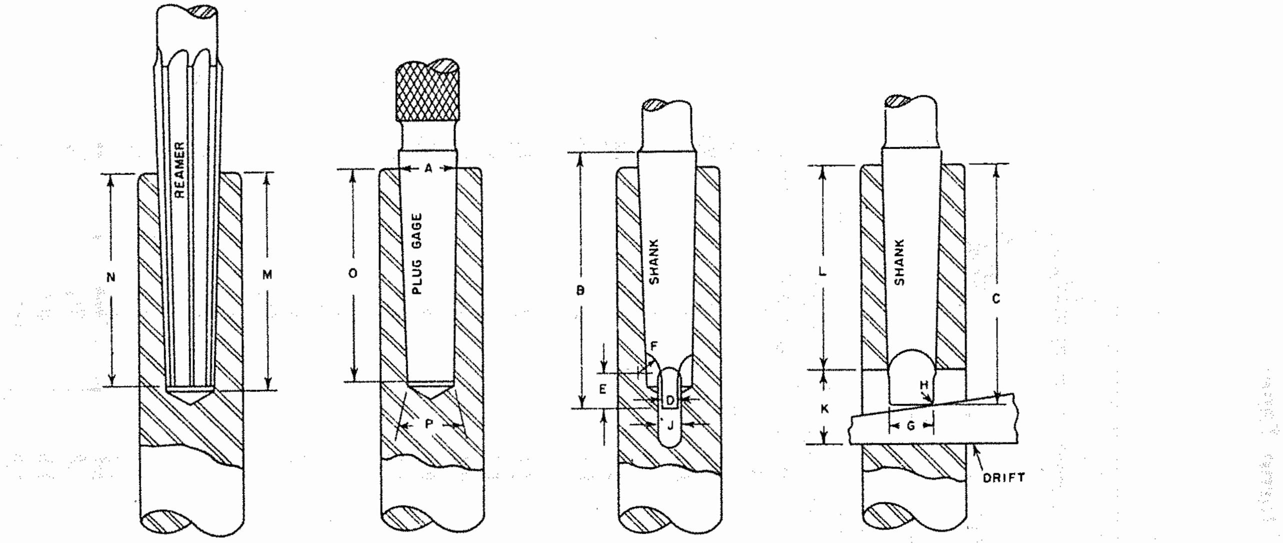
Table 14. Brown and Sharpe Tapers*



no. of taper	taper per foot	dia of plug at small end, D	plug depth, P			keyway from end of spindle, K	shank depth, S	length of key-way, L	width of key-way, W	length of arbor tongue, T	dia of arbor tongue, d	thick-ness of arbor tongue, t	radius of tongue circle, c	radius of tongue, a	limit fc tongue to projec throug test toc
			B&S stand-ard	for mill. mach	misc										
1	0.50200	0.20000	15/16	...	...	15/16	1 3/16	3/8	0.135	3/16	0.170	1/8	3/16	0.030	0.003
2	0.50200	0.25000	1 3/16	...	...	1 11/64	1 1/2	1/2	0.166	1/4	0.220	5/32	3/16	0.030	0.003
3	0.50200	0.31250	1 1/2	... ...	... 1 3/4 2	1 15/32 1 23/32 1 31/32	1 7/8 2 1/8 2 3/8	5/8 5/8 5/8	0.197 0.197 0.197	5/16 5/16 5/16	0.282 0.282 0.282	3/16 3/16 3/16	3/16 3/16 3/16	0.040 0.040 0.040	0.003 0.003 0.003
4	0.50240	0.35000	... 1 11/16	1 1/4 ...	... ...	1 13/64 1 41/64	1 21/32 2 3/32	11/16 11/16	0.228 0.228	11/32 11/32	0.320 0.320	7/32 7/32	5/16 5/16	0.050 0.050	0.003 0.003
5	0.50160	0.45000	... ... 2 1/8	1 3/4	... 2 ...	1 11/16 1 15/16 2 1/16	2 3/16 2 7/16 2 9/16	3/4 3/4 3/4	0.260 0.260 0.260	3/8 3/8 3/8	0.420 0.420 0.420	1/4 1/4 1/4	5/16 5/16 5/16	0.060 0.060 0.060	0.003 0.003 0.003
6	0.50329	0.50000	2 3/8	...	...	2 19/64	2 7/8	7/8	0.291	7/16	0.460	9/32	5/16	0.060	0.005
7	0.50147	0.60000	... 2 7/8 ...	 3	2 1/2	2 13/32 2 25/32 2 29/32	3 1/32 3 13/32 3 17/32	15/16 15/16 15/16	0.322 0.322 0.322	15/32 15/32 15/32	0.560 0.560 0.560	5/16 5/16 5/16	3/8 3/8 3/8	0.070 0.070 0.070	0.005 0.005 0.005
8	0.50100	0.75000	3 9/16	...	...	3 29/64	4 1/8	1	0.353	1/2	0.710	11/32	3/8	0.080	0.005
9	0.50085	0.90010	... 4 1/4	4 ...	... ...	3 7/8 4 1/8	4 5/8 4 7/8	1 1/8 1 1/8	0.385 0.385	9/16 9/16	0.860 0.860	3/8 3/8	7/16 7/16	0.100 0.100	0.005 0.005
10	0.51612	1.04465	5	... 5 11/16 ...	... ... 6 7/32	4 27/32 5 17/32 6 1/16	5 23/32 6 13/32 6 15/16	1 5/16 1 5/16 1 5/16	0.447 0.447 0.447	21/32 21/32 21/32	1.010 1.010 1.010	7/16 7/16 7/16	7/16 7/16 7/16	0.110 0.110 0.110	0.005 0.005 0.005
