TM 9-242

DEPARTMENT OF THE ARMY TECHNICAL MANUAL

FUNDAMENTALS OF ORDNANCE CORPS MACHINE TOOLS

HEADQUARTERS, DEPARTMENT OF THE ARMY
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HEADQUARTERS, DEPARTMENT OF THE ARMY
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***This manual supersedes TM 1-420, 29 November 1940, including C 1, 10 March 1942; TM 1-421, 20 April 1942; TM 1-422, 28 November 1940, including C 1, 14 March 1942; and TM 10-445, 12 November 1941.**

CHAPTER 1

INTRODUCTION

Section I. GENERAL

1. Purpose and Scope

This manual is published to provide ordnance personnel with a ready reference of principles, applications, and standard tabular data pertinent to power-driven machine tools in the Ordnance Corps supply system. It also supplements technical manuals in the TM 9–3400-, TM 9–5100-, and TM 9–9000-series covering power-driven machine tools.

a. This chapter contains a general overall history of machine tools. Individual chapters cover each type of tool as to function, tools and equipment used in conjunction with the machine tool, methods of mounting work, and general operating instructions. Instructions for special operations are also given.

b. The appendix contains a list of current references, including supply manuals, technical manuals, technical bulletins, and other available publications applicable to the machine tools covered by this manual.

c. This manual differs from TM 1–420, 29 November 1940, as follows:

(1) Adds information on—
Lathe types and attachments.

(2) Revises information on—
General and special lathe operations.
Lathe cutting speeds, feeds, and cutting oils.
Lathe cutting tools.
Screw thread forms.

(3) Deletes reference to—
Gear blank calculations.

d. This manual differs from TM 1–421, 20 April 1942, as follows:

(1) Adds information on—
Milling machine types.
Shaper types.

(2) Revises information on—
General and special milling machine operations.

General and special shaper and planer operations.
Milling machine attachments.
Milling machine and shaper cutting tools, speeds, and cutting oils.

(3) Deletes reference to—
Mathematical computations for helical milling.
Gear calculations.

e. This manual differs from TM 1–422, 26 November 1940, as follows:

(1) Adds information on—
Grinding machines and attachments.

(2) Revises information on—
Grinding abrasive wheels.
Grinding operations.
Finishing operations.

(3) Deletes reference to—
Grinding machines and attachments not found in the Ordnance Corps.

f. This manual differs from TM 10–445, 12 November 1941, as follows:

(1) Adds information on—
Miscellaneous machine tools.
Portable machine tools.
Band sawing machines.

(2) Revises information on—
Drilling machine operation and equipment.
Grinding machine operation.
Lathe operation and equipment.
Milling machine operation and equipment.
Shaper and planer speeds, feeds, and cutting oils.
Hack sawing machine operation.
Grinding abrasive wheels.
Screw thread forms.

(3) Deletes reference to—
Specialized machine tools.
Machine tools not found in the Ordnance Corps.

g. Machine tool operations requiring special equipment or tools not authorized for issue in the Ordnance Corps have been omitted from this manual in many cases. Similarly, complex machine tool operations generally applicable only to production machining have been omitted.

h. Any errors or omissions will be brought to the attention of the Commanding Officer, Raritan Arsenal, Metuchen, N. J., ATTN: ORDJR–CPRA, using DA Form 468 (Unsatisfactory Equipment Report).

2. Forms, Records, and Reports

a. General. Responsibility for the proper execution of forms, records, and reports rests upon the officers of all units maintaining equipment. However, the value of accurate records must be fully appreciated by all persons responsible for their compilation, maintenance, and use. Records, reports, and authorized forms are normally utilized to indicate the type, quantity, and condition of materiel to be inspected, to be repaired, or to be used in repair. Properly executed forms convey authorization and serve as records for repair or replacement of materiel in the hands of troops and for delivery of materiel requiring further repair to ordnance shops. The forms, records, and reports establish the work required, the progress of the work within the shops, and the status of the materiel upon completion of its repair.

b. Authorized Forms. The forms generally applicable to units operating this materiel are listed in the appendix. For a listing of all forms, refer to DA Pam 310–2. For instructions on the use of these forms, refer to FM 9–10.

c. Field Report of Accidents. The reports necessary to comply with the requirements of the Army safety program are prescribed in detail in AR 385–40. These reports are required whenever accidents involving injury to personnel or damage to materiel occur.

d. Report of Unsatisfactory Equipment or Materials. Any deficiencies detected in the equipment covered herein, which occur under the circumstances indicated in AR 700–38, should be immediately reported in accordance with the applicable instructions in cited regulation.

3. Definition of Machine Tools

Machine tools are defined as power-driven equipment designed to drill, bore, grind, or cut metals or other materials.

4. Listing of Machine Tools

A complete list of machine tools including specialized machine tools currently authorized for issue are listed in SM 9–1- and SM 9–5-series Department of the Army supply manuals.

5. Specialized Machine Tools

In view of the different design and operating features incorporated in specialized machine tools (cylinder boring machines, brake reliners, valve seat grinders, etc.) by various manufacturers, no attempt has been made to include information pertinent to them in this manual. For complete information on these tools, see pertinent TM 9–3400-, TM 9–5100-, and TM 9–9000-series technical manuals covering the specific machines.

Section II. HISTORY OF MACHINE TOOLS

6. General

a. This section provides a chronological history of each of the basic machine tools covered in this manual.

b. Most of these machine tools have their origin in the Industrial Revolution in England and America from the mideighteenth century to the midnineteenth century. The invention of the steam engine by James Watt in 1774 was impractical until John Wilkinson, in 1775, developed a boring mill with which cylinders for the steam engine could be produced with sufficient accuracy. From that time onward, most machine tools were invented to satisfy a particular need.

c. Each machine tool can be traced to a basic hand tool that has, in many cases, been in use for thousands of years. The early lathe was basically an adaption of the ancient potter's wheel and the knife. The ancient Egyptian bow drill and later the brace and bit evolved into the drilling machine. In a similar manner, the milling machine replaced the file, the planer and shaper replaced the chisel and the scraper, and the sawing machines supplanted the handsaw.

7. Lathes

a. Perhaps the earliest of all machine tools, the lathe was known to Leonardo da Vinci who drew several sketches of lathes in his notebook at the end of the fifteenth century. The earliest type of lathe, the bow lathe, was operated by a cord held taught by a piece of bowed wood and given a couple of turns around the workpiece. The operator rotated the workpiece by drawing the bow back and forth. The bow lathe evolved into the pole lathe in which the bow was replaced by a tree branch or wood strip above the machine and a foot lever beneath the machine. With this arrangement, the operator treaded on the foot lever to pull the cord downward and rotate the workpiece. The tree branch or wood strip would spring downward, being connected to the other end of the cord, and when the foot lever was released, the branch or strip would return the cord and foot lever to their original positions. The wood strip or "lath" used to spring the cord on these early pole lathes probably accounts for the name "lathe" being applied to the turning machine.

b. A screw cutting lathe was made by Jaques Besson before 1568 although it appears that this innovation exerted little influence on later lathe design. Besson's lathe (fig. 1) was driven by a cord passing over a pulley above the machine which, in turn, drove two other pulleys on the same shaft which rotated the workpiece and a crude, wooden lead screw. The other end of the cord supported a weight which replaced the conventional spring return of the overhead tree branch or wood strip. A slide rest was incorporated on this machine, perhaps the earliest application of a slide rest.

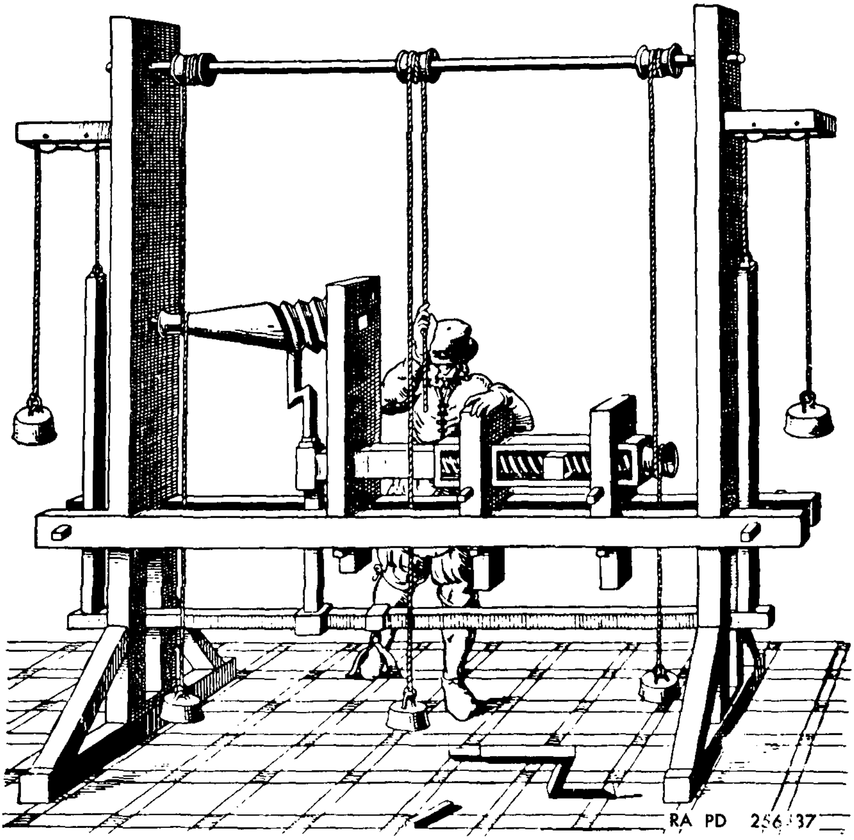

Figure 1. Besson's screw cutting lathe—1568.

c. During the 17th and 18th centuries, lathes were used to advantage by clockmakers. The heavy-duty lathe was not yet practical and only light work could be performed. Screw cutting lathes fitted with slide rests for supporting tools were again developed in the first half of the 18th century but these machines presented many difficulties in operation, and precision was unobtainable.

d. The first practical screw cutting lathe with a slide rest was developed by Henry Maudslay in England in 1797. This lathe incorporated a satisfactory lead screw which took Maudslay many years of experimentation to develop. The lathe was turned by a cord from a large wheel which was operated by a handcrank. A later development of Maudslay's in 1800 introduced change gears whereby different pitches of screws could be cut from the same lead screw. Later Maudslay, while continuing his work on the screw, developed still better lead screws and placed metalworking on a solid foundation. In 1830, he built a giant lathe with a 9-foot faceplate capable of turning flywheels 20 feet in diameter and boring steam cylinders 10 feet in diameter for early steam engines.

e. Lathe developments since the middle of the 19th century have not radically changed the Maudslay concept of the lathe. The major advances have been the improving of accuracy obtainable in workmanship, the designing of sturdier lathes, the increasing of the work speed, and the gradual conversion of manual operations to semiautomatic and automatic ones. The early cord drives were replaced by belt drives and eventually by electric motors. Lathes constructed before 1850 generally had wood beds upon which iron ways were mounted. The adaptation of the iron bed after 1850 made accurate turning of large workpieces practical. In 1853, an American named Freeland built a lathe having a back-geared head, a mechanism which with the lead screw, change gears, and slide rest constitutes the basic requirements of a modern engine lathe. The turret lathe was developed in America in 1890 and opened the way for the automatic lathes and automatic screw machines of today. The process was a gradual one, first making one motion and then another self-acting. The development of high-speed tool steel in 1898 and later, carbide-tipped cutting tools in about 1925 permitted speed increases for the lathe and made semiautomatic and automatic lathes more desirable for production work.

8. Milling Machines

a. The first milling machine was invented in America in 1818 by Eli Whitney, the inventor of the cotton gin. This machine (fig. 2) was developed to mass-produce interchangeable musket parts. He found that accuracy and uniformity could not be maintained using the old system of hand filing on filing jigs because the jigs were subjected to wear when the file touched the jig control surfaces, and only a few parts could therefore be accurately filed before the jig was inaccurate. The milling machine Whitney developed has a horizontal spindle to which disks containing cutter teeth in the rim could be mounted and rotated. A sliding table was devised by which the workpiece could be moved beneath the rotating disk. On Whitney's machine, the table feed was powered by a belt connecting a feed shaft with the milling machine spindle.

b. Later developments in milling machines were made by Robbins and Laurence in 1853 and by Brown and Sharpe Manufacturing Company in 1855. The Brown and Sharpe machine was used primarily for cutting spur gears. In 1861, Brown and Sharpe constructed the first universal milling machine which resembles the knee-type universal milling machines of today. This machine contained an indexing head and a variable speed table feed driven off the milling machine spindle. Its first important uses were the cutting of grooves in twist drills and the making of musket parts during the Civil War in 1864.

c. By 1915, the milling machine had been developed to such a degree that the machine was capable of doing much heavier work than the milling cutters that had been previously developed. Heavier arbors were substituted, and new cutters shaped more like drums than disks were developed so that more material could be removed from

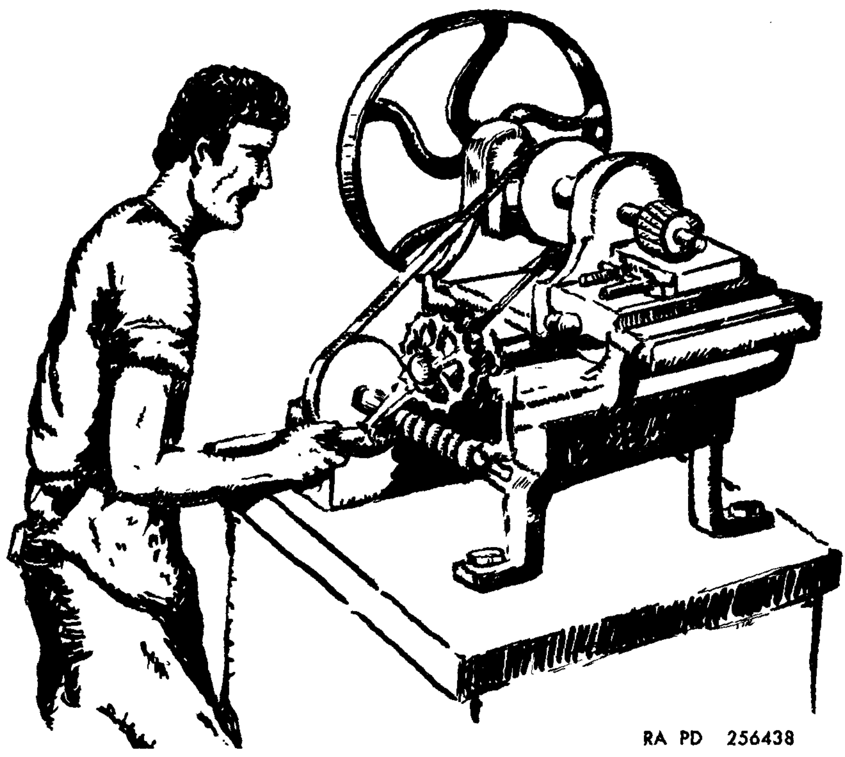

Figure 2. Whitney's milling machine—1818.

workpieces in one pass of the table. High-speed tool steel had been developed in 1898 and permitted fast cuts to be taken with these new cutters. Helical cutting teeth and staggered teeth were later developed to reduce the tendency of the tool to chatter while cutting. Variations of the milling machine were later developed to perform special milling operations. Among these machines are the vertical milling machine, the ram-type milling machine, and the profiling machine.

9. Shapers and Planers

a. Shapers and planers were developed during the early part of the 19th century to do the work of the hammer and chisel in producing flat surfaces on workpieces. Between 1814 and 1825 several independent inventors in England constructed planers. These men include

Richard Roberts and Richard Platt. Roberts' machine (fig. 3), constructed in 1817 had a chain-driven worktable which was reciprocated manually through a crank at the side of the machine. The cutting tool was fixed to a cross slide supported above the worktable on upright columns projecting from the bed or frame of the machine. Another planer of this period, perhaps the predecessor of the shaper, was a sturdy wall-mounted machine with which the workpiece remained stationary and the cutting tool and tool head moved across the workpiece on a track fixed to a brick wall.

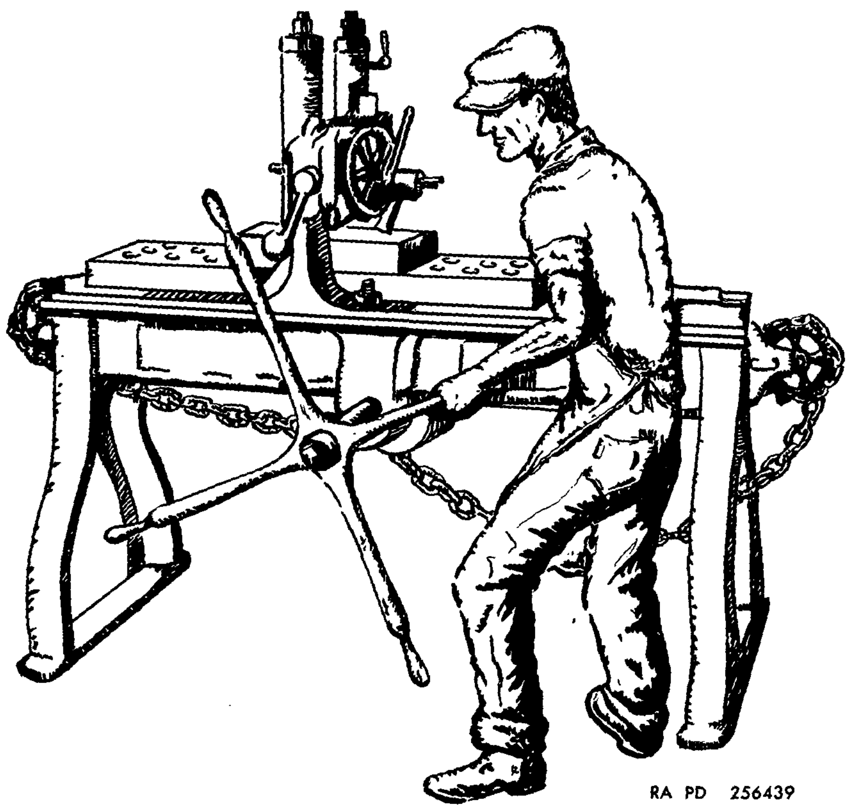

Figure 3. Robert's planer—1817.

b. The first shaper was invented by James Nasmyth in 1836 and featured a reciprocating arm which carried the cutting tool over a fixed workpiece to make the cut. This machine tool was referred to at that time as "Nasmyth's Steel Arm."

c. Joseph Whitworth of England, a brilliant inventor who was the founder of methods of precision in the working of metals, made major improvements to the early shapers and planers before 1850. He developed a quick-return reciprocating action for the shaper and planer by which the shaper ram and the planer worktable would speed up on their return strokes, thus shortening the time required for shaping or planing operations. Before this time, experimental planers had been fitted with double tool heads which would cut on both the forward and backward strokes. This method did not prove practical. Another improvement of this period was the enlarging of the planer bed. On the first planers, the worktable invariably overhung each end of the bed at the end of each stroke. The overhand caused the worktable to spring downward under pressure from the cutting tool, thereby decreasing the accuracy of the cut. The early chain-drive for the planer worktable was replaced by a rack and pinion, the rack being fixed to the underside of the worktable. An American, Sellers, drove the rack by a worm which was positioned diagonally across the planer bed. This driving device is still in use today.

d. Improvements to shapers and planers since 1900 have been chiefly engineering design advances to improve the rigidity of the machine tool, increase the accuracy of operation, and make the machines more versatile and more automatic. The spur gears used to drive the racks of planers were replaced by helical tooth gears which drive the planers much more smoothly. On large planers and shapers, the introduction of hydraulic cylinders to operate the worktable or ram further improved the smoothness of operation and provided a much wider range of cutting speeds. The development of carbide-tipped cutting tools allowed a further increase in production from heavy-duty planers which perform some of the largest metal cutting operations today.

10. Drilling Machines

a. The early drilling machines were probably adaptations of the ancient bow drill used in Egypt 3,800 years ago. The bow drill consisted of a cord tied at both ends to flexible stick and a rough cylindrical bronze drill. The cord was given a turn or two about the drill and the drill was supported against the workpiece. By drawing the bow back and forth, a reciprocating rotary motion was given the drill.

b. In the later part of the 18th century and the early part of the 19th century, drilling machines were developed by Focq and Crillon which had step cone drives whereby a restricted range of drill speed could be obtained. These machines were operated by handcranks or pedals before the advent of steam power. In 1840, James Nasmyth in England developed the first drilling machine to incorporate power feed as well as interchangeable speeds. The Nasmyth drilling machine (fig. 4) is considered the forerunner of the modern radial drilling machine used widely for production drilling. Another drilling machine of the early 19th century was James Watt's famous wall drilling machine installed in his Soho Foundry in England. This

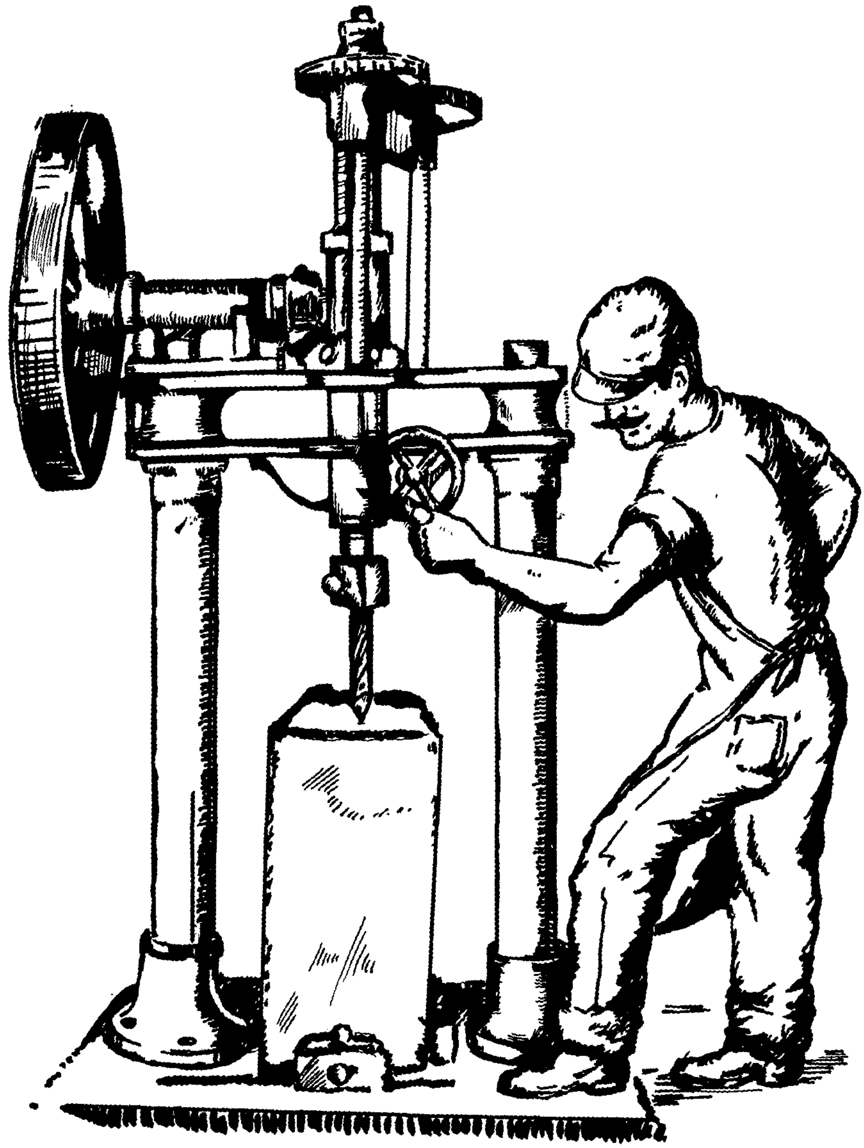

Figure 4. Nasmyth's drilling machine—1840.

machine was suspended from a brick wall and was belt driven from cumbersome shafting overhead. Watt's machine was limited as to speed and feed ranges, but was built very sturdy and is still usable today.

c. Drilling machine evolution since the developments in the middle 19th century has been mostly the perfection of design. Improvements in twist drills made possible by the introduction and development of the milling machine during the 19th century made greater accuracy attainable. The modern drilling machines are driven by individual electric motors instead of the earlier belt driven shafts. Many variable spindle speeds and feeds are available to increase the versatility of the machine.

11. Grinding Machines

a. The natural aluminum oxide abrasive substance, emery. has long been used in powder form for hand grinding and polishing operations. Early abrasive wheels were crude and could be used successfully only for snagging castings and other rough work. Meanwhile, emery cloth, or cloth that had been impregnated with emery abrasive, became widely employed for polishing workpieces on lathes.

b. In 1864, the first practical commercial grinding machine, a cylindrical grinding machine, was produced in America by Brown and Sharpe Manufacturing Company. This machine was used successfully for truing up tool steel workpieces that had warped or become distorted from hardening processes. Later this machine, called the "grinding lathe," became widely used for manufacturing sewing machine parts and for making needles.

c. Near the end of the 19th century, artificial abrasives such as silicon carbide and manufactured aluminum oxides were developed together with new bonding methods. The improvement of the grinding abrasive wheel permitted greater speeds and more applications for the grinding machine. Soon the grinding machine was developed to such an extent that it could be used for heavy cutting of metal, and the grinding process replaced certain operations once performed only on the milling machine or lathe.

d. At the present time, the grinding machine has taken its place as a basic machine tool, capable of producing work of the highest precision. Variable-speed motors permit precise adjustment of wheel speeds and feeds. Hydraulic pressure, used on some grinding machines for feeding the grinding abrasive wheel into the workpiece, permits automatic grinding to within one ten-thousandths of an inch of the desired size. The centerless grinding machine allows accurate production grinding of small cylindrical workpieces without having to mount each workpiece individually. The development of the magnetic chuck for surface grinding machines provided a simple and more accurate means for mounting workpieces beneath the grinding abrasive wheel.

12. Sawing Machines

a. Although the saw blade was developed over 2,000 years ago, no significant designs for sawing machines were made until 1803 when a practical design for a band sawing machine was patented. This machine, designed by Newberry, had three wheels arranged in a triangular pattern upon which the band saw blade was driven (fig. 5). The use of this early machine was hindered by imperfection of suitable continuous blade bands. In 1846, a Frenchman named Perin devised a satisfactory means for joining the band saw blade ends. The Newberry machine as well as other sawing machines developed before the end of the 19th century were used for sawing wood only.

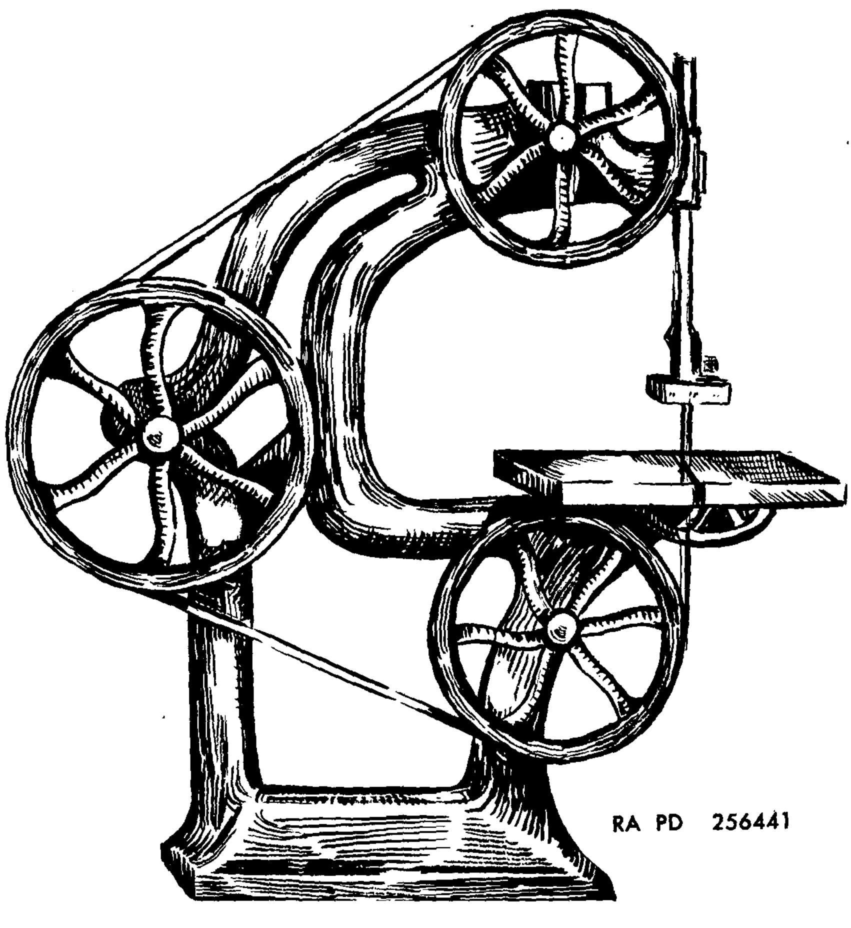

Figure 5. Newberry's band sawing machine—1803.

b. Hack sawing machines were developed near the turn of the century. They proved to be the first satisfactory metal cutting power-driven saws except for circular saw blades that had been in use for parting operations on the milling machine. The early hack sawing machines consisted merely of a mechanism for driving a hacksaw blade back and forth. Later, improvements were made to improve the sawing action. Devices were added to these machines to make the hacksaw blade lift on the return stroke to prevent dulling or snagging of the blade, and adjustable weights and counterbalances were added so that the feed of the machine could be controlled.

c. The metal cutting band sawing machine was developed after the hack sawing machine although the wood cutting band sawing machine had been used for close to a century at that time. Where the hack sawing machine was restricted to square or angle cutting of stock, the metal cutting band sawing machine could perform intricate contour cutting of shapes from steel plate.

d. Later advances to the hack sawing machine design have not changed the original concept of the machine. The modern hack sawing machine has adjustable cutting speeds and stroke lengths. Some of the newer machines have borrowed the quick-return mechanism of the shaper so that the sawing action can be increased without increasing the blade speed. The large production-type hack sawing machines have automatic feed devices whereby a bar or a number of bars of stock can be fed into the machine, clamped in the vise, and cut automatically.

e. The modern band sawing machine has variable saw blade speeds so that any metal, hard or soft, can be cut successfully. These machines incorporate power feed devices and are usually equipped with a number of accessories by which filing, polishing, circle cutting, and internal cutting can be performed. The band saw blade ends are butt welded to form a joint that will not interfere with the sawing of the workpiece. Many metal cutting band sawing machines contain built-in butt welders so that blade bands may be formed at the machine.

13. Forging Machine

a. The forging machine or forging hammer was used long before metal was obtained in a molten state. As early as the 13th century, crude hammers driven by water power or by animals were used to forge metal workpieces into shape by a hammering process.

b. Little change to the forging machine was made until the 19th century. In 1831, a steam-operated drop hammer with cast iron frames was developed. This machine was similar to the earliest hammers except that the hammer was lifted and dropped by cams which were rotated by steam power. Later in 1838, James Nasmyth invented a direct-action steam hammer. The stroke of this machine could be varied from a slight touch to a heavy blow.

c. The first power trip hammers were developed between 1865 and 1875. These hammers operated on a crank principle whereby the hammer lifted and pounded downward rapidly several times per second.

Section III. MACHINE SHOP WORK

14. General

Machine shop work is generally understood to include all cold metal work by which an operator, using either power-driven or hand tools removes a portion of the metal and shapes it to some specified form and size. Some cold metal work, such as that done in sheet metal work and copper smithing, is not usually regarded as a machine shop operation.

15. Laying Out Work

a. A machinist must be able to read working drawings from which he knows how to lay out and set up jobs. Instructions for reading working drawings are beyond the scope of this manual.

b. "Laying out" is a shop term which means to mark guiding lines, circles, and centers on the curved or flat surfaces of the workpiece. Such markings are, as a rule, transferred to the workpiece from a blueprint or other drawing. The process is somewhat similar to making a mechanical drawing but differs from it in the important respect that the position of every mark must be absolutely accurate if satisfactory results are expected. For that reason, a machinist keeps all his measuring and laying-out tools in good condition, sees that all his scribers, dividers, and punch points are sharp, and uses particular care to insure fine and accurate laying out.

c. In scribing lines, draw the scribe across the work once, holding the point close to the straightedge; reruling thickens the line and leads to inaccurate work.

16. Safety Precautions

a. General Safety Precautions. The use of the following general safety precautions are recommended to guard all workers against avoidable injury.

(1) Gears, pulleys, belts, couplings, ends of shafts having keyways, and other revolving or reciprocating parts should be guarded to a height of 6 feet above the floor. The guards should be removed only for repairing or adjusting the machine and replaced before operating it.

(2) Safety setscrews should be used in collars, on all revolving or reciprocating members of the machine tool or its equipment.

(3) Do not work without proper light.

(4) It is extremely dangerous to start or attempt to operate a machine until familiar with how it works and until its dangers have been fully explained by a qualified person. *Ignorance causes as many accidents in the machine shop as*

carelessness. Knowledge and care will prevent most accidents.

(5) Loose or torn clothing, particularly loose or torn sleeves, a flowing necktie, or a flapping belt end is dangerous because it can easily catch in moving parts and draw in and cut or mangle the fingers, the hand or the arm, or other parts of the body. Running gears are among the most dangerous of mechanisms. All gearing should be well guarded.

Caution: **Never wear gloves when operating a machine except when absolutely necessary.**

(6) Starting a machine while it is being adjusted or repaired is bad practice. Make sure that this does not happen.

(7) Do not lubricate a machine while it is in motion. Injury to the operator and damage to the machine may result from this practice.

(8) If metal chips, turnings, or shavings are removed with the hand, they may cause a serious cut. If the shavings are long, stop the machine tool and break them with the crooked end of a scratch awl or bent rod, and then brush them off the machine. Remove cast iron chips which break into small fragments with a brush. Never use waste to wipe away chips when the machine tool is operating.

b. Safety Precautions for Drilling Machines.

(1) Do not attempt to make adjustments to the workpiece when the drilling machine is operating.

(2) Never clean away chips from the workpiece with the hand or with some waste when the drilling machine is operating. If waste is used, it may snag on the twist drill and draw the hand into contact with the revolving drill. Use a brush to remove the chips.

(3) Do not support the workpiece by hand unless drilling in light wood is being performed. If the revolving drill should snag while drilling, the hand supported workpiece could wrench out of the operator's grip and cause injury to the operator, the workpiece, or the drilling machine.

(4) As with all machine tools having revolving cutting tools or workpieces, loose clothing is a potential hazard since it can catch on the revolving tool or workpiece and draw the operator into the moving parts of the machine tool.

c. Safety Precautions for Grinding Machines.

(1) Most accidents resulting from grinding machine operation are eye injuries from flying abrasive and workpiece particles. Eyeshields should be used wherever possible. Goggles should be worn for all grinding machine operations, whether eyeshields are present or not.

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(2) Grinding machines should be used with exhaust air systems wherever possible to prevent inhalation of harmful dust by the operator. Wet grinding, using an attachment to flood the workpiece and grinding abrasive wheel with a coolant, will help reduce dust.

(3) Never operate grinding abrasive wheels at speeds in excess of those recommended for the particular grinding abrasive wheel or grinding machine. Too high a speed may cause the grinding abrasive wheel to burst and cause injury from flying pieces.

(4) Be careful to keep the hands away from the revolving grinding abrasive wheel. Bodily contact with the revolving wheel can cause severe skin abrasions.

d. Safety Precautions for Lathes.

(1) Lathe accidents are commonly caused by loose clothing snagging on the revolving workpiece, the chuck, or the lathe dog; flying chips when turning cast iron or nonferrous metals; and contact of the hand or arm with the lathe dog, chuck, or workpiece.

(2) On turret lathes, care must be taken not to catch loose or torn clothing on stock supported in collet chucks and extending beyond the headstock of the lathe.

(3) If a coolant or cutting oil is used, take care when adjusting splash pans to prevent the liquid from splashing on the floor. The oiliness of the cutting oil or coolant can make the floor beneath the lathe slippery and cause the operator to lose his balance and suffer injury.

(4) Hand operations on the revolving lathe, such as hand filing, should not be performed with the back gears of the lathe engaged. The back-geared speeds are too slow for these operations, and the workpiece is moving under too much power to permit stalling of the lathe if anything gets caught in it.

e. Safety Precautions for Milling Machines. Although accidents resulting from milling machine operations are few in number, they are usually severe.

(1) The greatest hazard of milling machine operation is contact with the revolving milling cutter. Loose or torn clothing should not be worn when operating the milling machine. Chips should be removed from the workpiece with a brush, never with waste or with the hand.

(2) Flying chips can be dangerous when cast iron or nonferrous metals are being machined. Wear goggles or face shield to prevent eye or face injuries.

(3) Do not attempt to tighten arbor nuts using machine power.

(4) Never adjust the workpiece or work mounting devices when the machine tool is operating.

(5) When using a cutting oil, prevent splashing by use of appropriate splash pans. Cutting oil on the floor can cause a slippery conditon that could result in injury to the operator.

f. Safety Precautions for Shapers and Planers. Shaper and planer accidents, like milling machine accidents, are usually severe although not too frequent.

(1) Flying chips are common with shaper operation. Necessary precautions should be taken to prevent eye damage by wearing goggles.

(2) Accidents with the planer are caused by the operator getting into the way of the reciprocating table and being caught between the table and the bed or frame of the planer, or between the table and some other stationary object. Similar accidents are caused by being struck by the ram of the shaper when improperly adjusted. The operator should make sure that the area about the shaper or planer is clear of personnel before starting the machine.

(3) Never attempt any adjustments to the planer table stop dogs, the planer or shaper workpiece, or cutting tool when the machine tool is in operation.

(4) Be sure the cutting tool is tight and mounted securely before operation.

(5) Keep the hands away from the work table of the shaper while the shaper is cutting.

(6) Make sure the workpiece is mounted securely before attempting any operation.

g. Safety Precautions for Sawing Machines.

(1) Keep the hands away from the saw blade of the hack sawing machine or band sawing machine when in operation.

(2) Use a miter guide attachment, work-holding jaw device, or a wooden block for pushing metal workpieces into the blade of the band sawing machine wherever possible. Keep the fingers well clear of the band saw blade at all times.

(3) When removing and installing band saw blades, handle the blades carefully. A large, springy blade can be dangerous to handle if the operator does not exercise caution.

h. Safety Precautions for Miscellaneous Machine Tools.

(1) When supporting workpieces by hand while using the bench mounted utility reamer drive and the bench mounted horizontal honing machine, hold the workpiece firmly to prevent possible wrenching from the hands.

(2) Be cautious when handling workpieces that have been heated on the coal burning forge. Suitable tongs should be used

to grasp the workpieces, and asbestos gloves should be worn where practical.

(3) Extreme care must be exercised when operating the vertical hammer forging machine. Workpieces should be held between the dies with tongs. The operator should never place his hands between the dies when the drive motor of the machine is running.

(4) Extreme caution should be taken whenever operating the power driven metal punching and shearing machine. The hands should never be placed between the punch and die or the shear blades when the drive motor of the machine is running. Because of the close proximity of the notcher section to the punch section, and the coper section to the shear section, suitable guards must be provided to prevent accidental contact with one section's moving parts when another section is being operated. The notcher and punch sections will operate simultaneously when the pedal is depressed. The shear, coper, and bar cutter sections will operate simultaneously when the hand lever near the rear of the machine is operated. The motor must be stopped when changing, removing, installing, or adjusting punches and shear blades.

i. Safety Precautions for Portable Machine Tools.

(1) All portable electric tools should be equipped with 3-conductor flexible cords. The third conductor is an electrical ground attached to the chassis of the tool. This must be grounded to a suitable ground source when the plug is connected to the alternating- or direct-current power source. Failure to connect this ground may result in a severe shock to the operator while using the portable electric tool if the electrical insulation within the electric motor or portable tool housing should become damaged.

(2) Portable tools that function by revolving a cutting tool at high speeds should be used with caution and kept away from torn or loose clothing. A firm grip should be maintained when operating the portable tool to prevent its being wrenched from the hands of the operator.

(3) Never leave a portable pneumatic hammer with a chisel, star drill, rivet set, or other tool in its nozzle. If accidentally triggered, the hammer could eject the tool from its nozzle violently to cause injury to personnel or equipment.

(4) Observe common precautions applied to the use of firearms whenever handling the powder-actuated projectile unit driver. Never point the tool at any person; never look down the bore of the tool without first determining that the

barrel and chamber are empty; never use the tool for fastening lightweight, thin, or soft materials.

17. Tools and Equipment

Certain tools and equipment necessary for operating machine tools are issued with the machine and are listed in the ORD 7 portion of the Department of the Army supply manual pertaining to the machine. Tool and shop sets authorized for organizational, field, and depot maintenance and to personnel having certain military occupational specialties (MOS) in addition to containing machine tools, also contain tools and equipment for use with the machine tools. Components of these sets are listed in the appropriate sections of ORD 6 SNL J–7, J–8, J–9, and J–10 respectively.

CHAPTER 2

UPRIGHT DRILLING MACHINES

Section I. GENERAL

18. Purpose

A drilling machine, sometimes called a drill press, is used to cut holes into or through metal, wood, and other materials. Drilling machines are designed to use a drilling tool which has cutting edges at its point. The cutting tool is held in the drill press by a chuck and is rotated and fed into the work at variable speeds. Drilling machines can also perform other operations such as tapping, reaming, counterboring and countersinking, lapping, and spot facing.

19. Types of Drilling Machines

There are two types of drilling machines. They are upright drilling machines (figs. 6–11) having vertical spindles and horizontal drilling machines having horizontal spindles. Machines with horizontal spindles are used only for special production jobs. The average machinist will be concerned mostly with those having vertical spindles, thus this chapter will include only upright drilling machines.

20. Upright Drilling Machines

Upright drilling machines are classified as sensitive-type upright drilling machines (figs. 6 and 7), upright drilling machines (figs. 8 and 9), radial upright drilling machines (fig. 10), power-feed back-geared, upright drilling machines (fig. 11), and multiple-spindle upright drilling machines.

a. Sensitive-Type Upright Drilling Machines. Sensitive-type upright drilling machines are hand-fed by the operator with a feed handle so that he is able to "feel" the action of the cutting tool. They are driven by an electric motor through belts connecting the motor pulley and the spindle pulley. Several different feeds can be obtained by selecting mating steps of the cone pulleys. Sensitive-type drilling machines are essentially high-speed machines and are used on small workpieces requiring no larger than ½-inch drills. The head and table have vertical adjustments. Most work tables have no means of bolting the workpiece to them. Sensitive-type drilling machines are made in several different sizes and in both bench-type models (fig. 6) and floor-type models (fig. 7). The drill holding end of spindles in drilling machines are tapered. To hold straight-shanked tools, chucks, sockets, and sleeves are used.

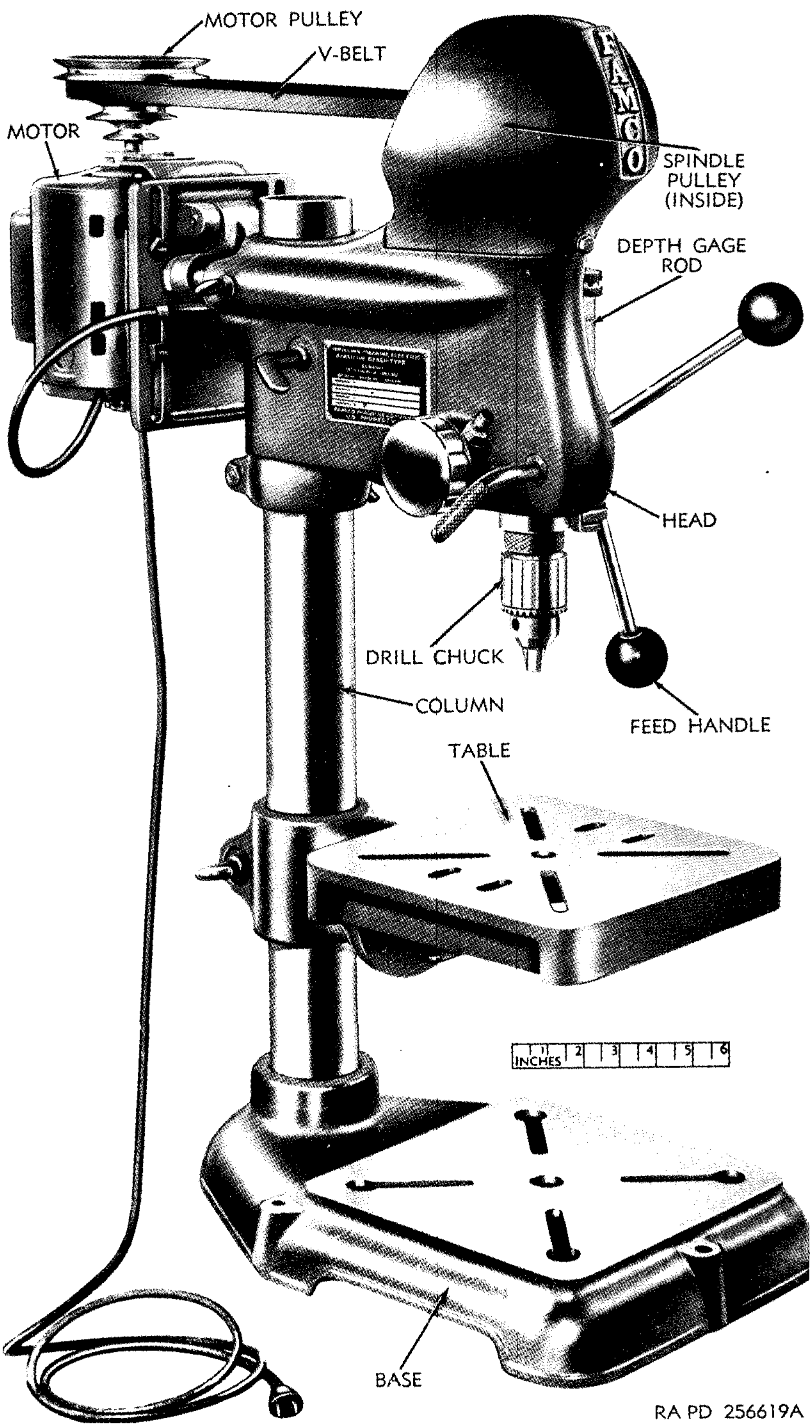


Figure 6. Bench-mounted sensitive-type upright drilling machine.

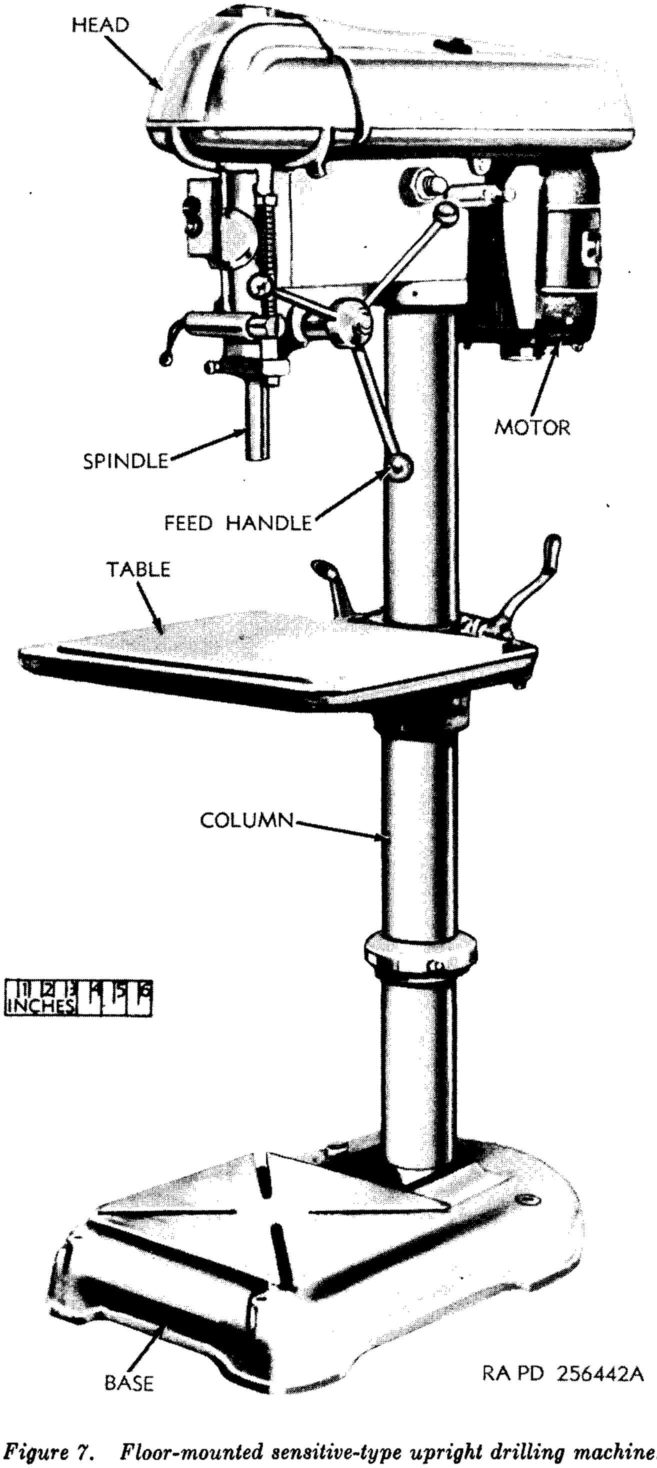


Figure 7. Floor-mounted sensitive-type upright drilling machine.

b. Upright Drilling Machines.

(1) Bench-type upright drilling machines (fig. 8) are used for small drilling jobs. They are operated by a motor through a belt and pulley system similar to that of the sensitive drilling machine. The steps on the motor pulley and spindle pulley give the typical machine four spindle speeds. Feed is controlled by a feed handle and the depth of the drilling action can be predetermined by a depth gage. The table may be raised or lowered, swung to one side, or removed from the columns. This permits workpieces of various heights to be mounted.

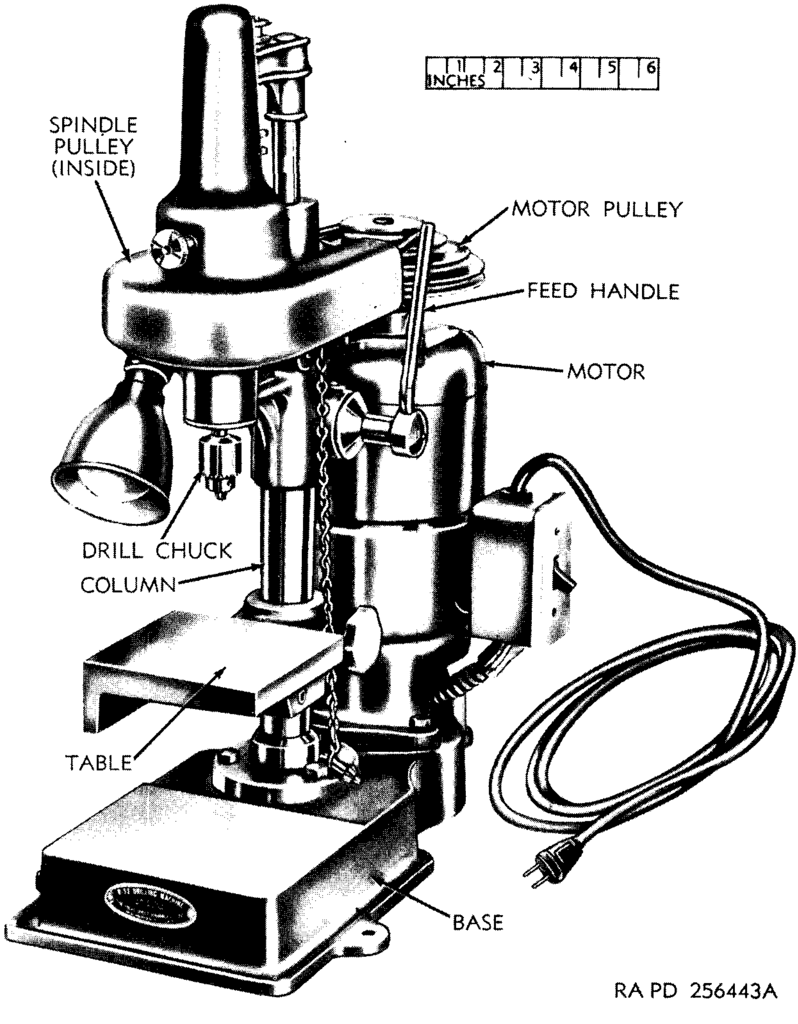


Figure 8. Bench-mounted upright drilling machine.

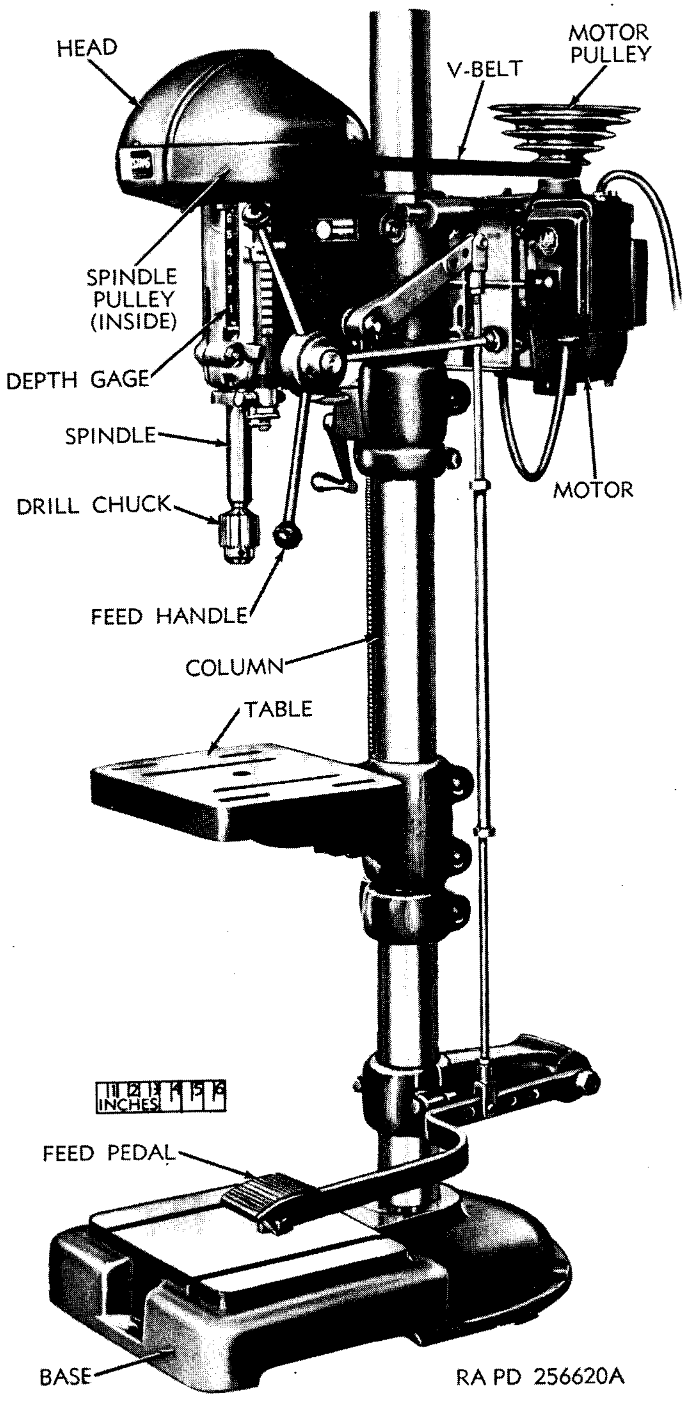


Figure 9. Floor-mounted upright drilling machine.

(2) Floor-mounted upright drilling machines (fig. 9) are designed for workpieces too large to be handled on bench-type drill presses and have several additional features. Tables on these drilling machines can be adjusted horizontally and vertically and can be tilted to allow the point of the drilling tool to be centered over any spot on the job. The head may also be swiveled and raised or lowered. Feed may be controlled either by power or by hand. Models with power feed have several spindle speeds and automatic feeds. Upright drilling machines are rated by the diameter of the largest piece that can be centrally drilled. Many styles of tables are used on floor-mounted drilling machines such as compound tables which are made for extreme accuracy, and combination vise tables which can be opened to clamp the piece in position.

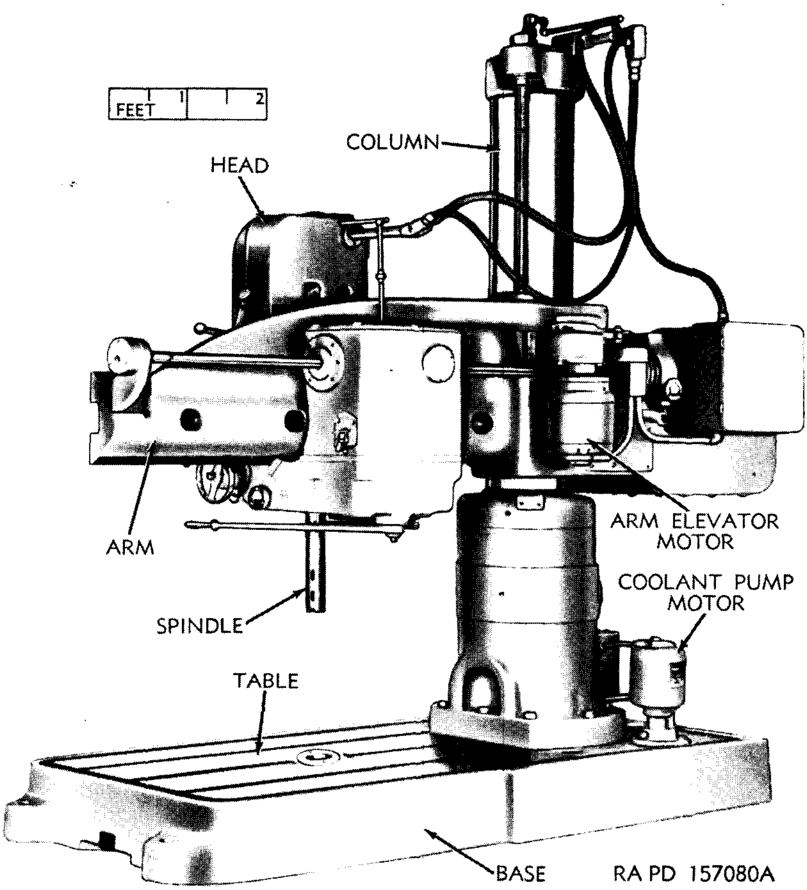


Figure 10. Radial upright drilling machine.

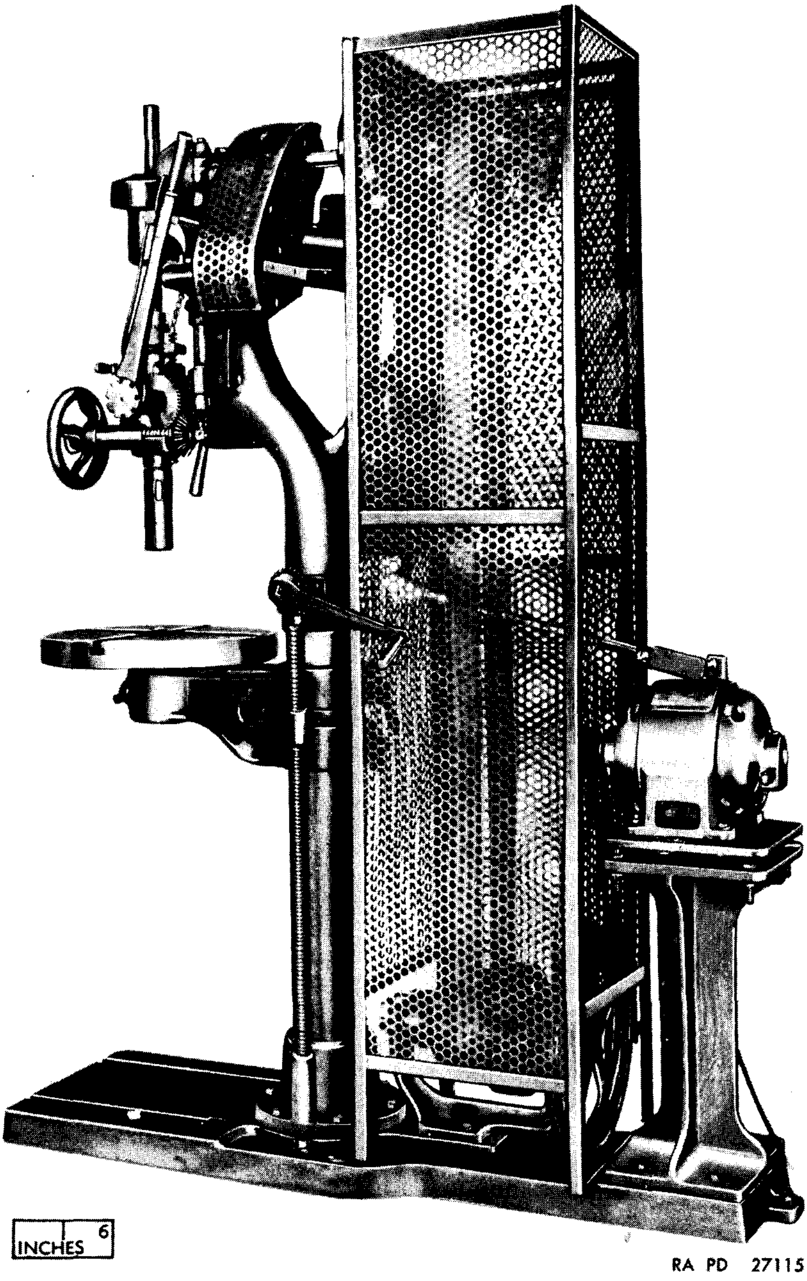


Figure 11. Power-feed back-geared upright drilling machine.

c. Radial Upright Drilling Machines. Radial upright drilling machines (fig. 10) are provided with an adjustable arm and movable spindle head which make it possible to locate the cutting tool anywhere within range of the machine. The arm can be swiveled horizontally about the column and moved vertically by power. The spindle head can be moved and locked anywhere along the arm. Several holes may be drilled in heavy pieces without moving the workpiece. Thus it is ideal for drilling larger and heavier workpieces where greater production is desirable. Workpieces can be mounted directly to the base or on a universal table which is bolted to the base for use. The universal table, when used, can be tilted up to 90° and swiveled up to 360°.

d. Power-Feed Back-Geared Upright Drilling Machines. Power-feed back-geared upright drilling machines (fig. 11) can be used for hand-feed and power-feed operations by engaging or disengaging the back gears. They have six or more spindle feeds and three or more automatic feeds. More heavily constructed than bench-mounted or floor-mounted drilling machines, they handle a greater range of work-pieces. Power-feed drilling machine tables can be adjusted vertically, in a horizontal plane 90° to the right of left and, generally, may be rotated 360° about center. The horizontal adjustment permits jobs to be mounted on the machine base which thus serves as an auxiliary table for large workpieces. The head may also be raised and lowered on some models. Depth stops enable the operator to predetermine the depth of the drilling action. A spindle reversing mechanism permits tapping operations.

e. Multiple-Spindle Upright Drilling Machines. Multiple-spindle upright drilling machines have two or more spindles which operate simultaneously. A number of holes may be drilled in the workpiece at one time. Thus it is a valuable production machine. Another multispindled drilling machine, the "gang drill," has a number of spindles set in a fixed relative position which do not operate simultaneously. These are actually separate drilling machines mounted on one base and with one table. Several different jobs may be performed in one piece by passing it from spindle to spindle.

Section II. TOOLS AND EQUIPMENT

21. Twist Drills

a. General. Twist drills are the most commonly used cutting tools in drilling machines. Twist drills are end-cutting tools made with one or more cutting edges at their points. Helical flutes or grooves winding around the body from the point to the neck of the drills appear to be twisted and give the drill its name. Drills are made with either straight or round taper shanks. Standard drilling machine spindle sockets are made with tapered ends to hold taper shank drills.

Straight-shank drills are fitted in the machines with chucks, sockets, and sleeves which have tapered ends to fit the spindles. Twist drills are made of either carbon steel or high-speed steel. Carbon steel, if heated excessively and allowed to cool, will lose its hardness. High-speed steel has the property of "red hardness," that is, it can become red hot without losing its temper. Consequently, high-speed steel twist drills should be selected for high-speed drilling of metal to obtain best results and a lasting cutting effectiveness.

b. Twist Drill Sizes.

(1) Twist drills are made in about 400 standard sizes ranging from 0.0135 inch (wire gage size No. 80) to 3½ inches in diameter. Nonstandard sizes up to 6 inches in diameter are used for some special jobs. The standard sizes used in the United States are known as the wire gage size number drills, the letter size drills, and the fractional size drills. There are also the millimeter size drills, but they are not commonly used in the United States.

(2) Wire gage size drills and letter size twist drills are generally used where other than standard fractional sizes are required such as drilling holes for tapping. In this case, the drilled hole forms the minor diameter of the thread to be cut, and the major diameter which is cut by tapping corresponds to the common fractional size of the screw.

(*a*) Wire gage size twist drills range from No. 80 (0.0135 inch) to No. 1 (0.2280 inch). Refer to table I for wire gage size twist drill diameters. Note that the larger the number, the smaller the diameter of the drill.

(*b*) Letter size twist drills range from A (0.234 inch) to Z (0.413 inch). Refer to table II for letter size twist drill diameters. Note in this case that as the letters progress, the diameters become larger.

(3) Fractional size drills range from 1/64 to 1¾ inches in 1/64-inch units, from 1/32 to 2¼ inches in 1/32-inch units, and from 1/16 to 3½ inches in 1/16-inch units.

(4) Millimeter size drills commonly range from 3 mm (0.1181 inch) to 77 mm (3.0315 inches) in ½-mm units. These drills are not commonly used in the United States.

c. Twist Drill Parts (Nomenclature). Familiarity with the parts of the twist drill is necessary in learning to sharpen drills properly. The parts of the twist drill are illustrated in figure 12 and described in (1) through (13) below.

(1) *Point.* The point is the entire conical-shaped end of the drill containing the cutting edges.

(2) *Body.* The body is the section between the point and the shank containing the flutes.

Table I. Wire Gage Sizes for Twist Drills

Wire gage size (No.)	Drill diameter (in.)	Wire gage size (No.)	Drill diameter (in.)
1	0. 2280	41	0. 0960
2	0. 2210	42	0. 0935
3	0. 2130	43	0. 0890
4	0. 2090	44	0. 0860
5	0. 2055	45	0. 0820
6	0. 2040	46	0. 0810
7	0. 2010	47	0. 0785
8	0. 1990	48	0. 0760
9	0. 1960	49	0. 0730
10	0. 1935	50	0. 0700
11	0. 1910	51	0. 0670
12	0. 1890	52	0. 0635
13	0. 1850	53	0. 0595
14	0. 1820	54	0. 0550
15	0. 1800	55	0. 0520
16	0. 1770	56	0. 0465
17	0. 1730	57	0. 0430
18	0. 1695	58	0. 0420
19	0. 1660	59	0. 0410
20	0. 1610	60	0. 0400
21	0. 1590	61	0. 0390
22	0. 1570	62	0. 0380
23	0. 1540	63	0. 0370
24	0. 1520	64	0. 0360
25	0. 1495	65	0. 0350
26	0. 1470	66	0. 0330
27	0. 1440	67	0. 0320
28	0. 1405	68	0. 0310
29	0. 1360	69	0. 0292
30	0. 1285	70	0. 0280
31	0. 1200	71	0. 0260
32	0. 1160	72	0. 0250
33	0. 1130	73	0. 0240
34	0. 1110	74	0. 0225
35	0. 1100	75	0. 0210
36	0. 1065	76	0. 0200
37	0. 1040	77	0. 0180
38	0. 1015	78	0. 0160
39	0. 0995	79	0. 0145
40	0. 0980	80	0. 0135

(3) *Shank.* The shank is the portion of the drill from the body to the back end and may be straight or tapered. It is held in the chuck or spindle of the drilling machine.

(4) *Chisel edge.* The chisel edge, also called the dead center, is the sharp edge at the extreme tip end of the drill across the web. It is formed by the intersection of the conical-

Table II. Letter Sizes for Twist Drills

Letter size	Drill diameter (in.)	Nearest fractional equivalent (in.)	Letter size	Drill diameter (in.)	Nearest fractional equivalent (in.)
A	0.234	15/64	N	0.302	
B	0.238		O	0.316	5/16
C	0.242		P	0.323	21/64
D	0.246		Q	0.332	
E	0.250	1/4	R	0.339	11/32
F	0.257		S	0.348	
G	0.261		T	0.358	23/64
H	0.266	17/64	U	0.368	
I	0.272		V	0.377	3/8
J	0.277		W	0.386	25/64
K	0.281	9/32	X	0.397	
L	0.290		Y	0.404	13/32
M	0.295	19/64	Z	0.413	

shaped surfaces of the point. The edge should always be centered exactly at the end of the drill's axis. The chisel edge cuts its own hole, acting as a flat drill.

(5) *Cutting edge lips.* The sharp edges formed by grinding the flutes to a conical point, and which slope from the chisel edge to the margin of the drill are known as cutting edge lips. These lips cut like a knife when fed and rotated into the workpiece.

(6) *Heel.* The heel is the conical-shaped portion of the point back of the cutting edge lips.

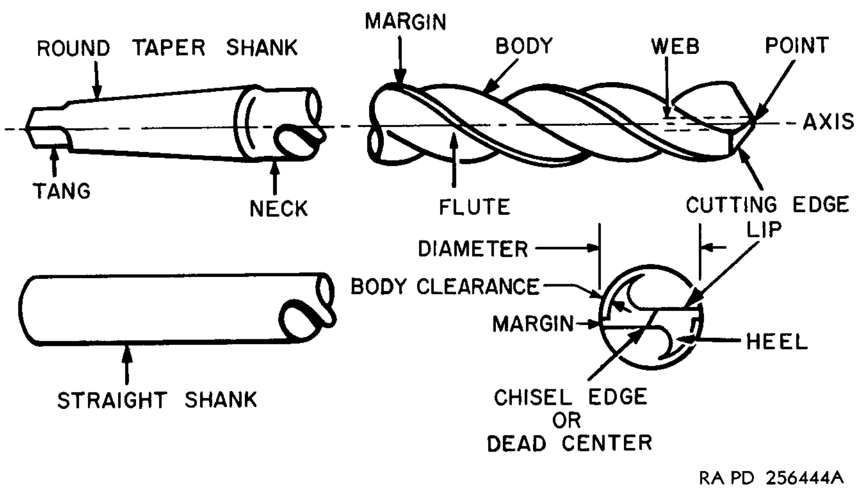


Figure 12. Twist drill nomenclature

(7) *Lip clearance.* The amount of slope given to the heel in back of the drill lips is called lip clearance. This clearance is necessary to keep the heel from rubbing the bottom of the hole being drilled. Rubbing would prevent the drill from cutting into the workpiece.

(8) *Flutes.* The helical grooves which appear twisted around the body of the drill are called flutes. They provide definite advantages to the drilling operation. They give correct rake to the lips, form channels through which chips can escape, permit cutting oil to flow to the edge of the cutting tool, and cause chips to curl tightly thus occupying less space.

(9) *Margin.* The margin is the narrow raised strip of the body which extends the full length of each flute. The distance from edge to edge of the margins (fig. 12) is the full diameter of the drill. The margin insures that the hole is the right size.

(10) *Body clearance.* The portion of the drill body that is relieved behind the margin is known as the body clearance. The diameter of this part is less than that of the margin and provides clearance so that all the body does not rub against the side of the hole and cause friction. The body clearance also permits passage of lubricants about the drill.

(11) *Tang.* The narrowed end of the tapered shank drill is called the tang. The tang fits the slot in the innermost end of the drill spindle, drill chuck, or other drill holding device and aids in driving the tool. It also prevents the drill from slipping.

(12) *Web.* The web of the drill is the metal section separating the flutes. It runs the length of the body between the flutes. The web gradually increases in thickness toward the shank, increasing the rigidity of the drill.

(13) *Axis.* An imaginary line through the center of the drill from end to end is the axis. The drill should rotate evenly about the axis at all times.

d. Sharpening Drills.

(1) *General.* Every drilling machine operator should be able to sharpen a twist drill properly for cutting the particular metal with which he is working. The drill grinding machine is designed to make the operation of sharpening a drill fairly simple but there are times when it is advisable and even necessary to grind the drill by hand. Carbon steel drills lose their temper when overheated so care must be taken not to let them get too hot. Occasional dipping of the drill in water is recommended. If part of a carbon steel drill being ground shows blue, it is an indication that the part has lost the temper. The drill must then be

shortened that much to eliminate the soft part. When grinding a high-speed drill, never cool it by immersing it in water as this will crack the lips. A drill-grinding gage should be used to check the accuracy of the grinding work. See table III for recommended grinding angles for twist drills. The operations in (2) through (5) below should be considered when sharpening a drill.

Table III. Lip Angles and Lip Clearances for Twist Drills

Materiel to be drilled	Lip angle (fig. 13) (deg)	Lip clearance (fig. 14) (deg)
Aluminum	30	12
Aluminum alloys	45	12 to 15
Bakelite	30	12
Brass	59	12 to 15
Bronze	59	12 to 15
Cast iron (soft)	45	12
Copper	50	12
Copper alloys	50	12
Fiber	30	12
Hard rubber	30	12
Plastic	59	30
Steel (hard)	75	7 to 12
Steel (heat-treated)	62½	12
Steel (soft and medium)	59	12 to 15
Wood	30	12

(2) *Grinding the cutting edge lips.* In grinding the lips of the drill, the following requirements should be met. The lips must be of the same length and of the same angle with the axis (fig. 13). After determining the lip angle (table III), the drill should be ground to that angle accurately. A point which is too flat will prevent the drill from centering properly in the workpiece. If the point is too steep, the drill will require more power and cut slowly. When the point is centered, but the angles of the cutting edges are different, only one lip will cut and the opposite side of the drill will bind (fig. 13). The hole will then be larger than the drill and the cutting edge will wear rapidly. When the angles of the lips are equal but the cutting edges are of different length, the point will no longer be central and will also result in oversize holes (fig. 13). When either or both the angle and length of the cutting edges are ground inaccurately, it results in strain on both the drill and drilling machine as well as poor quality. For most materials, each lip is commonly ground at an angle of about 59° with the axis.

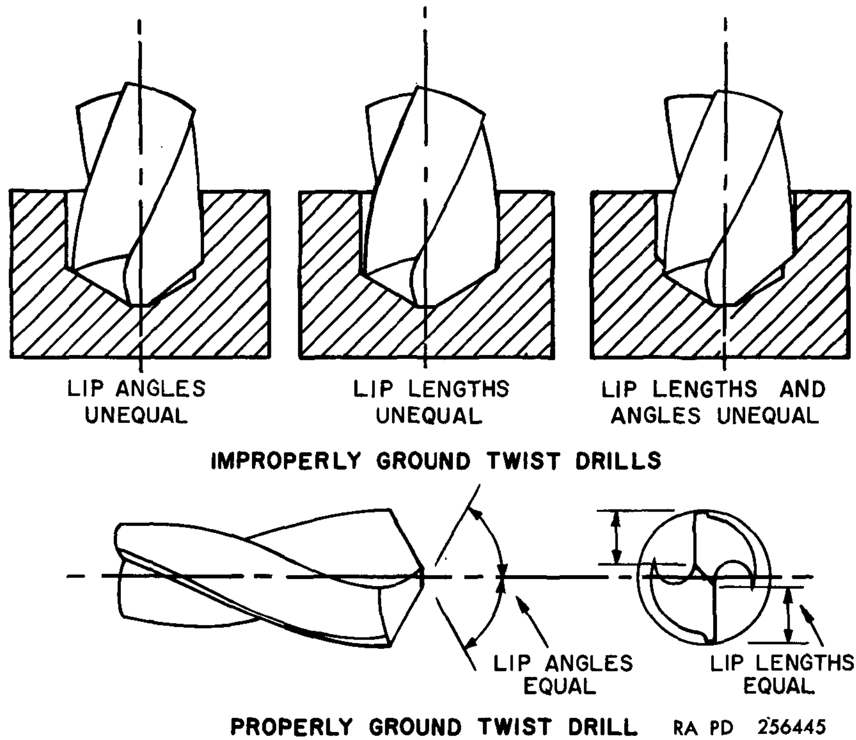


Figure 13. Effects of improperly ground lips.

(3) *Grinding the lip clearance angle.* The heel of the drill should be ground below the lips at an angle of from 12° to 15° measured at the circumference of the drill (fig. 14). At the center of the drill, the clearance angle will be greater than at the circumference. This is because the chips are distributed around a larger portion of the drill at the circumference than at the center. The chisel edge of a correctly ground drill should be at an angle of about 45° with the line of the cutting edges. The angle of the chisel edge with the lips is thus a guide to the clearance (fig. 14). Too much clearance will cause the drill to break down because of insufficient support of the lip and there will not be enough lip thickness to carry away generated heat. Too little clearance will result in the drill having little or no cutting edges and the increased pressure required to feed it into the hole will cause the drill to break. The drill may also make oversized holes.

(4) *Grinding the rake angle.* The angle between the flute and the axis of the drill that forms the cutting edge is known as the rake angle (fig. 14). Generally the angle of rake is

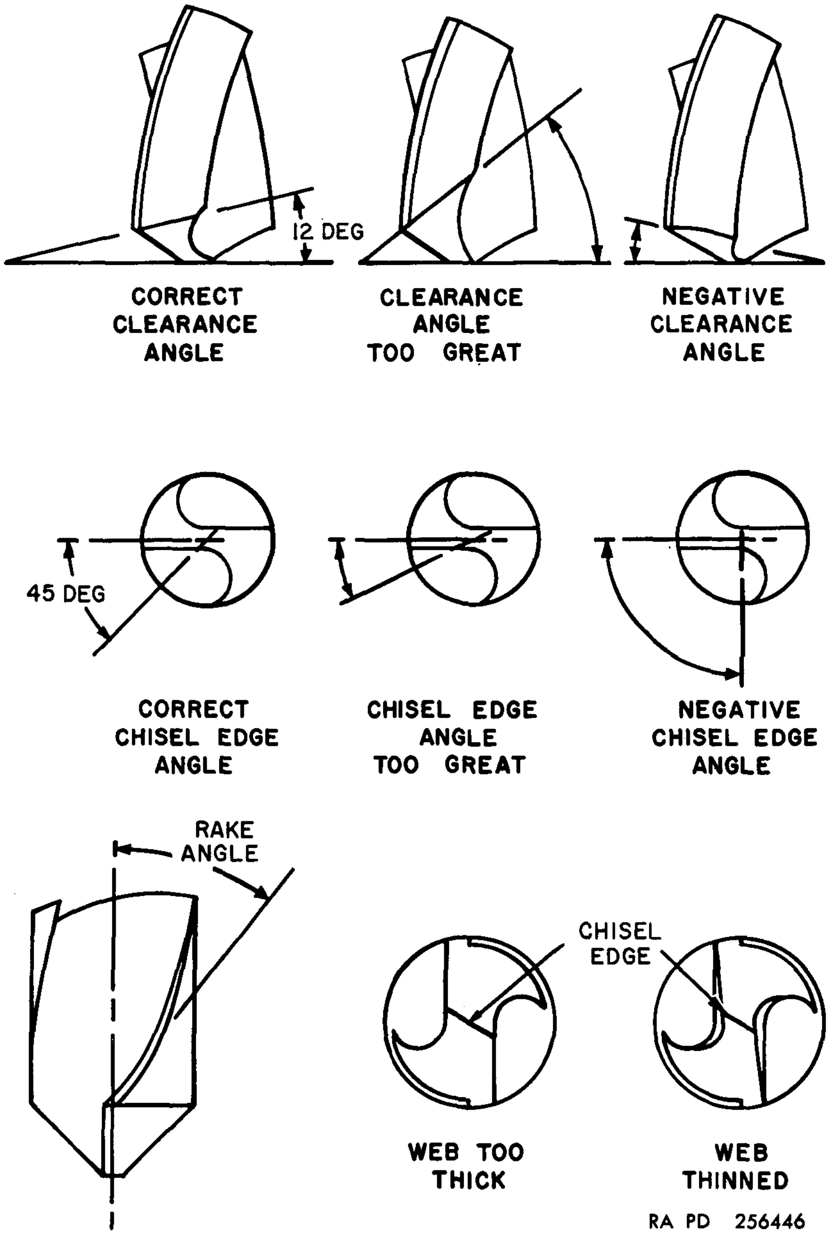


Figure 14. Identification of correct angles and web thickness.

between 18° and 45° with a rake angle of 30° being most common. However, very hard materials need a reduced rake angle to increase the support behind the cutting edge. Soft materials like brass or bronze also require a reduced rake angle to prevent the drill from grabbing. The rake angle partially governs the tightness with which the chips curl and hence the amount of space they occupy. If the rake angle is too small, the lips may be too thin and break under the strain of drilling. Too large a rake makes the cutting action of the lips inefficient.

(5) *Thinning the web.* The web of a drill is made thicker toward the shank to strengthen the tool. In smaller size drills, the difference is not noticeable but in larger drills when the point is ground back by repeated sharpening the thickness of the web becomes greater and the chisel edge of the drill becomes wider. This causes the chisel edge to scrape on the bottom of the hole and requires excessive pressure to be applied to the drill. This can be corrected by thinning the web. The point is ground thinner (fig. 14) on a thin grinding wheel with a rounded face to fit the flute. An equal amount of metal should be ground from each flute. The web should not be ground too thin which would weaken it and cause the drill to split.

22. Drill Grinding Machines

a. General. Drill grinding machines make the accurate grinding of all types and sizes of drills an easy job. Comparatively little skill is required to sharpen drills with these machines. They are particularly valuable when a large number of drills are required to be sharpened regularly.

b. Bench-Type Drill Grinding Machine. Two basic designs for bench-type drill grinding machines are described in (1) and (2) below. Both perform the same operations but use different drill holding devices. The capacity of these machines is stated in the horsepower of the electric motor and the sizes of drills which can be accommodated by the drill holding devices.

(1) The bench-type drill grinding machine illustrated at the top in figure 15 consists of an electric motor, a grinding abrasive wheel attached to the motor shaft, and fixtures to hold and position all types of twist drills for drill grinding procedures. A web thinning drill grinding attachment, drill holder assembly, and swinging arm hold the drill in a fixed position for each grinding operation and permit the cutting edge lips to be ground symmetrically at the correct angle and with the correct clearance to insure long life and efficient cutting. Collets and bushings are supplied with the drill grinding machine to hold a wide range of drill sizes. The grinding machine has a diamond set in the wheel dressing arm to dress the grinding abrasive wheel as necessary.

(2) Another bench-type drill grinding machine (fig. 15) is equipped with two grinding abrasive wheels, one at each end

of the motor shaft. One is a beveled wheel for thinning the web of the drill at the point. The other wheel is used for lip grinding. The grinder includes a drill holder assembly for mounting the drill and providing a means for bringing the drill into contact with the grinding abrasive wheel at the correct angle and feed to obtain proper clearance angles

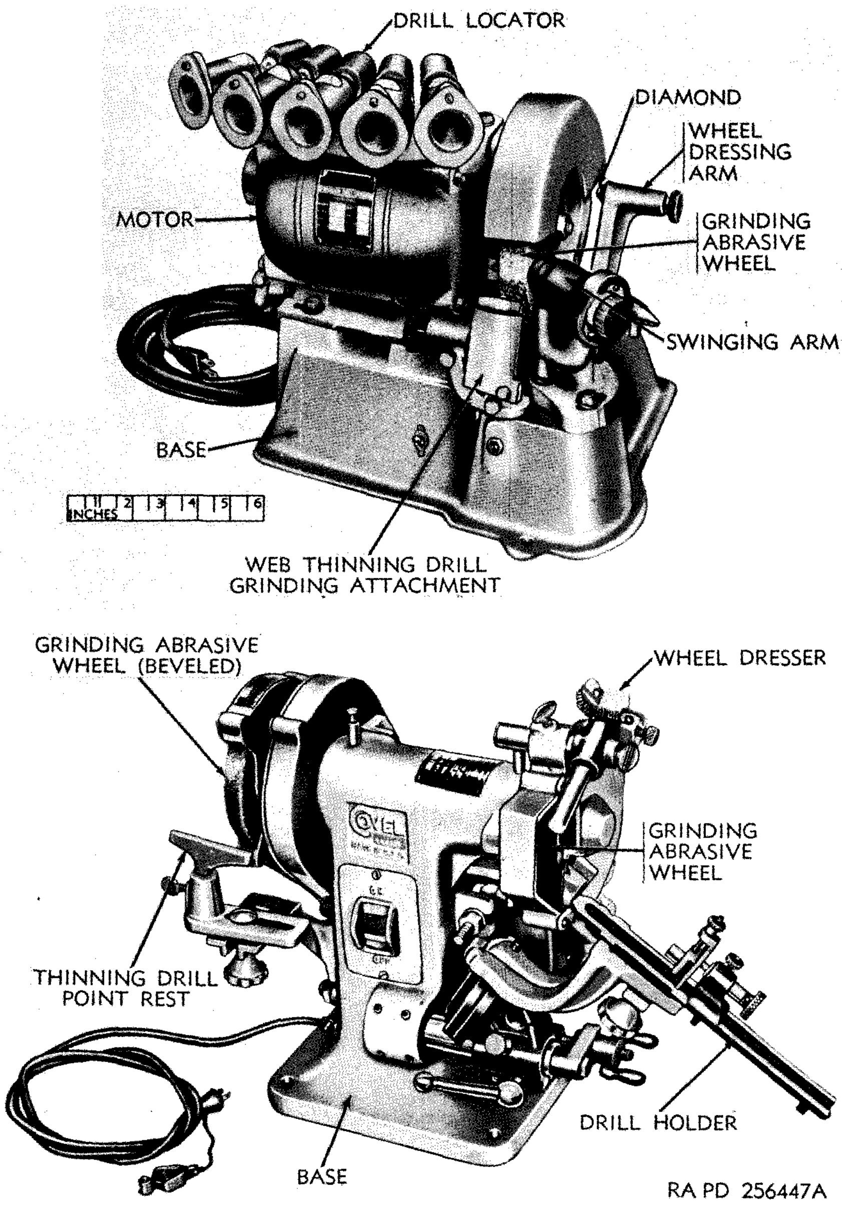


Figure 15. Bench-type drill grinding machines.

and form. A thinning drill point rest is mounted forward of the beveled grinding abrasive wheel to rest and guide the drill during web thinning operations. A wheel dresser is provided to dress the grinding abrasive wheel as necessary.

23. Special Drills

a. Three- and Four-Fluted Drills. These extra fluted drills (fig. 16) are not used to drill holes in solid material. They are adapted to enlarge cored, punched, or previously drilled holes. They are sometimes used in place of roughing reamers. These drills may be either straight or taper shanked.

b. Shell Drills. Shell drills (fig. 16) are made with a tapered hole and are used for the same purpose as three- and four-fluted drills. These drills are fitted on arbors.

c. Oilhole Drills. These drills are used for deep-hole drilling when lubrication is difficult. They have one or two oilholes for the cutting lubricant from the shank to the cutting point.

d. Oil Tube Drills. These drills (fig. 16) are similar to oilhole drills except they have oil tubes sunk in grooves in the body of the drill instead of holes.

e. Straight-Fluted Drills. Straight-fluted drills (fig. 16) have two flutes parallel to the axis of the drill. They are used for brass and other soft metals and will not grab or run ahead.

f. Dual-Cut Drills. Dual-cut drills (fig. 16) are two- or three-step combination drills with the bodies ground to size for the full length of the flutes. They are used in production work to perform drilling, counterboring, and countersinking in one operation.

g. High-Helix Drills These drills (fig. 16) have a helix or rake angle of about 40° for drilling of soft materials.

h. Bakelite Drills. Bakelite drills have wide, polished flutes for drilling in bakelite, fiber, and hard rubber.

i. Stove-Burner Drills. These drills (fig. 16) are made with very short flutes for great strength and are useful for drilling quantities of short holes.

j. Brass Drills. Brass drills are made of carbon steel with a special shape and are used for drilling brass.

k. Flat-Track Drills. Flat-track drills (fig. 16) are forged flat with a special milled point on the end.

l. Manganese Drills. These drills are short and stubby with a heavy cross section and thick web for drilling work-hardening manganese steels.

m. Flat Drills. Drills with the point flattened on two sides are used for extremely small holes. They may be made quickly if it is required to drill a hole for which no twist drill is available.

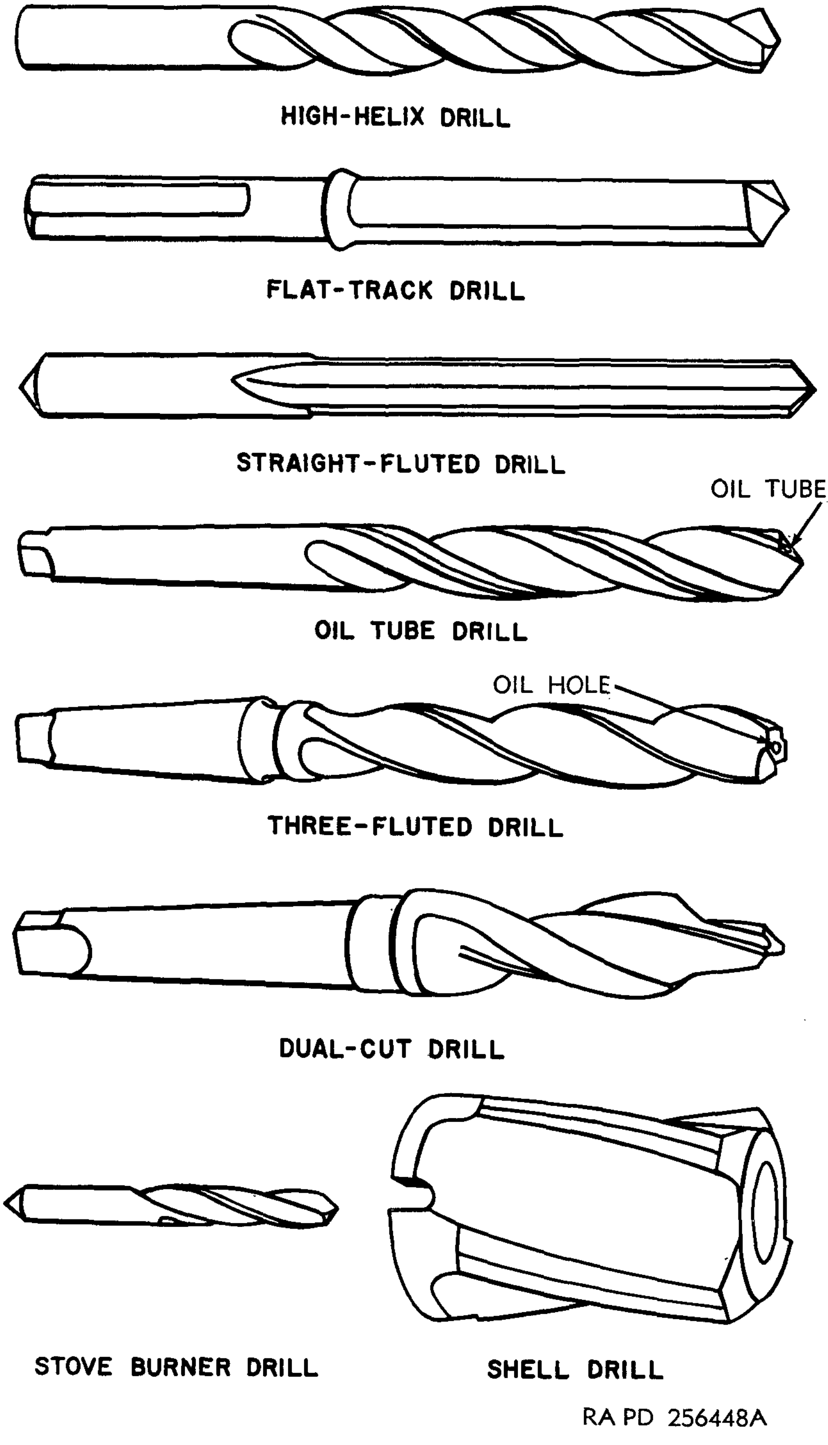


Figure 16. Special types of drills.

24. Drill Holding Devices

a. General. The revolving vertical spindle of the drilling machine holds and drives the cutting tool. The spindle is equipped with a hole through its center which has a standard Morse taper at the bottom end. The size of the taper varies with the size of the drilling machine. Tapers also vary on different size drills. Smaller cutting tools have no taper, being straight-shanked. Thus, in order to use the various sizes and shapes of drills in different machines, drill chucks, drill sockets, and drill sleeves (fig. 17) which fit the spindles of the drilling machines are used to hold the tool. Some drilling machines have solid spindles to accommodate chucks with internal threads or internal tapers.

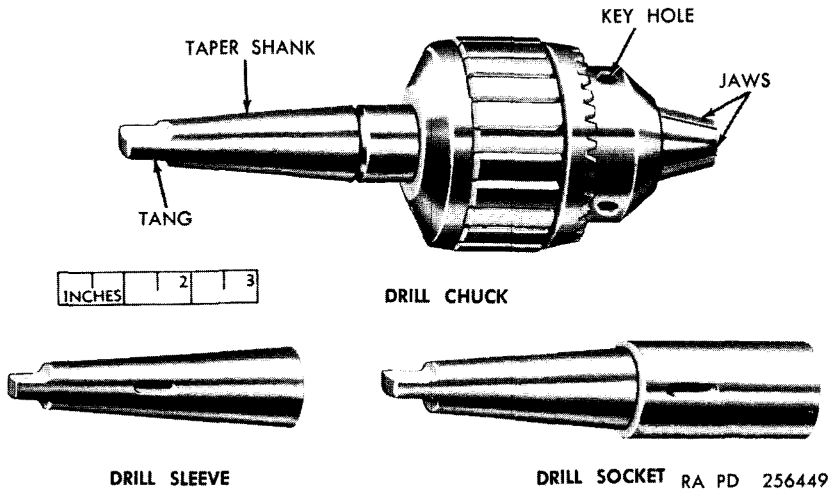


Figure 17. Drill holding devices.

b. Drill Chucks. Drills with straight shanks are held in drill chucks (fig. 17) which have two or more adjustable jaws set radially. Smaller size drills are made with straight shanks because of the extra cost of providing these sizes with tapers. Chucks are made in various sizes and a set of chucks may hold cutting tools from the smallest sizes up to 1 inch in diameter. The shank of the chuck is set into the spindle of the drilling machine and the drill is then locked into the chuck. The jaws of the chuck are tightened simultaneously by the use of a chuck key. Morse tapers to fit drill spindles are commonly used on drill chuck shanks.

c. Drill Sockets and Drill Sleeves. The size of the tapers of cutting tools often varies with the size of drilling machine spindles. Therefore, devices must be used to mount the various drills in the spindles of the machines. Drill sockets and drill sleeves (fig. 17) are used for this purpose either singly or in combination. A drill too small for a spindle may be fitted into a socket or sleeve which has a taper hole of the proper size to hold the drill and a taper shank of the proper size to fit the drill spindle. Sometimes more than one socket or sleeve is required to build up the drill size to fit the spindle. Sockets and sleeves may be obtained in a number of different sizes and hole-shank taper combinations.

25. Drill Drifts

Drill drifts (fig. 22) are flat, tapered keys with one rounded edge which are used to remove taper-shanked drills and holding devices from drilling machine spindles. They are forced through the slots in the drill sleeve, drill socket, or drilling machine spindle to wedge the drill from its seat.

26. Work-Holding Devices

a. Machine Table Vises. A machine table vise (fig. 18) is a device equipped with jaws which clamp against the workpiece, holding it secure. The vise is then bolted to the drilling machine table or supported by a stop which is bolted to the table.

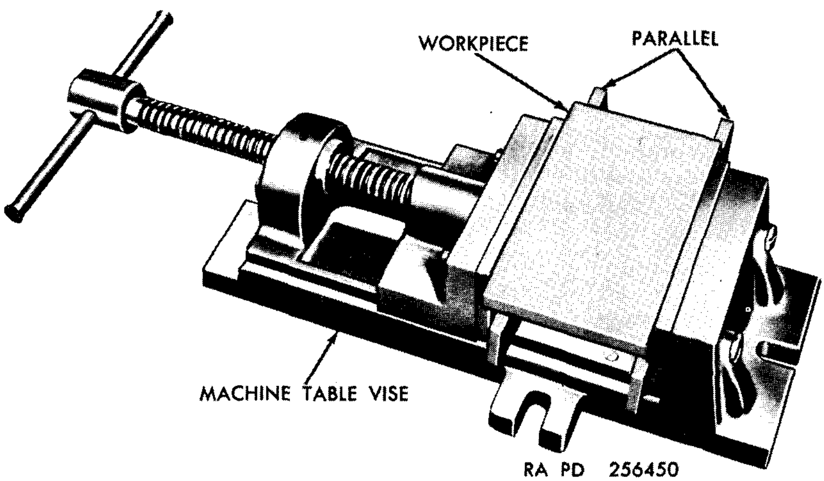


Figure 18. Machine table vise and parallels used to mount workpieces.

b. Parallels. To prevent the drilling tool from cutting on through the workpiece and into the table or vise, accurately machined parallel bars called parallels (fig. 18) are used between the workpiece and the table. The workpiece and parallels are clamped together to the table.

c. Blocks. A plain block of the required dimensions and suitable material may be used with a clamp to mount workpieces.

d. Step Blocks. Blocks with steps for workpieces of various heights are extremely useful in mounting different jobs (fig. 19).

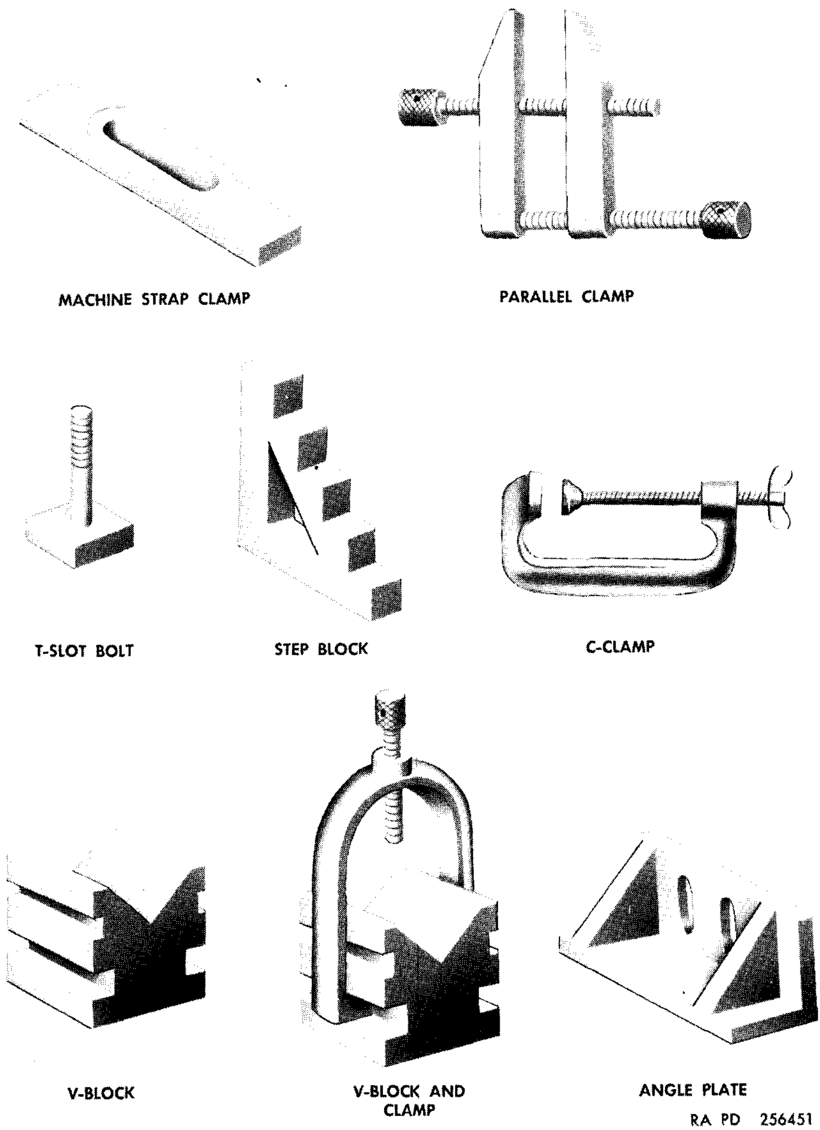


Figure 19. Various types of work holding devices.

e. Clamps. Clamps are small, portable vises or plates which bear against the workpiece and holding devices to steady the job. Clamps are made in numerous shapes to meet the varied work holding problems. Common types of clamps include the C-clamp, the parallel clamp, and the machine strap clamp (fig. 19).

f. V-Blocks. V-blocks (fig. 19) are used to hold round shaped workpieces. The size of the V-block used is determined by the diameter of the work. A V-block and clamp (fig. 19) are sometimes used to hold work securely.

g. Angle Plates. Angle plates (fig. 19) with holes and slots for clamps or bolts to secure the workpiece and fasten the plates to worktable are used for many drilling machine operations.

h. T-Slot Bolts. T-slot bolts (fig. 19) are inserted in the T-slots in worktables so equipped to fasten the workpiece or work holding device to the table. The studs of tapped T-slot bolt heads may be removed and a number of different lengths may be used.

i. Jigs. Drill jigs are used when several workpieces have to be drilled identically. The workpiece is clamped in the jig so that the hole or holes will be drilled in the same location on each piece. The jig may guide the cutting tool through a steel bushing to locate the holes accurately.

j. Shims. Thin pieces of metal or other material, called shims are used to build up or support the holding devices when extra adjustments are needed.

Section III. LAYING OUT AND MOUNTING WORK

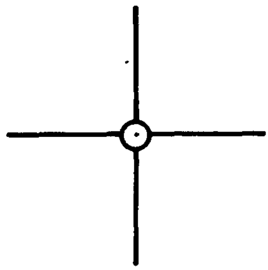
27. Laying Out Work

a. Laying out work for drilling operations consists of locating on the workpiece the centers of the holes to be drilled. If the work does not require extreme accuracy, laying out may be a simple operation. A chalk pencil and a steel rule are generally sufficiently accurate for approximate layouts. For more precise jobs, however, the workpiece should first be prepared with a light application of copper sulfate solution.

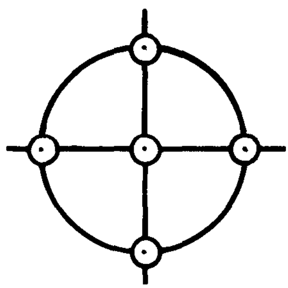
b. The position of the center of the hole to be drilled is marked by scribing two or more lines which intersect at the hole center (A, fig. 20). This point is then marked lightly with a prick punch and hammer. Check to see that the mark is exactly at the point of intersection of the lines, using a magnifying glass if necessary. A pair of dividers set to the radius of the hole to be drilled is used to scribe a circle on the workpiece (B, fig. 20). The prick punch is then used to make small indentations known as "witness marks," on the circumference. This marks the circle. If a check is anticipated to see that the layout has been followed after the hole has been drilled, a second circle should be scribed outside the first (C, fig. 20).

c. When all scribing has been done, enlarge the prick punch mark with a center punch. If this is done before the dividers are used, the dividers will have a tendency to walk. Enlarging the mark with a center punch allows the chisel edge of the drill to enter and also permits the cutting edge lips to cut.

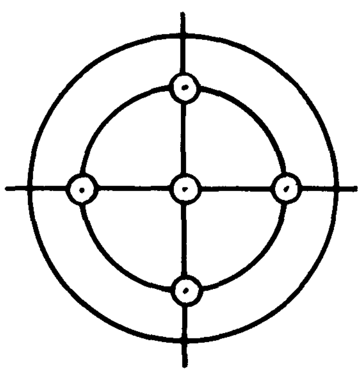
d. In drilling more than one hole in a workpiece when no jig is available, the hole locations must be laid out in relation to one another.



A. CENTER PUNCH MARK AT INTERSECTION OF SCRIBED LINES.



B. SCRIBE CIRCLE SAME SIZE AS HOLE TO BE DRILLED AND PUNCH WITNESS MARKS.



C. SCRIBE SECOND CIRCLE TO PERMIT CHECKING OF LAYOUT AFTER DRILLING HOLE.

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Figure 20. Laying out for accurate drilling.

The intersecting lines must first be made and then each circle and mark prepared as above. Check each hole carefully for its relation to the other and its position on the workpiece.

Note. When circles become more or less obscure, rescribing should be done from a prick punch mark rather than from a center-punch mark.

To help in gaging the central position of the hold before the drill cuts to its full diameter, a smaller circle can be scribed within the first from the center mark.

28. Mounting Workpieces

a. Before attempting to use a drilling machine, some provision must be made for holding the workpiece securely in place on the table of the drilling machine. The job should always be firmly fastened to the table if an accurately located hole is desired. Work holding devices (fig. 19) are used for holding the workpiece.

b. Most sensitive-type drilling machines have no means of clamping or bolting workpieces to the table. The workpiece must be secured

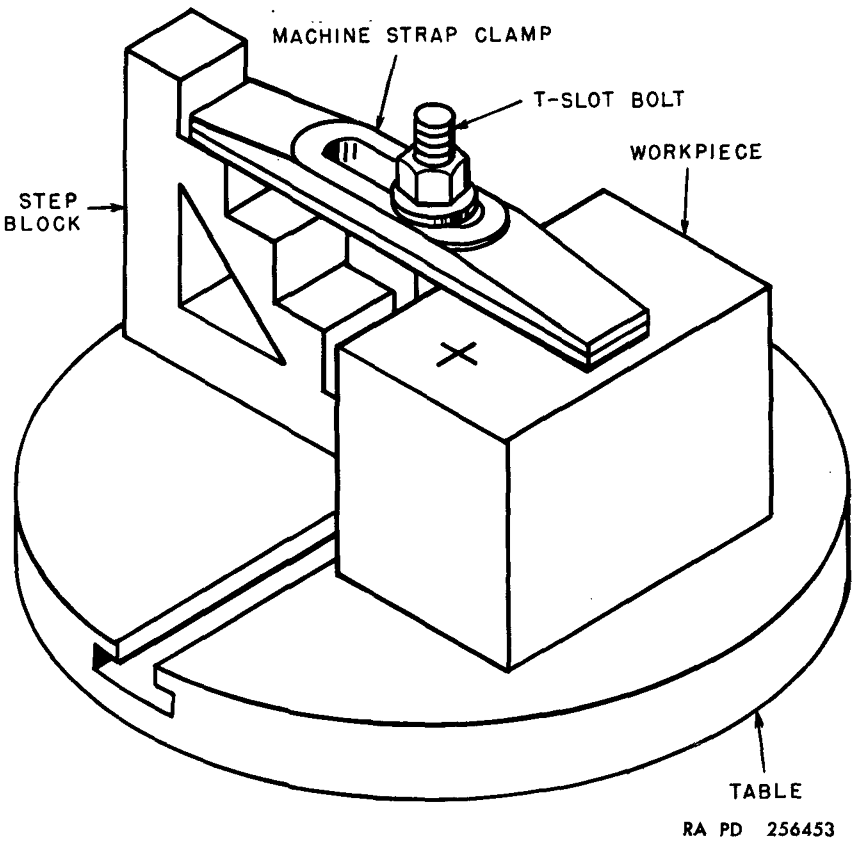


Figure 21. Mounting work using step block, machine strap clamp, and T-slot bolt.

tightly in a machine table vise (fig. 18) and centered under the drill by hand. Work done by sensitive-type drilling machines usually is comparatively light and the weight of the vise is sufficient to hold the workpiece steady. Other drilling machines have slotted tables so that the workpiece and work holding device can be bolted or clamped firmly. All workpieces should be either clamped to the table or set against a stop.

c. When a workpiece is well mounted, clamps are parallel to the table and bolts are as close to the workpiece as possible (fig. 21). Parallels should also be placed near the area to be drilled, as the workpiece tends to spring and bind the drill if they are too far apart. T-slot bolts should be just long enough for the job, and clamps and V-blocks should be of the right type and size.

Section IV. GENERAL DRILLING OPERATION

29. General

This section provides instructions for the operation of drilling machines after the workpiece has been laid out and mounted (pars. 27 and 28). For specific instructions peculiar to specific machines, refer to the pertinent TM 9–3400- and TM 9–9000-series manuals.

30. Selecting Drill Speed

a. Correct speeds are essential for satisfactory drilling machine operation. The speed at which a drill cuts is called the peripheral speed.

b. Peripheral speed is the speed of a drill at its circumference in feet per minute (sfpm). This speed is the distance a drill would travel if rolled on its side. For example, a peripheral speed of 30 feet per minute would enable a drill to roll 30 feet in 1 minute. Knowing the peripheral speeds, it is possible to compare cutting speeds regardless of whether either the tool or the workpiece is revolved, as in drilling and lathe operations. To calculate the revolutions per minute necessary for a drilling operation, use the following formula:

$$\text{rpm}=\frac{\text{sfpm}}{\pi D}$$

where, rpm = drill speed (in revolutions per minute);

sfpm = peripheral speed (in in. per minute);

$\pi = 3.1416$;

D = diameter (in in.) of drill.

For example, if a $\frac{1}{16}$-inch (0.0625-in.) drill is to cut 15 feet (180 in.) per minute to drill slate, the drill speed is calculated as follows:

$$\text{rpm}=\frac{\text{sfpm}}{\pi D}=\frac{180}{3.1416\times 0.0625}=916 \text{ rpm}$$

c. Since drilling machines are designed so that different spindle speeds (the speed at which the drill is rotated) may be selected, table IV

Table IV. Rotational Speed and Feed for High-Speed Steel[1] Twist Drills

Diameter of drill (in.)	Material and cutting speed (ft per minute)											Feed per revolution (in.)
	Aluminum	Brass	Cast iron	Mild steel 0.2–0.3 carbon	Steel 0.4–0.5 carbon	Tool steel 1.2 carbon and drop forgings	Conn. rod molybdenum steel	3.5 nickel steel	Stainless steel and monel metal	Malleable iron	Slate	
	300	200	100	110	80	60	55	65	50	85	15	
	Revolutions per minute											
1/16	18, 336	12, 224	6, 112	6, 724	4, 883	3, 668	3, 404	3, 976	3, 056	5, 192	916	0. 0015
1/8	9, 168	6, 112	3, 056	3, 362	2, 444	1, 834	1, 702	1, 988	1, 528	2, 596	458	0. 002–0. 003
3/16	6, 108	4, 072	2, 036	2, 242	1, 630	1, 222	1, 120	1, 324	1, 018	1, 734	306	0. 004
1/4	4, 584	3, 056	1, 528	1, 681	1, 222	917	851	994	764	1, 298	229	0. 005
5/16	3, 666	2, 444	1, 222	1, 344	978	733	672	794	611	1, 039	184	0. 005
3/8	3, 054	2, 036	1, 018	1, 121	815	611	560	662	509	867	153	0. 006
7/16	2, 622	1, 748	874	921	699	524	481	568	437	742	131	0. 007
1/2	2, 292	1, 528	764	840	611	459	420	497	382	649	115	0. 008
9/16	2, 037	1, 358	679	747	543	407	373	441	340	577	102	0. 008
5/8	1, 836	1, 224	612	673	489	367	337	398	306	520	92	0. 009
11/16	1, 665	1, 110	555	611	444	333	300	360	273	472	84	0. 009
3/4	1, 524	1, 016	508	559	408	306	279	330	254	433	77	0. 010
13/16	1, 422	948	474	521	379	285	261	308	237	403	71	0. 010
7/8	1, 314	876	438	482	349	262	241	285	219	371	66	0. 011
15/16	1, 221	814	407	448	326	244	224	265	204	346	61	0. 012
1	1, 146	764	382	420	306	229	210	258	191	325	58	0. 013
1 1/16	1, 077	718	359	395	287	215	197	233	180	305	54	0. 013
1 1/8	1, 020	680	340	374	272	204	187	221	170	288	51	0. 014
1 3/16	966	644	322	354	258	193	177	209	161	274	48	0. 014
1 1/4	918	612	306	337	245	183	168	199	153	260	46	0. 015

1 5/16	873	582	291	320	233	175	160	189	146	248	44	0. 015
1 3/8	834	556	278	306	222	167	153	180	139	236	42	0. 015
1 7/16	795	530	265	292	212	159	146	172	133	225	40	0. 015
1 1/2	762	508	254	279	204	153	140	165	127	216	38	0. 015
1 9/16	732	488	244	268	195	146	134	159	122	207	37	0. 016
1 5/8	702	468	234	257	188	141	129	152	117	201	35	0. 016
1 11/16	678	452	226	249	181	136	124	147	113	192	34	0. 016
1 3/4	654	436	218	240	175	131	120	142	109	186	33	0. 016
1 13/16	630	420	210	231	168	126	116	137	105	179	32	0. 016
1 7/8	612	408	204	224	163	122	112	133	102	173	31	0. 016
1 15/16	591	394	197	216	158	118	108	128	99	168	30	0. 016
2	573	382	191	210	153	115	105	124	96	162	29	0. 016

[1] Rotational speed values for carbon-steel twist drills are 40 to 50 percent higher with approximately the same feed.

is provided. This table will facilitate determining spindle speeds (rpm) for carbon-steel and high-speed twist drills of various sizes depending on the material to be drilled. Table V is provided for the machinist who wishes to make his own calculations using the formula in *b* above. If the exact revolutions per minute (rpm) desired is not available on the drilling machine, it is generally better to use a higher speed than a lower speed.

Table V. Drill Speeds for Different Materials (High-Speed Steel Drills [1])

Material	Cutting speed [1] (f. p. m.)
Aluminum and alloys	200–300
Bakelite	100–150
Brass	200–300
Bronze	200–300
Bronze, high tensile	70–150
Carbon, pure (carbide drills)	100
Cast iron, soft	100–150
Cast iron, hard	70–100
Cast iron, chilled	30–40
Copper graphite alloy (carbide drills)	60–70
Glass (carbide drills)	20–30
Iron, malleable	80–90
Magnesium and alloys	250–400
Marble	15–25
Marble (carbide drills)	60–80
Monel	40–60
Nickel	40–60
Slate	15–25
Slate (carbide drills)	40
Steel, machinery (0.2–0.3c)	80–110
Steel, annealed (0.4–0.5c)	70–80
Steel, tool (1.2c)	50–60
Steel, forged	50–60
Steel, alloy	50–60
Steel, alloy (300 to 400 Brinnel)	20–30
Steel, stainless, free machining	30–40
Steel, stainless, hard	30–40
Steel, manganese	15
Stone	15–25
Stone (carbide drills)	30
Wood	300–400

[1] These speeds are for high-speed steel drills except as indicated. Carbon steel drill speeds are 40 to 50 percent of high-speed drill speeds.

31. Selecting Drill Feed

Feed is the distance a drill travels into the workpiece during each revolution. It is expressed in fractions of an inch or decimals. The best feed depends on the size of the drill and the material being drilled.

Feed should increase as the size of the drill increases. Feed is the same for both high-speed steel and carbon steel drills. For drills less than ¼ inch, hand feed is used. When starting a hole, a very light feed should be used. If the drilling machine is power-fed, the drill should be started into the workpiece by hand. Too much feed will cause the cutting tool to split. For drills under ⅛ inch in diameter, use a feed of 0.001 to 0.002 inch per revolution; for drills ⅛ to ¼ inch, use a feed of about 0.003 inch; for drills ¼ to ½ inch, use a feed of about 0.005 inch; for drills ½ to 1 inch, use a feed of about 0.010 inch; and for drills over 1 inch, use a feed of about 0.015 inch. Feed for hard materials should be generally less than those given above and for soft materials, such as cast iron, brass and aluminum, the feed should be heavier. Refer to table IV for additional information.

32. Installing and Removing Drill

a. Before installing the drill into the drilling machine spindle, make sure that the inside of the spindle socket and the shank and tang of the drill are smooth, clean, and free from nicks and burs. Considerable power is needed to drive large drills and both shank and tang must carry part of the load. If the shank or taper hole is dirty or rough, the shank will not fit snugly. The tang will then have to carry all the strain and will twist or break. When using sockets, sleeves, and chucks make the same inspection.

b. Insert the taper shank of the drill or drill holding device into the spindle of the drilling machine so that the tang slips into the keyway in the smaller end of the spindle (fig. 22). The positive engagement of the tang in the keyway aids the frictional engagement of the taper shank in turning the drill. Frictional resistance of the taper alone is sufficient for small drills. The drill may be fitted into the spindle by striking the end of the drill with a rawhide hammer. Another method is to put a block of wood on the table of the drilling machine under the drill. Then, with the feed handle, bring the drill point down sharply against the wood to drive the shank snugly into the hole. When using a chuck, install it in the same way and then lock the drill in the chuck. To remove the drill, a drill drift is driven through the slot in the spindle or holding device. The rounded edge of side of the drill drift (fig. 22) is inserted and driven against the top side of the slot.

33. Starting Holes

a. Before beginning to drill, the height of the spindle should be adjusted so that the drill is close to the workpiece. If the drilling machine is of the power feed type, the proper speed for the particular drilling operation should be set (par. 30).

b. Lower the drill to the mounted workpiece and aline the point of the drill with the center punch mark by placing the point in the center punch impression. Start the machine and feed the drill slowly by hand until the impression is slightly larger than the center punch mark or about half to two-thirds the diameter of the drill.

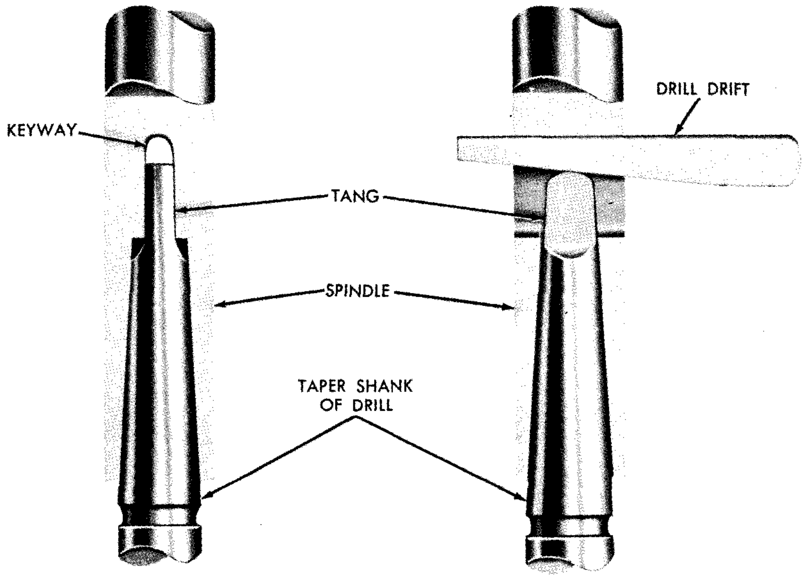


Figure 22. Installing and removing drill.

c. Lift the drill from the workpiece to see if this impression is concentric with the scribed circle or circles. Often the drill will not be correctly centered, sometimes due to a poorly made center punch mark or a hard spot in the metal. To draw the twist drill back to the position desired, a machinist's chisel is used to make one or more nicks or grooves on the side toward which the drill is to be drawn (fig. 23). The nicks are made on the side of the drilled hole. The chisel marks will draw the drill because the cutting tool always tries to follow the line of least resistance. Thus, it is important never to try to move the drill or the workpiece to try to recenter the hole. If moved, the drill will spring off center to follow the hole already started.

d. When the chisel mark has been made, the drill is again hand fed into the hole and is then rechecked for concentricity. This operation must be performed before the drill point has enlarged the hole to full diameter or the surface of the workpiece will be marred. If the drill has been properly centered, the hole will obliterate all of the smaller scribed circle, leaving half of each prick punch mark showing (fig. 23).

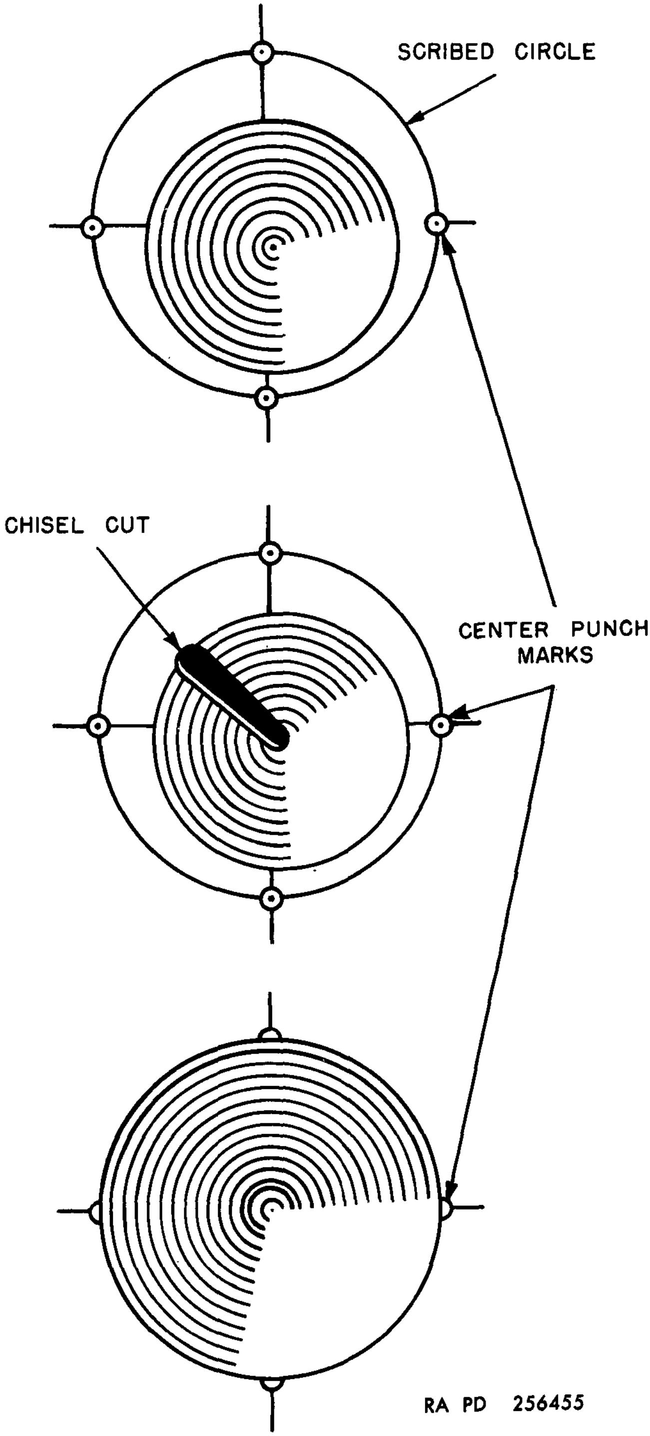


Figure 23. Drawing drill back to correct center.

e. When power-feed drilling machines are being used, the power feed may be accelerated after the drill is properly centered.

34. Drilling

a. After the hole has been started, lubricate and continue drilling at the speed (par. 30) and feed (par. 31) determined to be best for the job. Lubrication is necessary to maintain the speeds and feeds for various drilling operations, to obtain maximum cutting efficiency, and to avoid overheating either the drill or the workpiece. Cutting oils or lubricants to be used depend on the material being machined and are tabulated in table VI. They apply to carbon steel or high-speed steel drills. Use cutting oils freely.

Table VI. Cutting Oils for Drilling

Material to be drilled	Cutting oil
Aluminum	Soluble cutting oil; mineral-fatty-blend cutting oil.
Brass	Dry; soluble cutting oil; sulfurized-fatty-mineral cutting oil.
Bronze	Dry; soluble cutting oil; sulfurized-fatty-mineral cutting oil.
Cast iron	Dry.
Copper	Dry; mineral-fatty-blend cutting oil; soluble cutting oil.
Glass	Dry.
Iron, malleable	Dry; soda water, soluble cutting oil.
Marble	Dry.
Monel metal	Pure lard cutting oil; sulfurized-fatty-mineral cutting oil.
Slate	Dry.
Steel, alloy	Mineral-fatty-blend cutting oil; sulfurized-fatty-mineral cutting oil.
Steel, machine	Soluble cutting oil; mineral-fatty-blend cutting oil.
Steel, tool	Pure lard cutting oil; sulfurized-fatty-mineral cutting oil.
Steel, stainless	Pure lard cutting oil; sulfurized-fatty-mineral cutting oil.
Wood	Dry.

b. If the depth of the hole being drilled is greater than four times the diameter of the drill, remove the drill from the workpiece at frequent intervals and clean the chips from the flutes of the drill and the hole being drilled. A slight increase of speed and decrease of feed is often used to give the chips a greater freedom of movement.

c. If the drill is removed from the hole when drilling steel, check to see that no chip is lodged between the point of the drill and the bottom of the hole. When this happens and the machine is restarted, the drill will ride on the chip. This will cause a tremendous strain on the machine and if allowed to continue will cause either the machine or the cutting tool to break. Feed should always be started by hand to see that the drill is cutting properly before throwing in the power feed.

d. As drill sizes increase, the size of the web, and consequently the width of the chisel edge, increases. The chisel edge of the drill does not have a sharp cutting action, scraping rather than functioning as do the lips of the drill. In larger drills, this creates a considerable strain on the machine. To eliminate this strain when drilling a large hole, a pilot hole is drilled first and then followed with the large drill. A drill whose diameter is slightly larger than the web thickness of the large drill is used for the pilot hole. This hole should be drilled accurately as the larger drill will follow the small hole.

e. When average-size holes are to be drilled on small drilling machines the same procedure can be used. The small machine may not have enough power to drive the drill through the metal. Pilot holes should not be drilled larger than necessary as the large drill may chatter and drill out-of-round or may spoil the top of the hole.

f. When a hole is drilled entirely through a workpiece, ease up on the drill as it breaks through the bottom. The drill will have a tendency to "dig in" when breaking through, especially when drilling thin pieces.

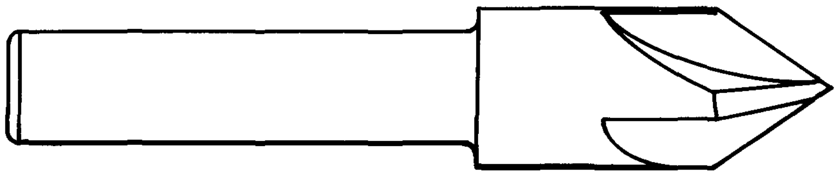
g. For drilling small or thin workpieces, it is sometimes convenient to set them on a block or piece of wood. The depth gage should be set to permit drilling through the workpiece but not through the wood.

35. Countersinking

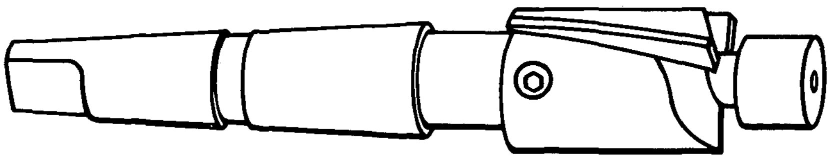
a. Countersinking is the tapering or beveling of the end of the hole with a conical cutter called a machine countersink. Often a hole is slightly countersunk to guide and prevent burring of pins which are to be driven into the workpiece, but more commonly, countersinking is used to form recesses for flat-head and oval-head screws, and is similar to counterboring (par. 38).

b. Machine countersinks (fig. 24) for machining recesses for screw heads have an included angle of 82°. Some machine countersinks have a pilot on the tip to guide the tool into the hole, although most common machine countersinks do not. With a pilot the countersink is limited in use to a single size hole and is therefore not practical for most small machine shop operations.

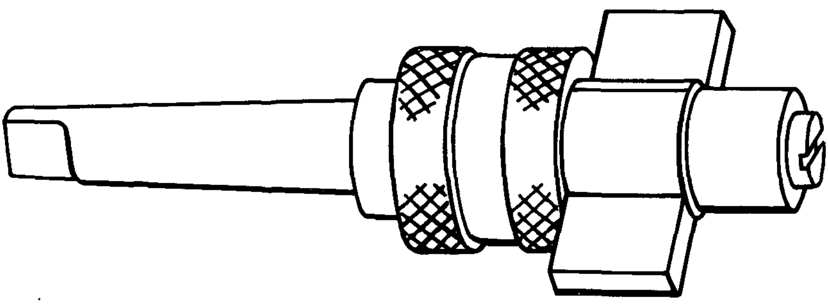
c. Proper alinement of the machine countersink and the hole to be recessed are important. Failure to aline the tool and spindle with the axis of the hole or failure to center the tool over the hole will result in an eccentric or out-of-round recess.



STRAIGHT SHANK MACHINE COUNTERSINK



TAPER SHANK COUNTERBORE



TAPER SHANK REMOVABLE-BLADE COUNTERBORE

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Figure 24. Countersink and counterbores.

d. Good countersinking procedure includes running the machine countersink slowly and feeding lightly. A proper cutting oil should be used to produce a smooth job. Rough countersinking is usually caused by too much speed, dull tools, and failure to clamp the workpiece firmly or aline it properly.

Section V. SPECIAL OPERATIONS ON DRILLING MACHINES

36. Tapping

a. Tapping is the cutting of a thread in a drilled hole. Two methods of tapping can be performed with the drilling machine.

b. When using the drilling machine only as a guide for hand tapping, the job is mounted on the table of the drilling machine or in a vise. An adjustable tap and reamer wrench is mounted on the square shank of the tap and a lathe center is installed in the drilling machine spindle. The tap is placed in the workpiece hole and the lathe center point is placed in the center hole in the shank end of the tap. The tap is held steady without forcing by keeping pressure on it with the hand-feed lever of the drilling machine.

c. Tables VII and VIII are provided for selecting the proper twist drill to use for drilling a hole that is to be tapped. Table VII lists American National Screw Thread pitches and appropriate tap drill sizes to be used. Table VIII lists National Taper Pipe Thread pitches and appropriate tap drill sizes. If a larger twist drill than the recommended size is used, the tap will not cut threads in the hole.

d. The alternate method for hand tapping is the use of a special tapping attachment. There are a number of tapping attachments with taper shanks which fit the drilling machine spindle. Tapping attachments are provided with friction clutches. When the tap jams in a hole, sticks, or has to perform under excessive pressure, the clutch will slip to keep the tap from breaking. A spindle reversing mechanism of the tapping attachment operates upon raising the spindle to cause the machine to back the tap out of the hole. The reversing mechanism is highly efficient when properly used. No automatic stop is provided, however, so the spindle must be stopped or reversed at the proper time. The feed stop only halts the spindle advance and not its rotation.

e. A typical attachment (fig. 25) has a tap holder held by spring tension in the body. To start the tap, a slight pressure is used. The tap advances and pulls the spindle until reaching the stop. When the spindle stops moving, the tap continues threading into the hole against the force of the spring until the driving pins disengage and the tap stops revolving. The spindle is reversed to draw the tap out. Identical holes may be tapped without trouble if the spindle stop is set properly. When tapping use, plenty of cutting oil and set the workpiece against one or more stops so it can center itself.

f. Power tapping is more accurate and less expensive than tapping by hand. The thread is usually clean and true and tap breakage is less frequent.

37. Reaming

a. Drilling operations are not always accurate or provide a smoothly finished hole. Drilling a hole to the exact size of the drill is almost impossible because it is extremely difficult to grind drills so that both cutting edges have exactly the same length. The difference in cutting edge length may be several thousandths of an inch. Drills, then, invariably cut a hole larger than their diameter.

Table VII. Amercian National Standard Screw Thread Pitches and Tap Drill Sizes

Screw thread size and pitch	Outside diameter of screw (in.)	Lettered, numbered or fractional size of tap drill	Decimal equivalent of drill size
National Coarse (NC) Series			
No. 1–64	0. 073	53	0. 0595
No. 2–56	0. 086	50	0. 0700
No. 3–48	0. 099	47	0. 0785
No. 4–40	0. 112	43	0. 0890
No. 5–40	0. 125	38	0. 1015
No. 6–32	0. 138	36	0. 1065
No. 8–32	0. 164	29	0. 1360
No. 10–24	0. 190	25	0. 1495
No. 12–24	0. 216	16	0. 1770
$\frac{1}{4}$–20	0. 250	7	0. 2010
$\frac{5}{16}$–18	0. 3125	F	0. 2570
$\frac{3}{8}$–16	0. 375	$\frac{5}{16}$	0. 3125
$\frac{7}{16}$–14	0. 4375	U	0. 3680
$\frac{1}{2}$–13	0. 500	$\frac{27}{64}$	0. 4219
$\frac{9}{16}$–12	0. 5625	$\frac{31}{64}$	0. 4843
$\frac{5}{8}$–11	0. 625	$\frac{17}{32}$	0. 5312
$\frac{3}{4}$–10	0. 750	$\frac{21}{32}$	0. 6562
$\frac{7}{8}$–9	0. 875	$\frac{49}{64}$	0. 7656
1–8	1. 000	$\frac{7}{8}$	0. 875
National Fine (NF) Series			
No. 0–80	0. 060	$\frac{3}{64}$	0. 0469
No. 1–72	0. 073	53	0. 0595
No. 2–64	0. 086	50	0. 0700
No. 3–56	0. 099	45	0. 0820
No. 4–48	0. 112	42	0. 0935
No. 5–44	0. 125	37	0. 1040
No. 6–40	0. 138	33	0. 1130
No. 8–36	0. 164	29	0. 1360
No. 10–32	0. 190	21	0. 1590
No. 12–28	0. 216	14	0. 1820
$\frac{1}{4}$–28	0. 250	3	0. 2130
$\frac{5}{16}$–24	0. 3125	I	0. 2720
$\frac{3}{8}$–24	0. 375	Q	0. 3320
$\frac{7}{16}$–20	0. 4375	$\frac{25}{64}$	0. 3906
$\frac{1}{2}$–20	0. 500	$\frac{29}{64}$	0. 4531
$\frac{9}{16}$–18	0. 5625	$\frac{33}{64}$	0. 5156
$\frac{5}{8}$–18	0. 625	$\frac{37}{64}$	0. 5781
$\frac{3}{4}$–16	0. 750	$\frac{11}{16}$	0. 6875
$\frac{7}{8}$–14	0. 875	$\frac{13}{16}$	0. 8125
1–14	1. 000	$\frac{15}{16}$	0. 9375

Table VIII. National Taper Pipe Thread Pitches and Tap Drill Sizes

Nominal thread size (in.)	Threads per inch	Major pipe diameter (in.)	Tap drill size (in.)	Decimal equivalent of drill size (in.)
1/8	27	0. 405	21/64	0. 32813
1/4	18	0. 540	29/64	0. 45313
3/8	18	0. 675	19/32	0. 59375
1/2	14	0. 840	23/32	0. 71875
3/4	14	1. 050	15/16	0. 9375
1	11 1/2	1. 315	1 3/16	1. 1875
1 1/4	11 1/2	1. 660	1 15/32	1. 46875
1 1/2	11 1/2	1. 900	1 23/32	1. 71875
2	11 1/2	2. 375	2 3/16	2. 1875
2 1/2	8	2. 875	2 11/16	2. 6875
3	8	3. 500	3 5/16	3. 3125
3 1/2	8	4. 00	3 13/16	3. 8125
4	8	4. 500	4 3/16	4. 1875

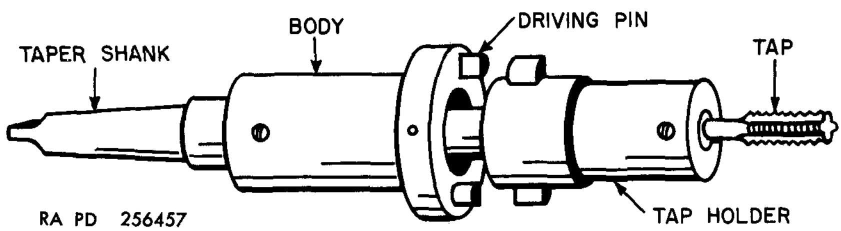


Figure 25. Drilling machine tapping attachment.

b. When accurate and smooth holes are desired, they are usually drilled 1/32 to 1/64 inch undersize and then reamed. Machine reaming may be done on a lathe or reamer drive as well as on a drilling machine. Hand reaming can be done with even more accuracy than machine reaming and is sometimes used to finish machine reamed workpieces. Machine reamers (fig. 26) for drilling machines have straight or taper shanks to fit the drilling machine spindle. Hand reamers (fig. 26) usually have straight shanks with square ends to fit into adjustable tap and reamer wrenches for use.

c. The reamer must run true to produce a good finish. Care should be used when starting the hole or the reamer may chatter and spoil the mouth of the hole. The machine should be stopped if chatter develops and then started again very slowly. Slight tapers at the end of the reamer help their entry into the hole, so they should be turned into the hole at least 1 1/2 inches to produce the proper size.

d. A center may be installed in the drilling machine spindle when reaming by hand to aline and steady the reamer until the job has been well started. With an adjustable tap and reamer wrench (fig. 26), the reamer is turned into the hole and then followed up with the center. The center should be fed by hand and should not be crowded.

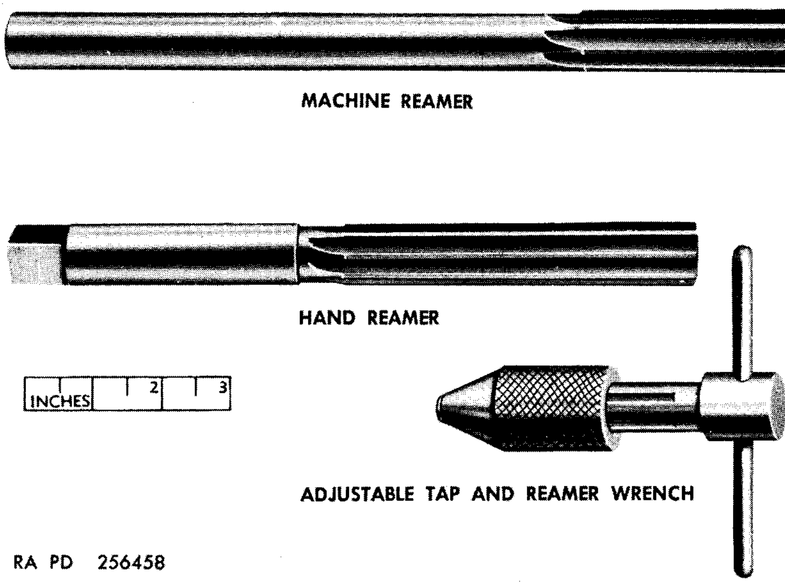


Figure 26. Tools used for reaming with the drilling machine

e. Sometimes it is necessary to duplicate a flat piece having two or more drilled and reamed holes. In such a case, use a drill the size of the reamed hole as a spotter. The workpieces should be mounted with the one to be drilled and reamed in position under the finished workpiece. The first hole should be alined under the spotting drill in the spindle of the drilling machine. After the hole has been spotted, a drill $\frac{1}{64}$ inch undersize should be used to drill the hole in the new piece. The hole should then be reamed with the machine reamer to finished size. Use a pin or plug through the two workpieces to keep them in line before proceeding to the next hole. Use additional plugs to keep the workpiece from shifting when three or more holes are to be made.

f. Reamer teeth should be sharp and smooth and the reamer should never be started on an uneven surface. Never turn a reamer backward.

38. Counterboring and Spot Facing

a. Counterboring is the appreciable enlarging of the end of a hole to a certain depth. The axis of the enlarged hole coincides with the axis of the original hole. Counterbored holes are used for receiving the heads of fillister-head machine screws and setscrews and to provide recessed shoulders for other applications.

b. Counterboring is performed with a counterbore (fig. 24). The counterbore fits into the drilling machine spindle in the same manner as a taper shank drill. At the end of the tool is a pilot which fits into the original hole and guides the cutting tool. The cutting tool is a flat cutting drill of the diameter of the hole to be machined. Counterbores may be either solid tools or removable-blade tools. The advantage of the removable-blade tool is that a tool with one size pilot may be used with different size blades to enlarge holes to a number of different diameters. The cutting tool may have two or more cutting edges.

c. When counterboring, it is absolutely necessary to aline the workpiece accurately with the pilot of the counterbore. The hole to be counterbored must aline with the axis of the counterbore or the pilot will pull the tool off center as the tool cuts into the workpiece. The feed should be less than that required for normal drilling operations (par. 31) and the spindle speed (par. 30) should be reduced about 25 percent. Adequate cutting oils should be applied. However, when counterboring in cast iron, do not use any cutting oil.

d. Spot facing is the smoothing off and squaring of the surface around a hole to permit seating of a washer, nut, or bolthead. The operation of spot facing is identical to that of counterboring, and the counterbore is used. Generally, the pilot of the counterbore is alined with the hole and the tool is hand fed only far enough to machine an even face on the surface of the workpiece.

39. Lapping

a. Lapping is the process of improving the quality of a machined surface by use of very fine abrasives. The lapping process can be controlled to remove as much as 0.003 inch of material by rough lapping or as little as 0.0001 inch by fine lapping. The basic purpose of lapping is to reduce roughness, waviness, and defects from a surface, but it is not done for appearance alone, other methods being cheaper for that purpose.

b. Loose abrasive mixed with a vehicle such as clear or soapy water, oil, or grease is used for lapping. The abrasive may be fine or superfine depending upon the degree of finish desired. Grain sizes range from No. 120 to superfine flours. Diamond dust is sometimes used for lapping very hard materials. Lapping compounds consisting of abrasive and vehicles are available in many grain or flour grades.

c. The abrasive is applied to the material to be lapped by charging a lap or laps with the abrasive, and rubbing the lap against the workpiece. Laps are made mostly of soft, close-grained cast iron, copper, brass, or lead, the face of which is charged with imbedded particles of the abrasive compound. Grooves cut in the lap faces collect excess abrasive and dirt during the lapping process.

d. Lapping on the drilling machine is accomplished by fitting a suitable lap in the drilling machine spindle and supporting the piece to be lapped by hand. The speed of the lap should be generally slower than that used for drilling. Refer to paragraph 56 for additional information on the lapping process.

CHAPTER 3
GRINDING MACHINES

Section I. GENERAL

40. Purpose

a. Grinding is the process of removing metal by application of abrasives which are bonded to a rotating wheel. When the moving abrasive particles contact the workpiece, they act as tiny cutting tools, each particle cutting a tiny chip from the workpiece. It is a common error to believe that grinding abrasive wheels remove material by a rubbing action; actually the process is as much a cutting action as drilling, milling, and lathe turning.

b. The purpose of the grinding machine is to support and rotate the grinding abrasive wheel, and often to support and position the workpiece in proper relation to the grinding abrasive wheel.

c. The grinding machine is used for roughing and finishing of flat, cylindrical, and conical surfaces, finishing of internal cylinders or bores, forming and sharpening of cutting tools, snagging or removing rough projections from castings and stampings, cleaning of surfaces, polishing, and buffing. Once strictly a finishing machine, the modern production grinding machines are used for complete roughing and finishing of certain classes of work.

41. Types of Grinding Machines.

a. General. From the simplest type of grinding machine to the most complex type, grinding machines can be classified as utility grinding machines, disk and belt grinding machines, cylindrical grinding machines, and surface grinding machines. The average machinist will be concerned mostly with floor-mounted and bench-mounted utility grinding machines, the bench-type utility grinding and buffing machine, and the reciprocating surface grinding machine.

b. Utility Grinding Machines.

(1) *Description.* The utility grinding machine is intended for offhand grinding or grinding where the workpiece is supported in the hand and brought to bear against the rotating grinding abrasive wheel. The accuracy of this type of grinding machine is necessarily dependent upon the dexterity and skill of the operator and his knowledge of the capabilities

of the machine and the nature of the work. The utility grinding machine consists of a horizontally mounted motor with a grinding abrasive wheel attached to each end of the motor shaft. The electric motor driven machine is simple and common. It may be bench mounted or floor mounted. Generally, the condition and design of the shaft bearings as well as the motor rating determine the wheel size capacity of the machine. Suitable wheel guards and tool rests are provided for safety and ease of operation.

(2) *Floor-mounted utility grinding machine* (fig. 27).

(*a*) The typical floor-mounted utility grinding machine stands at waist-high level and is secured to the floor by bolts. The floor-mounted utility grinding machine shown on figure 27 mounts two 12-inch diameter by 2-inch wide grinding abrasive wheels. The two-wheel arrangement permits installing a coarse grain wheel for roughing purposes on one end of the shaft and a fine grain wheel for finishing purposes on the other end of the shaft, thus saving the time which would be otherwise consumed in changing wheels.

(*b*) Each grinding abrasive wheel is covered by a wheel guard to increase the safety of the machine. Transparent eyeshields, spark arrestors, and adjustable tool rests are provided for each grinding wheel. On the side of the base or pedestal are mounted a tool tray and a water pan. The water pan is used for quenching carbon steel cutting tools as they are being ground. The 2-horsepower electric motor driving this machine has a maximum speed of 1,750 revolutions per minute. Using the 12-inch wheel, the machine provides a maximum cutting speed of approximately 5,500 surface feet per minute.

(3) *Bench-type utility grinding machine* (fig. 28). The bench-type utility grinding machine shown in figure 28 is typical of this type of machine. Two grinding abrasive wheels 7 inches in diameter and ½ inch wide are mounted to the ends of the motor shaft. Like the floor-mounted utility grinding machine ((2) above), one coarse grain wheel and one fine grain wheel are usually mounted to the machine for convenience of operation. Each wheel is provided with an adjustable tool rest and an eyeshield for protection of the operator during grinding operations. On this machine, the motor is equipped with a thermal overload switch to stop the motor if excessive pressure is applied to the grinding abrasive wheels, thus preventing possible burning out of the motor. The motor revolves at 3,450 revolutions per minute maximum to provide a maximum

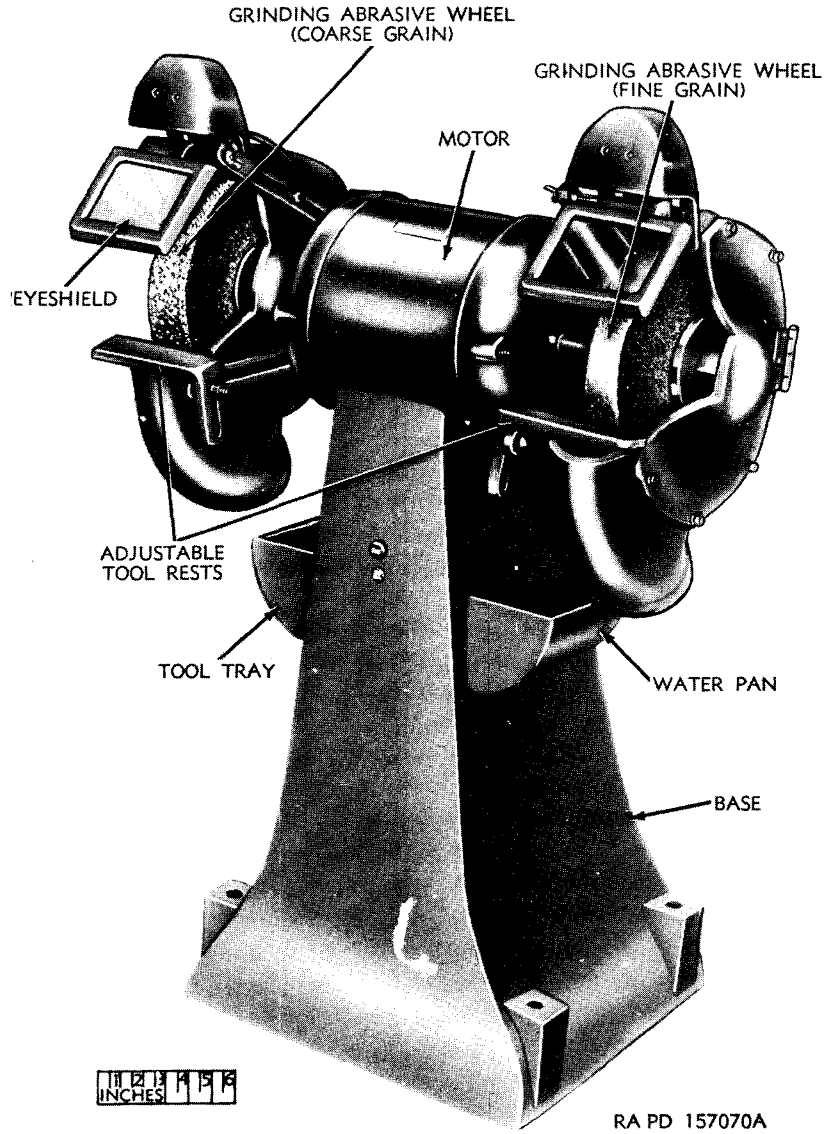


Figure 27. Floor-mounted utility grinding machine.

cutting speed for the 7-inch grinding abrasive wheels of approximately 6,300 surface feet per minute.

(4) *Bench-type utility grinding and buffing machine* (fig. 29). The bench-type utility grinding and buffing machine is more suitable for miscellaneous grinding, cleaning, and buffing operations than for cutting tool grinding since it contains no tool rests, eyeshields, or wheel guards. This

machine normally mounts a 4-inch diameter grinding abrasive wheel on one end of the motor shaft and a 4-inch wire wheel on the other end. The wire wheel is used for cleaning operations and the abrasive wheel is used for general grinding operations such as snagging. One of the two wheels can be removed and a buffing wheel mounted in its place for buffing and polishing of items. The ¼-horsepower electric motor revolves at a maximum of 3,450 revolutions per minute. The maximum cutting speed of the 4-inch diameter wheel is approximately 3,600 surface feet per minute.

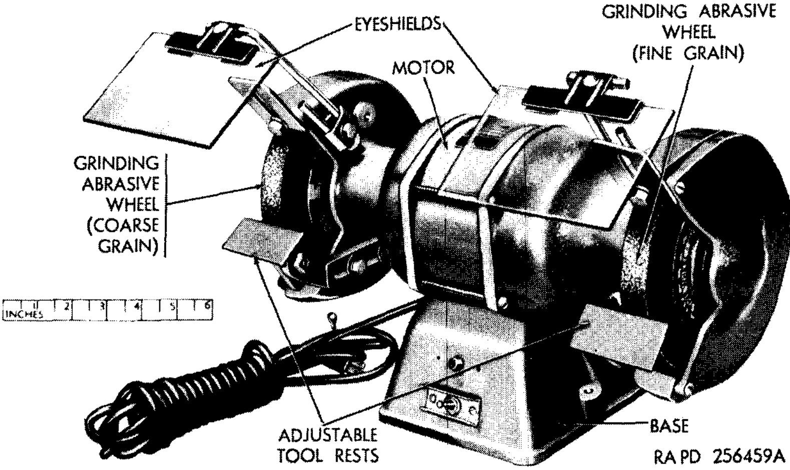


Figure 28. Bench-type utility grinding machine.

c. *Cylindrical Grinding Machine.*

(1) *General.* The cylindrical grinding machine performs grinding operations on workpieces which are mounted between centers and rotated in a direction opposite to that of the grinding abrasive wheel. Nonspecialized cylindrical grinding machines in the Ordnance Corps include the tool post grinding machine (fig. 65) and the milling and grinding lathe attachment (fig. 66).

(2) *Tools post grinding machine* (fig. 65). The tool post grinding machine is a machine tool attachment designed to mount to the tool post of engine lathes. It is used for internal and external grinding of cylindrical workpieces. Refer to paragraph 70 for a description of this machine.

(3) *Milling and grinding lathe attachment* (fig. 66). The milling and grinding lathe attachment is a versatile machine tool attachment that mounts to the carriage of a lathe, and performs internal and external cylindrical grinding opera-

tions among its other functions. Refer to paragraph 71 for a general description of this machine.

d. Surface Grinding Machine.

(1) *General.* The surface grinding machine is used for grinding flat surfaces. The workpiece is supported on a rectangular table which moves back and forth or reciprocates beneath the grinding abrasive wheel. Reciprocating surface grinding machines generally have horizontal wheel spindles and mount straight or cylinder-type grinding abrasive wheels.

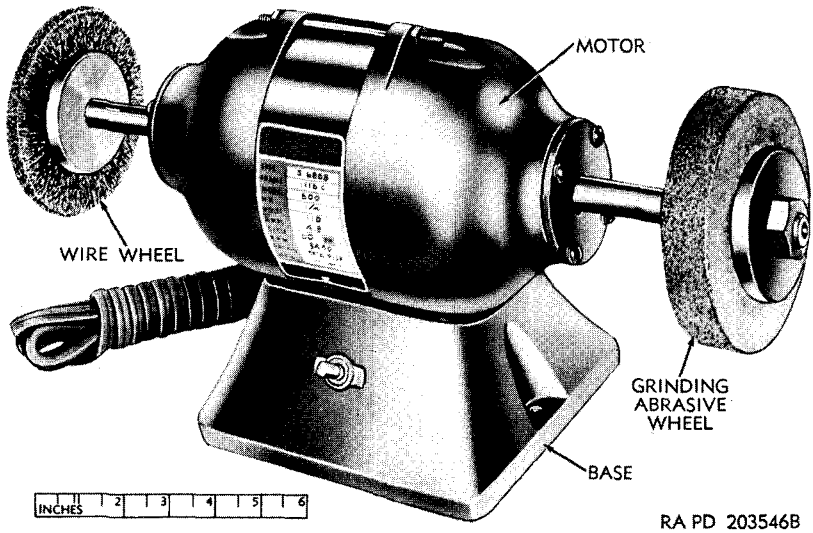


Figure 29. Bench-type utility grinding and buffing machine.

(2) *Reciprocating surface grinding machine* (fig. 30). The reciprocating surface grinding machine illustrated on figure 30 is a horizontal-type surface grinding machine. Workpieces are fastened to the table and can be moved beneath the grinding abrasive wheel by hand or by power feed. A magnetic chuck, when available, may be used for fastening the workpieces to the table. This grinding machine has an integral pump and piping network for automatic application and recirculation of a coolant to the workpiece and wheel. The grinding abrasive wheel, mounted to the horizontal spindle, is of the straight type and cuts on its circumferential surface only. Grinding wheel speeds are adjustable.

Section II. TOOLS AND EQUIPMENT

42. Grinding Abrasive Wheels

Note. The grinding abrasive wheels included in this paragraph are not necessarily adaptable to the grinding machines described in this chapter. The different wheel types and shapes may be used on the tool post grinding machine or the milling and grinding lathe attachment (pars. 70 and 71), the bench-type tool and cutter grinding machine (par. 97*d*), or on the portable electric or pneumatic grinders (pars. 217 and 218). However, the theory of the wheels is common to all grinding abrasive wheels.

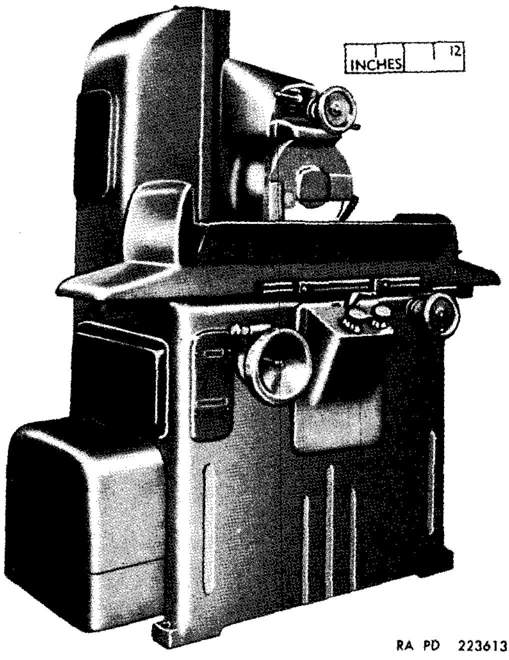


Figure 30. Reciprocating surface grinding machine.

a. General. All grinding abrasive wheels consist of abrasive grain and a bond substance which holds the grain in place and releases the grain as it is worn down. Between the grain and the bond are air spaces or voids which provide clearance space for the chips that are cut from the work by each abrasive grain. Wheels are identified and classified by wheel size, wheel shape and type, abrasive material, grade of hardness, size of grain, bond material, and structure or density of the wheel.

b. Standard Types of Grinding Abrasive Wheels (fig. 31). Grinding abrasive wheels are made in many different types or styles for performing a variety of operations. The nine most popular types are illustrated in figure 31. Other shapes, known as nonstandard shapes, are also available. Standard types are often identified by number instead of by name.

c. Standard Shapes of Grinding Abrasive Wheel Faces (fig. 32). Grinding abrasive wheels of the standard types (*b* above) can be supplied in a number of face shapes for special purposes. The standard face shapes illustrated in figure 32 are identified by letter designations.

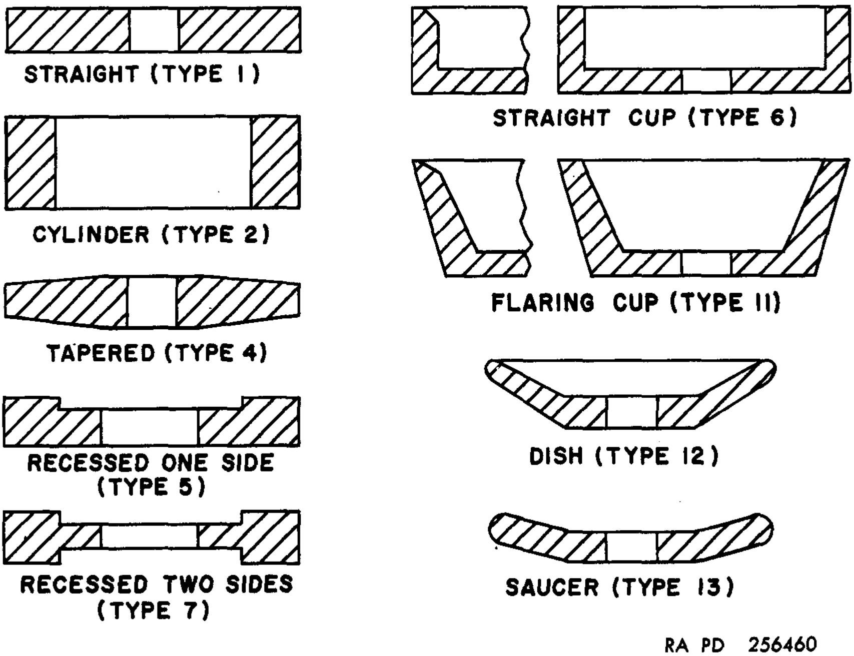


Figure 31. Standard types of grinding abrasive wheels.

d. Abrasive Materials. Common grinding wheel abrasives are natural or manufactured. Emery and corundum are natural aluminum oxide abrasives; manufactured abrasives are either aluminum oxide or silicon carbide sold under various trade names. Manufactured abrasives are the more widely used because the electric furnace process by which they are produced makes them uniform. Silicon carbide abrasive is a much harder and more brittle substance than the aluminum oxides, and is suitable for grinding tough materials with low tensile strength such as cast iron, brass, stone, and rubber. Aluminum oxide abrasive, although softer than silicon carbide, is tougher and does not fracture so easily. Aluminum oxide is generally used for grinding high tensile strength materials like hard steels.

e. Abrasive Grain Size. Abrasive grains are selected according to the mesh of a sieve through which they are sorted. For example, grain No. 40 indicates that the abrasive grain passed through a sieve having approximately 40 meshes to the linear inch. A grinding abrasive wheel is designated coarse, medium, or fine according to the size of the individual abrasive grains making up the wheel. The grain sizes generally used and their relative coarseness or fineness are as follows:

Very coarse	*Coarse*	*Medium*	*Fine*	*Very fine*	*Flour*
8	12	30	70	150	280
10	14	36	80	180	320
	16	46	90	220	400
	20	60	100	240	500
	24	--	120	---	600

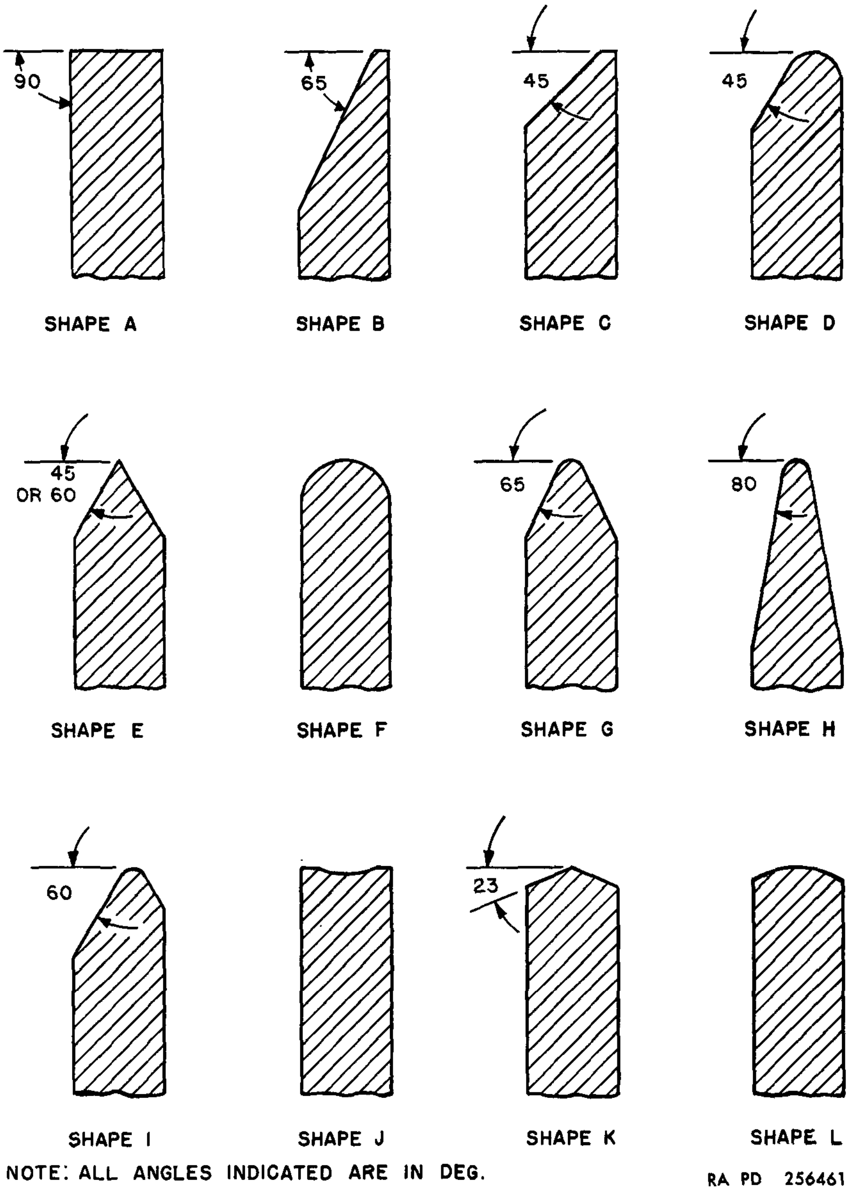


Figure 32. Standard shapes of grinding abrasive wheel faces.

f. Bond Material.

(1) The material that holds the abrasive grains together and forms the grinding abrasive wheel is known as the bond. Bonds for abrasive wheels are classified as vitrified, silicate, or elastic.

(2) Vitrified grinding abrasive wheels are bonded with clays which are mixed with the abrasive grain and pressed or

molded in the wheel shape and then fired or burned in kilns. Vitrified wheels are characterized by open texture, free cutting qualities, excellent resistance to water, oils, acids, soda, and effects of time and temperature, and lack of elasticity. Wheels of this type range from very soft grades of bond to very hard grades.

(3) Silicate grinding abrasive wheels, bonded with clay fluxed with silicate of sodium, are not as stable as vitrified wheels in regard to effects of moisture. Silicate wheels have some elasticity, very little porosity, and a lower range of hardness than that of vitrified wheels. Made by a tamping process, silicate wheels can be made much greater in thickness and larger in diameter than wheels made by other bonding processes.

(4) Elastic grinding abrasive wheels are bonded with organic gums, the most common of which are shellac and other resins and rubber. These wheels being very elastic can be made in very thin shapes.

(*a*) Resinoid bond is a phenolic resin compound which forms the majority of elastic grinding abrasive wheels. Resinoid wheels are porous in structure, cool cutting, and remove stock rapidly. They are commonly used for snagging castings, cutting off, grinding cylindrical objects, and gumming saw blades.

(*b*) Rubber bond wheels are particularly adaptable to finish grinding. The rubber bonding material completely fills the voids between the grains and therefore leaves little clearance for chips. Besides having a high degree of elasticity so the wheels so bonded can be made very thin and delicate, rubber wheels act as a buffer to polish out grain marks because the rubber softens under the heat of grinding and cushions the particles of abrasive so they do do not cut deeply. Wheels as thin as 0.005 inch are made of rubber for special operations such as slotting pen-points.

(*c*) Shellac bonded wheels behave similarly to rubber wheels except that they are slightly more porous and will take deeper cuts without burning. These wheels have a cool cutting action.

g. Grades of Hardness.

(1) The grade of a grinding abrasive wheel designates the hardness of the bonding material. A soft wheel is one on which the cutting particles break away rapidly while a hard wheel is one on which the bond successfully opposes this breaking away of the abrasive grain.

(2) Most wheels are graded according to hardness by a letter system. Most manufacturers of grinding abrasive wheels use a letter code ranging from E (very soft) to Z (very hard). Vitrified and silicate bonds usually range from very soft to very hard, shellac and resinoid bonds usually range from very soft to hard, and rubber bonds are limited to the medium to hard range. Typical grades for vitrified wheels are as follows:

Very 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

(3) The grade of hardness of the wheel should be selected as carefully as the grain size. A grinding abrasive wheel that is too soft will wear away too rapidly, the abrasive grain being discarded from the wheel before its useful life is realized. On the other hand, if the wheel is too hard for the job, the abrasive particles will become dull because the bond will not release the abrasive grain, and the efficiency of the wheel will be impaired.

h. Abrasive Wheel Structure or Density.

(1) Bond strength of a grinding abrasive wheel is not wholly dependent upon the grade of hardness but depends equally on the structure of the wheel, or in other words, the spacing of the grain or its density. The structure or spacing is measured in number of grains per cubic inch of wheel volume.

(2) Figure 33 illustrates sections of three grinding abrasive wheels with different spacing of grains. If the grain and bond material in each of these wheels are alike in size and hardness, the wheel with the wider spacing will be softer than the wheel with the closer grain spacing. Thus, the actual hardness of the grinding wheel is equally dependent on grade of hardness and spacing of the grains or structure.

(3) The structure or spacing of the abrasive grain is designated by the following numbers:

Close spacing	*Medium spacing*	*Wide spacing*
1	4	7
2	5	8
3	6	9
		10
		11
		12

Note. Some types of wheels are produced in only one structure in which case no structure number is given.

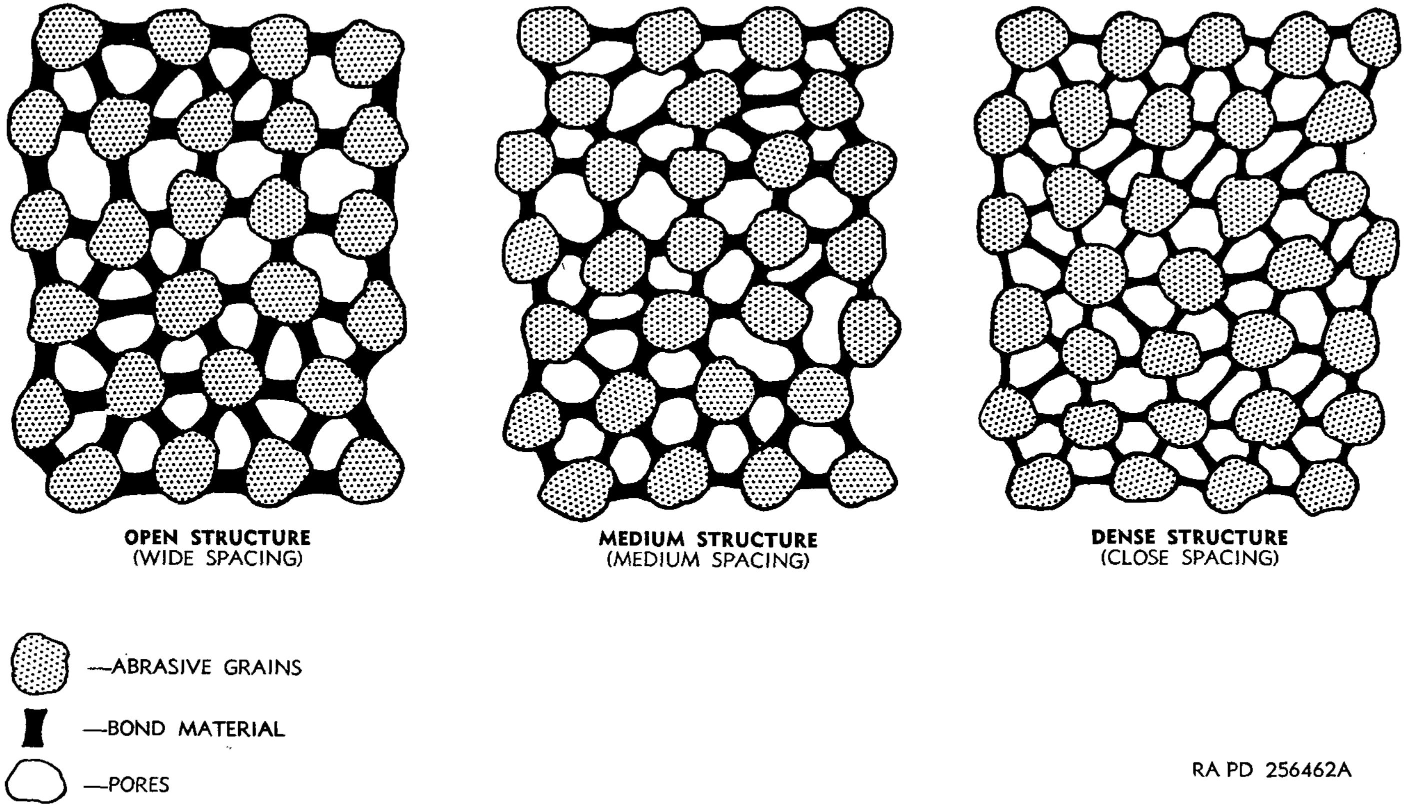


Figure 33. Grinding abrasive wheel abrasive spacing.

i. Selection of Grinding Abrasive Wheels.

(1) *General.* Conditions under which grinding abrasive wheels are used vary considerably and a wheel that is satisfactory on one machine may be too hard or soft for the same operation on another machine. The following basic factors should be considered when selecting grinding abrasive wheels though it should be understood that the rules and conditions listed are flexible and subject to occasional exceptions.

(2) *Tensile strength of material.* The tensile strength of the material to be ground is the main factor in the selection of the abrasive to be used.

(*a*) An aluminum oxide abrasive should be chosen for materials of high tensile strength such as carbon steel, high-speed steel, stellite, malleable iron, and hard bronze.

(*b*) A silicon carbide abrasive should be used for materials of low tensile strength such as cast iron, chilled iron, brass, soft bronze, rubber, granite, and marble.

(3) *Factors affecting grain size.* Grain size to be chosen when selecting a grinding abrasive wheel depends upon the factors described in (*a*) through (*c*) below.

(*a*) The softer and more ductile the material, the coarser should be the grain size.

(*b*) The larger the amount of stock to be removed, the coarser should be the grain size.

(*c*) The finer the finish desired, the finer should be the grain size.

(4) *Factors affecting the grade of hardness.* The factors described in (*a*) through (*d*) below will determine the proper grade of hardness of the grinding abrasive wheel.

(*a*) The harder the material, the softer the grade should be.

(*b*) The smaller the arc of contact, the harder the grade should be. By arc of contact is meant the arc, measured along the periphery of the wheel, that is in contact with the work at any instant. It follows that the larger the grinding abrasive wheel, the greater the arc of contact and therefore a softer wheel can be used.

(*c*) The higher the work speed with relation to the wheel speed, the milder the grinding action and the harder the grade should be.

(*d*) The better the condition of the grinding machine and spindle bearings, the softer the wheel can be.

(5) *Factors affecting the structure.* The structure or spacing of the abrasive grains of the wheel depends upon the factors described in (*a*) through (*d*) below.

(*a*) The softer, tougher, and more ductile the material, the wider should be the grain spacing.

(b) The finer the finish desired, the closer, or more dense, should be the grain spacing.

(c) Surfacing operations require open structure (wide grain spacing).

(d) Cylindrical grinding operations and tool and cutter grinding are best performed with wheels of medium structure (medium grain spacing).

(6) *Factors affecting bond material.* The factors described in (a) through (d) below affect the selection of bond material for the wheel desired.

(a) Thin cutoff wheels and other wheels subject to bending strains require resinoid, shellac, or rubber bonds.

(b) Solid wheels of very large diameters require a silicate bond.

(c) Vitrified wheels are usually best for speeds up to 6,500 surface feet per minute (sfpm) and resinoid, shellac, or rubber wheels are best for speeds above 6,500 (sfpm).

(d) Resinoid, shellac, or rubber bonds are generally best where a high finish is required.

(7) *Selection.* Refer to table IX for specific requirements for typical grinding operations and materials.

. *Mounting Grinding Abrasive Wheels.*

(1) The proper mounting of grinding abrasive wheels is very important since an improperly mounted wheel may be improperly balanced or insecurely fastened so as to become potentially dangerous at high speeds.

(2) The specified wheel size for the particular grinding machine to be used should not be exceeded either in wheel diameter or in wheel width.

(3) Figure 34 illustrates a correctly mounted grinding abrasive wheel.

(a) Note that the wheel is mounted between two flanges which are relieved on their inner sides so that they support the wheel only at their outer edges. This holds the wheel more securely with less pressure and with less danger of breaking it. For good support, the flanges between which the wheel is mounted should be at least one-third and preferably one-half the wheel diameter in size.

(b) The spindle hole in the wheel should be large enough to fit over the wheel spindle easily but not loosely, since a loose fit will result in difficulty in centering the wheel. If the hole is too large, wrap paper around the spindle to make the wheel fit. If the wheel is greatly oversize, select another wheel of the proper size, or if no others are available, fit a suitable bushing over the spindle to adapt the spindle to the hole.

(c) Most grinding abrasive wheels have paper disks on each side of the wheel. If these disks are missing, cut washers of a suitable size of heavy blotter or thin rubber and place these disks between the grinding abrasive wheel and each flange. These disks serve as cushions to minimize wheel breakage.

(4) When installing the grinding abrasive wheel on the wheel spindle, tighten the spindle nut firmly but not so tight that undue strain will be put on the wheel.

k. Dressing Grinding Abrasive Wheels. Periodically throughout the use of a grinding abrasive wheel, it is necessary to dress or true up the wheel to restore its cutting qualities and keep its cutting surface true. Refer to paragraph 45 for dressing procedures.

43. Wire Wheels

A wire wheel consists of many strands of wires bound to a hub and radiating outward from the hub in the shape of a wheel. The wire wheel is used in place of a grinding abrasive wheel for cleaning operations such as removal of rust or corrosion from metal objects and for the rough polishing of castings, hot-rolled steel, etc. The wire wheel fastens to the wheel spindle of the grinding machine in the same manner as a grinding abrasive wheel (par. 42*j*).

44. Buffing and Polishing Wheels

a. Buffing and polishing wheels are formed of layers of cloth, felt, or leather glued or sewed together to form a flexible, soft wheel.

b. Buffing wheels are generally softer than those used for polishing, and are often made of bleached muslin (sheeting), flannel, or other soft cloth materials. The material is cut in various diameters and sewed together in sections which are put together to make up the buffing wheel. The buffing wheel is often slotted or perforated to provide ventilation.

c. Polishing wheels are made of canvas, felt, or leather that is sewed or glued together to provide various wheel grades from soft to hard. The harder or firmer wheels are generally used for heavier work while the soft and more flexible wheels are used for delicate contour polishing and finishing of parts on which corners and edges must be kept within rather strict specifications.

d. Buffing and polishing wheels are charged with abrasives for operation. The canvas wheels are generally suitable for use with medium grain abrasives while felt, leather, and muslin wheels are suitable for fine grain abrasives. Buffing abrasives are usually made in the form of cakes, paste, or sticks which are applied to the wheel in this form. Polishing abrasives are fixed to polishing wheels with glue.

Table IX. Selection of Grinding Abrasive Wheels

Class of work	Operation	Grinding abrasive wheel				
		Abrasive	Grain	Grade	Structure	Bond
Aluminum	Cylindrical grinding	Silicon carbide	Med	Soft	Med	Vitrified.
	Surface grinding	Al-oxide	Med	Soft	Wide	Vitrified.
	Snagging	Silicon carbide	Coarse	Med	Med	Vitrified.
Armatures (laminations)	Cylindrical grinding	Al-oxide	Med	Med	Med	Vitrified.
Brass and soft bronze	Cylindrical grinding	Silicon carbide	Med	Soft	Med	Vitrified.
	Internal grinding	Silicon carbide	Med	Soft	Med	Vitrified.
	Surface grinding (stght wheel)	Silicon carbide	Med	Soft	Med	Vitrified.
	Snagging	Silicon carbide	Coarse	Hard	Med	Vitrified.
Bronze (hard)	Cylindrical grinding	Al-oxide	Med	Soft	Med	Vitrified.
	Internal grinding	Al-oxide	Med	Soft	Med	Vitrified.
	Snagging	Al-oxide	Coarse	Hard	Wide	Vitrified.
Cast iron	Cylindrical grinding	Silicon carbide	Med	Soft	Med	Vitrified.
	Internal grinding	Silicon carbide	Med	Soft	Med	Vitrified.
	Surface grinding (stght wheel)	Silicon carbide	Med	Soft	Wide	Vitrified.
	Snagging	Silicon carbide	Coarse	Hard	Med	Vitrified.
Commutators	Finishing	Silicon carbide	Med	Med	Med	Resinoid.
Copper	Cylindrical grinding	Silicon carbide	Fine	Soft	Med	Resinoid.
Cutters (milling)	Backing off	Al-oxide	Med	Soft	Med	Vitrified.
Drills (small)	Off-hand sharpening	Al-oxide	Med	Med	Med	Vitrified.
(large)	Off-hand sharpening	Al-oxide	Med	Hard	Med	Vitrified.
Monel metal	Snagging	Al-oxide	Coarse	Hard	Med	Vitrified.
Reamers	Forming and sharpening	Al-oxide	Med	Med	Med	Vitrified.
Rubber (hard)	Cylindrical grinding	Silicon carbide	Med	Soft	Med	Resinoid.
Rubber (soft)	Cylindrical grinding	Silicon carbide	Coarse	Soft	Med	Resinoid.
Saws (circular)	Gumming	Al-oxide	Med	Med	Med	Vitrified.
Saws (metal)	Backing-off	Al-oxide	Med	Hard	Med	Vitrified.

Scissors and shears	Resharpening	Al-oxide	Fine	Med	Med	Vitrified.
Steel (hard)	Cylindrical grinding	Al-oxide	Med	Med	Med	Vitrified.
	Surface grinding (stght wheel)	Al-oxide	Med	Soft	Wide	Vitrified.
	Internal grinding	Al-oxide	Med	Soft	Med	Vitrified.
	Cutting-off	Al-oxide	Med	Hard	Wide	Resinoid.
Steel (soft)	General off-hand grinding	Al-oxide	Med	Med	Med	Vitrified.
	Cylindrical grinding	Al-oxide	Med	Med	Med	Vitrified.
	Surface grinding (stght wheel)	Al-oxide	Med	Med	Wide	Vitrified.
	Internal grinding	Al-oxide	Med	Med	Med	Vitrified.
Steel (stainless)	Cylindrical grinding	Silicon carbide	Med	Med	Med	Vitrified.
Stellite tools	Off-hand grinding	Al-oxide	Med	Med	Med	Vitrified.
Taps	Fluting	Al-oxide	Med	Hard	Med	Resinoid.
Tools (high-speed steel)	Off-hand sharpening	Al-oxide	Med	Med	Med	Vitrified.
Tools (tungsten-carbide tip)	Off-hand grinding	Silicon carbide	Med	Soft	Wide	Vitrified.
Valves (automotive)	Grinding seats	Al-oxide	Fine	Med	Med	Vitrified.
Welds	Slow speed smoothing	Al-oxide	Coarse	Hard	Wide	Vitrified.
	High speed smoothing	Al-oxide	Coarse	Hard	Med	Resinoid.

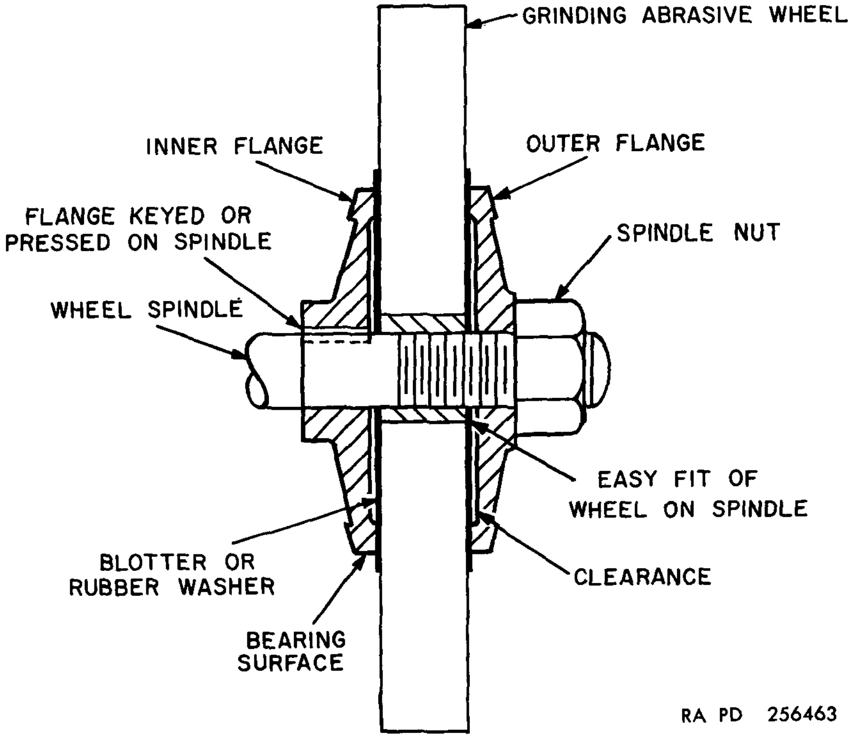


Figure 34. Correctly mounted grinding abrasive wheel.

45. Abrasive Wheel Dressers

a. General.

(1) Grinding abrasive wheels wear unevenly under most general grinding operations due to uneven pressure applied to the face of the wheel when it cuts. Also when the proper wheel has not been used for certain operations, the wheel may become charged with metal particles, or the abrasive grain may become dull before it is broken loose from the wheel bond. In the above cases, it is necessary that the wheel be dressed or trued to restore its efficiency and accuracy.

(2) Dressing is the action of cutting the face of a grinding abrasive wheel to restore its original cutting qualities. Truing is the action of restoring the wheel's concentricity or reforming its cutting face to a desired shape. Both operations are performed with a tool called an abrasive wheel dresser.

b. Types of Abrasive Wheel Dressers. Abrasive wheel dressers are supplied in several styles and shapes. They use hard abrasives, industrial diamonds, or steel cutters to remove the abrasive or bonding material from the surface of the grinding abrasive wheels.

(1) The tube-type abrasive wheel dresser (fig. 35) consists of a steel tube filled with a very hard abrasive mixture or contain-

ing a diamond set in its end. The abrasive or diamond is brought against the grinding abrasive wheel to cut down the wheel to its correct shape. This dresser can be used for both truing and dressing operations.

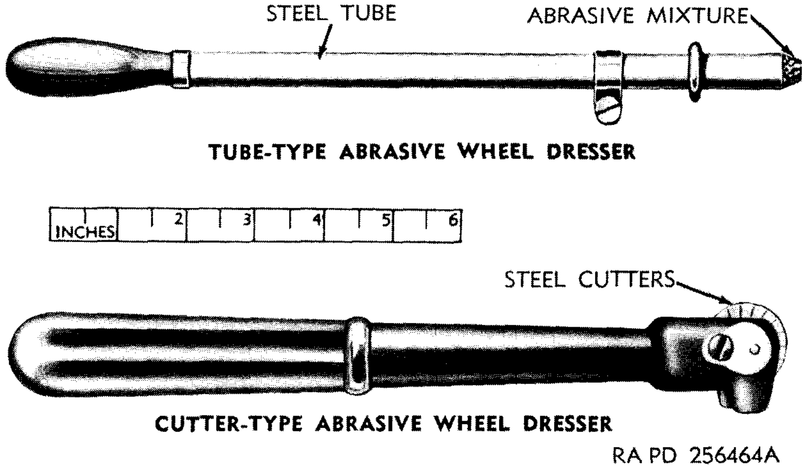


Figure 35. Abrasive wheel dressers.

(2) The cutter-type abrasive wheel dresser (fig. 35) is made of steel cutters which contain teeth or have corrugated edges. The cutters are fitted on a shaft or pin so that they revolve with the wheel during the dressing operation. In operation, the cutters cut or shear the surface of the grinding abrasive wheel to remove spent abrasive grains and open up the bond. This type of wheel dresser is used mostly for dressing and is not especially suitable for truing.

c. Dressing Grinding Abrasive Wheels. It is very important in the production of accurate work to keep the wheel properly dressed. The object of dressing the cutting face of a wheel is to sharpen the cutting grains and remove excess bonding material so that the grains will cut freely without generating undue heat. The wheel is trued to a certain extent by the action of the dresser, although this truing is not sufficient for precision grinding. For utility grinding machines or grinding machines where the wheel is to be used for off-hand grinding, additional truing is unnecessary. A cutter-type abrasive wheel dresser (*b*(2) above) (fig. 36) is best for this operation and can be hand held against a suitable tool rest. If a tube-type abrasive wheel dresser is used, the dresser should be supported against the grinding abrasive wheel at an angle of from 10° to 15° (fig. 36) so that the dresser drags on the wheel, thus preventing possible gouging of the wheel.

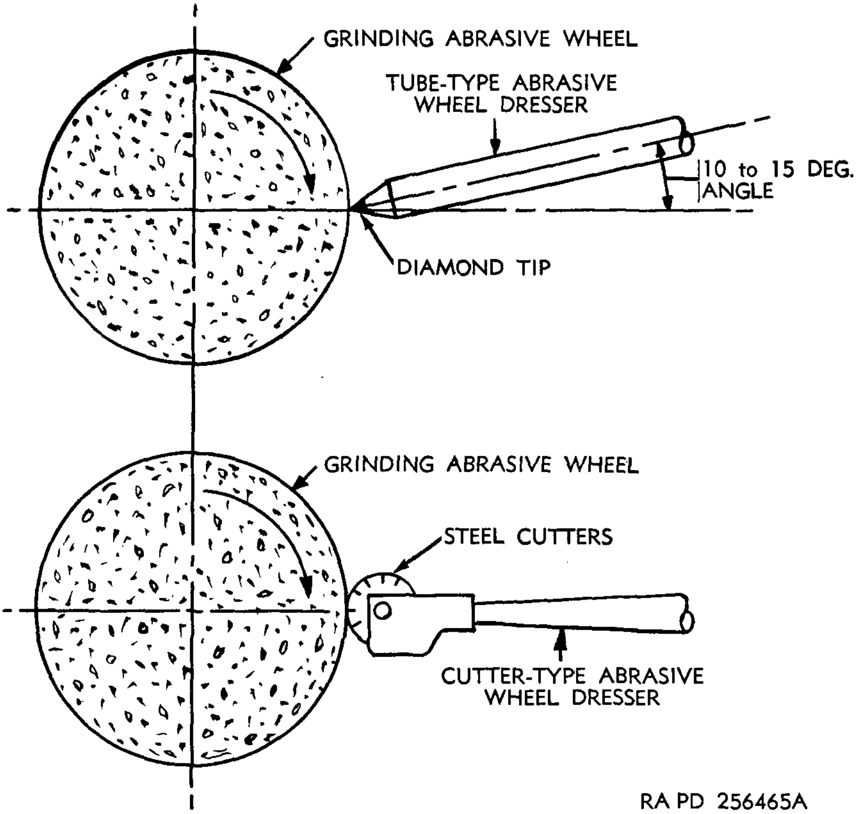


Figure 36. Correct application of abrasive wheel dressers for dressing and truing grinding abrasive wheels.

d. Truing Grinding Abrasive Wheels.