11	0.50100	1.24995	5 15/16 ...	... 6 3/4	... ...	5 25/32 6 19/32	6 21/32 7 15/32	1 5/16 1 5/16	0.447 0.447	21/32 21/32	1.210 1.210	7/16 7/16	1/2 1/2	0.130 0.130	0.005 0.005
12	0.49973	1.50010	7 1/8 ...	7 1/8 ...	... 6 1/4	6 15/16	7 15/16	1 1/2	0.510	3/4	1.460	1/2	1/2	0.150	0.005
13	0.50020	1.75005	7 3/4	...	...	7 9/16	8 9/16	1 1/2	0.510	3/4	1.710	1/2	5/8	0.170	0.010
14	0.50000	2.00000	8 1/4	8 1/4	...	8 1/32	9 5/32	1 11/16	0.572	27/32	1.960	9/16	3/4	0.190	0.010
15	0.50000	2.25000	8 3/4	...	...	8 17/32	9 21/32	1 11/16	0.572	27/32	2.210	9/16	7/8	0.210	0.010
16	0.50000	2.50000	9 1/4	...	...	9	10 1/4	1 7/8	0.635	15/16	2.450	5/8	1	0.230	0.010
17	0.50000	2.75000	9 3/4												
18	0.50000	3.00000	10 1/4												

*All dimensions are in inches.

Table 15. American Standard Tapers (Morse)*



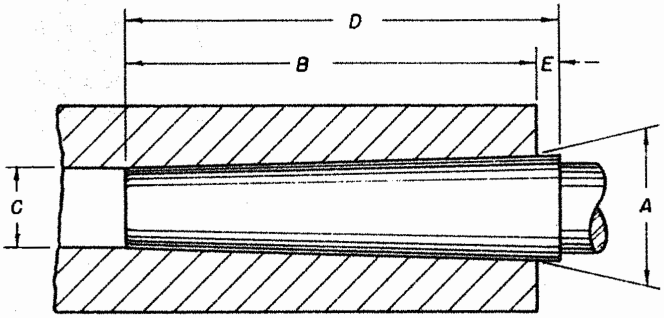
no. of taper	dia of plug at small end, P	dia of gage line, A	shank: whole length, B	shank: depth, C	depth of drilled hole, M	depth of reamed hole, N	standard plug depth, O	tang: thickness, D	tang: length, E	tang: radius, F	tang: diameter, G	tang: radius, H	tang slot: width, J	tang slot: length, K	end of socket to tang slot, L	taper per inch	taper per foot	no. of drift
0†	0.252	0.356	2 11/32	2 7/32	2 1/16	2 1/32	2	0.156	1/4	5/32	15/64	3/64	0.166	9/16	1 15/16	0.052000	0.62400	0†
1	0.369	0.475	2 9/16	2 7/16	2 3/16	2 5/32	2 1/8	0.203	3/8	3/16	11/32	3/64	0.213	3/4	2 1/16	0.049882	0.59858	1
2	0.572	0.700	3 1/8	2 15/16	2 21/32	2 39/64	2 9/16	0.250	7/16	1/4	17/32	1/16	0.260	7/8	2 1/2	0.049951	0.59941	2
3	0.778	0.938	3 7/8	3 11/16	3 5/16	3 1/4	3 3/16	0.312	9/16	9/32	23/32	5/64	0.322	1 3/16	3 1/16	0.050196	0.60235	3
4	1.020	1.231	4 7/8	4 5/8	4 3/16	4 1/8	4 1/16	0.469	5/8	5/16	31/32	3/32	0.479	1 1/4	3 7/8	0.051938	0.62326	4
5	1.475	1.748	6 1/8	5 7/8	5 5/16	5 1/4	5 3/16	0.625	3/4	3/8	1 13/32	1/8	0.635	1 1/2	4 15/16	0.052626	0.63151	5
6	2.116	2.494	8 9/16	8 1/4	7 13/32	7 21/64	7 1/4	0.750	1 1/8	1/2	2	5/32	0.760	1 3/4	7	0.052137	0.62565	5‡
7	2.750	3.270	11 5/8	11 1/4	10 5/32	10 5/64	10	1.125	1 3/8	3/4	2 5/8	3/16	1.135	2 5/8	9 1/2	0.052000	0.62400	