(1) Truing a grinding abrasive wheel gives it a clean face and produces a surface that revolves concentrically with the wheel spindle. It must be performed whenever precision is desired although all grinding wheels should be trued immediately after mounting.

(2) A tube-type abrasive wheel dresser with either a diamond tip or a very hard abrasive should be used for truing. The dresser should be supported at an angle of 10° to 15° to the grinding abrasive wheel (fig. 36). The dresser must point in the same direction as the grinding abrasive wheel rotates to prevent gouging the wheel face. If available, a diamond-tip dresser should be used for the first truing cut. Abrasive sticks, a tube-type abrasive wheel dresser with a hard carbide abrasive, or a broken piece of a grinding abrasive wheel can be used for subsequent operations.

(3) The truing device should be held by mechanical means if at all possible.

(4) As the diamond or other abrasive wears, the abrasive wheel dresser should be rotated 180° to insure a sharp cutting action at all times. Failure to do this will cause the wheel to glaze, dulling its cutting points, and reducing the efficiency of the wheel.

(5) The grinding abrasive wheel face usually wears more on the edges leaving a hump in the center. It is therefore necessary to start making lateral passes of the truing device away from the wheel and gradually moving toward the wheel center.

(6) The feed of the abrasive wheel dresser across the iace of the wheel should be greater for soft wheels than for hard wheels. The speed of the grinding abrasive wheel should be equal to average cutting speeds for hard materials.

Section III. LAYING OUT AND MOUNTING WORK

46. Laying Out Work

a. General. There are no special rules for laying out work for grinding operations. Most layout requirements will be dictated by the specific grinding machine to be used. In many cases, the workpiece will be turned on a lathe or machined in some other manner before grinding, the grinding being intended for finishing the workpiece to desired dimensions.

b. Grinding Allowance. In planning work to be ground, the amount of metal to be removed should be based on the capabilities of the grinding machine. If the grinding machine is modern and in good condition, leave as much as 1/32 inch or even more on large machine steel parts, but generally not more than 1/64 inch on small machine parts.

c. Cylindrical Grinding. If cylindrical grinding such as a grinding of workpieces mounted in the lathe is to be performed, it is necessary to drill and countersink center holes in the workpiece so that it can be mounted between centers. The procedure for drilling and countersinking center holes for cylindrical grinding is the same as that prescribed for lathe work (par. 72*f*). The drilled centers should then be smoothed by lapping. This can be accomplished by charging with abrasive a stick that is turned or filed to a 60° point.

47. Mounting Workpieces.

a. General. Mounting instructions for tool and cutter grinding will be found in the appropriate chapters of this manual applicable to the tools to be ground. General off-hand grinding requires no mounting of the workpiece. Mounting for cylindrical grinding and surface grinding is described in *b* and *c* below.

b. Mounting Workpiece for Cylindrical Grinding.

(1) *General.* Cylindrical grinding may be done either with the workpiece set up between centers, held in a chuck and supported by a center rest, or clamped to a faceplate as in lathe setups (pars. 73–75).

(2) *Workpiece mounted between centers.*

(*a*) When the workpiece is held between centers, the use of a dead center in the tailstock spindle is preferable as this method eliminates any error that may be caused by wear in the spindle bearings of the machine. Before starting a grinding operation, the centers should be checked for accuracy and alinement and then corrected if necessary.

(*b*) To grind the centers, proceed as outlined for grinding lathe centers (par. 73*b*).

(*c*) After the centers are accurate, aline the centers by one of the methods prescribed for alining lathe centers (par. 73*c*).

(*d*) The workpiece is positioned between the centers and a lathe dog is used to revolve the piece.

(3) *Workpiece mounted for conical grinding.*

(*a*) Workpieces for conical grinding can be set up in the lathe either between centers (par. 73) or in a chuck (par. 74).

(*b*) When mounting workpieces between centers, the lathe tailstock is set over (par. 84*c*) or the taper attachment is engaged (par. 84*e*) so that the tool post grinding machine or the milling and grinding lathe attachment will move along the lathe carriage at an angle to the workpiece axis. In cases where the taper is to be ground at the end of the workpiece, the piece is placed against the headstock center and supported by a rawhide lacing passed over the lathe dog and tied to the faceplate. The free end of the piece is supported by a steady rest (par. 69*b*).

(*c*) If the workpiece is supported in a chuck, the compound rest of the lathe must be swiveled to an angle equal to one-half the included angle of the conical surface desired. The tool post grinding machine or the milling and grinding lathe attachment is then alined upon the compound rest so that the abrasive wheel face is parallel to the direction of travel of the compound rest.

(*d*) It should be remembered that when a workpiece is to be conically ground, the workpiece axis and the grinding abrasive wheel axis must be at the same height. Otherwise, the workpiece will not be ground at the correct angle set on the lathe taper attachment or the compound rest.

(4) *Workpiece mounted for internal grinding.*

(*a*) The workpiece is attached to the headstock of the lathe in a chuck. Steady rests are used to provide rigid mounting of long workpieces.

(*b*) If both internal and external grinding operation are to be performed on a workpiece such as a bushing, the internal bore is finished first, using an appropriate size grinding abrasive wheel mounted to the spindle of the tool post grinding machine on the milling and grinding lathe attachment. A large grinding abrasive wheel is then used to finish the external surface.

c. *Mounting Workpiece for Surface Grinding.*

(1) A workpiece for surface grinding is usually held to the reciprocating worktable by means of a vise. It may also be clamped directly to the surface of the table.

(2) When using a vise in connection with surface grinding, care must be taken to avoid springing the workpiece out of shape by setting the vise too tight. The vise and table must be perfectly clean before the setup is made.

(3) If a workpiece is held by clamps, care must be used to provide some means of support under each clamp. It should be remembered that the grinding operation applies pressure to the surface being ground and any large unsupported area, if the workpiece is relatively thin, will spring away from the grinding abrasive wheel and result in inaccuracies.

(4) Magnetic chucks are commonly used to hold work to the tables of surface grinders. Both permanent-magnet-type and electric chucks are used. The electrified chucks are built in larger sizes and are more powerful. However, the permanent-magnet-type chucks are less dangerous, since accidental release of work (due to power failure) is not likely to occur.

Section IV. GENERAL GRINDING OPERATIONS

48. General

a. Efficient grinding depends primarily upon the proper setup of the machine being used. If the machine is not securely mounted, vibration will result, causing the grinder to produce an irregular surface. Improper alinement also affects the grinding accuracy and it is good practice to check the security and plumb of the machine every few months. It is advisable to place a strip of cushioning material under the mounting flanges, along with any necessary alining shims, to help absorb vibration.

b. When a grinding abrasive wheel is functioning properly, the abrasive grains cut very small chips from the workpiece and at the same time a portion of the bond of the wheel is worn away. As long as the bond is being worn away as fast as the abrasive grains of the wheel become dull, the wheel will continue to work well. If the bond is worn away too rapidly, the wheel is too soft and will not last as long as it should. If the cutting grains wear down faster than the bond, the face of the wheel becomes glazed and the wheel will not cut freely.

c. Precision and semiprecision grinding may be divided into the following classes: cylindrical grinding, surface grinding, and tool and cutter grinding.

(1) Cylindrical grinding denotes the grinding of a cylindrical surface. Usually cylindrical grinding designates external cylindrical grinding and the term internal grinding is used to designate internal cylindrical grinding. Another form of cylindrical grinding is conical grinding or the grinding of tapered workpieces.

(2) Surface grinding is the grinding of simple plain surfaces.

(3) Tool and cutter grinding is the generally complex operation of forming and resharpening the cutting edges of tool and cutter bits, gages, milling cutters, reamers, and so forth.

d. The grinding abrasive wheel for any grinding operation should be carefully chosen (par. 42) and the workpiece set up properly in the grinding machine before commencing any grinding operation. Grinding speeds and feeds should be selected for the particular job as outlined in paragraph 49. Wherever practical, a coolant (par. 50) should be applied to the point of contact of the wheel and the workpiece to keep the wheel and workpiece cool, to wash away the loose abrasive, and to produce a better finish.

49. Grinding Speeds and Feeds

a. General. In grinding, the speed of the grinding abrasive wheel in surface feet per minute and the feed of the grinding abrasive wheel per revolution is as important, and sometimes more so, as the proper wheel selection. Too slow a speed will result in waste of abrasive, whereas an excessive speed will cause a hard grinding action and glaze the wheel to make the grinding inefficient. The feed of the grinding abrasive wheel will determine to a certain extent the finish produced on the work and will vary for different types and shapes of grinding abrasive wheels.

b. Factors Governing Speed. The various factors governing the speed in surface feet per minute of a grinding abrasive wheel are as described in (1) through (4) below.

(1) *Safety.* The grinding abrasive wheel should never be run at speeds in excess of manufacturer's recommendations. Usually, each grinding abrasive wheel has a tag attached to it which states the maximum safe operating speed of the wheel.

***Warning:* If a wheel is permitted to exceed the maximum safe speed, it may cause injury to the operator and to the grinding machine.**

(2) *Condition of the machine.* Modern grinding machines and machines that are in good condition can safely turn a grinding abrasive wheel at speeds greater than machines that are older or in poor condition. Most grinding machines are equipped with spindle bearings designed for certain speeds which should not be exceeded. Poor quality will result from vibrations caused by inadequate rigidity or sloppy bearings in a grinding machine that is not in the best of conditions. Higher speeds will accentuate these defects.

(3) *Material being ground.* The material being ground will generally determine the grain, grade, structure, and bond of wheel to be selected (par. 42). However, if the best wheel for a particular material is not available, the speed can be varied slightly to compensate for the mismatch of the wheel. Fox example, if the wheel is too sort for the material being cut, an increase in speed will make the wheel act harder. Conversely, if the wheel is too hard, a slower speed will make the wheel act softer.

(4) *Type of grinding abrasive wheel.* The type of grinding abrasive wheel employed for a particular operation is one of the major considerations in the proper selection of cutting speed. In general practice, the wheel will be selected for the material to be cut (par. 42). The recommended cutting speed can then be determined by the wheel type, bond, and grade of hardness from table X. The figures in table X are approximate and can be varied as necessary.

Table X. Cutting Speeds for Standard Types of Grinding Abrasive Wheels

Wheel type (fig. 31)	Cutting speeds (s. f. p. m.)					
	Vitrified bond			Resinoid bond		
	Soft	Med	Hard	Soft	Med	Hard
Straight wheels (type 1)	5, 500	6, 000	6, 500	6, 500	8, 000	9, 500
Cutoff wheels (type 1)	-------	-------	-------	-------	10, 000	12, 000
Cylinder wheels (type 2)	4, 500	5, 500	6, 000	6, 000	8, 000	9, 500
Tapered wheels (type 4)	5, 500	6, 000	6, 500	6, 500	8, 000	9, 500
Recessed wheels (types 5 and 7)	5, 500	6, 000	6, 500	6, 500	8, 000	9, 500
Straight cup wheels (type 6)	4, 500	5, 000	5, 500	6, 000	7, 500	9, 000
Flaring cup and dish wheels (types 11 and 12)	4, 500	5, 500	6, 000	6, 000	8, 000	9, 500

c. Calculating Wheel Size or Speeds.

(1) *Wheel size.* Both cutting speed in surface feet per minute and rotational speed in revolutions per minute must be known to determine the size wheel to be used on a fixed-speed grinding machine. To determine the grinding abrasive wheel size, use the following formula:

$$D=\frac{12\times \text{sfpm}}{\pi \text{ rpm}}$$

where, sfpm = cutting speed of wheel (in surface feet per minute);

$\pi = 3.14$;
rpm = revolutions per minute of wheel;
D = the calculated wheel diameter (in in.).

(2) *Wheel cutting speed.* To obtain the cutting speed in surface feet per minute when wheel diameter and revolutions per minute are given, use the same formula in a modified form:

$$\text{sfpm}=\frac{\pi D \text{ rpm}}{12}$$

(3) *Wheel rotational speed.* To obtain the rotational speed in revolutions per minute when the wheel diameter and desired cutting speed are known, use the same formula in another modified form:

$$\text{rpm}=\frac{12 \text{ sfpm}}{\pi D}$$

Note. As a grinding abrasive wheel wears down and as it is continually trued and dressed, the wheel diameter decreases resulting in loss of cutting speed. As this occurs, it is necessary to increase the rotational speed of the wheel or replace the wheel to maintain efficiency in grinding.

(4) *Tabulated values of speeds.* Table XI is provided for determining wheel diameter and revolutions per minute without performing the calculations in (1) through (3) above. Refer to the column for the desired cutting speed and wheel diameter and rotational speed combinations which will provide the desired cutting speed.

d. Work Speed for Cylindrical Grinding. In cylindrical grinding, it is difficult to recommend any work speeds since these are dependent upon whether the material is rigid enough to hold its shape, whether the diameter of the workpiece is large or small, and so forth.

(1) The larger the diameter of the workpiece, the greater is its arc of contact with the wheel. The cutting speed suitable for one diameter of workpiece might be unsuitable for another.

Table XI. Rotational Speeds for Various Diameters of Grinding Abrasive Wheels

Cutting speed (sfpm)	4,000 fpm	5,000 fpm	5,500 fpm	6,000 fpm	6,500 fpm
Wheel diameter (in.)	Revolutions per minute				
1	15, 279	19, 079	21, 000	22, 918	24, 828
2	7, 639	9, 549	10, 500	11, 459	12, 414
3	5, 093	6, 366	7, 350	7, 369	8, 276
4	3, 820	4, 775	5, 250	5, 730	6, 207
5	3, 056	3, 820	4, 200	4, 584	4, 966
6	2, 546	3, 183	3, 500	3, 820	4, 138
7	2, 183	2, 728	3, 000	3, 274	3, 547
8	1, 910	2, 387	2, 600	2, 865	3, 103
10	1, 528	1, 910	2, 100	2, 292	2, 483
12	1, 273	1, 592	1, 750	1, 910	2, 069
14	1, 093	1, 364	1, 500	1, 637	1, 773
16	955	1, 194	1, 300	1, 432	1, 552
18	849	1, 061	1, 150	1, 273	1, 379

(2) The highest work speed that the machine and wheel will stand should be used for roughing.

(3) The following cylindrical work speeds are only typical: Steel shafts, 50–55 fpm; hard steel rolls, 80–85 fpm; chilled iron rolls, 80–200 fpm; cast iron pistons, 150–400 fpm; crankshaft bearings, 45–50 fpm; and crankshaft pins, 35–40 fpm.

(4) Higher work speeds increase the cutting action of the wheel and may indicate that a harder wheel and a smaller depth of cut be used to minimize wheel wear.

e. Work Speed for Surface Grinding. Surface grinding machines usually have fixed work speeds of approximately 50 surface feet per minute or have variable work speed ranges between 0 and 80 surface feet per minute. As with cylindrical grinding, the higher work speeds mean that more material is being cut per surface foot of wheel rotation and therefore more wear is liable to occur on the wheel.

f. Feeds. The feed of the grinding abrasive wheel is the distance the wheel moves laterally across the workpiece for each revolution of the piece in cylindrical grinding or in each pass of the piece in surface grinding.

(1) The feed should be proportional to the width of wheel face and the finish desired. In general, the narrower the face of the wheel, the slower must be the traverse speed, and the wider the wheel face, the faster can be the traverse speed.

(2) For roughing, the table should traverse about three-fourths the wheel width per revolution or pass of the workpiece.

(3) For an average finish, the wheel should traverse one-third to one-half the width of the wheel per revolution or pass of the workpiece.

(4) In surface grinding with wheels less than 1 inch in width, the table traverse speed should be reduced about one-half.

g. Depth of Cut.

(1) *Roughing.* In roughing, the cut should be as deep as the grinding abrasive wheel will stand, without crowding or springing the work. The depth of cut also depends on the hardness of the material. In cylindrical grinding, in addition to these factors, the cut depends on the diameter of the work. In any case, experience is the best guide. Generally, a cut of 0.001 to 0.003 inch in depth is used, depending on the size and condition of the grinding machine.

(2) *Finishing.* For finishing, the depth of cut is always slight, generally from 0.0005 inch to as little as 0.00005 inch.

(3) *Sparks.* An indication of the depth of cut is given by the volume of sparks thrown off while an uneven amount of sparks indicates that the workpiece or wheel is out of true.

50. Coolants

a. Where precision or semiprecision grinding is performed, it is best to use a coolant if a coolant attachment (par. 246) is available. A coolant serves several important functions—it reduces the temperature of the grinding abrasive wheel and the workpiece preventing undue distortion caused by expansion of the material; it keeps the wheel clean and free cutting by washing away the discarded abrasive grain and the metal particles cut from the workpiece; it enables the wheel to produce a better finish through its lubricating qualities.

b. Clear water may be used as a coolant but various compounds containing alkali are usually added to improve its lubricating quality and prevent rusting of the machine and workpiece.

c. An inexpensive coolant often used for all metals except aluminum, consists of a solution of approximately one-quarter pound of sodium carbonate (sal soda) dissolved in 1 gallon of water. Another good coolant is made by dissolving soluble cutting oil in water, For grinding aluminum and its alloys, a clear water coolant will produce fairly good results.

51. Off-Hand Grinding

a. Off-hand grinding is the process of positioning and feeding the workpiece against a grinding abrasive wheel by hand. Off-hand grinding operations include the snagging of castings, reduction of weld marks and imperfections on workpieces, and general lathe tool, planer tool, shaper tool, and drill grinding operations. Judgment so far as depth of cut and feed is based on the operator's knowledge of grinding.

b. Off-hand grinding is performed on utility grinding machines which generally have fixed spindle speeds and fixed wheel size requirements so that the cutting speed of the wheel is constant and cannot be changed for different materials. Therefore, the operator must use care in feeding not to overload the wheel by taking too heavy a cut which would cause excess wear to the grinding abrasive wheel. Similarly, he must be careful not to glaze the wheel by applying insufficient pressure against the wheel.

c. The one variable factor in most off-hand grinding is the selection of grinding abrasive wheels although limited to one diameter. For example, a softer or harder wheel can be substituted for the standard medium grade wheel when conditions and materials warrant such a change.

d. Planer, shaper, and lathe tool grinding is described in the chapters pertaining to these machine tools. Drill sharpening and drill grinding attachments and fixtures are described in chapter 2.

52. Tool and Cutter Grinding

The sharpening of milling cutters and reamers is an operation usually performed on universal tool and cutter grinding machines or special grinding machine attachments. It is a specialized grinding operation requiring knowledge of the types of cutters and their various cutting edges and angles. Refer to paragraph 97 for detailed information on the grinding of milling cutters and to paragraph 191*f* for the sharpening of reamers Planer, lathe, and shaper tool sharpening is generally an off-hand grinding procedure and is described in detail in appropriate chapters on the applicable machine tool.

53. Cylindrical Grinding

a. General. Cylindrical grinding is the practice of grinding cylindrical or conical workpieces by revolving the workpiece in contact with the grinding abrasive wheel. Cylindrical grinding is divided into three general operations: plain cylindrical grinding, conical grinding (taper grinding), and internal grinding. The workpiece and wheel are set to rotate in opposite directions (fig. 37).

b. Plain Cylindrical Grinding (fig. 38) The step-by-step procedure for grinding a straight shaft section is given in (1) through (15) below. The shaft has been roughly turned prior to grinding.

(1) Mount tool post grinding machine (par. 70) or milling and grinding lathe attachment (par. 71) to compound rest of lathe. Install external grinding head as required.

(2) Check and grind headstock and tailstock lathe centers if necessary (pars. 47*b* and 73*b*).

(3) Check drilled centers of workpiece for accuracy and lap centers (par. 46*c*).

(4) Mount lathe dog (par. 67) on headstock end of workpiece.

(5) Mount workpiece between headstock and tailstock centers of lathe. Use lubricant (oil and white lead mixture) on

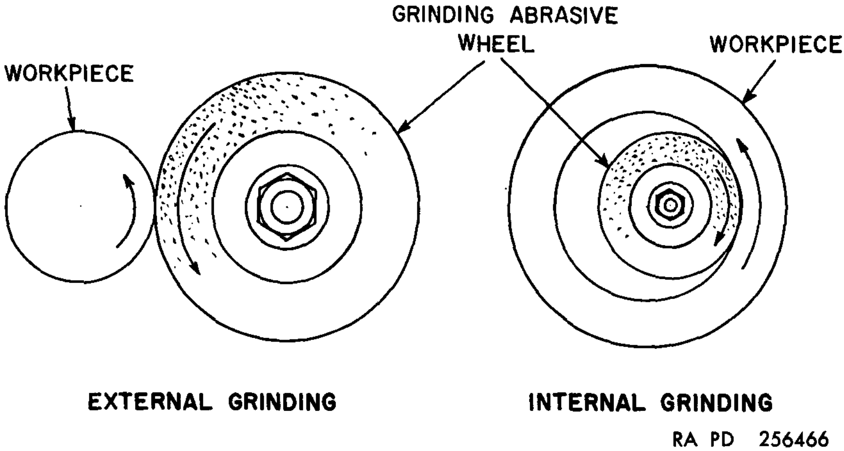


Figure 37. Direction of rotation for cylindrical grinding.

tailstock center and drilled center of workpiece Make sure centers fit drilled centers correctly with no play.

(6) Place a grinding abrasive wheel of the proper grain, grade, structure, and bond on wheel spindle.

(7) Place wheel guard or grinding abrasive wheel and check grinding machine and lathe carriage for stability and backlash in adjustable members.

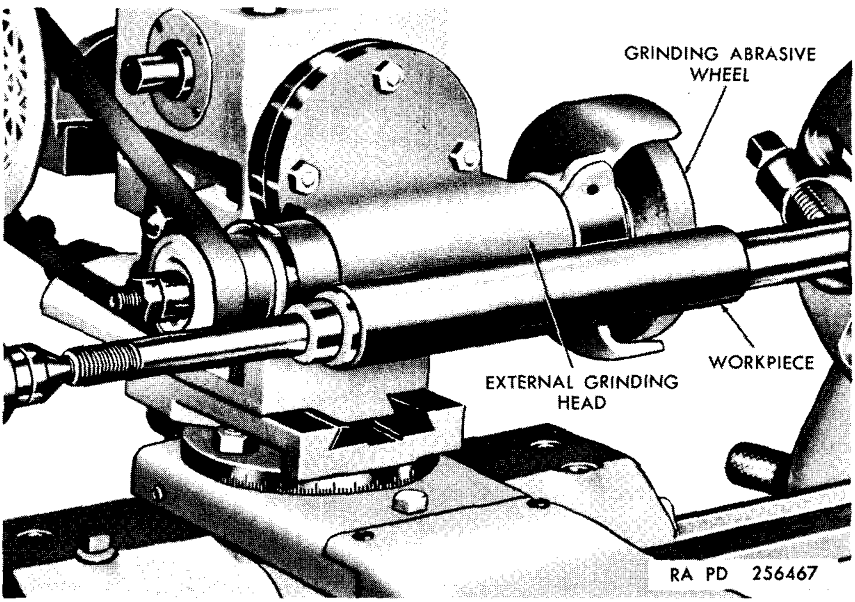


Figure 38. Plain cylindrical grinding operation, using milling and grinding lathe attachment.

(8) True and dress grinding abrasive wheel (par. 45*c* and *d*).

(9) Set proper wheel speed on grinding machine (table X).

(10) Set proper rotational work speed on lathe The general range of work speed for cylindrical grinding is 60 to 100 surface feet per minute Heavy, rough grinding is sometimes performed at work speeds as low as 20 or 30 feet per minute and soft metals such as aluminum are sometimes ground at speeds up to 200 feet per minute.

(11) Set the lathe carriage for power feed. The feed for grinding is based on the width of the grinding abrasive wheel. The traverse should never exceed three-quarters of the wheel width per revolution.

(12) Grind, using appropriate coolant and regulating depth of cut. The cut may be a plunge cut for rough grinding and a traversing cut for finish grinding if desired. For plunge cuts, the wheel is plunged into the workpiece and retracted, making as many plunges as are necessary to rough grind the shaft. A very slow traversing speed must be used for plunge cutting. The finishing cut is then made by traversing the wheel from one end to the other of the section being ground. The grinding abrasive wheel should overlap each end of the workpiece not more than one-half the wheel width to assure a uniform straight cut over the length of the workpiece.

(13) Check the workpiece size often during cutting with micrometer calipers. Check the tailstock center often and readjust if expansion in the workpiece has caused excess pressure against the drilled center in the workpiece.

(14) The finishing cut should be slight, never greater than 0.001 inch, and taken with a fine feed and a fine grain wheel.

(15) If two or more grinding abrasive wheels of different grain size are used during the grinding procedure, each wheel should be dressed and trued as soon as it is mounted in the grinding machine.

c. Conical Grinding. Most conical grinding operations are performed in the same manner as plain cylindrical grinding (*b* above), using the tool post grinding machine or the milling and grinding lathe attachment mounted to a lathe. Small conical portions can be ground in the manner set forth for grinding lathe centers (par. 73*b*). Larger conical sections are achieved by setting over the lathe tailstock (par. 84*c*) or setting the desired taper on the lathe taper attachment (par. 84*e*).

d. Internal Grinding (fig. 39).

(1) The internal grinding head is bolted to the milling and grinding lathe attachment or the tool post grinding machine is fitted with a chuck assembly to permit installation of the

small, arbor-mounted grinding abrasive wheel. A smaller pulley than is used when external grinding is performed is mounted to the end of the wheel spindle. The pulley ratio increases the rotational speed of the internal grinding attachment spindle to about three times that of the wheel spindle, thus compensating for the extremely small grinding abrasive wheels used for internal grinding.

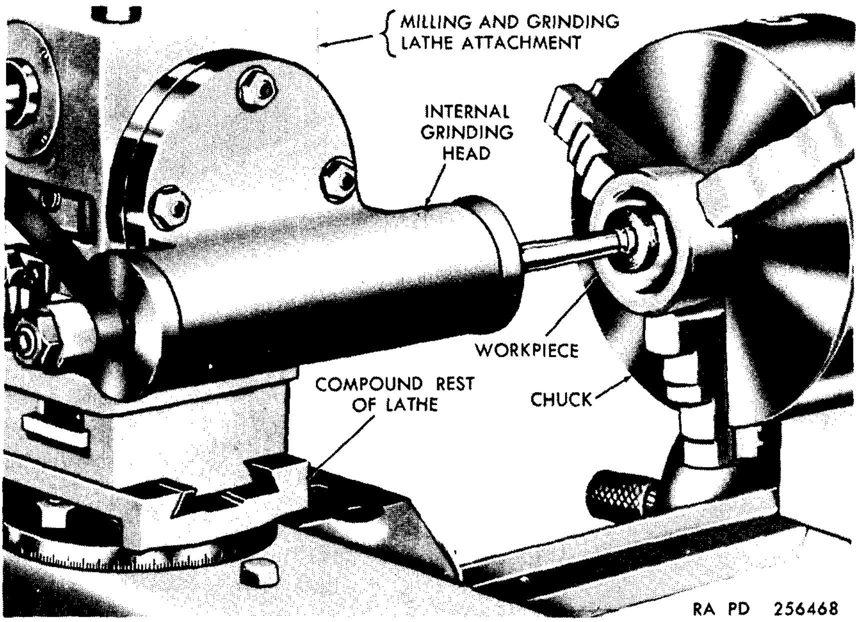


Figure 39. Internal grinding operation, using milling and grinding lathe attachment.

(2) The workpiece should be set to rotate in the opposite direction as that of the grinding abrasive wheel (fig. 37).

(3) The step-by-step procedure for grinding the bore of a bushing is outlined below as an example.

(*a*) Set up workpiece in an independent chuck and check and adjust its alinement (par. 74*b*).

(*b*) Mount milling and grinding lathe attachment of tool post grinding machine to tool post or compound rest of lathe, and adjust its position so that the wheel spindle axis is parallel to the lathe bed ways and the grinding abrasive wheel is centered vertically with the mounted workpiece.

(*c*) True and dress grinding abrasive wheel (par. 45*c* and *d*).

(*d*) Set proper wheel speed on grinding machine by adjusting the pulleys and belts connecting wheel spindle to drive motor shaft.

(e) Set proper rotational work feed on lathe. The proper speed should be 60 to 100 surface feet per minute.

(f) Be sure sufficient clearance is allowed when setting traversing speed so that grinding abrasive wheel will not strike any part of workpiece or setup when wheel is fed into and retracted from workpiece.

(g) Grind and check for accuracy. If two or more grinding abrasive wheels are used to complete the internal grinding operation, true each wheel after mounting it to the spindle of the internal grinding attachment.

54. Surface Grinding

a. General. Surface grinding, or the grinding of flat surfaces, is characterized by a large contact area of the wheel with the workpiece as opposed to cylindrical grinding where a relatively small area of contact is present. As a result, the force of each abrasive grain against the workpiece is much smaller than that applied to each grain in cylindrical grinding. In surface grinding the grinding abrasive wheel should be generally softer in grade and wider in structure than for cylindrical grinding.

b. Operation. The following sequence is provided as a step-by-step example of a typical surface grinding operation.

(1) Adjust surface grinding machine so that grinding head and worktable are absolutely parallel.

(2) Place a grinding abrasive wheel of the proper grain, grade, structure, and bond on the wheel spindle.

(3) Place guard on wheel and check security of all adjustable members of grinding machine, checking for rigidity and lack of backlash.

(4) True and dress grinding abrasive wheel (par. 45*c* and *d*).

(5) Mount workpiece to worktable (par. 47*c*). Make sure surface to be ground is parallel to the worktable and the grinding abrasive wheel.

(6) Adjust wheel speed, work speed, and work feed (par. 49*b*, *c*, *e*, and *f*).

(7) Proceed with grinding operation, adjusting depth of cut as necessary. Check for accuracy between each cut and determine that workpiece is square and wheel is not out of alinement. If it is necessary to use more than one grinding abrasive wheel to complete the grinding operation, each wheel should be trued and dressed after it is mounted.

Section V. SPECIAL OPERATIONS ON GRINDING MACHINES

55. Cleaning

a. A wire wheel mounted to a utility grinding machine is used for cleaning operations such as removal of rust, paint, or dirt from metal objects. If the utility grinding machine on which the wire wheel is to be mounted is equipped with wheel guards and tool rests, these parts should be removed or swung out of the way so that the objects to be cleaned can be brought against the wheel without interference.

b. To clean objects with a wire wheel, place the object firmly against the wire wheel. Work the object back and forth across the face of the wheel until all traces of rust, paint, or dirt are removed. Avoid excessive pressure against the face of the wire wheel to prevent spreading of its steel wires.

56. Polishing, Buffing, and Lapping

a. General. Polishing, buffing, and lapping are three closely related methods for finishing metal parts.

(1) *Polishing.* Polishing is an abrading process in which small amounts of metal are removed to produce a smooth or glossy surface by application of cushion wheels impregnated or coated with abrasives. Polishing may have for its objective the reduction or smoothing of the surface to a common level for high finish where accuracy is not important, or it may be employed for removing relatively large amounts of material from parts of irregular contour. Rough polishing is performed on a dry wheel using abrasives of No. 60 grain (60 grains per linear inch) or coarser. Dry finish polishing is the similar process where No. 70 grain to No. 120 grain abrasives are used. Oiling is the term applied to polishing with abrasives finer than No. 120 grain; in this process, the abrasive is usually greased with tallow or a similar substance.

(2) *Buffing.* Buffing is a smoothing operation which is accomplished more by plastic flow of the metal than by abrading. The abrasives are generally finer than those used in polishing, and instead of being firmly cemented to the wheel are merely held by a "grease cake" or similar substance. Buffing is used to produce a high luster or color without any particular regard to accuracy of dimension or plane. Cutdown buffing produces a rapid smoothing action with fast cutting abrasives and relatively hard buffing wheels. It is accomplished with high speeds and heavy pressures to allow a combined plastic flow and abrading action to occur. Color buffing is the imparting of a high luster finish on the workpiece by use of soft abrasives and soft buffing wheels.

(3) *Lapping.* Lapping, like polishing, is an abrading process in

which small amounts of material are removed. Unlike polishing however, lapping is intended for producing very smooth, accurate surfaces, and is never used instead of polishing or buffing when appearance is the only consideration. Lapping is accomplished by charging metal forms called laps with flour fine abrasives and then rubbing the workpiece with the lap. The lap may be of any shape and may be designed to fit into most power machine tools. The only requirements of the lap is that it be of softer material than the material being lapped, and that it be sufficiently porous to accept the imbedded abrasive grain. Common materials for laps are soft cast iron, copper, brass, and lead. Some laps are flat; some are cylindrical to fit on steel arbors for internal lapping of bores. A cutting oil is recommended for most lapping operations.

b. Polishing and Buffing Speeds. The proper speed for polishing and buffing is goverened by the type of wheel, workpiece material, and finish desired. For polishing and buffing operations in general where the wheels are in perfect balance and correctly mounted, a speed of approximately 7,500 revolutions per minute is safe and gives satisfactory results for most operations.

c. Polishing Abrasives. The abrasive grains used for polishing must vary in characteristics for the different operations to which they are applied. Abrasive grains for polishing are supplied in bulk form and are not supplied mixed with any vehicle. The abrasives, usually aluminum oxide or silicon carbide, range from coarse to fine (16 to 240 grains per inch).

d. Buffing Abrasives. Buffing abrasives are comparatively fine and are often made up in the form of paste, sticks, or cakes, the abrasive being bonded together by means of grease or a similar vehicle. The abrasive sizes for buffing are 280, 320, 400, 500, and 600. Some manufacturers use letters and numbers to designate grain size such as F, 2F, 3F, 4F, and XF (from fine to very fine). Pumice, rottenstone, and rouge are often used as buffing abrasives.

e. Lapping Abrasives. Only the finest abrasives are used for lapping and may be either natural or artificial. Abrasives for lapping range from No. 220 to No. 600 or No. 800 which are very fine flours. Lapping compounds are generally mixed with water or oil so that they can be readily applied to the lap.

f. Impregnating Polishing Wheels With Abrasives.

(1) Polishing abrasives are applied to polishing wheels with specially prepared glue. The glue must be strong and flexible in order to firmly hold the abrasive grain to the wheel face. It should be stored in a cool, dry place before use.

(2) The glue should be soaked in distilled water for 3 to 12 hours before mixing. When heating and mixing the temperature

should never be allowed to rise higher than 140° F. Mixed glue should not be allowed to stand overnight before using.

(3) The polishing wheel and abrasive should be heated to approximately 120° F. when the glue is applied to the wheel. Coarse grains require relatively thick glue while fine grains require thin glue. The glue should be thinned with water to suit the grain.

(4) After the polishing wheel is glued, it should be set aside for at least 48 hours before being used.

g. Charging Laps With Abrasives.

(1) To charge a flat cast iron lap, a very thin coating of prepared abrasive is spread over the surface of the lap and the small particles pressed into the lap with a hard steel block. There should be as little rubbing as possible and when the surface is apparently charged, it should be cleaned and examined for bright spots. If the surface has a uniform gray appearance it is fully charged, but if bright spots are visible, the charging operation should be repeated. The surface should not be allowed to become dry when lapping.

(2) To charge a cylindrical lap for internal lapping, a thin coating of prepared abrasive is spread over the surface of a hard steel block. The lap is then rolled and pressed over the block to imbed the abrasive into its surface.

h. Polishing Operation. It is often necessary to use more than one polishing wheel for certain workpieces. For example, one wheel may be charged with coarse abrasive to remove scale or rust caused from heat-treating, a second wheel may be charged with a fine abrasive to remove the marks left by the first, and a third wheel may be charged with flour abrasive for the final finish. Tools such as wrenches and screwdrivers are polished in this manner. On other tools, only certain parts are polished such as grooves or flutes in reamers and milling cutters.

i. Buffing Operation. The abrasive is applied to buffing wheels when the wheel is stopped in the case of paste abrasives or when the wheel is rotating in the case of stick or cake abrasives. Buffing abrasives do not adhere to the buffing wheel strongly and it is often necessary to reapply abrasive to the wheel at intervals during the operation.

j. Lapping Operation. Lapping should always be performed using a suitable cutting oil or lubricant. The best all-around cutting oil for this purpose is pure lard cutting oil. Soda water or soluble cutting oil solutions may be used but they are not nearly as effective as pure lard cutting oil. The speed for lapping should not be great. Good results are obtained by hand lapping whereby the workpiece is rubbed over a flat lap or turned by hand, as well as by machine lapping where the lap or workpiece is revolved or reciprocated by power.

CHAPTER 4

LATHES

Section I. GENERAL

57. Purpose

The lathe is a machine tool used principally for shaping articles of metal, wood, or other material by causing the workpiece to revolve while the cutter bit, held either by hand or by a mechanical holder, is applied to the workpiece. Principal capabilities of the lathe are the shaping of straight, tapered, or irregularly outlined cylinders, the facing or radial turning of cylindrical sections, the cutting of screw threads, and boring or enlarging internal diameters. The typical lathe provides a variety of rotating speeds and suitable manual and automatic controls for moving the cutting tool. In the hands of a competent operator, a lathe is the most versatile of all machine tools.

58. Types of Lathes

Lathes can be conveniently classified as engine lathes, turret lathes, and special purpose lathes. All engine lathes and most turret and special purpose lathes have horizontal spindles and for that reason are sometimes referred to as horizontal lathes. The smaller lathes in all classes may be further classified as bench lathes or floor or pedestal lathes, the reference in this case being the means of support. Engine lathes, turret lathes, and special purpose lathes are described more fully in paragraphs 59 through 61.

59. Engine Lathes

a. General. The engine lathe is intended for general purpose lathe work and is the usual lathe found in the machine shop. The engine lathe may be bench type or floor mounted, it may be referred to as a toolroom-type lathe, or it may be a sliding-gap- or extension-type lathe. The engine lathe consists mainly of a headstock, a tailstock, a carriage, and a bed upon which the tailstock and carriage move. Most engine lathes are back-geared to provide exceptionally slow spindle speeds and high torque which are required for the machining of large diameter workpieces and the taking of heavy cuts. The usual engine lathe has power longitudinal and crossfeeds for moving the carriage, and has a lead screw with gears to provide various controlled feeds for cutting threads. Lathes are made in various sizes, the size being determined by the diameter of the workpiece that can be swung in it and by the overall length of the bed. The swing is measured in inches and the bed is measured in feet. A third dimension is sometimes given: the distance between centers. This dimension, measured in inches, indicates the longest length of material that can be placed in the lathe.

b. Bench-Type Engine Lathe (fig. 40).

(1) The bench-type engine lathe is the most common general purpose screw cutting lathe in the small shop. It commonly has an 8- to 12-inch swing and a 3- to 5-foot bed length, the size being limited by the practicality of bench mounting. The bench upon which the lathe is mounted may be a standard wood-topped shop bench or a special metal lathe bench with drawers for storing the lathe accessories.

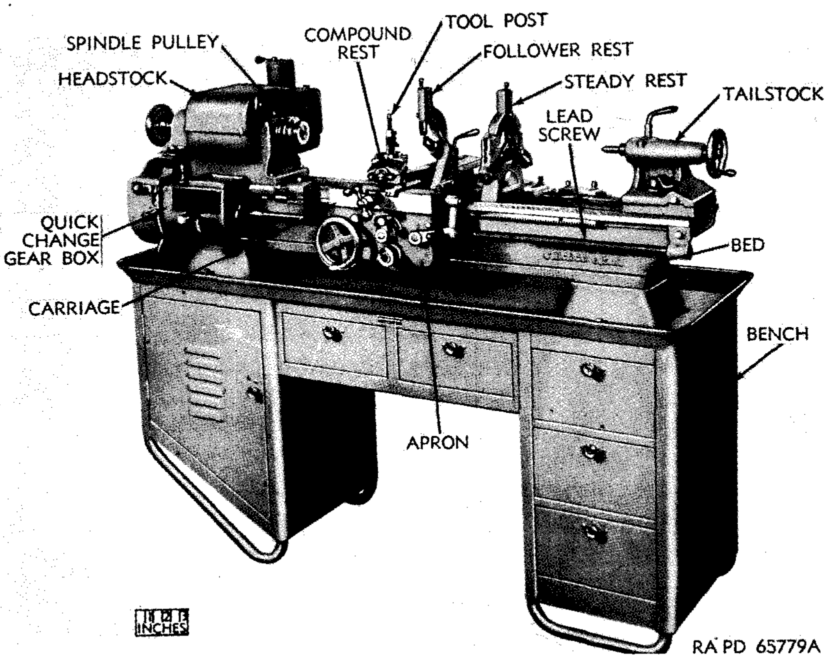


Figure 40. Bench-type engine lathe.

(2) The bench-type engine lathe is generally powered by an electric motor, mounted to the bench behind the lathe headstock, and driven by means of a flat leather belt. Some bench lathes use an underneath motor drive where the drive belt passes through a hole in the bench. This arrangement is convenient where space in the shop is limited. The bench-type engine lathe is generally equipped with the necessary tools, chucks, lathe dogs, and centers for normal operation. The lathe may have a quick-change gear box for rapid

change of threading feeds, or may be supplied with loose gears which have to be installed singly or in combination to achieve the proper threading feeds. The bench lathe may or may not have a power-operated crossfeed drive.

c. Floor-Mounted Engine Lathe (fig. 41). The floor-mounted engine lathe, or pedestal-type engine lathe, is inherently more rigid than the bench-type lathe and may have a swing as great as 16 or 20 inches and a bed length as great as 12 feet in length with 105 inches between centers. The drive motor is located in the pedestal beneath the lathe headstock. A tension release mechanism for loosening the drive belt is usually provided so that the drive belt may be quickly changed to different pulley combinations for speed changes. The headstock spindle is back-geared to provide slow spindle speeds, and a quick-change gear box for controlling the lead screw is present on all currently manufactured floor-mounted lathes. The floor-mounted engine lathe usually has a power-operated crossfeed mechanism.

d. Toolroom Lathe. The toolroom lathe is an engine lathe equipped with more precision accessories and built to greater standards of accuracy than the standard engine lathes. It may be either a floor-mounted toolroom-type engine lathe, or a bench-mounted toolroom-type engine lathe (fig. 42). The toolroom-type lathe is usually supplied with a very precise lead screw for threading operations, and comes equipped with precision accessories such as a collet chuck attachment, taper attachment, and micrometer carriage stop. Therefore, work of a better class and of a more complete nature may be accomplished on a toolroom-type engine lathe.

e. Sliding Gap-Type Floor-Mounted Engine Lathe (fig. 43). The sliding gap-type floor-mounted engine lathe or extension gap lathe contains two lathe beds, the top bed or sliding bed, and the bottom bed. The sliding bed mounts the carriage and tailstock and can be moved outward, away from the headstock as desired. By extending the sliding bed, material up to 28 inches in diameter may be swung on this lathe. The sliding bed may also be extended to accept workpieces between centers that would not normally fit in a standard lathe of the same size. Except for the sliding gap feature, this lathe is similar in features to the floor-mounted engine lathe.

60. Turret Lathes

a. General. The turret lathe is a lathe used extensively for the high-speed production of duplicate parts. The turret lathe is so named because it has a hexagonal turret, or multiple toolholder, in place of the tailstock found on the engine lathe. Most turret lathes are equipped with a pump and basin for the automatic application of a coolant or cutting oil to the workpiece.

b. Floor-Mounted Horizontal Turret Lathe (fig. 44). The floor-mounted horizontal turret lathe is intended for quick turning of bar

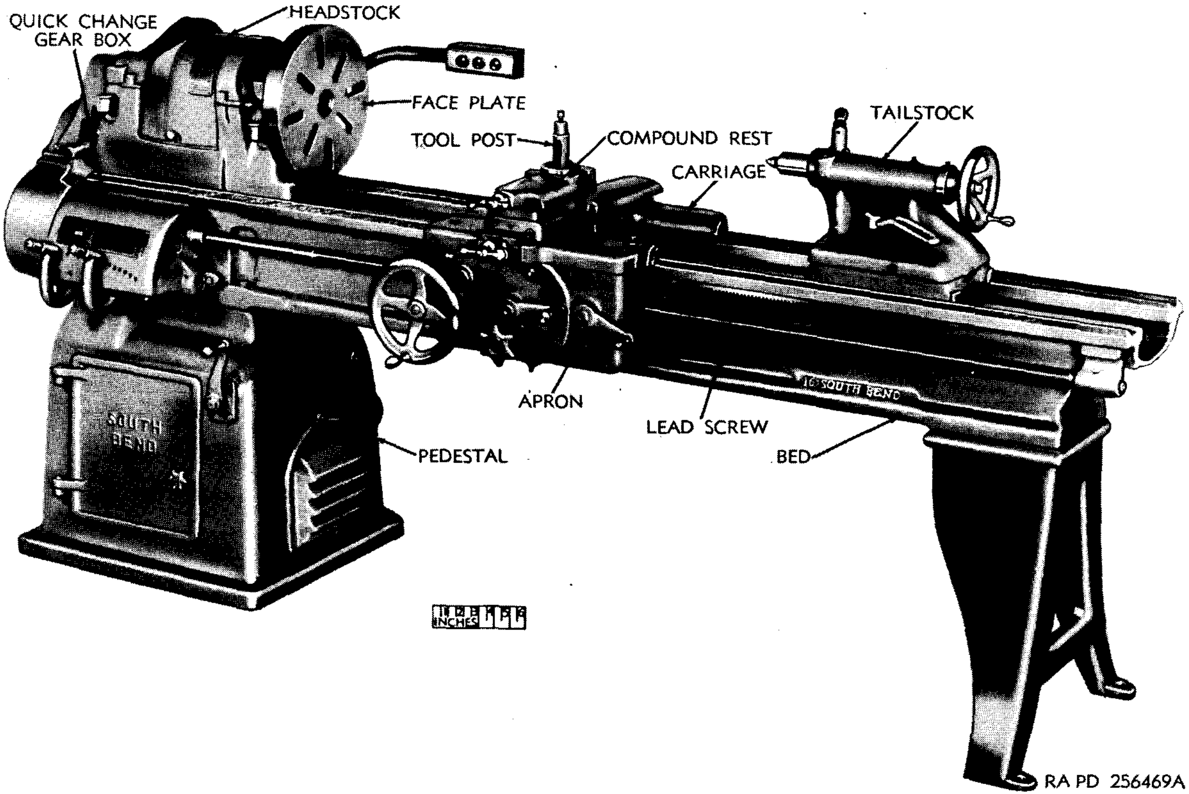


Figure 41. Floor-mounted engine lathe.

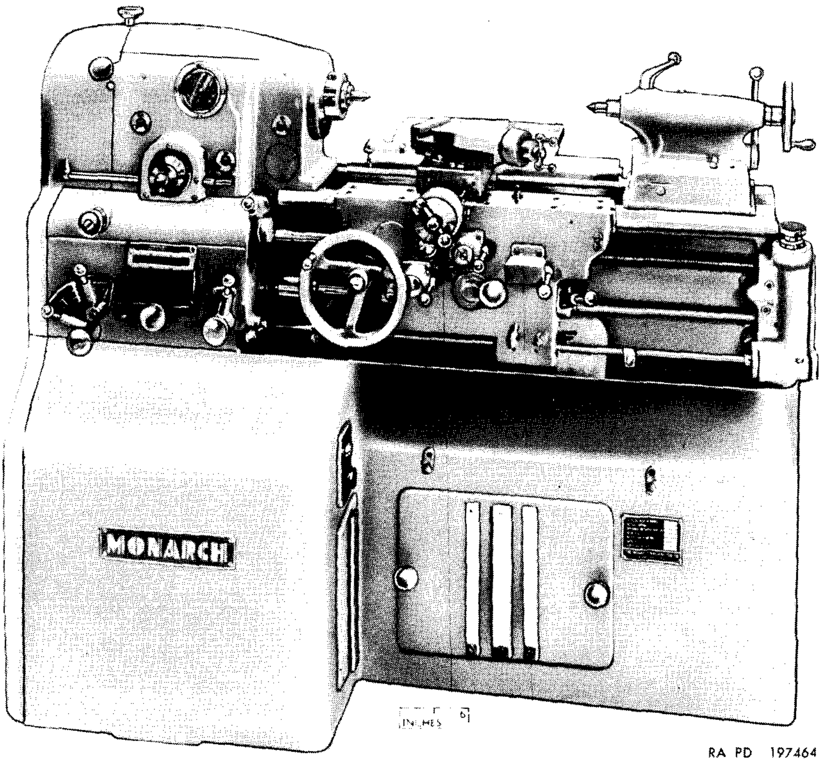


Figure 42. Bench-mounted toolroom-type engine lathe.

stock and chucked workpieces with a minimum of adjustments between operations. The lathe uses a collet chuck and a hollow headstock spindle for feeding bar stock into the machine, or may use a universal scroll chuck for swinging the workpiece. The size of the horizontal turret lathe is usually given as the diameter of bar stock that can be fed into the lathe through the headstock spindle, and sometimes is classified by the swing. The turret of the turret lathe is usually power operated and contains an indexing mechanism for bringing the tools held on its six faces against the workpiece in a preselected order. Separate feed stops are provided for each face of the turret. A quick hand-indexed four-sided turret is commonly mounted on the front of the cross-slide, and a holder for one or more tools often is mounted on the rear. The cross-slide may be either hand or power operated.

61. Special Purpose Lathes

a. General. Some lathes have characteristics that enable them to do certain work well. Some of these lathes are of the heavy-production type where large numbers of identical parts must be

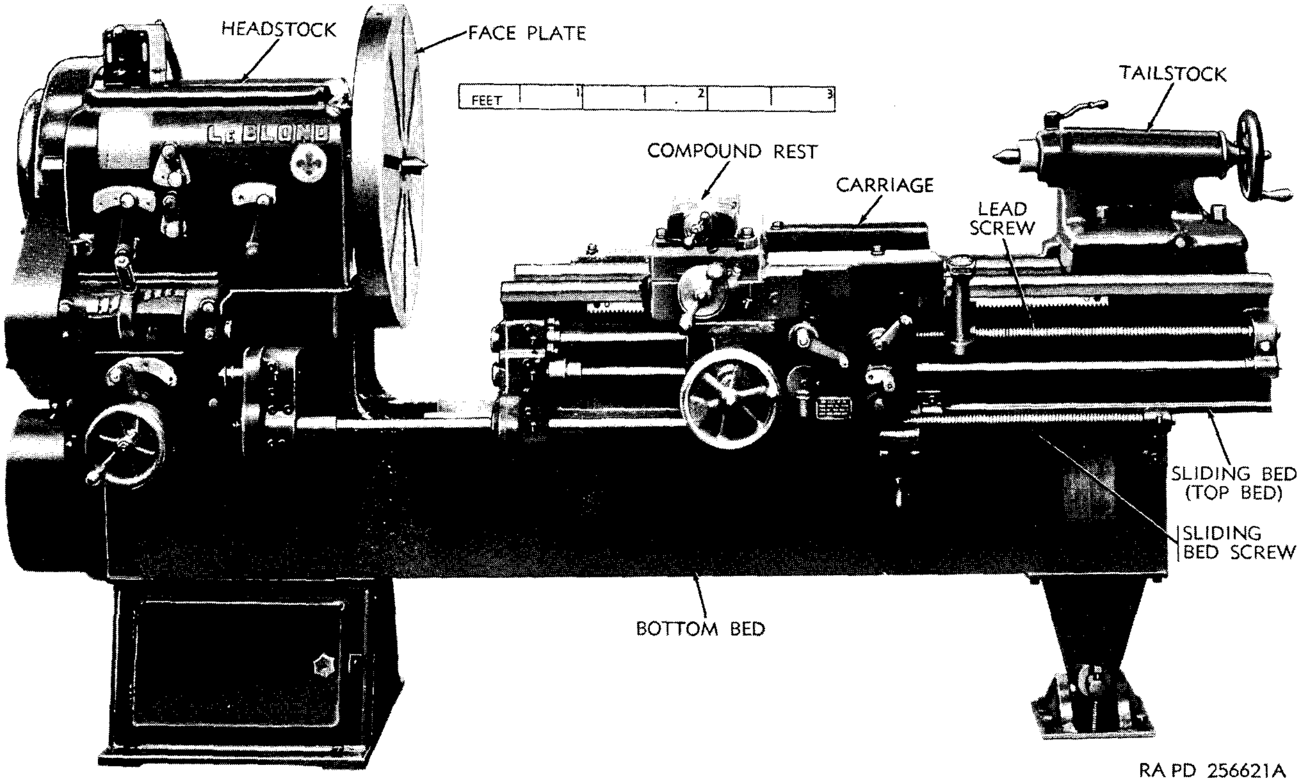


Figure 43. Sliding gap-type floor-mounted engine lathe.

produced to make the operation economical. Other special purpose lathes are specialized for machining specific items and cannot be adapted to common types of lathe operations.

b. Bench-Type Jewelers Lathe (fig. 45). The bench-type jewelers lathe is actually a miniature engine lathe designed for the precision machining of small parts. The usual jewelers lathe contains a collet-type chuck, lead screw, and change gears for threading operations, and a precise manual crossfeed. Controls and feeds are calibrated in smaller increments than with the engine lathe, and as a result workpieces of small dimensions can be machined to a great degree of accuracy. The jewelers lathe is belt driven by an independent motor which can be mounted above or behind the lathe.

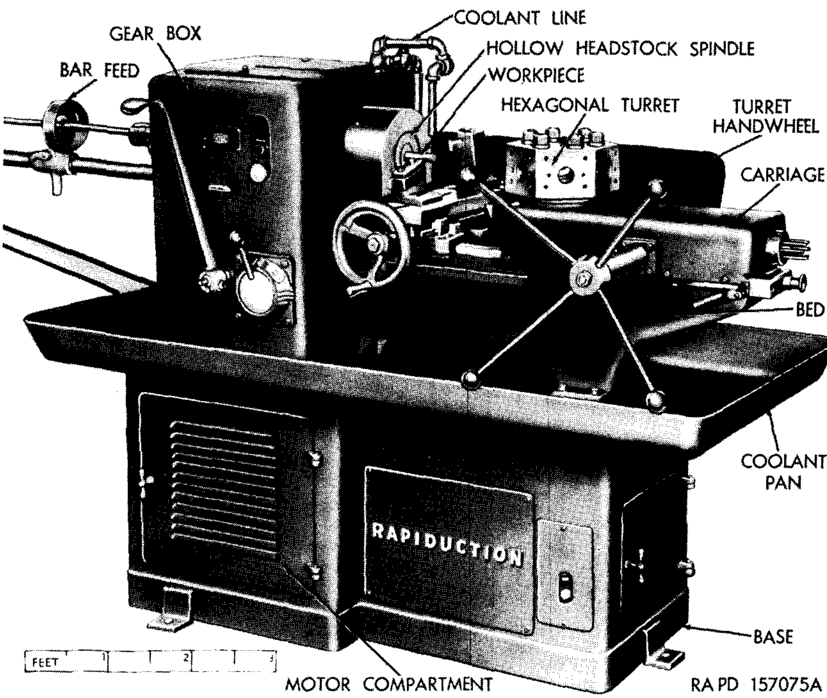


Figure 44. Floor-mounted horizontal turret lathe.

c. Other Special Purpose Lathes. Other special purpose lathes include the production lathe, the automatic lathe, the automatic screw machine, the brakedrum lathe, the crankshaft lathe, the duplicating lathe, the multiple spindle lathe, and lathes designed for turning car axles or forming sheet metal.

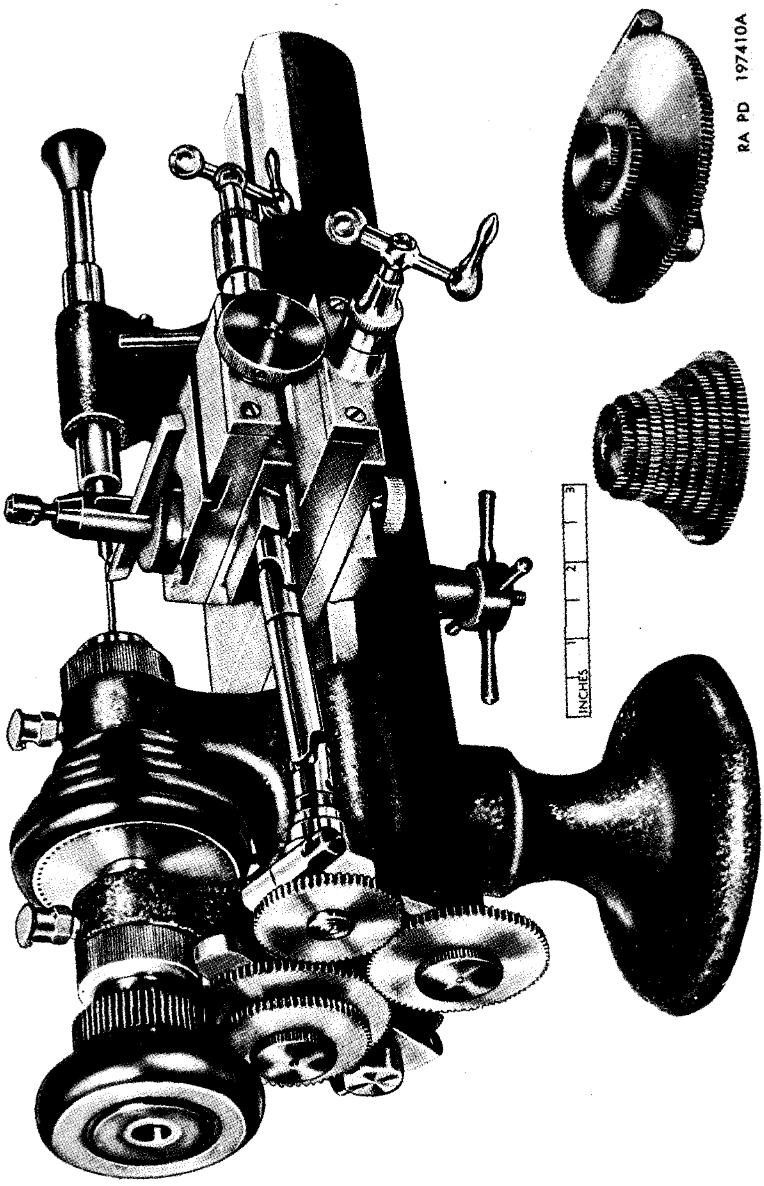


Figure 45. Bench-type jewelers lathe.

Section II. TOOLS AND EQUIPMENT

62. Lathe Cutting Tools

a. General. Lathe cutter bits may be considered as wedges which are forced into the material to cause compression with a resulting rupture or plastic flow of the material. This rupture or plastic flow is called cutting. To machine metal efficiently and accurately, it is necessary that the cutter bits have keen, well-supported cutting edges, and that they be ground for the particular metal being machined and the type of cut desired. Cutter bits are made from several types of steel, the most common of which are described in (1) through (5) below.

(1) *Carbon steel.* Carbon steel, or tool steel high in carbon content, hardens to a high degree when properly heated and quenched. The carbon-steel tool will give good results as long as constant care is taken to avoid overheating or "bluing," since the steel will lose its temper or hardness at a relatively low heat. For low-speed turning, carbon steel gives satisfactory results and is more economical than other materials.

(2) *High-speed steel.* High-speed steel is alloyed with tungsten and sometimes chromium, vanadium, or molybdenum. Although not as hard as properly tempered carbon steel, the majority of lathe cutting tools are made of high-speed steel because it retains its hardness at extremely high temperatures. Cutter bits made of this material can be used without damage at speeds and feeds which heat the cutting edges to a dull red.

(3) *Stellite.* Stellite, composed of chromium, cobalt, and sometimes tungsten must be cast into form and cannot be forged as can carbon and high-speed steels. Stellite cutter bits under favorable conditions will stand exceptionally fast speeds and heavy cuts.

(4) *Tungsten carbide.* Tungsten carbide is used to tip cutter bits when maximum speed and efficiency is required for materials which are difficult to machine. Although expensive, tungsten carbide tipped cutter bits are highly efficient for machining cast iron, alloyed cast iron, copper, brass, bronze, aluminum babbitt metal, and such abrasive nonmetallic materials as fiber, hard rubber, and bakelite. Cutter bits of this type require very rigid support and are usually held in openside tool posts. They require special grinding wheels for sharpening since tungsten carbide is too hard to be redressed on ordinary grinding abrasive wheels.

(5) *Tantalum carbide and titanium carbide.* Tantalum carbide and titanium carbide are also used to tip cutter bits (fig. 48) for machining steel.

b. Terms and Definitions Applied to Single-Point Cutter Bits (fig. 46). The terms and definitions described in (1) through (7) below are provided to orient the reader with respect to the basic areas and surfaces of the cutter bit.

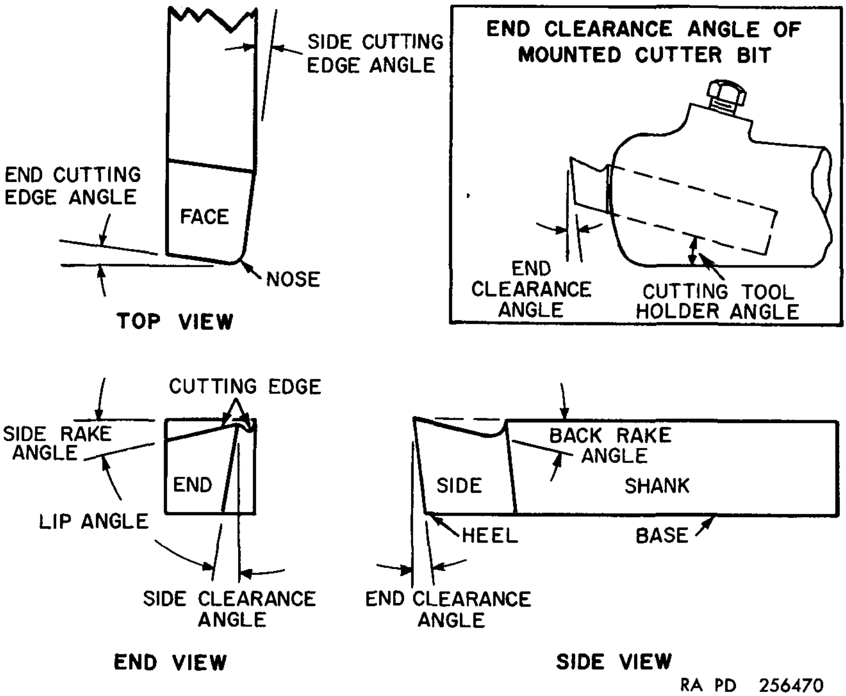


Figure 46. Terms applied to single-point cutter bits.

(1) *Shank.* The shank is the body of the cutter bit on the end(s) of which the nose(s) is formed or the tip is mounted. On single-point cutter bits, the cutting edge is formed on one end of the shank.

(2) *Nose.* The nose is the part of the cutter bit which is shaped to produce the cutting edges.

(3) *Face.* The face of the cutter bit is the surface at the upper side of the cutting edge on which the chip strikes as it is separated from the workpiece.

(4) *Side.* The side of the cutter bit is the near-vertical surface which, with the end of the bit, forms the profile of the bit. The side is the leading surface of the cutter bit when cutting.

(5) *Base.* The base is the bottom surface of the shank of the cutter bit.

(6) *End.* The end of the cutter bit is the near-vertical surface which, with the side of the bit, forms the profile of the bit. The end is the trailing surface of the cutter bit when cutting.

(7) *Heel.* The heel is the portion of the cutter bit base immediately below and supporting the face.

c. Angles of Cutter Bits (fig. 46). The successful operation of the lathe and the quality of work that may be achieved depend largely on the angles that form the cutting edge of the cutter bit. The profiles of the bit (*e* below) may be of any shape so long as the cutting edge is properly shaped. The five angles defined below are used to define the cutting edge, to prevent supporting surfaces of the bit from rubbing against the workpiece, and to establish a path for the chips being removed. Improperly ground angles will result in weakening and breaking of the cutting edge and overheating of the bit. Refer to *d* below for recommended angles for machining specific materials.

(1) *Lip angle.* The lip angle is the angle of keenness of the cutting edge. It is the angle included by the side and face of the cutter bit, measured at the cutting edge. The angle may be more acute for cutting soft, easily machined materials than for hard or tough materials since hard materials require more support for the cutting edge than do soft materials. If the lip angle is too acute to provide proper support for the cutting edge, the edge will break. If the lip angle is less acute or greater than required for support, the bit will cut unnecessarily slow. It has been found that a lip angle of 61° is most efficient for the machining of soft steel. Common cast iron requires a lip angle of 71° while very hard grades of cast iron, chilled iron, hard steel, bronze, etc. may require lip angles as great as 85°. If free cutting Bessemer screw stock is to be machined, the angle may be slightly less than 61°.

(2) *Clearance (relief) angles.* Only the cutting edge of the cutter bit must touch the workpiece, and therefore the end and side surfaces of the bit which form the profile of the cutting edge must be cut back or relieved on the underside to prevent their rubbing against the workpiece.

(*a*) *End clearance (relief) angle.* The end clearance angle is the angle formed by the end of the cutter bit and a line perpendicular to the diameter of the workpiece at the point of tool contact. If the bit is centered on the workpiece, the angle may be measured from the vertical.

(*b*) *Side clearance (relief) angle.* The side clearance angle is the angle measured between the side of the cutter bit at the cutting edge and the vertical.

(3) *Rake angles.* The angle which the face of the cutter bit makes with the horizontal is called the rake angle. Rake adds to the keenness of the tool and facilitates the removal of chips. If the slant of the rake is away from the workpiece,

it is known as a back rake angle (fig. 46); if the slant is in the direction of the workpiece axis, it is known as a side rake angle (fig. 46). When a back rake angle slopes toward the shank of the bit, the bit is said to have a positive rake, and conversely, when the back rake angle slopes away from the shank, it is said to have a negative rake. Cutter bits may be ground with either a back rake or a side rake or a combination of both.

(4) *Cutting tool holder angle.* When determining the end clearance angle ((2)(*a*) above) and the back rake angle ((3) above), the cutting tool holder angle (fig. 46) must be taken into consideration because any slant of the cutter bit shank will change these angles. When checking angles of the unmounted cutter bit, add the cutting tool holder angle to the end clearance angle and subtract the cutting tool holder angle from the back rake angle.

d. Recommended Clearance and Rake Angles. Table XII lists clearance angles and rake angles for various materials to be machined. When grinding cutter bits, the lip angle (*c*(1) above) should also be considered in selecting the proper angles from the table.

Table XII. Clearance and Rake Angles for Lathe Cutter Bits

Material	Side clearance angle (deg.)	End clearance angle (deg.)	Back rake angle (deg.)	Side rake angle (deg.)
Aluminum	5–10	5–9	10–30	16–20
Brass	5–10	5–8	0–8	0–8
Bronze, free cutting	5–10	5–9	0–8	2–8
Bronze, tough	10–15	8–12	6–15	7–25
Cast iron	5–10	5–9	5–8	12–14
Copper	7–14	7–12	8–16	16–25
Magnesium alloy	6–10	6–10	5–9	3–5
Monel	6–15	6–13	4–10	10–14
Plastic, cast	12	10	30	25
Plastic, cold molded	10	10	0	0
Plastic, hot molded	6	6	10	20
Plastic, laminated	8	8	30	30
Steel, hard	5–10	5–9	6–14	10–14
Steel, soft	5–12	5–9	8–17	14–20
Steel, stainless	5–12	5–10	8–17	0–10
Steel, very hard	5–10	5–9	4–10	6–12
Wood	20	20	30	30

e. Common Types of Cutter Bits (fig. 47). Cutter bits are made from standard sizes of bar stock to fit into cutting tool holders which in turn are fastened to the tool post of the lathe. The following cutter bits are identified by their function. If the cutter bit is to be used for heavy roughing where a finished surface is not expected, the nose should be ground with a very small radius (aprx. 1/64 in.). If the cutter bit is to be used for general shaping and finishing, the nose should be more rounded (aprx. 1/32- to 1/16-in. radius).

(1) *Right hand turning cutter bit.* The right hand turning cutter bit is shaped to be fed from right to left. The cutting edge is on the left side of the bit and the face slopes down away from the cutting edge, the left side and end of the tool are ground with sufficient clearance to permit the cutting edge to bear upon the workpiece without the heel of the bit rubbing against the workpiece. The right hand turning cutter bit is ideal for taking light roughing cuts as well as general all-round machine work.

(2) *Left hand turning cutter bit.* The left hand cutter bit is just the opposite of the right hand turning cutter bit, being designed to cut when fed from left to right. It is used for all-round machine work when right-to-left turning is impractical.

(3) *Round-nose turning cutter bit* (fig. 47). The round-nose turning cutter bit is used for all-round machine work and may be used for taking light roughing or finishing cuts. Usually the face is ground with a right sloping side rake so that the bit may be fed from right to left, although it is often ground without any side rake so that the feed may be in either direction.

(4) *Right hand facing cutter bit.* The right hand facing cutter bit is intended for facing on right hand side shoulders and the right end of the workpiece. The cutting edge is on the left hand side of the bit, and the nose is sharp to permit machining a square corner. The direction of feed for the facing bit should be away from the axis of the workpiece.

(5) *Left hand facing cutter bit.* The left hand facing cutter bit is just the opposite of the right hand facing cutter bit; it is intended for facing the left sides of shoulders.

(6) *Parting cutter bit.* The parting cutter bit has its principal cutting edge at the end. Both sides must have sufficient clearance to prevent binding and should be ground slightly narrower at the back than at the cutting edge. The bit is convenient for machining necks and grooves, square corners, etc., as well as for cutting off operations.

(7) *Thread cutter bit.* The thread cutter bit has its cutting edge ground to a symmetrical 60° angle and in this form will cut sharp V-threads. Usually the face of this bit is ground flat and has clearances ground on both sides so that it will cut on both sides. For American (National) Standard

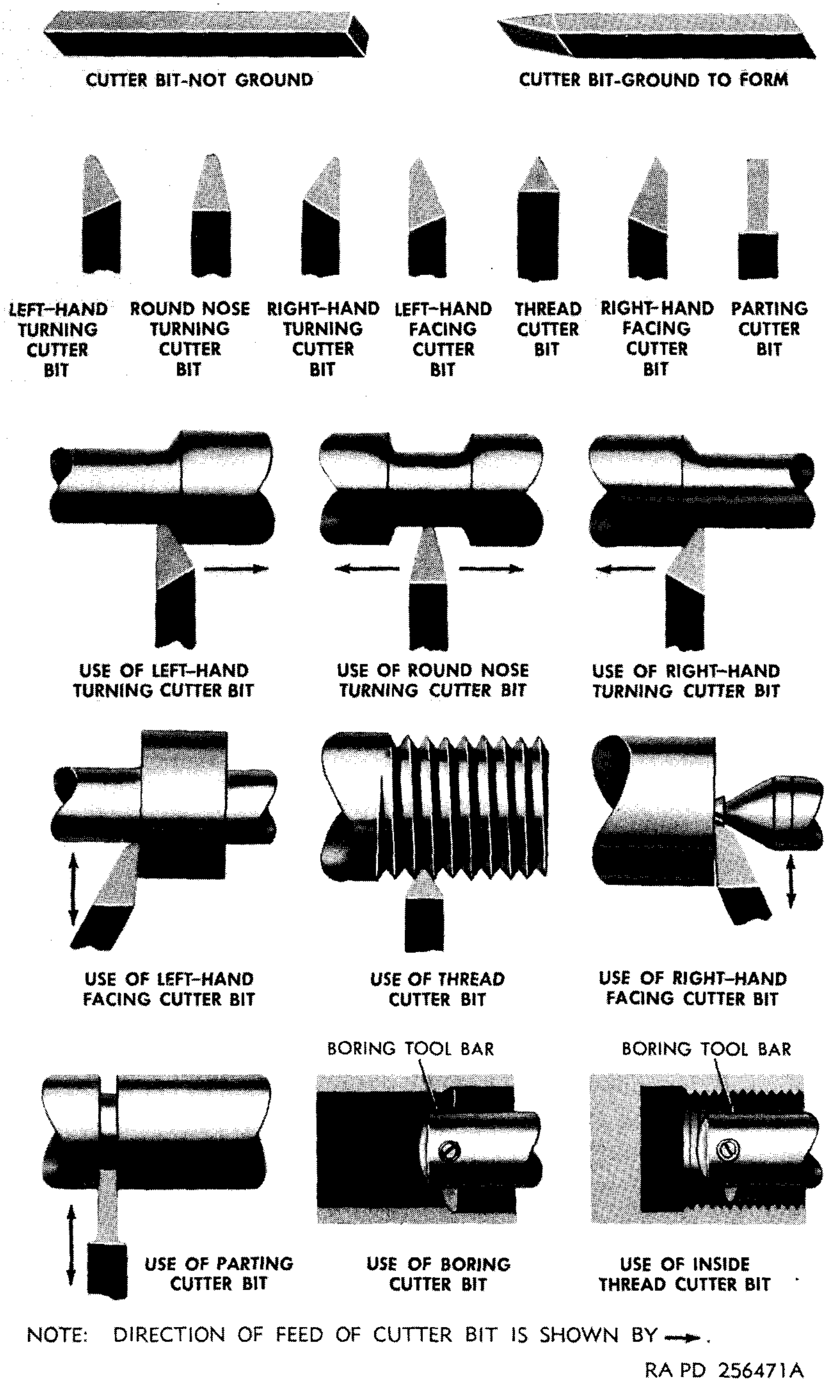


Figure 47. Common types of cutter bits and their application.

screw threads, the bit is further ground with a flat at the nose to cut the flat root of the thread. The width of the flat at the nose is determined by the pitch of the screw to be cut (par. 85*c*(2)).

f. Special Types of Lathe Cutting Tools. Besides the common cutter bits (*e* above), special lathe operations and heavy production work require special types of cutting tools. Some of the more common of these tools are described in (1) through (5) below.

(1) *Tipped cutter bits* (fig. 48). Tungsten carbide, tantalum carbide, or titanium carbide-tipped cutter bits are commonly used in production work where high speeds and heavy cuts are necessary, and where exceptionally hard and tough materials are encountered. The tipped cutter bit generally has a shank size larger than the common cutter bit and is mounted in an open side cutting tool holder, a turret tool block, or directly in the tool post of the lathe. Tipped cutter bits come in shapes for use in left hand and right hand turning, general purpose work, and cutting threads.

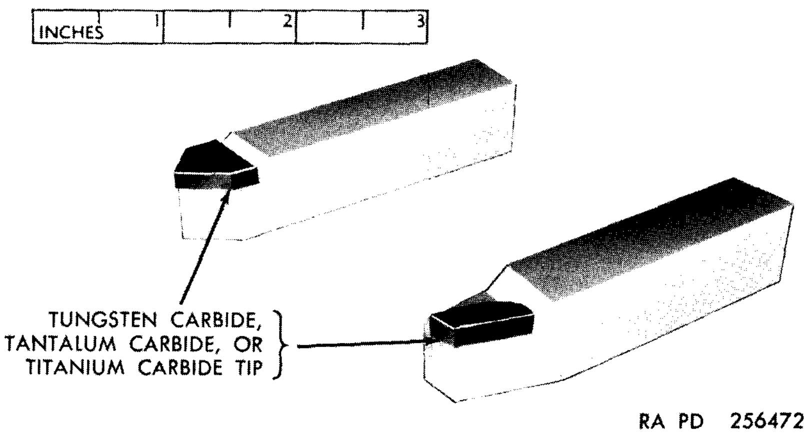
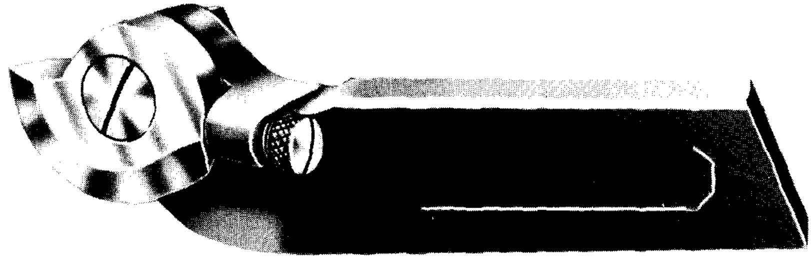


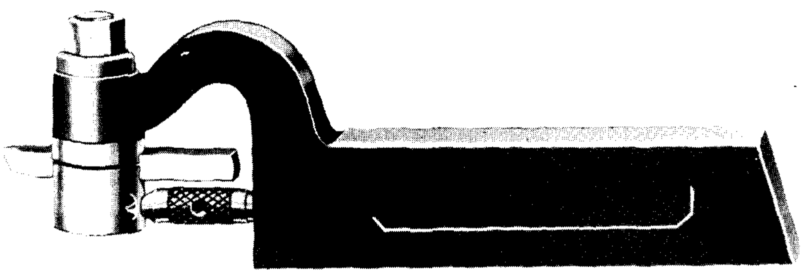
Figure 48. Tipped cutter bits.

(2) *Thread cutting tool holder with cutter* (fig. 49). The thread cutting tool holder with cutter is used where considerable thread cutting is to be done. The cutter is formed with the correct thread contour and needs only grinding on the face to sharpen. The cutter is used in a specially designed tool holder which in turn mounts to the lathe tool post.

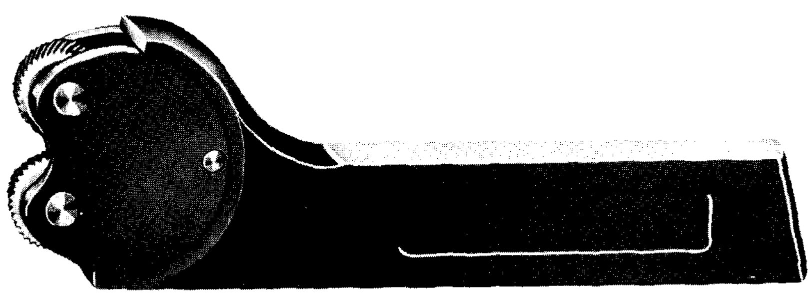
(3) *Spring thread cutting tool holder with cutter bit* (fig. 49). The spring thread cutting tool holder with cutter bit consists of a specially designed cutting tool holder that mounts a thread cutter bit (*e*(7) above). The mounted cutter bit



THREAD CUTTING TOOL HOLDER
WITH CUTTER



SPRING THREAD CUTTING TOOL HOLDER
WITH CUTTER BIT



KNURLING TOOL

INCHES 1 2 3

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Figure 49. Special types of lathe cutting tools.

can be rotated to positions 30° either side of center to provide clearance for the holder when cutting threads close to either end of the workpiece. A spring device in the holder permits the cutter bit to spring downward under excess pressure, thereby preventing breakage of the cutter bit.

(4) *Knurling tool* (fig. 49). The knurling tool consists of two cylindrical cutters called knurls which rotate in a specially designed toolholder. The knurls contain teeth which are rolled against the surface of the workpiece to form depressed patterns on the workpiece. The knurling tool accepts dif-

ferent pairs of knurls, each pair having a different pattern or a different pitch. The diamond pattern is most widely used, and is generally supplied in three pitches: 14-pitch, 21-pitch, and 33-pitch to produce coarse, medium, and fine diamond patterns (fig. 50).

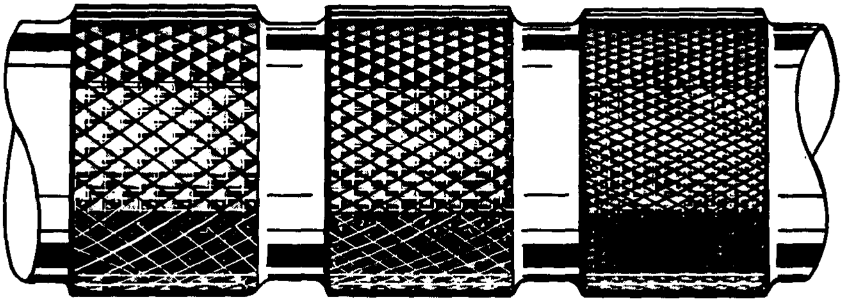

Figure 50. Diamond knurling tool patterns.

(5) *Boring tools.* Boring tools are ground similar to left hand turning cutter bits (*e*(2) above) and thread cutter bits (*e*(7) above) but with more attention given to the end clearance angle to prevent the heel of the bit from rubbing against the surface of the bore. The boring cutter bit (fig. 47) is clamped to a boring tool bar which in turn is supported in a boring tool holder (par. 63*f*) which mounts to the lathe tool post.

g. Grinding of Lathe Cutter Bits.

(1) *General.*

(*a*) Before attempting to grind cutter bits, refer to paragraphs 48 through 54 for instruction in the proper use of grinding machines.

(*b*) The most satisfactory equipment for grinding cutter bits is the utility grinding machine with two 7-inch vitrified grinding abrasive wheels, 36 grain for rough grinding and 60 grain for fine grinding. The wheel should be run at a surface speed of about 5,000 feet per minute and should have close fitting guards and tool rests.

(2) *Carbon-steel cutter bits.* Carbon-steel cutter bits can be distinguished from high-speed steel cutter bits by taking a trial cut on the grinding abrasive wheel. If the bit is made of carbon steel, the sparks produced will be light orange colored; if the bit is made of high-speed steel, the sparks produced will be dark red. When grinding carbon-steel

bits, a small container of water should be available for quenching the bit. A wet wheel or a water-drip grindstone may also be used for grinding bits made of carbon steel. In either case, water cooling is necessary to prevent the bit from losing its hardness by overheating.

(3) *High-speed steel cutter bits.* The high-speed steel cutter bit is identified by the red sparks given off when placed against the grinding abrasive wheel. High-speed steel cutter bits must be ground on a dry wheel; when hot they must never be dipped into water or the bit will crack and the cutting edge crumble.

(4) *Carbide-tipped cutter bits.* Cutter bits tipped with tungsten carbide, tantalum carbide, and titanium carbide cannot be ground with standard grinding abrasive wheels but must be ground using a special grinding wheel such as one that is diamond impregnated. Because the carbide is extremely brittle, it must be handled with extreme care. The cutting edge must always be well supported and the amount of grinding should be restricted to minor redressing of the cutting edge.

(5) *Procedure.* Figure 51 shows the steps involved in grinding a round-nose turning cutter bit to be fed from right to left for general turning operations. Other bits are ground in a similar manner. Remove the bit from the cutting tool holder before grinding to prevent damaging the cutting tool holder.

(*a*) Grind the left side of the bit, holding it against the grinding abrasive wheel at the correct angle to form the side clearance (step 1, fig. 51). Use the coarse wheel to remove most of the metal and finish on the fine wheel.

(*b*) Grind the right side of the bit (step 2, fig. 51). Do not remove any more metal than is necessary from this side as it requires no clearance and the more metal left on the bit the better the heat-dissipation qualities of the bit.

(*c*) Grind the radius or rounding on the nose of the bit by holding it against the wheel and turning it from side to side (step 3, fig. 51). The radius should be approximately 1/32 to 3/64 inch.

(*d*) Grind the end clearance by holding the bit against the side of the wheel at the correct angle (step 4, fig. 51).

(*e*) Grind the face of the bit (step 5, fig. 51), holding it at the correct angle to obtain the necessary back rake and side rake.

(*f*) After bits have been ground on a grinding abrasive wheel, they will produce better quality work and have longer life if the cutting edges are honed with an oilstone.

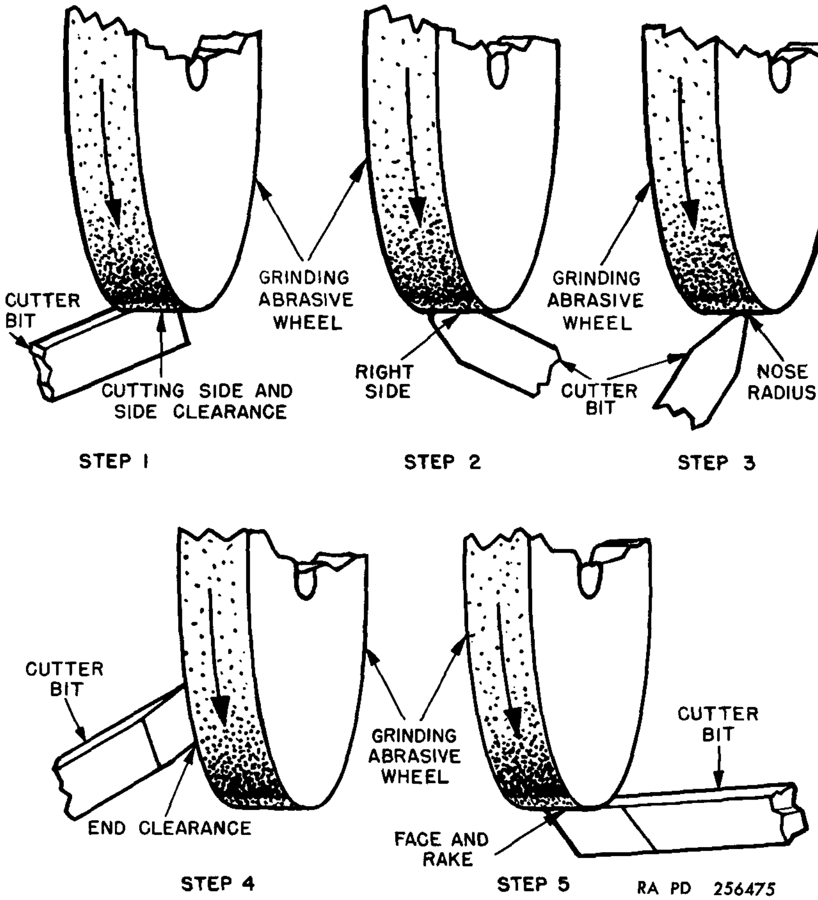

Figure 51. Grinding a round-nose turning cutter bit.

63. Cutting Tool Holders

a. General. Common cutter bits are generally made from standard sizes of bar stock to fit into a forged cutting tool holder which in turn is fastened to the tool post of the lathe. Special tools such as the knurling tool and the thread cutting tool holder with cutter are furnished with their own special forged tool holders and therefore may be fastened directly to the tool post of the lathe. Carbide-tipped cutter bits are generally unsuitable for mounting in forged tool holders and are fastened directly to the lathe tool post (fig. 52) or mounted in an open side tool post to provide rigid support for the bit.

b. Straight-Shank Cutting Tool Holder (fig. 53). The straight-shank cutting tool holder may be used to support round-nose turning cutter bits, right hand and left hand turning cutter bits, and thread cutter bits. The holder is made of forged steel and contains a hardened steel setscrew for locking the cutter bit in place.

c. Right and Left Hand Offset Cutting Tool Holder (fig. 53). The right and left hand offset cutting tool holders are designed to support right hand and left hand facing cutter bits which require that the bit be supported at an angle to the workpiece axis. The holder has a setscrew for locking the cutter bit in place.

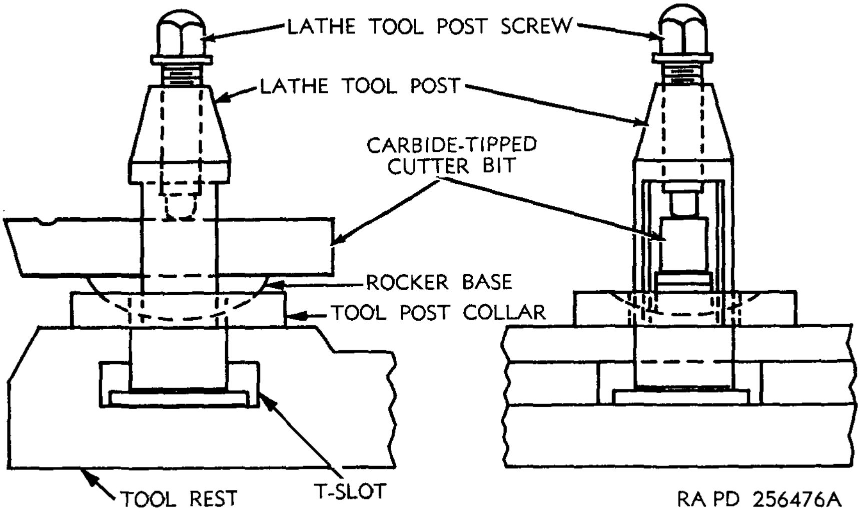

Figure 52. Carbide-tipped cutter bit mounted directly to tool post of lathe.

d. Straight Parting Cutting Tool Holder (fig. 53). The straight parting cutting tool holder is a forged steel holder shaped to hold flat, thin sectioned parting tools which are used to separate pieces on the lathe.

e. Right and Left Hand Offset Parting Cutting Tool Holder (fig. 53). The right and left hand offset parting cutting tool holders are similar to the straight parting cutting tool holder but are designed to hold the parting cutter bit at an angle to the holder shank. The offset holder is generally used when the workpiece to be parted or the stationary parts of the lathe may interfere with the holder if the straight parting cutting tool holder is used. In either case, the compound rest of the lathe must be adjusted so that the parting cutter bit enters the workpiece at right angles to the workpiece axis.

f. Boring Bar Cutting Tool Holder (fig. 54). The boring bar cutting tool holder for the lathe comes in several commercial types, one of which is illustrated in figure 54. The boring bar cutting tool holder consists of three parts, the holder, the interchangeable end cap, and the boring tool bar. The boring tool bar is a rod with one end threaded to accept an end cap. Three end caps are supplied, each end cap slotted at different angles to accept a cutter bit. The standard angles are 30°, 45°, and 90°. Plain boring tool bars without end

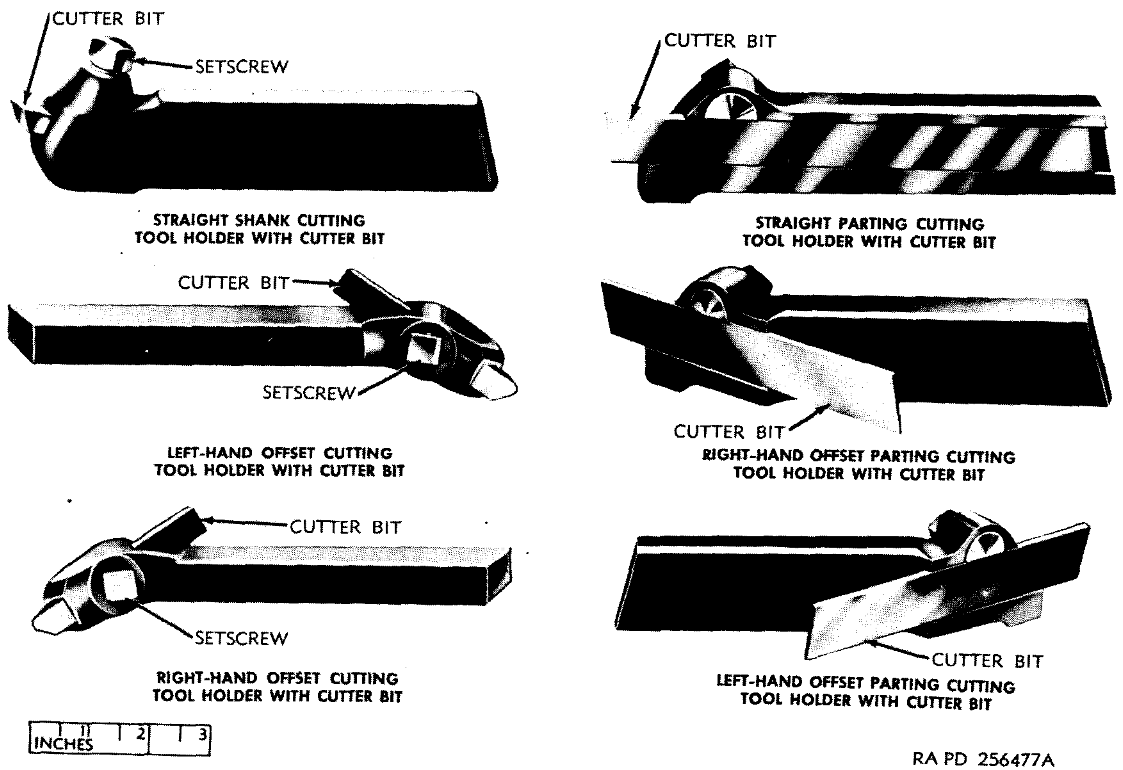

Figure 58. Types of cutting tool holders

caps are often made to accept cutter bits at each end, one end having a 90° slot, and the other end having a 45° slot. The holder is made of forged steel. It has a shank similar to that of the other cutting tool holders. The holder is secured to the lathe tool post by the lathe tool post screw. The boring tool bar is adjustable in the holder and can be locked in any desired position.

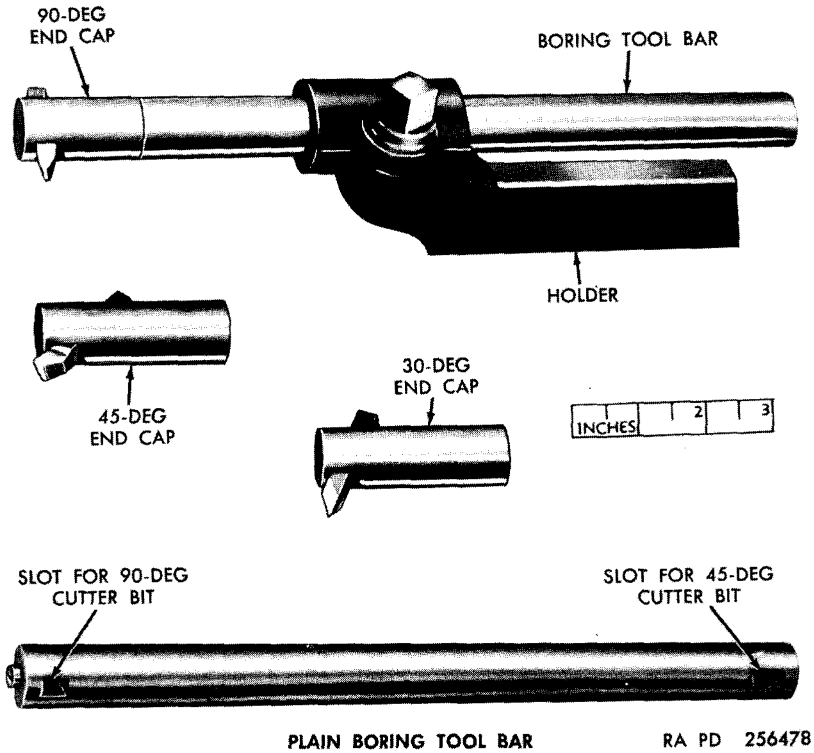

Figure 54. Boring bar cutting tool holder with end caps and cutter bits.

64. Chucks

a. General. Workpieces are held to the headstock spindle of the lathe with chucks, face plates (par. 65), or lathe centers (par. 66). A lathe chuck is a device that exerts pressure on the workpiece to hold it secure to the headstock spindle or tailstock spindle. Commonly used with the lathe are the independent chuck, the universal scroll chuck, the combination chuck, the drill chuck, the hollow headstock spindle chuck, the lathe tailstock chuck, the collet chuck, and the step chuck.

b. Independent Chuck (fig. 55).

(1) The independent chuck generally has four jaws which are adjusted individually on the chuck face by means of adjust-

ing screws. The chuck face is scribed with concentric circles which are used for rough alinement of the jaws when chucking round workpieces. The final adjustment is made by turning the workpiece slowly and using gages to determine its concentricity. The jaws are then readjusted as necessary to aline the workpiece within very small tolerances.

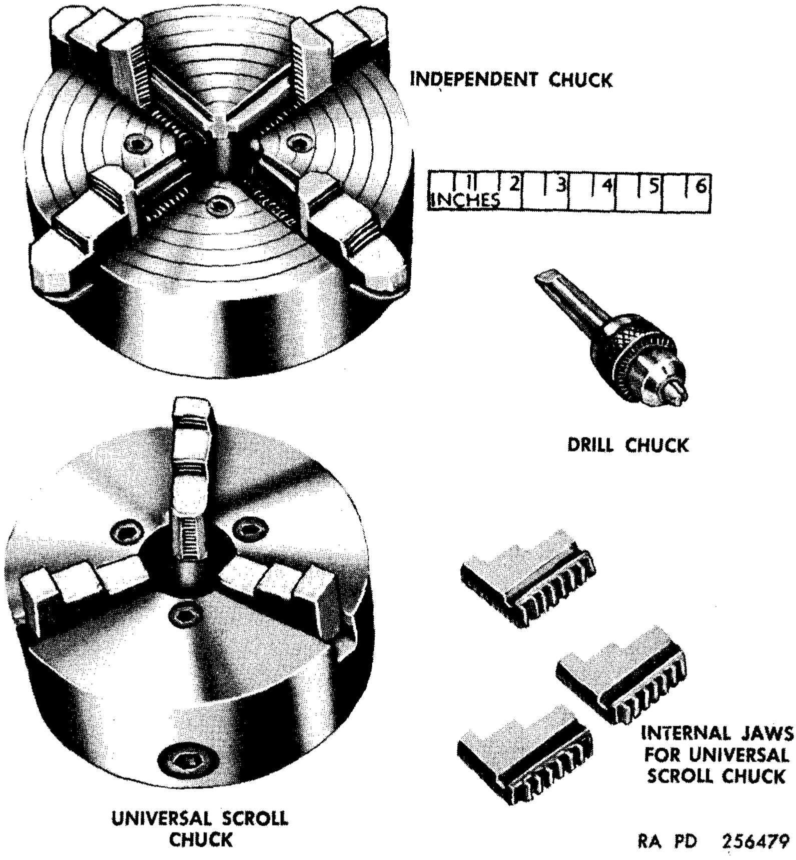

Figure 55. Independent chuck, universal scroll chuck, and drill chuck used with the lathe.

(2) The jaws of the independent chuck may be used as illustrated in figure 55 or may be reversed so that the steps face in the opposite direction; thus workpieces can be gripped either externally or internally. The independent chuck can be used to hold square, round, octagonal, or irregularly shaped workpieces in either a concentric or eccentric position due to the independent operation of each jaw.

(3) Because of its versatility and capacity for fine adjustment, the independent chuck is commonly used for mounting workpieces which must be held with extreme accuracy.

c. Universal Scroll Chuck (fig. 55).

(1) The universal scroll chuck usually has three jaws which move in unison as an adjusting pinion is rotated. The advantage of the universal scroll chuck is its ease of operation in centering work for concentric turning. This chuck is not as accurate as the independent chuck, but when in good condition it will center work automatically within 0.003 inch of complete accuracy.

(2) The jaws are moved simultaneously within the chuck by means of a scroll or spiral threaded plate. The jaws are threaded to the scroll and move an equal distance inward or outward as the scroll is rotated by means of the adjusting pinion. Since the jaws are individually alined on the scroll, the jaws cannot be reversed. However, the chuck is usually supplied with two sets of jaws which can be interchanged.

(3) The universal scroll chuck can be used to hold and automatically center round or hexagonal workpieces. Having only three jaws, the chuck cannot be used effectively to hold square, octagonal, or irregular shapes.

d. Combination Chuck. A combination chuck combines the features of the independent chuck and the universal scroll chuck and can have either three or four jaws. The jaws can be moved in unison on a scroll for automatic centering or can be moved individually if desired by separate adjusting screws.

e. Drill Chuck (fig. 55). The drill chuck is a small universal-type chuck which can be used in either the headstock spindle or in the tailstock for holding straight-shank drills, reamers, taps, or small diameter workpieces. The drill chuck has three or four hardened steel jaws which are moved together or apart by adjusting a tapered sleeve within which they are contained. The drill chuck is capable of centering tools and small diameter workpieces to within 0.002 or 0.003 inch when firmly tightened.

f. Hollow Headstock Spindle Chuck (fig. 56). The hollow headstock spindle chuck is similar to a drill chuck but is hollow and is provided with threads to screw onto the headstock spindle nose. This chuck can be used to hold rods, tubes, or bars which are passed through the headstock spindle. It is generally capable of centering workpieces to an accuracy of 0.002 inch.

g. Collet Chuck.

(1) The collet chuck is the most accurate means of holding small workpieces in the lathe. The collet chuck consists of a spring machine collet (fig. 57) and a collet attachment which

secures and regulates the collet on the headstock spindle of the lathe.

(2) The spring machine collet (fig. 57) is a thin metal bushing with an accurately machined bore and a tapered exterior. The collet has three lengthwise slots to permit its sides being sprung slightly inward to grip the workpiece. To grip the workpiece accurately, the collet must be no more than 0.001 inch larger or smaller than the diameter of the piece to be chucked. For this reason spring machine collets are generally supplied in sets with various capacities in 1/16-, 1/32-, or 1/64-inch increments. For general purposes, the spring machine collets are limited in capacity to 1 inch in diameter.

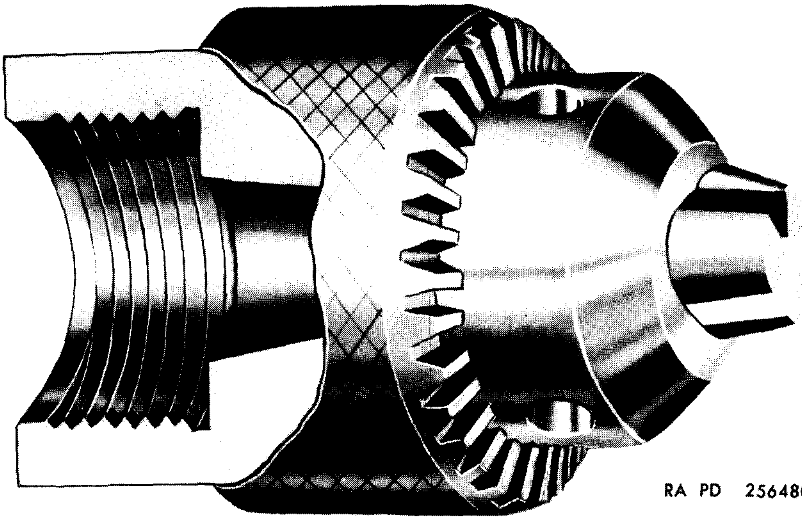

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Figure 56. Hollow headstock spindle chuck.

(3) The collet attachment which with the spring machine collet forms the collet chuck, consists of a collet sleeve, a draw bar, and a handwheel or hand lever to move the draw bar. Figure 58 illustrates a typical collet chuck installation. The collet sleeve is fitted to the right end of the headstock spindle. The draw bar passes through the headstock spindle and is threaded to the spring machine collet. When the draw bar is rotated by means of the handwheel, the collet is pulled inward and the collet walls are cammed together by contact with the collet sleeve, tightening the chuck to the workpiece.

(4) Collet chucks are usually standard equipment on toolroom-type engine lathes and on horizontal turret lathes. Spring machine collets are available in different shapes (fig. 57) to

chuck square and hexagonal workpieces of small dimensions as well as round workpieces.

h. Step Chuck. The step chuck is a variation of the collet chuck, but is intended for very accurate holding of workpieces larger than 1 inch in diameter. The step chuck consists of the handwheel or hand lever collet attachment (*g* above) and a step chuck machine collet (fig. 59) in place of the regular spring machine collet. The step

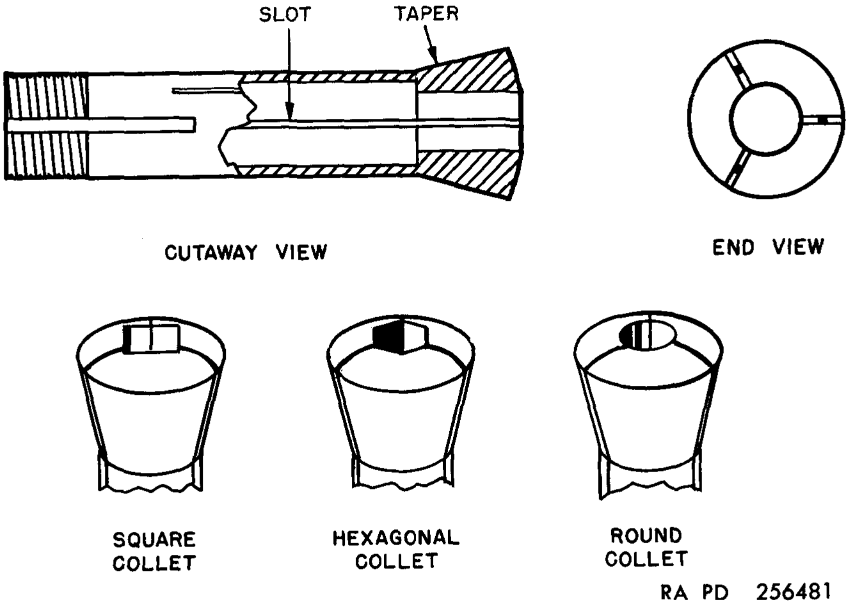


Figure 57. Spring machine collet shapes.

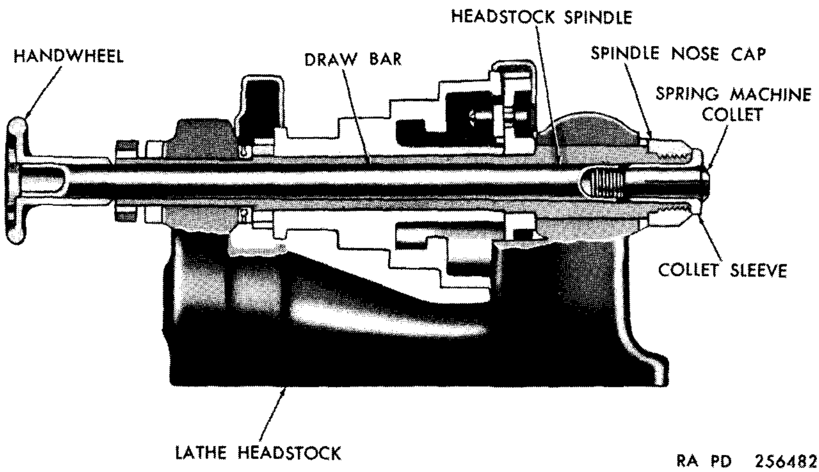


Figure 58. Typical installation of collet chuck.

chuck machine collet, which is split into three sections like the spring machine collet, is threaded to the drawbar of the collet attachment. As the step chuck machine collet is drawn into the collet sleeve, the three sections of the collet are cammed against the workpiece by an inside taper in the collet sleeve. The step chuck is supplied in 2, 3, 4, and 5 inch sizes, the size indicating the maximum diameter of workpieces that can be supported. The step chuck machine collets are furnished blank and machined on the lathe to the desired step diameter.

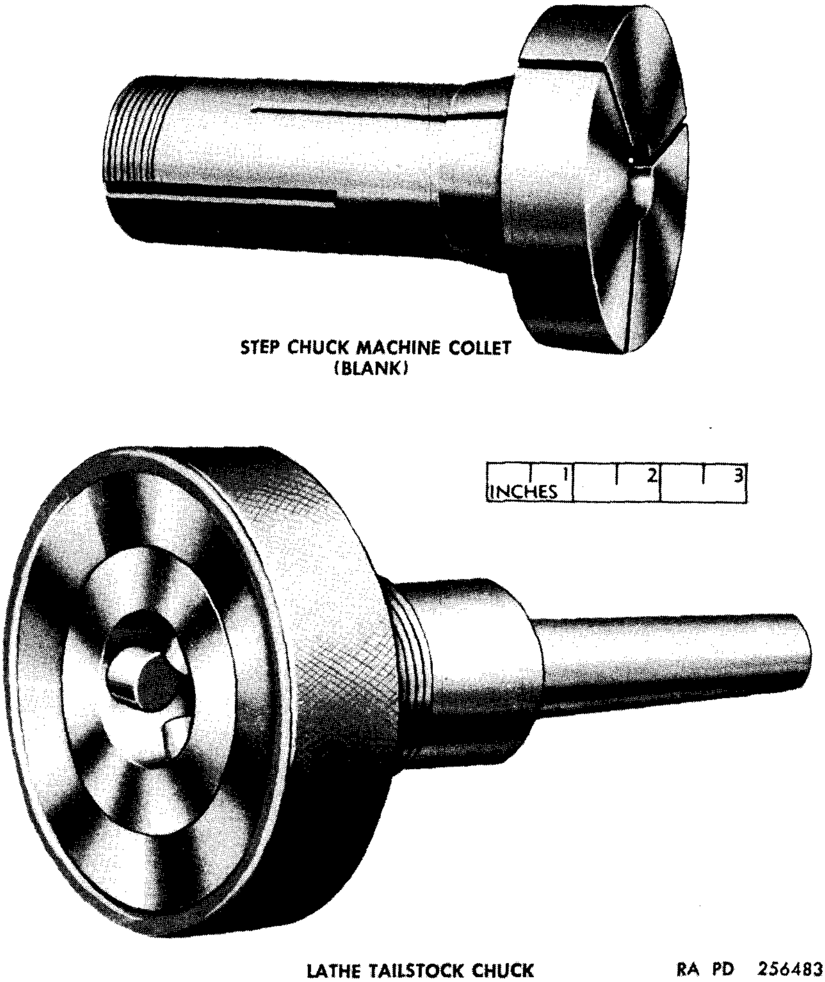


Figure 59. Step chuck machine collet and lathe tailstock chuck.

i. Lathe Tailstock Chuck (fig. 59). The lathe tailstock chuck is a device designed to support the ends of workpieces in the tailstock when a lathe center cannot be conveniently used. The chuck has a taper arbor that fits the lathe tailstock spindle. The three bronze self-centering jaws of the chuck will accurately close upon workpieces between ¼ and 1 inch in diameter. The bronze jaws provide a good bearing surface for the workpiece. The jaws are adjusted to the diameter of the workpiece and then locked in place.

65. Lathe Face Plates

(fig. 60)

a. A lathe face plate is a flat, round plate that threads to the headstock spindle of the lathe. The face plate is used for irregularly-shaped workpieces that cannot be successfully held by chucks or mounted between centers. The workpiece is either attached to the face plate using angle plates or brackets or bolted directly to the plate. Radial T-slots in the face plate surface facilitate mounting of workpieces. The face plate is valuable for mounting workpieces in which an eccentric hole or projection is to be machined. The number of applications of the face plates depends upon the ingenuity of the machinist.

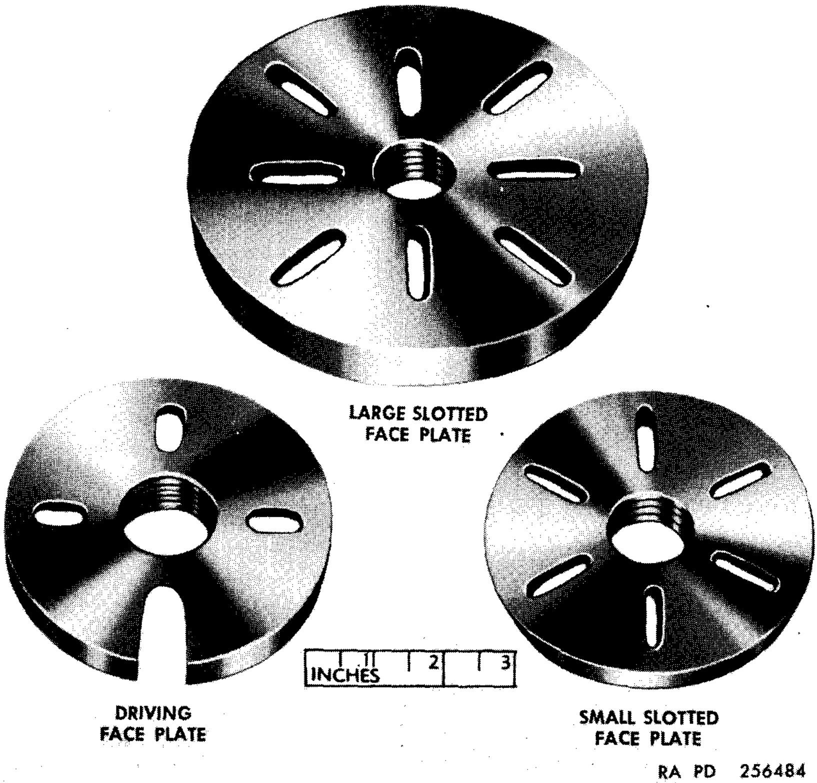


Figure 60. Lathe face plates.

b. A small face plate known as a driving face plate is used to drive the lathe dog for workpieces mounted between centers. The driving face plate usually has fewer T-slots than the larger face plates. When the workpiece is supported between centers, a lathe dog (par. 67) is fastened to the workpiece and engaged in a slot of the driving face plate.

66. Lathe Centers

a. *General*. Lathe centers are the most common devices for supporting workpieces in the lathe. Most lathe centers have a tapered point with a 60° included angle to fit workpiece holes with the same angle. The workpiece is supported between two centers, one in the headstock spindle and one in the tailstock spindle. Centers for lathe work have standard tapered shanks that fit into the tailstock directly and into the headstock spindle, using a center sleeve to convert the larger bore of the spindle to the smaller taper size of the lathe center. The centers are referred to as live centers or dead centers depending upon whether they move with the workpiece or remain stationary. The most common types of centers are described in *b* through *f* below.

b. *Male Center* (fig. 61). The male center or plain center is the type used in pairs for most general lathe turning operations. The point is ground to a 60° cone angle. When used in the headstock spindle where it revolves with the workpiece, it is commonly called a live center. When used in the tailstock spindle where it remains stationary when the workpiece is turned, it is called a dead center. Dead centers are always hard and must be lubricated very often to prevent overheating.

c. *Pipe Center* (fig. 61). The pipe center is similar to the male center but its cone is ground to a greater angle and is larger in size. It is used for holding pipe and tubing in the lathe.

d. *Female Center* (fig. 61). The female center is conically bored at the tip and is used to support workpieces that are pointed on the end.

e. *Half Male Center* (fig. 61). The half male center is a male center that has a portion of the 60° cone cut away. The half male center is used as a deadcenter in the tailstock where complete facing is to be performed. The cutaway portion of the center faces the cutting tool and provides the necessary clearance for the tool when facing the surface immediately around the drilled center in the workpiece.

f. *V-Center* (fig. 61). The V-center is used to support round workpieces at right angles to the lathe axis for special operations such as drilling or reaming.

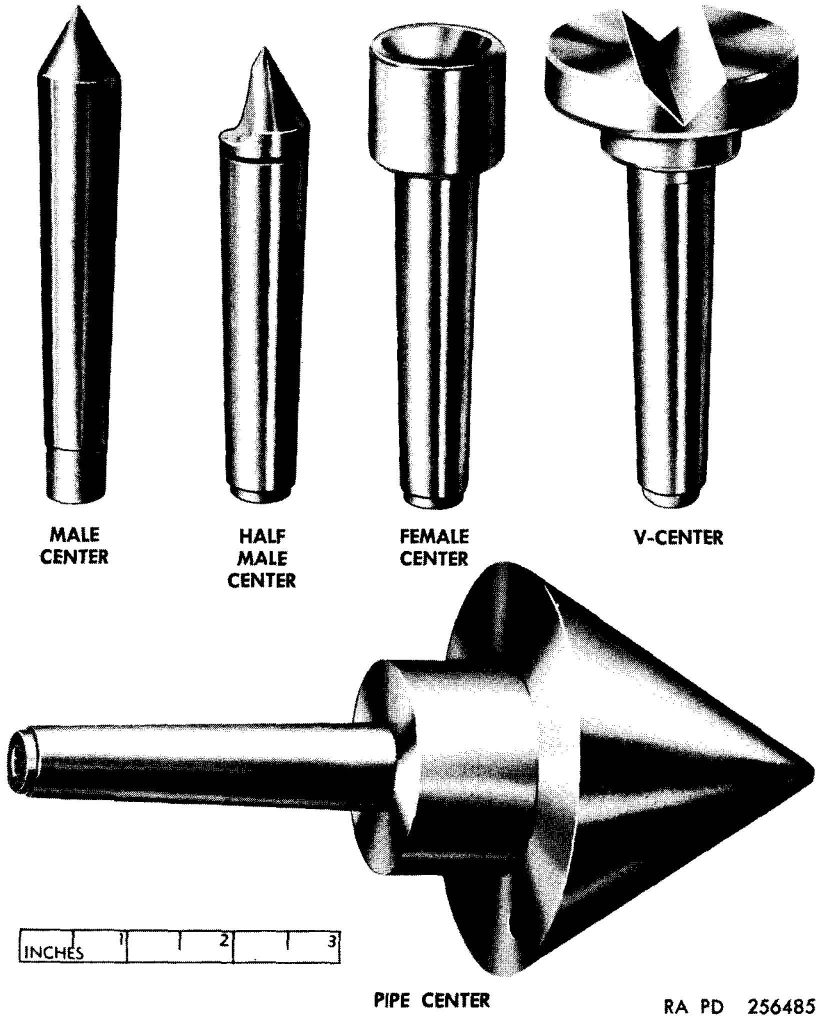


Figure 61. Types of lathe centers.

67. Lathe Dogs
(fig. 62)

a. Lathe dogs are cast metal devices used to provide a firm connection between the headstock spindle and the workpiece mounted between centers. This firm connection permits the workpiece to be driven at the same speed as the spindle under the strain of cutting. Three common types of lathe dogs are illustrated in figure 62. Lathe dogs may have bent tails or straight tails. When bent tail dogs are used, the tail fits into a slot of the driving face plate. When straight tail dogs are used, the tail bears against a stud projecting from the face plate.

b. The bent tail lathe dog with headless setscrew is considered safer than the dog with the square head screw because the headless setscrew reduces the danger of the dog catching in the operator's clothing and causing an accident.

c. The bent tail clamp lathe dog is used primarily for holding rectangular workpieces.

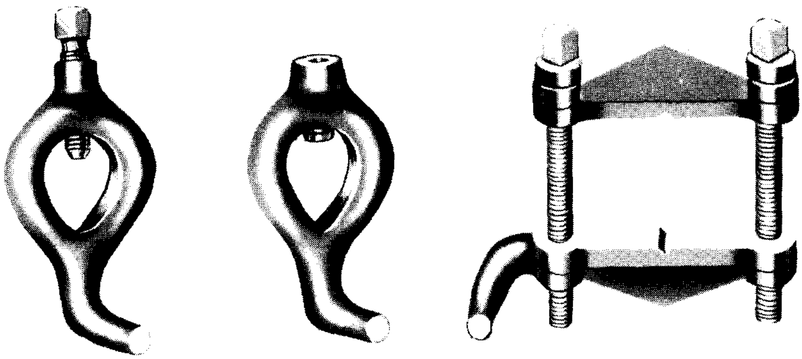


Figure 62. Common types of lathe dogs.

68. Mandrels

a. General. A workpiece which cannot be held between centers because its axis has been drilled or bored and which is not suitable for holding in a chuck or against a face plate is usually machined on a mandrel. A mandrel is a tapered axle pressed into the bore of the workpiece to support it between centers. A mandrel should not be confused with an arbor which is a similar device but used for holding tools rather than workpieces.

b. Solid Machine Mandrel (fig. 63). A solid machine mandrel is generally made from hardened steel and ground to a slight taper of from 0.0005 to 0.0006 inch per inch. It has very accurately countersunk centers at each end for mounting between centers. The ends of the mandrel are smaller than the body and have machined flats for the lathe dog to grip. The size of the solid machine mandrel is always stamped on the large end of the taper.

c. Expansion Mandrel (fig. 63). Since solid machine mandrels have a very slight taper, they are limited to workpieces with specific inside diameters. An expansion mandrel will accept workpieces having a greater range of sizes. The expansion mandrel is, in effect, a chuck arranged so that the grips can be forced outward against the interior of the hole in the workpiece.

69. Rests

a. General. Workpieces often need extra support, especially long, thin workpieces that tend to spring away from the cutter bit. Two common supports or rests are the steady rest and the follower rest.

b. Steady Rest (fig. 64). The steady rest, or center rest, as it is also called, is used to support long workpieces for turning and boring operations. It is also used for internal threading operations where the workpiece projects a considerable distance from the chuck or face plate. The steady rest is clamped to the lathe bed at the desired location and supports the workpiece within three adjustable jaws. The workpiece must be machined with a concentric bearing surface at the point where the steady rest is to be applied. The jaws must be carefully adjusted for proper alinement and locked in position. The area of contact must be lubricated frequently. The top section of the steady rest swings away from the bottom section to permit removal of the workpiece without disturbing the jaw setting.

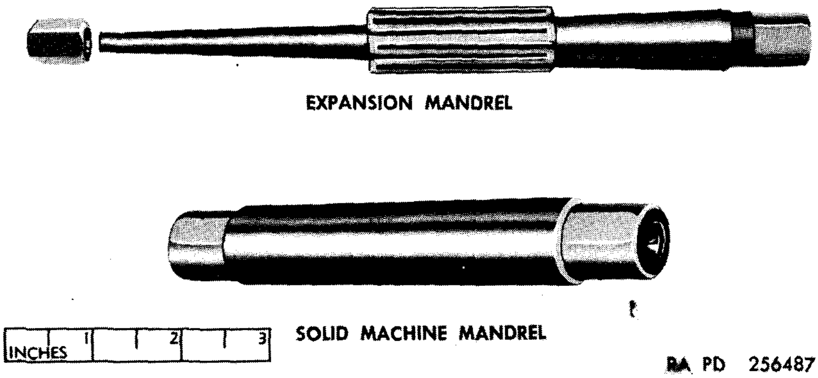


Figure 63. Types of mandrels.

c. Follower Rest (fig. 64). The follower rest has one or two jaws that bear against the workpiece. The rest is fastened to the lathe carriage so that it will follow the cutter bit and bear upon the portion of the workpiece that has just been turned. The cut must first be started and continued for a short longitudinal distance before the follower rest may be applied. The rest is generally used only for straight turning and for threading of long, thin workpieces.

70. Tool Post Grinding Machine

The tool post grinding machine (fig. 65) is a machine tool attachment specially designed for cylindrical grinding operations on the lathe. It consists primarily of a ¼- or ⅛-horsepower electric motor and a wheel spindle connected by means of pulleys and a belt. The machine fastens to the compound rest of the lathe with a T-slot bolt which fits in the T-slot of the compound rest in the same manner as the lathe tool post. The tool post grinding machine mounts grinding abrasive wheels ranging from ¼ to 3 or 4 inches in diameter for internal and external grinding operations, and the pulleys on the wheel spindle and motor shaft are interchangeable to provide proper cutting speeds for the various wheel sizes. The larger grinding abrasive wheels used for external grinding are attached to the wheel spindle with an arbor. Small, mounted grinding abrasive wheels for internal grinding are fixed in a chuck which screws to the wheel spindle. The electric motor is connected to an electrical power source by means of a cable and plug. A switch is usually provided at the attachment to facilitate starting and stopping of the motor.

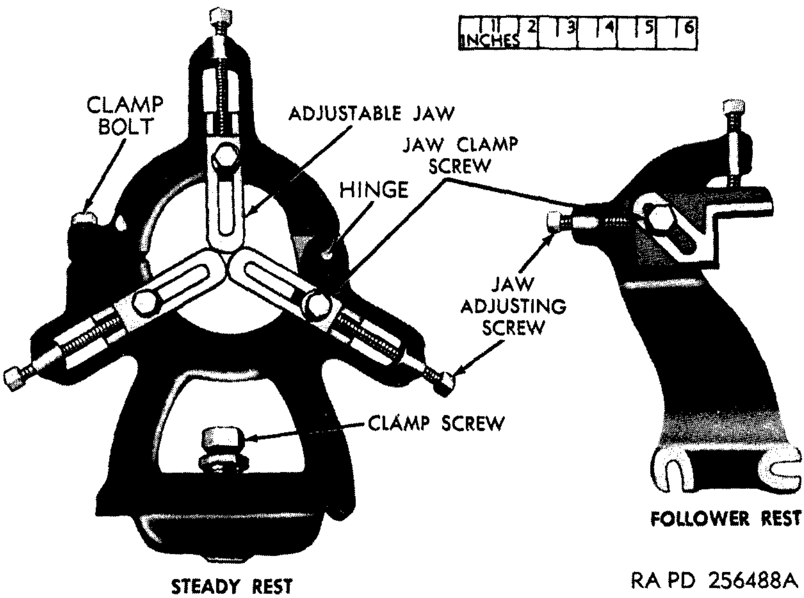


Figure 64. Steady and follower rests.

71. Milling and Grinding Lathe Attachment

The milling and grinding lathe attachment (fig. 66) is a versatile, self-powered attachment that fits to the carriage of the lathe. The attachment is used for milling slots, flats, or keyways on lathe mounted workpieces, for performing internal and external grinding operations, for drilling holes in the periphery of lathe mounted workpieces, for reaming and boring operations, and for milling gear teeth and square tooth threads. The spindle of the milling and grinding lathe attachment is vertically adjustable, riding on four shafts and controlled by a screw and handwheel. Different head accessories adapt the attachment for performing the variety of functions mentioned above.

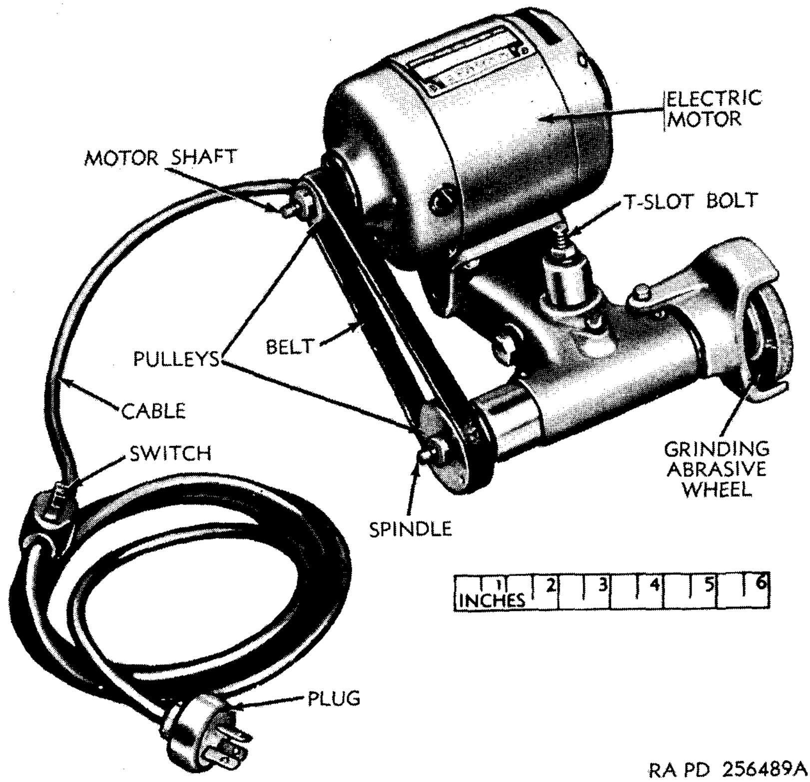


Figure 65. Tool post grinding machine.

Section III. LAYING OUT AND MOUNTING WORK

72. Laying Out Work

a. General. Laying out work for the lathe consists primarily of determining the best method for supporting the workpiece in the lathe and then locating and preparing centers if necessary.

b. Methods for Supporting Workpieces. If the workpiece is to be turned or threaded and is reasonably small in diameter and reasonably long, the usual method of mounting is between centers. If extensive facing, boring, or internal threading is to be done, the usual method of mounting is in a chuck, and if the piece is very long, a steady rest should be used near the end to be worked. If the workpiece to be machined is irregular in shape and not easily adaptable to chucking, the workpiece is usually fastened to a face plate.

c. Locating Centers of Cylindrical Workpieces. If the workpiece is to be mounted between lathe centers in the headstock and tailstock, it is necessary to locate the centers of the workpiece accurately. Accurate centering is important so that the entire diameter will finish to size, and the depth of cut will be uniform throughout. Several methods of centering bar stock are described in (1) through (3) below.

(1) *Hermaphrodite caliper method* (fig. 67). Set a pair of hermaphrodite calipers to approximately one-half the workpiece diameter and scribe four short arcs. The arcs will inclose the center.

Note. To make the scribed lines visible, the surface may be first lightly covered with pigment such as red lead or Prussian blue, or it may be treated with a light application of copper sulfate solution.

(2) *Center head method* (fig. 67). Hold the center head of a combination machinist's square firmly against the workpiece and scribe a line close to the blade. Give the workpiece a quarter

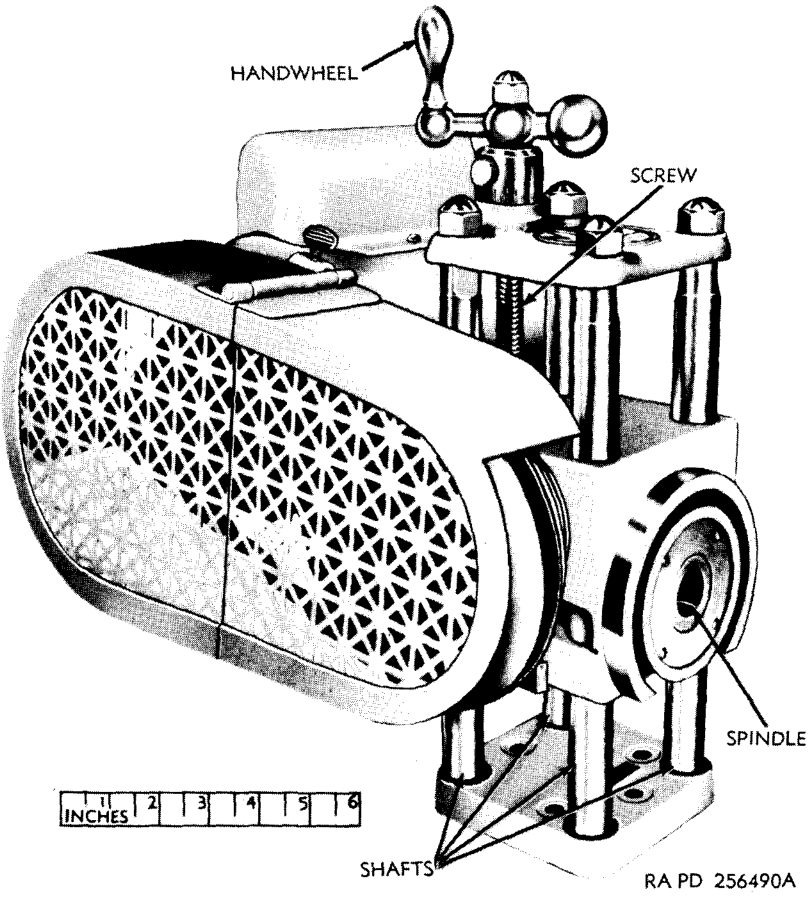


Figure 66. Milling and grinding lathe attachment.

turn and scribe a similar line. The point at which the lines intersect will be the center.

(3) *Divider method* (fig. 67). With the workpiece on a flat surface, set the dividers to approximately one-half the diameter of the piece and scribe four lines across each end. The center will be within the small square thus formed.

d. Locating Centers of Irregular Workpieces. No definite rules can be given for centering irregular workpieces. Common sense, good judgment, and some layout experience are required if the centers are to be located correctly.

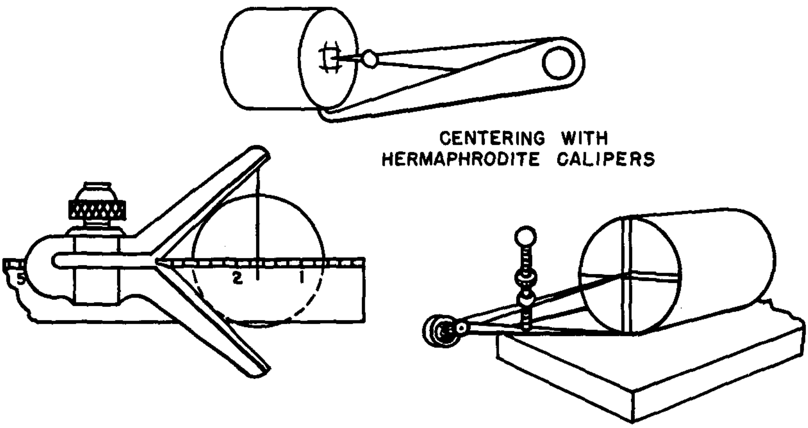


Figure 67. Locating centers on bar stock.

e. Testing Centers. When the centers are accurately located, they should be tested before drilling and countersinking. Carefully indent the centers lightly with a center punch. Place the workpiece in the lathe between lathe centers (par. 73). Hold a piece of chalk lightly against the workpiece and, supporting the chalk well, rotate the workpiece slowly by hand (fig. 68). High spots can be clearly marked in this manner at either end of the piece, and the centers can be corrected as necessary. If it is necessary to change the center marks after testing, a satisfactory method of doing so is to support the piece in a vise and, holding a center punch at an angle, drive the center mark in the desired direction.

f. Drilling and Countersinking Center Holes.

(1) After the centers have been properly located on the ends of the workpiece, drill and countersink centers to the proper depth and shape to fit the lathe centers. This can be done using a small twist drill followed by a 60° center countersink

(fig. 69) or, more commonly, using a countersink and drill which combines both tools (fig. 69).

(2) It is very important that the center holes are drilled and countersunk so that they will fit the lathe centers exactly. Incorrectly drilled holes will subject the lathe centers to unnecessary wear, and the workpiece will not run true because of poor bearing surfaces. A correctly drilled and countersunk hole has a uniform 60° taper and has clearance at the bottom for the point of the lathe center. Figure 70 illustrates correctly and incorrectly drilled center holes. The holes should have a polished appearance so not to score the lathe centers.

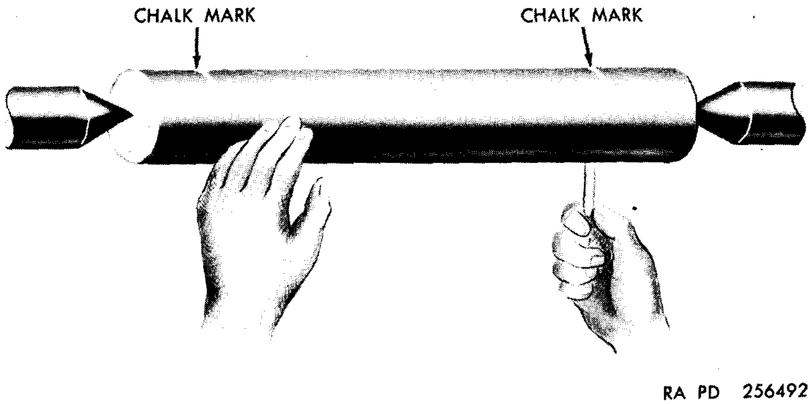


Figure 68. Method of testing location of centers.

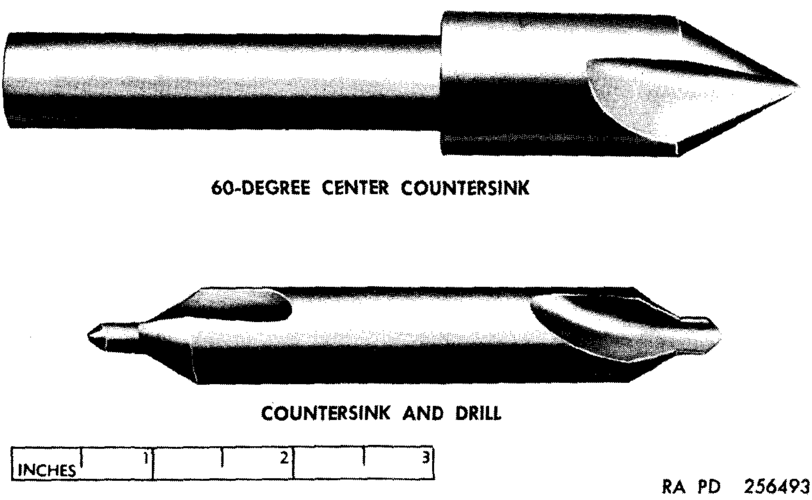
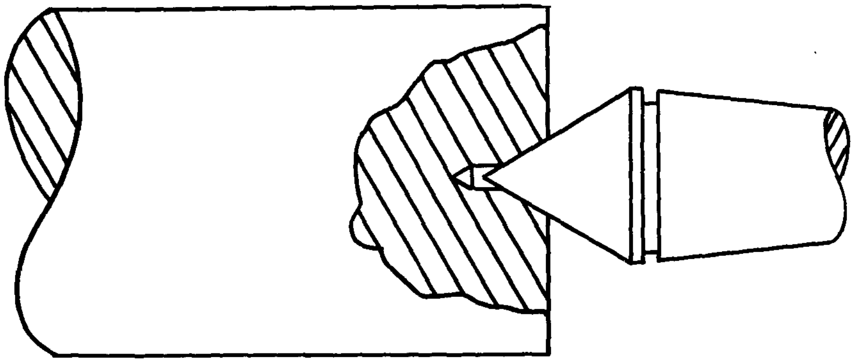
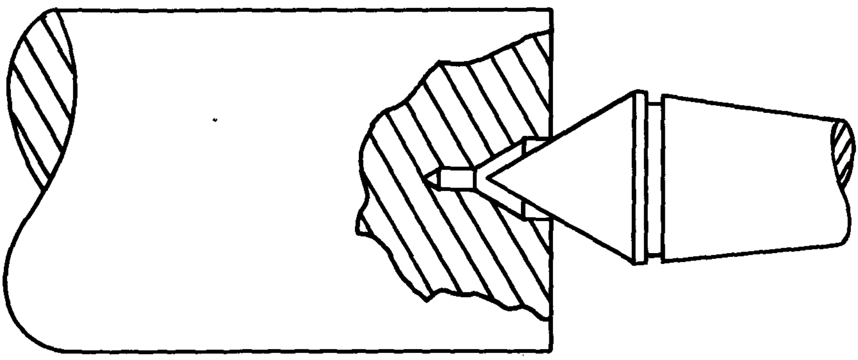


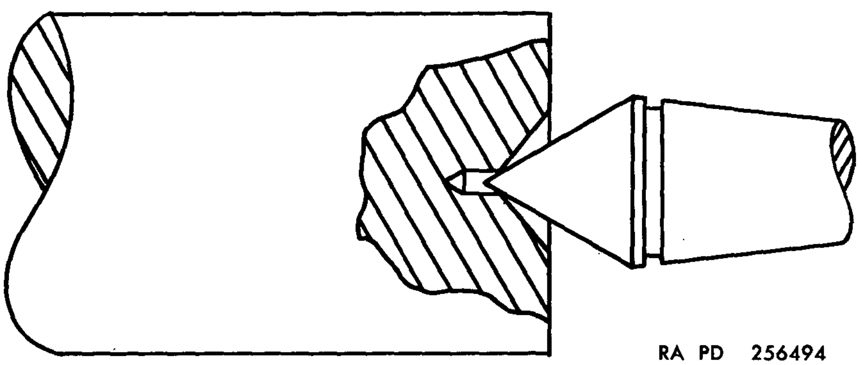
Figure 69. Tools for drilling and countersinking center holes.



CORRECTLY DRILLED HOLE



HOLE DRILLED TOO DEEP



HOLE DRILLED AT INCORRECT ANGLE

Figure 70. Correctly and incorrectly drilled center holes.

(3) The actual drilling and countersinking of center holes can be done on a drilling machine or by drilling in the lathe itself (par. 91). The spindle speed should be about 600 revolutions per minute and the feed should be kept comparatively light to prevent any possibility of breaking the drill point. A broken drill point requires that the end of the workpiece and broken point be annealed so that the point can be drilled out. This procedure is slow and might result in spoiling of the workpiece. When drilling and countersinking the center holes, make allowance for the thickness of metal that will be removed by facing; failure to do so may result in insufficient bearing surface for the lathe center after the facing operation is accomplished.

(4) The suggested drill sizes for ½- and 2-inch diameter workpieces are 0.043 and 0.157 inch respectively. The suggested countersink diameters for ½- and 2-inch diameter workpieces are ⅛ and 7/16 inch respectively.

73. Mounting Workpiece Between Centers

a. Inserting and Removing Lathe Centers. The quality of workmanship depends as much on the condition of the lathe centers as on the proper drilling of the center holes (par. 72*f*). Before mounting lathe centers in the headstock or tailstock, thoroughly clean the centers, the center sleeve, and the tapered sockets in the headstock and tailstock spindles. Any dirt or chips on the centers or in their sockets will prevent the centers from seating properly, and will cause the centers to run out of true.

(1) Install the lathe center in the tailstock spindle with a light twisting motion to insure a clean fit. Install the center sleeve into the headstock spindle and install the lathe center into the center sleeve with a light twisting motion.

Note. When male centers are supplied in pairs, the tailstock center is usually distinguished from the headstock center by a groove close to the tapered point. This groove indicates that the tailstock center has been hardened and tempered for use as a deadcenter. The ungrooved headstock center is not hardened because it will rotate with the work as a live center.

(2) Remove the center from the headstock spindle by holding the pointed end with a cloth or rag in one hand and giving the center a sharp tap with a rod or knockout bar inserted through the hollow headstock spindle.

(3) Remove the center from the tailstock by turning the tailstock handwheel to draw the tailstock spindle into the tailstock. The center will contact the tailstock screw and will be bumped loose from its socket.

b. *Grinding Lathe Centers* (fig. 71). Occasionally, it will be necessary to grind or redress the lathe centers when they become scored, misalined, or worn. The grinding is accomplished in the following manner:

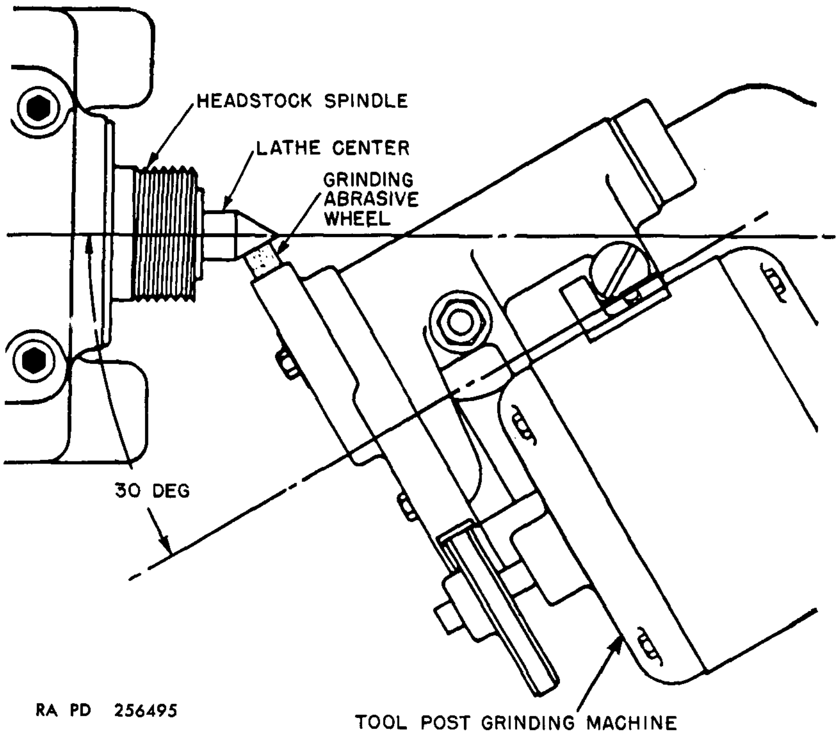


Figure 71. Grinding lathe centers with a tool post grinding machine.

(1) Carefully clean the spindle taper socket, lathe center, and center sleeve. Inspect these mating parts carefully and see that they are free from burs and scoring.

(2) Insert the lathe center and center sleeve solidly in the headstock spindle.

(3) Set the compound rest at an angle of 30° to the axis of the lathe.

(4) Clean and lubricate the dovetail slide upon which the compound rest moves. Adjust the tapered gib at the side of the compound rest to remove all looseness without causing the rest to bind.

(5) Cover the carriage and ways with paper or cloth to protect them from particles of abrasive grit from the grinding abrasive wheel. This step is important, for the grit could become imbedded and quickly destroy the accuracy of the lathe.

(6) Mount a tool post grinding machine in the T-slot of the compound rest. Adjust the face of the grinding abrasive wheel parallel to the conical surface of the center. See that the point of the lathe center is alined with the center hole in the end of the arbor which retains the grinding abrasive wheel on the wheel spindle. Check the grinding machine for end play and adjust if necessary. True the grinding abrasive wheel (par. 45*d*).

(7) Set the compound rest near the center of its travel and move the carriage and crossfeed to position the grinding abrasive wheel within a few thousandths of an inch from the lathe center. Lock the carriage in this position to prevent movement during the grinding operation.

(8) Start lathe at moderate speed (60 to 100 fpm) and then start the grinding machine, making sure that the lathe and grinding abrasive wheel both rotate in the same direction (the workpiece and the wheel will be moving in opposite directions at the point of contact).

Note. Generally the lathe will be placed in reverse gear.

(9) Move the grinding abrasive wheel until it touches the rotating lathe center. Set depth of cut between 0.001 and 0.002 inch. Carefully feed the grinding abrasive wheel along the face of the lathe center by turning compound rest feed handle, starting at the point of the lathe center, and feeding toward the headstock. Make additional passes in the same direction, increasing the feed with each pass until the center is true and smooth.

(10) Stop the lathe and grinding machine and use a 60° angle center gage (fig. 88) to check the center for accuracy. If the angle is not a true 60°, readjust the compound rest and repeat (8) and (9) above.

(11) Polish the center with a strip of fine emery cloth after grinding. Use a high spindle speed. It is good practice to grind the tailstock center first and grind the headstock center last so that the headstock center need not be removed from the lathe after grinding. This practice will give the headstock spindle more accuracy.

Note. Remove sharp points of centers to prevent personnel injury.

c. Checking Alinement of Centers.

(1) In order to turn a shaft straight and true between centers, it is necessary that the centers be in a plane parallel to the ways of the lathe. The tailstock may be moved laterally to accomplish this alinement by means of adjusting screws after it has been released from the ways. Two zero lines are located at the rear of the tailstock and the centers are approxi-

mately alined when these lines coincide (fig. 72). This alinement may be checked by moving the tailstock up close to the headstock so that the centers almost touch, and observing their relative positions (fig. 72).

(2) The preferred method of checking alinement of centers is by mounting the workpiece between centers and taking light cuts at both ends without changing the carriage adjustments. Measure each end thus cut with calipers or a micrometer. If the tailstock end is greater in diameter than the headstock end, the tailstock is displaced to the rear, and if the tailstock end is smaller in diameter than the headstock end, the tailstock is displaced to the front. Take additional cuts in the same manner after each adjustment until both cuts measure the same.

(3) Another good method of checking alinement of centers may be obtained by mounting a test bar (one in which the uniformity of the diameter is known) between the centers and bringing both ends of the bar to a zero reading on a dial indicator clamped to the lathe tool post (fig. 72). The tailstock must be clamped firmly to the bed ways and the test bar must be firmly set between the centers when taking the indicator readings.

d. Setting Up Workpieces Between Centers.

(1) After the lathe centers have been properly installed and alined, and the workpiece correctly drilled and countersunk, mount the piece in the lathe using a driving face plate and a lathe dog (fig. 73).

(2) Make sure that the external threads of the headstock spindle are clean before screwing on the driving face plate. Screw the face plate securely onto the spindle. Clamp the lathe dog on the workpiece so that its tail overhangs the end of the workpiece. If the workpiece is finished, place a split ring of soft material such as brass between the setscrew of the dog and workpiece. Mount the workpiece between the centers. Make sure that the lathe dog tail fits freely in the slot of the face plate and does not bind.

(3) Since the tailstock center is a deadcenter and does not revolve with the workpiece, it requires lubrication. A few drops of oil mixed with white lead should be applied to the center before the workpiece is set up. The tailstock should be adjusted so that the deadcenter fits firmly into the center hole of the workpiece but does not bind. The lathe should be stopped at intervals and additional oil and white lead mixture applied to the deadcenter to prevent overheating and harm to the center and the workpiece.

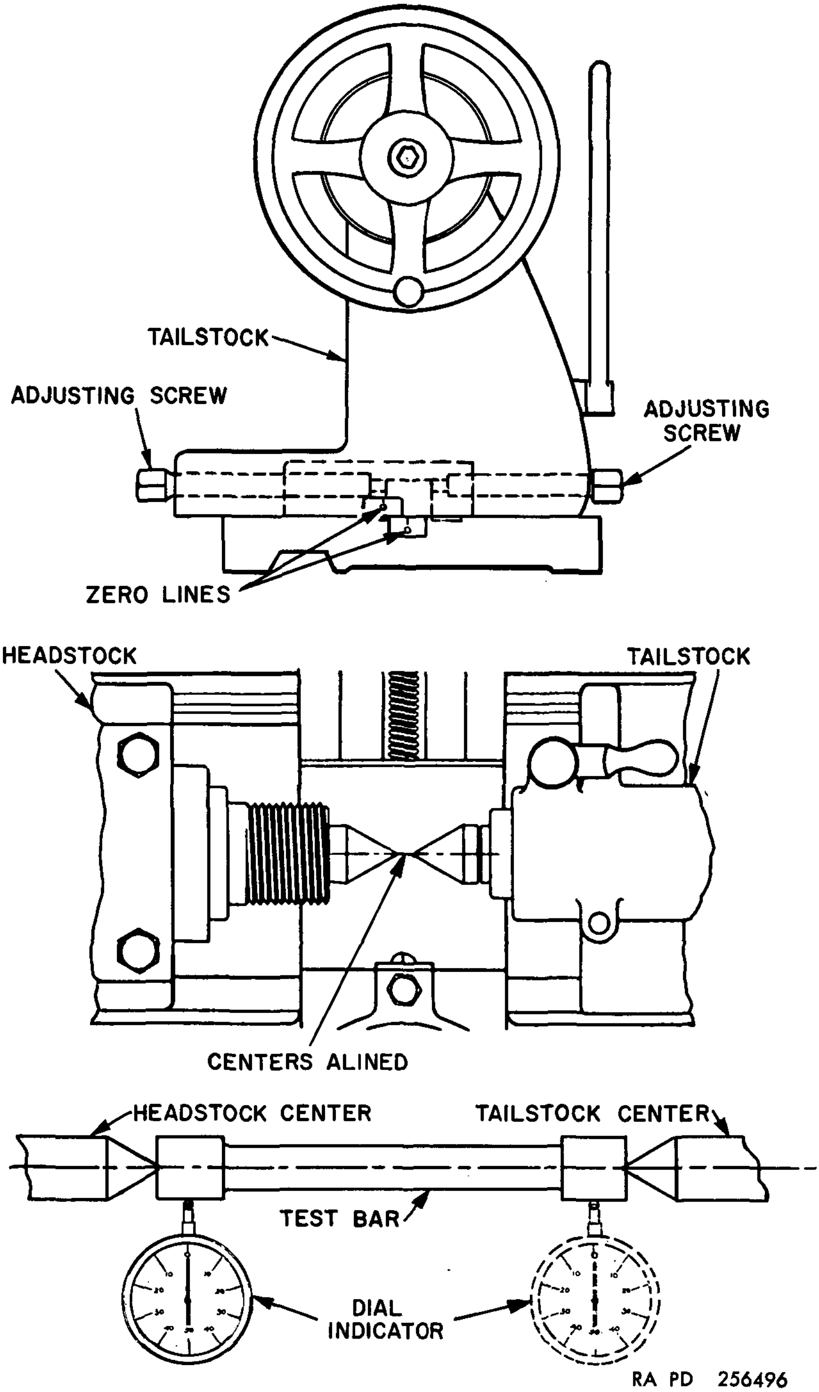


Figure 72. Alinement of lathe centers.

74. Mounting Workpieces in Chucks

a. Installing the Chuck. When installing the chuck or any attachment that screws onto the lathe headstock spindle, the threads and bearing surfaces of both spindle and chuck must be cleaned and oiled. In cleaning the internal threads of the chuck, a spring thread cleaner is very useful. Thread the chuck firmly on the headstock spindle by holding the chuck stationary and slowly rotating the lathe spindle by hand.

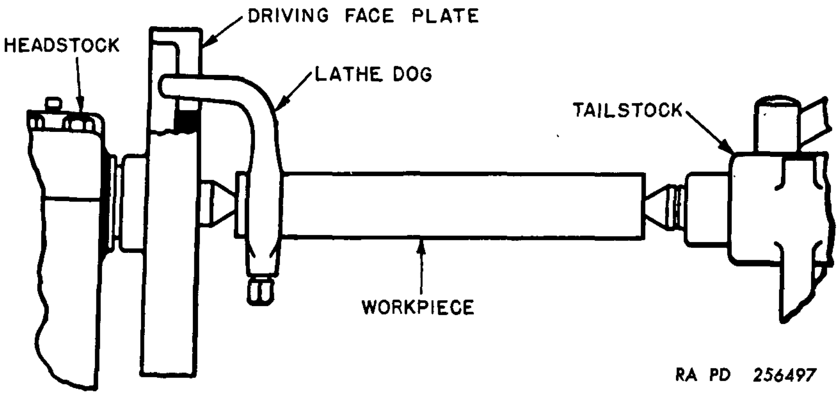


Figure 73. Work correctly mounted between centers in lathe.

b. Mounting and Alining Workpieces in the Independent Chuck.

(1) Place the workpiece between the chuck jaws and adjust the jaws to an approximate centered position by referring to the concentric rings scribed on the chuck face.

(2) Start the lathe and hold a piece of chalk lightly against the revolving workpiece until a mark shows on the workpiece. Readjust the chuck by loosening the jaw or jaws opposite the chalk mark and tightening the jaw or jaws on the chalk mark side. Repeat the above process until the workpiece is satisfactorily alined.

(3) To center a workpiece having a smooth surface, the best method is to use a dial test indicator. Place the point of the indicator against the outside or inside diameter of the workpiece (fig. 74). Revolve the workpiece slowly by hand and notice any deviations on the dial. This method will indicate any inaccuracy of the centering in thousandths of an inch. Test the face of the workpiece for wobble with a dial test indicator against the face of the piece (fig. 75).

(4) If an irregular shaped workpiece is mounted in the chuck, the alinement can be checked with a center indicator. Attach the center indicator to the lathe tool post and place the short end of the indicator pointer in the center punch

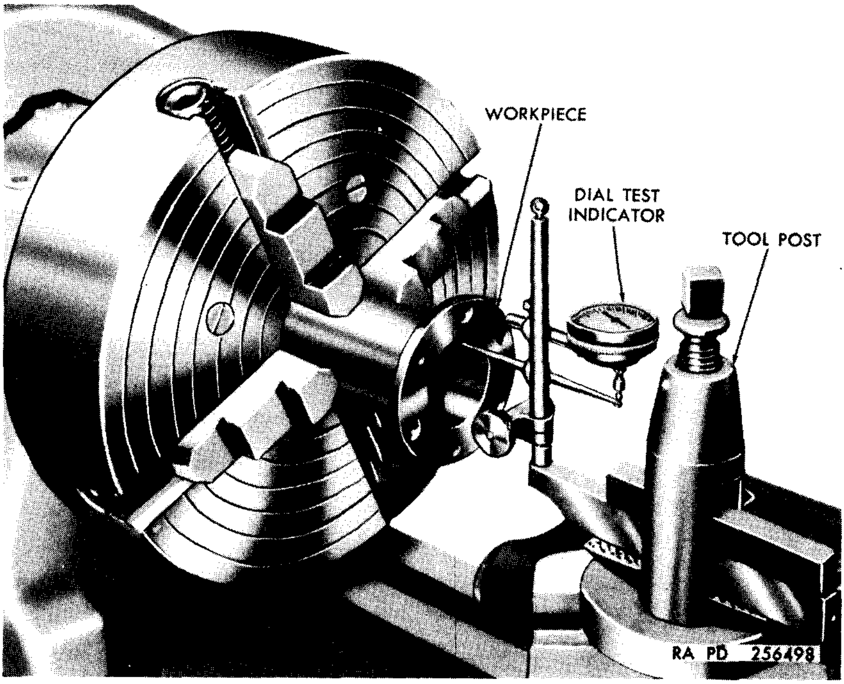


Figure 74. Centering work with dial test indicator.

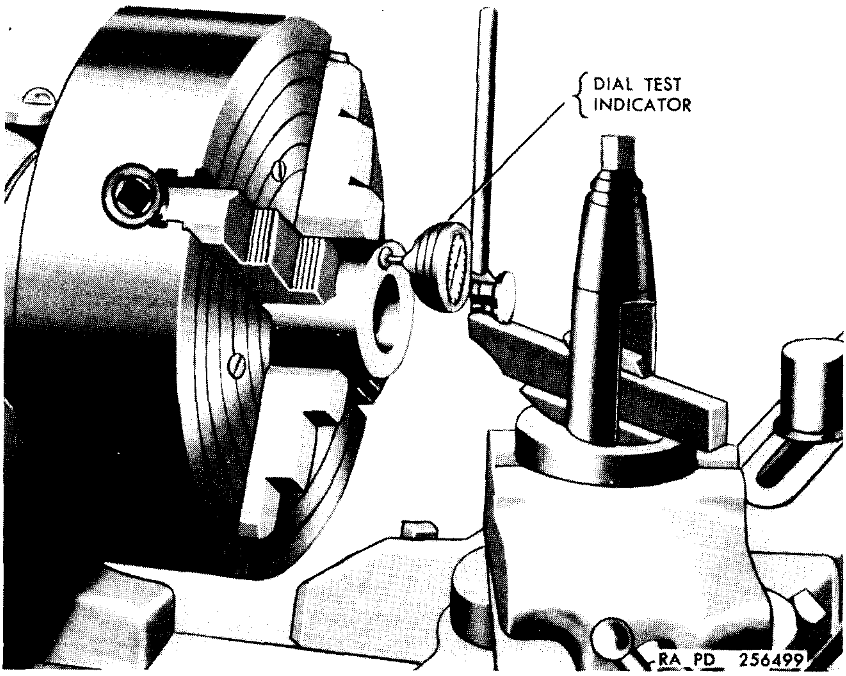


Figure 75. Testing face of workpiece for wobble.

mark in the piece (fig. 76). Move the tailstock center close to the long end of the indicator pointer, and adjust the tool post so that the pointer is approximately in line with the tailstock center. Revolve the headstock spindle slowly by hand and observe any movement of the long end of the indicator pointer in relation to the tailstock center. The long end of the indicator will magnify any inaccuracy of centering; if it remains stationary, the workpiece is accurately centered.

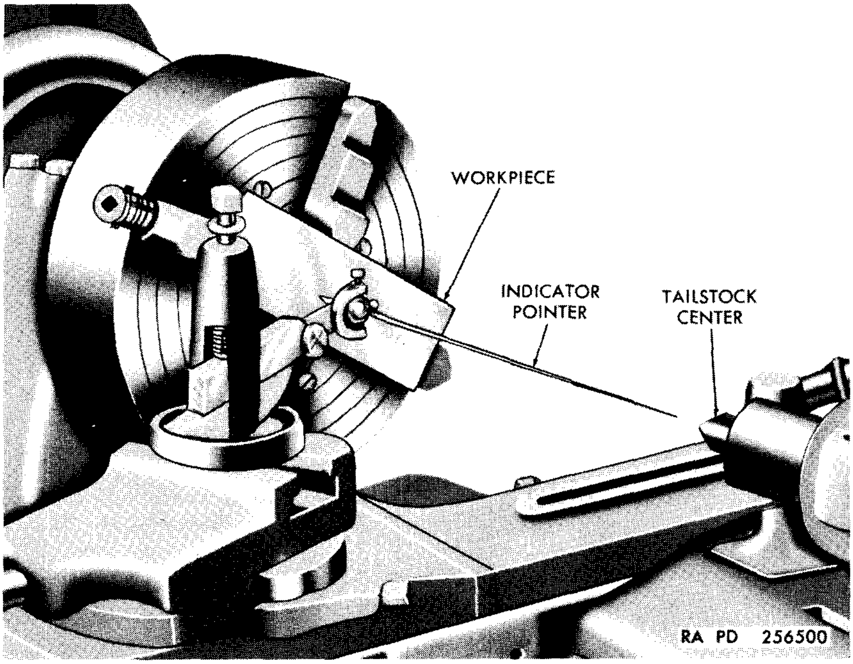


Figure 76. Using a center indicator to check workpiece alinement.

c. Setting Workpiece in Universal Scroll Chuck, Hollow Spindle Chuck, or Drill Chuck. No satisfactory centering adjustments are possible with universal scroll chucks, hollow spindle chucks, and drill chucks; therefore, if the workpiece cannot be satisfactorily centered in one of these chucks, the independent chuck must be used (*b* above). To set up the workpiece in the universal scroll chuck, place the piece between the jaws and turn the adjusting pinion to bring the jaws firmly against the piece.

d. Removing Chucks From the Lathe. To remove chucks that are screwed to the headstock spindle of the lathe, a chuck-removing wrench should be used. If a wrench is unavailable, place a wood block between the ways of the lathe and another wood block between a way of the lathe and one chuck jaw (fig. 77). Then, set lathe spindle in reverse and start in low gear to loosen chuck from spindle.

***Caution:* A wood plate should always be placed on the lathe bed before this operation to prevent the lathe bed or chuck from being damaged if the chuck should drop.**

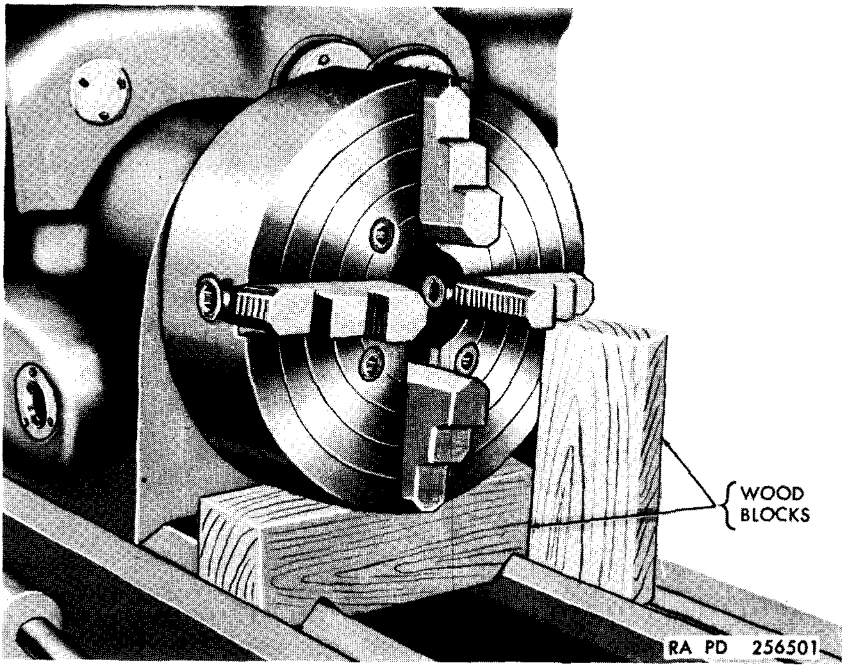


Figure 77. Removing chuck from lathe spindle by means of a wood block.

75. Mounting Workpieces to Face Plates

a. Installing and Alining the Face Plate. When screwing the face plate on the headstock spindle, the same cleaning and lubricating procedures described for chucks (par. 74*a*) should be observed. The accuracy of the bearing surface of the face plate is extremely important. Any unevenness of this surface should be removed by taking a facing cut (par. 80).

b. Mounting Workpiece to Face Plate. The workpiece is attached to the face plate by bolting angle plates and brackets to secure the workpiece. Care should be exercised when clamping the piece so that neither the piece nor the face plate will be sprung. To eliminate any spring or vibration caused by having the piece offset on the face plate, balance weights may be used. Paper placed between the face plate and the piece will help reduce possible slippage caused by slight unevennesses on the workpiece or face plate. Figure 78 illustrates a typical setup using the face plate.

c. Checking Centering of Workpiece on Face Plate. The alinement or centering of a workpiece on face plates should be checked by using a dial test indicator (par. 74*b*(3)) or a center indicator (par. 74*b*(4)).

d. Removing the Face Plate From the Lathe. The face plate should be removed from the lathe in the same manner described for removing chucks (par. 74*d*). If the wood block method is used, bolt a projecting bracket or lug to the face plate to grip the wood block when the spindle is rotated.

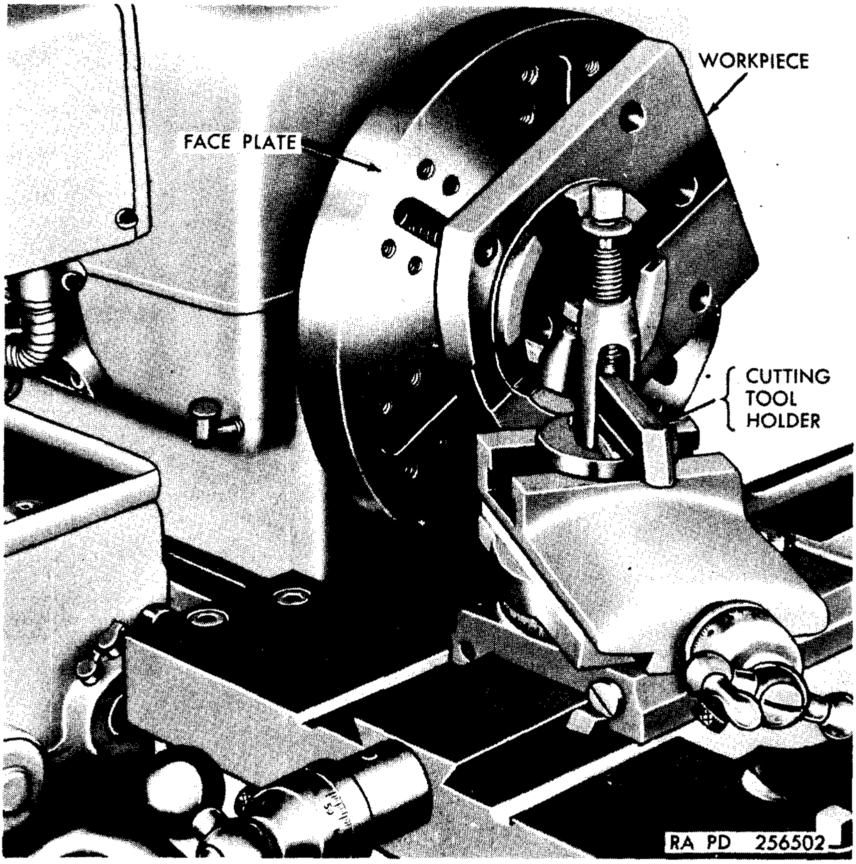


Figure 78. Typical face plate setup.

76. Mounting Workpieces on Mandrels.

a. Make sure the mandrel selected is of the proper size for the workpiece to be mounted. The bore of the workpiece and the mandrel must be free of burs and both surfaces must be thoroughly clean.

b. Lubricate both the workpiece and the mandrel, and press the mandrel into the workpiece. Set up the mandrel between centers as though it were part of the workpiece (par. 73). Figure 79 shows a pulley supported in the lathe by a mandrel. Note the attachment of the lathe dog to the flat at the end of the mandrel, not to the machined taper surface.

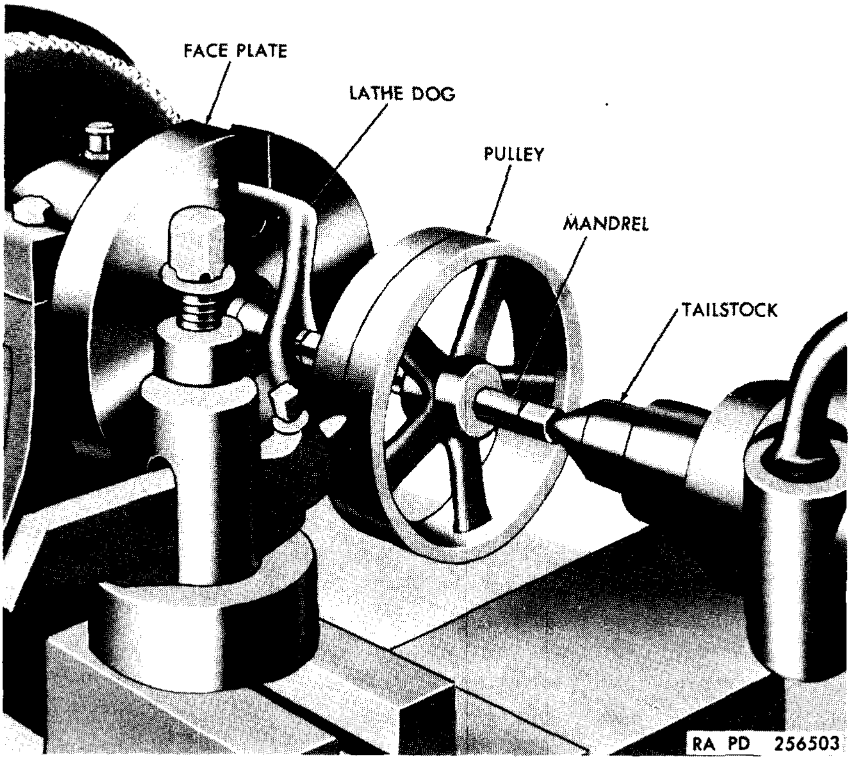


Figure 79. Pulley mounted in lathe on a mandrel.

Section IV. GENERAL LATHE OPERATION

77. General

To obtain good results on the lathe, a knowledge of the variable factors of speeds, feeds, cutting oils, and materials is necessary as well as the mechanical application of the cutter bits to the workpiece. Cutting speeds, feeds, depth of cut, and cutting oils, if used, are different for each material and each operation; failure to keep these factors within proper limits may cause damage to the lathe and lathe tools and will result in spoiling of the workpiece. The methods of operation described in this section are general in nature. With experience the machinist will be able to vary certain procedures with success for individual operations.

78. Lathe Speeds and Feeds

a. General. Determining the most advantageous feeds and speeds for a particular lathe operation depends on numerous factors such as the kind of material being worked, the type of tool, the diameter and length of the workpiece, the type of cut desired (rough or finished), the cutting oil used if any, and the condition of the lathe.

b. Cutting Speed.

(1) The cutting speed of a cutter bit is defined as the number of feet of workpiece surface, measured at the circumference, that pass the cutter bit in 1 minute. The cutting speed expressed in feet per minute (fpm), must not be confused with the spindle speed of the lathe which is expressed in revolutions per minute (rpm). To obtain uniform cutting speed, the lathe spindle must be revolved faster for workpieces of small diameter and slower for workpieces of large diameter.

(2) The proper cutting speed for a given job depends upon the hardness of the material being worked, the material of the cutter bit, and the feed and depth of cut (*c* and *d* below) to be used. Table XIII lists specific ranges of cutting speeds for straight turning and for threading under normal conditions. It is proper to start machining operations at these speeds and observe the effect on the cutter bit and workpiece. If the cutter bit does not cut satisfactorily, the speed should be reduced. Carbon-steel tools, when used, require a reduction in speed because they cannot withstand the heat produced as a result of high-speed turning. Carbide-tipped tools, however, will stand speeds in excess of those recommended for high-speed steel tools. The feed and depth of cut should be average as described in *c* and *d* below for the

Table XIII. Lathe Cutting Speeds for Straight Turning and Threading

Material	Straight turning speed (fpm) [1]	Threading speed (fpm) [1]
Aluminum	200 to 300	50
Brass, yellow	150 to 200	50
Bronze, soft	80 to 100	30
Bronze, hard	30 to 80	20
Cast iron	50 to 80	25
Copper	60 to 80	25
Monel metal	100 to 120	35
Steel, high carbon (tool)	35 to 40	15
Steel, low carbon	80 to 100	35
Steel, medium carbon	60 to 80	25
Steel, stainless	40 to 50	15

[1] The speeds are based on the use of high-speed steel cutter bits. These speeds may be increased 25 to 50 percent, if a cutting oil is used. If stellite or carbide-tipped cutter bits are used, speeds may be 2 or 3 times as high as those given for high-speed steel cutter bits. If carbon-steel cutter bits are used, the speed should be reduced by about 25 percent.

recommended speeds in table XIII. If it is desired to increase either the feed or the depth of cut, the cutting speed should be proportionally reduced to prevent overheating and excessive cutter bit wear.

(3) To determine the rotational speed necessary to produce a given cutting speed, it is necessary to know the diameter of the workpiece to be cut. To calculate the spindle speed, knowing the diameter of the workpiece, use the following formula:

$$\text{rpm} = \frac{12 \text{ fpm}}{\pi D}$$

where, rpm = spindle speed (in revolutions per minute);
fpm = cutting speed (in ft per minute);
$\pi = 3.1416$;
D = diameter (in in.) of workpiece.

For example; if a 2.250-inch diameter workpiece is to be cut at the rate of 120 feet per minute, the spindle speed is calculated as follows:

$$\text{rpm} = \frac{\text{fpm}}{D} = \frac{12 \times 120}{3.1416 \times 2.250} = 204 \text{ rpm.}$$

Spindle speed for drills and other rotating cutters can be determined using the same formula by substituting the cutting diameter of the drill or cutter for the diameter of the workpiece. Table XIV may be used to save time when computing rotational spindle speeds for common cutting speeds and common workpiece diameters.

(4) Other factors to consider when selecting cutting speed include use of cutting oil, length and diameter of the workpiece, and the condition of the lathe. If a large stream of proper cutting oil is applied to the workpiece at the cutter bit, the cutting speed can be increased as much as 40 percent. If the diameter of the workpiece is small and its length great enough to set up vibrations due to speed, a poor finish will result; to correct this condition, the speed must necessarily be reduced. The lathe may also be in poor condition so that high speeds will cause harmful vibrations.

(5) The technical manual for the lathe being used should be consulted for instructions in setting the spindle speed for operation. If a desired spindle speed is not available on the lathe, select a speed nearest that which is desired, generally the first slower speed available. For efficient lathe operation, the machinist should be able to recognize too slow a speed as well as too fast a speed.

Table XIV. *Lathe Rotational Spindle Speeds*

Cutting speed (fpm)	30	40	50	60	70	80	90	100	120	140	160	180	200	250
Workpiece diameter (in.)	Spindle speed (rpm)													
¼	458	611	764	917	1, 070	1, 222	1, 376	1, 528	1, 834	2, 139	2, 445	2, 750	3, 056	3, 820
⅜	306	408	509	611	713	815	916	1, 018	1, 222	1, 425	1, 629	1, 832	2, 036	2, 545
½	229	306	382	459	535	611	688	764	917	1, 070	1, 222	1, 375	1, 528	1, 910
⅝	184	245	306	367	428	489	552	612	736	857	979	1, 102	1, 224	1, 530
¾	153	203	254	306	357	408	458	508	610	711	813	914	1, 016	1, 270
⅞	131	175	219	262	306	349	392	438	526	613	701	788	876	1, 095
1	115	153	191	229	267	306	344	382	458	535	611	688	764	955
1⅛	102	136	170	204	238	272	306	340	408	476	544	612	680	850
1¼	91. 8	123	153	183	214	245	274	306	367	428	490	551	612	765
1⅜	83. 3	111	139	167	195	222	250	278	334	389	445	500	556	705
1½	76. 3	102	127	153	178	204	230	254	305	356	406	457	508	635
1¾	65. 5	87. 3	109	131	153	175	196	218	262	305	349	392	436	545
2	57. 3	76. 4	95. 5	114	134	153	172	191	229	267	306	344	382	478
2¼	51. 0	68	85. 5	102	119	136	153	170	204	238	272	306	340	428
2½	45. 8	61. 2	76. 3	91. 7	107	122	138	153	184	213	245	275	306	382
2¾	41. 7	55. 6	69. 5	83. 4	97. 2	111	125	139	167	195	222	250	278	348
3	38. 2	51	63. 7	76. 4	89. 1	102	114	127	152	178	203	228	254	318
3¼	35. 1	46. 8	58. 5	70. 2	81. 9	93. 6	105	117	140	164	188	211	234	293
3½	32. 7	43. 6	54. 5	65. 5	76. 4	87. 4	98. 1	109	131	153	174	196	218	273
3¾	30. 6	40. 8	51	61. 2	71. 4	81. 6	91. 8	102	122	143	163	184	205	255
4	28. 7	38. 2	47. 8	57. 3	66. 9	76. 4	86	95. 6	115	134	153	172	191	239
4½	25. 4	34	42. 4	51	59. 4	67. 9	76. 3	84. 8	102	119	136	153	170	210
5	22. 9	30. 6	38. 2	45. 9	53. 5	61. 1	69	76. 4	91. 7	107	122	138	153	191
5½	20. 8	27. 8	34. 7	41. 7	48. 6	55. 6	62	69. 4	83. 3	97. 2	111	125	139	173

6	19. 1	25. 5	31. 8	38. 2	44. 6	51	57	63. 6	76. 3	89	102	114	127	159
6½	17. 6	23. 5	29. 4	35. 2	41. 1	47	53	58. 7	70. 4	82. 2	93. 9	106	117	147
7	16. 4	21. 8	27. 3	32. 7	38. 2	43. 7	49	54. 6	65. 5	76. 4	87. 4	98. 3	109	136
7½	15. 3	20. 4	25. 4	30. 5	35. 6	40. 7	46	50. 9	61. 1	71	81. 4	91. 6	102	127
8	14. 3	19. 1	23. 9	28. 7	33. 4	38. 2	43	47. 8	57. 4	66. 9	76. 5	86	95. 6	119
8½	13. 3	18. 0	22	27	31	36	40	45. 1	54	62	72	80	90. 2	110
9	12. 6	17. 0	21. 2	25	30	34	38	42. 4	51	60	68	76	44. 8	106
9½	12. 0	16. 1	20. 1	24	28	32	36	40. 3	48	56	64	72	80. 6	101
10	11. 3	15. 3	19. 1	23	27	31	34	38. 2	46	54	62	68	76. 4	96
11	10. 3	13. 9	17. 4	20. 8	24	28	31	35	41	48	56	62	70. 0	87
12	9. 7	12. 7	15. 9	19. 1	22	25	29	31. 8	38	44	50	58	63. 6	79. 5
13	8. 6	11. 8	14. 7	17. 6	20. 6	23	26	29. 3	35	41	46	52	58. 6	73. 5
14	8. 0	10. 9	13. 6	16. 4	19. 1	22	24	27. 3	33	38	44	48	54. 6	68. 0
15	7. 7	10. 2	12. 7	15. 3	17. 8	20. 4	23	24. 6	30	35	41	46	49. 2	63. 5
16	7. 1	9. 5	11. 9	14. 3	16. 7	19. 1	21. 4	23. 9	29	33	38	43	47. 8	59. 5
17	6. 7	9. 0	11. 2	13. 5	15. 7	18. 0	20. 2	22. 1	27	31	36	40	44. 2	56. 0
18	6. 4	8. 5	10. 6	12. 7	14. 8	17. 0	19. 1	21. 2	25	30	34	38	42. 4	53. 0

c. Feed.

(1) *General.* Feed is the term applied to the distance the cutter bit advances for each revolution of the workpiece. Feed is specified in inches per revolution. Since the best feed depends upon a number of factors such as depth of cut, type of material, size of workpiece, and condition of the lathe, it is difficult to list the best feed for different materials.

(2) *Rough cuts.* For rough cuts, the feed may be relatively heavy since the surface need not be exceptionally smooth. For most materials, the feed for rough cuts should be 0.010 to 0.020 inch per revolution. The feed may be 0.040 inch on large lathes with larger diameter workpieces. Care must be taken when turning slender workpieces as a heavy cut may bend the piece, ruining it. In this case, it is best to reduce the feed to 0.008 to 0.015 inch per revolution.

(3) *Finish cuts.* For finish cuts, a light feed is necessary since a heavy feed causes a built-up edge to form on the surface which produces a poor finish. If a large amount of stock is to be removed, it is advisable to take one or more roughing cuts ((2) above) and then take light finishing cuts at relatively high speeds. For most materials, the feed for finishing cuts should be 0.003 to 0.010 inch per revolution. An exception is the finishing of soft metals like aluminum where a broadnose cutter bit is used at feeds as great as 1/8 to 1/2 inch per revolution.

d. Depth of Cut.

(1) *General.* The depth of cut regulates the reduction in diameter of the workpiece for each longitudinal traverse of the cutter bit. The workpiece diameter is reduced by twice the depth of cut in each complete traverse of the cutter bit. Generally, the deeper the cut, the slower the speed, since a deep cut requires more power.

(2) *Rough cuts.* The depth of cut for roughing is generally five to ten times deeper than the feed. The reason for this is that more of the cutting edge of the cutter bit is in contact with the workpiece for the amount of metal being removed and permits a greater speed to be used. For roughing with feeds of from 0.010 to 0.020 inch per revolution, the depth of cut should be between 3/16 and 1/4 inch. Deeper cuts up to 1/2 inch can be taken but the feed should be proportionately reduced. A heavy cut may cause the workpiece and cutter bit to chatter and in this case the depth of cut should be reduced.

(3) *Finish cuts.* Finish cuts are generally very light, and the cutting speed therefore can be increased since the chip is thin.

79. Cutting Oils

a. General. The chief purpose of a cutting oil is to cool the cutter bit and workpiece, and the name coolant is often given to the oil. A cutter bit will last longer and will be capable of withstanding greater speeds without overheating when a cutting oil is used. A cutting oil also helps lubricate cutter bits, improves the finish of the workpiece, guards against rusting, and washes away chips from the cutting area.

b. Use. In production operations, the practice is to flood the workpiece and cutter bit with cutting oil in order to obtain a full benefit of its use. For effective cooling, it is important that the oil be directed at the exact point of the cutter bit contact. A large stream at low velocity is to be preferred to a small stream at high velocity. In small shops where pump equipment is not available, cutting oils are used only for finishing and delicate operations. It is general practice in this case to apply the cutting oil only when actually required.

c. Types of Cutting Oils. Cutting oils most commonly used and their general applications are described in (1) through (7) below. Table XV lists cutting oils for specific lathe operations for different materials to be machined.

(1) *Lard oil.* Pure lard oil is one of the oldest and best cutting oils. It is especially good for thread cutting, tapping, deep hole drilling, and reaming. Lard oil has a high degree of adhesion or oiliness, a relatively high specific heat, and its fluidity changes slightly with temperature. It is an excellent rust preventive and produces a smooth finish on the workpiece. Because lard oil is expensive, it is seldom used in a pure state but is combined with other ingredients to form good cutting oil mixtures.

(2) *Mineral oil.* Mineral oils are petroleum-base oils that range in viscosity from kerosene to light paraffin oils. Mineral oil is very stable and does not develop disagreeable odors like lard oil; however, it lacks some of the good qualities of lard oil such as adhesion, oiliness, and high specific heat. Because it is relatively inexpensive, it is commonly mixed with lard oil or other chemicals to provide cutting oils with desirable characteristics. Two mineral oils, kerosene and turpentine, are often used alone for machining aluminum and magnesium. Paraffin oil is used alone or with lard oil for machining copper and brass.

(3) *Mineral-lard cutting oil mixture.* Various mixtures of mineral oils and lard oil are used to make cutting oils which combine the good points of both ingredients but prove more economical and often as effective as pure lard oil.

(4) *Sulfurized-fatty-mineral oil.* Most good cutting oils contain mineral oil and lard oil with various amounts of sulfur and

Table XV. *Cutting Oils for Lathe Operations*

Material	Cutting Oil		
	Heavy cutting	Light cutting	Threading
Aluminum	Dry; soluble cutting oil.	Dry	Mineral-fatty-blend cutting oil.
Brass	Dry; soluble cutting oil.	Dry	Sulfurized-fatty-mineral cutting oil.
Bronze	Soluble cutting oil	Soluble cutting oil	Sulfur-treated mineral-lard cutting oil.
Cast iron	Dry	Dry	Sulfurized-fatty-mineral cutting oil.
Copper	Dry; mineral-fatty-blend cutting oil.	Dry; mineral-fatty-blend cutting oil.	Mineral-fatty-blend cutting oil.
Monel metal	Soluble cutting oil; sulfurized-fatty-mineral cutting oil.	Soluble cutting oil; sulfurized-fatty-mineral cutting oil.	Pure lard cutting oil; sulfurized-fatty-mineral cutting oil.
Steel, machine	Soluble cutting oil	Mineral-fatty-blend cutting oil; soluble cutting oil.	Sulfurized-fatty-mineral cutting oil.
Steel, tool	Soluble cutting oil; sulfurized-fatty-mineral cutting oil.	Soluble cutting oil; sulfurized-fatty-mineral cutting oil.	Pure lard cutting oil; sulfurized-fatty-mineral cutting oil.
Steel, stainless	Soluble cutting oil; sulfurized-fatty-mineral cutting oil.	Soluble cutting oil; sulfurized-fatty-mineral cutting oil.	Pure lard cutting oil; sulfurized-fatty-mineral cutting oil.

chlorine which give the oils good antiweld properties and promote free machining. These oils play an important part in present day machining because they provide good finishes on most materials and aid the cutting of tough material.

(5) *Soluble cutting oils.* Water is an excellent cooling medium but has little lubricating value and hastens rust and corrosion. Therefore mineral oils or lard oils which are miscible with water are often mixed with water to form a cutting oil. Soluble oil and water has lubricating qualities dependent upon the strength of the solution. Generally, soluble oil and water is used for rough cutting where quick dissipation of heat is most important. Borax and trisodium phosphate

are sometimes added to the solution to improve its corrosion resistance.

(6) *Soda water mixtures.* Salts such as soda ash and trisodium phosphate are sometimes added to water to help control rust. This mixture is the cheapest of all coolants and has practically no lubricating value. Lard oil and soap in small quantities are sometimes added to the mixture to improve its lubricating qualities. Generally, soda water is used only where cooling is the prime consideration and lubrication a secondary consideration. It is especially suitable in reaming and threading operations on cast iron where a better finish is desired.

(7) *White lead and lard oil mixture.* White lead can be mixed with either lard oil or mineral oil to form a cutting oil which is especially suitable for difficult machining of very hard metals.