*The dimensions agree essentially with dimensions of the American Standard on Machine Tapers.

†The size O taper is not listed in the American Standard on Machine Tapers.

‡The No. 5 drift will also eject No. 6 taper shank tools.

Table 16. Jarno Tapers



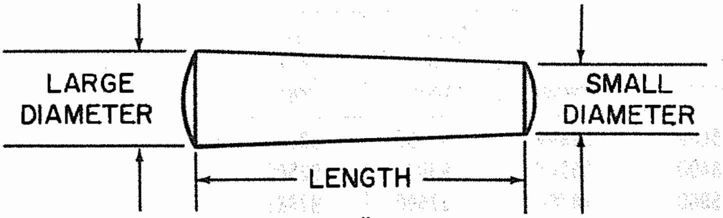
taper per foot = 0.600

no. of taper	large end of hole, A	depth of hole, B	small end of hole, C	length of shank, D	clearance, E
1	0.125	0.5	0.1	9/16	1/16
2	0.250	1.0	0.2	1 1/8	1/8
3	0.375	1.5	0.3	1 5/8	1/8
4	0.500	2.0	0.4	2 3/16	3/16
5	0.625	2.5	0.5	2 11/16	3/16
6	0.750	3.0	0.6	3 3/16	3/16
7	0.875	3.5	0.7	3 11/16	3/16
8	1.000	4.0	0.8	4 3/16	3/16
9	1.125	4.5	0.9	4 11/16	3/16
10	1.250	5.0	1.0	5 1/4	1/4
11	1.375	5.5	1.1	5 3/4	1/4
12	1.500	6.0	1.2	6 1/4	1/4
13	1.625	6.5	1.3	6 3/4	1/4
14	1.750	7.0	1.4	7 1/4	1/4
15	1.875	7.5	1.5	7 3/4	1/4
16	2.000	8.0	1.6	8 3/8	3/8
17	2.125	8.5	1.7	8 7/8	3/8
18	2.250	9.0	1.8	9 3/8	3/8
19	2.375	9.5	1.9	9 7/8	3/8
20	2.500	10.0	2.0	10 3/8	3/8

Table 17. Jacobs Tapers

Jacobs taper	large diameter	small diameter	length of taper	taper per foot
0	.25000	.22844	.43750	.59145
1	.38400	.33341	.65625	.92508
2	.55900	.48764	.87500	.97861
2 short	.54880	.48764	.75000	.97861
3	.81100	.76410	1.21875	.63898
4	1.12400	1.03720	1.65625	.62886
5	1.41300	1.31611	1.87500	.62010
6	.67600	.62409	1.00000	.62292
33	.62401	.56051	1.00000	.76194
E	.78860	.74717	.79680	.62400