80. Facing

a. General. Facing is the square finishing of the ends of the workpiece and is often used to bring the piece to a specified length. In facing operations, the cutter bit does not traverse laterally (left or right) but cuts inward or outward from the axis of the piece. Facing of ends is usually performed before turning operations.

b. Mounting Workpiece for Facing. The workpiece to be faced may be mounted between centers (par. 73) or in a lathe chuck (par. 74). If the right end of the piece is to be faced and the piece is to be mounted between centers, a half center is often used in the tailstock spindle (par. 66*e*). The half center permits complete facing to the center hole without interference with the center. With the piece mounted between centers, the left end cannot be faced if a lathe dog is used. It is advisable to reverse the piece for this operation.

c. Proper Cutter Bit for Facing. The right hand facing cutter bit (fig. 47) is used for facing the right end of the workpiece and shoulders which face to the right. The left hand facing cutter bit is used for facing the left end of the workpiece and shoulders which face to the left.

d. Position of the Cutter Bit for Facing (fig. 80). With the cutter bit positioned in the cutting tool holder, fasten the holder to the tool post. Carefully adjust the holder so that the cutting edge of the bit is exactly on the horizontal centerline of the workpiece. If the cutting edge is not on center, the end cannot be faced to the center of the piece, and the rake and clearance angles will not be correct. Adjust the cutting edge of the bit to a slight angle to the workpiece surface by adjusting the compound rest of the lathe.

e. Facing Operation. For the first or roughing cut, set the cutter bit (*d* above) and begin the cut as close as possible to the axis of the workpiece, feeding the bit outward, away from the axis (fig. 80). Remove only enough metal to square the end over its entire surface. If the piece must be faced to a specified length, take two or more roughing cuts in the same manner, leaving a small amount of metal to be removed for the finishing cut. For the finishing cut, readjust the bit so that the cutting edge is set nearly flat against the workpiece surface, removing only a light, thin chip. The finishing cut can be taken in either direction, from the axis outward as in the roughing cut,

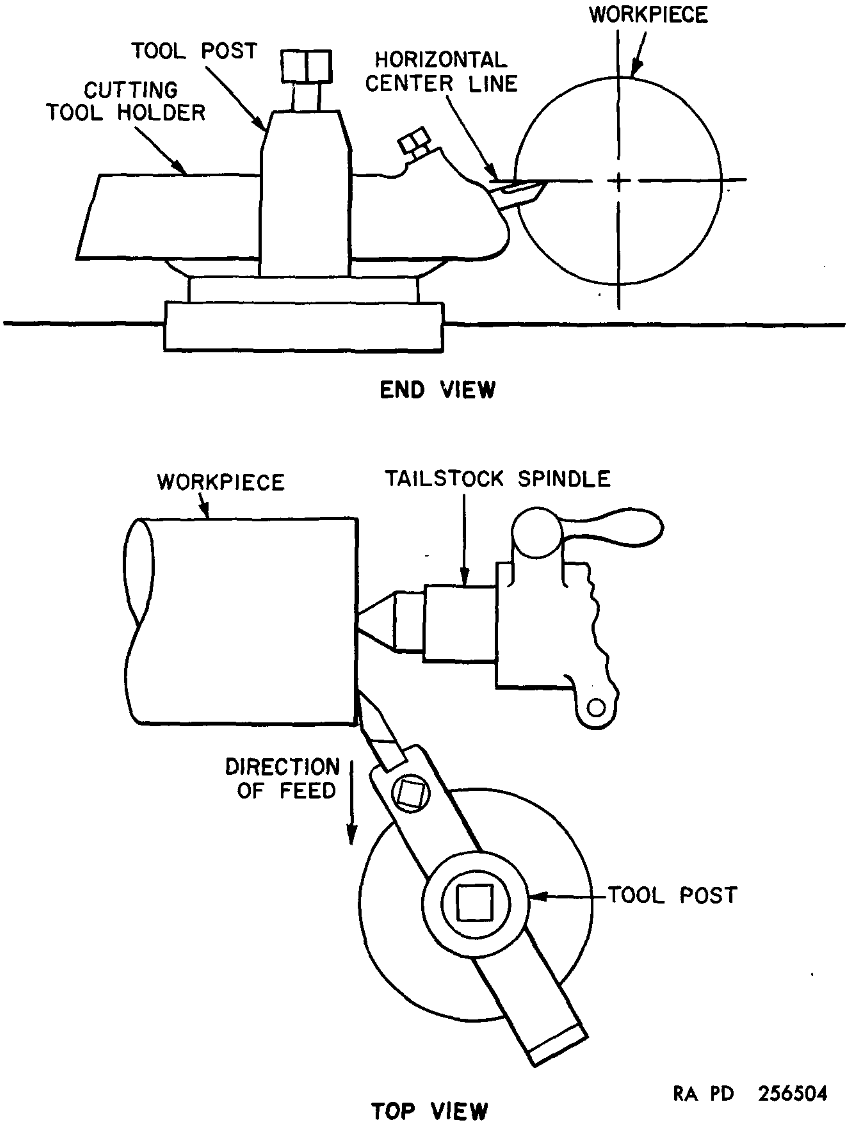


Figure 80. Position of the cutter bit for facing.

or from the circumference of the workpiece inward toward the axis. In facing, care is needed to see that the bit does not contact the tailstock center.

81. Straight Turning.

a. General. Straight turning may be performed upon a workpiece supported in a chuck (par. 74) but the majority of workpieces turned on an engine lathe are turned between lathe centers (par. 73). Turning is the removal of metal from the external surface of cylindrical workpieces.

b. Mounting Workpieces for Straight Turning. Lathe centers must be in good condition and carefully alined if the turning operation is to be accurate. If necessary, regrind the centers (par. 73*b*) and check their alinement (par. 73*c*). When turning the workpiece, considerable heat will be generated which will cause the workpiece to expand. Lathe centers that are too tight may cause binding of the workpiece due to this expansion. The tailstock center or deadcenter must be well lubricated to prevent its overheating. The center hole and the tailstock center should be lubricated before the cutting operation with a mixture of white lead and motor oil. During the turning operation, feel the dead center frequently to determine whether lubrication or adjustment is necessary.

c. Proper Cutter Bits for Straight Turning. Straight turning is accomplished with the left hand turning cutter bit, the right hand turning cutter bit, or the round-nose turning cutter bit (fig. 47). Wherever possible, the right hand turning cutter bit or a round-nose bit ground for right to left turning is used and the bit is fed toward the headstock. If circumstances demand that the bit feed from left to right, such as in turning up to a shoulder, the left hand cutter bit is used. The round nose turning cutter bit is especially efficient for finishing cuts.

d. Position of Cutter Bit for Straight Turning. The cutter bit should be locked in the cutting tool holder and the holder should be fixed to the tool post so that the cutting edge of the bit touches the workpiece surface at about 5° above the horizontal centerline of the piece (fig. 81) since this position gives the bit a better cutting action. The distance above center is governed by the diameter of the workpiece and front clearance angle of the bit. As a general rule, the point of contact of the cutting edge is raised $\frac{3}{16}$ inch above center for each inch of workpiece diameter. In a horizontal plane, the bit and holder should be positioned at a right angle to the workpiece axis or at a slight leading angle so that the bit will not dig into the piece if the bit or tool holder should accidentally loosen on the tool post.

e. Straight Turning Operation. As a rule, the workpiece is turned down by a number of roughing cuts to a predetermined diameter which is within $\frac{1}{32}$ to $\frac{1}{64}$ inch of the diameter desired. The remaining metal is removed by a finish cut with a fine feed to produce a good surface. After taking the first roughing cut along the entire workpiece surface, check the center alinement by measuring each end with calipers. If the ends are of different diameters, the tailstock center is out of alinement with the headstock spindle and realinement (par. 73*c*) is necessary. Continue cutting after alinement is effected, stopping the lathe at intervals to check the tailstock center (*b* above).

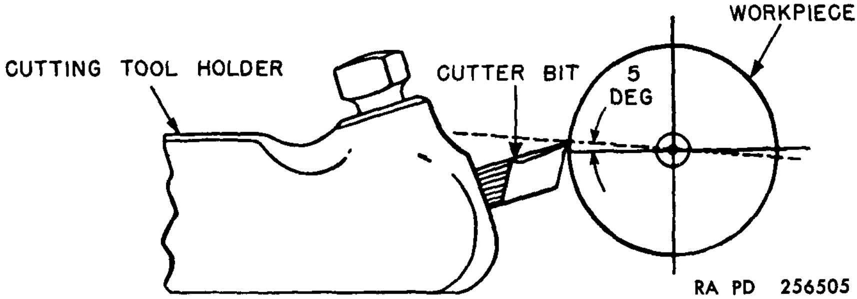


Figure 81. Position of cutter bit for straight turning.

After roughing, reverse the ends of the workpiece so that the area held by the lathe dog can be turned. When the piece is within 1/32 to 1/64 inch of the desired size, reduce the depth of cut, reduce the feed, increase the speed, and take light finishing cuts to the proper dimension. Caliper the piece after each cut, using micrometer calipers. Reverse the piece again and, using shims under the lathe dog to prevent scoring of the machined surface, finish the other end of the piece.

Note. Remember that if the workpiece is turned smaller than the desired finished size, it cannot be made larger and is ruined.

82. Shoulder Turning

a. General. It is frequently necessary to turn a workpiece so that it will have two or more diameters in its length. For example, a bar 12 inches long might be 3 inches in diameter for half its length, and 3½ inches in diameter for the other half. It would therefore have an abrupt step or shoulder ¼ inch high 6 inches from the small end. The shoulder may be machined so that it forms a sharp corner with the small diameter, or a fillet may be formed so that the corner is slightly rounded instead of square.

b. Mounting Workpiece for Shoulder Turning. The workpiece may be mounted in a chuck (par. 74) or between centers (par. 73) as for straight turning.

c. Proper Cutter Bits for Shoulder Turning. For turning the small diameter portion of the workpiece down to the desired size, a round-nose turning cutter bit (fig. 47) is preferred. The shoulder is finish turned to size using a facing cutter bit (fig. 47) if a square shoulder is required, or with a round-nose turning cutter bit if a fillet is required. The round-nose cutter bit may be specially ground to produce a special size fillet if necessary. A parting cutter bit (fig. 47) may be used at the shoulder location to mark the position of the shoulder and in some cases to provide an undercut or recess (fig. 82) if a bearing is to be carried on the shoulder.

d. Shoulder Turning Operation.

(1) The first important step in machining a shoulder is to locate the shoulder correctly. Usually, the position is marked by chalking the workpiece after it has been rough turned to the larger diameter and accurately indicating the shoulder location with hermaphrodite calipers (fig. 82).

(2) The small diameter portion of the workpiece is then turned down by a series of roughing cuts taken toward the shoulder. Take care to stop the traverse of the cutter bit about $\frac{1}{32}$ inch before it reaches the scribed line; this $\frac{1}{32}$ inch is important because it leaves sufficient metal on the shoulder to provide for facing operation after the smaller diameter portion has been turned to size.

(3) An alternate method of shoulder turning is to cut in at the shoulder mark with a parting cutter bit (fig. 47). If this is done, be sure the bit does not cut deeper than the required small diameter for square finished shoulders or deeper than the small diameter less the radius of the intended fillet if a filleted shoulder is required. However, if the shoulder is to carry a bearing, it may be desirable that an undercut or recess be left to assure good fit (fig. 82). The workpiece is then turned to size, stopping the traverse of the cutter bit at the recess.

(4) As in straight turning, the workpiece should be rough turned to within $\frac{1}{32}$ to $\frac{1}{64}$ inch of its finished diameter. The procedure described in (*a*) or (*b*) below should be followed for the finishing cut.

(*a*) *Filleted shoulder finish.* To finish a filleted shoulder, use longitudinal feed and turn the small diameter up to the shoulder with a roundnose turning cutter bit positioned as shown in figure 82. Engage the crossfeed and allow the bit to face the shoulder, moving outward from the axis.

(*b*) *Squared shoulder finish.* To finish a square shoulder, set the compound rest parallel to the ways of the lathe, and use a facing cutter bit to cut out the fillet left in the corner by the roughing bit. Using longitudinal feed, finish the small diameter up to the finished size of the shoulder. Lock the carriage and use the compound rest to feed the bit the

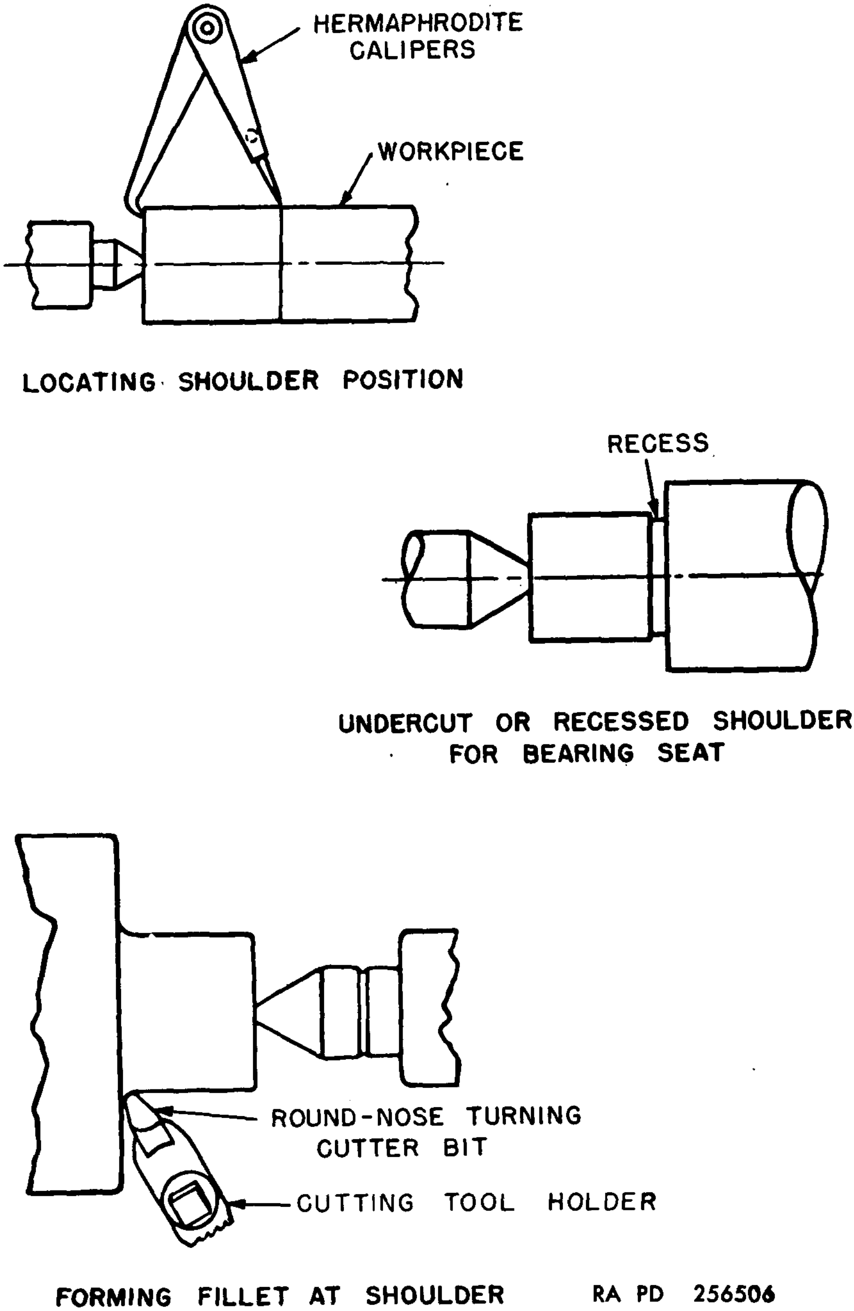


Figure 82. Location of shoulder position and types of shoulder formations.

additional amount necessary to finish the workpiece to the proper length. Engage the crossfeed to carry the bit away from the small diameter and face the shoulder.

83. Parting.

a. General. Parting is the procedure of cutting a piece of stock in two on the lathe. A parting cutter bit (fig. 47) is used for this operation and must be carefully ground to provide side clearances on both sides to prevent binding. Cutting oils should be used for most parting operations since the bit is subjected to greater heat due to the large cutting surface.

b. Mounting Workpieces for Parting. It is best to mount a workpiece to be parted in a chuck (par. 74), although parting can be accomplished between centers (par. 73) if the piece cannot be successfully chuck-mounted. Steady rests or follower rests (par. 69*c*) should be set up on each side of the parting cutter bit if the piece is between centers. For successful parting, the lathe spindle bearings must fit snugly and the cross slide and compound rest gibs should be taken up fairly tight to avoid lost motion.

c. Position of Parting Cutter Bit. The parting cutter bit should be positioned perpendicular to the axis of the workpiece with its cutting edge centered on the horizontal center line of the piece as in facing (fig. 80).

d. Parting Operation. The cutting speed for parting should be comparable to turning speeds, and the feed should be sufficient to keep a thin chip coming from the workpiece continuously. A power feed of approximately 0.002 inch per revolution may be used although it is sometimes advisable to feed by hand, thereby retaining control of the cutter bit in case of emergency. If too much pressure is applied on the crossfeed, the bit will gouge; if insufficient pressure is applied, the bit will chatter. When parting a workpiece mounted between centers, do not cut through completely with the parting cutter bit, but leave a small amount of stock and finish cutting with a hacksaw or chisel. If the workpiece is supported between centers and the bit is permitted to cut too far, the piece will bend and squeeze the bit, probably breaking the bit and damaging the piece. Except for the parting of cast iron and brass, a suitable cutting oil should be used.

84. Taper Turning

a. General. Taper turning is the process of machining a workpiece to a diameter which increases uniformly, thus forming a section of a cone. Tapers can be either external or internal; if a bar has a tapered outside diameter, it has an external taper; if the walls of a hole are tapered, the piece has an internal taper. External tapers can be turned on a lathe by setting over the tailstock spindle, by setting an angle on the compound rest, or by using a taper attachment if the lathe is so equipped. The method used depends on the length of taper, the angle of taper, and the number of pieces to be machined.

b. Characteristics of Tapers.

(1) The usual method of expressing the taper of a workpiece is in changes of the diameter in inches of diameter per foot of length. For example, if a piece of metal 1 foot long is 3 inches in diameter at one end and 1 inch in diameter at the other end, the taper is said to be 2 inches per foot.

(2) To determine the taper in inches per foot (tpf) of a workpiece, use the following formula:

$$\text{tpf} = \frac{D_1 - D_2}{L}$$

where, tpf = taper (in in. per ft);
D_1 = diameter (in in.) of workpiece at large end;
D_2 = diameter (in in.) of workpiece at small end;
L = length of taper (in ft) measured along centerline of workpiece.

For example a workpiece 3 feet long which is 4 inches in diameter at one end and 2 inches in diameter at the other end has a taper calculated as follows:

$$\text{tpf} = \frac{D_1 - D_2}{L} = \frac{4-2}{3} = \frac{2}{3} \text{ inch per foot.}$$

(3) Another means of expressing the taper is to specify the included angle between the sides of the workpiece (not the angle between a side and the centerline). The formula for calculating *one-half* of the angle is as follows:

$$\text{tangent } \propto = \frac{\text{tpf}}{24}$$

where, $\propto$ = one-half of included angle between sides;
tpf = taper (in inches per foot).

For example, a workpiece with a taper of 2/3 inch per foot has an included angle calculated as follows:

$$\text{tangent } \propto = \frac{\text{tpf}}{24} = \frac{2/3}{24} = \frac{2}{72} = 0.2778$$

The angle $\propto$ whose tangent is 0.2778 equals 81°35′, nearly; then, since angle $\propto$ is one half of the included angle, the included angle is equal to twice angle $\propto$ or 3° and 10′.

(4) Table XVI is provided to facilitate taper computations. Included angles for tapers between 1/16 inch per foot and 1 1/4 inches per foot are given in this table.

Table XVI. Taper Sizes and Angles

Taper (in. per ft.)	Included angle Deg.	Min.	Sec.	Difference in diameters for workpiece lengths 6 inches	12 inches	18 inches	24 inches
1/16	0	17	53	0. 03125	0. 0625	0. 09375	0. 125
3/32	0	26	52	0. 04688	0. 09375	0. 14063	0. 1875
1/8	0	35	47	0. 0625	0. 125	0. 1875	0. 25
5/32	0	44	45	0. 07813	0. 15625	0. 23438	0. 3125
3/16	0	53	44	0. 09375	0. 1875	0. 28125	0. 375
7/32	1	2	39	0. 10938	0. 21875	0. 32813	0. 4375
1/4	1	11	38	0. 125	0. 25	0. 375	0. 5
9/32	1	20	33	0. 14063	0. 28125	0. 42188	0. 5625
5/16	1	29	31	0. 15625	0. 3125	0. 46875	0. 625
11/32	1	38	30	0. 17188	0. 34375	0. 51563	0. 6875
3/8	1	47	25	0. 1875	0. 375	0. 5625	0. 75
13/32	1	56	24	0. 20313	0. 40625	0. 60938	0. 8125
7/16	2	5	18	0. 21875	0. 4375	0. 65625	0. 875
15/32	2	14	17	0. 23438	0. 46875	0. 70313	0. 9375
1/2	2	23	12	0. 25	0. 5	0. 75	1. 0
17/32	2	32	10	0. 26563	0. 53125	0. 79688	1. 0625
9/16	2	41	7	0. 28125	0. 5625	0. 84375	1. 125
19/32	2	50	4	0. 29688	0. 59375	0. 89063	1. 1875
5/8	2	59	3	0. 3125	0. 625	0. 9375	1. 25
21/32	3	7	57	0. 32813	0. 65625	0. 98438	1. 3125
11/16	3	16	56	0. 34375	0. 6875	1. 03125	1. 375
23/32	3	25	51	0. 35938	0. 71875	1. 07813	1. 4375
3/4	3	34	48	0. 375	0. 75	1. 125	1. 5
13/16	3	52	42	0. 40625	0. 8125	1. 21875	1. 625
7/8	4	10	32	0. 4375	0. 875	1. 3125	1. 75
15/16	4	28	26	0. 46875	0. 9375	1. 40625	1. 875
1	4	46	19	0. 5	1. 0	1. 5	2. 0
1 1/8	5	22	2	0. 5625	1. 125	1. 6875	2. 25
1 1/4	5	57	45	0. 625	1. 25	1. 875	2. 5

(5) Taper turning operations will often be the reproduction of widely used tapers such as the Morse standard tapers which are used for lathe and drill press spindles by most manufacturers, the Brown and Sharpe tapers which are commonly used for milling machine spindles and milling cutter shanks, and several other standard tapers. The Morse taper is approximately 5/8 inch per foot and the Brown and Sharpe taper is 1/2 inch per foot. Taper pins used in some assembly work have a taper of 1/4 inch per foot.

c. Taper Turning With the Tailstock Setover.

(1) Setting the tailstock out of alinement is a common method for turning a taper. This method is applicable only to comparatively slight tapers because the lathe centers do not have full bearing on the workpiece. Center holes are likely to wear out of their true positions if the bearing of the lathe centers is set over too far, causing poor results and damaging the lathe centers.

(2) The most difficult operation in taper turning by offsetting the tailstock is determining the proper distance the tailstock should be moved over to achieve the desired taper. Two factors affect the amount of tailstock setover; the taper per foot desired and the length of the workpiece. If the setover remains constant, pieces of different lengths will be machined with different tapers (fig. 83).

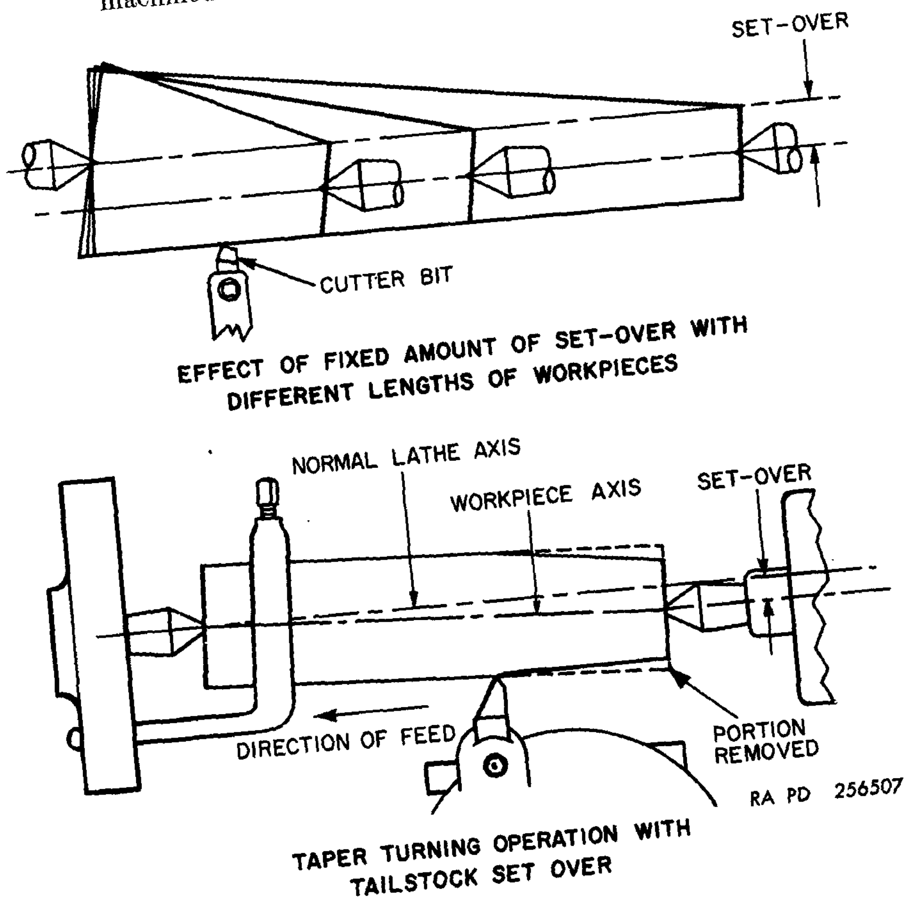


Figure 83. Taper turning with tailstock setover.

(a) The formula for calculating the correct setover for a given taper is as follows:

$$\text{setover}=\frac{\text{tpf}}{2}\times 2$$

where, setover=setover (in in.);
tpf=taper (in in. per ft);
L=length of taper (in ft) measured along center of workpiece.

For example, the amount of setover required to machine a bar 42 inches (3.5 ft) long with a taper of ½ inch per foot is calculated as follows:

$$\text{setover}=\frac{\text{tpf}}{2}\times L=\frac{\frac{1}{2}}{2}\times 3.5=\frac{3.5}{4}=0.875\text{ inch.}$$

Therefore, the tailstock should be set forward 0.875 inch.

(b) The formula for calculating the correct setover when diameters for each end of the workpiece are given instead of the taper is as follows:

$$\text{setover}=\frac{D_1-D_2}{2}\times\frac{L_2}{L_1}$$

where, setover=setover (in in.);
D_1=diameter (in in.) of workpiece at large end;
D_2=diameter (in in.) of workpiece at small end;
L_2=total length (in ft) of workpiece;
L_1=length of taper (in ft) measured along centerline of workpiece.

For example, the amount of setover required to machine a bar 36 inches (3 feet) in length for a distance of 18 inches (1.5 feet) when the diameter at one end is 1½ (1.500) inches and 1¾ (1.750) inches at the other is calculated as follows:

$$\text{setover}=\frac{D_1-D_2}{2}\times\frac{L_2}{L_1}=\frac{1.750-1.500}{2}\times\frac{3}{1.5}=\frac{0.250}{2}\times\frac{3}{1.5}=0.250\text{ inch.}$$

Therefore, the tailstock should be set forward 0.250 inch.

(3) Another important consideration in calculating the setover is the distance that the lathe centers enter the workpiece. The length of the workpiece (L_2 in formula in c(2)(b) above) should be considered as the distance between the points of the centers for the above computations. Therefore, if the centers enter the workpiece ⅛ inch on each end and the

length of the workpiece is 18 inches, subtract ¼ inch from 18 inches, and compute the setover of the tailstock using 17¾ inches as the length (L_2).

(4) To set the tailstock over, loosen the forward adjusting screw on the tailstock cricket and tighten the rear adjusting screw. Move the tailstock center to the headstock center (fig. 72) so that the distance of offset can be measured by a rule placed between the centers. Normally, the tailstock is set forward (fig. 83) of its alinement position which results in a taper with the small diameter at the tailstock end of the workpiece. If the small diameter is desired at the headstock end of the workpiece, set the tailstock rearward of its alinement position.

(5) To cut the taper, start the rough turning at the end which will be the small diameter and feed longitudinally toward the large end (fig. 83). If the tailstock is set over to the front, the feed will be from right to left; and the cutter bit, a right hand turning cutter bit or a round-nose turning cutter bit, should have its cutting edge exactly at the horizontal centerline of the workpiece, not above center as with straight turning.

d. Taper Turning With Compound Rest.

(1) One of the three commonly used methods for turning tapers on a lathe is by use of the compound rest. This method is especially suitable for turning or boring short, steep tapers, or bevels and is generally unsuitable for turning tapers greater than 2 to 3 inches in length because of the limited movement of the compound rest slide on most lathes.

(2) To machine a taper by this method, the compound rest is swiveled and locked at an angle which is one-half the included angle (*b*(3) above) of the taper, or the angle (angle α in formula in *b*(3) above) formed between one side of the taper and the axis. The cutter bit is then fed by turning the compound rest feed handle to move the tool along the axis of the compound rest.

(3) The angle of the taper must be known to set the compound rest. If the taper is given in taper inches per foot, the angle will have to be computed (*b*(3) above) or taken from table XVI. This angle will then have to be divided by two because only one-half of the angle must be set on the compound rest.

(4) The cutter bit should be set exactly on center for height. Turn the compound rest handle to move the compound rest near its right rear limit of travel to assure sufficient traverse of the compound rest slide to complete the taper. Bring the bit up to the workpiece by traversing and crossfeeding the

carriage. Lock the carriage to the lathe bed when the bit is in position. Cut from right to left, adjusting the depth of feed for each cut by moving the crossfeed handle. Feed the bit by hand, using the compound rest feed handle. Roughing and finishing cuts should be consistent with the practice prescribed for straight turning (par. 81).

e. Taper Turning With a Taper Attachment.

(1) The third method in general use for tapers turning in the lathe is by means of a taper attachment (fig. 84). Some engine lathes are equipped with a taper attachment as standard equipment, and most lathe manufacturers have a taper attachment available. Taper turning with a taper attachment although generally limited to a taper of 3 inches per foot and to a set length of 12 to 24 inches, affords the most accurate means for turning or boring tapers. The taper can be set directly on the taper attachment in inches per foot and on some attachments the taper can be set in degrees as well.

(2) A typical taper attachment for the lathe is illustrated on figure 84.

Note. Before using the taper attachment, the crossfeed screw must be disconnected by removing the crossfeed screw bolt.

A bed bracket attaches to the lathe bed and keeps the angle plate from moving to the left or right. The carriage bracket moves along the underside of the angle plate in a dovetail and keeps the angle plate from moving in or out on the bed bracket. The taper to be cut is set by placing the guide bar, which clamps to the angle plate, at an angle to the ways of the lathe bed. Graduations on one or both ends of the guide bar permit this adjustment without measurement being necessary. A sliding block which rides on a dovetail on the upper surface of the guide bar is secured, during operation, to the cross slide bar of the carriage, the crossfeed screw of the carriage being disconnected. Therefore, as the carriage is traversed during the feeding operation, the cross slide bar follows the guide bar, moving at the predetermined angle from the ways of the bed to cut the taper. It is not necessary to remove the taper attachment when straight turning is desired; the guide bar can be set parallel to the ways, or the clamp handle can be released permitting the sliding block to move without affecting the cross slide bar, and the crossfeed screw can be reengaged to permit power crossfeed and control of the cross slide from the apron of the carriage.

(3) The taper attachment gives very accurate results when the workpiece is mounted between centers because the lathe

centers have full bearing on the piece throughout the operation.

(4) A telescopic taper attachment which is similar to the plain attachment ((2) above), except that it is equipped with a telescopic crossfeed screw which eliminates the necessity of disconnecting the crossfeed screw, is sometimes used. To use the telescopic attachment, first set the cutting bit for the required diameter of the work and engage the attachment by tightening the binding screws. To change back to plain turning, it is necessary only to loosen the binding screws.

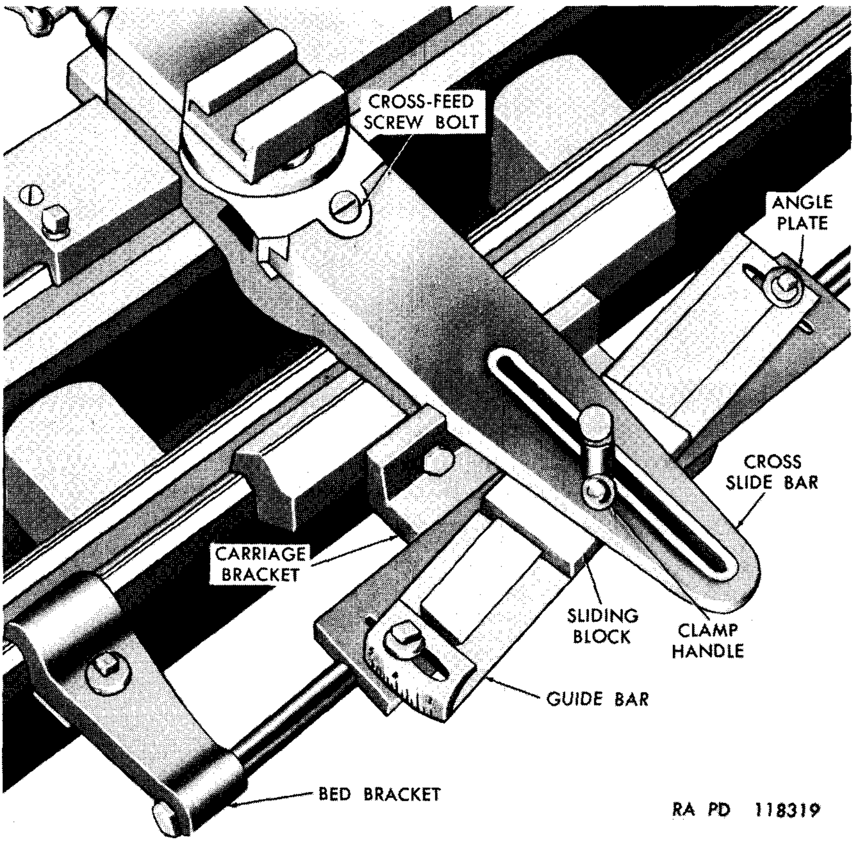


Figure 84. Typical lathe taper attachment.

(5) When cutting a taper using the taper attachment, the feed of the cut should be from the intended small diameter toward the intended large diameter. Cutting in this manner, the depth of cut is greater at the start of each cut and therefore can be better controlled to prevent damage to the cutter bit, workpiece, and lathe by forcing too deep a cut.

f. Checking Tapers for Accuracy.

(1) While the taper is being turned, it is good practice to stop the lathe after complete traverses of the cutter bit and measure the diameters at each end to determine that the taper is being cut to the required dimensions. An error in calculation must be discovered early because it may be too late for correction when the workpiece is completely rough turned. Also, lay a straightedge along one side of the taper to assure that the taper is uniform. Lack of uniformity can be caused by the presence of backlash in a taper attachment on byplay in the compound rest if the compound rest method is being used.

(2) After the taper is completed, it should be tested in a taper plug gage or taper socket gage. If no gage is available, the taper is should be tested in the hole it is to fit. To test the taper with a gage, mark the piece to be tested with chalk or Prussian blue pigment, insert it snugly into the gage, and turn it through one whole revolution. If the marks on the workpiece have been rubbed evenly, the taper is correct; if they have been rubbed off at only one end, the fit is inaccurate and the taper has been cut incorrectly. To test an internal taper, the procedure is identical except the gage should be marked instead of the workpiece.

85. Screw Thread Cutting

a. General. A screw thread is a helical projection of uniform section on the internal or external surface of a cylinder or cone. Threads may be formed on the lathe by use of taps and dies (par. 93) or by cutting them with the thread cutting mechanisms of the lathe. Cutting screw threads is among the most common of lathe operations. Before attempting such operations, however, the operator should have some familiarity with the fundamental principles of threads and the types generally in use.

b. Screw Thread Terminology (fig. 85). The common terms and definitions below are used in calculating screw threads and will be used in discussing threads and thread cutting.

(1) *External or male thread.* A thread on the outside of a cylinder or cone.

(2) *Internal or female thread.* A thread on the inside of a hollow cylinder or bore.

(3) *Pitch.* The distance from a given point on one thread to a similar point on a thread next to it, measured parallel to the axis of the cylinder. The pitch in inches is equal to one divided by the number of threads per inch.

(4) *Lead.* The distance a screw thread advances axially in one complete revolution. On a single-thread screw, the lead is

equal to the pitch ((3) above). On a double-thread screw the lead is equal to twice the pitch, and on a triple-thread screw, the lead is equal to three times the pitch.

(5) *Crest (also called "flat").* The top or outer surface of the thread joining the two sides.

(6) *Root.* The bottom or inner surface joining the sides of two adjacent threads.

(7) *Side.* The side of a thread is the surface which connects the crest and the root.

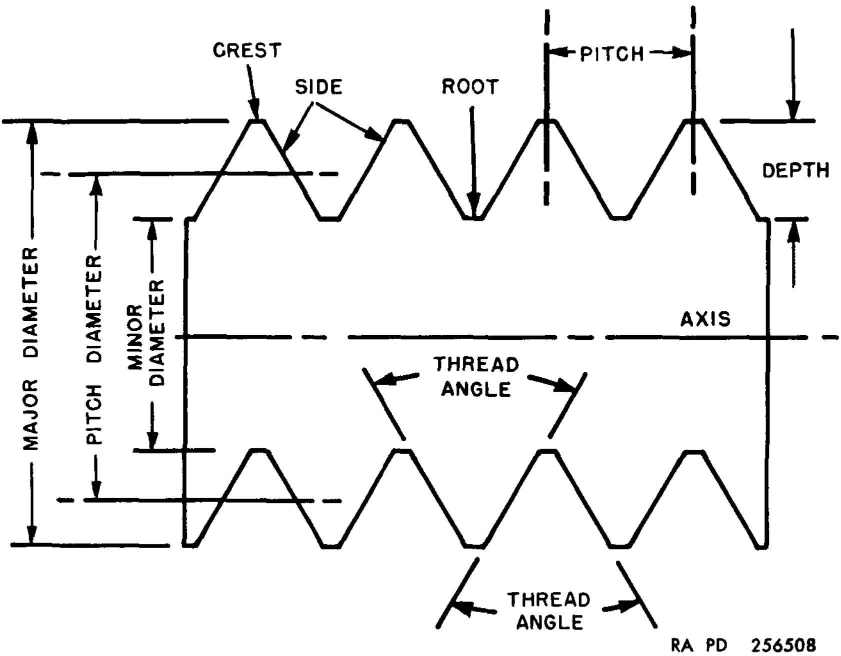


Figure 85. Terms applied to screw threads.

(8) *Thread angle.* The angle included between the sides of adjacent threads, measured in an axial plane. For most V-threads, the angle is fixed at 60°.

(9) *Depth.* The depth of a thread is the distance between the crest and root of a thread, measured perpendicular to the axis.

(10) *Major diameter.* The major diameter is the largest diameter of a screw thread.

(11) *Minor diameter.* The minor diameter is the smallest diameter of a screw thread.

(12) *Pitch diameter.* The pitch diameter is the diameter of an imaginary cylinder, the surface of which would pass through the threads at such points to equalize the widths of the threads and spaces cut by the surface of the cylinder.

c. Screw Thread Forms. The most commonly used screw thread forms are discussed below. Of these threads, the unified screw thread and the American (National) Standard thread are the most widely required for locking devices. The Acme, square, and 29° worm threads are most common for devices which function to transmit motion.

(1) *Unified screw thread* (fig. 86). The unified screw thread is the newest of standard thread forms, being acceptable for interchangeable parts by the United States, Great Britain, and Canada. The unified thread is a variation of the American (National) Standard thread form, having an included thread angle of 60°. On external threads of the unified form, the root is rounded and the crest is optionally rounded or left flat; in the United States, the flat crest is preferred. The internal thread of the unified form is like the American (National) thread form but is not cut as deep, leaving a crest of one-fourth the pitch instead of one-eighth the pitch. The pitches, basic dimensions, and tolerances for sizes ¼ inch and larger are basically the same for the unified and American (National) thread forms. The coarse thread series of the unified system is designated UNC and the fine thread series UNF.

(2) *American (National) Standard thread* (fig. 86).

(*a*) The American (National) Standard thread form is the most commonly used thread form in the United States. It is a modification of the 60° sharp V-thread, having its crest and root flattened, the flats produced being equal to one-eighth the pitch of the screw. This form has a locking capacity similar to the old sharp V-thread but will stand greater abuse without damage, having no sharp angles.

(*b*) The American National Standard thread form is used in five series of pitches as follows:

National Fine (NF) (formerly the SAE Standard screw thread).
National 8-Pitch.
National 12-Pitch.
National 16-Pitch.
National Coarse (NC) (formerly the USS screw thread).

In the coarse and fine series, the number of threads per inch decreases as the diameters increase. These series are intended for general use. Eight-pitch is used for bolts, cylinder head studs, high-pressure pipe flanges, and so on. Twelve-pitch is used in modern machine and boiler con-

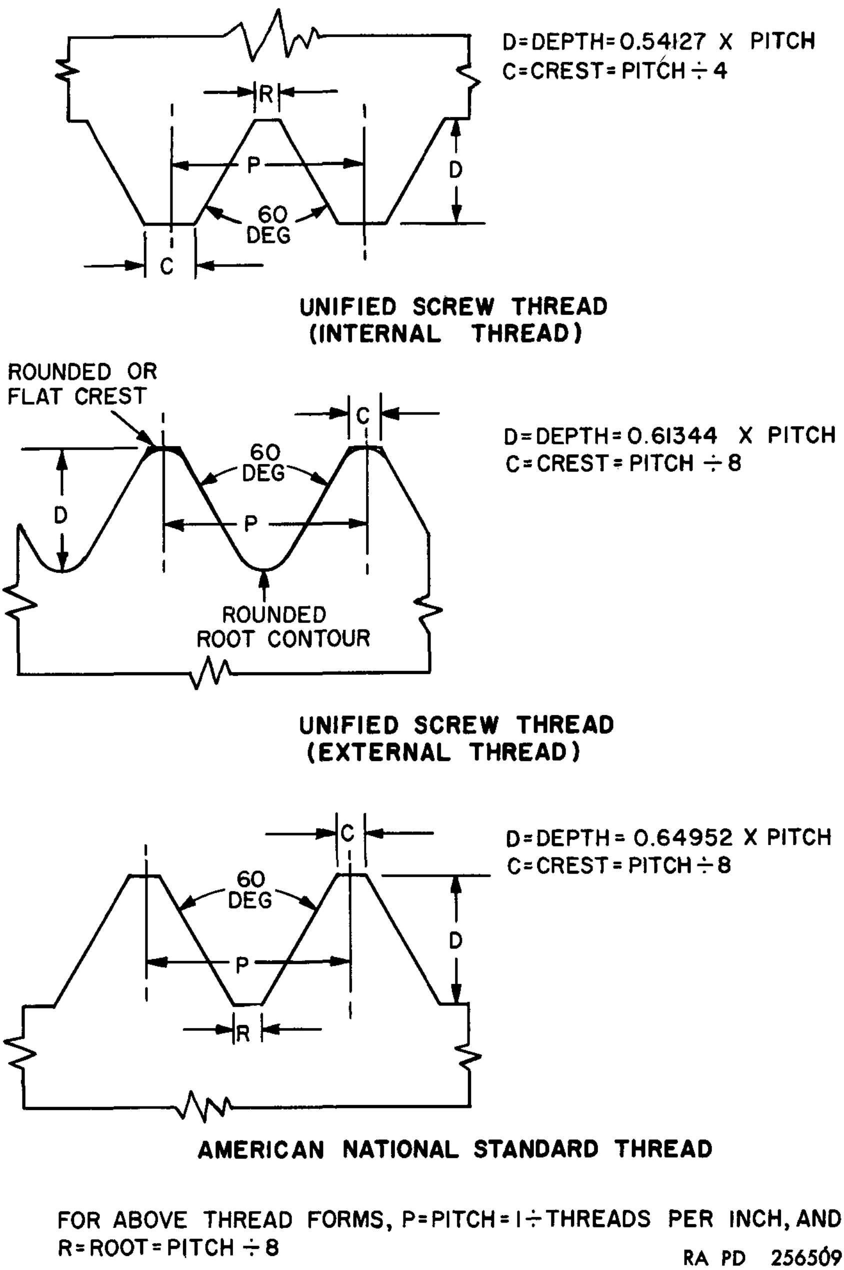


Figure 86. General form dimensions for unified and American (National) Standard screw threads.

struction for thin nuts, shafts, and sleeves. Sixteen-pitch is intended for adjusting collars, bearing retaining nuts, or any part requiring a fine thread.

(c) Table XVII lists the general dimensions for the American (National) Standard Screw Thread, both the National Coarse series and the National Fine series of pitches. These figures are basic and do not account for different classes of fit, tolerances, and allowances (*d* below).

Table XVII. General Dimensions of American (National) Standard Screw Thread

Size	Threads per inch	Major diameter (in.)	Pitch diameter (in.)	Minor diameter (in.)
National Coarse (NC) Series				
No. 1 (0.073)	64	0. 0730	0. 0629	0. 0527
No. 2 (0.086)	56	0. 0860	0. 0744	0. 0628
No. 3 (0.099)	48	0. 0990	0. 0855	0. 0719
No. 4 (0.112)	40	0. 1120	0. 0958	0. 0795
No. 5 (0.125)	40	0. 1250	0. 1088	0. 0925
No. 6 (0.138)	32	0. 1380	0. 1177	0. 0974
No. 8 (0.164)	32	0. 1640	0. 1437	0. 1234
No. 10 (0.190)	24	0. 1900	0. 1629	0. 1359
No. 12 (0.216)	24	0. 2160	0. 1889	0. 1619
¼	20	0. 2500	0. 2175	0. 1850
5/16	18	0. 3125	0. 2764	0. 2403
⅜	16	0. 3750	0. 3344	0. 2938
7/16	14	0. 4375	0. 3911	0. 3447
½	13	0. 5000	0. 4500	0. 4001
9/16	12	0. 5625	0. 5084	0. 4542
⅝	11	0. 6250	0. 5660	0. 5069
¾	10	0. 7500	0. 6850	0. 6201
⅞	9	0. 8750	0. 8028	0. 7307
1	8	1. 0000	0. 9188	0. 8376
1⅛	7	1. 1250	1. 0322	0. 9394
1¼	7	1. 2500	1. 1572	1. 0644
1⅜	6	1. 3750	1. 2667	1. 1585
1½	6	1. 5000	1. 3917	1. 2835
1¾	5	1. 7500	1. 6201	1. 4902
2	4½	2. 0000	1. 8557	1. 7113
2¼	4½	2. 2500	2. 1057	1. 9613
2½	4	2. 5000	2. 3376	2. 1752
2¾	4	2. 7500	2. 5876	2. 4252
3	4	3. 0000	2. 8376	2. 6752
3¼	4	3. 2500	3. 0876	2. 9252
3½	4	3. 5000	3. 3376	3. 1752
3¾	4	3. 7500	3. 5876	3. 4252
4	4	4. 0000	3. 8376	3. 6752

Table XVII. General Dimensions of American (National) Standard Screw Thread—Continued

Size	Threads per inch	Major diameter (in.)	Pitch diameter (in.)	Minor diameter (in.)
National Fine (NF) Series				
No. 0 (0.060)	80	0. 0600	0. 0519	0. 0438
No. 1 (0.073)	72	0. 0730	0. 0640	0. 0550
No. 2 (0.086)	64	0. 0860	0. 0759	0. 0657
No. 3 (0.099)	56	0. 0990	0. 0874	0. 0758
No. 4 (0.112)	48	0. 1120	0. 0985	0. 0849
No. 5 (0.125)	44	0. 1250	0. 1102	0. 0955
No. 6 (0.138)	40	0. 1380	0. 1218	0. 1055
No. 8 (0.164)	36	0. 1640	0. 1460	0. 1279
No. 10 (0.190)	32	0. 1900	0. 1697	0. 1494
No. 12 (0.216)	28	0. 2160	0. 1928	0. 1696
1/4	28	0. 2500	0. 2268	0. 2036
5/16	24	0. 3125	0. 2854	0. 2584
3/8	24	0. 3750	0. 3479	0. 3209
7/16	20	0. 4375	0. 4050	0. 3725
1/2	20	0. 5000	0. 4675	0. 4350
9/16	18	0. 5625	0. 5264	0. 4903
5/8	18	0. 6250	0. 5889	0. 5528
3/4	16	0. 7500	0. 7094	0. 6688
7/8	14	0. 8750	0. 8286	0. 7822
1	14	1. 0000	0. 9536	0. 9072
1 1/8	12	1. 1250	1. 0709	1. 0167
1 1/4	12	1. 2500	1. 1959	1. 1417
1 3/8	12	1. 3750	1. 3209	1. 2667
1 1/2	12	1. 5000	1. 4459	1. 3917

(3) *SAE extra fine threads.* The SAE Extra Fine Thread Series has many more threads per inch for given diameters than any series of the American (National) Standard ((2) above). The form of thread is the same as the American (National) Standard. These small threads are used in thin metal where the length of thread engagement is small, in cases where close adjustment is required, and where vibration is great. It is designated EF (Extra Fine).

(4) *Acme screw thread* (fig. 87). The Acme screw thread form is classified as a power-transmitting type of thread. This is because the 29° included thread angle at which its sides are established reduces the amount of friction when matching parts are under load. Because the root and crest are wide, this thread form is strong and capable of carrying a heavy load. The Acme thread form is especially suitable for lathe lead screws and similar power transmitting uses.

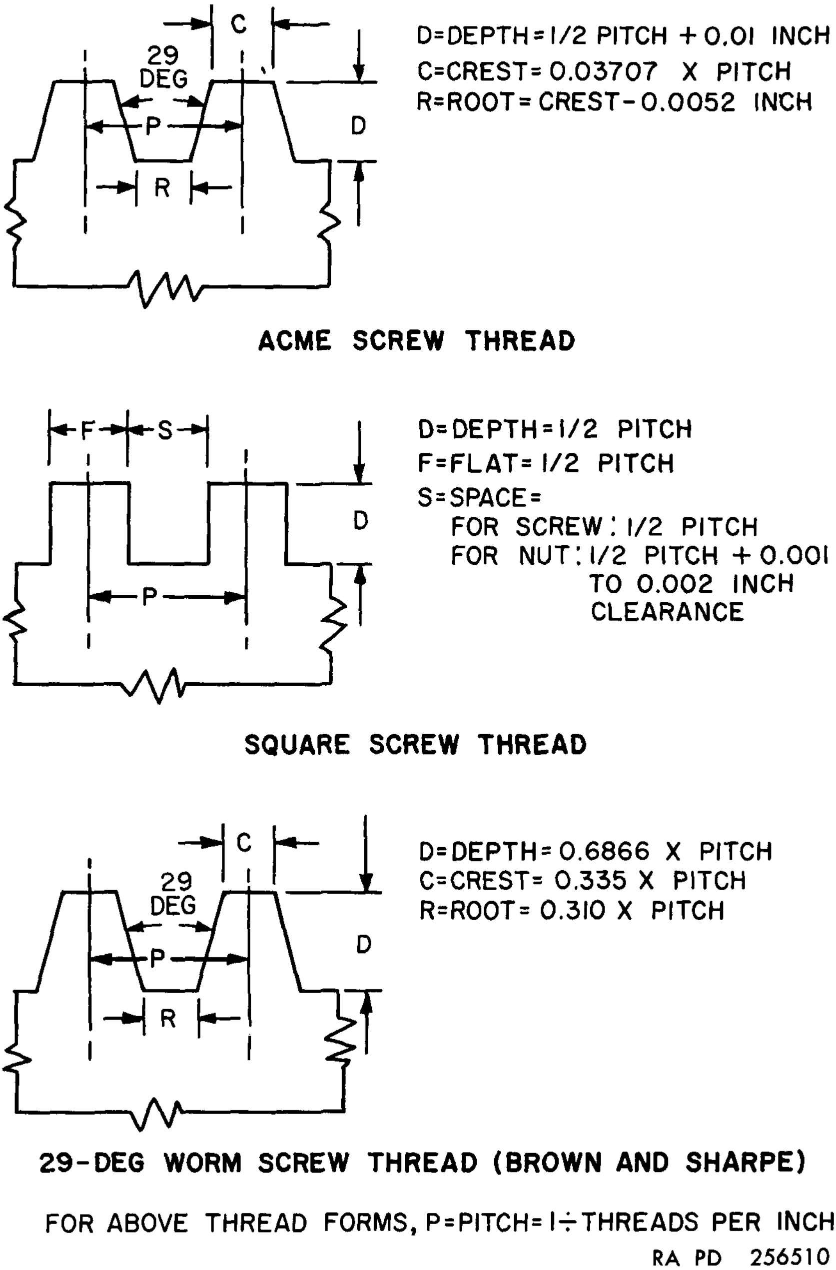


Figure 87. General form dimensions for Acme, square, and 29° worm screw thread forms.

(5) *Twenty-nine-degree worm screw thread* (fig. 87). The 29° worm screw thread and the Acme thread are similar in that they both have an included thread angle of 29°. However, these thread forms should not be confused since they are different in depth of thread and width of crest and root.

(6) *Square screw thread* (fig. 87). Because of their design and strength, square screw threads are used for vise screws, jack screws, and other devices where maximum transmission of power is needed. All surfaces of the square thread are square with each other and the sides are perpendicular to the center axis of the threaded part. Because the contact areas are relatively small and do not wedge, friction between matching threads is reduced to a minimum under heavy pressure.

d. Thread Fit and Designations.

(1) *Thread fit.*

(*a*) The Unified and American (National) Standard thread forms designate classifications for fit to insure that mated threaded parts fit to the tolerances specified.

(*b*) The Unified screw thread form specifies several classes of threads which are classes 1A, 2A, and 3A for screws or external threaded parts, and 1B, 2B, and 3B for nuts or internal threaded parts. Classes 1A and 1B are for a loose fit where quick assembly and rapid production are important and shake or play is not objectionable. Classes 2A and 2B provide a small amount of play to prevent galling and seizure in assembly and use, and sufficient clearance for some plating; classes 2A and 2B are recommended for standard practice in making commercial screws, bolts, and nuts. Classes 3A and 3B have no allowance and 75 percent of the tolerance of classes 2A and 2B. A screw and nut in this class may vary from a fit having no play to one with a small amount of play. Only high grade products are held to class 3 specifications.

(*c*) Four distinct classes of screw thread fits between mating threads (as between bolt and nut) have been designated for the American (National) Standard screw thread form. Fit is defined as "the relation between two mating parts with reference to ease of assembly." These four fits are produced by the application of tolerances which are listed in the standards. The four fits are described as follows:

1. Class 1 fit. This fit is recommended only for screw thread work where clearance between mating parts is essential for rapid assembly and where shake or play is not objectionable.

2. Class 2 fit. This fit represents a high quality of commercial thread product, and is recommended for the great bulk of interchangeable screw thread work.

3. Class 3 fit. This fit represents an exceptionally high quality of commercially threaded product and is recommended only in cases where the high cost of precision tools and continual checking are warranted.

4. Class 4 fit. This fit is intended to meet very unusual requirements more exacing than those for which class 3 is intended. It is a selective fit if initial assembly by hand is required. It is not, as yet, adaptable to quantity production.

(2) *Thread designations.* In general, screw thread designations give the screw number (or diameter) first, then the initial letters of the series, NC (National Coarse), UNF (Unified Fine), NS (National Special), etc., followed by the class of fit. If a thread is left hand, the letters L. H. follow the fit. Examples of designations are as follows:

(*a*) No. 10 (0.190)–24NC–3—This is a number 10 (0.190-in. dia) thread, 24 National Coarse threads per inch, and a class 3 fit.

(*b*) ¼–28UNF–2A L. H.—This is a ¼-inch diameter thread, 28 Unified Fine threads per inch, left hand thread, and a class 2A fit.

(*c*) 0.205–26NS–2—This is a 0.205-inch diameter, 26 National Special threads per inch, and a class 2 fit.

e. Thread Cutter Bits and Cutters.

(1) The basic forms of thread cutting bits and cutters are described in paragraph 62*e*(7) and *f*(2).

(2) It should be noted that these tools as mentioned are intended for cutting sharp V-threads with a 60° thread angle. For cutting threads to the Unified or American (National) Standard forms, it is necessary to grind the point of the cutter bit to the shape of the thread root. In the case of the American (National) Standard thread, a flat should be carefully ground at the point of the bit, perpendicular to the center line of the 60° thread angle. For the Unified thread, the end of the bit should be ground with the required radius for external threads or the required flat for internal threads. In both cases, the tool should be ground to the angle specified by the pitch of the thread.

(3) For Acme and 29° wormscrew threads, the cutter bit must be ground to form a point angle of 29°. Side clearances must be sufficient to prevent rubbing on threads of steep pitch. The end of the bit is then ground to a flat which

agrees with the width of the root for the specific pitch being cut. Thread cutting tool gages (fig. 88) are available to simplify the procedure and make computations unnecessary.

(4) To cut square threads, a special thread cutter bit is required.

(*a*) Before the square thread cutter bit can be ground it is necessary to compute the helix angle of the thread to be cut (fig. 89). Compute the helix angle by drawing a line equal in length to the thread circumference at its minor diameter (this is accomplished by multiplying the minor

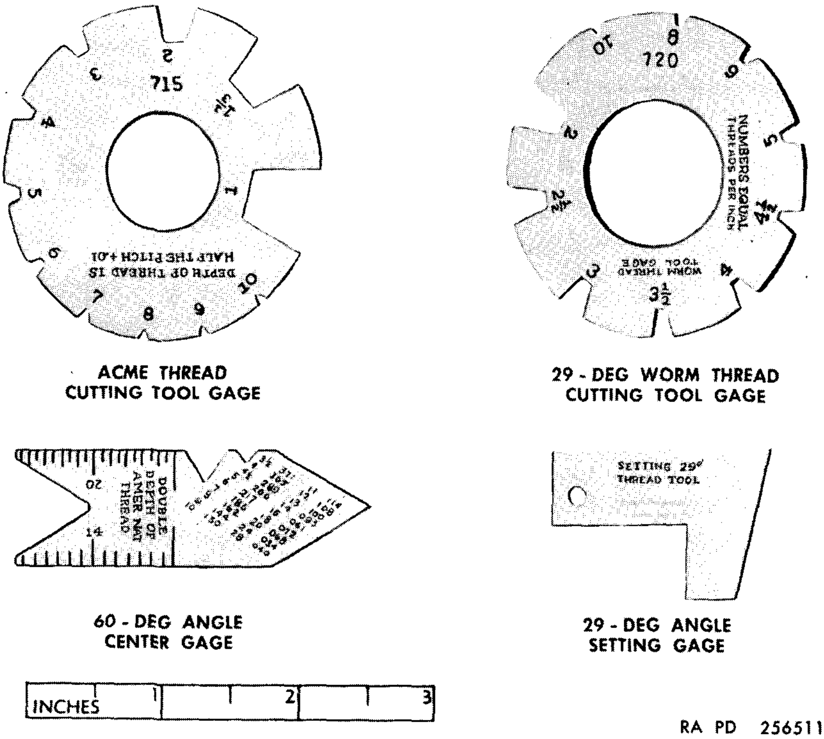


Figure 88. Thread cutting tool gages.

diameter by 3.1416 (*pi*)). Next draw a line perpendicular to and at one end of the first line, equal in length to the lead of the thread. If the screw is to have a single thread, the lead will be equal to the pitch (*b*(3) above). Connect the ends of the angle so formed to obtain the helix angle.

(*b*) The tool bit should be ground to the helix angle (fig. 89) and the clearance angles for the sides should be within the helix angle. Note that the sides are also ground in toward the shank to provide additional clearance.

(c) The end of the tool (fig. 89) should be ground flat, the flat being equal to one-half the pitch of the thread to produce equal flats and spaces on the threaded part.

f. Position of Thread Cutter Bit for Use.

(1) The thread cutter bit must be placed exactly on line horizontally with the axis of the workpiece. This is especially important for thread cutter bits since a slight variation in the vertical position of the bit will change the thread angle being cut.

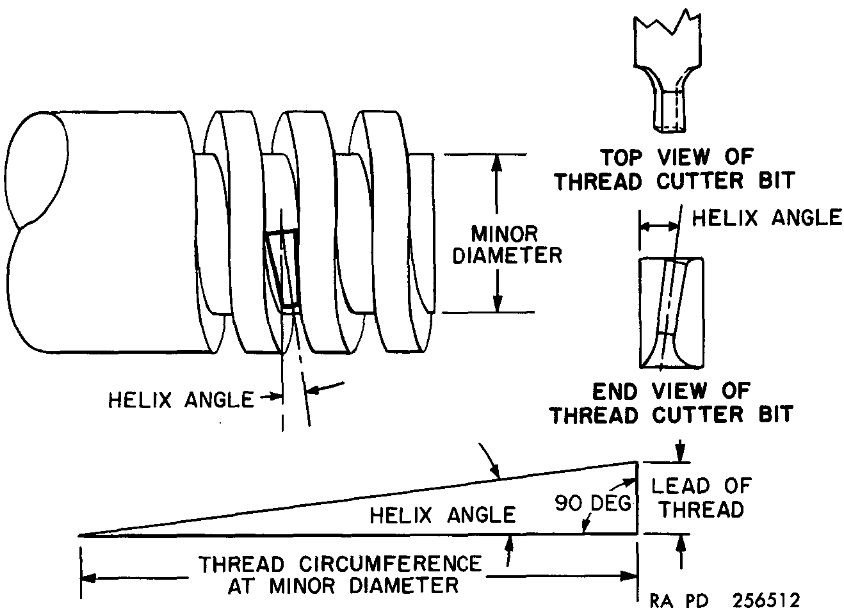
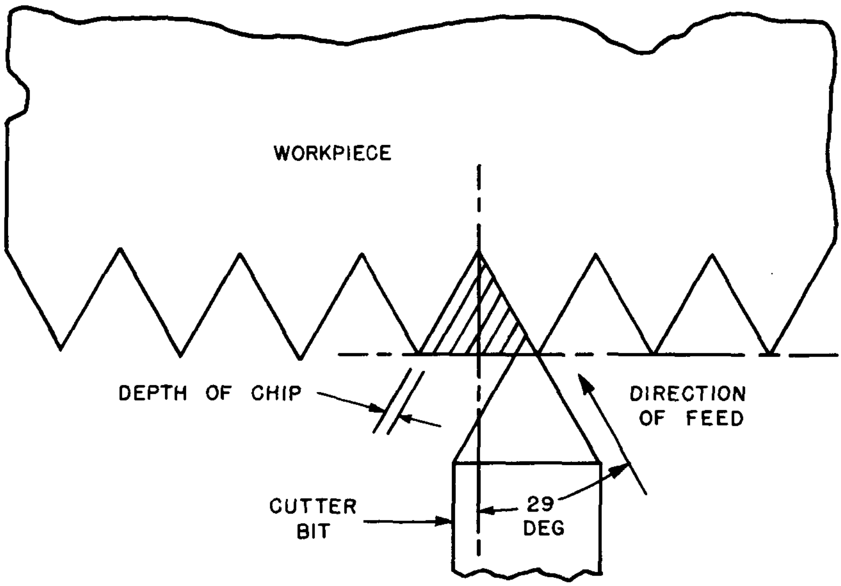


Figure 89. Thread cutter bit for square threads.

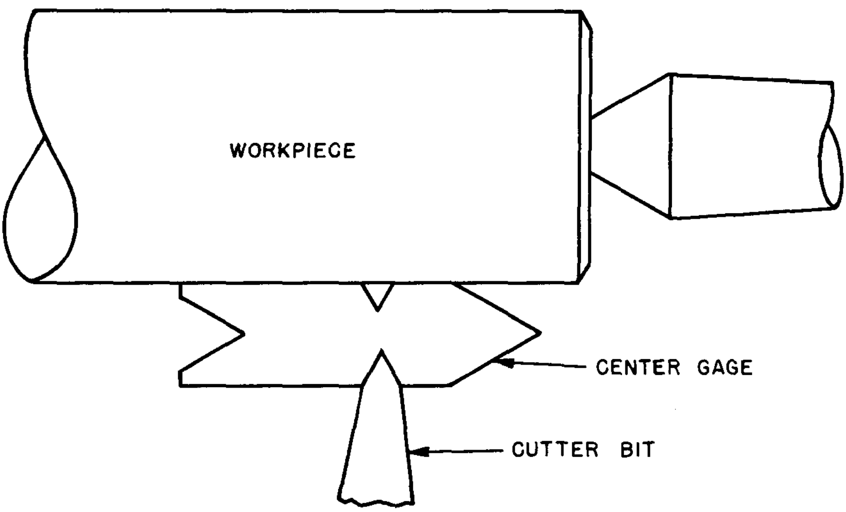
(2) The thread cutter bit must be positioned so that the centerline of the thread angle ground on the bit is exactly perpendicular to the axis of the workpiece. The easiest way to make this alinement is by use of a center gage (fig. 88). The center gage will permit checking the point angle at the same time as the alinement is being effected. The center gage is placed against the workpiece, and the cutter bit is adjusted on the tool post so that its point fits snugly in the 60° angle notch of the center gage (fig. 90).

g. Setting Lathe Thread Cutting Mechanism for Proper Feed.

(1) *General.* In cutting threads on a lathe, the pitch of the thread or number of threads per inch obtained is determined by the speed ratio of the headstock spindle and the lead screw which drives the carriage. Lathes equipped for



THREAD CUTTING WITH COMPOUND REST SET AT 29-DEGREE ANGLE



USING CENTER GAGE TO SET CUTTER BIT

RA PD 256513

Figure 90. Setting up cutter bit for thread cutting operation.

thread cutting have gear arrangements for varying the speed of the lead screw. Most modern lathes have a quick-change gear box for varying the lead screw to spindle ratio, but many older lathes, modern inexpensive lathes, and special types of lathes come equipped with standard change gears which must be arranged by computation to achieve the desired speed ratio.

(2) *Quick-change gear box.* For lathes equipped with quick-change gear boxes, the operator need only follow the instructions on the direction plates of the lathe to set the proper feed to produce the desired number of threads per inch. Once set to a specific number of threads per inch, the spindle speed can be varied depending upon the material being cut and the size of the workpiece, without affecting the threads per inch.

(3) *Standard-change gears.* Lathes equipped with standard-change gears require that the operator be familiar with the methods of selecting the proper gears to produce the desired thread pitch in case the manufacturer-supplied gear tables are missing. On most lathes with standard-change gears, the gears may be arranged in a simple gear train or in a compound gear train.

(*a*) *Simple gear train* (fig. 91).

1. The basic gears which control the ratio between spindle speed and lead screw speed are the stud gear and the lead screw gear. The stud gear mounts to a shaft which revolves at the same speed as the spindle and therefore can be considered in this discussion as representing spindle speed in revolutions per minute. The lead screw gear is usually connected directly to the lead screw and therefore moves at the same speed as the lead screw. In a simple gear train, the stud gear and the

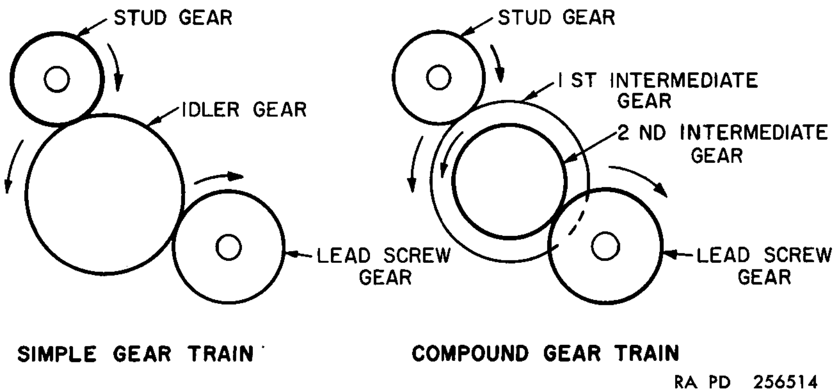


Figure 91. Simple and compound gear trains.

lead screw are meshed together or coupled by an idler gear. If the idler gear is used, it can be of any size or number of teeth convenient for coupling since it only transmits motion from one gear to the other and does not affect the ratio of the stud or lead screw gears.

2. The threads per inch of the lead screw must be known to compute the gearing for a specific ratio. The rule for determining the number of teeth of the stud gear and lead screw gear for a simple gear train is as follows: Multiply the number of threads per inch of the lead screw and the number of threads to be cut by a common number. The products will be the number of teeth that the stud gear and lead screw gear should have respectively. For example, suppose that a machinist wants to cut a screw with 10 threads per inch on a lathe having a lead screw with 4 threads per inch. The procedure would be to multiply 10 and 4 by any convenient number, say 6. Then, $6\times4=24$ and $6\times10=60$. The stud gear should have 24 teeth and the lead screw gear should have 60 teeth to produce the desired ratio to cut 10 threads per inch. If gears of 24 and 60 teeth are not available, multiply 10 and 4 by another number until the products coincide with the number of teeth on available gears.

3. Whenever the thread to be cut is finer than the thread of the lead screw, the gear with the fewest teeth will be the stud gear. If the thread to be cut is coarser than the lead screw, the gear with the fewest teeth will be the lead screw gear.

(*b*) *Compound gear train* (fig. 91).

1. If the proper ratio between spindle and lead screw cannot be obtained by simple gearing, a compound gear train must be used. For example, if it is desired to cut 80 threads per inch with a lead screw having 8 threads per inch, and the smallest change gear available has 24 teeth, the lead screw gear must have 240 teeth which would be too large in diameter to fit the lathe. By compounding the gears, it would be possible to cut 80 threads per inch with the gears generally available.

2. In the compound gear train, two intermediate gears replace the idler gear of the simple gear train. The intermediate gears are mounted to the same shaft and are keyed together. The gear driven by the stud gear is known as the first intermediate gear and the gear that drives the lead screw gear is known as the second intermediate gear. An idler gear can be used if necessary in this gear train, but will reverse the direction of the lead screw gear, and make reversal of the stud gear-to-spindle connection necessary.

3. To compute compound gear arrangements, the following rule should be applied: Establish the ratio between the number of threads per inch to be cut and the number of threads per inch of the lead screw. Factor each term of the ratio, that is, determine two numbers for each term which, when multiplied by each other, result in the number of the ratio term. The resulting four numbers when each are multiplied by a convenient number will be the number of teeth in the four gears, the stud gear and second intermediate gear representing the smaller term, and the first intermediate gear and lead screw gear representing the larger term of the ratio. For example, to cut 80 threads per inch with a lathe having a lead screw of 8 threads per inch, the ratio would be 8:80 (8 units to 80 units). Factoring each term, $8=2\times4$ (factors), and $80=8\times10$ (factors). Then multiplying 2, 4, 8, and 10 each by a convenient number, say 12, the result is the ratio, $24\times48:96\times120$. The gearing then must be:

Stud gear	24 teeth
First intermediate gear	96 teeth
Second intermediate gear	48 teeth
Lead screw gear	120 teeth

(4) *Engaging the feed.* The carriage is connected to the lead screw of the lathe for threading operations by engaging the half nut on the carriage apron with the lead screw. A control is available to reverse the direction of the lead screw, and it should be determined that the screw turns in the desired direction, for left or right hand threading as desired. Feed the cutter bit from right to left to produce a right hand thread. Feed the cutter bit from left to right to produce a left hand thread.

h. Direction of Feed.

(1) For standard 60° threads of the sharp V-type, the American (National) Standard form and the Unified form, the cutter bit should be moved in at an angle of 29° (fig. 90) so that the left side of the bit does most of the cutting and a free curling chip may result. The direction is controlled by setting the compound rest at the 29° angle before adjusting the cutter bit perpendicular to the workpiece axis. The depth of cut is then controlled by the compound rest feed handle.

(2) For Acme, 29° worm, and square threads, the cutter bit is fed into the workpiece at an angle perpendicular to the workpiece axis.

i. Threading Cutting Operation.

(1) Before cutting threads, turn down the workpiece to the major diameter of the thread to be cut. The workpiece may be set up in a chuck (par. 74) or between centers (par. 73). If a long thread is to be cut, it is advisable to use a center rest because thread cutting can place a great strain on the workpiece.

(2) The usual practice in cutting threads is to take a very light initial cut and then check to see that the lathe has been geared correctly for the right number of threads per inch. If it is correctly geared, continue taking cuts until the thread reaches the depth wanted; in the case of Unified and American (National) Standard threads, this is determined by measuring the crest of the thread and in the case of sharp V-threads, when the thread becomes pointed.

(3) After each pass of the cutter bit, the operator must move the bit out of engagement with the thread being cut, and traverse the carriage and bit back to the beginning of the thread. At the end of each cut, the half nuts are usually disconnected and the carriage returned to position of the next cut by hand. Some device must be provided, therefore, to engage the half nuts for the following cut at a point on the lead screw which will cause the cutter bit to follow the previous cut. If such a device is not available, it is necessary to leave the half nuts engaged at the end of the cut and return the cutter bit by reversing the feed.

(4) The usual device for accomplishing correct alinement of the cutter bit after the half nuts have been disengaged is the thread chasing dial (fig. 92). This device is supplied as standard or optional equipment on all screw cutting lathes. It consists of a worm wheel which meshes with the lead screw, a dial, and a short shaft connecting the worm wheel to the dial. It is usually mounted to the right side of the carriage apron. The dial is calibrated with four numbered lines and four unnumbered lines between them. To use the thread chasing dial, engage the half nuts when the dial is alined for the particular number of threads per inch being cut. If the number of threads per inch is an *even number*, the half nuts can be reengaged for following cuts when *any line* on the dial is opposite the index. When cutting odd numbered threads, the half nuts can be reengaged where

any numbered line is opposite the index. To cut all threads having *a half a thread per inch* (such as 11½ threads per in.), the half nuts can be reengaged when *any odd numbered* line is opposite the index.

(5) Some lathes are equipped with a thread chasing stop bolted to the carriage which can be set to regulate the depth of cut for each traverse of the cutter bit or can be set to regulate the total depth of cut of the thread.

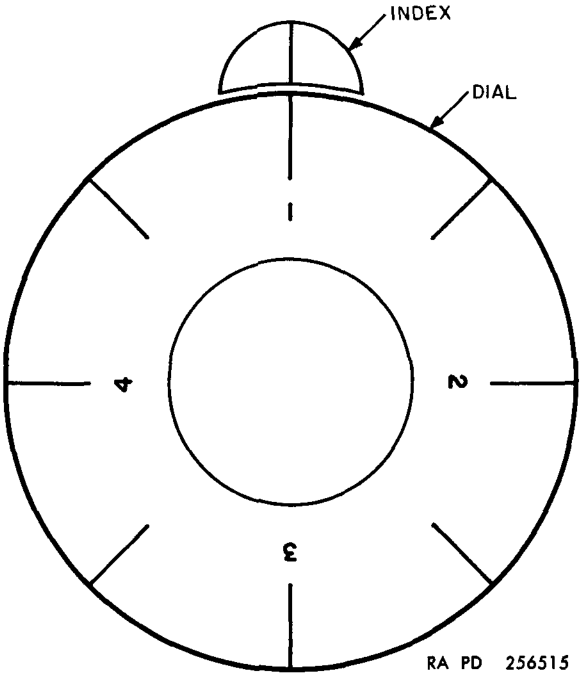


Figure 92. Thread chasing dial.

(6) When the thread is cut, the end must be finished in some way. The most common means of finishing the end is with a specially ground or 45-degree angle chamfer cutting bit (fig. 93). To produce a rounded end, a cutter bit with the desired shape should be specially ground for that purpose.

j. Taper Screw Threads. Taper screw threads or pipe threads can be cut on the lathe by setting the tailstock over or by using a taper attachment (par. 84*e*). For the National Taper Pipe thread form, the taper is ¾-inch per foot. Refer to table VIII for threads per inch and nominal measurements for this thread form.

Note. In cutting a taper thread, the cutter bit should be set at right angles to the axis of the workpiece. Do not set the thread cutter bit at right angles to the taper of the thread.

Check the thread cutter bit carefully for clearances before cutting since the bit will not be entering the workpiece at right angles to the tapered workpiece surface.

k. Thread Measurement.

(1) The pitch of the threaded part must often be measured with close accuracy. A machinist's steel rule or a screw pitch gage is convenient for determining the pitch of any thread. When measuring with a machinist's steel rule (fig. 94), do not count the thread at the end of the rule. Count the number of threads in 1 inch, or if a thread does not coincide with the inch mark, count the number of threads in 2 inches and divide by 2 to determine the threads per inch. When using the screw pitch gage (fig. 94), select a gage that fits the threads to be measured exactly. The pitch or thread per inch can be read directly from the gage.

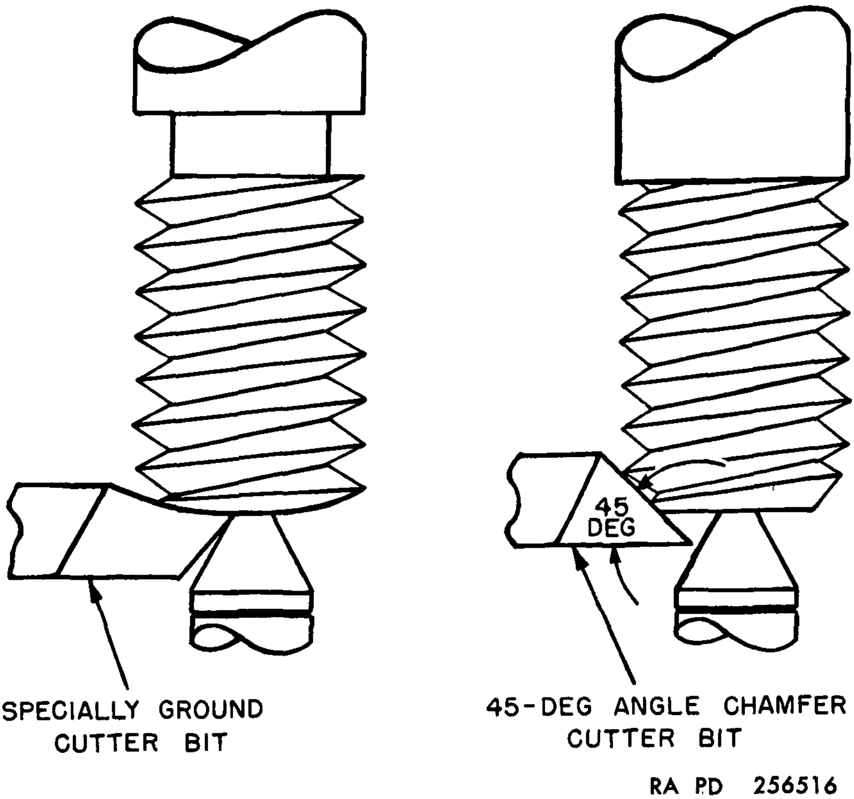


Figure 93. Two methods of finishing ends of threads.

(2) The measurement of thread angles and pitch diameters is somewhat more involved but equally necessary if accurate fits are to be obtained. The simplest way to check the

accuracy of a screw thread is to try it in the part which it is to fit. If this is impractical, a plug thread gage or a ring thread gage, if available, can be used to test the internally or externally threaded part. The ring or plug gage must be accurately machined and should be of the exact requirements of the part being tested in diameter, threads per inch, and class of fit.

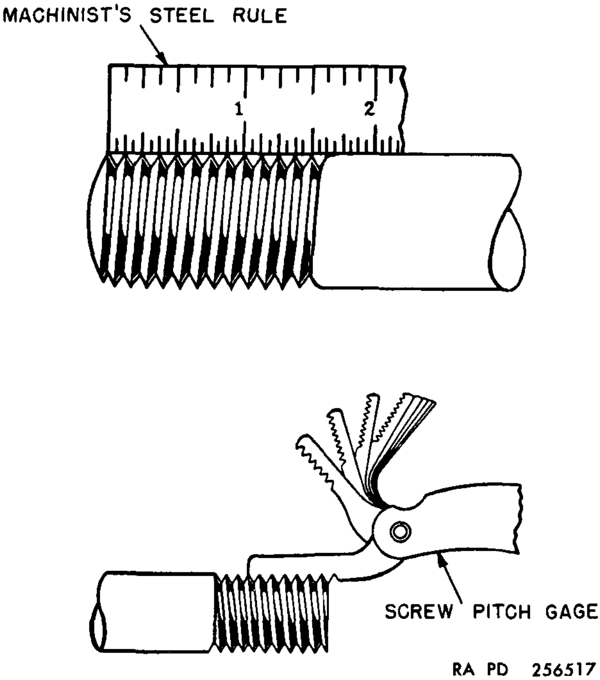


Figure 94. Two methods of measuring pitch of a screw.

(3) Accurate measurement of the pitch diameter of an externally threaded piece is achieved by measuring the thread with a thread micrometer caliper if available, or by the three-wire method (fig. 95) which employs an outside micrometer caliper.

(*a*) *Measuring with thread micrometer caliper.*

1. The thread micrometer caliper is made with the spindle pointed and the anvil notched so as to bear on the sidewalls of the thread. The point on the spindle is blunt to prevent interference with the root of the thread groove, and this bluntness limits the micrometer caliper to a specific range of thread sizes. Thread micrometer calipers are therefore manufactured in different size ranges, such as 1 inch: 8 to 13 threads, 14 to 20 threads, 22 to 30 threads; 2 inches: 14 to 20 threads, 22 to 30 threads, etc.

2. The thread micrometer caliper measures the pitch diameter of the thread by subtracting the single depth of the thread from its outside diameter. To use the thread micrometer caliper, first select the proper size micrometer caliper for the thread to be measured, look up in a table the correct pitch diameter for the screw, and lastly take a reading with the micrometer caliper.

(*b*) *Measuring by the three-wire method* (fig. 95).

1. The three-wire method of measuring threads is considered the best method for extremely accurate measurement of pitch diameter. Three wires of the same diameter are placed into the thread groove and the outside micrometer caliper is used to measure over the wires. The pitch diameter is determined by subtracting the amount of wire projection above the pitch diameter from the micrometer caliper reading.

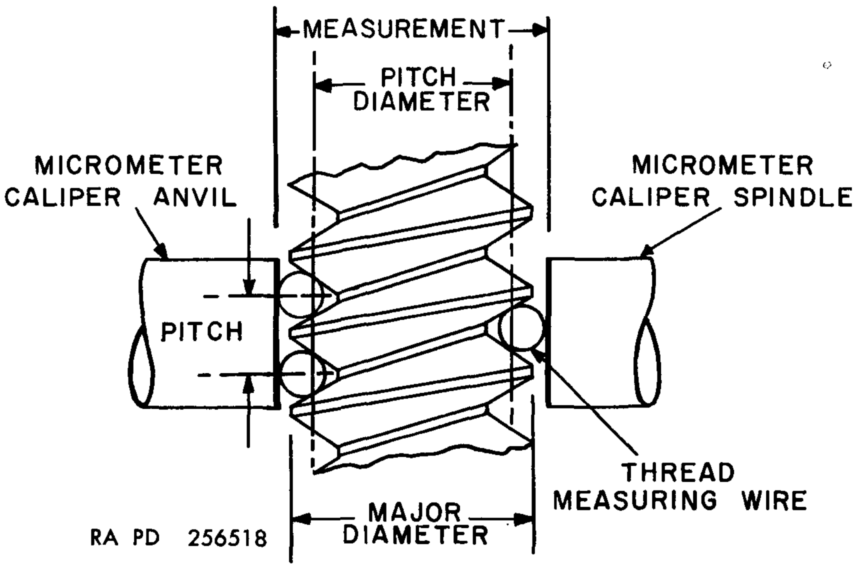


Figure 95. Measuring threads by the three-wire method.

2. This method is dependent upon using the best wire size foe measuring. The best wire is the size which touches thr sides of the thread at the center of their slopes, in other words, at the pitch diameter. Table XVIII lists wire sizes for standard thread pitches. A formula by which the proper wire size may be determined if the pitch for a particular thread is not included in table XVIII is as follows:

$$D_w = \frac{0.57735}{N}$$

where, D_w = diameter of wire (in inches)
N = threads per inch.

For example, if 8 threads per inch have been cut, then,

$D_w = \frac{0.57735}{N} = \frac{0.57735}{8} = 0.072$ inch is correct diameter of wire to use.

Table XVIII. Wire Sizes for Measuring 60° Threads by the Three-Wire Method

Threads per inch of part being measured	Wire size (in.)	Threads per inch of part being measured	Wire size (in.)
80	0. 00722	14	0. 04124
72	0. 00802	13	0. 04441
64	0. 00902	12	0. 04811
56	0. 01031	11½	0. 05020
48	0. 01203	11	0. 05249
44	0. 01312	10	0. 05773
40	0. 01443	9	0. 06415
36	0. 01604	8	0. 07217
32	0. 01804	7	0. 08248
28	0. 02062	6	0. 09623
27	0. 02138	5	0. 11547
24	0. 02406	4½	0. 12830
20	0. 02887	4	0. 14434
18	0. 03208	3½	0. 16496
16	0. 03608	3	0. 19245

3. The wire to be used should be hardened and lapped steel wire, preferably within 0.0002 inch of wire size in table XVIII.

4. To find the correct micrometer caliper measurement for a screw size, use the following formula:

$$M = D_m + 3D_w - \frac{1.5155}{N}$$

where, M = Measurement across wires (in inches)
D_m = Major diameter (in inches) of screw
D_w = Diameter (in inches) of wire
N = Threads per inch.

For example, a ½-inch, 12-pitch thread (using a wire 0.04811 in. in diameter (table XVIII)) has a measurement across wires calculated as follows:

$$M=D_m+3D_w-\frac{1.5155}{N}$$

$$=0.500+3(0.04811)-\frac{1.5155}{12}=0.51803 \text{ inch}$$

0.51803 inch is the correct micrometer caliper measurement for the screw size.

86. Knurling

a. General. Knurling is the process of grooving the surface of a workpiece by rolling depressions into it. This embossing procedure is done with a knurling tool pressed against the workpiece as it revolves. Knurling is used to provide a hand grip on the workpiece, for decorative appearance, and to enlarge diameters of work.

b. Setup for Knurling. A workpiece can be knurled between centers (par. 73) or in a chuck (par. 74). It is important that the piece be well supported since considerable pressure is required to emboss the pattern on some materials. The piece to be knurled is mounted between centers in the same manner as for straight turning.

c. Knurling Tool. The knurling tool (fig. 49) supports two knurls which revolve independently. The knurls may be of the diamond or the straight line pattern. The diamond pattern, which is more common, generally comes in three pitches: 14 (coarse), 21 (medium), and 33 (fine). These patterns are illustrated on figure 50.

d. Knurling Operation.

(1) First it is necessary to locate the limits of the surface to be knurled, that is, the beginning and end of the knurled portion. Set the knurling tool so that the top knurl is the same distance above horizontal centerline of the workpiece as the lower knurl is below this centerline. The working faces of the knurls should be set parallel to the workpiece surface.

(2) Set the lathe to run at the lowest speed of the lathe back gear. Adjust the feed selector levers or change gears to provide a feed of approximately one-half the width of the knurl per revolution of the workpiece.

(3) Move the cross slide and carriage to position the knurling tool at the right end of the portion to be knurled. Start the lathe and force the knurls into the workpiece to a depth of about 1/64 inch by use of the hand crossfeed control.

(4) Check at this point to see that the knurling tool is mounted square to the workpiece. A perfect diamond pattern should be produced. If the knurls do not track properly and the

diamond marking is split by one of the knurls, it is an indication that the knurling tool is not square or is mounted above or below center. When the tool makes the proper knurl, go over the entire surface. The workpiece and knurls should be well lubricated with cutting oil during the knurling operation.

87. Boring

a. General.

(1) Boring is the enlarging and truing of a hole by removal of material from internal surfaces with a single-point cutter bit. On the lathe, boring is accomplished in either of the two methods following:

(*a*) Mounting the holder and boring tool bar with cutter bit on the tool post and revolving the workpiece.

(*b*) Mounting the workpiece in a fixed position to the carriage and revolving the boring tool bar and cutter bit in a chuck attached to the headstock spindle.

(2) Boring is necessary in many cases to produce accurate holes or bores. Drilled holes are seldom straight due to imperfections in the material which cause drills to move out of alinement. Therefore, where accuracy is important, drilled holes are usually made undersize and then bored or reamed (par. 92) to the proper dimensions. Boring is also useful in truing large holes in flat material. In this case, the hole is cut undersize with a welding torch or band saw, and is trued to proper dimension by boring.

b. Mounting Workpiece for Boring. The workpiece may be supported in a chuck or fastened to a face plate for boring operations, depending upon the shape of the material to be machined. When boring is to be performed on the ends of long stock, the workpiece is mounted in a chuck and a steady rest is used to support the right end near the cutter bit. Some boring operations require the use of special chuck mounted mandrels to hold workpieces that cannot be successfully mounted otherwise.

c. Boring Cutter Bit Setup.

(1) The cutter bit used for boring is similar to that used for external turning on the lathe. The bit is usually held in a soft or semisoft bar called a boring tool bar. The boring tool bar (fig. 54) is supported by a cutting tool holder which fits into the lathe tool post.

(2) Boring tool bars are supplied in several types and sizes for holding different cutter bits. The bit is supported in the boring tool bar at a 90°, 30°, or 45° angle, depending upon the nature of the workpiece being bored. Most general boring is accomplished with a 90° cutter bit (fig. 54). The

bit is mounted at a 30° or 45° angle to the axis of the boring tool bar when it is necessary to cut up to the bottom of a hole or finish the side of an internal shoulder. Note the relative size of the cutter bit and boring tool bar to the workpiece dimensions shown on figure 47. It is desirable that the boring tool bar be as large as possible without interfering with the walls of the hole. The cutter bit should not extend far beyond the boring tool bar and the bit should be as short as possible to be gripped securely in the bar yet not have the shank end protrude far from the bar.

(3) The cutter bits used for boring are shaped like left hand turning and facing cutter bits (par. 62). Greater attention must be given to the end clearance angle and the back rake angle because of the curvature of the hole.

(4) The boring tool bar should be clamped as close to the holder and tool post as possible considering the depth of boring to be done. The bar will have a tendency to spring away from the workpiece if the bar overhangs the tool post too far. If deep boring is to be performed, it will be necessary that the bar be as large as possible to counteract this springing tendency.

d. Straight Boring Operation.

(1) The cutter bit is positioned for straight boring operations with its cutting edge contacting the workpiece approximately 5° above center (fig. 96). The cutting edge faces

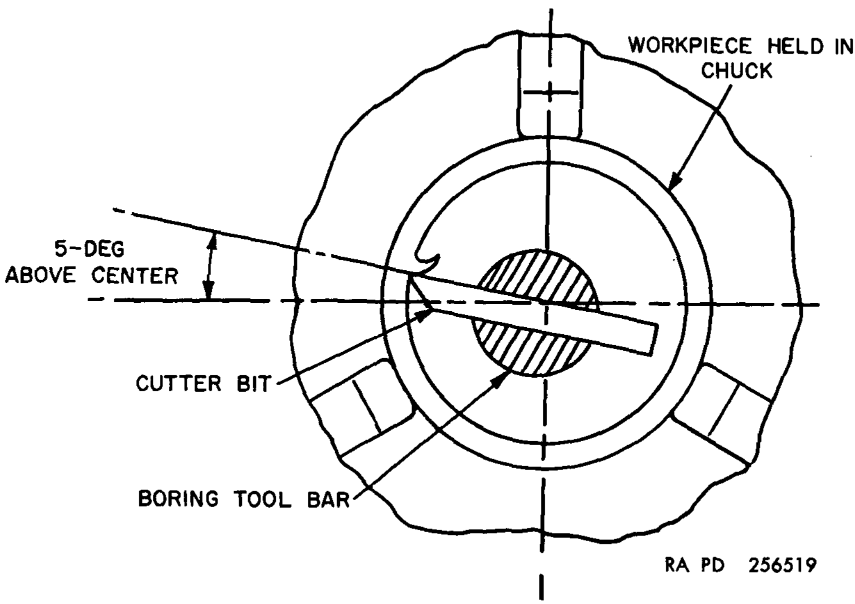


Figure 96. Cutter bit position for straight boring.

forward for most operations so that the lathe can turn in its normal counterclockwise direction. If for a special operation it becomes necessary to position the cutter bit against the rear wall of the hole, a right hand turning cutter bit is used and the spindle rotation is reversed.

(2) Position the cutter bit so that the cutting edge is immediately to the right of the workpiece and clears the wall of the hole by about $\frac{1}{16}$ inch. Traverse the carriage by hand without starting the lathe to move the cutter bit and boring tool bar into the hole to the depth of the intended boring and out again to ascertain whether there is sufficient clearance to prevent the back of the cutter bit and the boring tool bar from rubbing the inside of the hole. When the clearance is satisfactory, position the cutter bit to the right of the workpiece ready for the first cut.

(3) The same speeds and feeds recommended for straight turning (par. 78) should be used for straight boring. It is often advisable to feed the cutter bit into the hole to the desired depth and then reverse the feed and let the cutter bit move out of the hole without changing the depth of feed. This practice will correct any irregularities caused by the bit or boring tool bar springing because of the pressure applied to the bit.

e. *Taper Boring Operation.*

(1) Taper boring is accomplished in the same manner as taper turning (par. 84). However, only two of the three methods of taper turning are applicable—using the compound rest (par. 84*d*) and using a taper attachment (par. 84*e*). As with taper turning, the compound rest can only be used for short, steep tapers since the movement of the compound rest is limited.

(2) The clearance of the cutter bit shank and boring tool bar must be determined for the smaller diameter of the taper. As with turning external tapers, it is also necessary to position the cutting edge exactly on the horizontal centerline of the workpiece, not 5 degrees above center as with straight boring.

f. *Internal Thread Cutting.*

(1) Internal threads are cut in nuts and castings by the same general methods used in external thread cutting (par. 85).

(2) The internal threading operation will usually follow a boring operation, and therefore the same workpiece holder can be used without disturbing the setup. Only the lathe speed will have to be changed to those recommended for external threading.

(3) The clearance of the cutter bit shank and boring tool bar to prevent rubbing must be greater for threading than for straight boring because of the necessity of moving the bit clear of the threads when returning the bit to the right after each cut.

(4) The compound rest should be set at a 29-degree angle to the saddle so that the cutter bit will feed after each cut forward and to the left (fig. 97).

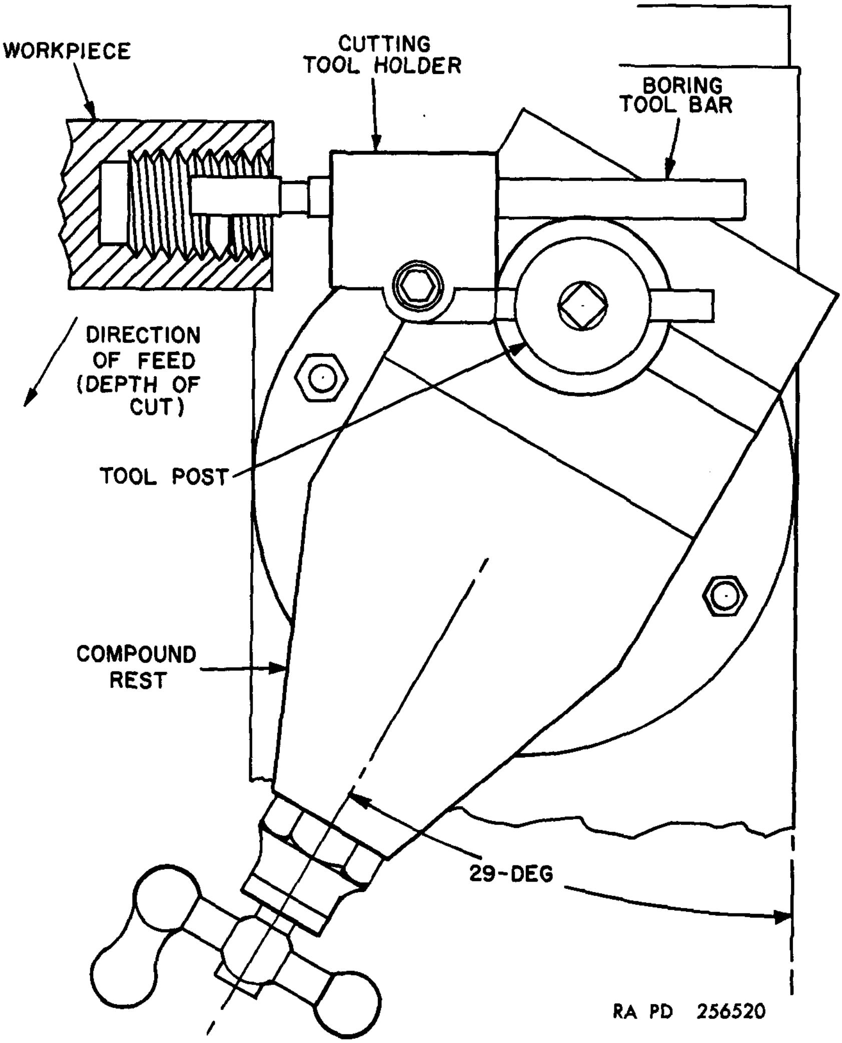


Figure 97. Setup for internal threading.

88. Eccentric Turning

a. General. Eccentric means off-center and applied to lathe operations, refers to turning a section of the workpiece which has a different axis than the main body of the piece. The principle of eccentric turning on the lathe is to set up the piece so that the portion of the workpiece to be turned is axially alined with the headstock and tailstock spindles.

b. Mounting Work for Eccentric Turning.

(1) A good example of eccentric turning is the turning of a crank pin on a crankshaft (fig. 98). The main journals are on one axis while the crank pin is on another axis several inches from the main journal axis. The main journals can be machined in the same manner as bar stock by centering and drilling the ends of the journals and setting the crankshaft in the lathe. To machine the crank pin, it is necessary to revolve the crankshaft about the crank pin axis. This is accomplished by using adapters (fig. 98) on the ends of the main journals to permit proper mounting of the crankshaft so that the crank pin can be turned.

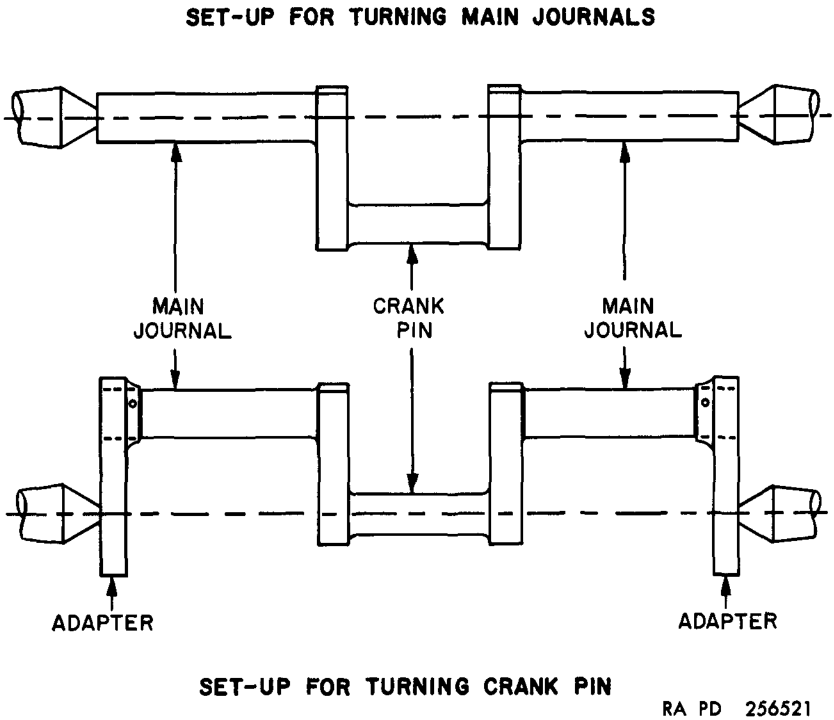


Figure 98. Example of eccentric turning.

(2) If the workpiece cannot be mounted successfully between centers, it can be mounted in an independent chuck (par. 64*b*) or fastened to a face plate (par. 65). In either case, it is necessary to true the portion to be turned eccentrically and not the major portion of the piece. In some cases, it will be necessary to counterbalance the workpiece if the piece is mounted appreciably off balance.

c. Eccentric Turning Operation. Once the workpiece is set up correctly, it is turned in the same manner prescribed for straight turning (par. 81). In the example of the crankshaft (*b*(1) above), the cutter bit, cutting tool holder, and compound rest must be positioned so that the swinging main journals will not contact any part of the lathe or equipment. In the particular example, two cutter bits, a left hand turning cutter bit, and a right hand turning cutter bit would be used for turning the crank pin so that the pin could be turned out to the edges without interfering with the swinging main journals.

89. Filing and Polishing

a. General. Filing and polishing are performed in the lathe to remove toolmarks, reduce the dimension slightly, or improve the finish.

b. Filing.

(1) Mill files are generally considered best for lathe filing. The bastard cut mill-type hand file is used for roughing and the second cut mill-type hand file for the finer class of work. Other types such as the round, half-round, and flat-hand files may also be used for finishing irregular shaped workpieces.

(2) For filing ferrous metals, the lathe-spindle speed should be four or five times greater than the rough turning speed. For filing nonferrous metals, the lathe-spindle speed should be only two or three times greater than the roughing speed. Too slow a speed may cause the workpiece to be filed out-of-round, while too high a speed will cause the file to slide over the workpiece, dulling the file and glazing the piece.

(3) The file is held at an angle of about 10° to the right and moved with a slow sliding motion from left to right so that the teeth will have a shearing action. The direction of stroke and angle should never be the opposite, as this will cause chatter marks on the piece. The file should be passed slowly over the workpiece so that the piece will have made several revolutions before the stroke is completed.

(4) The pressure exerted on the file with the hands should be less than when filing at the bench. Since there are less teeth in contact with the workpiece, the file must be cleaned frequently to avoid scratching.

(5) Since filing should be used for little more than to remove toolmarks from the workpiece, only 0.002 to 0.005 inch should be left for the filing operation.

c. *Polishing.*

(1) Polishing with either abrasive cloth or abrasive paper is desirable to improve the surface finish after filing. Emery abrasive cloth is best for ferrous metals while abrasive paper often gives better results on nonferrous materials. The most effective speed for polishing with ordinary abrasives is approximately 5,000 feet per minute. Since most lathes are not capable of a speed this great for average size workpieces, it is necessary to select as high a speed as conditions will permit.

(2) In most cases the abrasive cloth or paper is held directly in the hand and applied to the workpiece, although it may be tacked over a piece of wood and used in the same manner as a file. Improvised clamps may also be used to polish plain round work.

(3) Since polishing will slightly reduce the dimensions of the workpiece, 0.00025 to 0.0005 inch should be allowed for this operation. The use of oil with the abrasive will produce a satin finish, while dry polishing will leave a bright surface. Crocus cloth may be used after the abrasive cloth or abrasive paper to produce a higher luster on the surface.

Section V. SPECIAL OPERATIONS ON LATHES

90. General

The special lathe operations described in this section are normally performed on machine tools other than the lathe, but can be and often are performed on the lathe. These operations include drilling, reaming, tapping and die cutting, and milling.

91. Drilling With the Lathe

a. General. Drilling is done in the lathe by either of two methods, by revolving the workpiece in the lathe chuck with the twist drill held in the tailstock, or by revolving the twist drill in a chuck in the headstock and supporting the workpiece with some attachment such as V-center in the tailstock.

b. Methods of Supporting Twist Drill in the Tailstock.

(1) Straight-shank twist drills are usually held in a drill chuck (fig. 99) which is placed in the taper socket of the tailstock spindle. Combination drill and countersinks can also be supported in this way.

(2) Taper-shank twist drills may be held directly in the tailstock spindle as long as they have a good fit. For this purpose,

drill sockets or drill sleeves (par. 24*c*) can be used to reduce the taper socket in the tailstock spindle to the proper taper and size of the twist drill.

(3) An expedient method of supporting a large twist drill in the tailstock is to fasten a lathe dog (fig. 100) to the drill shank and support the rear of the drill with the tailstock center in the center hole in the tang of the drill. The lathe dog should rest against the cross slide or compound rest. The drill must be supported by hand until it is held secure by the pressure between the tailstock center and the workpiece. When this method is used, never withdraw or loosen the tailstock spindle while the lathe is in operation. To withdraw the drill, it is necessary to stop the lathe completely.

c. Methods of Supporting Drill in Headstock.

(1) Straight-shank twist drills are supported in the headstock by a drill chuck mounted in the headstock spindle.

(2) Taper-shank twist drills can be mounted in the headstock by placing the drill in a drill socket or sleeve which has a cylindrical outer surface like the spindle of a drilling machine. The socket or sleeve is then fastened in a universal or independent chuck. If the taper shank of the drill is compatible with the taper socket in the headstock spindle, the drill can be mounted directly.

d. Mounting the Workpiece for Drilling.

(1) If the workpiece is to be rotated and the twist drill is to be fed into the workpiece with the tailstock spindle, the piece may be mounted in a universal chuck (fig. 99), independent chuck, or to a face plate. The center of the hole to be drilled should be accurately marked and punched as described for drilling machine setups (par. 27).

(2) Before drilling, check the centering of the punch mark by using a center indicator (par. 74*b*(4)). The drill will not cut accurately unless the punch mark indicating the hole coincides exactly with the axis of the headstock spindle.

(3) If the twist drill is to be rotated by the headstock spindle and the workpiece is to be supported by a V-center (par. 66*f*), the piece should be carefully positioned by hand and the drill moved lightly into contact with the piece before the lathe is started. The piece must be well supported during drilling operations to prevent the piece from rotating with the drill.

e. Drilling Operation (fig. 99).

(1) Drilling feeds and speeds should be determined by consulting the pertinent information ir paragraphs 30 and 31. The spindle speed in revolutions per minute is determined by the

size of twist drill for a particular material and will be the same for a particular drill size whether the drill is revolved or the workpiece is revolved.

(2) The feed is controlled by turning the tailstock hand screw. The graduations on the tailstock spindle are used to determine the depth of cut.

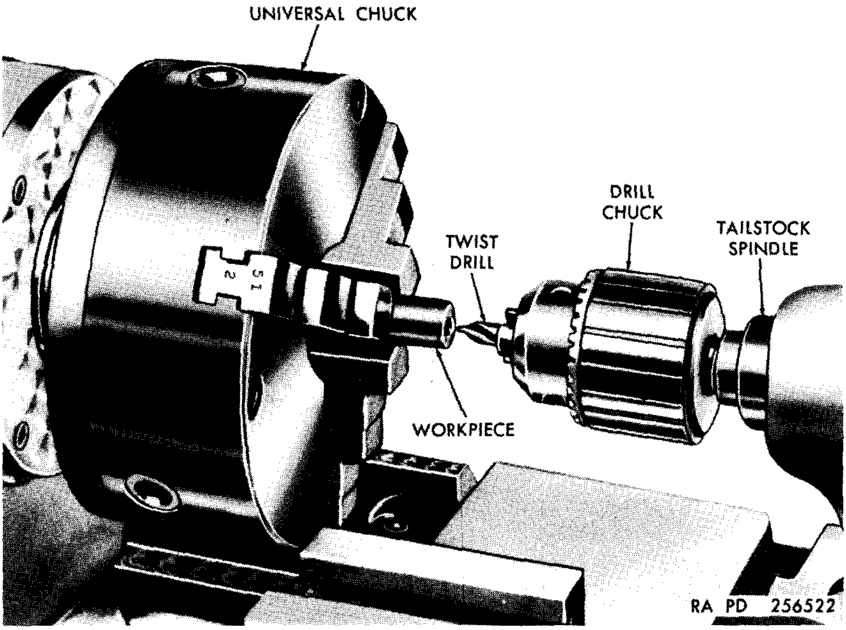


Figure 99. Drilling workpiece in the lathe.

(3) If large size twist drills are to be used, the drill should be preceded by a lead drill, the diameter of which must not be greater than the thickness of the web of the large drill.

92. Reaming With the Lathe

a. General. Reamers are used to finish drilled holes or bores quickly and accurately to a specified diameter. When a hole is to be reamed, it must first be drilled or bored to within 0.004 to 0.012 inch of the finished size since the reamer is not designed to remove much material.

b. Machine Reaming.

(1) The hole to be reamed with a machine reamer must be drilled or bored to within 0.012 inch of the finished size so that the machine reamer will only have to remove the cutter bit marks.

(2) The workpiece is mounted in a chuck at the headstock spindle and the reamer is supported by the tailstock in one of the

methods described for holding a twist drill in the tailstock (par. 91*b*). Figure 100 illustrates the machine reamer supported by a lathe dog and tailstock center.

(3) The lathe speed for machine reaming should be approximately one-half that used for drilling (par. 30).

c. Hand Reaming.

(1) The hole to be reamed by hand must be within 0.005 inch of the required finished size.

(2) The workpiece is mounted to the headstock spindle in a chuck and the headstock spindle is locked after the piece is accurately set up. The hand reamer is mounted in an adjustable tap and reamer wrench and supported with the tailstock center. As the wrench is revolved by hand, the hand reamer is fed into the hole simultaneously by turning the tailstock handwheel.

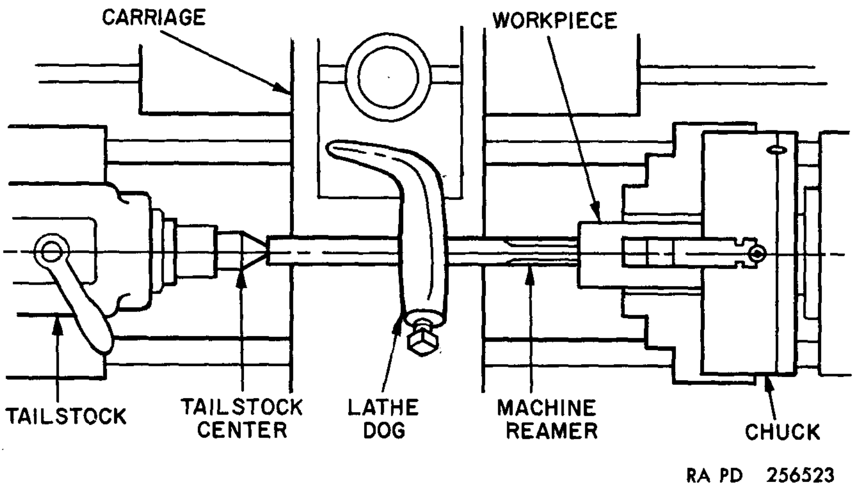


Figure 100. Reaming on the lathe.

(3) The reamer should be withdrawn from the hole carefully, turning it in the same direction as when reaming. Never turn a reamer backward.

93. Tapping and Die Cutting Threads

a. General. Internal and external threads are often cut on the lathe by means of taps and dies. The advantage of tapping and die cutting on the lathe over doing it on the bench is that the tap or die can be centered accurately so that the threads produced are generally more accurate in regard to the axis of the workpiece. Refer to paragraph 85 for general information applicable to thread forms and sizes. Refer to tables VII and VIII for tap drill sizes which will produce proper size holes for tapping screw threads and pipe threads.

b. Tapping Threads on the Lathe. Threads may be tapped in the lathe by either of the two following methods:

(1) With the headstock spindle of the lathe locked and the workpiece held in the chuck, the tap is placed in the workpiece bore and the tailstock center run against the countersunk end of the tap. The tap is turned by means of a fixed open end wrench while pressure is applied to it with the tailstock handwheel. This method is recommended for large taps and for material that does not machine easily.

(2) When tapping free-machining material, the tap may be held by an adjustable tap and reamer wrench, the handle resting against the compound rest of the carriage, and the tailstock center bearing against the countersunk end of the tap. The lathe is operated at very slow speed while constant pressure is maintained against the tap by means of the tailstock handwheel.

c. Die Cutting on the Lathe. When cutting threads with a die, the workpiece is usually held in the headstock and the die set on the workpiece with the die stock resting upon the compound rest of the carriage. The threads are cut in a similar manner to tapping by causing the lathe to revolve at a very slow speed while pressure is applied by means of the tailstock handwheel.

94. Milling on the Lathe

a. General. Milling operations may be performed on the lathe through use of the milling and grinding lathe attachment (par. 71) which, in effect, converts the lathe into a milling machine. The milling and grinding lathe attachment (fig. 66) contains a mechanism for vertical adjustment of the milling head but utilizes the carriage and feed controls of the lathe to move the milling head in horizontal directions. A dividing head supplied with the attachment is installed on the headstock spindle of the lathe to permit indexing of the workpiece. Although the workpiece is mounted in a conventional manner in the lathe, the headstock spindle is never rotated by power for milling functions. Cutting is done by the milling cutter which is mounted to the milling head of the milling and grinding lathe attachment and driven by the self-contained electric motor of the attachment.

b. Mounting Workpieces for Milling on the Lathe. Workpieces are supported in the lathe between centers, against a face plate, or in a chuck fixed to the headstock spindle. A lathe dog is used to secure the workpiece to the driving face plate if the workpiece is mounted between centers. If long workpieces are chuck mounted, a steady rest or a follower rest is used to support the free end of the workpiece.

c. Indexing Workpieces for Milling on the Lathe.

(1) Indexing is the process of controlling the rotational position of a workpiece which is mounted axially. Workpieces

mounted in the lathe for milling with the milling and grinding lathe attachment are indexed with the dividing head, a part of the attachment.

(2) The dividing head (fig. 101) attaches to the left end of the lathe headstock and connects to the lathe headstock spindle with a collet. With the dividing head affixed to the headstock and headstock spindle, the spindle will not rotate freely but will move when the crank of the dividing head is turned. Forty turns of the crank will move headstock spindle through one complete revolution. Index plates contain-

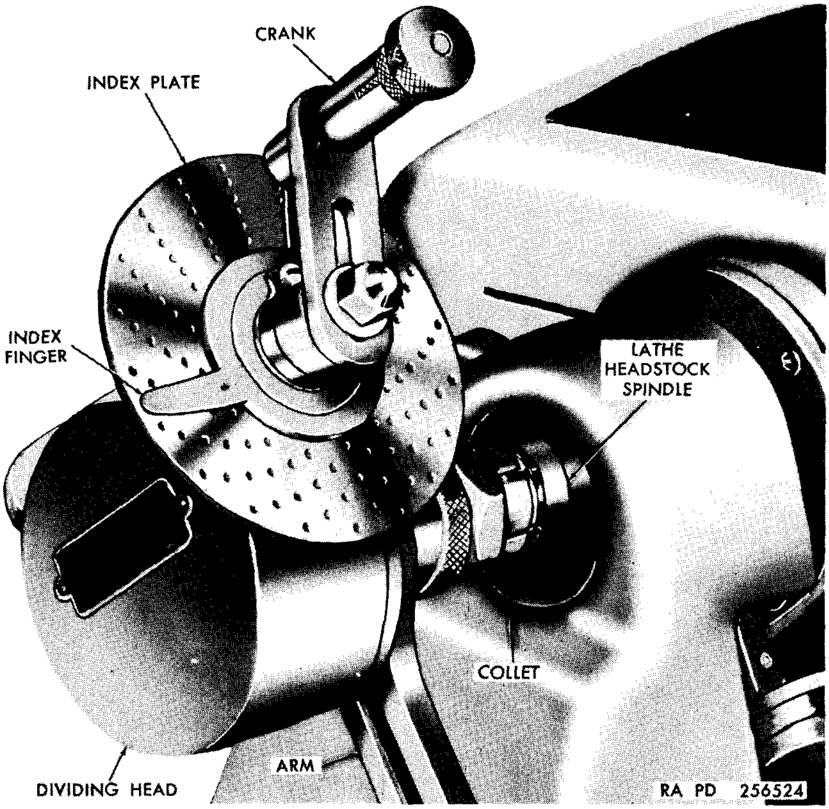


Figure 101. Dividing head of the milling and grinding lathe attachment installed on the lathe.

ing concentric rings of evenly spaced holes fasten to the index plate beneath the crank. Each concentric ring has a different number of holes per circle, and each index plate has six concentric rings.

(3) The workpiece is indexed by moving the crank (fig. 101) from one hole in the index plate to another. An index

finger (fig. 101) can be set to indicate a certain number of holes thereby making the counting of individual holes unnecessary.

(4) To determine the number of holes and the proper ring of holes for any specific division of the workpiece, refer to paragraph 111 which explains the calculations required for indexing on the milling machine.

d. Milling Operation (fig. 102). Plain milling, angular milling, face milling, form milling, keyway milling, spline milling, gear cutting, and drilling and boring operations can be successfully performed on the lathe by using the milling and grinding lathe attachment. Refer to paragraphs 112 through 127 for instructions on each of the above classes of milling procedure.

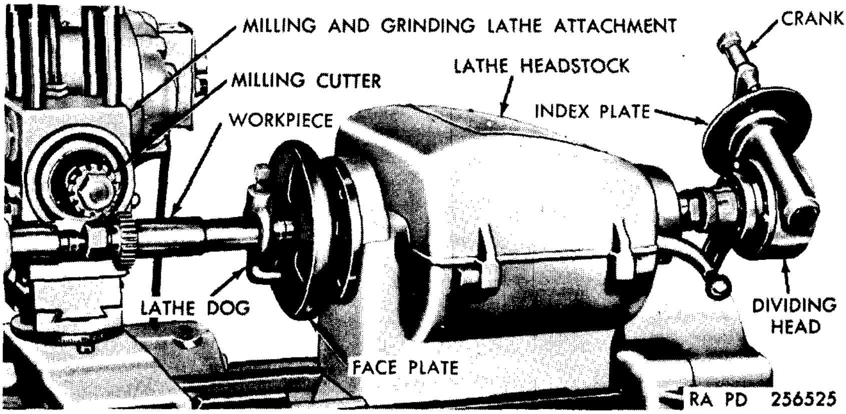


Figure 102. Milling operation on the lathe.

(1) The basic difference between milling on a horizontal milling machine and milling with the milling and grinding lathe attachment is that with the milling machine the worktable reciprocates beneath a milling cutter, while with the attachment the milling head feeds along the stationary workpiece.

(2) Milling cutter speeds and worktable feeds should be consistent with those speeds and feeds recommended for milling machine operation (pars. 113 and 114).

(3) Select a cutting speed consistent with the material being milled (table XX). If the recommended speed cannot be matched by one of the available speeds of the milling and grinding lathe attachment, select the next lower speed.

(4) If a coolant attachment is available, flood the milling cutter and workpiece contact area with an appropriate cutting oil (table XXII). If a coolant attachment is not available, apply a cutting oil generously from a hand oiler during operation.

CHAPTER 5

MILLING MACHINES

Section I. GENERAL

95. Purpose

a. Milling is the process of machining flat, curved, or irregular surfaces by feeding the workpiece against a rotating cutter containing a number of cutting edges. The process is identical in method to circular sawing; it is exactly opposed in method to lathe turning where the workpiece rotates against a stationary cutter bit.

b. The milling machine consists basically of a motor driven spindle, which mounts and revolves the milling cutter, and a reciprocating adjustable worktable which mounts and feeds the workpiece past the milling cutter.

c. It is not possible to list every operation within the capabilities of the milling machine. The milling machine is excellent for forming flat surfaces, cutting dovetails and keyways, forming and fluting milling cutters and reamers, cutting gears, and so forth. Many special operations can be performed with the attachments available for milling machine use.

96. Types of Milling Machines

a. General. Milling machines are basically classified as being horizontal or vertical to indicate the axis of the milling machine spindle. These machines are also classified as being knee-type milling machines, ram-type milling machines, manufacturing or bed-type milling machines, and planer-type milling machines. Most milling machines have self-contained electric drive motors, coolant systems, variable spindle speeds, and power-operated table feeds.

b. Knee-Type Milling Machines.

(1) *Description.* Knee-type milling machines are characterized by a vertically adjustable worktable resting on a saddle which is supported by a knee. The knee is a massive casting that rides vertically on the milling machine column and can be clamped rigidly to the column in a position where the milling head and milling machine spindle are properly adjusted vertically for operation. Of the knee-type class of milling machines, the most popular machines

are the plain horizontal milling machine and the universal horizontal milling machine.

(2) *Floor-mounted plain horizontal milling machine* (fig. 103).

(*a*) The floor-mounted plain horizontal milling machine's column contains the drive motor and gearing and a fixed-position horizontal milling machine spindle. An adjustable overhead arm containing one or more arbor supports projects forward from the top of the column. The arm and arbor supports are used to stabilize long arbors upon which the milling cutters are fixed. The arbor supports can be moved along the overhead arm to support the arbor where support is desired depending on the position of the milling cutter or cutters.

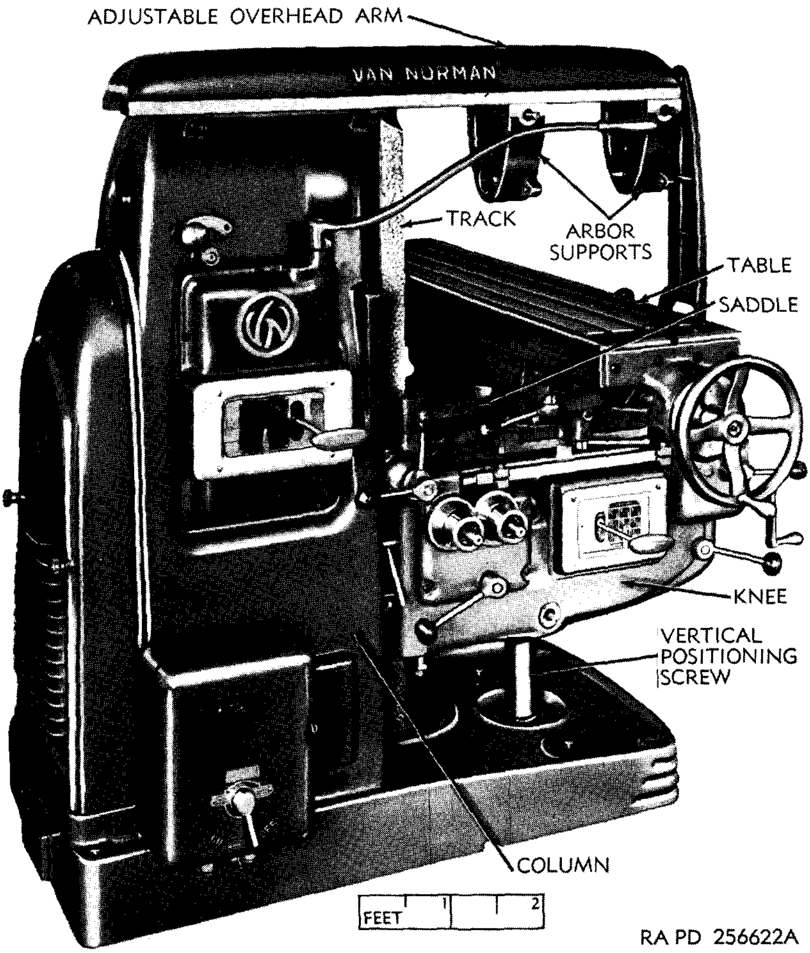


Figure 103. Knee-type floor-mounted plain horizontal milling machine.

(*b*) The knee of the machine rides up or down the column on a rigid track. A heavy, vertical positioning screw beneath the knee is used for raising and lowering. The saddle rests upon the knee and supports the worktable. The saddle moves in and out on a dovetail to control cross feed of the worktable. The worktable traverses to the right or left upon the saddle for feeding the workpiece past the milling cutter. The table may be manually controlled or power fed.

(3) *Bench-type plain horizontal milling machine* (fig. 104). The bench-type plain horizontal milling machine is a small version of the machine described in (2) above, being mounted to a bench or a pedestal instead of directly to the floor. The milling machine spindle is horizontal and fixed in position. An adjustable overhead arm and arbor support are provided. The worktable is generally not power fed on this size machine. The saddle slides on a dovetail on the knee providing crossfeed adjustment. The knee moves vertically up or down the column to position the worktable in relation to the spindle.

(4) *Floor-mounted universal horizontal milling machine* (fig. 105).

(*a*) The basic difference between a universal horizontal milling machine and a plain horizontal milling machine ((2) and

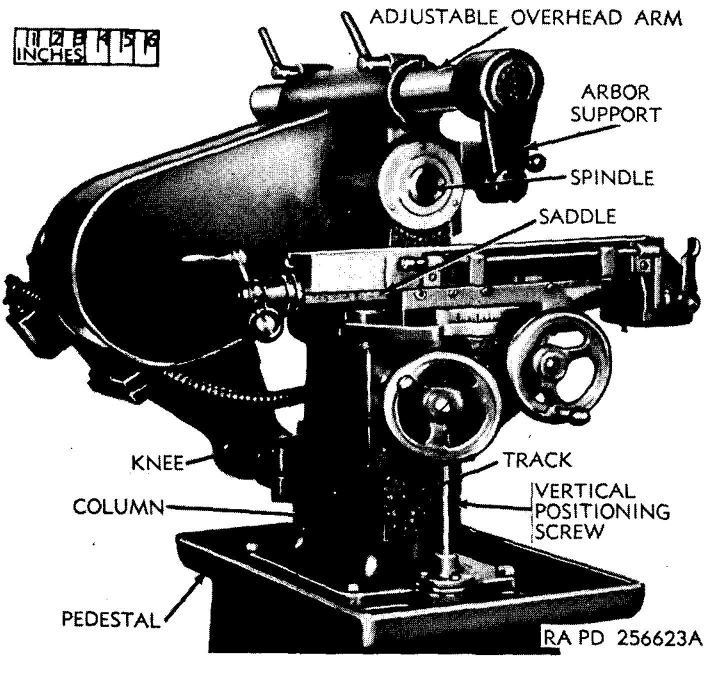


Figure 104. Bench-type plain horizontal milling machine.

(3) above) is in the adjustment of the worktable and the number of attachments and accessories available for performing various special milling operations. The universal horizontal milling machine has a worktable that can swivel on the saddle with respect to the axis of the milling machine spindle permitting workpieces to be adjusted in any position in relation to the milling cutter or cutters. The universal machine is always supplied with attachments such as the indexing fixture.

(*b*) The universal horizontal milling machine illustrated in figure 105 also differs from the plain horizontal milling

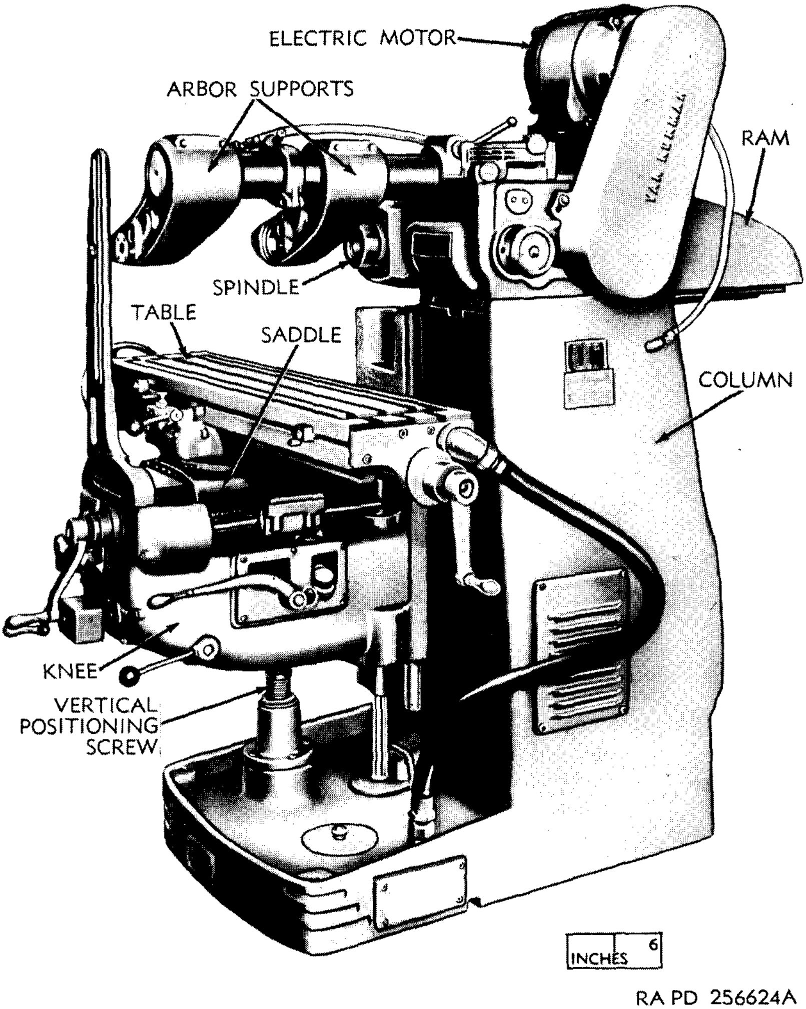


Figure 105. Floor-mounted universal horizontal milling machine.

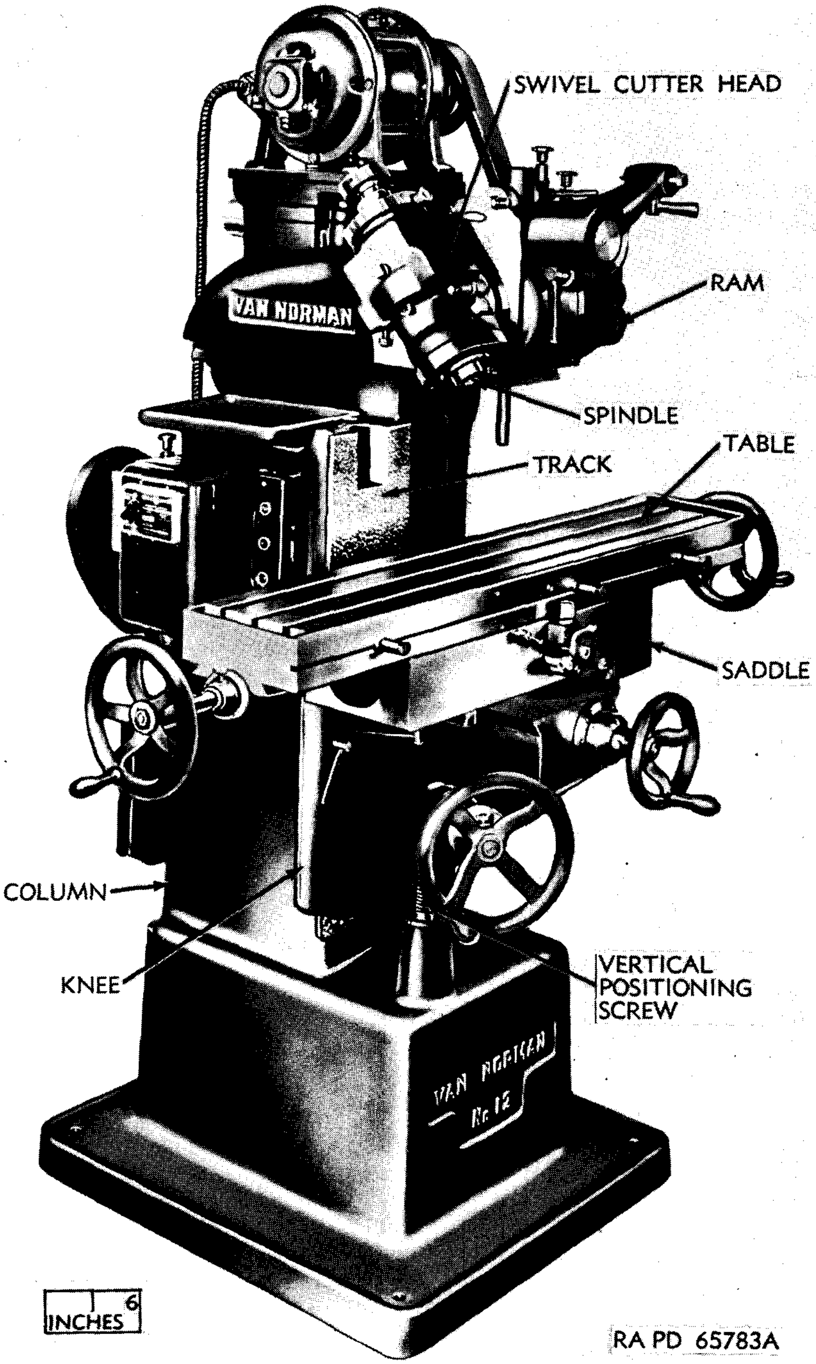


Figure 106. Swivel cutter head ram-type milling machine.

machine in figure 103 in that it is of the ram type; the milling machine spindle is mounted in a ram at the top of the column that can be moved in and out to provide crossfeed for milling operations. This feature permits additional rigidity of the worktable since a crossfeed dovetail is not necessary between the knee and the saddle.

c. *Ram-Type Milling Machines.*

(1) *Description.* The ram-type milling machine is characterized by a spindle mounted to a movable housing on the column to permit feeding the milling cutter forward or rearward in a horizontal plane. Two popular ram-type milling machines are the floor-mounted universal milling machine (*b*(4) above) and the swivel cutter head ram-type milling machine ((2) below).

(2) *Swivel cutter head ram-type milling machine* (fig. 106). This milling machine can be classified as a universal milling machine. A cutter head containing the milling machine spindle is attached to the ram. The cutter head can be swiveled from a vertical spindle position to a horizontal spindle position or can be fixed at any desired angular position between vertical and horizontal. The saddle and knee are hand driven for vertical and crossfeed adjustment while the worktable can be either hand driven or power driven at the operator's choice.

Section II. TOOLS AND EQUIPMENT

97. Milling Cutters

a. *Classification of Milling Cutters.*

(1) *General.* Milling is the process of removing metal by means of a rotating cutting tool or tools having a number of cutting edges called teeth. Such tools are known as milling cutters or mills. They are usually made of high-speed steel and are available in a great variety of shapes and sizes for various purposes. (There are over 50 kinds of cutters in general use, over 4,000 stock sizes.) The names of the most common classifications of cutters, their uses, and in a general way the sizes best suited to the work in hand should be known.

(2) *Milling cutter nomenclature.* Figure 107 shows two views of a common milling cutter with its parts and angles identified. These parts and angles in some form are common to all types of cutters.

(*a*) *Pitch.* The pitch refers to the angular distance between like parts on adjacent teeth. The pitch is determined by the number of teeth.

(*b*) *Face of tooth.* The tooth face is the forward facing surface of the tooth that forms the cutting edge.

(*c*) *Cutting edge.* The cutting edge is the angle on each tooth that performs the cutting.

(*d*) *Land.* The land is the narrow surface behind the cutting edge on each tooth.

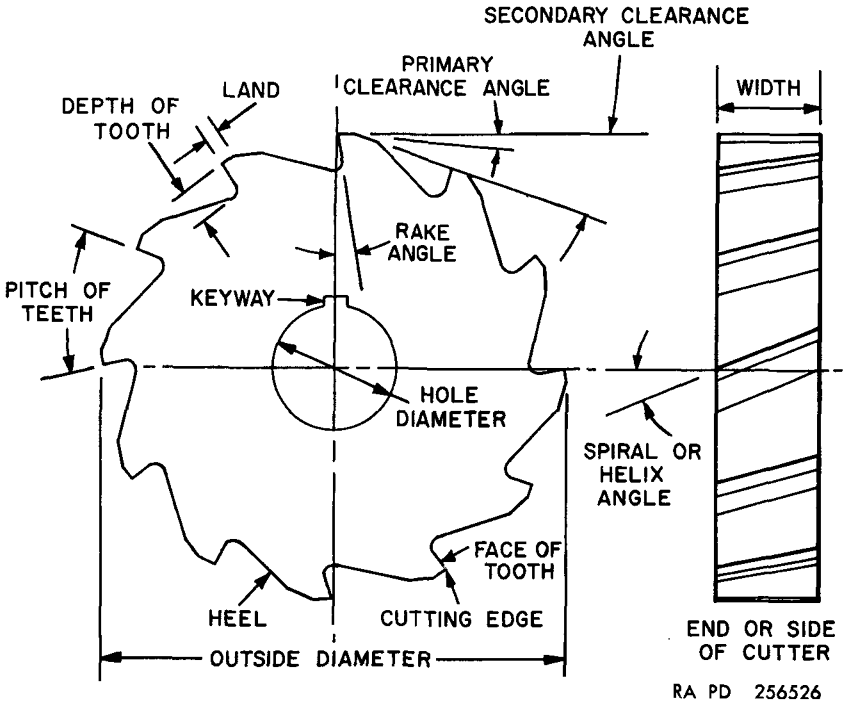


Figure 107. Milling cutter nomenclature.

(*e*) *Rake angle.* The rake angle is the angle formed between the face of the tooth and the centerline of the cutter. The rake angle defines the cutting edge and provides a path for chips that are cut from the workpiece.

(*f*) *Primary clearance angle.* The primary clearance angle is the angle of the land of each tooth measured from a line tangent to the centerline of the cutter at the cutting edge. This angle prevents each tooth from rubbing against the workpiece after it makes its cut.

(*g*) *Secondary clearance angle.* This angle defines the land of each tooth and provides additional clearance for passage of cutting oil and chips.

(*h*) *Hole diameter.* The hole diameter determines the size arbor necessary to mount the milling cutter.

(*i*) *Keyway.* A keyway is present on all arbor-mounting cutters for locking the cutter to the arbor.

(*j*) *Spiral or helix angle.* The spiral or helix angle, if present, refers to the spiral deflection of the teeth of the milling cutter.

(3) *Types of teeth.* The teeth of milling cutters are either right hand or left hand, viewed from the back of the machine. Right hand milling cutters cut when rotated clockwise; left hand milling cutters cut when rotated counterclockwise.

(*a*) *Saw teeth.* Saw teeth similar to those shown in figure 107 are either straight or helical in the smaller sizes of plain milling cutters, metal slitting saw milling cutters, and end milling cutters. The cutting edge is usually given about 5° primary clearance. Sometimes the teeth are provided with offset nicks which break up the chips and make coarser feeds possible.

(*b*) *Formed teeth.* Formed teeth are usually specially made for machining irregular surfaces or profiles. The possible varieties of formed-tooth milling cutters are almost unlimited. The convex, concave, and corner-rounding milling cutters ((4) below) are of this type. Formed cutters are sharpened by grinding the faces of the teeth radially and repeated sharpenings are possible without changing the contour of the cutting edge.

(*c*) *Inserted teeth.* Inserted teeth are blades of high-speed steel inserted and rigidly held in a blank of machine steel or cast iron. Different manufacturers use different methods of holding the blades in place. Inserted teeth are especially economical and convenient for large-sized cutters because of their reasonable initial costs and because worn out or broken blades can be replaced easily.

(4) *Kinds of milling cutters.*

(*a*) *Plain milling cutter* (fig. 108). The most common kind of milling cutter is known as a plain milling cutter. It is merely a cylinder having teeth cut on its periphery for producing a flat horizontal surface (or a flat vertical surface in the case of a vertical spindle machine). When the cutter is over ¾ inch wide, the teeth are usually helical, which gives the tool a shearing action and requires less power, reduces chatter, and produces a smoother finish. Cutters with faces less than ¾ inch wide are sometimes made with staggered or alternate right and left hand helical teeth. The shearing action, alternately right and left, eliminates side thrust on the cutter and arbor. When a plain milling cutter is considerably wider than the diameter, it is often called a slabbing cutter; slabbing cutters generally have nicked teeth. The nicked teeth prevent formation of overly large chips.

(*b*) *Metal slitting saw milling cutter* (fig. 109). The metal slitting saw milling cutter is essentially a very thin plain milling cutter. It is ground slightly thinner toward the center to provide side clearance. It is used for metal sawing and for cutting narrow slots.

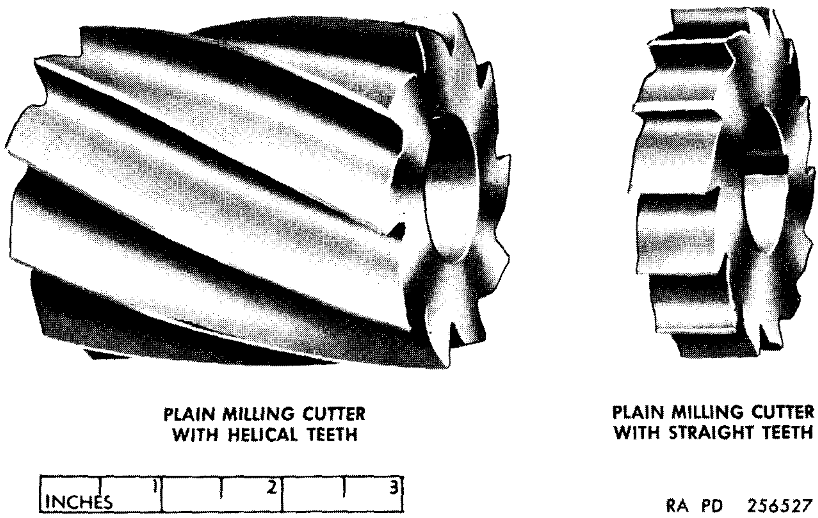


Figure 108. Plain milling cutters.

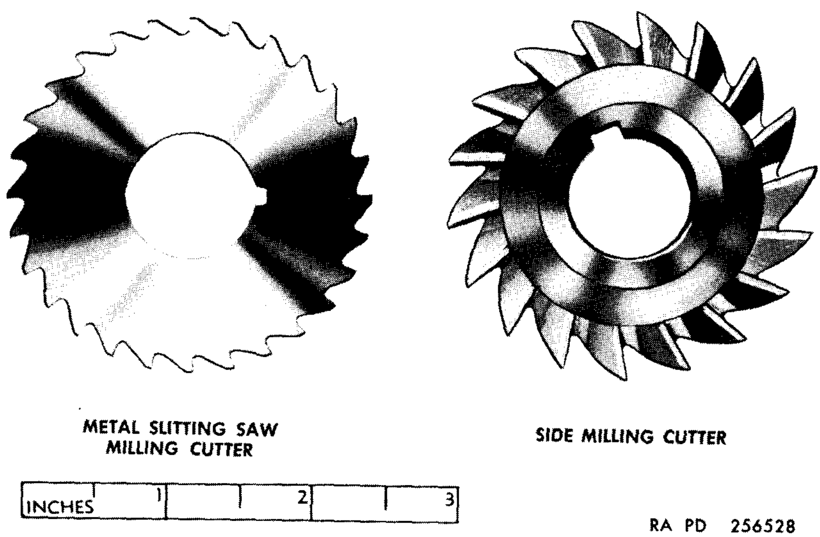


Figure 109. Side and metal slitting saw milling cutters.

(*c*) *Side milling cutters.* Side milling cutters are essentially plain milling cutters with the addition of teeth on one or both sides.

1. A plain side milling cutter (fig. 109) has teeth on both sides and on the periphery. When teeth are added to one side only, the cutter is called a half-side milling cutter and is identified as being either a right hand or left hand cutter. Side milling cutters are generally used for slotting and straddle milling.

2. Interlocking tooth side milling cutters and staggered tooth side milling cutters (fig. 110) are used for cutting relatively wide slots with accuracy. Interlocking tooth side milling cutters can be repeatedly sharpened without changing the width of the slot they will machine. After each sharpening, a washer is placed between the two cutters to compensate for the ground-off metal. The staggered tooth cutter is the most efficient type for milling slots where the depth exceeds the width.

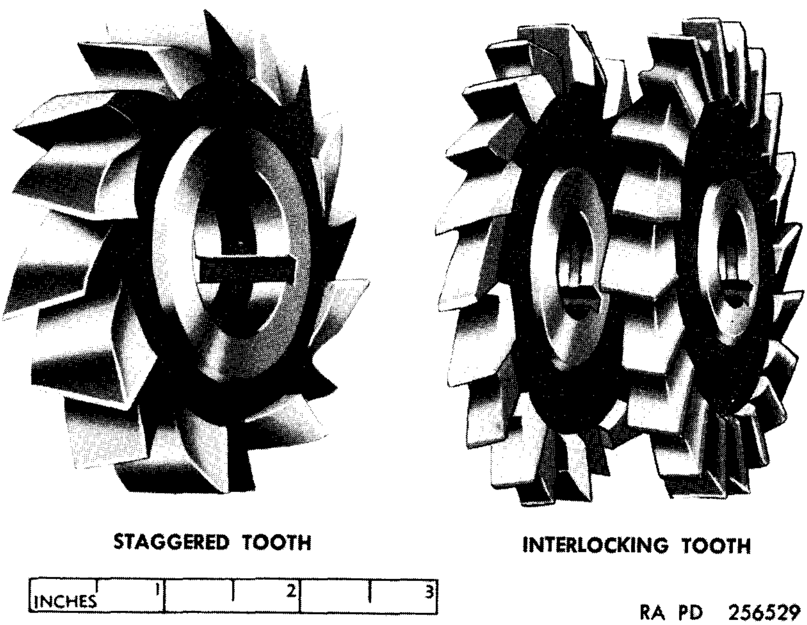


Figure 110. Staggered and interlocking tooth side milling cutters.

(*d*) *End milling cutters.*

1. End milling cutters, also called end mills, have teeth on the end as well as the periphery. The smaller end milling cutters have shanks (fig. 111) for chuck mounting or direct spindle mounting. Larger end milling cutters (over 2 inches in diameter) are called shell end milling cutters and are mounted on arbors (fig. 122) like plain milling cutters. End milling cutters are employed in the production of slots, keyways, recesses, and tangs. They are also used for milling the edges of workpieces.

2. End milling cutters may have straight or spiral flutes. Spiral flute end milling cutters (fig. 111) are classified as left hand or right hand cutters depending on the direction of rotation of the flutes. If they are small cutters, they may have either a straight or tapered shank.

3. Several common types of end milling cutters are illustrated in figure 111. The most common end milling cutter is the spiral flute end milling cutter which contains four flutes. Single-end spiral flute end milling cutters are used for milling slots and keyways where no drilled hole is provided for starting the cut. These cutters drill their own starting holes. Straight flute end milling

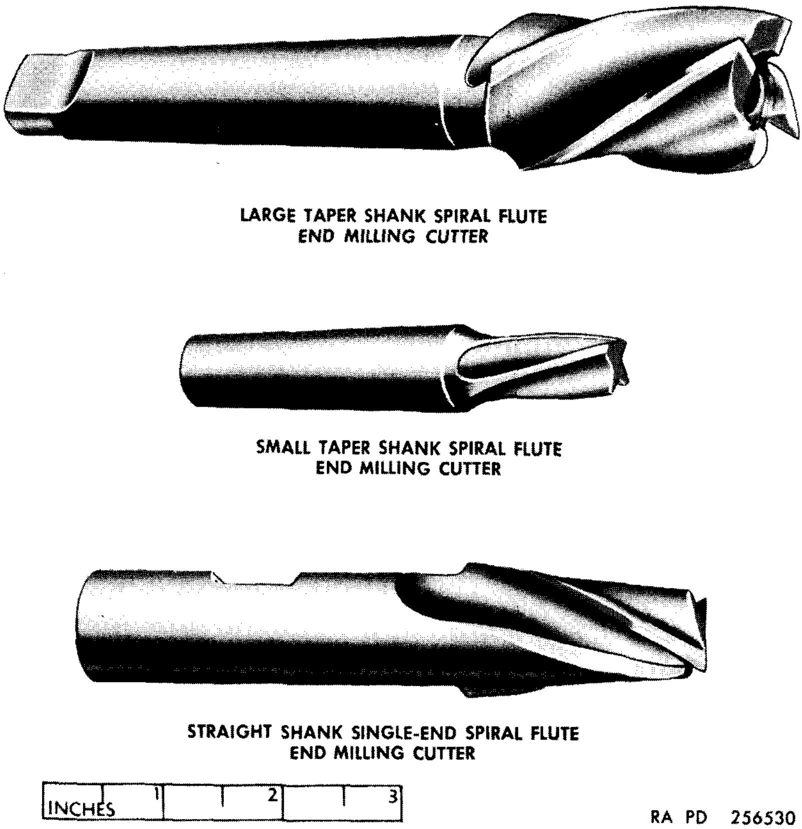
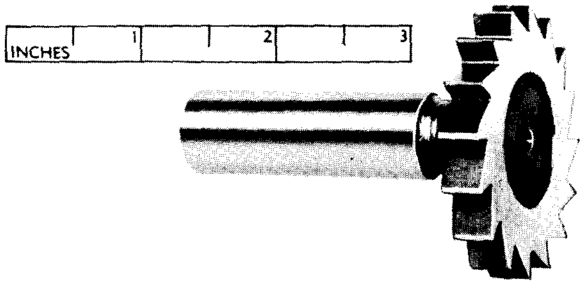


Figure 111. End milling cutters.

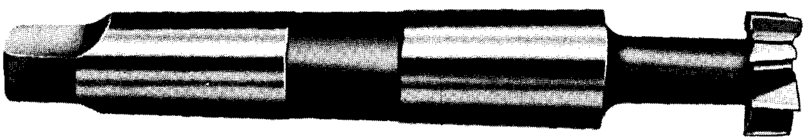
cutters are generally used for milling soft or tough materials while spiral flute cutters are used mostly for cutting steels.

(*e*) *Face milling cutter.* Face milling cutters are cutters of large diameter having no shanks. They are fastened directly to the milling machine spindle with adapters. Face milling cutters are generally made with inserted teeth of high-speed steel or tungsten carbide in a soft steel hub.

(*f*) T-*slot milling cutter* (fig. 112). The T-slot milling cutter is used to machine T-slot grooves in worktables, fixtures, and other holding devices. The cutter has a plain or side milling cutter mounted to the end of a narrow shank. The throat of the T-slot is first milled with a side or end milling cutter and the headspace is then milled with the T-slot milling cutter.



WOODRUFF KEYSLOT MILLING CUTTER



T-SLOT MILLING CUTTER RA PD 256531

Figure 112. T-*slot and woodruff keyslot milling cutters.*

(*g*) *Woodruff keyslot milling cutter* (fig. 112). The woodruff keyslot milling cutter is made in both shanked and arbor mounted types. The most common cutters of this type, those under 1½ inches in diameter, are provided with a shank. They have teeth on the circumferential surface and slightly concave sides to provide clearance. These cutters are used for milling semicylindrical keyways in shafts.

(*h*) *Angle milling cutters.* An angle milling cutter is a cutter that has peripheral teeth which are neither parallel nor perpendicular to the cutter axis. Common operations performed with angle cutters are cutting teeth in ratchet wheels, milling dovetails, and cutting V-grooves. Angle cutters may be single-angle milling cutters (fig. 113) or double-angle milling cutters. The single-angle cutter contains side cutting teeth on the flat side of the cutter. The angle of the cutter edge is usually 45°, 60°, or 80° for most operations. Double-angle cutters are used for helical milling and have one side at an angle of 12° to the axis and the other side at an included angle of 40°, 48°, or 50° to the first side.

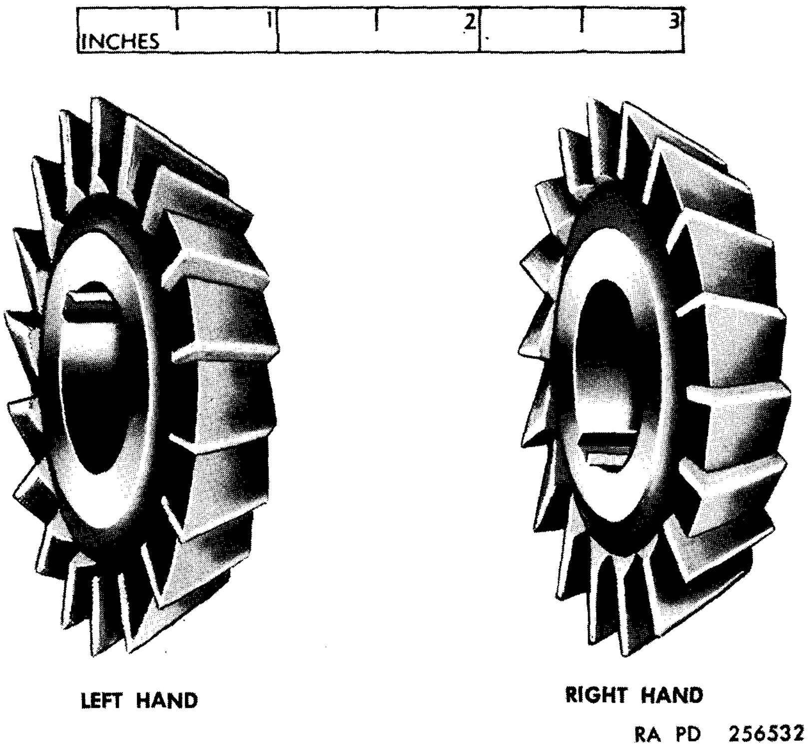


Figure 113. Single-angle milling cutters.

(*i*) *Concave and convex milling cutters* (fig. 114). Concave and convex milling cutters are formed tooth cutters shaped to produce concave and convex contours of one-half circle or less. The size of the cutter is specified by the diameter of the circular form the cutter produces.

(*j*) *Corner rounding milling cutter* (fig. 114). The corner rounding milling cutter is a formed tooth cutter used for milling rounded corners on workpieces up to and including one quarter of a circle. The size of the cutter is specified by the diameter of the circular form as with concave and convex cutters.

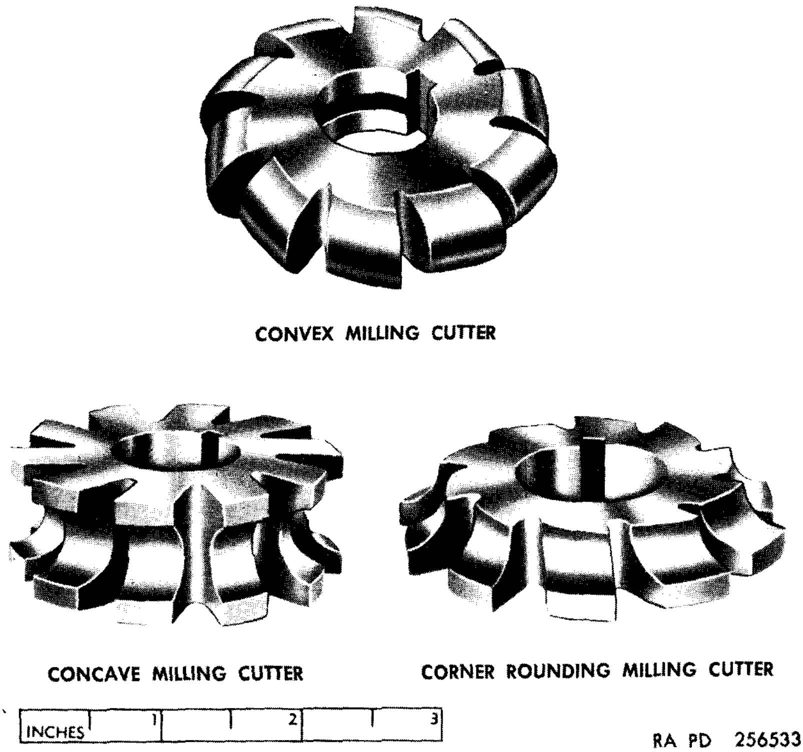


Figure 114. Concave, convex, and corner rounding milling cutters.

(*k*) *Gear hob.* The gear hob is a formed-tooth milling cutter with helical teeth arranged like the thread on a screw. These teeth are fluted to produce the required cutting edges. Hobs are generally used for such work as finishing spur gears, spiral gears, and worm wheels. They may also be employed for cutting ratchets and spline shafts.

(*l*) *Special shape formed milling cutter.* Formed milling cutters have the advantage of being adaptable to any specific shape for special operations. The cutter is made specially for each specific job. The cutter can be sharpened many times without destroying the shape of the cut.

b. Selection of Milling Cutters. The following factors should be considered in the choice of milling cutters.

(1) *Type of machine to be used.* High-speed steel, stellite, and cemented carbide cutters have the distinct advantage of being capable of rapid production when used on a machine that can reach the proper speed.

(2) *Method of holding the workpiece.* For example, 45° angular cuts may either be made with a 45° single-angle milling cutter while the workpiece is held in a swivel vise, or with an end milling cutter while the workpiece is set at the required angle in a universal vise.

(3) *Hardness of the material to be cut.* The harder the material, the greater will be the heat that is is generated in cutting. Cutters should be selected for their heat-resisting properties.

(4) *Amount of material to be removed.* A coarse-toothed milling cutter should be used for roughing cuts, whereas a finer toothed milling cutter may be used for light cuts and finishing operations.

(5) *Number of pieces to be cut.* For example, when milling stock to length, the choice of using a pair of side milling cutters to straddle the workpiece, a single-side milling cutter, or an end milling cutter will depend upon the number of pieces to be cut.

(6) *Class of work being done.* Some operations can be accomplished with more than one type of cutter such as in milling the square end on a shaft or reamer shank. In this case, one or two side milling cutters or an end milling cutter may be used. However, for the majority of operations, cutters are specially designed and named for the operation they are to accomplish.

(7) *Rigidity and size of the workpiece.* The milling cutter used should be small enough in diameter so that the pressure of the cut will not cause the workpiece to be sprung or displaced while being milled.

(8) *Size of the milling cutter.* In selecting a milling cutter for a particular job, it should be remembered that a small diameter cutter will pass over a surface in a shorter time than a large diameter cutter which is fed at the same speed. This fact is illustrated in figure 115.

c. Care and Maintenance of Milling Cutters. The life of a milling cutter can be greatly prolonged by intelligent use and proper storage. General rules for the care and maintenance of milling cutters are given below.

(1) New cutters received from stock are usually wrapped in oilpaper which should not be removed until the cutter is used.

(2) Care should be taken to operate the machine at the proper speed for the cutter being used, as excessive speed will cause the cutter to wear rapidly from overheating.

(3) Whenever practicable, the proper cutting oil should be used on the cutter and workpiece during operation, since lubrication helps prevent overheating and consequent cutter wear.

(4) Cutters should be kept sharp, because dull cutters require more power to drive and this power being transformed into heat softens the cutting edges. Dull cutters should be marked as such and set aside for grinding (*d* below).

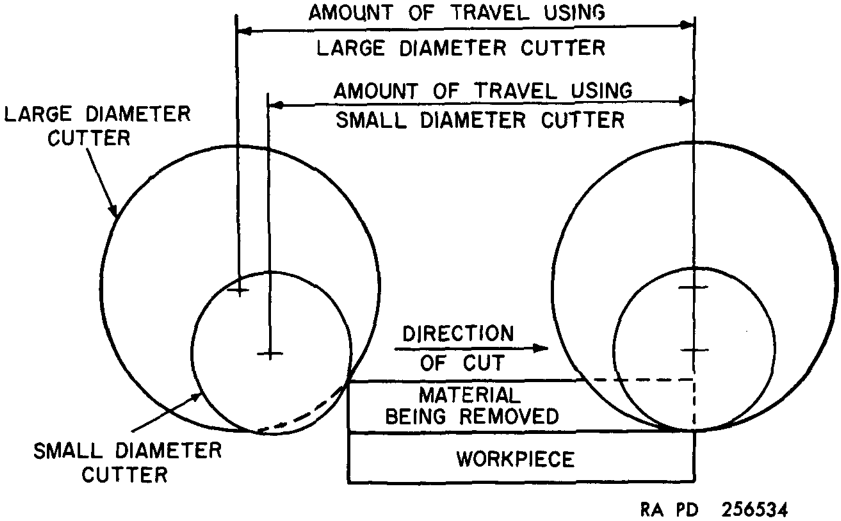


Figure 115. Effect of milling cutter diameter on workpiece travel.

(5) A cutter should never be operated backward because, due to the clearance angle, the cutter will rub producing a great deal of frictional heat. Operating the cutter backward may result in cutter breakage.

(6) Care should be taken to prevent the cutter from striking the hard jaws of the vise, chuck, clamping bolts, or nuts.

(7) A milling cutter should be thoroughly cleaned and lightly coated with oil before storing.

(8) Cutters should be placed in drawers or bins in such a manner that their cutting edges will not strike each other. Small cutters that have a hole in the center should be hung on hooks or pegs, while large cutters should be set on end. Taper and straight shank cutters may be placed in separate drawers, bins, or racks provided with suitable sized holes to receive the shanks.

d. Grinding Milling Cutters.

(1) *Purpose.* Milling cutters must be sharpened occasionally

to keep them in good operating condition. When grinding milling cutters, care must be exercised to maintain the proper angles and clearances of the cutter. Improper grinding can result in poor cutting edges, lack of concentricity, and loss of form in the case of formed tooth cutters. Milling cutters cannot be sharpened by off-hand grinding. A tool and cutter grinding machine must be used.

(2) *Bench-type tool and cutter grinding machine* (fig. 116). The bench-type tool and cutter grinding machine described here is typical of tool and cutter grinding machines. It is designed for precision sharpening of milling cutters, spot facers and counterbores, reamers, and saw blades. The grinding machine contains a ¼-horsepower electric motor mounted to a swivel-type support bracket which can be adjusted vertically and radially on the grinder column. The column is fixed to the grinder base which contains T-slots for attaching grinder fixtures used to support the tools that are to be ground. The motor shaft or wheel spindle accepts grinding wheels on each end. One end of the spindle contains a wheel guard and tool rest for off-hand grinding of lathe tools and so forth. Cup, straight, and 15° bevel taper abrasive grinding wheels are used with this machine. Fixtures used for grinding tools and cutters include a center fixture for mounting reamers, taps, and so forth between centers; an outside diameter fixture for chucking arbor-type milling cutters and shanked peripheral cutting edge tools; and an end mill fixture for supporting end cutting tools to the grinder base.

(3) *Grinding formed milling cutters.*

(*a*) Formed milling cutters are usually ground with a cup or disk grinding abrasive wheel of medium grain (36 to 60 grain).

(*b*) It is important that formed cutters be ground only on the face, never on the land. Grinding of the land would destroy the shape of the cutter. Also important, the face must be ground so that the exact rake angle is retained or the cutter will cut unevenly.

(*c*) Formed cutters are ground by radial grinding. Correctly ground cutter teeth are shown at A and B, figure 117. At A, the tooth is ground without rake; only cutters originally shaped without rake should be reground without rake. B, figure 117 shows a correctly ground tooth with positive rake; rake angles are commonly between 10° and 15° from the radius passing through the cutting edge, 12° being the most commonly used angle. The tooth shown

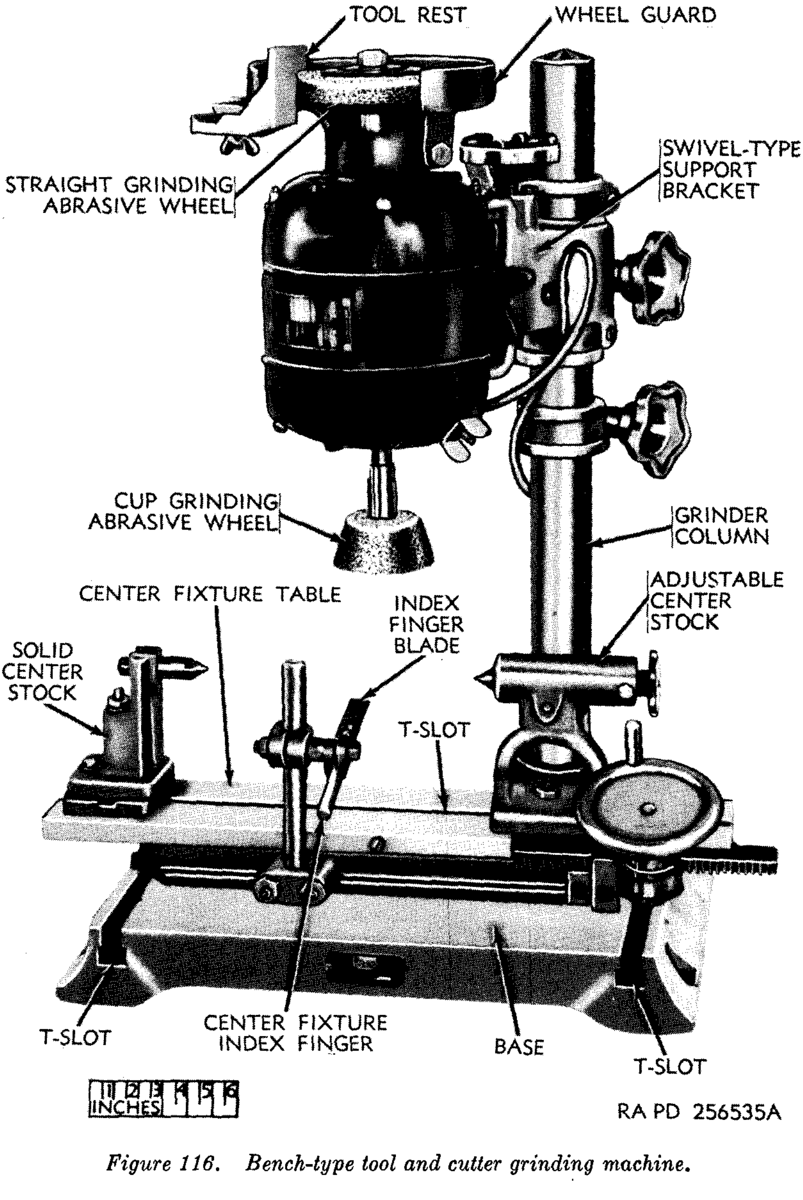


Figure 116. Bench-type tool and cutter grinding machine.

at C, figure 117 has excessive positive rake; this tooth will gouge, make an excessively deep cut, and the cutting edge will dull rapidly with hard materials. The tooth shown at D, figure 117 has negative rake; this tooth will drag and make a shallow cut.

Note. A positive rake angle is a rake angle that increases the keenness of the cutting edge. A negative rake angle is one that decreases or makes more blunt the cutting edge.

(*d*) On new cutters, the back (fig. 117) of each tooth should be ground accurately before grinding the face. This procedure is recommended so that an accurate reference surface is provided for the index finger of the grinding machine attachment. Another method of assuring this alinement is by mounting another cutter containing the same number of teeth on the same arbor with the cutter being ground. With the second cutter properly alined and locked in place, the index finger can be used against the second cutter's teeth.

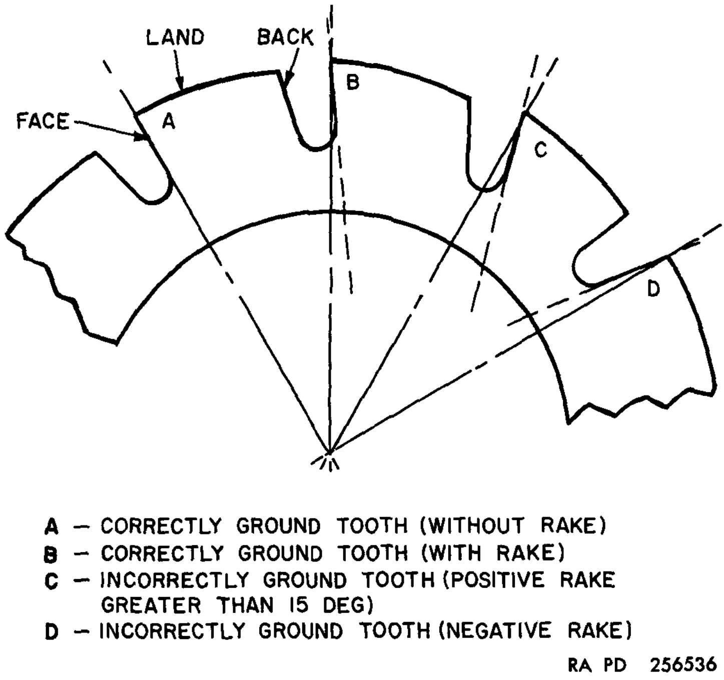


Figure 117. Correct and incorrect grinding of formed milling cutter teeth.

(*e*) The grinding abrasive wheel should be set up so that the wheel traverse is alined with the face of one tooth (fig. 118). The alinement should be checked by moving the grinding abrasive wheel away from the cutter, rotating the cutter, and rechecking the traverse on another tooth. After this alinement is effected, the depth of cut for the grinding operation is regulated by rotating the cutter slightly, thus maintaining the same rake angle on the sharpened cutter.

(*f*) The depth of cut should never be obtained by moving the cutter or grinding abrasive wheel in a direction parallel to the wheel spindle. Doing this would change the rake angle of the cutter.

(4) *Grinding plain milling cutters.*

(*a*) Plain milling cutters with saw tooth-type teeth are sharpened by grinding the lands on the periphery of the teeth. The lands may be ground using a straight grinding abrasive wheel or a cup shape grinding abrasive wheel.

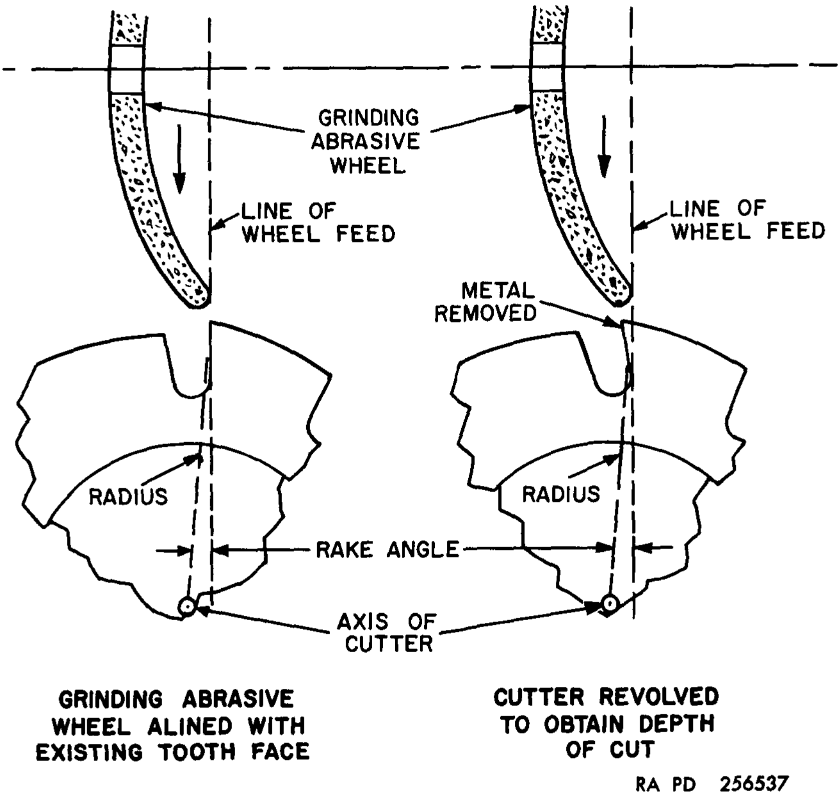


Figure 118. Alining formed milling cutter and grinding abrasive wheel.

(*b*) The important consideration when grinding this type of cutter is the primary clearance angle or relief angle of the land (fig. 107). If the primary clearance angle is too large, the cutting edge will be too sharp and the cutter will dull quickly. If the primary clearance angle is too small, the cutter will rub rather than cut and excessive heat will be generated.

(*c*) The primary clearance angle (fig. 107) should be between 3° and 5° for hard materials, and about 10° for soft materials like aluminum. For cutters under 3 inches in diameter, a larger clearance angle should be used: 7° for hard materials and 12° for soft materials.

(*d*) The clearance angle for end and side teeth should be about 2° and the face of these cutters should be ground 0.001- or 0.002-inch concave toward the center to avoid any drag.

(*e*) To grind the lands of milling cutter teeth to the primary clearance angle, the teeth are positioned against the grinding abrasive wheel below the wheel's axis (fig. 119).

1. To obtain the primary clearance angle when grinding with a straight wheel, lower the indexing finger or raise the grinding abrasive wheel a distance equivalent to 0.0088 times the clearance angle times the diameter of the grinding wheel. For example, to find the distance below center of the indexing finger (fig. 119) for a cutter with a 5° clearance angle, being ground by a straight wheel 6 inches in diameter, the calculation is as follows: $0.0088 \times 5 \times 6 = 0.264$ inch. The indexing finger would then be set 0.264 inch below the wheel axis. The milling cutter axis should also be 0.264 inch below the wheel axis.

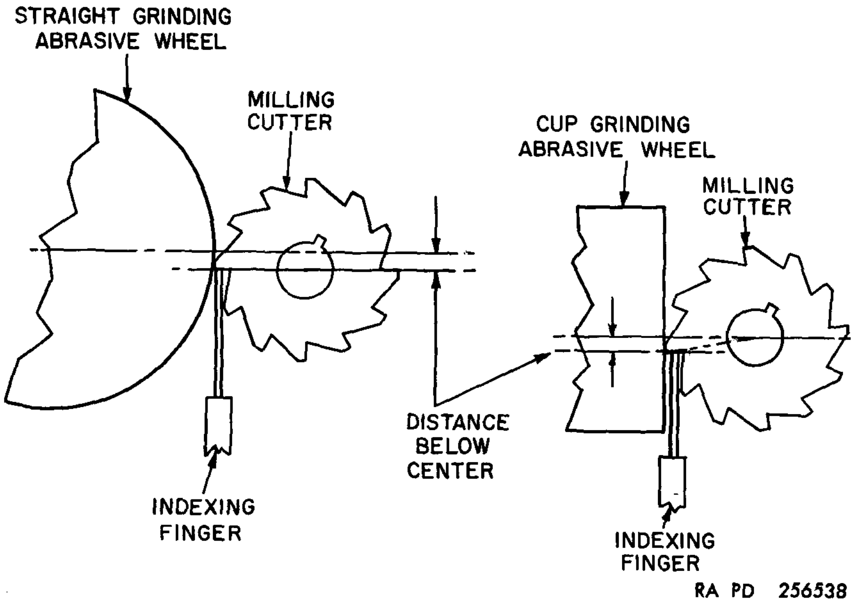


Figure 119. Grinding primary clearance angle on plain milling cutters.

2. To obtain the primary clearance angle when grinding with a cup wheel, the formula for a straight wheel is used except that instead of wheel diameter being used in the formula, the cutter diameter is used. In this case, the index finger is set to the calculated distance below the axis of the milling cutter (fig. 119) instead of below the axis of the wheel.

3. Table XIX is provided to save time in calculating distances below center for primary clearance angles. The same figures can be used for straight wheel or cup wheel grinding, substituting the wheel diameter for the cutter diameter or vice versa (*1* or *2* above).

Table XIX. Primary Clearance Angle Calculations for Straight and Cup Grinding Abrasive Wheels

Diameter in inches of wheel (straight wheel) or cutter (cup wheel)	Distance in inches below center (fig. 119) for indexing finger for primary clearance angles				
	3°	4°	5°	6°	7°
¼	0. 0066	0. 0088	0. 011	0. 013	0. 015
⅜	0. 0099	0. 013	0. 015	0. 0198	0. 022
½	0. 013	0. 0176	0. 022	0. 026	0. 030
⅝	0. 0165	0. 022	0. 028	0. 033	0. 037
¾	0. 0198	0. 026	0. 033	0. 0396	0. 045
⅞	0. 023	0. 030	0. 037	0. 046	0. 052
1	0. 0264	0. 035	0. 044	0. 0528	0. 060
1¼	0. 033	0. 044	0. 055	0. 066	0. 075
1½	0. 0396	0. 0528	0. 066	0. 079	0. 090
1¾	0. 046	0. 0616	0. 077	0. 092	0. 105
2	0. 0528	0. 070	0. 088	0. 1056	0. 125
2¼	0. 059	0. 079	0. 099	0. 1188	0. 141
2½	0. 066	0. 088	0. 110	0. 132	0. 156
2¾	0. 0726	0. 0968	0. 125	0. 145	0. 172
3	0. 079	0. 1056	0. 132	0. 158	0. 187
3¼	0. 0858	0. 114	0. 143	0. 171	0. 203
3½	0. 092	0. 123	0. 154	0. 1848	0. 219
3¾	0. 099	0. 132	0. 165	0. 198	0. 234
4	0. 1056	0. 1408	0. 176	0. 211	0. 250
4¼	0. 112	0. 1496	0. 187	0. 224	0. 265
4½	0. 1188	0. 158	0. 198	0. 237	0. 281
4¾	0. 125	0. 167	0. 209	0. 250	0. 297
5	0. 132	0. 176	0. 220	0. 264	0. 312
5¼	0. 1386	0. 1848	0. 231	0. 277	0. 328
5½	0. 145	0. 1936	0. 242	0. 290	0. 344
5¾	0. 1518	0. 202	0. 253	0. 303	0. 359
6	0. 158	0. 211	0. 264	0. 3168	0. 375
6¼	0. 165	0. 220	0. 275	0. 330	0. 390
6½	0. 171	0. 2288	0. 286	0. 343	0. 406
6¾	0. 178	0. 237	0. 297	0. 356	0. 421
7	0. 184	0. 246	0. 308	0. 396	0. 437

(*f*) The land of each tooth (fig. 107) should be from 1/32 to 1/16 inch wide, depending upon the type and size of the milling cutter. As a result of repeated grinding of the primary clearance angle, the land may become so wide as to cause the heel of the tooth to drag on the workpiece. To control the land width, a secondary clearance angle (fig. 107) is ground. This angle is usually ground to 30°, although the exact angle is not critical. Generally, an angle between 20° and 30° is sufficient to define the land of the tooth.

(5) *Grinding end milling cutters.*

(*a*) The peripheral teeth of end milling cutters are ground in the same manner as plain milling cutter ((4) above).

(*b*) When grinding the end teeth of coarse tooth end milling cutters, the cutter is supported vertically in a taper sleeve of the end mill fixture and then tilted to obtain the required clearance angle. The end mill fixture is offset slightly to grind the teeth 0.001- to 0.002-inch lower in the center to prevent dragging. A dish-shaped grinding abrasive wheel (fig. 31) revolving about a vertical spindle is used to grind end milling cutters.

(6) *Removing burs.* After the milling cutter is ground, the cutting edges should be honed with a fine oilstone to remove any burs caused by grinding. This practice will add to the keenness of the cutting edges and keep the cutting edges sharper for a longer period of time.

98. Arbors

a. Description.

(1) An arbor is a shaft or mandrel used to mount cutting tools for machining operations. Arbors are used in the milling machine spindle to secure and to drive milling cutters that cannot be mounted directly in the spindle.

(2) Arbors are supplied with one of three tapers to fit the milling machine spindle, the Milling Machines Standard taper, the Brown and Sharpe taper, and the Brown and Sharpe taper with tang (fig. 120).

(3) The Milling Machine Standard taper (fig. 120) is used on most machines of recent manufacture. It was originated by milling machine manufacturers to facilitate removal of the arbor from the spindle.

(4) The Brown and Sharpe taper (fig. 120) is found mostly on older machines. Adapters or collets are used to adapt these tapers to fit machines whose spindles have Milling Machine Standard tapers.

(5) The Brown and Sharpe taper with tang is used on some older machines. The tang engages a slot in the spindle to assist in driving the arbor.

b. Standard Milling Machine Arbor (figs. 121 and 122).

(1) The Standard Milling Machine arbor has a straight, cylindrical shape with a Standard Milling Machine taper on the driving end and a threaded portion on the opposite end to

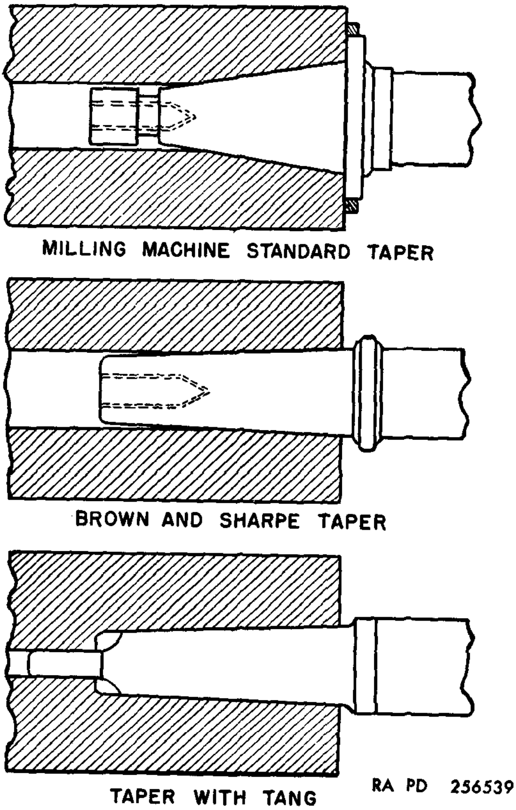


Figure 120. Tapers used for milling machine arbors.

receive the arbor nut. One or more milling cutters may be placed on the straight cylindrical portion of the arbor and held in position by means of sleeves and the arbor nut. The Standard Milling Machine arbor is usually splined and keys are used to lock each cutter to the arbor shaft. These arbors are supplied in various lengths and standard diameters.

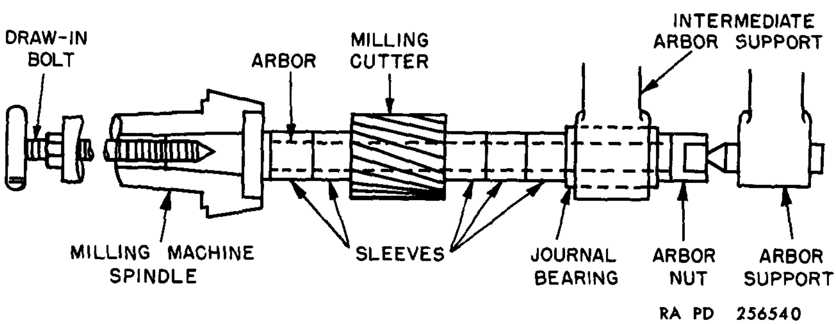


Figure 121. Standard milling machine arbor installed on the milling machine.

(2) The end of the arbor opposite the taper is supported by the arbor supports of the milling machine. One or more supports are used depending on the length of the arbor and the degree of rigidity required. The end may be supported by a lathe center bearing against the arbor nut (fig. 121) or by a bearing surface of the arbor fitting inside a bushing of the arbor support. Journal bearings are placed over the arbor in place of sleeves where an intermediate arbor support is positioned.

(3) The most common means of fastening the arbor in the milling machine spindle is by use of a draw-in bolt (fig. 121). The bolt threads into the taper shank of the arbor to draw the taper into the spindle and hold it in place. Arbors secured in this manner are removed by backing out the draw-in bolt and tapping the end of the bolt to loosen the taper.

c. Screw Arbor (fig. 122). Screw arbors are used to hold small cutters that have threaded holes. These arbors have a taper next to the threaded portion to provide alinement and support for tools that require a nut to hold them against a taper surface. A right hand threaded arbor must be used for right hand cutters while a left hand threaded arbor is used to mount left hand cutters.

d. Slitting Saw Milling Cutter Arbor (fig. 122). The slitting saw milling cutter arbor is a short arbor having two flanges between which the milling cutter is secured by tightening a clamping nut. This arbor is used to hold metal slitting saw milling cutters used for slotting, slitting, and sawing operations.

e. End Milling Cutter Arbor. The end milling cutter arbor has a bore in the end in which straight shank end milling cutters fit and are locked in place by means of a setscrew.

f. Shell End Milling Cutter Arbor (fig. 122). The shell end milling cutter arbor holds shell end milling cutters by means of a retaining screw in the end of the arbor. Two lugs on the arbor fit into the slots of the cutter to prevent the cutter from rotating on the arbor.

g. Fly Cutter Arbor (fig. 122). The fly cutter arbor is used to support a single-edge lathe, shaper, or planer cutter bit for boring and gear cutting operations on the milling machine.

99. Collets and Spindle Adapters

a. Description. Milling cutters that contain their own straight or tapered shanks are mounted to the milling machine spindle with collets or spindle adapters which adapt the cutter shank to the spindle.

b. Collets. Collets for milling machines serve to step up or increase taper sizes so that small shank tools can be fitted into large spindle recesses. They are similar to drilling machine sockets and sleeves except that their tapers are not alike.

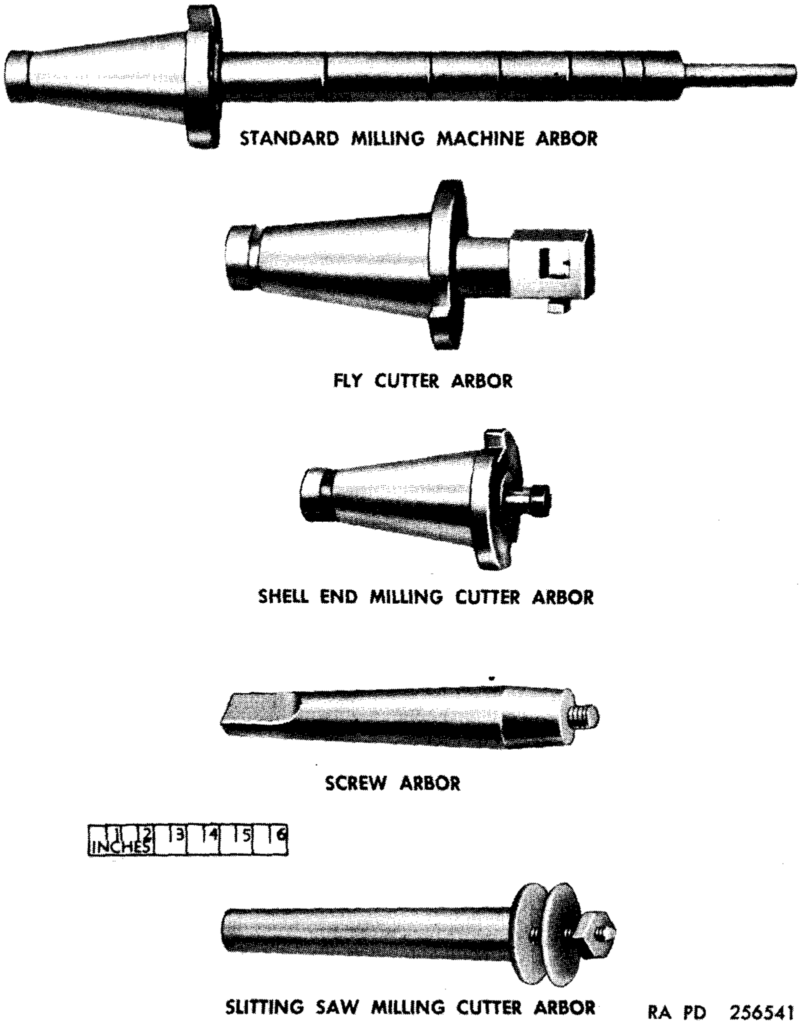


Figure 122. Types of milling machine arbors.

c. Spindle Adapters. Spindle adapters are used to adapt arbors and milling cutters to the standard tapers used for milling machine spindles. With the proper spindle adapters, any taper or straight shank cutter or arbor can be fitted to any milling machine if sizes and tapers are standard.

100. Chucks

a. Various forms of chucks can be fitted to milling machine spindles for holding drills, reamers, and small cutters for special operations.

b. Spring chucks generally consist of a collet adapter, a spring collet, and a clamping device. The collet adapter is inserted into the milling machine spindle, being manufactured with one of the three standard spindle tapers (par. 98*a*). The spring collet closes against the shank of the tool by means of a cap nut that forces the jaws against a tapered seat in the adapter.

c. Drill chucks can be fitted into spindle adapters or collets so that they may be held to the milling machine spindle.

101. Vises

Either a plain or swivel-type vise is furnished with each milling machine. The plain vise, similar to the machine table vise (par. 26*a*), is used for milling straight workpieces and is bolted to the milling machine table at right angles or parallel to the machine arbor. The swivel vise (fig. 123) can be rotated and contains a scale graduated in degrees at its base to facilitate the milling of workpieces at any angle on a horizontal plane. The universal vise, which may be obtained as extra equipment, is designed so that it can be set at both horizontal and vertical angles. This type of vise may be used for all classes of flat and angular milling.

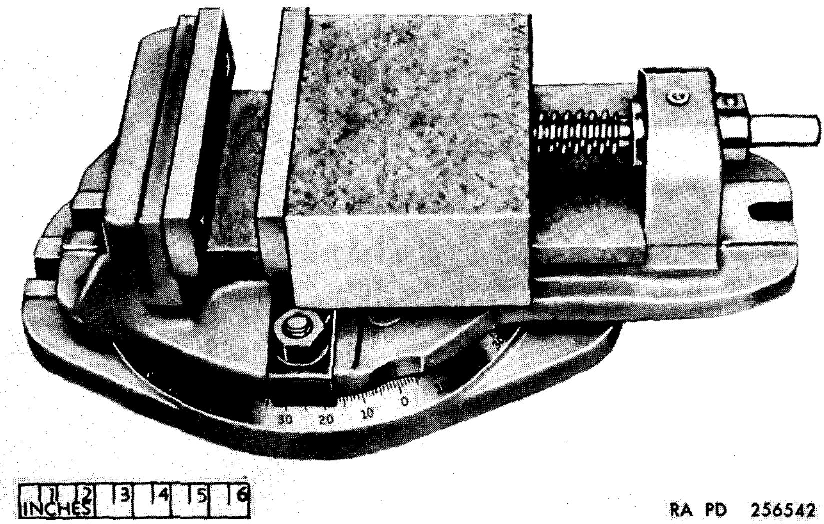


Figure 123. Swivel vise.

102. Adjustable Angle Plate

The adjustable angle plate is a workpiece-holding device similar to the universal vise in operation. Workpieces are mounted to the angle plate with T-bolts and clamps in the same manner used to fasten workpieces to the worktable of the milling machine. The angle plate can be adjusted to any angle so that bevels and tapers can be cut without using a special milling cutter or an adjustable cutter head.