Table 18. Drill Sizes for Taper Pins



NOTE:
DRILL SIZE SHOULD BE APPROXIMATELY 0.005 SMALLER THAN THE SMALL DIAMETER

TAPER = $\frac{1}{4}''$ PER FOOT

SMALL DIAMETER = LARGE DIAMETER − LENGTH X 0.02083

NUMBER	7/0	6/0	5/0	4/0	3/0	2/0	0	1	2	3	4	5	6	7	8	9	10	11	
DIAMETER AT LARGE END	0.0625	0.078	0.094	0.109	0.125	0.141	0.156	0.172	0.193	0.219	0.250	0.289	0.341	0.409	0.492	0.591	0.707	0.857	¼
LENGTH	DIAMETER OF SMALL END OF PIN AND DRILL SIZE																		LENGTH
¼	0.0573	0.0728	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	¼
	54	50																	
⅜	0.0547	0.0702	0.0862	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	⅜
	55	51	45																
½	0.0521	0.0676	0.0836	0.0986	0.1146	0.1306	0.1456	0.1616	......	......	......	......	......	......	......	......	......	......	½
	56	52	46	41	34	30	9/64	5/32											
⅝	0.0495	0.0650	0.0810	0.0960	0.1120	0.1280	0.1430	0.1590	......	......	......	......	......	......	......	......	......	......	⅝
	56	52	5/64	3/32	7/64	⅛	9/64	23											
¾	0.0469	0.0624	0.0784	0.0934	0.1094	0.1254	0.1404	0.1564	0.1774	0.2034	0.2344	......	......	......	......	......	......	......	¾
	56	53	48	43	36	31	29	24	11/64	8	1								
⅞	......	0.0598	0.0758	0.0908	0.1068	0.1228	0.1378	0.1538	0.1748	0.2008	0.2318	......	......	......	......	......	......	......	⅞
	......	54	49	43	37	31	29	25	18	9	1								
1	......	0.0572	0.0732	0.0882	0.1042	0.1202	0.1352	0.1512	0.1722	0.1982	0.2292	0.2682	0.3202	......	......	......	......	......	1
		54	50	44	38	32	30	26	19	10	2	G	O						
1⅛	......	......	......	0.0856	0.1016	0.1176	0.1326	0.1486	0.1696	0.1956	0.2266	0.2656	0.3176	......	......	......	......	......	1⅛
				45	39	33	30	27	19	11	2	G	5/16						
1¼	......	......	......	0.0830	0.0990	0.1150	0.1300	0.1460	0.1670	0.1930	0.2240	0.2630	0.3150	0.3830	......	......	......	......	1¼
				46	41	33	⅛	9/64	20	3/16	7/32	F	N	⅜					
1⅜	......	......	......	......	0.0964	0.1124	0.1274	0.1434	0.1644	0.1904	0.2214	0.2604	0.3124	0.3804	......	......	......	......	1⅜
					3/32	7/64	⅛	9/64	20	3/16	3	F	N	⅜					
1½	......	......	......	......	0.0938	0.1098	0.1248	0.1408	0.1618	0.1878	0.2188	0.2578	0.3098	0.3778	0.4608	......	......	......	1½
					43	36	31	29	5/32	14	3	¼	N	U	29/64				
1¾	......	......	......	......	......	0.1045	0.1195	0.1355	0.1565	0.1825	0.2135	0.2525	0.3045	0.3725	0.4555	......	......	......	1¾
						38	32	30	24	16	4	D	19/64	U	7/16				
2	......	......	......	......	......	0.0993	0.1143	0.1303	0.1513	0.1773	0.2203	0.2473	0.2993	0.3673	0.4503	0.5494	......	......	2
						41	34	⅛	26	11/64	15/64	C	M	23/64	7/16	17/32	......	......	
2¼	......	......	......	......	......	......	......	0.1251	0.1461	0.1721	0.2031	0.2421	0.2941	0.3621	0.4451	0.5442	......	......	2¼
								31	27	19	8	B	L	T	7/16	17/32			
2½	......	......	......	......	......	......	......	0.1199	0.1409	0.1669	0.1979	0.2369	0.2889	0.3569	0.4399	0.5390	0.6540	......	2½
								32	29	20	10	15/64	9/32	S	27/64	17/32	41/64		
2¾	......	......	......	......	......	......	......	......	0.1357	0.1617	0.1927	0.2317	0.2837	0.3517	0.4347	0.5338	0.6488	......	2¾
									30	5/32	3/16	I	J	11/32	27/64	33/64	41/64		

Table 18. Drill Sizes for Taper Pins (continued)