103. Indexing Fixture

(fig. 124)

a. The indexing fixture is an indispensable accessory for the milling machine. Basically, it is a device for mounting workpieces and rotating them a specified amount about the workpiece axis, as from one tooth space to another on a gear or cutter.

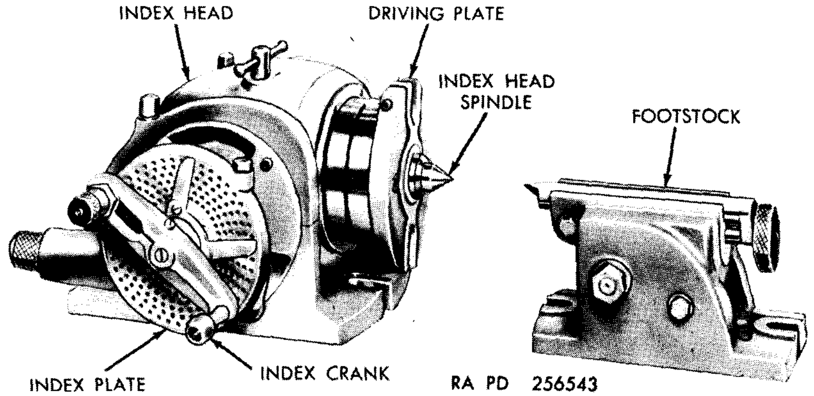


Figure 124. Indexing fixture.

b. The index fixture consists of an index head, also called a dividing head, and a footstock which is similar to the tailstock of a lathe. The index head and footstock attach to the worktable of the milling machine by T-slot bolts. An index plate containing graduations is used to control the rotation of the index head spindle. The plate is fixed to the index head, and an index crank, connected to the index head spindle by a worm gear and shaft, is moved about the index plate. Workpieces are held between centers by the index head spindle and footstock. Workpieces may also be held in a chuck mounted to the index head spindle or may be fitted directly into the taper spindle recess of some indexing fixtures.

c. There are many variations of the indexing fixture. Universal index head is the name applied to an index head designed to permit power drive of the spindle so that helixes may be cut on the milling machine. Gear cutting attachment is another name applied to an indexing fixture; in this case, one that is primarily intended for cutting gears on the milling machine.

104. High-Speed Milling Attachment

The rate of spindle speed of the milling machine may be increased from 1½ to 6 times by the use of the high-speed milling attachment.

This attachment is essential when using cutters and twist drills which must be driven at a high rate of speed in order to obtain an efficient surface speed. The attachment is clamped to the column of the machine and is driven by a set of gears from the milling machine spindle.

105. Vertical Spindle Attachment

This attachment converts the horizontal spindle of a horizontal milling machine to a vertical spindle. It is clamped to the column and driven from the horizontal spindle. It incorporates provisions for setting the head at any angle, from the vertical to the horizontal, in a plane at right angles to the machine spindle. End milling and face milling operations are more easily accomplished with this attachment, due to the fact that the cutter and the surface being cut are in plain view.

106. Universal Milling Attachment

This device is similar to the vertical spindle attachment (par. 105) but is more versatile. The cutter head can be swiveled to any angle in any plane, whereas the vertical spindle attachment only rotates in one plane from horizontal to vertical.

107. Circular Milling Attachment

This attachment consists of a circular worktable containing T-slots for mounting of workpieces. The circular table revolves on a base which attaches to the milling machine worktable. The attachment can be either hand or power driven, being connected to the table drive shaft if power driven. It may be used for milling circles, arcs, segments, and circular slots, as well as for slotting internal and external gears. The table of the attachment is divided in degrees.

108. Offset Boring Head

The offset boring head is an attachment that fits to the milling machine spindle and permits a single-edge cutting tool, such as a lathe cutter bit, to be mounted off-center on the milling machine. Workpieces can be mounted in a vise attached to the worktable and can be bored with this attachment.

Section III. MOUNTING AND INDEXING WORK

109. General

a. An efficient and positive method of holding workpieces to the milling machine table is important if the machine tool is to be used to advantage. Regardless of the method used in holding, there are certain factors that should be observed in every case. The workpiece must not be sprung in clamping; it must be secured to prevent it from springing or moving away from the cutter; and it must be so alined that it may be correctly machined.

b. Milling machine worktables are provided with several T-slots which are used either for clamping and locating the workpiece itself or for mounting the various holding devices and attachments. These T-slots extend the length of the table and are parallel to its line of travel. Most milling machine attachments, such as vises and index fixtures, have keys or tongues on the underside of their bases so that they may be located correctly in relation to the T-slots.

110. Methods of Mounting Workpieces

a. Clamping a Workpiece to the Table. When clamping workpieces to the worktable of the milling machine, the table and workpiece should be free from dirt and burs. Workpieces having smooth machined surfaces may be clamped directly to the table, provided the cutter does not come in contact with the table surface during the machining operation. When clamping workpieces with unfinished surfaces in this way, the table face should be protected by pieces of soft metal. Clamps should be placed squarely across the workpiece to give a full bearing surface. These clamps are held by T-slot bolts inserted in the T-slots of the table. Clamping bolts should be placed as near to the workpiece as possible so that full advantage of the fulcrum principle may be obtained. When it is necessary to place a clamp on an overhanging part, a support should be provided between the overhang and the table to prevent springing or possible breakage. A stop should be placed at the end of the workpiece where it will receive the thrust of the cutter when heavy cuts are being taken.

b. Clamping a Workpiece to the Angle Plate. Workpieces clamped to the angle plate (par. 102) may be machined with surfaces parallel, perpendicular, or at an angle to a given surface. When using this method of holding a workpiece, precautions should be taken similar to those mentioned for clamping directly to the table. Angle plates may be of either the adjustable or the nonadjustable type and are generally held in alinement by means of keys or tongues that fit into the table T-slots.

c. Clamping Workpieces in Fixtures. Fixtures are generally used in production work where a number of identical pieces are to be machined. The design of the fixture is dependent upon the shape of the piece and the operations to be performed. Fixtures are always constructed to secure maximum clamping surfaces and are built to use a minimum number of clamps or bolts in order to reduce the time required for setting up. Fixtures should always be provided with keys to assure positive alinement with the table T-slots.

d. Holding Workpieces Between Centers. The indexing fixture is used to support workpieces which are centered on both ends. When the piece has been previously reamed or bored, it may be pressed upon a mandrel and then mounted between the centers as with a lathe (par. 76).

(1) Two types of mandrels may be used for mounting workpieces between centers. The solid mandrel is satisfactory for many operations, while one having a shank tapered to fit into the index head spindle is preferred in certain cases.

(2) A steady rest is used to prevent springing of long slender workpieces held between centers or workpieces that extend some distance from the chuck.

(3) Workpieces mounted between centers are fixed to the index head spindle by means of a lathe dog. The bent tail of the dog should be fastened between the setscrews provided in the driving center clamp, in such a manner as to avoid backlash and prevent springing of the mandrel. When milling certain types of workpieces, a milling machine dog may be utilized to advantage. The tail of this dog is held in a flexible ball joint which eliminates shake or spring of the dog or the workpiece. The flexible ball joint allows the tail of the dog to move in a radius along the axis of the workpiece, making it particularly useful in the rapid milling of tapers.

e. Holding Workpieces in a Chuck. Before screwing the chuck to the index head spindle, it should be cleaned and any burs on the spindle or chuck removed. Burs may be removed with a smooth cut, three-cornered file or scraper, while cleaning should be accomplished with a piece of spring-steel wire bent and formed to fit the angle of the threads, or by the use of compressed air. The chuck should not be tightened on the spindle so tightly that a wrench or bar is required to remove it. Cylindrical workpieces, held in the universal chuck, may be checked for trueness by using a test indicator mounted upon a base resting upon the milling machine table. The indicator point should contact the circumference of small diameter workpieces, or the circumference and exposed face of large diameter pieces. While checking, the workpiece should be revolved by rotating the index head spindle.

f. Holding Workpieces in the Vise. As previously mentioned, three types of vises are manufactured in various sizes for holding milling machine workpieces. These vises have locating keys or tongues on the underside of the base so that they may be located correctly in relation to the T-slots on the milling machine table.

(1) The plain vise may be fastened to the milling machine table and located either parallel or perpendicular to the arbor by means of the keys.

(2) The swivel vise (fig. 123) is fitted into a graduated circular

base which is fastened to the milling machine table and located by means of keys placed in the T-slots. By loosening the bolts which clamp the vise to its graduated base, the vise may be moved to hold the workpiece at any angle in a horizontal plane. To set a swivel vise accurately with the machine spindle, a test indicator should be clamped to the machine arbor and a check made to determine the setting by moving either the transverse or the longitudinal feeds, depending upon the position of the vise jaws. Any deviation as shown by the test indicator should be corrected by swiveling the vise on its base.

(3) The universal vise is constructed in such a way as to allow it to be set at any angle, either horizontally or vertically, to the axis of the milling machine spindle. Due to the flexibility of this vise, it is not adaptable for heavy milling.

(4) When rough or unfinished workpieces are to be vise mounted, a piece of protecting material should be placed between the vise and the workpiece to eliminate any marring of the jaws.

(5) When it is necessary to position a workpiece above the vise jaws, parallels of the same size and of the proper height should be used. These parallels should only be high enough to allow the required cut as excessive raising reduces the holding ability of the jaws. When holding a workpiece on parallels, a soft hammer should be used to tap the top surface of the piece after the vise jaws have been tightened. This tapping should be continued until the parallels cannot be moved by hand and after once being set, additional tightening of the vise should not be attempted, as such tightening has a tendency to raise the work off the parallels. Correct selection of parallels is illustrated in figure 125.

(6) If the workpiece is so thin that it is impossible to let it extend over the top of the vise, hold-down straps, such as those illustrated in figure 126, are generally used. These straps are hardened pieces of steel, having one vertical side tapered to form an angle of about 92 degrees with the bottom side and the other vertical side tapered to a narrow edge. By means of these tapered surfaces, the workpiece is forced downward onto the parallels, holding them firmly and leaving the top surface of the workpiece fully exposed to the milling cutter.

(7) Whenever possible, the workpiece should be clamped in the center of the vise jaws; however, when necessary to mill a short workpiece which must be held at the end of the vise, a spacing block of the same thickness as the piece should be placed at the opposite end of the jaws. This will avoid

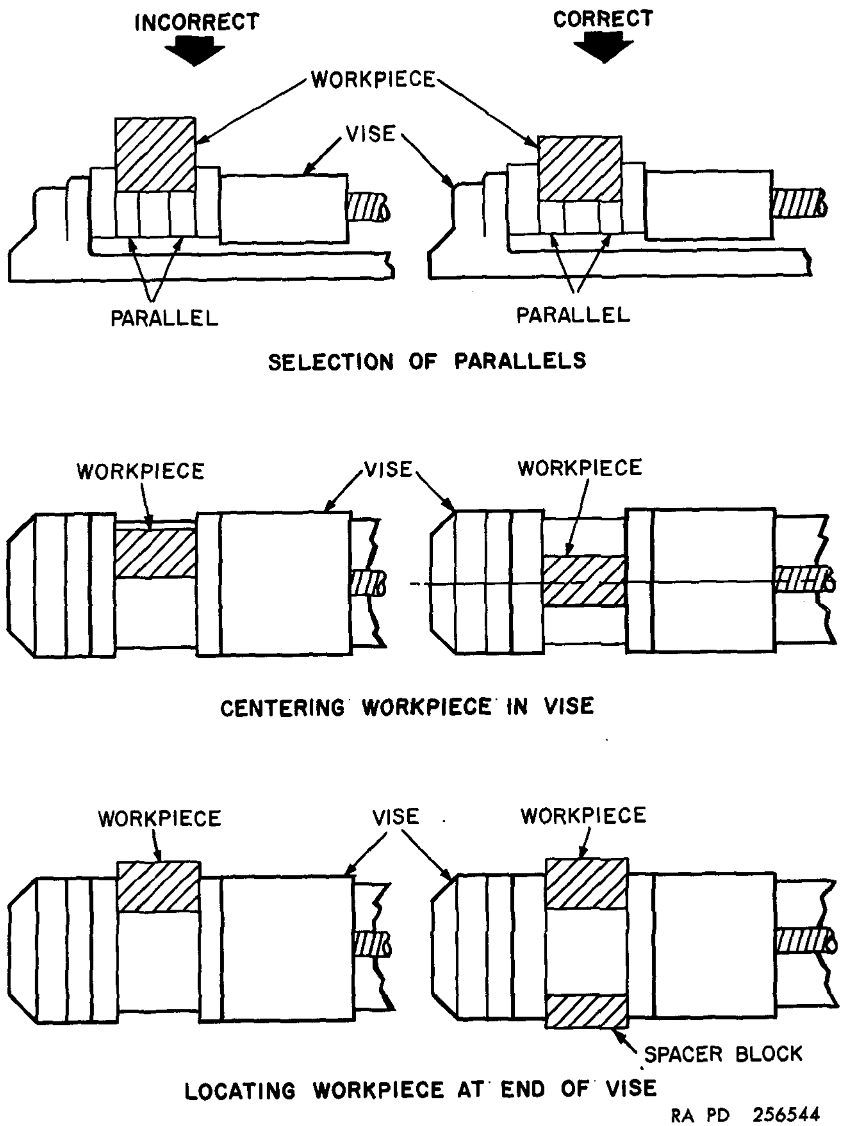


Figure 125. Mounting workpiece in the vise.

strain on the movable jaw and prevent the piece from slipping. Figure 125 illustrates the correct method of holding a workpiece in this manner.

111. Indexing Workpieces

a. General. Indexing as applied to machining practices is the process of evenly dividing or spacing workpieces such as is required in the cutting of tooth spaces on gears, the milling of grooves in reamers and taps, and the forming of teeth on milling cutters. The index head of the indexing fixture (par. 103) is used for this purpose

b. Index Head. The index head of the indexing fixture (fig. 124) contains an indexing mechanism which is used to control the rotation of the index head spindle to space or divide a workpiece accurately. Figure 127 illustrates a simple indexing mechanism. It consists of a

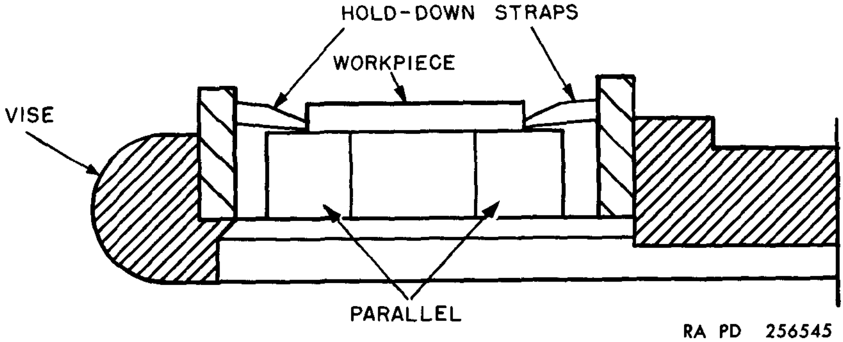


Figure 126. Application of hold-down straps.

40-tooth worm wheel fastened to the index head spindle, a single-cut worm, a crank for turning the worm shaft, and an index plate and sector. Since there are 40 teeth in the worm wheel, one turn of the index crank causes the worm wheel, and consequently the index head spindle, to make one-fortieth of a turn; so 40 turns of the index crank revolve the spindle one full turn.

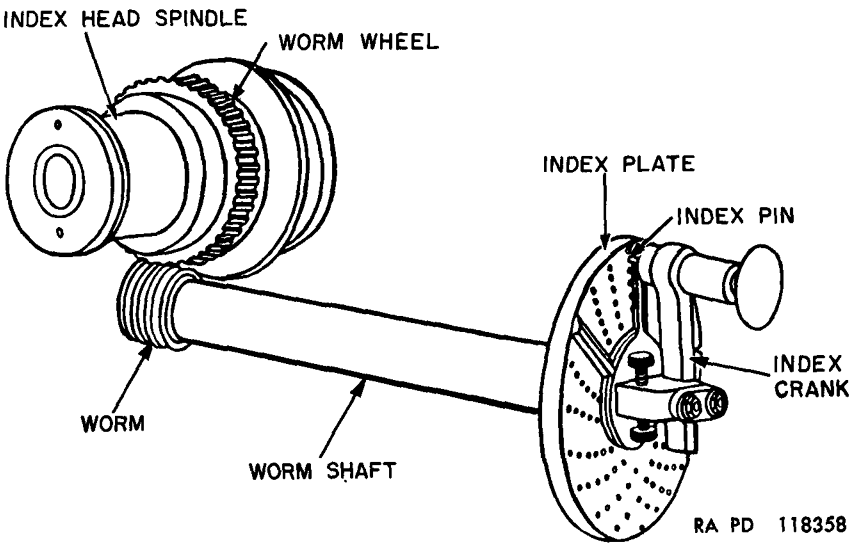


Figure 127. Simple indexing mechanism.

c. Plain Indexing.

(1) *General.* The following principles apply to basic indexing of workpieces:

(*a*) Suppose it is desired to mill a spur gear with 8 equally spaced teeth. Since 40 turns of the index crank will turn the spindle one full turn, one-eighth of 40 or 5 turns of crank after each cut will space the gear for 8 teeth. If it is desired to space equally for, say, 10 teeth, one-tenth of 40 or 4 turns would produce the correct spacing.

(*b*) The same principle applies whether or not the divisions required divide evenly into 40. For example, if it is desired to index for 6 divisions, 6 divided into 40 equals 6⅔ turns; similarly, to index for, say, 14 spaces, 14 divided into 40 equals 2$\frac{6}{7}$ turns. These examples may be multiplied indefinitely and from them the following rule is derived: To determine the number of turns of the index crank needed to obtain one division of any number of equal divisions on the workpiece, divide 40 by the number of equal divisions desired (provided the worm wheel has 40 teeth, which is standard practice).

(2) *Index plate.* The index plate (fig. 128) is a round plate with a series of six or more circles of equally spaced holes; the index pin on the crank can be inserted in any hole in any circle. With the interchangeable plates regularly furnished with most index heads, the spacings necessary for most gears, bolt heads, milling cutters, splines, and so forth, can be obtained. The following sets of plates are standard equipment:

(*a*) Brown and Sharpe type, 3 plates of 6 circles each, drilled as follows:

Plate 1—15, 16, 17, 18, 19, 20 holes.
Plate 2—21, 23, 27, 29, 31, 33 holes.
Plate 3—37, 39, 41, 43, 47, 49 holes.

(*b*) Cincinnati type, one plate drilled on both sides with circles divided as follows:

First side—24, 25, 28, 30, 34, 37, 38, 39, 41, 42, 43 holes.
Second side—46, 47, 49, 51, 53, 54, 57, 58, 59, 62, 66 holes.

(3) *Indexing operation.* The two following examples show how the index plate is used to obtain any desired part of a whole spindle turn by plain indexing.

(*a*) *To mill a hexagon.* Using the rule previously given in (1)(*b*) above, divide 40 by 6, which equals 6⅔ turns, or six full turns plus ⅔ of a turn on any circle whose number of holes is divisible by 3. Therefore, 6 full turns of the crank plus 12 spaces on an 18-hole circle, or 6 full turns plus 26 spaces on a 39-hole circle will produce the desired rotation of the workpiece.

(b) *To cut a gear of 42 teeth.* Using the rule again, divide 40 by 42 which equals $^{40}/_{42}$ or $^{20}/_{21}$ turns, or 40 spaces on a 42-hole circle, or 20 spaces on a 21-hole circle. To use the rule given, select a circle having a number of holes divisible by the denominator of the required fraction of a turn reduced to its lowest terms. The number of spaces between holes gives the desired fractional part of the whole circle. When counting holes, start with the first hole ahead of the index pin.

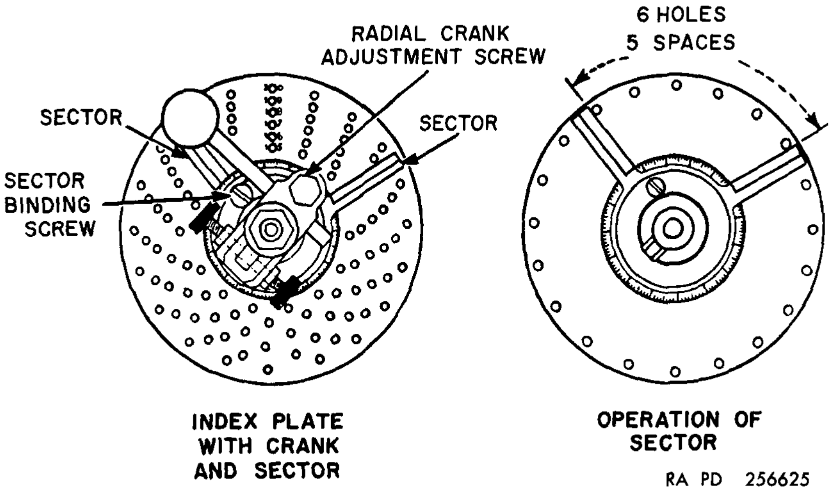


Figure 128. Index plate and sector.

(4) *Sector.* The sector (fig. 128) indicates the next hole in which the pin is to be inserted and makes it unnecessary to count holes when moving the index crank after each cut. It consists of two radial, beveled arms which can be set at any angle to each other and then moved together around the center of the index plate. Suppose that as shown in figure 128 it is desired to make a series of cuts, moving the index crank 1¼ turns after each cut. Since the circle illustrated has 20 holes, turn the crank one full turn, plus 5 spaces, after each cut. Set the sector arms to include the desired fractional part of a turn, or 5 spaces, between the beveled edges of its arms, as shown. If the first cut is taken with the index pin against the left hand arm, to take the next cut, move the pin once around the circle and into the hole against the right hand arm of the sector. Before taking the second cut, move the arms so that the left hand arm is

again against the pin; this moves the right hand arm another five spaces ahead of the pin. Then take the second cut, repeat the operation until all the cuts have been completed.

Note. It is good practice always to index clockwise on the plate.

d. Direct Indexing. The construction of some index heads permits the worm to be disengaged from the worm wheel, making possible a quicker method of indexing called direct indexing. The index head is provided with a knob which when turned through part of a revolution operates an eccentric and disengages the worm. Direct indexing is accomplished by an additional index plate fastened to the index head spindle. A stationary plunger in the index head fits the holes in this index plate. By moving this plate by hand to index directly, the spindle and the workpiece rotate an equal distance. Direct index plates usually have 24 holes and offer a quick means of milling squares, hexagons, taps, etc. Any number of divisions which is a factor of 24 can be indexed quickly and conveniently by the direct indexing method.

e. Differential Indexing. Sometimes a number of divisions is required which cannot be obtained by simple indexing with the index plates regularly supplied. To obtain these divisions, a differential index head is used. The index crank is connected to the worm shaft by a train of gears instead of a direct coupling as with simple indexing. The selection of these gears involves calculations similar to those used in calculating change gear ratios for lathe thread cutting.

f. Indexing in Degrees. Workpieces can be indexed in degrees as well as fractions of a turn with the usual index head. There are 360° in a complete circle and one turn of the index crank revolves the spindle one-fortieth of a revolution or 9°. Therefore one-ninth turn of the crank rotates the spindle 1°. Workpieces can therefore be indexed in degrees by using a circle of holes divisible by 9. For example, moving the crank 2 spaces on an 18-hole circle, 3 spaces on a 27-hole circle, or 4 spaces on a 36-hole circle will rotate the spindle 1°. Smaller crank movements further subdivide the circle: moving 1 space on an 18-hole circle turns the spindle ½° (30 min.), 1 space on a 27-hole circle turns the spindle ⅓° (20 min.), and so forth.

Section IV. GENERAL MILLING OPERATIONS

112. General

a. The success of any milling operation depends to a great extent upon the judgment in setting up the job, selecting the proper milling cutter, and holding the cutter by the best means under the circumstances. Some fundamental practices have been proved by experience to be necessary for good results on all jobs. Some of these practices are mentioned below.

(1) Before setting up a job, be sure that the workpiece, the

table, the bore in the spindle, and the arbor or cutter shank are all clean and free from chips, nicks, or burs.

(2) Set up every job as close to the milling machine column as the circumstances permit.

(3) Do not select a milling cutter of larger diameter than is necessary.

(4) Keep milling cutters sharp at all times.

(5) Do not change feeds or speeds while the milling machine is in operation.

(6) Always lower the table before backing the workpiece under a revolving milling cutter.

(7) Feed the workpiece in a direction opposite to the rotation of the milling cutter, except when milling long or deep slots or when cutting off stock (par. 114*d*).

(8) Never run a milling cutter backward.

(9) When using clamps to secure workpieces, be sure that they are tight and that the piece is held so that it will not spring or vibrate under cut.

(10) Use a recommended cutting oil liberally.

(11) Keep chips away from the table and from around the workpiece; brush them out of the way by any convenient means, but do not do so by hand or with waste.

(12) Use good judgment and common sense in planning every job, and profit by previous mistakes.

b. Milling operations may be classified under four general headings as follows:

(1) Face milling—machining flat surfaces which are at right angles to the axis of the cutter.

(2) Plain or slab milling—machining flat surfaces which are parallel to the axis of the cutter.

(3) Angular milling—machining flat surfaces which are at an inclination to the axis of the cutter.

(4) Form milling—machining surfaces having an irregular outline.

c. Explanatory names, such as sawing, slotting, gear cutting, etc., have been given to special operations. Routing is a term applied to the milling of an irregular outline while controlling the workpiece movement by hand feed. The grooving of reamers and taps is called fluting. "Gang" milling is the term applied to an operation in which two or more milling cutters are used together on one arbor. "Straddle" milling is the term given to an operation in which two milling cutters are used to straddle the workpiece and mill opposite sides at the same time.

113. Speeds for Milling Cutters

a. General. The speed of a milling cutter is the distance in feet per minute each tooth travels as it cuts its chip. The number of spindle revolutions per minute necessary to give a desired peripheral speed depends on the size of the milling cutter. The best speed is determined by the kind of material being cut and the material, size, and type of cutter used. The smoothness of finish desired and power available are other factors relating to cutter speed.

b. Factors Governing Speed. There are no hard and fast rules governing the speed of milling cutters; experience has shown that the following factors must be considered in regulating speed:

(1) A metal slitting saw milling cutter can be rotated faster than a plain milling cutter having a broad face.

(2) Cutters having undercut teeth (positive rake) cut more freely than those having radial teeth (without rake) faces; hence, they may be run at higher speeds.

(3) Angle cutters must be run at slower speeds than plain or side cutters.

(4) Cutters with inserted teeth generally will not stand as much speed as solid cutters.

(5) A sharp cutter may be operated at greater speeds than a dull one.

(6) A plentiful supply of cutting oil will permit the cutter to be run at higher speeds than without a cutting oil.

c. Selecting Proper Cutting Speed.

(1) The approximate values given in table XX may be used as a guide for selecting the proper cutting speed. If the operator finds that the machine, the milling cutter, or the workpiece cannot be handled suitably at these speeds, immediate readjustment should be made.

Table XX. Milling Machine Cutting Speeds for High-Speed Steel Milling Cutters

Material	Cutting speed (sfpm)[1] [2]			
	Plain milling cutters		End milling cutters	
	Roughing	Finishing	Roughing	Finishing
Aluminum	400 to 1,000	400 to 1,000	400 to 1,000	400 to 1,000
Brass, composition	125 to 200	90 to 200	90 to 150	90 to 150
Brass, yellow	150 to 200	100 to 250	100 to 200	100 to 200
Bronze, phosphor and manganese.	30 to 80	25 to 100	30 to 80	30 to 80
Cast iron (hard)	25 to 40	10 to 30	25 to 40	20 to 45
Cast iron (soft and medium).	40 to 75	25 to 80	35 to 65	30 to 80
Monel metal	50 to 75	50 to 75	40 to 60	40 to 60
Steel, hard	25 to 50	25 to 70	25 to 50	25 to 70
Steel, soft	60 to 120	45 to 110	50 to 85	45 to 100

[1] For carbon steel cutters, decrease values by 50 percent.
[2] For carbide-tipped cutters, increase values by 100 percent.

(2) Table XX lists speeds for high-speed steel milling cutters. If carbon steel cutters are used, the speed should be about one-half the recommended speed in the table. If carbide-tipped cutters are used, the speed can be doubled.

(3) If a plentiful supply of cutting oil is applied to the milling cutter and the workpiece, speeds can be increased 50 to 100 percent.

(4) For roughing cuts, a moderate speed and coarse feed often give best results; for finishing cuts, the best practice is to reverse these conditions, using a higher speed and a lighter feed.

d. Speed Computation.

(1) The formula for calculating spindle speed in revolutions per minute is as follows:

$$\text{rpm}=\frac{12\ \text{fpm}}{\pi D}$$

where, rpm=spindle speed (in revolutions per minute);
fpm=cutting speed of milling cutter (in surface ft per minute);
$\pi=3.14$;
D=Diameter of milling cutter (in in.).

For example, the spindle speed for machining a piece of steel at a speed of 35 sfpm with a cutter 2 inches in diameter is calculated as follows:

$$\text{rpm}=\frac{12\ \text{fpm}}{\pi D}=\frac{12\times 35}{3.14\times 2}=66.9\ \text{rpm}.$$

Therefore, the milling machine spindle would be set for approximately 67 rpm.

(2) Table XXI is provided to facilitate spindle speed computations for standard cutting speeds and standard milling cutters.

114. Feeds for Milling

a. General. The rate of feed, or the speed at which the workpiece passes the cutter, determines the time required for cutting a job. In selecting the feed, there are several factors which should be considered. These factors are discussed in (1) through (4) below.

(1) Forces are exerted against the workpiece, the cutter, and their holding devices during the cutting process. The force exerted varies directly with the amount of metal removed and can be regulated by the feed and depth of cut. Therefore, the correct amount of feed and depth of cut are interrelated, and in turn are dependent upon the rigidity and power of the machine. Milling machines are limited by the power they can develop to turn the cutter and the amount of vibration they can resist when using coarse feeds and deep cuts.

Table XXI. Milling Cutter Rotational Speeds

Diameter of cutter (in.)	Cutting speed (sfpm)													
	25	30	35	40	50	60	70	80	90	100	120	140	160	200
	Cutter revolutions per minute													
1/4	382	458	535	611	764	917	1,070	1,222	1,376	1,528	1,834	2,139	2,445	3,056
5/16	306	367	428	489	611	733	856	978	1,100	1,222	1,466	1,711	1,955	2,444
3/8	255	306	357	408	509	611	713	815	916	1,018	1,222	1,425	1,629	2,036
7/16	218	262	306	349	437	524	611	699	786	874	1,049	1,224	1,398	1,748
1/2	191	229	268	306	382	459	535	611	688	764	917	1,070	1,222	1,528
5/8	153	184	214	245	306	367	428	489	552	612	736	857	979	1,224
3/4	127	153	178	203	254	306	357	408	458	508	610	711	813	1,016
7/8	109	131	153	175	219	262	306	349	392	438	526	613	701	876
1	95.5	115	134	153	191	229	267	306	344	382	458	535	611	764
1 1/4	76.3	91.8	107	123	153	183	214	245	274	306	367	428	490	612
1 1/2	63.7	76.3	89.2	102	127	153	178	204	230	254	305	356	406	508
1 3/4	54.5	65.5	76.4	87.3	109	131	153	175	196	218	262	305	349	438
2	47.8	57.3	66.9	76.4	95.5	115	134	153	172	191	229	267	306	382
2 1/2	38.2	45.8	53.5	61.2	76.3	91.7	107	122	138	153	184	213	245	306
3	31.8	38.2	44.6	51	63.7	76.4	89.1	102	114	127	152	178	203	254
3 1/2	27.3	32.7	38.2	43.6	54.5	65.5	76.4	87.4	98.1	109	131	153	174	218
4	23.9	28.7	33.4	38.2	47.8	57.3	66.9	76.4	86	95.6	115	134	153	191
5	19.1	22.9	26.7	30.6	38.2	45.9	53.5	61.1	68.8	76.4	91.7	107	122	153
6	15.9	19.1	22.3	25.5	31.8	38.2	44.6	51.0	57.2	63.6	76.3	89	102	127
7	13.6	16.4	19.1	21.8	27.3	32.7	38.2	43.7	49.1	54.6	65.5	76.4	87.4	109
8	11.9	14.3	16.7	19.1	23.9	28.7	33.4	38.2	43	47.8	57.4	66.9	76.5	95.6

(2) The feed and depth of cut also depend upon the type of milling cutter being used. For example, deep cuts or coarse feeds should not be attempted when using a small diameter end milling cutter as such an attempt would spring or break the cutter. Coarse cutters with strong cutting teeth can be fed at a faster rate of feed because the chips may be washed out more easily by the cutting oil.

(3) Coarse feeds and deep cuts should not be used on a frail workpiece or on a piece mounted in such a way that its holding device is not able to prevent springing or bending.

(4) The degree of finish required often determines the amount of feed. Using a coarse feed, the metal is removed more rapidly but the appearance and accuracy of the surface produced may not reach the standard desired for the finished product. Because of this fact, finer feeds and increased speeds are used for finer, more accurate finishes, while for roughing it is good practice to use a comparatively low speed and a heavy feed. More mistakes are made on the side of overspeeding and underfeeding than on underspeeding and overspeeding. Overspeeding may be detected by the occurence of a squeaking, scraping sound. If vibration (referred to as "chattering") occurs in the milling machine during the cutting process, the speed should be reduced and the feed increased. Too much cutter clearance, a poorly supported workpiece, or a badly worn machine gear are common causes of "chattering."

b. Designation of Feed. The feed of the milling machine may be designated either in "inches per minute" or "thousandths of an inch per revolution of the spindle."

(1) The "inches per minute" system is used in the newer machines, in which feed and spindle speed operate independently of each other.

(2) The "thousandths of an inch per revolution of spindle" system is used on the cone drive machines on which speed and feed are interdependent, and a change in speed causes a similar change in feed.

c. Typical Feeds.

(1) Feed for milling cutters will generally run from 0.002 to 0.250 inch per cutter revolution depending upon the diameter of the cutter, the kind of material, the width and depth of the cut, the size of the workpiece, and the condition of the machine.

(2) Good finishes may usually be obtained using a 3-inch plain milling cutter at a 40 feet per minute speed, with a feed of 0.040-inch per cutter revolution.

d. Direction of Feed.

(1) It is usually regarded as standard practice to feed the workpiece against the milling cutter (fig. 129). When the piece is fed against the milling cutter, the teeth cut under any scale on the workpiece surface and any backlash in the feed screw is taken up by the force of the cut.

(2) As an exception to this recommendation, it is advisable to feed with the milling cutter (fig. 129) when cutting off stock or when milling comparatively deep or long slots.

(3) The direction of cutter rotation is related to the manner in which the workpiece is held. The cutter should rotate so that the piece springs away from the cutter; then there will be no tendency for the force of the cut to loosen the piece. No milling cutter should ever be rotated backward; this will break the teeth. If it is necessary to stop the machine during a finishing cut, the power feed should never be thrown out, nor should the workpiece be fed back under the cutter unless the cutter is stopped or the workpiece lowered. Never change feeds while the cutter is rotating.

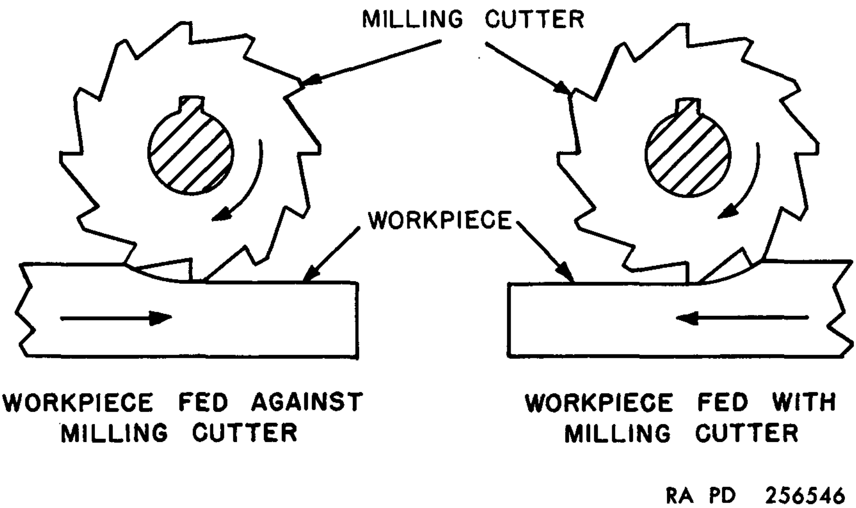


Figure 129. Direction of feed for milling.

115. Cutting Oils

a. The major advantage of a cutting oil is that it reduces frictional heat, thereby giving longer life to the cutting edges of the teeth. The oil also serves to lubricate the cutter face and to flush away the chips, consequently reducing the possibility of marring the finish.

b. Cutting oil compounds for various metals are given in table XXII. In general, a simple coolant is all that is required for roughing. Finishing requires a cutting oil with good lubricating properties to help produce a good finish on the workpiece. Aluminum and cast iron are almost always machined dry.

c. The cutting oil or coolant should be directed by means of a coolant drip can or pump system to the point where the cutter contacts the workpiece. Regardless of method used, the cutting oil should be allowed to flow freely over the workpiece and cutter.

Table XXII. Cutting Oils for Milling Operations

Material	Cutting fluid	
	Roughing	Finishing
Aluminum	Dry	Dry.
Brass, composition	Dry; soda water mixture.	Dry; turpentine.
Brass, yellow	Dry; soda water mixture	Dry.
Bronze, phosphor and manganese.	Soluble cutting oil	Sulfurized fatty mineral cutting oil; pure lard cutting oil.
Cast iron (hard)	Dry; soda water mixture	Dry; turpentine.
Cast iron (soft and medium).	Dry	Dry.
Monel metal	Dry; soluble cutting oil	Mineral fatty blend cutting oil.
Steel, hard	Soluble cutting oil; mineral fatty blend cutting oil.	Sulfurized fatty mineral cutting oil; pure lard cutting oil.
Steel, soft	Soluble cutting oil	Mineral fatty blend cutting oil.

116. Plain Milling

a. Plain milling, also called surface milling and slab milling, is the milling of flat surfaces with the milling cutter axis parallel to the surface being milled. Generally, plain milling is accomplished with the workpiece surface mounted parallel to the surface of the milling machine table and the milling cutter mounted on a standard milling machine arbor. The arbor is well supported in a horizontal plane between the milling machine spindle and one or more arbor supports.

b. The workpiece is generally clamped directly to the table or supported in a vise for plain milling. The milling machine table should be checked for alinement before starting to cut. If the workpiece surface to be milled is at an angle to the base plane of the piece, the workpiece should be mounted in a universal vise or on an adjustable angle plate. The holding device should be adjusted so that the workpiece surface is parallel to the table of the milling machine.

c. A plain milling cutter (fig. 108) should be used. Deeper cuts may generally be taken when using narrow cutters than with wide cutters. The choice of milling cutters should be based on the size of the workpiece. If a wide area is to be milled, fewer traverses will be required using a wide cutter.

d. A typical setup for plain milling is illustrated in figure 130. Note that the milling cutter is positioned on the arbor with sleeves so that it is as close as practical to the milling machine spindle while maintaining sufficient clearance between the vise and the milling machine column. This practice reduces torque in the arbor and permits more rigid support for the cutter.

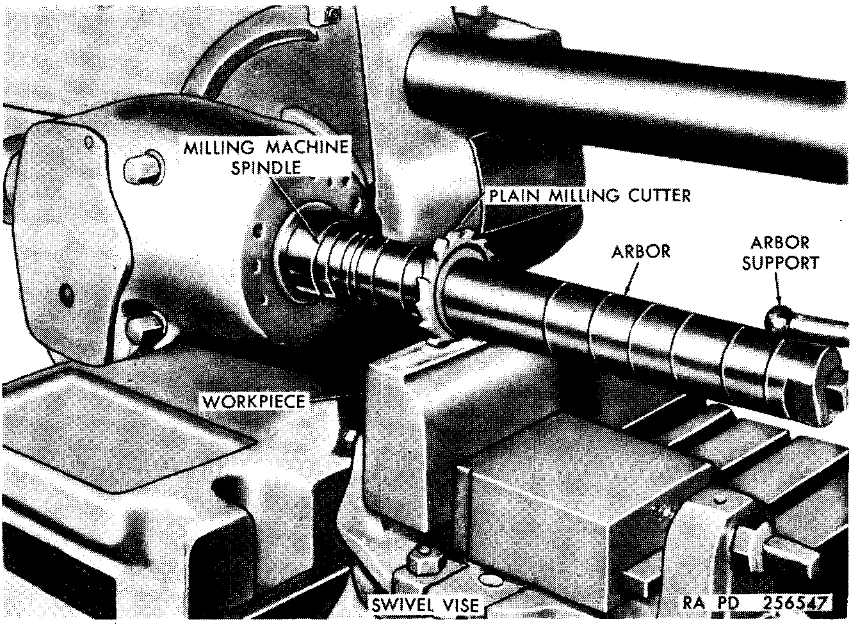


Figure 130. Plain milling operation.

e. If large quantities of metal are to be removed, a coarse tooth cutter should be used for roughing and a finer tooth cutter should be used for finishing. A relatively slow cutting speed and fast table feed should be used for roughing, and a relatively fast cutting speed and slow table feed used for finishing. The surface should be checked for accuracy after each completed cut.

117. Angular Milling

a. Angular milling, or angle milling, is the milling of flat surfaces which are neither parallel nor perpendicular to the axis of the milling cutter. A single-angle milling cutter (fig. 113) is used for this operation. The milling of dovetails is a typical example of angular milling.

b. When milling dovetails, the usual angle of the cutter is 45°, 50°, 55°, or 60° based on common dovetail designs.

(1) When cutting dovetails in the milling machine, the workpiece may be held in the vise, clamped to the table, or clamped to

an angle plate. Figure 131 shows the workpiece mounted to a lathe face plate for angular, milling with the milling and grinding lathe attachment. The tongue or groove is first roughed-out using a side milling cutter, after which the angular sides and base are finished with an angle milling cutter.

(2) In general practice, the dovetail is laid out on the workpiece surface before the milling operation is started. To do this, the required outline should be inscribed and the line prick punched. These lines and punch marks may then be used as a guide during the cutting operation.

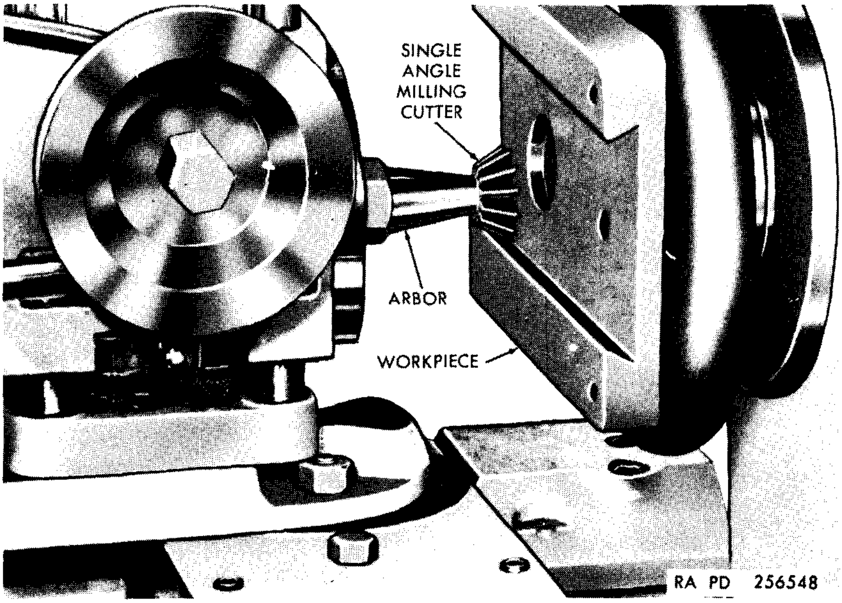


Figure 131. Angular milling of dovetail using the milling and grinding lathe attachment.

118. Straddle Milling

a. When two or more parallel vertical surfaces are machined at a single cut the operation is called straddle milling. Straddle milling is accomplished by mounting two side milling cutters on the same arbor, set apart so they straddle the workpiece.

b. Figure 144 illustrates a typical example of straddle milling. In this case, a spline is being cut but the same operation may be applied to the cutting of squares or hexagons on the end of a cylindrical workpiece. The workpiece is usually mounted between centers in the indexing fixture or mounted vertically in a swivel vise. The two side milling cutters are separated by spacers, washers, and shims so that the distance between the cutting teeth of each cutter is exactly equal to the width of the workpiece area required. When cutting a square by this method, two opposite sides of the square are cut, and then the spindle of the indexing fixture or the swivel vise is rotated 90°, and the other two sides of the workpiece are straddle milled.

119. Face Milling

a. Face milling, also called end milling and side milling, is the machining of surfaces perpendicular to the axis of the milling cutter.

b. Face milling cutters, end milling cutters (fig. 132), and side milling cutters are used for face milling operations, the size and nature of the workpiece determining the type and size of cutter required.

(1) In face milling, the teeth on the periphery of the cutter do practically all of the cutting. However, where the cutter is properly ground, the face teeth actually remove a small amount of stock which is left as a result of the springing of the workpiece or cutter, thereby producing a finer finish.

(2) It is important in face milling to have the cutter securely mounted and to see that all end play or sloppiness in the machine spindle is eliminated.

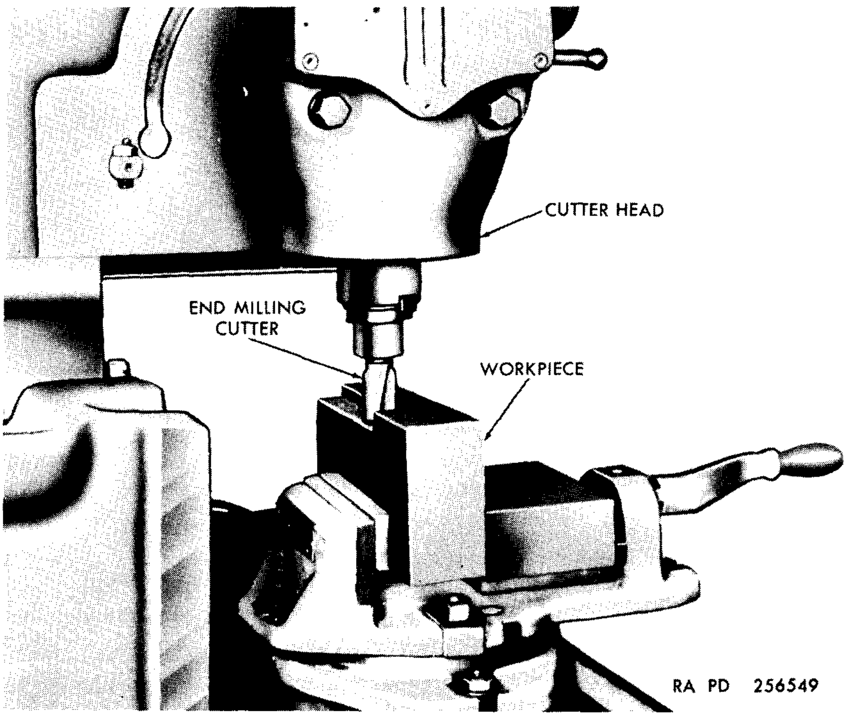


Figure 132. Face milling with vertical milling machine spindle.

c. When face milling, the workpiece may be clamped to the table or angle plate or supported in a vise, fixture, or jig.

(1) Large surfaces are generally face milled on vertical milling machines with the workpiece clamped directly to the milling machine table to simplify handling and clamping operations.

(2) Figure 132 illustrates face milling performed with a swivel cutter head milling machine with its spindle in a vertical position. The workpiece is supported parallel to the table in a swivel vise.

(3) Angular surfaces can also be face milled on a swivel cutter head milling machine (fig. 133). In this case, the workpiece is mounted parallel to the table and the cutter head is swiveled to bring the end milling cutter perpendicular to the surface to be produced.

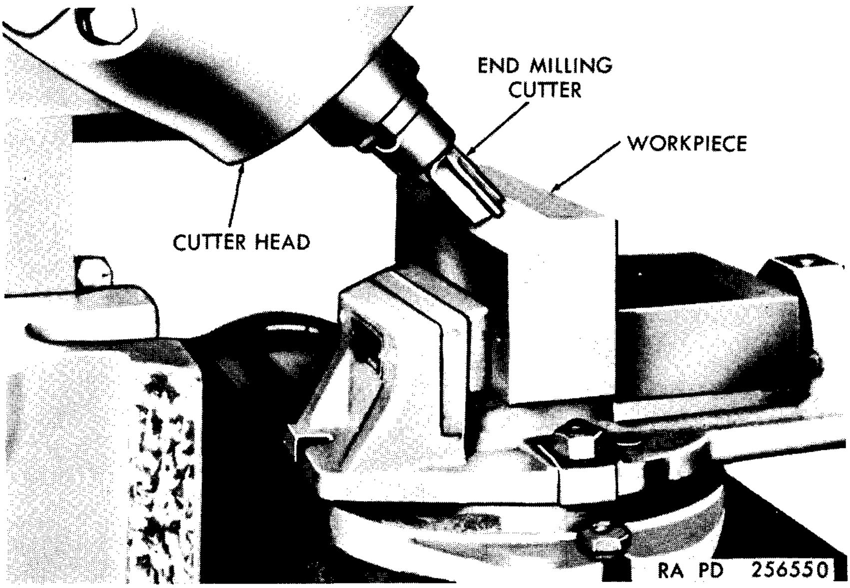


Figure 133. Angular face milling.

(4) During face milling operations, the workpiece should be fed against the milling cutter (par. 114*d*) so that the pressure of the cut is downward, thereby holding the piece against the table.

(5) Whenever possible, the edge of the workpiece should be in line with the center of the cutter. This position of the workpiece in relation to the cutter will help eliminate slippage.

d. When setting the depth of cut, the workpiece should be brought up to the cutter so that it will just tear a thin piece of paper held between the piece and the cutter teeth. At this point, the graduated dial on the traverse feed is locked and used as a guide in determining the depth of cut.

(1) When starting the cut, the workpiece should be moved so that the cutter is nearly in contact with its edge, after which the automatic feed may be engaged.

(2) When a cut is started by hand, care must be taken to avoid pushing the corner of the workpiece between the teeth of the cutter too quickly, as this may result in cutter tooth breakage.

(3) In order to avoid having any waste of time during the operation, the feed trips should be adjusted to stop the table travel just as the cutter clears the workpiece.

120. Gang Milling

When two or more parallel horizontal surfaces are milled at one cut, the operation is known as *gang milling*. The usual method is to mount two or more plain milling cutters of different diameters and widths on an arbor as shown in figure 134. The cutters so mounted are called a gang. The possible cutter combinations are unlimited and are determined in each case by the nature of the job.

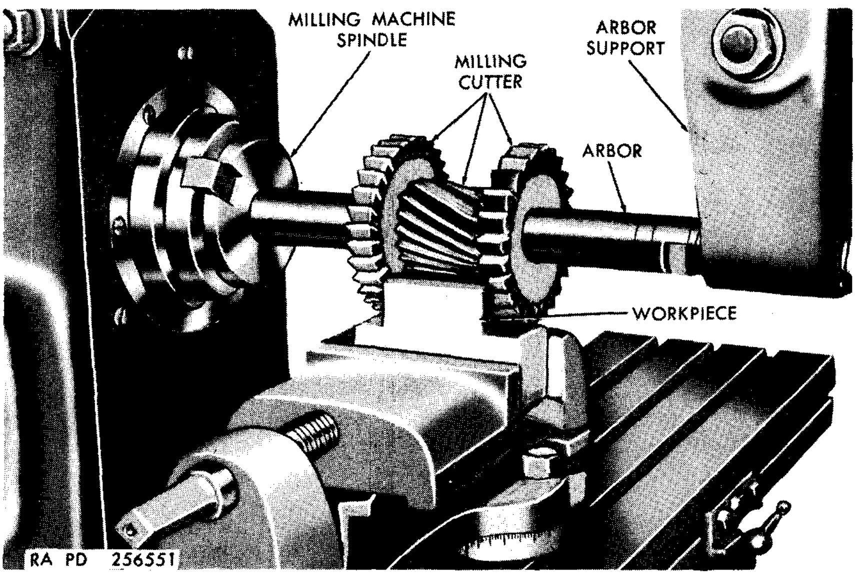


Figure 134. Gang milling operation.

121. Form Milling

a. Form milling is the process of machining special contours composed of curves and straight lines, or entirely of curves, at a single cut. This is done with formed milling cutters, shaped to the contour to be cut.

b. The more common form milling operations involve the milling of half-round recesses and beads and quarter-round radii on workpieces (fig. 135). This operation is accomplished by using convex, concave, and corner rounding milling cutters ground to the desired circle diameter.

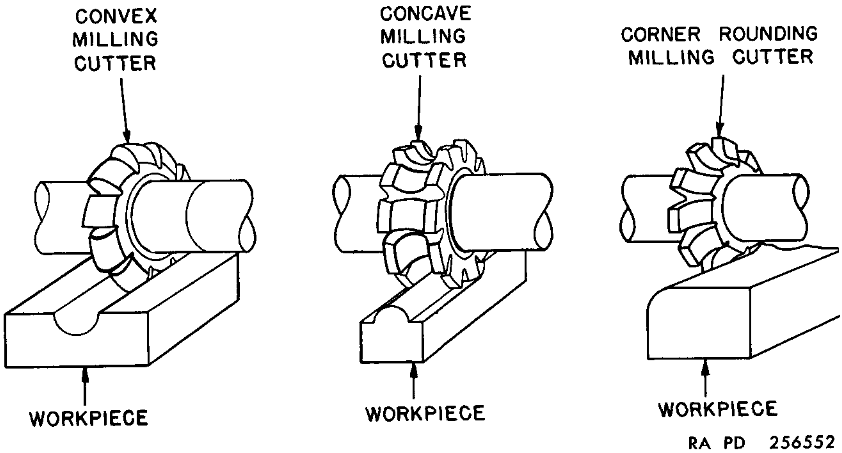


Figure 135. Form milling operation.

c. Other jobs for formed milling cutters include the milling of intricate patterns on workpieces and the milling of several complex surfaces in a single cut such as are produced by gang milling.

122. Keyway Milling

a. *General.*

(1) Keyways are grooves of different shapes cut along the axis of the cylindrical surface of shafts, into which keys are fitted to provide a positive method of locating and driving members mounted on the shafts. A keyway is also machined in the mounted member to receive the key.

(2) The type of key and corresponding keyway to be used depends upon the class of work for which it is intended. The most commonly used types of keys are the woodruff key (fig. 136), the square-ends machine key (fig. 137), and the round-ends machine key (fig. 138).

b. *Woodruff Key* (fig. 136).

(1) The woodruff keys are semicylindrical in shape and are manufactured in various diameters and widths. The circular side of the key is seated into a keyway which is milled in the shaft with a woodruff keyslot milling cutter (fig. 112) having the same diameter as that of the key.

(2) Woodruff key sizes are designated by a code number in which the last two digits indicate the diameter of the key in eighths

of an inch, and the digits preceding the last two digits give the width of the key in thirty-seconds of an inch. Thus, a number 204 woodruff key would be 4/8 or 1/2 inch in diameter and 2/32 or 1/16 inch wide, while a number 1012 woodruff key would be 12/8 or 1 1/2 inches in diameter and 10/32 or 5/16 inch wide.

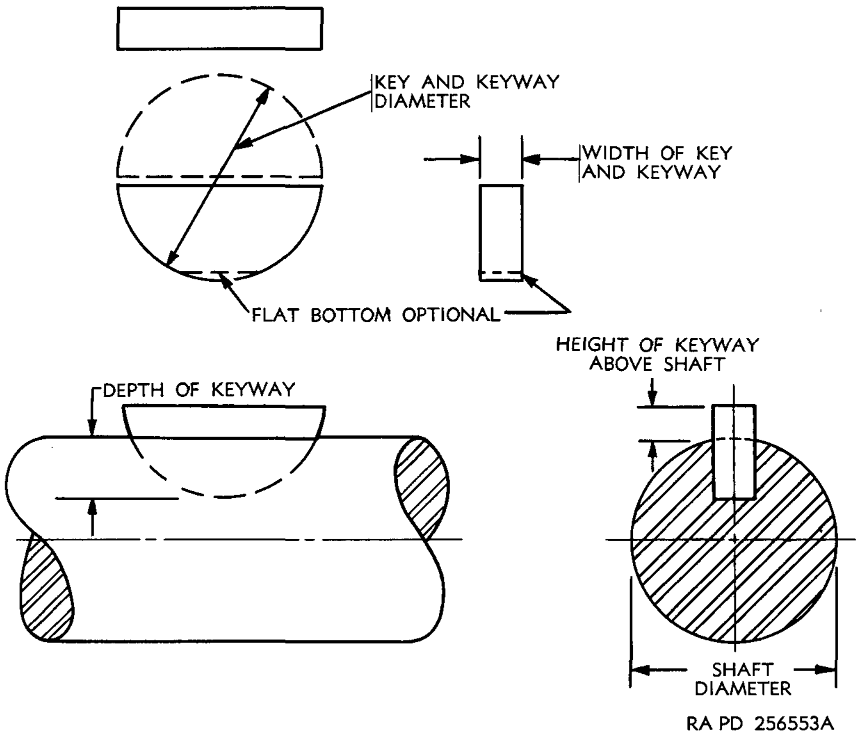


Figure 136. Woodruff key and keyway dimensions

(3) Table XXIII lists woodruff keys commonly used by the Ordnance Corps and pertinent information applicable to their machining. Woodruff keyslot milling cutters (fig. 112) of the same diameter and width as the key are used.

(4) In order that proper assembly of the keyed members may be made, a clearance is required between the top surface of the key and the keyway of the bore. This clearance may be from a minimum of 0.002 inch to a maximum of 0.005 inch. Positive fitting of the key in the shaft keyway is provided by making the key 0.0005 to 0.001 inch wider than the keyway.

c. *Square-Ends Machine Key* (fig. 137).

(1) Square-ends machine keys are square or rectangular in section and several times as long as they are wide. For the purpose of interchangeability and standardization, these

Table XXIII. Sizes of Woodruff Keys

Key number	Key dimensions		Shaft diameter		Height of key above shaft	Depth of keyway
	Diameter	Width	Minimum	Maximum		
204	1/2	1/16	5/16	3/8	0.0312	0.1718
304	1/2	3/32	7/16	1/2	0.0469	0.1561
404	1/2	1/8	9/16	3/4	0.0625	0.1405
405	5/8	1/8	9/16	3/4	0.0625	0.1875
505	5/8	5/32	13/16	15/16	0.0781	0.1719
406	3/4	1/8	11/16	3/4	0.0625	0.2505
606	3/4	3/16	1	1 1/8	0.0937	0.2193
507	7/8	5/32	7/8	15/16	0.0781	0.2969
807	7/8	1/4	15/16	1 1/8	0.1250	0.2500
608	1	3/16	1	1 7/16	0.0937	0.3443
1008	1	5/16	1 1/16	1 5/8	0.1562	0.2818
609	1 1/8	3/16	1 1/16	1 7/16	0.0937	0.3903
810	1 1/4	1/4	1 1/4	1 3/4	0.1250	0.4220
1210	1 1/4	3/8	1 1/2	1 7/8	0.1875	0.3595
1011	1 3/8	5/16	1 13/16	2	0.1562	0.4378

Note. Dimensions given in table are illustrated on figure 136.

keys are usually proportioned with relation to the shaft diameter in the following method:

(*a*) Key width equals one-quarter of the shaft diameter.

(*b*) Key thickness for rectangular section keys (flat keys) equals one-sixth of the shaft diameter.

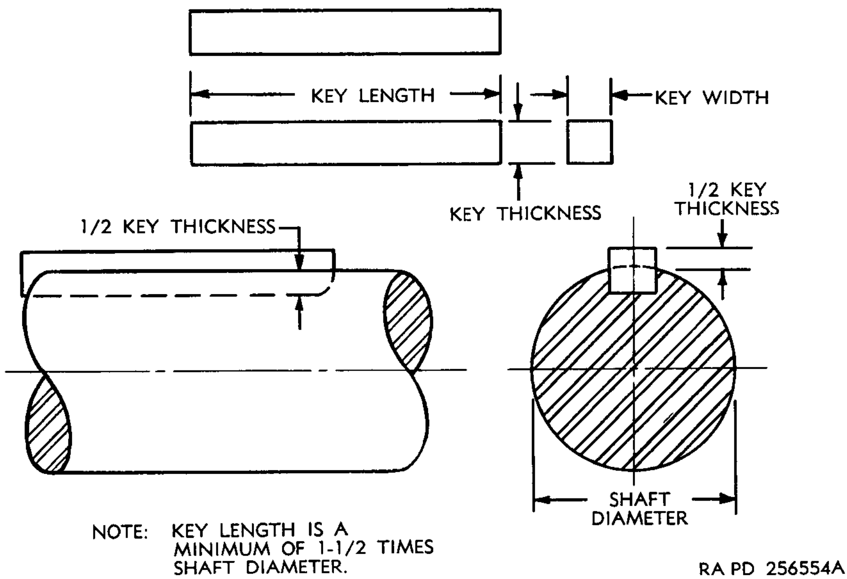


Figure 137. Square-ends machine key and keyway dimensions.

(c) Minimum length of the key equals 1½ times the shaft diameter.

(d) Depth of the keyway for square section keys is one-half the width of the key.

(e) Depth of the keyway for rectangular section keys (flat keys) is one-half the thickness of the key.

(2) Table XXIV lists common sizes for square-ends machine keys. The length of each key is not included because the key may be of any length as long as it equals at least 1½ times the shaft thickness.

Table XXIV. Dimensions of Square-Ends Machine Keys

Shaft diameter (in.)	Square section keys		Flat section keys		
	Width and thickness (in.)	Bottom of keyway to opposite side of shaft (in.)	Width (in.)	Thickness (in.)	Bottom of keyway to opposite side of shaft (in.)
½	⅛	0.430	⅛	3/32	0.455
9/16	⅛	0.493	⅛	3/32	0.509
⅝	3/16	0.517	3/16	⅛	0.548
11/16	3/16	0.581	3/16	⅛	0.612
¾	3/16	0.644	3/16	⅛	0.676
13/16	3/16	0.708	3/16	⅛	0.739
⅞	3/16	0.771	3/16	⅛	0.802
15/16	¼	0.796	¼	3/16	0.827
1	¼	0.859	¼	3/16	0.890
1 1/16	¼	0.923	¼	3/16	0.954
1⅛	¼	0.986	¼	3/16	1.017
1 3/16	¼	1.049	¼	3/16	1.081
1¼	¼	1.112	¼	3/16	1.144
1 5/16	5/16	1.137	5/16	¼	1.169
1⅜	5/16	1.201	5/16	¼	1.232
1 7/16	⅜	1.225	⅜	¼	1.288
1½	⅜	1.289	⅜	¼	1.351
1 9/16	⅜	1.352	⅜	¼	1.415
1⅝	⅜	1.416	⅜	¼	1.478
1 11/16	⅜	1.479	⅜	¼	1.542
1¾	⅜	1.542	⅜	¼	1.605
1 13/16	½	1.527	½	⅜	1.590
1⅞	½	1.591	½	⅜	1.654
1 15/16	½	1.655	½	⅜	1.717
2	½	1.718	½	⅜	1.781

Note. Dimensions given in table are illustrated on figure 137.

d. Round-Ends Machine Key (fig. 138). The round-ends machine keys are square in section with either one or both ends rounded off. These keys are similar to square-ends machine keys in measurements (table XXIV).

e. Milling Cutters Used for Milling Keyways.

(1) Shaft keyways for woodruff keys are milled with side milling cutters (fig. 108) or woodruff keyslot milling cutters (fig. 112). The woodruff keyslot milling cutters are numbered by the same system employed for identifying woodruff keys. Thus a number 204 woodruff keyslot cutter has the proper diameter and width for milling a keyway to fit a number 204 woodruff key. If a side milling cutter is used, it must be of the same width and diameter of the woodruff key, and it must attach to an arbor that is small enough in diameter to permit cutting the keyway to its proper depth.

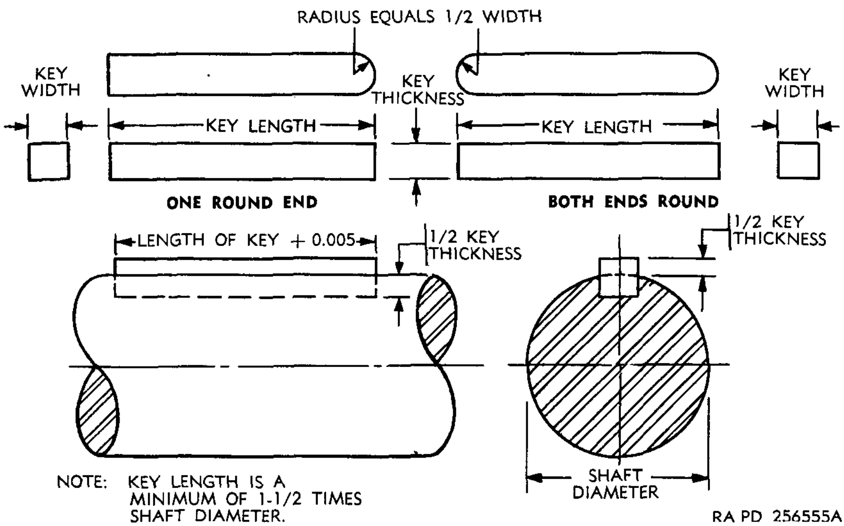


Figure 138. Round-ends machine key and keyway dimensions.

(2) Square-ends machine key shaft keyways can be cut with a plain milling cutter (fig. 108), or a side milling cutter (fig. 109) of the proper width for the key may also be used.

(3) Round-ends machine key shaft keyways must be milled with end milling cutters (fig. 111) so that the rounded end or ends of the key may fit the ends of the keyway. The cutter should be equal in diameter to the width of the key.

f. Alinement of Milling Cutters. When milling keyways, the shaft may be supported in the vise or chuck, mounted between centers or clamped to the milling machine table. The cutter must be set centrally with the axis of the workpiece and this alinement is accomplished by using one of the following methods:

(1) When using a woodruff keyslot milling cutter (fig. 112) or side milling cutter, the shaft or cutter should be positioned so

that the side of the cutter is tangent to the circumference of the shaft. This is accomplished by moving the shaft transversely to a point that permits tearing of a thin piece of paper held between the workpiece and the cutter side teeth. At this point, the graduated dial on the crossfeed is locked and the milling machine table is lowered. Then, using the crossfeed graduated dial as a guide, the shaft is moved transversely a distance equal to the radius of the shaft plus one-half the width of the cutter.

(2) End mills may be alined centrally by first causing the workpiece to contact the periphery of the cutter, then proceeding as in (1) above.

(3) A convenient method of alining the milling cutter and workpiece for keyway cutting is to center the cutter approximately over the center of the workpiece, and take a very light cut from the workpiece surface. If the cutter is off center, the shoulder on one side of the cut will be deeper and a pattern such as illustrated in dotted lines on figure 139 will appear. When the cutter is centered, the shoulders on each side will be equal and the pattern at the end of the cut will be symmetrical. By careful visual inspection, the milling cutter can be positioned quite accurately by this method.

(4) When the workpiece is held so that it can be revolved by the index head of the indexing fixture, alinement of the cutter may be accomplished by inscribing a line along the peripheral surface of the workpiece parallel to the axis and at the same height as the centers of the index head. After this has been done, the workpiece is indexed one-fourth of a revolution (ten turns) to bring the line on top center, and the milling machine table is adjusted to a position which places the line directly under one edge of the cutter. With the cutter revolving, the workpiece is raised in order to produce tool marks on its periphery, then moved transversely to bring the line to the edge of the cutter. At this point, the graduated dial on the transverse feed is locked and used as a guide in moving the work transversely, one-half the width of the cutter.

(5) An approximate or visual method of alinement may be used where extreme accuracy is not required. This is done by setting the cutter as near the center of the workpiece as is possible by eye and making the final alinement, by measuring the distance between each side of the workpiece and the sides of the milling cutter using a machinist's square and a machinist's steel rule as illustrated in figure 140.

g. Milling Woodruff Keyways (fig. 136). The woodruff keyslot milling cutter (fig. 112) is mounted in a spring collet or adapter which has been inserted in the spindle of the milling machine. With the

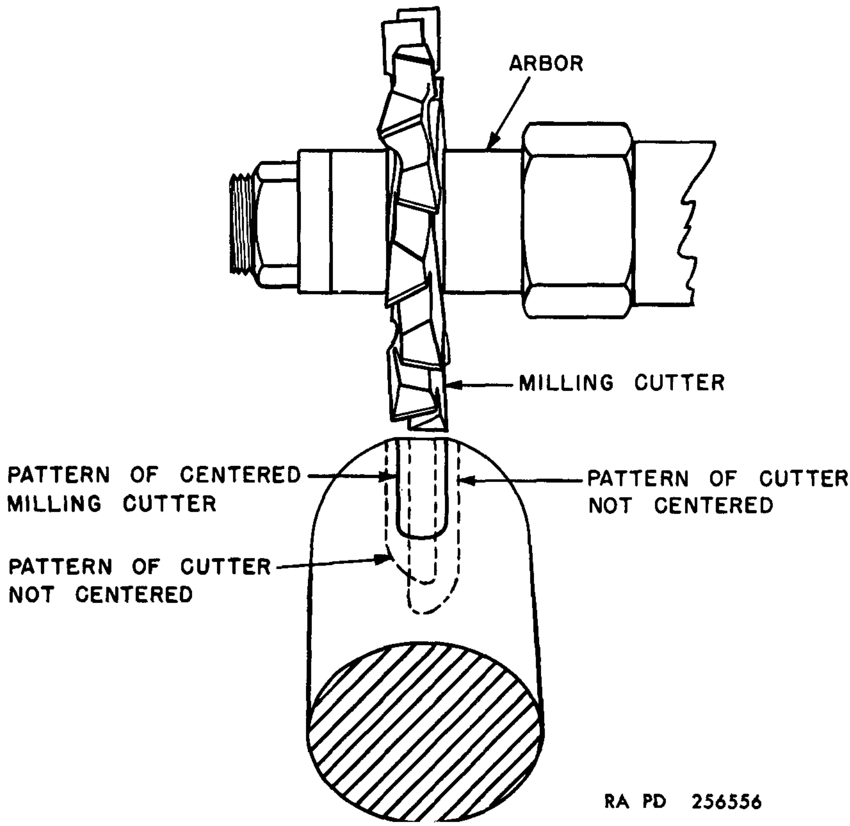


Figure 139. Alining milling cutter for cutting keyway by visual method.

milling cutter located over the position in which the keyway is to be cut, the workpiece should be raised or the cutter lowered until the cutter tears a piece of thin paper held between the peripheral teeth of the cutter and the workpiece. At this point the graduated dial on the vertical feed adjustment should be locked and the clamp on the table set. Using vertical feed, with the graduated dial as a guide, the workpiece is raised or the cutter lowered until the full depth of the keyslot is cut, completing the operation (fig. 141). Refer to table XXIII for correct depth of keyway cut for standard woodruff key sizes.

h. Milling Keyway for Square-Ends Machine Key (fig. 137). The workpiece should be properly mounted, the cutter centrally located, and the workpiece raised or the cutter lowered until the milling cutter tears a piece of thin paper held between the peripheral teeth of the cutter and the piece. At this point the graduated dial on the vertical feed is locked and the workpiece or milling head moved longitudinally to allow the cutter to clear the piece. The vertical hand feed screw is then used to raise the workpiece or lower the cutter the total depth of cut. After this adjustment, the vertical adjustment control should

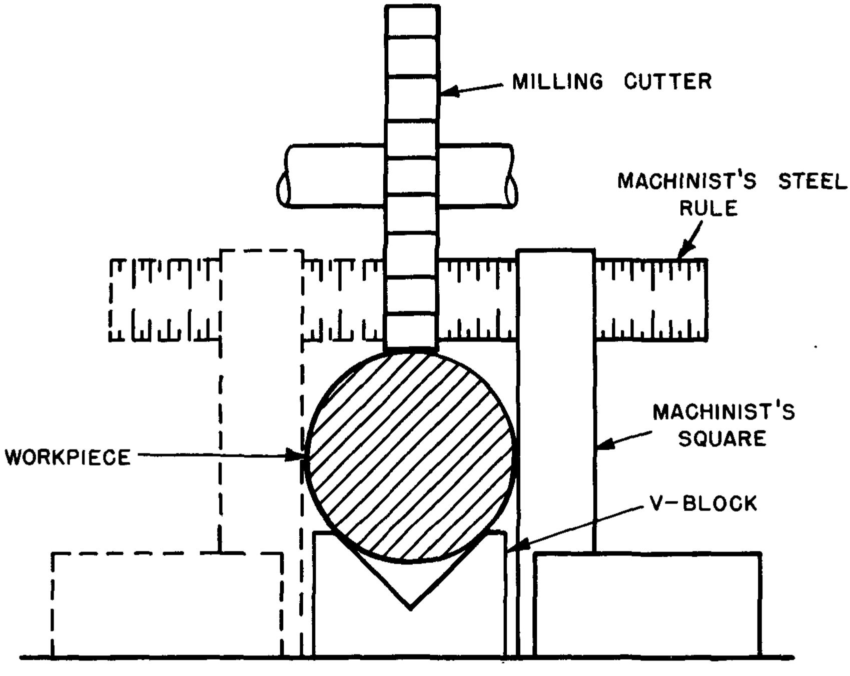


Figure 140. Alining milling cutter for cutting keyway using machinist's square.

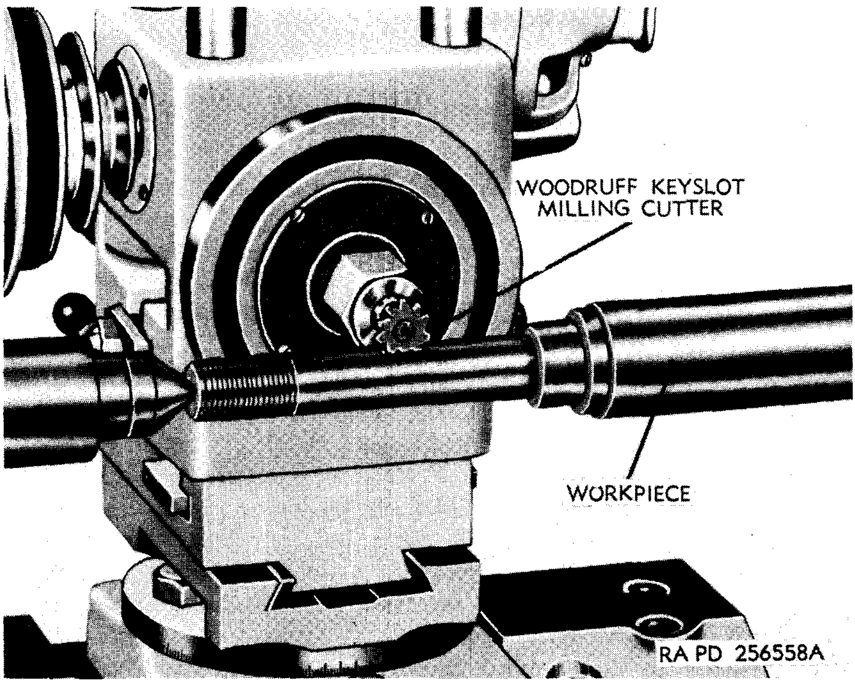


Figure 141. Woodruff keyway milling using the milling and grinding lathe attachment.

be locked, and the cut made by feeding the table or milling head longitudinally.

i. Milling Keyway for Round-Ends Machine Key (fig. 138). Round end keyways are milled with an end milling cutter of the proper diameter. As in the case of square-ends machine key keyways, the workpiece should be properly mounted and the cutter centrally located with respect to the shaft. The shaft or cutter is then positioned to permit the end of the cutter to tear a piece of thin paper held between the cutter and the workpiece. At this point the graduated feed dial should be locked and used as a guide for setting the cutter to the total depth. The ends of the keyway should be well marked and the workpiece or cutter moved back and forth, making several passes to eliminate error due to spring of the cutter.

123. T-Slot Milling

a. General. The cutting of T-slots in workpiece holding devices is a typical milling operation. The size of the T-slots depends upon the size of the T-slot bolts which will be used. Dimensions of T-slot bolts and T-slots are standardized for specific bolt diameters. The dimensions for bolt diameters commonly used by the Ordnance Corps are given in table XXV.

b. Selection of Milling Cutters. Two milling cutters are required for milling T-slots, a T-slot milling cutter (fig. 112) and either a side milling cutter or an end milling cutter. The side milling cutter, preferably of the staggered tooth type (fig. 110), or the end milling cutter (fig. 111) is used to cut a slot in the workpiece equal in width to the throat width of the T-slot and equal in depth to slightly less than the head space depth plus the throat depth (fig. 142). The T-slot milling cutter is then used to cut the head space to the prescribed dimensions.

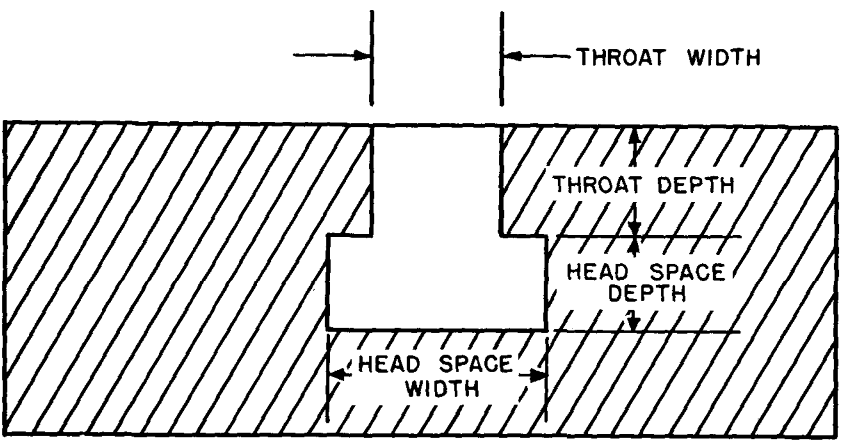


Figure 142. T-Slot dimensions.

Table XXV. Dimensions of T-Slots

T-bolt size (diameter in in.)	Throat width (in.)	Throat depth (in.)		Head space (in.)	
		Max.	Min.	Width	Depth
1/4	9/32	3/8	1/8	9/16	15/64
5/16	11/32	7/16	5/32	21/32	17/64
3/8	7/16	9/16	7/32	25/32	21/64
1/2	9/16	11/16	5/16	31/32	25/64
5/8	11/16	7/8	7/16	1 1/4	31/64
3/4	13/16	1 1/16	9/16	1 15/32	1 3/32

Note. Dimensions given in table are illustrated on figure 142.

c. Milling the T-slot.

(1) The position of the T-slot is layed out on the workpiece. The throat depth (fig. 142) is determined by taking into consideration the thickness of the workpiece and the maximum and minimum dimesions allowable (table XXV).

(2) A side milling cutter or an end milling cutter is then selected. The cutter should be of proper size to mill a slot equal in width to the throat width prescribed for the T-slot size desired. Cut a plain groove equal to about 1/64 inch less than the combined throat depth and head space depth (fig. 142).

(3) Select a T-slot milling cutter for the size T-slot to be cut. T-slot milling cutters are identified by the T-slot bolt diameter, and are manufactured with the proper diameter and width to cut the head space to the dimensions given in table XXV. Position the T-slot milling cutter over the edge of the workpiece and aline it with the previously cut groove. Feed the table or milling head longitudinally to make the cut. Flood the cutter and workpiece with cutting oil during this operation.

124. Sawing and Parting

a. Metal slitting saw milling cutters (fig. 109) are used to part stock on a milling machine. The stock may be held by any one of the methods described in paragraph 110, although care must be taken to mount the piece rigidly. Figure 143 illustrates the parting of solid stock. The workpiece is being fed against the rotation of the cutter (par. 114*d*).

b. For greater rigidity while parting thin material such as sheet metal, the workpiece may be clamped directly to the table with the line of cut over one of the table T-slots. In this case the workpiece should be fed into, with the rotation of the milling cutter to prevent it from being raised off the table. Every precaution should be taken to eliminate backlash and spring in order to prevent climbing or gouging of the workpiece.

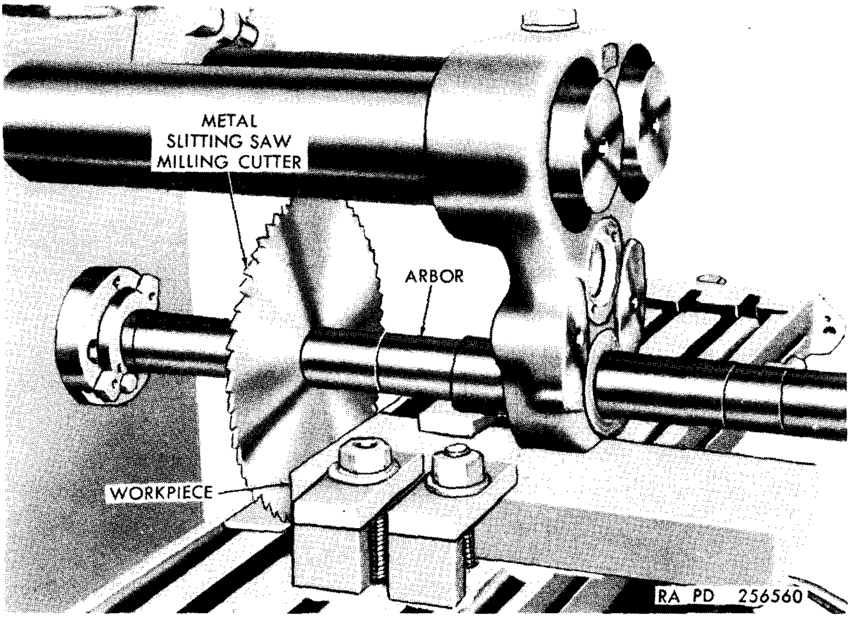


Figure 143. Parting solid stock.

125. Helical Milling

a. A helix may be defined as a regular curved path, such as is formed by winding a cord around the surface of a cylinder. Helical parts, most commonly cut on the milling machine, include helical gears, spiral flute milling cutters, twist drills, and helical cam grooves. When milling a helix, a universal index head (par. 103*c*) is used to rotate the workpiece at the proper rate of speed while the piece is fed against the cutter. A train of gears between the table feed screw and the index head serves to rotate the workpiece the required amount for a given longitudinal movement of the table.

b. The milling of helical parts requires the use of special formed milling cutters and double-angle milling cutters not available in the Ordnance Corps. Also, the calculations and formulas necessary to compute proper worktable angles, gear adjustments, and cutter angles and positions, are beyond the scope of this manual.

126. Gear Cutting

a. Gear teeth are cut on the milling machine using formed milling cutters called involute gear cutters. These cutters are manufactured in many pitch sizes and shapes for different numbers of teeth per gear.

b. Involute gear cutters are not available in the Ordnance Corps. Therefore gear cutting is not practical except in emergencies when gear teeth must be restored on gears that cannot be replaced. In this case a fly cutter arbor (fig. 122) is mounted in the milling machine spindle. A lathe cutter bit (par. 62) is ground to approximate the shape of the gear tooth spaces. The gear is milled in the following manner:

Note. This method of gear cutting is not accurate and should be used only for emergency cutting of gear teeth which have been built up in the Ordnance shop by welding.

(1) Fasten the indexing fixture to the milling machine table. Use a mandrel to mount the gear between the index head and footstock centers. Adjust the indexing fixture on the milling machine table or adjust the position of the cutter to make the gear axis perpendicular to the milling machine spindle axis.

(2) Fasten the cutter bit that has been ground to the shape of the gear tooth spaces in the fly cutter arbor (fig. 122). Adjust the cutter centrally with the axis of the gear. Rotate the milling machine spindle to position the cutter bit in the fly cutter so that its cutting edge is downward

(3) Aline the tooth space to be cut with the fly cutter arbor and cutter bit by turning the index crank on the index head.

(4) Proceed to mill the tooth in the same manner as milling a keyway (par. 122).

Section V. SPECIAL OPERATIONS ON MILLING MACHINES

127. Spline Milling

a. Splines are often used instead of keys for the transmission of power from a shaft to a hub, or from a hub to a shaft. Splines are, in effect, a series of parallel keys formed integral with the shaft, mating corresponding grooves in the hub or fitting. They are particularly useful where the hub must slide axially on the shaft, either under load or freely. Typical applications for splines are found in geared transmissions, machine tool drives, and in automotive mechanisms.

b. Spline shafts and spline fittings are generally cut by hobbing and broaching on special machines. However, when spline shafts must be cut for a repair job, the operation may be accomplished on the milling machine in a manner similar to that described for cutting keyways (par. 122).

c. Standard spline shafts and spline fittings are cut with 4, 6, 10, or 16 splines (fig. 144), and their dimensions depend upon the class of fit for the desired application: a permanent fit, a sliding fit when not under load, and a sliding fit under load. Table XXVI lists the standard dimensions for 4-, 6-, 10-, and 16-spline shafts.

d. Spline shafts can be milled on the milling machine in a similar manner to the cutting of keyways.

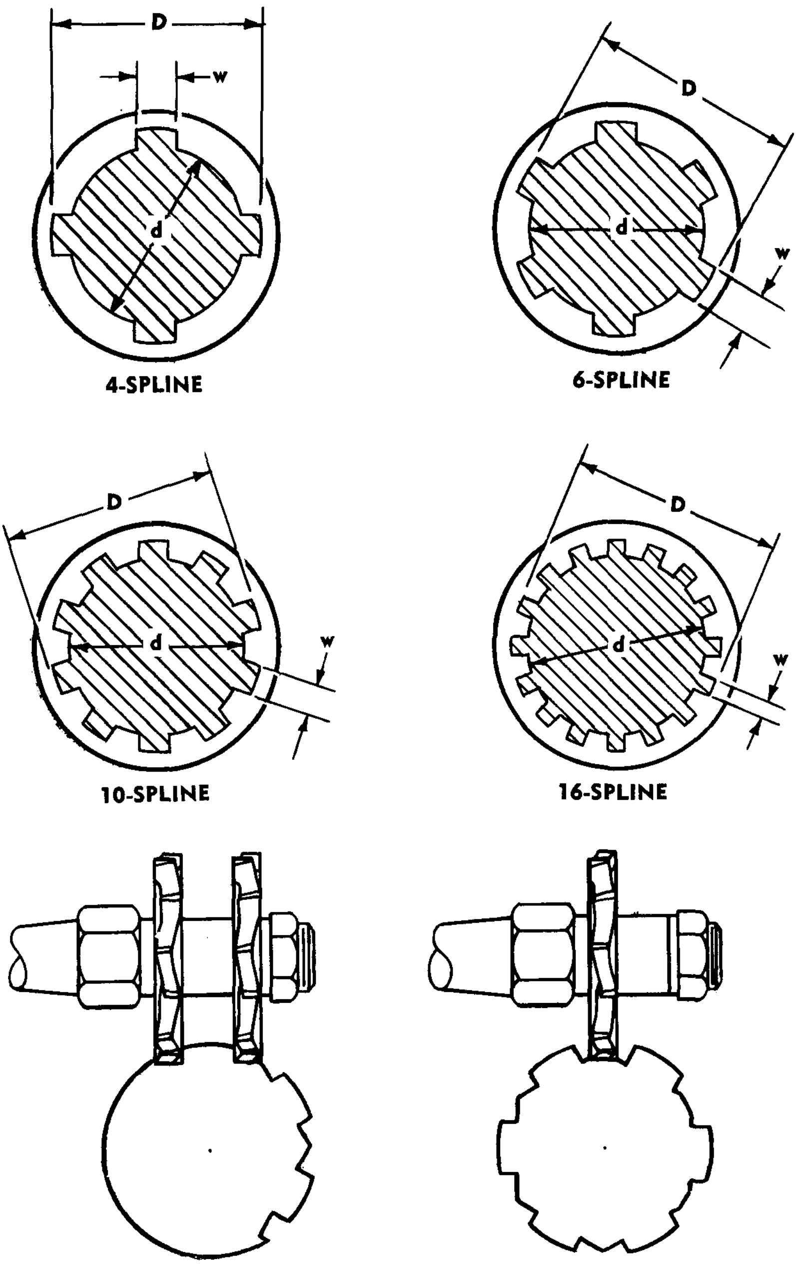
(1) The shaft to be splined is set up between centers in the indexing fixture.

Table XXVI. Standard Spline Dimensions

Major diameter of spline shaft (D, fig. 144)	Width of spline (all fits)[1] (w, fig. 144)				Permanent fit[2] Minor diameter (d, fig. 144)				Sliding fit when not under load[2] Minor diameter (d, fig. 144)				Sliding fit when under load[2] Minor diameter (d, fig. 144)		
	4-Spline (0.241 D)	6-Spline (0.250 D)	10-Spline (0.156 D)	16-Spline (0.098 D)	4-Spline (0.850 D)	6-Spline (0.900 D)	10-Spline (0.910 D)	16-Spline (0.910 D)	4-Spline (0.750 D)	6-Spline (0.850 D)	10-Spline (0.860 D)	16-Spline (0.860 D)	6-Spline (0.800 D)	10-Spline (0.810 D)	16-Spline (0.810 D)
¾ (.750)	0. 181	0. 188	0. 117	------	0. 637	0. 675	0. 683	------	0. 562	0. 638	0. 645	------	0. 600	0. 608	------
⅞ (.875)	0. 211	0. 219	0. 137	------	0. 744	0. 788	0. 796	------	0. 656	0. 744	0. 753	------	0. 700	0. 709	------
1 (1.000)	0. 241	0. 250	0. 156	------	0. 850	0. 900	0. 910	------	0. 750	0. 850	0. 860	------	0. 800	0. 810	------
1⅛ (1.125)	0. 271	0. 281	0. 176	------	0. 956	1. 013	1. 024	------	0. 844	0. 956	0. 968	------	0. 900	0. 911	------
1¼ (1.250)	0. 301	0. 313	0. 195	------	1. 062	1. 125	1. 138	------	0. 937	1. 063	1. 075	------	1. 000	1. 013	------
1⅜ (1.375)	0. 331	0. 344	0. 215	------	1. 169	1. 238	1. 251	------	1. 031	1. 169	1. 183	------	1. 100	1. 114	------
1½ (1.500)	0. 361	0. 375	0. 234	------	1. 275	1. 350	1. 365	------	1. 125	1. 275	1. 290	------	1. 200	1. 215	------
1⅝ (1.625)	0. 391	0. 406	0. 254	------	1. 381	1. 463	1. 479	------	1. 219	1. 381	1. 398	------	1. 300	1. 316	------
1¾ (1.750)	0. 422	0. 438	0. 273	------	1. 487	1. 575	1. 593	------	1. 312	1. 488	1. 505	------	1. 400	1. 418	------
2 (2.000)	0. 482	0. 500	0. 312	0. 196	1. 700	1. 800	1. 820	1. 820	1. 500	1. 700	1. 720	1. 720	1. 600	1. 620	1. 620
2¼ (2.250)	0. 542	0. 563	0. 351	------	1. 912	2. 025	2. 043	------	1. 687	1. 913	1. 935	------	1. 800	1. 823	------
2½ (2.500)	0. 602	0. 625	0. 390	0. 245	2. 125	2. 250	2. 275	2. 275	1. 875	2. 125	2. 150	2. 150	2. 000	2. 025	2. 025
3 (3.000)	0. 723	0. 750	0. 468	0. 294	2. 550	2. 700	2. 730	2. 730	2. 250	2. 550	2. 580	2. 580	2. 400	2. 430	2. 430
3½ (3.500)	------	------	0. 546	0. 343	------	------	3. 185	3. 185	------	------	3. 010	3. 010	------	2. 835	2. 835
4 (4.000)	------	------	0. 624	0. 392	------	------	3. 640	3. 640	------	------	3. 440	3. 440	------	3. 240	3. 240
4½ (4.500)	------	------	0. 702	0. 441	------	------	4. 095	4. 095	------	------	3. 870	3. 870	------	3. 645	3. 645
5 (5.000)	------	------	0. 780	0. 490	------	------	4. 550	4. 550	------	------	4. 300	4. 300	------	4. 050	4. 050
5½ (5.500)	------	------	0. 858	0. 539	------	------	5. 005	5. 005	------	------	4. 730	4. 730	------	4. 455	4. 455
6 (6.000)	------	------	0. 936	0. 588	------	------	5. 460	5. 460	------	------	5. 160	5. 160	------	4. 860	4. 860

[1] Tolerance allowed is −0.002 inch for shafts ¾ to 1¾ inches in diameter inclusive, and −0.003 inch for larger sizes.

[2] Tolerance allowed is −0.001 inch for shafts ¾ to 1¾ inches in diameter inclusive, −0.002 inch for shafts 2 to 3 inches in diameter inclusive, and −0.003 inch for larger sizes.



NOTES:
D = MAJOR DIAMETER
d = MINOR DIAMETER
w = WIDTH OF SPLINE

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Figure 144. Milling spline shafts.

(2) Two side milling cutters are mounted to an arbor with a spacer and shims inserted between them. The spacer and shims are chosen to make the space between the inner teeth of the cutters equal to the width of the spline to be cut (table XXVI).

(3) The arbor and cutters are mounted to the milling machine spindle, and the milling machine is adjusted so that the cutters are centered over the shaft.

(4) The splines are cut (fig. 144) by straddle milling each spline to the required depth (table XXVI) and using the index head of the indexing fixture to rotate the workpiece the correct distance between each spline position.

(5) After the splines are milled to the correct depth, mount a narrow plain milling cutter in the arbor, and mill the spaces between the splines to the proper depth (fig. 144). It will be necessary to make several passes to cut the groove uniformly so that the spline fitting will not interfere with the grooves. A formed spline milling cutter, if available, can be used for this operation.