NUMBER	7/0	6/0	5/0	4/0	3/0	2/0	0	1	2	3	4	5	6	7	8	9	10	11	
DIAMETER AT LARGE END	0.0625	0.078	0.094	0.109	0.125	0.141	0.156	0.172	0.193	0.219	0.250	0.289	0.341	0.409	0.492	0.591	0.707	0.857	¼
LENGTH	DIAMETER OF SMALL END OF PIN AND DRILL SIZE																		LENGTH
3	......	......	......	......	......	......	......	......	0.1305	0.1565	0.1875	0.2265	0.2785	0.3465	0.4295	0.5285	0.6435	0.7975	3
									30	24	14	2	1	R	27/64	33/64	5/8	25/32	
3¼	......	......	......	......	......	......	......	......	......	......	0.1823	0.2213	0.2733	0.3413	0.4243	0.5233	0.6383	0.7923	3¼
											16	7/32	17/64	Q	Z	33/64	5/8	25/32	
3½	......	......	......	......	......	......	......	......	......	......	0.1771	0.2161	0.2681	0.3361	0.4191	0.5181	0.6331	0.7871	3½
											11/64	3	G	Q	13/32	½	5/8	25/32	
3¾	......	......	......	......	......	......	......	......	......	......	......	......	0.2629	0.3309	0.4139	0.5129	0.6279	0.7819	3¾
													F	21/64	13/32	½	39/64	49/64	
4	......	......	......	......	......	......	......	......	......	......	......	......	0.2577	0.3257	0.4087	0.5077	0.6227	0.7767	4
													¼	P	Y	½	39/64	49/64	
4¼	......	......	......	......	......	......	......	......	......	......	......	......	......	0.3205	0.4035	0.5025	0.6175	0.7715	4¼
														O	X	31/64	39/64	49/64	
4½	......	......	......	......	......	......	......	......	......	......	......	......	......	0.3153	0.3983	0.4973	0.6123	0.7663	4½
														5/16	25/64	31/64	19/32	¾	
4¾	......	......	......	......	......	......	......	......	......	......	......	......	......	......	0.3931	0.4921	0.6071	0.7611	4¾
															W	31/64	19/32	¾	
5	......	......	......	......	......	......	......	......	......	......	......	......	......	......	0.3879	0.4869	0.6019	0.7559	5
															3/8	15/32	19/32	¾	
5¼	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	0.4817	0.5967	0.7507	5¼
																15/32	37/64	47/64	
5½	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	0.4765	0.5915	0.7455	5½
																15/32	37/64	47/64	
5¾	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	0.4713	0.5863	0.7403	5¾
																29/64	37/64	47/64	
6	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	0.4660	0.5810	0.7350	6
																29/64	9/16	23/32	
6¼	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	0.5758	0.7298	6¼
																	9/16	23/32	
6½	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	0.5706	0.7246	6½
																	9/16	23/32	
6¾	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	0.5654	0.7194	6¾
																	35/64	45/64	
7	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	0.5602	0.7142	7
																	35/64	45/64	
7¼	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	0.7090	7¼
																		45/64	
7½	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	0.7038	7½
																		11/16	

Supplementary References

To supplement the material in this book, these McGraw-Hill publications may be of interest.

Sidney H. Avner, *An Introduction to Physical Metallurgy*

Aaron Axelrod, *Machine Shop Mathematics*

Paul H. Black, *Theory of Metal Cutting*

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Cyril Donaldson and George H. LeCain, *Tool Design*

John L. Feirer, *Machine Tool Metalworking: Principles and Practice*

Thomas E. French, Carl L. Svensen, Jay D. Helsel, Byron Urbanick, *Mechanical Drawing*

William T. Frier, *Elementary Metallurgy*

Charles R. Hine, *Machine Tools and Processes for Engineers*

Daniel Irvin, *Power Tool Maintenance*

George L. Kehl, *The Principles of Metallographic Laboratory Practice*

Philip Kissam, *Optical Tooling for Precise Manufacture and Alignment*

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W. A. Nordoff, *Machine Shop Estimating*

Gilbert S. Schaller, *Engineering Manufacturing Methods*

Bertrand B. Singer, *Mathematics for Industrial Careers*

Society of Manufacturing Engineers, Frank W. Wilson, Editor-in-Chief: *Tool Engineers Handbook; Handbook of Fixture Design; Manufacturing Planning and Estimating Handbook; Numerical Control in Manufacturing*

Herbert W. Wage, *Manufacturing Engineering*

John H. Wolfe and Everett R. Phelps, *Practical Shop Mathematics*

INDEX