128. Drilling

a. The milling machine may be used effectively for drilling, since accurate location of the hole may be secured by means of the feed screw graduations. The spacing of holes in a circular path, such as the holes in an index plate, may be accomplished by indexing with the index head positioned vertically.

b. Twist drills may be supported in drill chucks fastened in the milling machine spindle or mounted directly in milling machine collets or adapters. The workpiece to be drilled is fastened to the milling machine table by means of clamps, vises, or angle plates. Refer to paragraphs 30 and 31 for proper speeds and feeds for drilling.

129. Boring

a. Various types of boring tool holders may be used for boring on the milling machine, the boring tools being provided with either straight shanks to be held in chucks and holders, or taper shanks to fit collets and adapters. The two attachments most commonly used for boring are the fly cutter arbor (par. 98*g*) and the offset boring head.

b. The single-edge cutting tool used for boring on the milling machine is the same as a lathe cutter bit (par. 62). Cutting speeds, feeds, and depth of cut should be the same as that prescribed for lathe operations.

CHAPTER 6

SAWING MACHINE

Section I. GENERAL

130. Purpose

The sawing machine is a machine tool designed to cut off bar stock, tubing, pipe, or any metal stock within its capacity, or to cut heavy sheet stock to desired contours. The sawing machine functions by bringing a saw blade containing cutting teeth in contact with the workpiece to be cut, and drawing the cutting teeth across the workpiece. The sawing machine is much faster and easier than hand sawing and is used principally to produce an accurate square or mitered cut on rectangular or cylindrical material.

131. Types of Sawing Machines

a. Two common types of sawing machines are used for metal cutting in the machine shop. They are the hack sawing machine and the band sawing machine.

b. The hack sawing machine cuts by drawing a flat narrow cutting blade, called a hacksaw blade, across the workpiece in a reciprocating motion. The hacksaw blade bears against the piece for cutting on the draw stroke, and is lifted away from the workpiece on the return stroke. The hack sawing machine is used for the square or angle cutting of stock.

c. The band sawing machine cuts by drawing a continuous metal band, called a band saw blade, across the workpiece. The band saw blade is supported and driven by a drive wheel and an idler wheel.

132. Hack Sawing Machines

a. Description. All hack sawing machines are basically similar in design. All machines lift the hacksaw blade clear of the workpiece on the return stroke. Some machines feed by gravity, the saw frame being provided with weights that can be shifted to give greater or less pressure on the blade. Other machines are power fed with the feed being adjustable. On these machines the feed is usually stopped or reduced automatically when a hard spot is encountered in the material, thus allowing the blade to cut through the hard spot without breaking. Ordinarily, power hack sawing machines range in capacity from stock

4 inches square up to stock 13 x 16. The stroke of the saw determines the largest width stock that can be cut in the machine. Most hack sawing machines have a single speed; some larger machines have several speeds which can be selected. Larger hack sawing machines are designed for wet cutting, and contain a coolant system and drip pan to recirculate a cutting oil or lubricant. Smaller machines are intended for dry cutting.

b. Horizontal Hack Sawing Machine (fig. 145). The horizontal hack sawing machine illustrated in figure 145 is typical of most dry-cutting hack sawing machines. The machine is powered by a ½-horsepower electric motor attached to the frame of the machine. This machine is capable of cutting stock measuring 6 inches square. The feed is controlled by a wedge arrangement which retards the feed when desired, and by a feed spring which increases the feed when desired. Hacksaw blades measuring from 12 to 18 inches in length can be fitted to the machine; a 17-inch blade is recommended by the manufacturer. Stock is supported in the machine with a vise. The movable jaw of the vise can be quickly positioned for holding various sizes of stock. The vise is intended for cutting off stock at right angles, but it may be adjusted to an angle for mitered cuts. The horizontal hack sawing machine has a single speed of 65 strokes per minute.

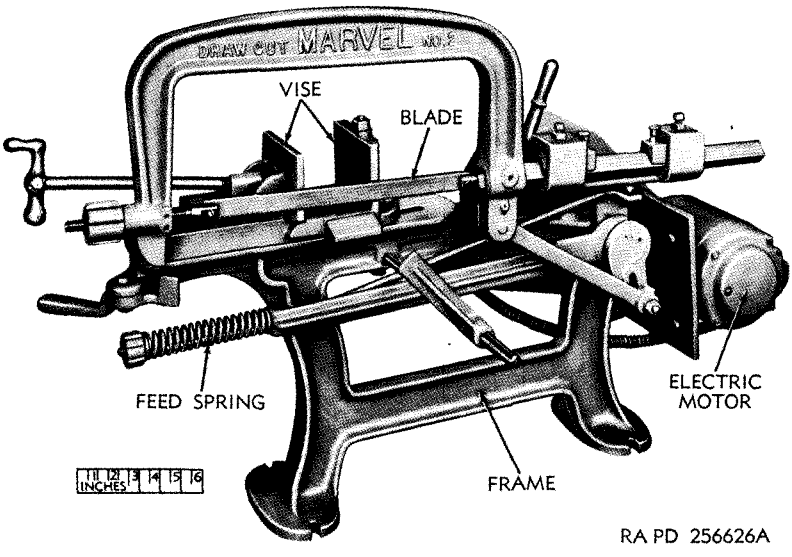


Figure 145. Horizontal hack sawing machine.

133. Band Sawing Machines

a. Description. Metal cutting band saw machines fall into two basic categories, horizontal machines (fig. 147) and vertical machines (fig. 146). The vertical band sawing machines are most commonly in use. On the vertical machines, the blade in its cutting position is vertical and it cuts into the side of the stock. The blade rotates on a fixed track, the idler wheel being mounted above the worktable and the drive wheel being mounted beneath the worktable. The stock is moved against the blade to make the cut. On the horizontal band sawing machine, the band saw blade in its cutting position is horizontal, and cuts downward into the stock. The drive and idler wheels are positioned lengthwise on the sawing machine frame which pivots from a corner of the sawing machine bed. With the horizontal machine, the stock is fixed rigidly in a vise to the bed of the machine, and the blade is fed downward into the workpiece. The horizontal band sawing machine is used primarily for cutting stock to length, either at right angles or to any desired miter angle. The vertical machine is more versatile and can be used for contour cutting, filing, and polishing, as well as simple cutting of stock.

b. Metal Cutting Band Sawing Machine (fig. 146). The metal cutting band sawing machine is a vertical machine. Being much more common than horizontal machines, vertical band sawing machines are usually identified as "band sawing machines" without using the word "vertical" in their descriptions. The machine illustrated in figure 146 is driven by a ¾-horsepower electric motor through a belt transmission which permits adjustable blade speeds from 50 feet per minute to 1,500 feet per minute although other band sawing machines have speed ranges up to 2,000 feet per minute. The table may be tilted front-to-back or sideways to cut mitered edges. The metal cutting band sawing machine does not require preformed band saw blade bands. An electric butt welder and grinding wheel are built into the sawing machine column. The welder is used to weld a length of blade into a continuous band, and the grinding wheel is used to remove beads caused by the welding. Since the machine can weld its own blade bands, internal cutting is possible. In this case the blade is inserted through a hole cut in the workpiece and then the blade is welded into a band and mounted to the machine. After cutting the internal shape in the piece, the band is cut so that it can be removed. An attachment for the metal cutting band sawing machine twists the band saw blade 30 or 90° so that stock which normally could not be cut because of insufficient clearance of the sawing machine column, can be successfully cut. Other attachments permit the use of band files and polishing bands in place of the band saw blade. Adjustable guides for holding and feeding workpieces are also provided. The machine has a power feed mechanism operated by counterweights. Forced air for cooling and chip removal is supplied by an air pump in the base of the machine.

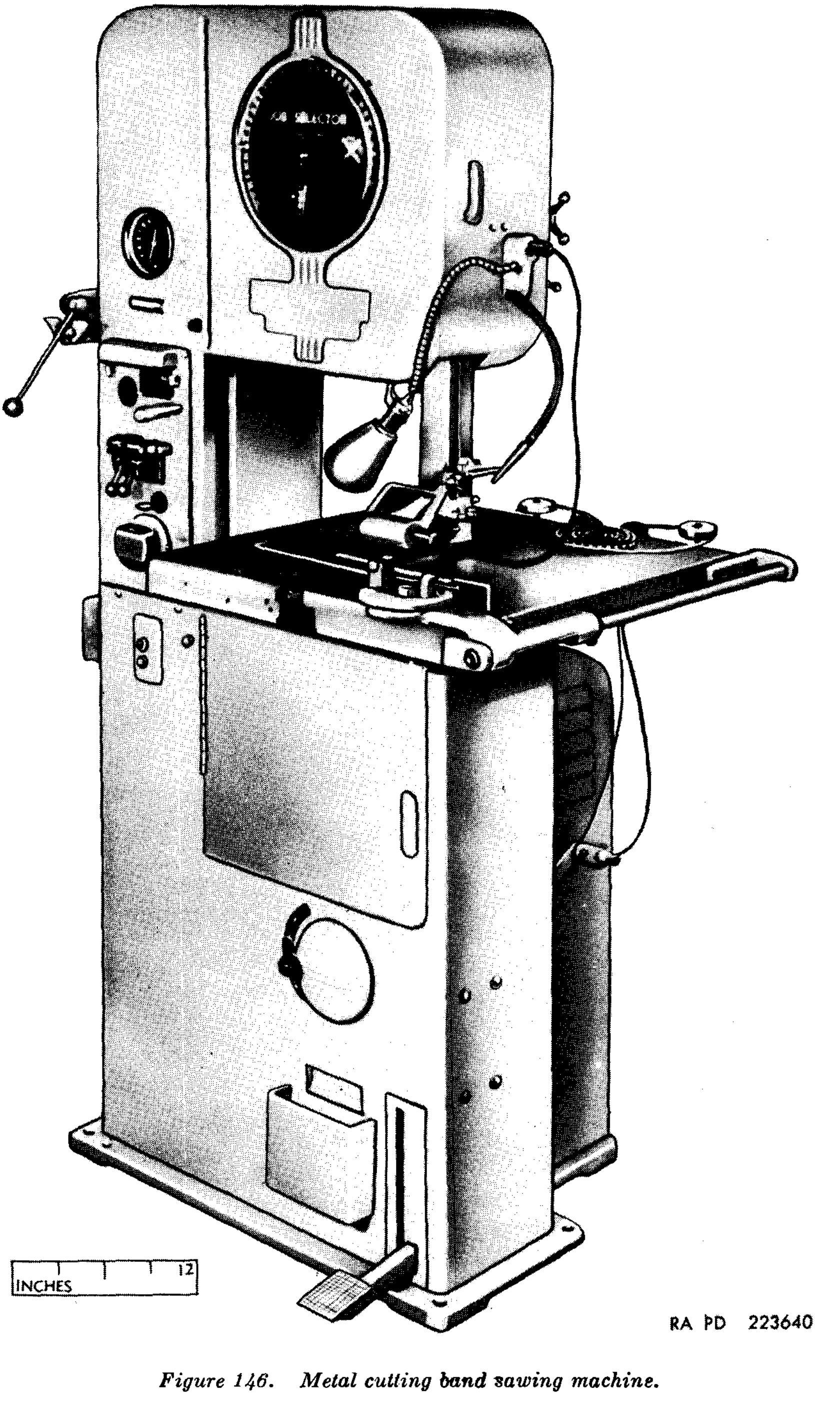


Figure 146. Metal cutting band sawing machine.

c. Metal Cutting Horizontal Band Sawing Machine (fig. 147). The metal cutting horizontal band sawing machine is a floor-mounted machine used for simple cutting of solid steel, tubing, and odd shapes of material. The material to be cut is mounted in a vise attached to the bed of the machine. A ½-horsepower electric motor drives the band saw blade through a belt and pulley arrangement by which three speeds may be obtained. The sawing machine frame upon which the drive wheel, idler wheel, band saw blade, and motor are mounted, pivots from one corner of the sawing machine bed. The frame is

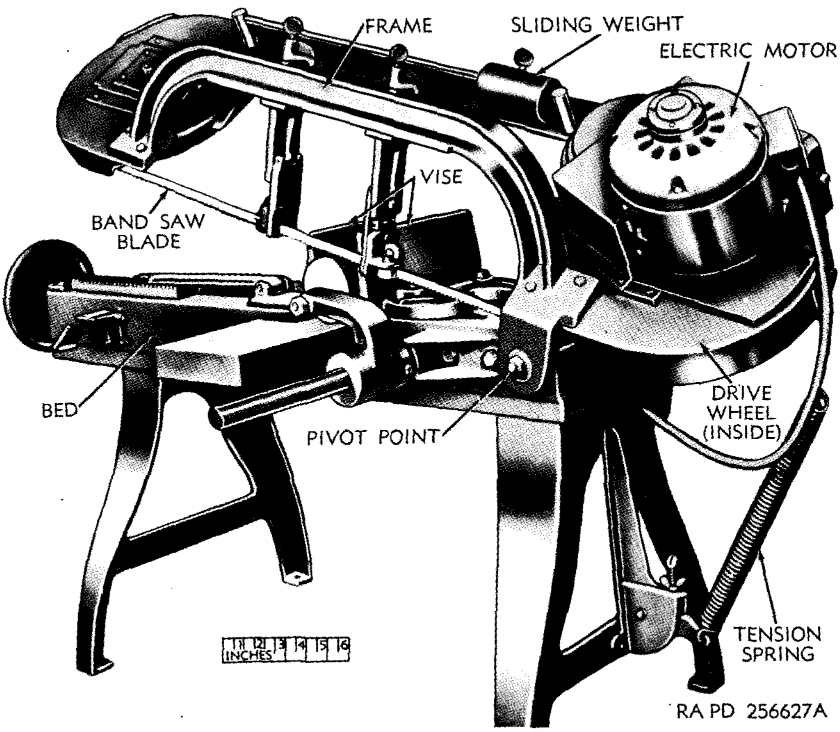


Figure 147. Metal cutting horizontal band sawing machine.

counterbalanced by a tension spring between the frame and the bed. Feed is controlled by positioning a sliding weight along a bar fixed to the top side of the sawing machine frame. A dash pot is positioned between the frame and bed to stabilize the feed movement and prevent any quick movement of the frame that could cause damage to the band saw blade. The vise used to hold the stock being cut is a quick positioning type and can be adjusted easily to any angle. An adjustable workpiece stop is provided for rapid positioning of production workpieces.

Section II. TOOLS AND EQUIPMENT

134. Power Hacksaw Blades

a. General. Power hacksaw blades differ from hand hacksaw blades in that they are generally heavier, made in longer sizes, and have fewer teeth per inch. Hacksaw blades are usually discarded when they become dull; sharpening is very seldom practical.

b. Materials. The materials commonly used in the manufacture of power hacksaw blades are high-speed tungsten steel and high-speed molybdenum (moly) steel. Ordinary carbon steel as used in the manufacture of hand hacksaw blades will not stand the heat generated by power hack sawing machine use. On some blades only the teeth are hardened leaving the body of the blade flexible. Other blades are hardened throughout their body.

c. Setting of Teeth. All hacksaw blades have teeth set to produce a cut, or kerf, slightly wider than the thickness of the blade to prevent the blade from being pinched by the stock on either side of the cut. The kerf is obtained by setting over the teeth to one side or the other. Three types of settings are commonly used for hacksaw blades.

(1) *Regular-alternate.* The regular-alternate setting (fig. 148) has one tooth bent over to the right and the next tooth bent over to the left, and so on. This setting is generally used for blades having coarse teeth. Most power hacksaw blades fall in this class.

(2) *Double-alternate.* When the teeth are set over in pairs, first two teeth to the right, next two teeth to the left, and so forth, the pattern is called the double-alternate setting (fig. 148). Hacksaw blades having between 24 and 32 teeth per inch are usually set this way.

(3) *Wave set.* Wave set teeth (fig. 148) are those in which groups of teeth are set alternately to the left and the right, giving the blade a waving appearance. It is especially adaptable to the cutting of thin materials since the teeth do not tend to bind. This setting is not commonly used on power hacksaw blades.

d. Pitch of Teeth. The pitch of hacksaw blade teeth (fig. 148) is the number of teeth per linear inch of the blade. For example, a blade having 10 teeth per inch is said to be 10 pitch, or might be indicated as 10 teeth per inch. Power hacksaw blades are coarser in pitch than hand hacksaw blades. Whereas common pitches for hand hacksaw blades range from 14 to 32 teeth per inch, power hacksaw blades range from 4 to 14 teeth per inch.

e. Selection of Power Hacksaw Blades.

(1) Power hacksaw blades are selected according to the type and thickness of the material to be cut.

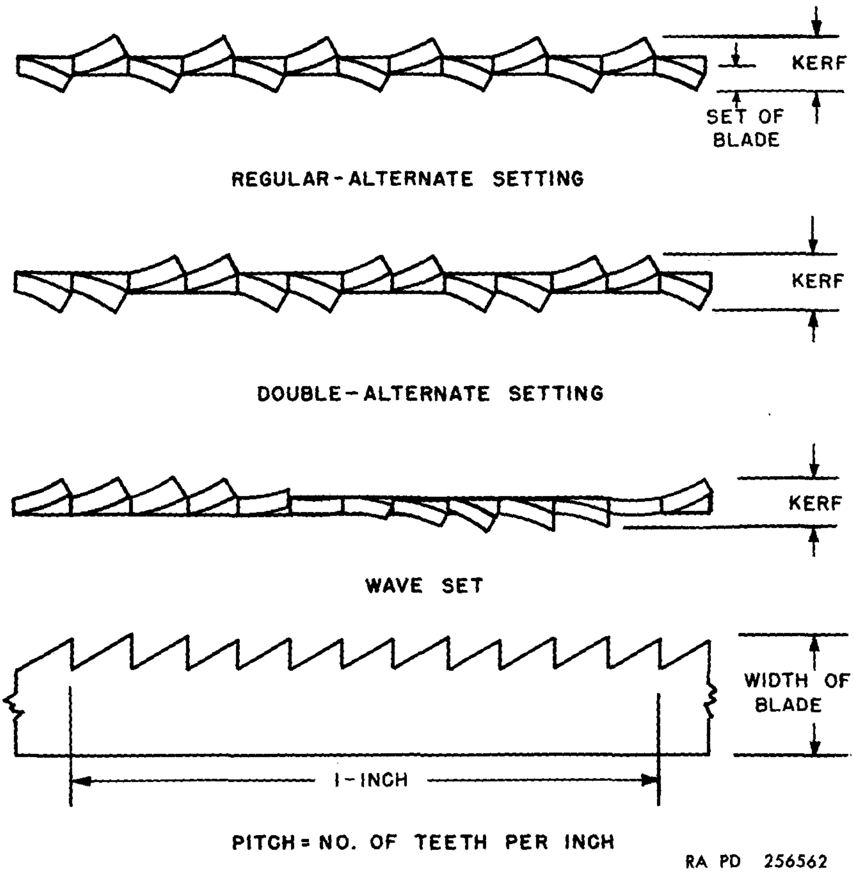


Figure 148. Characteristics of hacksaw blades.

(2) Soft materials require a coarser blade to provide adequate spaces between the teeth for removal of chips. Hard material requires a finer blade to distribute the cutting pressure to a number of teeth thereby reducing wear to the blade.

(3) At least two or three teeth must be in contact with the workpiece at all times or the blade will snag on the piece and break teeth from the blade (fig. 149). Therefore, when sheet metal and tubing are to be cut, a blade must be selected with sufficient pitch so that two or more teeth will be in contact with the workpiece, no matter what type of material is being cut.

(4) Table XXVII is provided to assist in the proper selection of power hacksaw blades. Note that sheet metal and tubing are listed separate from solid stock. It is assumed that the solid stock will be sufficiently thick that two or more teeth will be in contact with the stock.

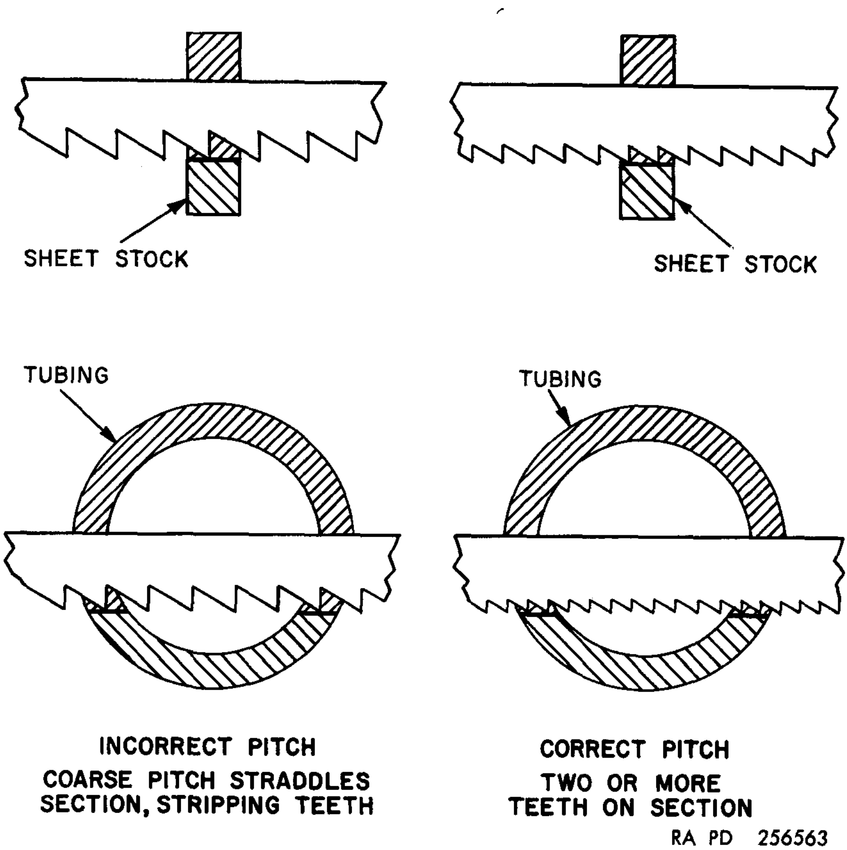


Figure 149. Correct and incorrect pitch of hacksaw blades.

Table XXVII. Selection of Power Hacksaw Blades

Material	Hacksaw blade teeth per inch (pitch)
Sheet metal	14
Solid stock: [1]	
Aluminum	4
Brass	10
Bronze	4
Cast iron	4
Copper	4
Steel, alloy	6
Steel, high-speed	6
Steel, machine	4
Steel, stainless	6
Steel, tool (annealed)	6
Steel, tool (unannealed)	4
Tubing, thin	14
Tubing, heavy	10

[1] Two or more teeth must contact the workpiece at all times to prevent blade damage. If the recommended pitch for a material fails to meet this requirement, a blade with more teeth to the inch should be used.

(5) Power hacksaw blades are generally manufactured in 12-, 14-, 17-, 18-, 21-, and 24-inch lengths to fit different size machines. The stroke, or pass, of the blade in the hack sawing machine and the maximum blade length which the machine will accept determine the size workpiece that can be cut. Therefore, if a maximum size workpiece is to be cut, it is necessary that the correct blade length be selected. If a smaller piece is to be cut, it is permissible to use a shorter length blade, provided the shorter blade can be securely mounted to the machine, and the stroke can be reduced to permit cutting of the piece.

135. Band Saw Blades

a. General. Band saw blades are manufactured in two forms. They are supplied in rolls of 50 to 400 feet for use on machines that have butt welders for forming their own blade bands. Band saw blades are also supplied in continuous welded bands in standard sizes for machines having no provisions for welding blade bands.

b. Materials. Band saw blades are made from special alloy steels. The blades are made flexible by annealing the body of the blade and hardening only the teeth. Most metal cutting band saw blades are not capable of being sharpened but there are some coarse tooth blades commercially available which are made of Swedish steel and have coarser teeth than usual which can be resharpened like woodcutting band saw blades.

c. Setting of Teeth. Metal cutting band saw blades have their teeth set to produce a kerf, or cut, slightly wider than the thickness of the blade to prevent the blade from being pinched by the stock. The setting of the teeth for most band saw blades is called the raker setting. Raker tooth blades have one tooth bent over to the right, the next tooth bent over to the left, and the third tooth set straight (fig. 150). This pattern is especially suitable to blades that cut at high speeds.

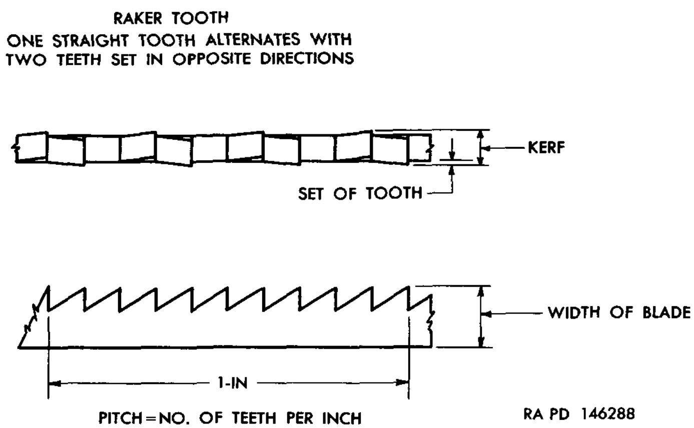


Figure 150. Characteristics of band saw blades.

d. Pitch of Teeth. The pitch of band saw blade teeth (fig. 150) is the number of teeth per linear inch of the blade. For example, if a blade has 14 teeth per inch (tpi), it has a pitch of 14, or it may be stated as being a 14-pitch blade. Metal cutting band saw blades range from 6 to 32 teeth per inch, the finer tooth blades being used for sawing thin stock, and the coarse tooth blades being used for sawing large stock and soft metals.

e. Selection of Band Saw Blades.

(1) Band saw blades are selected according to the type of material to be cut, the thickness of the material to be cut, and the sawing operation to be performed.

(2) Soft or gummy materials and thick stock require coarse tooth blades to provide adequate chip clearance. Hard materials generally require finer tooth blades. Fine tooth blades are also necessary if a good finish is desired.

(3) Two or three teeth of the band saw blade must be in contact with the workpiece at all times to prevent chatter and shearing off of teeth (fig. 149). Therefore, fine tooth blades are used to cut sheet metal and tubing. If sheet metal is too thin to meet this requirement with the finest tooth blade available, the metal should first be mounted on plywood, fiber, or thicker metal to stiffen it.

(4) Table XXVIII is provided as a guide in selecting the proper pitch band saw blade for different metals and metal thicknesses. If the stock is exceptionally large, coarser tooth blades than those recommended for solid stock may be used.

Table XXVIII. Selection of Band Saw Blades

Material	Band saw blade (tpi)	Material	Band saw blade (tpi)
Sheet metal, under ⅛ inch thick	24–32	Solid stock [1]—Continued	
Sheet metal, over ⅛ inch thick	18	Steel, alloy	12–14
Solid stock: [1]		Steel, high-speed	12–14
Aluminum	6–10	Steel, machine	10–14
Brass	10–12	Steel, stainless	12–14
Bronze	12–14	Steel, tool	12–14
Cast iron	10–12	Tubing, under ⅛-inch wall thickness	24–32
Copper	10–12	Tubing, over ⅛-inch wall thickness	18

[1] Two or more teeth must contact the workpiece at all times to prevent shearing of the blade teeth. If the recommended pitch for solid stock fails to meet this requirement, a blade with finer pitch must be selected.

(5) For straight sawing, the widest blade available of the proper pitch should be used. Thinner blades are required for contour sawing to prevent the body of the blade from rubbing

the sides of the cut when cutting sharp curves. When curves or radii are to be cut on the band sawing machine, the widest blade adaptable to the sharpest radius to be cut should be used. Narrow blades are much more easily broken than wide blades and should be used only where necessary. Table XXIX lists blade sizes which can be used for cutting different size radii.

Table XXIX. Band Sawing Radius Guide

Radius to be cut (in.)	Width of band saw blade to use [1] (in.)	Radius to be cut (in.)	Width of band saw blade to use [1] (in.)
2½ and larger	½	⅝ to 1 5/16	¼
1 7/16 to 2 7/16	⅜	5/16 to 9/16	3/16
1 to 1⅜	5/16	⅛ to ¼	⅛

[1] If the proper size blade for the radius to be cut is not available, the next size narrower blade should be used.

f. Band Saw Blade Wear.

(1) Band saw blades become dull naturally from prolonged use, but some conditions promote greater than normal wear on the blades. Blades dull quickly if used at too high a speed for the material being cut. Also, if the material to be cut is too hard for the pitch of the blade, abnormal wear will result. This can be caused by hard spots in cast iron or welded metal, and usually can be anticipated so that the operator can reduce the feed. Rubber and some fibers or plastics contain abrasive material that will dull saw blades regardless of the sawing speed and feed. Premature blade dulling often occurs from using too fine a pitch blade and from feeding too heavily.

(2) The following symptoms indicate a dull band saw blade. When these symptoms are noticed, the blade should be replaced.

(*a*) The band saw blade cuts slowly or not at all when the workpiece is fed by hand.

(*b*) The teeth of the blade are bright on the cutting edge.

(*c*) It becomes difficult to follow a line; the blade forces to one side or the other.

(*d*) The chips cut by the band saw blade are granular on metals other than cast iron which always produces granular chips.

(*e*) With the machine stopped, or the band saw blade removed from the machine, run a finger slowly over the teeth in the cutting direction. Sharp edges cannot be felt.

136. File Bands

a. General. The metal cutting band sawing machine is adapted for filing operations by use of the band file attachment (par. 138). A band file is then fitted over the drive and idler wheels in place of the band saw blade. Band files (fig. 151) consist of many interlocking file segments that are riveted to flexible steel bands. These bands are attached to each other, end to end, to form a continuous band. The file segments are attached to the steel bands in such a manner that they form a continuous filing surface when held in a straight line, but separate from each other as they move about the idler and drive wheels. The band file attachment provides a support behind the file above the table so that the band file cannot be forced backward by the pressure of the workpiece as it is filed.

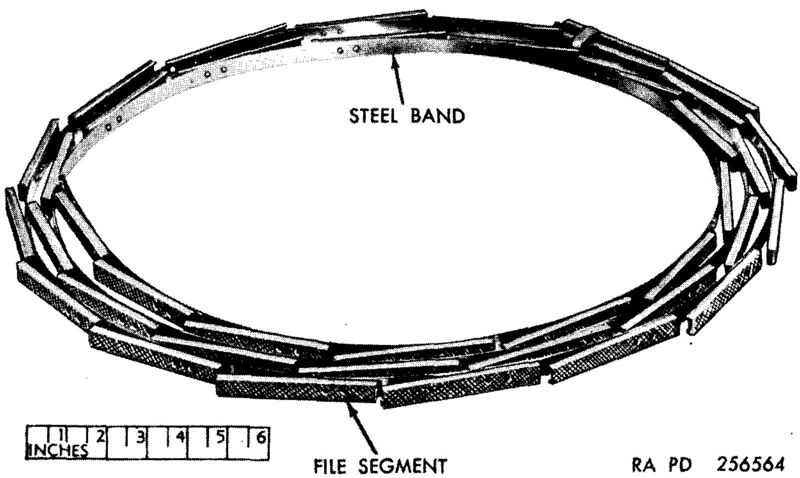


Figure 151. Band file.

b. Cut of File Teeth.

(1) Most files are classed as single-cut or double-cut files according to the kind of teeth. Single-cut files have rows of parallel teeth extending across the face of the file at an angle. Double-cut files have two rows of parallel teeth which cross each other. The first row, usually cut at about a 45° angle, is coarser and deeper than the second row which is generally cut at an angle of from 70° to 80°. Band files are always of the double-cut type.

(2) Double-cut files of medium pitch are called bastard-cut files. These files usually have between 12 and 24 teeth per inch. Bastard-cut band files are commonly used for filing of steel and other hard metals on the band sawing machine.

(3) Short angle-cut files are double-cut files in which the two rows of teeth have been cut at shorter angles than those of the bastard-cut file. Short angle-cut files are usually of coarse pitch having 10 or 11 teeth per inch. Short angle-cut band files are commonly used for filing soft metals on the band sawing machine.

c. Band File Shapes. Band files are manufactured in flat and oval shapes. Flat band files are used for the majority of filing jobs. Oval band files have a curved face and are used for filing inside curves and contours. Band files of the flat and oval shapes are made in widths of ¼, ⅜, and ½ inch.

d. Selection of Band Files.

(1) Band files should be chosen on the basis of workpiece thickness and kind of material to be filed.

(2) In general as the workpiece becomes thicker, the file should be more coarse. This is due to a larger total chip accumulated from thick pieces thus requiring additional space for the chips between the teeth. On thin sheet metal, a fine pitch file is required to prevent chatter.

(3) Narrower fine pitch files should be used for tough carbon and alloy steels; wider and coarser pitch files should be used for softer, more free-cutting materials such as cast iron and nonferrous metals.

(4) Table XXX is provided to aid in selecting the proper file for specific materials. If sheet metal is to be filed, a finer tooth file should be used if necessary to reduce chatter and produce a better finish on the workpiece.

Table XXX. Selection of Band Files

Material	Band file	
	Cut of teeth	Teeth per inch
Aluminum	Short angle- or bastard-cut	10–12
Brass	Short angle- or bastard-cut	10–12
Bronze	Short angle- or bastard-cut	10–12
Cast iron	Short angle- or bastard-cut	10–12
Copper	Short angle- or bastard-cut	10–12
Fiber	Short angle- or bastard-cut	10–12
Magnesium	Short angle- or bastard-cut	10–12
Steel, alloy	Bastard-cut	14–24
Steel, machine	Bastard-cut	14–16
Steel, tool	Bastard-cut	14–24

e. Care and Cleaning of Band Files.

(1) The particles of metal removed by the file often lodge in the file teeth, reducing the cutting efficiency of the file and effect-

ing the quality of the finish. If hard metal particles are thus lodged, the workpiece may be scratched by these particles.

(2) When steel is to be filed, chalk can be rubbed into the file before filing; the chalk will reduce the tendency for hard particles to adhere to the file.

(3) Clean the file often using a stiff brush or a file card. The brush should be moved in the direction of each cut of the file to dislodge all particles hidden between the teeth.

137. Polishing Bands

a. General. Polishing operations can be performed on the metal cutting band sawing machine upon installation of the polishing attachment (par. 139) and substitution of a polishing band for the band saw blade. The polishing band is usually 1 inch wide and has a heavy fabric backing.

b. Types of Polishing Bands. Polishing bands for band sawing machines are usually supplied in three grain sizes of aluminum-oxide abrasive, No. 50 grain (medium) for light grinding operations with the band sawing machine, No. 80 grain (medium-fine) for coarse polishing operations, and No. 120 or No. 150 grain (fine) for fine polishing operations. The bands are preformed in continuous bands in appropriate sizes to fit the metal cutting band sawing machine.

c. Selection of Polishing Bands. Polishing bands should be selected according to the particular job to be performed. For general removal of toolmarks and smoothing of edges, the No. 50 grain polishing band should be used. This band will remove small amounts of metal by grinding and is not in the true sense of the work a polishing band. When finer grain polishing bands are used on the band sawing machine, soft metals like aluminum, or cast iron should not be polished or the band will quickly fill with metal particles, reducing the cutting action of the polishing band.

138. Band File Attachment

a. A band file attachment (fig. 152) is provided with most metal cutting band sawing machines to permit the use of band files in the machine. A typical band file attachment consists of a band file guide and upper and lower guide supports that attach to the frame and post of the sawing machine to provide a rigid track upon which the band file can ride. A special filing filler plate is provided to adapt the table slot to the extra width and depth required for the band file and file band guide.

b. Most band file attachments have either adjustable guides and guide supports, or two or more file band guides so that different width file bands can be accommodated.

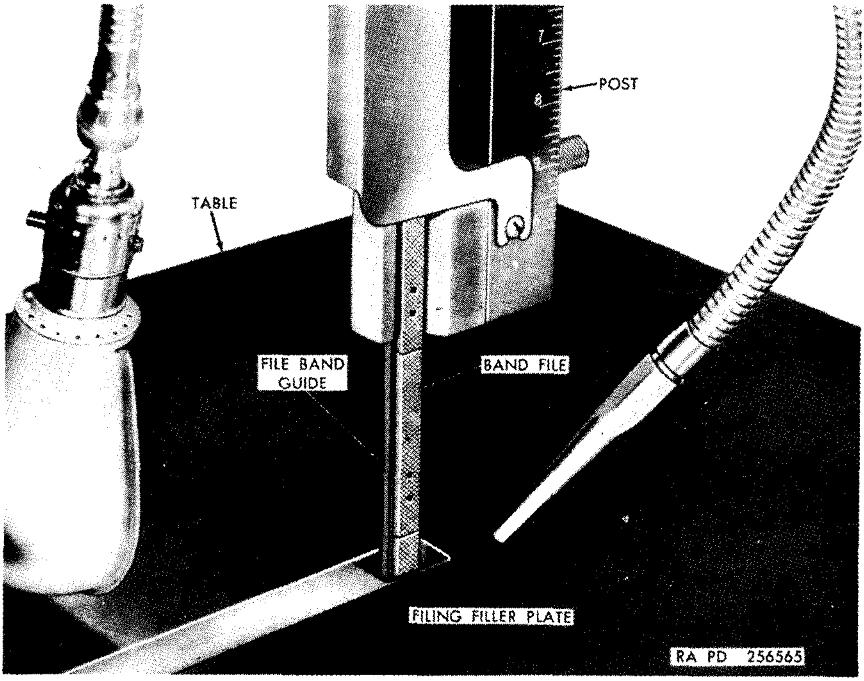


Figure 152. Band file attachment installed on band sawing machine.

139. Polishing Attachment

A polishing attachment (fig. 153) is provided with most metal cutting band sawing machines to allow polishing with the machine. The attachment, similar to the band file attachment (par. 138), provides support for the polishing band with the polishing band plate which is supported between the post and frame of the band sawing machine. The polishing band plate acts as a solid backing for the polishing band to prevent stretching and distorting the polishing band when the workpiece is held against it. A polishing band filler plate (fig. 153) is used to fill the table slot so that workpiece can be supported close to the polishing band.

140. Disk Cutting Saw Attachment

a. The disk cutting saw attachment is a device that enables circular shapes to be cut on the metal cutting band sawing machine.

b. A typical disk cutting saw attachment (fig. 154) consists of a radius arm that extends outward from the post of the machine above the table. A radius arm clamp containing a knurled adjusting wheel mounts to the radius arm. This clamp can be adjusted on the arm for cutting any radius from 1½ to 12½ inches. A center pin set into a center pin clamp is supported by the radius arm clamp. The center pin clamp can be swiveled to move the center pin closer to or away

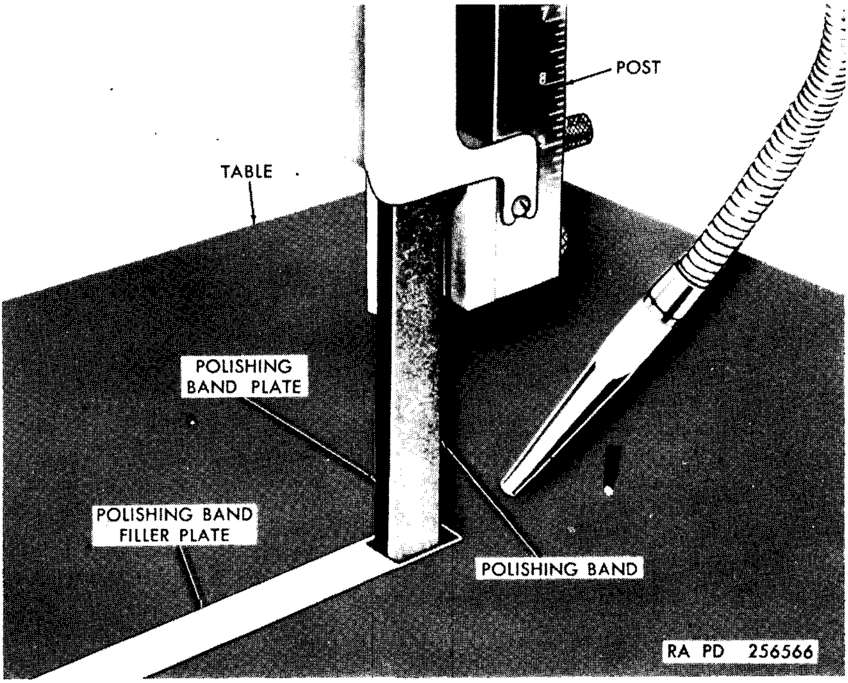


Figure 153. Polishing attachment installed on band sawing machine.

from the radius arm, the object being to aline the center pin perpendicular to the band saw blade.

141. Angular Blade Guide Attachment

a. An angular blade guide attachment (fig. 155) is furnished with most metal cutting band sawing machines. This attachment twists the band saw blade so that large or long workpieces that would not normally clear the band sawing machine column can be cut. The blade is twisted 30° on some machines and 90° on others.

b. The angular blade guide attachment consists of an upper band saw blade guide that attaches to the sawing machine post (fig. 155) and a lower band saw blade guide that attaches to the frame beneath the table.

142. Miter Guide Attachment

a. The miter guide attachment is a device used to support and guide workpieces to the band saw blade. The attachment can be swiveled and locked to guide the workpiece at any convenient angle.

b. A typical miter guide attachment is illustrated in figure 156. The workpiece is supported against the miter head which attaches to the slide arm. A stop collar is positioned to the rod upon which the slide arm travels, and can be set to stop the miter head as soon as the

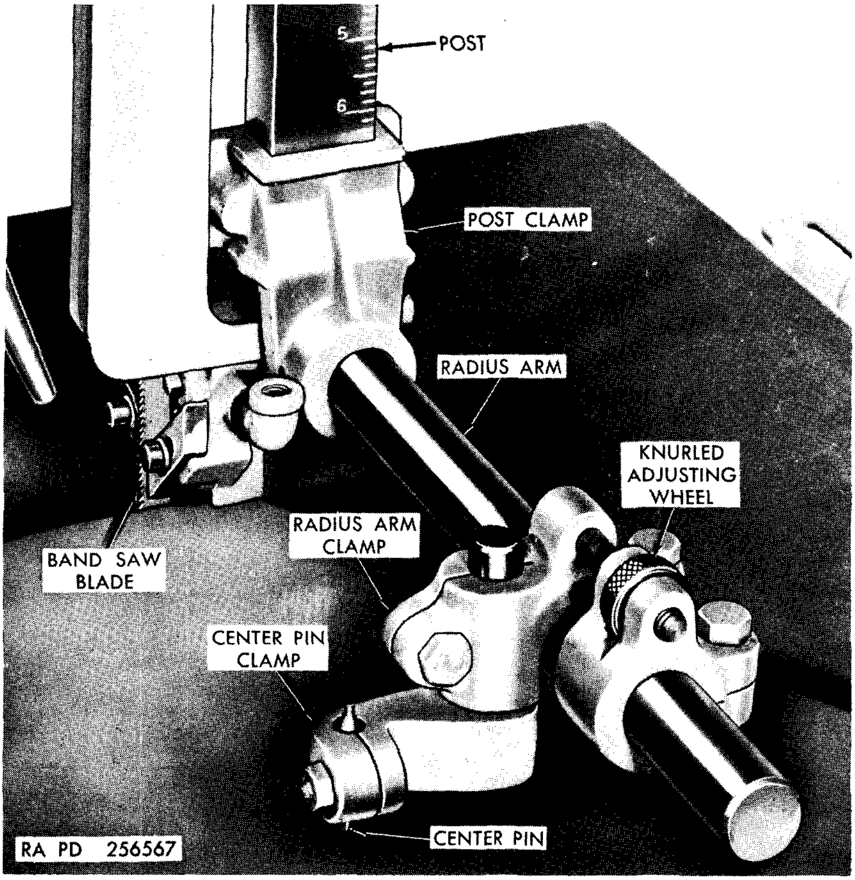


Figure 154. Disk cutting saw attachment installed on band sawing machine.

piece is cut through or cut to the desired depth. A gage rod is adjustable on the miter head and can be set to cut several pieces of stock to the same length with accuracy. The miter guide attachment is moved by hand to guide the workpiece.

143. Screw Feed Device

a. The screw feed device (fig. 157) is a machine tool attachment on some makes of metal cutting band sawing machines and is a component part of other band sawing machines. The screw feed device is hand-operated method of feeding the workpiece into the band saw blade or band file. The device is used with a work holding jaw device to feed the workpiece into the blade at angles other than 90° to the blade.

b. The screw feed device (fig. 157) is operated by turning a handwheel to move a feed screw toward the band saw blade. A slow, even feed is achieved in this manner. The feed screw can be quickly

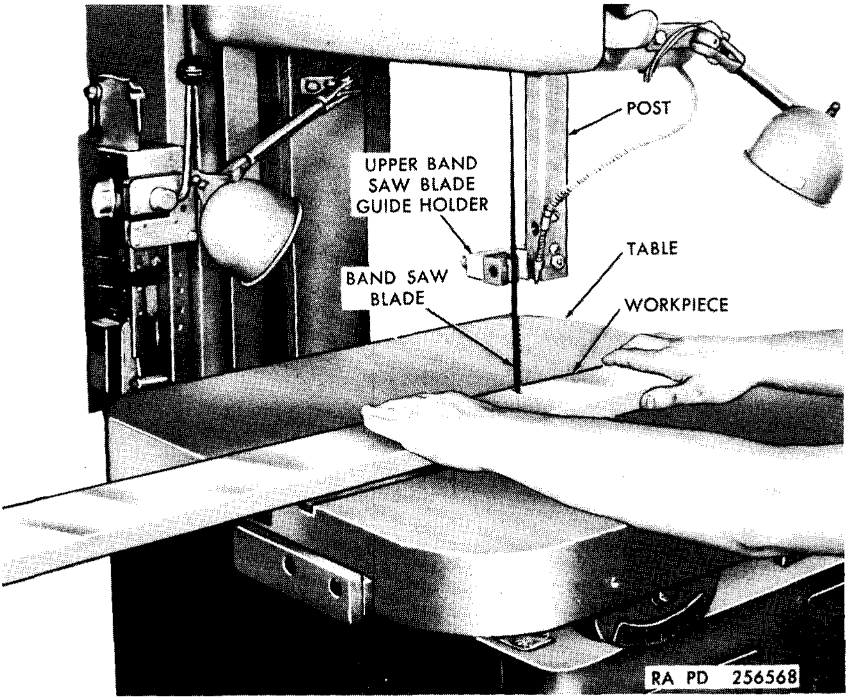


Figure 155. Sawing operation using the angular blade guide attachment.

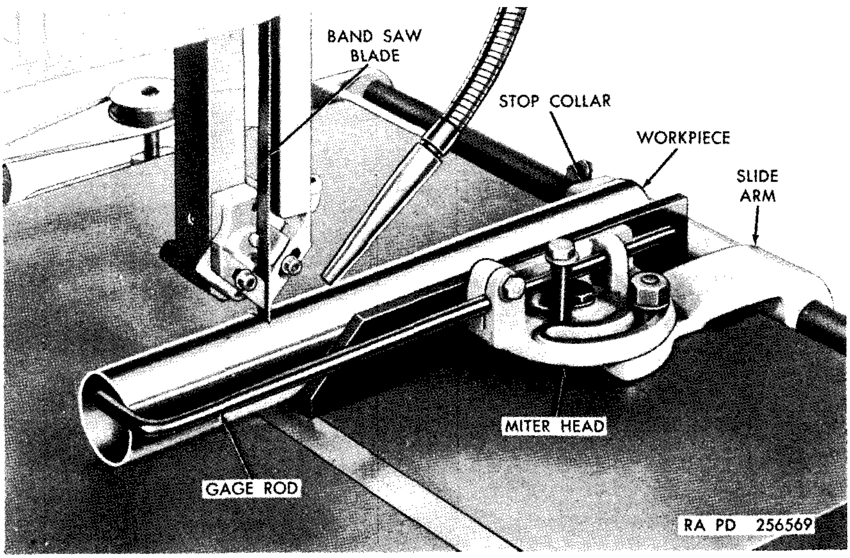


Figure 156. Sawing operation using the miter guide attachment.

retracted by disengaging the half nut and sliding the screw to the rear. A workpiece to be cut is positioned in the V-shape jaw of the work holding jaw device. The device is then positioned to a desired angle and the feed screw is brought forward to engage a notch in the rear of the jaw device. Once the cut is started, the feed screw and jaw device maintain the proper angle of the cut.

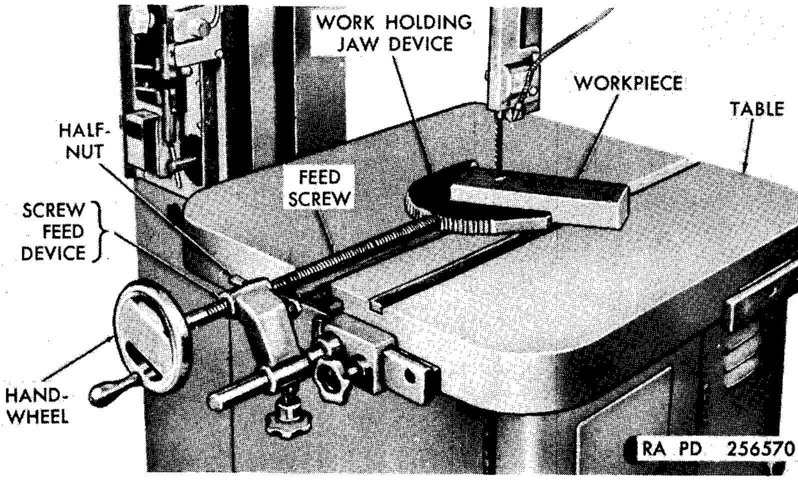


Figure 157. Sawing operation using the screw feed device.

c. The screw feed device can also be used without the work holding jaw device for straight cuts. In this case, the feed screw (fig. 157) bears against the rear side of the workpiece, and being directly alined with the band saw blade, guides the piece into the blade for a straight cut.

Section III. LAYING OUT AND MOUNTING WORK

144. Laying Out and Mounting Workpieces for Hack Sawing Machines

a. Hack sawing machines are primarily intended for the straight line cutting of stock to specific lengths. Laying out of the workpiece consists of measuring the length to be cut and indicating the position for the cut by scribing a line on the stock. The stock is then mounted in the vise and alined with the hacksaw blade.

b. Before mounting the stock to be cut, the vise should be checked for squareness with the hacksaw blade. Place a machinist's square against the blade and the stationary vise jaw. Adjust the jaw, if necessary, at 90° to the blade. If the workpiece is to be cut at an angle other than 90°, loosen the vise and swivel it to the desired angle, measuring the angle carefully with a protractor.

c. Move the blade frame and hacksaw blade by hand through one draw stroke and one return stroke. Observe whether the stroke is centered on the work and whether the blade holders will clear the workpiece at the end of a stroke. Readjust the position of the vise if the stroke is not centered on the workpiece. Shorten the stroke if the blade holders hit the workpiece at the end of each stroke.

d. A stop gage is provided on most hack sawing machines to speed up mounting of stock when several pieces of the same length are to be cut. The first piece should be mounted in the vise and alined with the hacksaw blade to cut at the scribed line. When the workpiece is correctly positioned, move the stop gate up to the end of the workpiece and lock it in place. Subsequent pieces are cut by moving the stock up to the stop gage and clamping the workpiece in the vise at this position.

e. The vise must be securely tightened on the workpiece to prevent loosening during cutting. Blade breakage might result from shifting of workpieces not clamped tightly in the vise.

145. Laying Out and Mounting Workpieces for Horizontal Band Sawing Machines

a. Since the horizontal band sawing machine is used primarily for cutting stock to desired lengths and for cutting miter angles, the procedures for laying out and mounting of workpieces consists of positioning the stock at the proper angle and length in the vise of the sawing machine.

b. Before mounting the stock in the vise, the blade guides should be checked for vertical alinement. If the blade guides should be out of alinement, the cut edge will not be smooth, and the blade may break.

c. The stock should be measured and the position of the cut scribed on its surface. Check the angle of the vise by placing a machinists' square or a protractor against the band saw blade and the stationary vise jaw. Position the stock in the vise so that the band saw blade alines with the scribed line on the stock. If more than one piece is to be cut to the same size, move the stock stop arm against the end of the stock and lock it in place. Subsequent pieces can then be placed in the vise and moved up against the stop to produce pieces equal in length to the first piece.

146. Laying Out and Mounting Workpieces for Band Sawing Machines

a. General. When laying out workpieces for band sawing operations, the size of the stock must be considered in relation to the clearance of the band sawing machine column. For straight line sawing the clearance is easy to judge, but for contour sawing of large size stock the directions of cut must be carefully figured to prevent the stock from hitting the column. If a small section is to be cut from a large sheet of metal, the section should be roughly cut oversize from the sheet and then carefully cut to the prescribed outline.

b. Laying Out Workpieces for Circle Sawing. When a circle or disk is to be sawed using the disk cutting saw attachment (par. 140), lay out the circle on the stock as follows.

(1) Using a compass or pair of dividers, scribe a circle of the desired diameter on the stock. The circle should be scribed tangent to one edge of the stock if possible so that the band saw blade may start the cut without preliminary sawing or notching.

(2) Drill a center hole in the disk to accept the center pin of the disk cutting saw attachment. Make the hole only as deep and as large as required for the center pin; too large a hole will cause the center pin to fit loosely which will result in an inaccurate cut.

c. Laying Out Workpieces for Contour Sawing. When an outline to be cut consists of more than two intersecting lines, the following procedure should be followed.

(1) Scribe the exact shape required on the stock. Take advantage of straight, clean edges on the uncut stock in laying out the piece to save unnecessary cuts.

(2) Determine the band saw blade size necessary to cut the smallest radius layed out on the workpiece (par. 135*e*(5)).

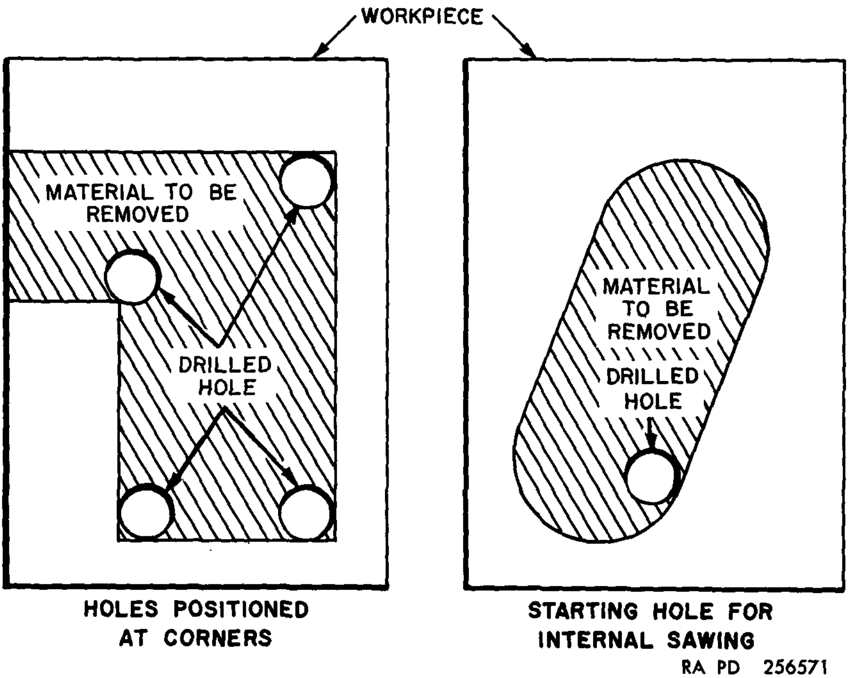


Figure 158. Hole layouts for contour sawing.

(3) Select a twist drill equal to or greater in diameter than the width of the band saw blade. Drill a hole in the solid stock in each corner of the pattern (fig. 158), making sure the holes fall completely within the section of material that will be removed. These holes are necessary when sawing to permit changing direction of the band saw blade from one cut to another. The corner segments behind the holes are notched out after the piece is cut.

(4) If an internal section is to be removed from the stock and the edge must remain unbroken, lay out and drill a starting hole (fig. 158) using a drill larger in diameter than the width of the band saw blade. The band saw blade will be inserted through this hole before being welded into a band and installed on the band sawing machine.

d. Mounting Workpieces. Workpieces for the metal cutting band sawing machine are not mounted to the machine but are supported on the table of the machine and guided by one of the sawing machine attachments or by hand.

Section IV. GENERAL SAWING OPERATIONS

147. General

Efficient sawing with sawing machines requires sharp saw blades in good condition. To prevent unnecessary dulling and breakage of saw blades, proper speeds and feeds must be maintained. The speed of the saw blade for any specific operation depends upon the nature of the material being cut.

148. Feeds and Speeds for Hack Sawing

a. General.

(1) Hack sawing machines cut by drawing the hacksaw blade toward the motor end of the machine. At the completion of this movement called the draw stroke, the hacksaw blade is lifted slightly to clear the material being cut and is moved an equal distance in the opposite direction. The second movement of the cycle is called the return stroke, and it serves to position the blade for another draw stroke.

(2) The cutting speed of hack sawing machines is measured in strokes per minute, referring only to the draw strokes, or the strokes in which the hacksaw blade cuts.

(3) The feed of hack sawing machines can be mechanical or gravity operated. Mechanical feeds are measured in fractions of an inch per stroke. Gravity feeds are not measured by a linear system, but are controlled by increasing and decreasing downward pressure on the hacksaw blade.

b. Hack Sawing Machine Speeds.

(1) Since the cutting speed of the hack sawing machines is measured in strokes per minute, the length of the stroke is an important consideration. A longer stroke at a given speed will cut faster than a shorter stroke at the same speed. Thus, to obtain a proper cutting speed the length of the stroke must be specified.

(2) The length of the stroke of most hack sawing machines is between 4 and 10 inches, depending upon the size of the machine. The longer the stroke, the narrower the stock must be because the hacksaw blade must be at least as long as the stock width plus the stroke length to prevent the blade holders from hitting the stock.

(3) With most hack sawing machines, the stroke length is adjustable within 2 or 3 inches, and on some machines more than one speed can be selected. On single-speed hack sawing machines the speed must be regulated by changing the stroke. If the stroke is doubled, the machine will cut twice as fast, and if the stroke is decreased by one half, the machine will cut half as fast. This proportion can be applied to any fraction to increase or decrease the cutting speed of the machine.

(4) Recommended speeds in strokes per minute are listed in table XXXI for various types of metals. In general, the faster speeds are used for cutting soft materials and the slower speeds are used for cutting harder materials. If a recommended speed cannot be approximated either by changing the stroke or changing the speed, the feed can be decreased to prevent undue wear to the hacksaw blade.

Table XXXI. Hack Sawing Machine Speeds

Material	Speed in strokes per minute	
	4 to 6 inch stroke	8 to 10 inch stroke
Aluminum	135	65
Brass	135	65
Bronze	90	45
Cast iron	90	45
Copper	135	65
Steel, alloy	90	45
Steel, high-speed	60	30
Steel, machine	135	65
Steel, stainless	60	30
Steel, tool (annealed)	90	45
Steel, tool (unannealed)	60	30

c. Hack Sawing Machine Feeds.

(1) Hack sawing machines having a mechanical feed can usually be regulated to feed the saw downward from 0.001 to 0.025 inch per stroke, depending upon the type and size of the material cut. On these machines a device to stop the feed when hard spots are encountered is usually incorporated in the design.

(2) The feed of machines having gravity feed is regulated by the weight of the saw frame and any additional weights or springs that might be connected or attached to the frame to increase or decrease the downward force of the hacksaw blade. Maximum and minimum blade pressures obtainable are determined by the manufacturer of the hack sawing machine, and must be specified relatively as light or heavy.

(3) The following general rules apply for selecting proper feeds for hack sawing machines.

(*a*) The feed should be very light when starting a cut and can be increased after the cut is well started.

(*b*) A lighter feed is required for hard materials than for soft materials; the feed should be reduced when hard spots in materials such as welds are encountered.

(*c*) Wide material requires a heavier feed than narrow material because the pressure is distributed over a larger surface.

(*d*) Sharp hacksaw blades will cut well with lighter feeds. Heavier feeds are necessary for cutting with duller blades.

149. Feeds and Speeds for Band Sawing

a. General. The cutting speed of a band sawing machine is the speed of the band saw blade as it passes the table, measured in feet per minute. The feed of horizontal band sawing machines is the downward movement or pressure applied to the material being cut by the band saw blade. The feed of (vertical) band sawing machines is the pressure applied to the band saw blade by the material being cut.

b. Band Sawing Speeds.

(1) Proper band sawing speeds are important in conserving band saw blades. Too great a speed for the material being cut will cause abnormally rapid blade wear, while too slow a speed will result in inefficient production.

(2) All metal cutting band sawing machines have several cutting speeds which can be selected. Since the diameter of the drive wheel of the band sawing machine establishes a fixed ratio between the motor or transmission speed in revolutions per minute to the blade speed in feet per minute, it is not necessary to convert revolutions per minute into feet per minute as with most other machine tool operations. The speeds are identified in feet per minute on the sawing machine

speed selector controls. Some machines have a speed indicator with which careful check may be made of sawing speeds when the machine is operating with or without a load.

(3) In general, the following principles apply to speeds of band saw blades.

(*a*) The harder the material, the slower the speed; conversely, the softer the material, the faster the speed.

(*b*) The tougher or more fibrous the material the slower the speed.

(*c*) The faster the speed, the finer is the finish produced on the cut surfaces. This principle applies to light feeds in conjunction with fast speeds.

(4) Refer to table XXXII for recommended sawing speeds for different materials. Generally the faster speeds should be used for thin material and the slower speeds should be used for thick materials.

Table XXXII. Band Sawing Speeds

Material	Band sawing speed (fpm)	Material	Band sawing speed (fpm)
Aluminum	200 to 2,000	Rubber, hard	150 to 250
Bakelite	200 to 900	Steel, alloy	50 to 100
Brass, soft	175 to 300	Steel, high carbon	50 to 100
Brass, hard	75 to 150	Steel, high-speed	50 to 90
Brass, sheets	200 to 900	Steel, machine	75 to 175
Bronze	75 to 150	Steel, sheet	150 to 200
Cast iron	50 to 100	Steel, stainless	50 to 75
Copper	115 to 175	Steel, tool	50 to 150
Monel metal	50 to 100		

c. Horizontal Band Sawing Machine Feeds.

(1) Feed of horizontal band sawing machines is controlled by adjusting the pressure applied by the saw blade against the material being cut, as with hack sawing machines.

(2) The horizontal band sawing machine illustrated in figure 147 has a spring counterbalance and a sliding weight to adjust the pressure of the blade. When the sliding weight is moved toward the pivotal point of the saw frame, the band saw blade pressure is reduced, and when the weight is moved away from the pivotal point, the pressure is increased.

(3) The following general principles should be applied when regulating the feed of horizontal band sawing machines.

(*a*) The feed should be very light when starting a cut. After the cut is started, increase the feed.

(*b*) Wider material requires a heavier feed than narrow material.

(*c*) Wide band saw blades will stand greater pressure than narrow band saw blades, and can therefore be used with heavier feeds.

(*d*) A lighter feed is required for hard materials; a heavier feed can be used for soft materials.

(*e*) Feed should be reduced when hard spots in the material are encountered such as chilled spots in cast iron and welds in joined sections.

d. *(Vertical) Band Sawing Machine Feeds.*

(1) With (vertical) band sawing machines, the feed is applied to the workpiece instead of to the saw blade. The workpiece may be hand fed or power fed depending upon the operation to be performed. Power feed can be applied only on straight-line cuts. The cutting of curves or special contours requires that the workpiece be guided and fed into the band saw blade by hand.

(2) The power feed on band sawing machines is operated by adjustable weights in the machine pedestal. The weights are connected by cables to one of the work holding attachments of the sawing machine to pull the workpiece against the band saw blade. To operate the power feed, the weights are raised by depressing a pedal and the cables are then fixed to the work holding attachment. When the pedal is released, the weights pull the piece into the blade.

(3) The following general rules apply to the feeding of workpieces on band sawing machines.

(*a*) The feed should be light when starting a cut. The pressure can be increased after the cut is established.

(*b*) Hard materials require lighter feeds than softer materials.

(*c*) Wide band saw blades will stand greater pressures than narrow band saw blades and can therefore be used with heavier feeds

(*d*) When hard spots in the material being cut are encountered, the feed should be reduced until the spots are cut through.

(*e*) A light feed should be used when cutting curves; a heavier feed can be used for straight-line cutting.

150. Cutting Oils

a. The sawing machines used by the Ordnance Corps are dry-cutting machines; that is, they are not intended for use with liquid cutting oils.

b. The metal cutting (vertical) band sawing machines contain air pumps and hoses through which a jet of air is directed against the band saw blade and workpiece. The air acts as both a coolant and a means of removing chips from the cutting area. The nozzle of the air hose should always be directed at the contact area of the blade and workpiece.

151. Straight-Line Sawing

a. General. Straight-line sawing is the most common of sawing operations. It is performed using the metal cutting hack sawing machine, the metal cutting horizontal band sawing machine, and the metal cutting (vertical) band sawing machine.

b. Hack Sawing Machine Operation. The metal cutting hack sawing machine is designed primarily for straight-line sawing operations. A typical sawing operation is outlined below.

(1) Select a hacksaw blade of the proper length for the machine and proper pitch for the nature of material to be cut (par. 134). Install the hacksaw blade with the teeth downward and pointing toward the motor end of the hack sawing machine.

(2) Check the alinement of the vise and hacksaw blade, and mount the workpiece in the vise (par. 144). Make sure the vise holds the workpiece securely.

(3) Check the stroke of the hack sawing machine and adjust if necessary (par. 148*b*). After adjusting the stroke, move the hacksaw blade and sawing machine frame through one cycle (draw stroke and return stroke) by hand to check the blade clearance at each end of the workpiece. Readjust the position of the vise if necessary.

(4) Position the hacksaw blade about ¼ inch above the workpiece and set the feed control to its lightest feed setting.

(5) Set the desired speed on the hack sawing machine (par. 148*b*).

(6) Start the machine, and let the blade feed lightly into the workpiece for about ¼ inch. Readjust the feed to whatever the material will stand for normal cutting operations (par. 148*c*).

(7) Permit the hacksaw blade to cut completely through the workpiece. The blade frame will trip a switch on the sawing machine bed to stop the sawing machine.

c. Horizontal Band Sawing Machine Operation. Like hack sawing machines, the metal cutting horizontal band sawing machine is used primarily for straight-line sawing operations. The typical sequence of operation for this machine is outlined below.

(1) Select and install a band saw blade of the proper pitch for the type and size of material to be cut (par. 135).

(2) Set the vise to the desired angle and check the angle by measuring it from the line of the band saw blade.

(3) Mount the workpiece in the vise (par. 145). Make sure the workpiece is secure and will not loosen during cutting.

(4) Check the alinement of the blade guides for vertical positioning and adjust if necessary.

(5) Position the saw frame so that the band saw blade is ¼ inch above the workpiece. The power feed weight should be placed at its lightest feed setting.

(6) Set the desired speed on the horizontal band sawing machine (par. 149*b*).

(7) Start the machine and let the band saw blade cut into the workpiece about ¼ inch. After the cut has been established, readjust the feed weight to exert the desired amount of pressure on the workpiece (par. 149*c*).

(8) The machine will stop itself when it cuts completely through the workpiece.

d. (Vertical) Band Sawing Machine Operation.

(1) Straight-line sawing is performed on the metal cutting band sawing machine by using one or a combination of several mechanisms or attachments: the miter guide attachment (par. 142) with or without power feed, the screw feed device (par. 143) with or without the work holding jaw device, the work holding jaw device with power feed, and the angular blade guide attachment (par. 141).

(*a*) The miter guide attachment (par. 142) on some machines can be connected to the power feed mechanism and on others must be fed by hand. The workpiece is clamped or hand-held against the miter guide attachment and the workpiece and attachment are moved against the band saw blade. The miter guide assembly moves on a track parallel to the blade, thereby assuring a straight-line cut.

(*b*) The screw feed device (par. 143) is used to push the workpiece against the band saw blade in a direction parallel to the blade. The feed screw may be applied directly to the workpiece or used to push the work holding jaw device in which the workpiece can be positioned at various angles.

(*c*) The work holding jaw device on some machines can be connected to power feed to produce straight-line cuts (fig. 159).

(*d*) The angular blade guide attachment (par. 141) is used for straight-line sawing when the workpiece cannot be cut in the normal manner because it is too large or too long to clear the column of the band sawing machine frame. When the angular blade guide attachment is used, the piece must be guided and fed by hand.

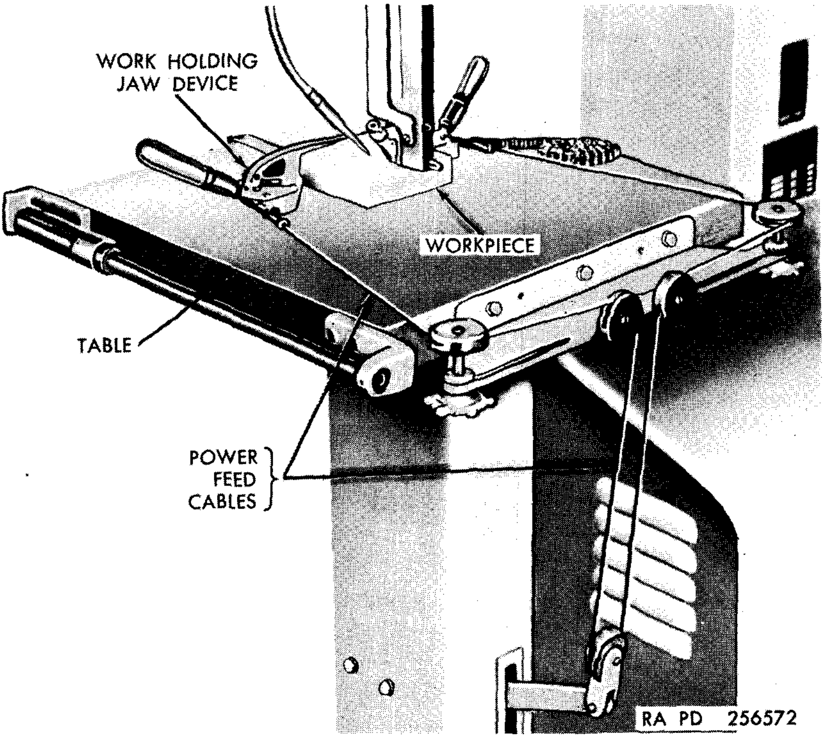


Figure 159. Work holding jaw device used for straight-line sawing with power feed.

(2) A typical example of a straight-line sawing operation is outlined below.

(*a*) Select a band saw blade (par. 135) of the desired pitch for the nature of material to be cut. The blade should be as wide as possible for straight-line sawing.

(*b*) Set the desired speed on the band sawing machine (par. 149*b*).

(*c*) Position the workpiece at the desired angle in one of the band sawing machine attachments (1) above, and connect the cable to the power feed mechanism if power feed is to be used.

(*d*) Start the band sawing machine and feed the workpiece lightly into the blade to start the cut. Once the cut is started, the feed can be increased. If feed is by hand, the pressure applied to the workpiece by the operator can be varied to find the best cutting conditions.

152. Curve Sawing

a. Curve sawing is performed on the metal cutting band sawing machine by either guiding the workpiece by hand or by using the disk cutting saw attachment (par. 140).

b. Care must be taken to select a band saw blade of the proper width for the radius or curve to be cut (par. 135*e*(5)). If a blade is too wide for the radius, the heel of the blade will press against the outer edge of the kerf (fig. 160). When the heel contacts this edge, any further twisting of the workpiece in attempt to cut a sharper radius will twist the band saw blade without cutting a sharper radius.

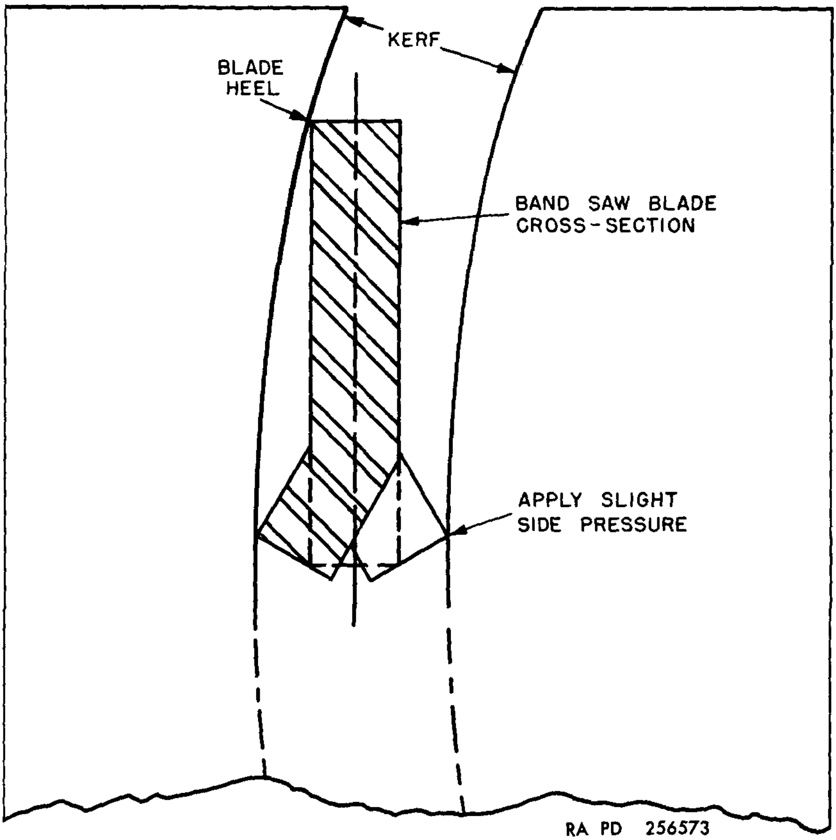


Figure 160. Curve limitation for band saw blades.

c. When cutting curves, a slight side pressure should be applied at the inner cutting edge of the band saw blade (fig. 160). This pressure will give the blade a tendency to provide additional clearance at the blade heel.

d. On curve cutting, less pressure must be applied to the workpiece than on straight-line cutting, and the smaller the curve the more care must be exercised. It should be understood that when any material is cut with a flexible band saw blade, the blade deflects to the rear in proportion to the amount of pressure applied to the workpiece (fig. 161). This deflection, referred to as "drag," will not affect a straight-line cut because the sides of the blade remain parallel to the cut. However, when curves are cut on the band sawing machine, the "drag" will cause a "belly" in the cut section. To reduce the "belly" to a minimum, the "drag" must be reduced to a minimum, and this can only be done by reducing the pressure applied in feeding the workpiece into the blade.

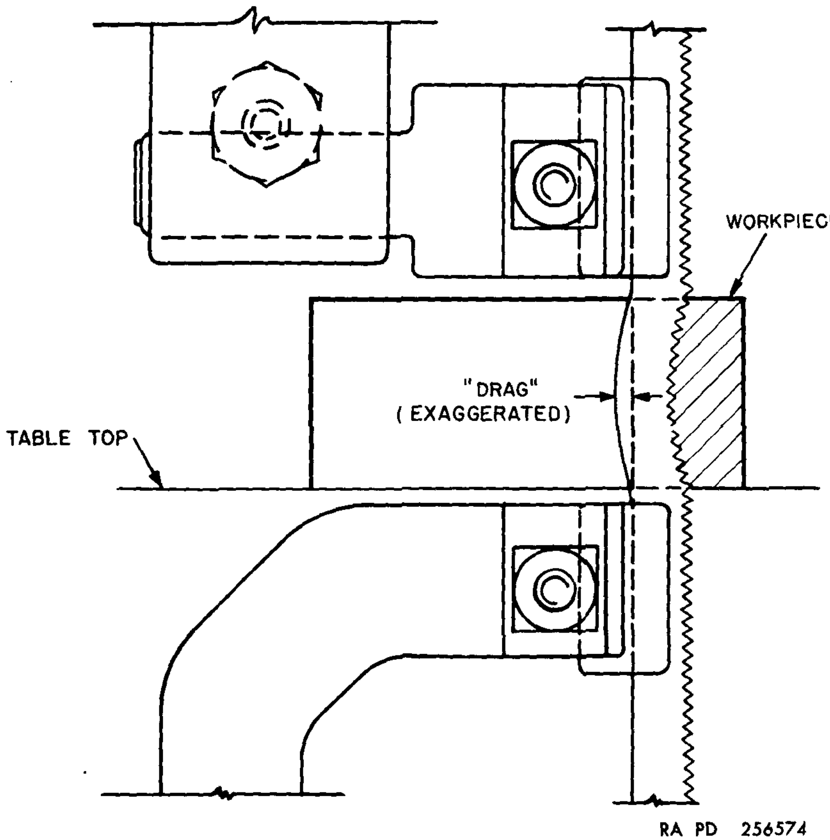


Figure 161. Example of blade drag caused by feed pressure.

e. When sawing at an angle with the table tilted, a curve or radius will be shaped like a cone section, with a larger radius on one workpiece surface and a smaller radius on the other workpiece surface. It is very important when cutting at angles that the smaller of the two radii be used to determine the band saw blade size.

153. Contour Sawing

a. Contour sawing is the process of cutting shapes in which the direction of the cut must be changed at intervals.

b. Holes larger in diameter than the width of the saw blade must be drilled at each corner where a change of direction of the band saw blade will occur (par. 146*c*).

c. Figure 162 illustrates the methods of changing direction of a cut at a hole.

(1) *Sawing away from hole.* To saw away from the hole on a line tangent to the hole, the band saw blade must cut away from the center of the hole, or the blade will bow causing a "belly" in the cut. The cut should be started as in A, figure 162, in which a curve is cut outward from the hole to meet the layout line, leaving a piece of excess metal which can be removed later by filing. An alternate method is

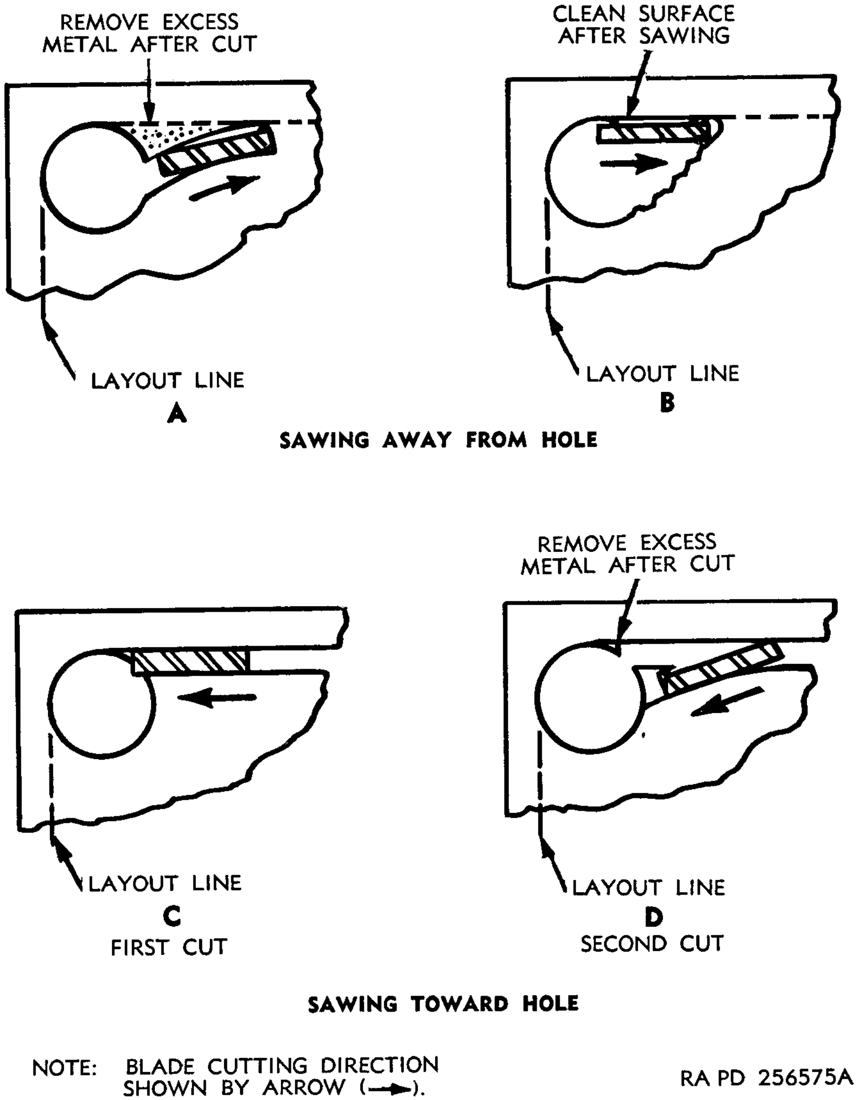


Figure 162. Methods of sawing to and away from holes.

shown at B, figure 162, in which a section of metal is notched out with the saw blade by several short cuts to give the blade clearance for starting the cut along the layout line.

(2) *Sawing toward hole.* The diagrams at C and D, figure 162, show the proper method of sawing up to a hole in two cuts. The excess metal can be removed later by filing.

d. After the shape is cut and the slug or waste metal is removed, the corners should be finished by filing or notching. The band saw blade should not be used for these operations because the blade will bow and cut unevenly.

154. Internal Sawing

a. Internal sawing is performed in the same manner as contour sawing (par. 153) except that the band saw blade cannot start cutting from the edge of the workpiece, but must start cutting from a drilled hole in the workpiece (fig. 158).

b. With the pattern to be cut layed out on the workpiece and the starting hole drilled (par. 146*c*), insert an unwelded band saw blade of the proper length through the starting hole. Bring the two ends of the blade together at the butt welder of the band sawing machine, and weld the blade into a continuous band as described in the pertinent operation manual for the machine. Install the band saw blade on the sawing machine and make the necessary adjustments to the machine.

c. The sawing is performed as described in paragraph 153, the cut being started from the hole as shown in A or B, figure 162. When the sawing operation is completed, the band saw blade is cut so that it can be removed from the workpiece.

Section V. SPECIAL OPERATIONS ON SAWING MACHINES

155. Band Filing

a. General. Filing operations are performed on the metal cutting band sawing machine using a band file (par. 136) and the band file attachment (par. 138). As with sawing operations, the quality of filing and the economical wear of the band file depend upon proper selection of files and filing speeds for different materials and conditions.

b. Band Filing Speed. Band files should be run at relatively slow speeds as compared to speeds used for band sawing. Table XXXIII lists recommended filing speeds for band filing. Note that in general, the slower speeds are used for filing harder metals and faster speeds are used for filing softer metals.

c. Band Filing Feeds. Work pressure on the band file should not be excessive. A medium amount of pressure applied against the band file moving at the proper speed will produce curled chips which will not clog the file. Heavy pressure will cause clogging and can cause

Table XXXIII. Band Filing Speeds

Material	Band filing speed (fpm)	Material	Band filing speed (fpm)
Aluminum	75 to 175	Fiber	115 to 175
Brass	115 to 260	Magnesium	75 to 175
Bronze	75 to 115	Steel, alloy	50 to 115
Cast iron	50 to 115	Steel, machine	75 to 175
Copper	115 to 260	Steel, tool	50 to 75

breaking of the file or stalling of the machine. A light pressure should be used for finish filing, with a slow sideways motion that will not leave vertical file marks on the workpiece.

156. Polishing

a. General. Polishing bands (par. 137) and a polishing attachment (par. 139) are provided with the metal cutting band sawing machine so that light polishing opreations can be performed. The polishing bands are intended primarily for the removal of saw marks on the cut edges of workpieces.

b. Polishing Speeds. Polishing bands should be moved at speeds between 75 and 260 feet per minute, the faster speeds being used for softer materials and the slower speeds being used for harder materials.

c. Polishing Feeds. Feeds should be light for polishing operations. Use a slow sideways motion so that the polishing band will leave no marks on the workpiece. If the band does not remove the tool marks quickly, change to a coarser polishing band.

CHAPTER 7

SHAPERS AND PLANERS

Section I. GENERAL

157. Purpose

a. Shapers and planers are machine tools used principally for the production of flat and angular surfaces on metal workpieces. Both shapers and planers use a single-edge cutter bit. The chief difference in application between shapers and planers lies in the size workpiece each machine will accept. Shapers are restricted to the machining of small and medium size workpieces, while planers are used to machine medium and large size workpieces.

b. Although planers are not in use in the Ordnance Corps, they are described briefly in this chapter because of the overall similarity in performing work done on the shaper. Where information is the same for shapers and planers, paragraph headings and attendant instructions will include the planer. Instructions peculiar to operation of planers have been omitted, but may be included in the form of a change to this manual at such time as planers are introduced into the Ordnance Corps.

c. The shaper uses a reciprocating ram to push and pull the cutter bit across the face of the workpiece. The ram on all shapers except specialized shapers moves in a horizontal direction. The cutting action of the cutter bit is on the forward stroke of the ram, which is delivered at a slower speed than the return stroke. The workpiece, which is mounted to the shaper table, moves sideways after each forward stroke of the ram to aline the workpiece for the next cut. The size of a shaper is designated by the maximum length of its stroke; thus, a 16-inch shaper will machine workpieces up to 16 inches in length.

d. The operation of the planer may be considered exactly opposite to that of the shaper. Instead of moving the cutter bit across the stationary workpiece, the planer carries the workpiece on a reciprocating worktable past the stationary cutter bit. As in the case of the shaper, the planer cuts only on the forward stroke, after which the worktable is caused to make a quick return to bring the workpiece in position for the next cut. The cutter bit is affixed to the tool slide which in turn moves laterally on a cross slide to feed the cutter bit sideways for each pass of the table. The cross slide moves vertically on either a single housing or two housings to position the cutter bit above the workpiece. The size of a planer is designated by the maximum size workpiece that can be clamped and machined on its worktable; thus, a 30-inch x 30-inch x 6-foot planer is one that can accommodate workpieces up to these dimensions.

158. Types of Shapers

a. General. The most common shapers in use are the horizontal shapers in which the ram moves back and forth horizontally on the top of the shaper column. Most horizontal shapers have either a crank drive mechanism or a hydraulic drive mechanism. In crank-driven horizontal shapers, the crank drive mechanism is used to change rotary motion to reciprocating motion. A large gear called a bull gear receives a rotary motion from the electric motor. A crank pin, mounted eccentrically to the bull gear, drives a rocker arm back and forth as the bull gear rotates. The rocker arm, pivoting from the shaper base drives the ram back and forth. With hydraulic horizontal shapers, the ram is moved back and forth by a piston moving in a cylinder under the ram. Oil pressure in the cylinder is controlled to act first against one side of the piston and then against the other side of the piston to give the ram a positive drive.

b. Bench-Mounted Horizontal Metal Cutting Shaper (fig. 163). The bench-mounted horizontal metal cutting shaper has a crank-driven ram with a maximum stroke of 7 inches. The shaper is powered by a one-third-horsepower electric motor which is connected to the bull gear by V-belts and pulleys. The drive pulley V-belt can be shifted to give speeds ranging from 40 to 180 strokes per minute. The stroke can be adjusted to any length up to 7 inches, and the ram can be adjusted in relation to the shaper table for centering the stroke over the workpiece. The crossrail, located across the front of the shaper frame, supports the shaper table and permits lateral and vertical movement of the table. Lateral movement required to feed the workpiece after each stroke of the ram can be controlled by hand or automatic feed. Workpieces can be mounted directly to the shaper table or held in a swivel vise, shaper rotary table, or indexing fixture attached to the shaper table.

c. Floor-Mounted Horizontal Metal Cutting Shaper. Most floor-mounted horizontal metal cutting shapers are heavy-duty machines having a maximum stroke of 16 inches or more. These shapers may have either crank-driven or hydraulic-driven rams, the latter usually having a greater range of speeds and feeds. Otherwise, the floor-mounted horizontal metal cutting shaper is similar in all major respects to the bench-mounted shaper (*b* above).

159. Types of Planers

a. General. The two common types of planers in use are the double-housing planer and the open-side planer.

b. Double-Housing Planer. The double-housing planer has two columns (housings) that rise vertically from each side of the planer bed and support the crossrail. The crossrail supports the tool head or tool heads, and can be raised or lowered on the columns to accommodate different sizes of workpieces on the worktable. One or more tool heads can be mounted on the crossrail at one time, each tool head mounting a cutter bit.

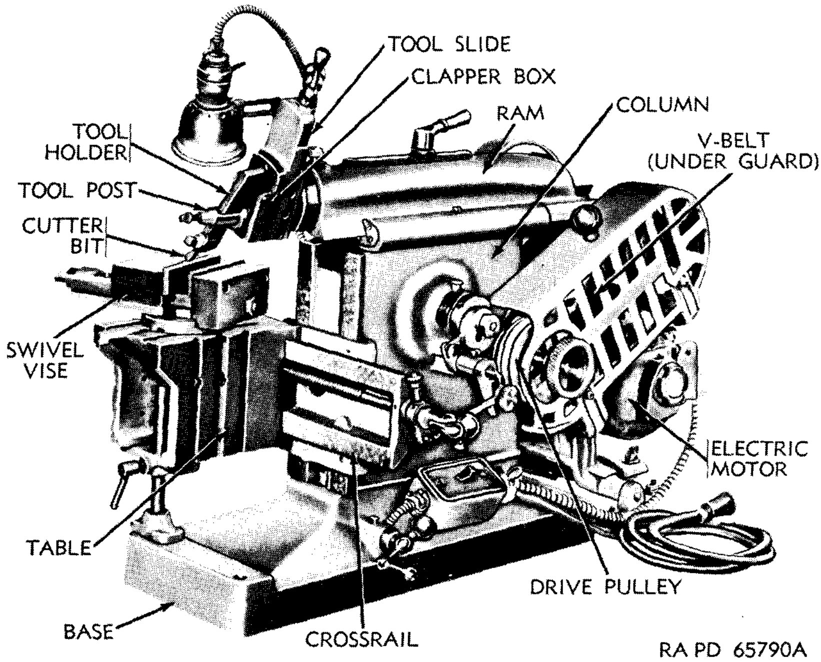


Figure 163. Bench-mounted horizontal metal cutting shaper.

c. Open-Side Planer. The open-side planer differs from the double-housing planer in that it has only one column which supports the crossrail, the crossrail being cantilevered over the worktable. The advantage of the open-side planer is that workpieces wider than the worktable can be accommodated, provided these workpieces can be adequately supported. The working parts of this machine are essentially the same as on the double-housing planer.

Section II. TOOLS AND EQUIPMENT

160. Shaper and Planer Cutting Tools

a. General. The single-edge cutting tools used for shaper and planer work are called cutter bits, and are similar to cutter bits used for lathe cutting (par. 62). Shaper and planer cutter bits are made of high-speed steel or may consist of a mild steel shank with an inserted carbide or high-speed steel tip. Interchangeable cutter bits ground for different cutting operations are easily fastened to the shaper or planer tool post or to a cutter bit tool holder. The cutter bit may be mounted at different angles depending on the nature of the cutting operation.

b. Types of Shaper and Planer Cutter Bits. In general, shaper and planer cutter bits are identified as roughing or finishing tools. Finishing cutter bits usually contain sharp corners so that the tool can be fed into the angles of dovetails or used to finish the inside angles of shoulders where a radius or fillet is not desired. These finishing cutter bits are not suitable for the heavy cutting required of roughing cutter bits because their sharp cutting radii will dull or break off easily. Roughing cutter bits have rounded corners to distribute the force of the cut over a wider area, and can therefore be used with heavy feeds and deep cuts.

(1) *Round-nose roughing cutter bit* (fig. 164). The round-nose roughing cutter bit is used for general purpose roughing cuts with either right-hand or left-hand feed. This cutter

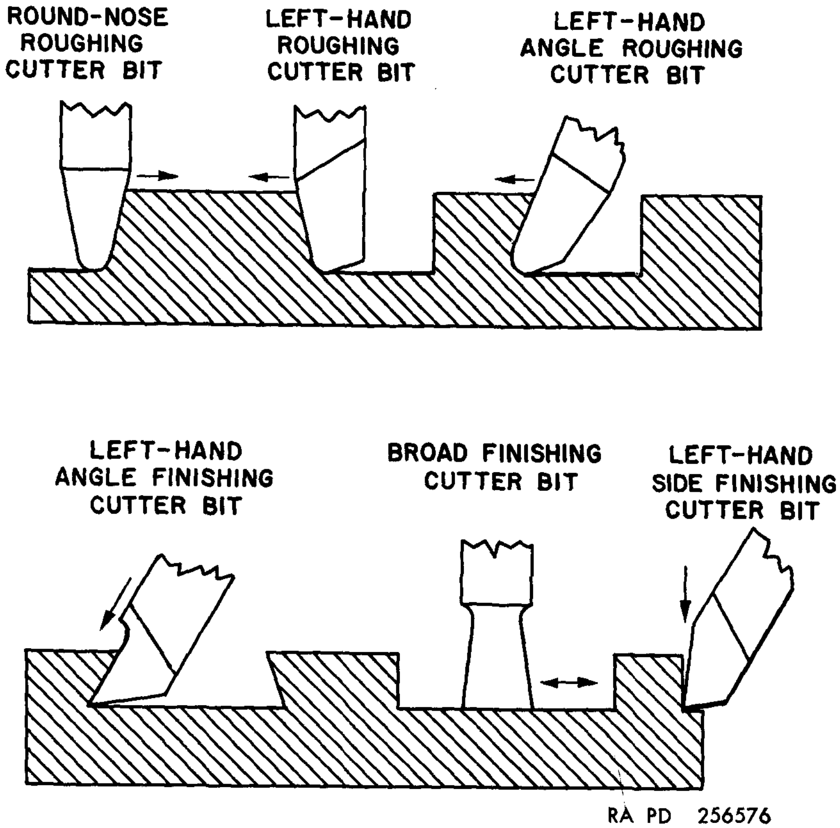


Figure 164. Shaper and planer cutter bits.

bit usually contains no back rake or side rake. The round-nose roughing cutter bit is used mostly for light roughing on cast iron workpieces. A narrow round-nose roughing cutter bit (fig. 165) is often used for miscellaneous roughing operations on small workpieces, and for groove cutting.

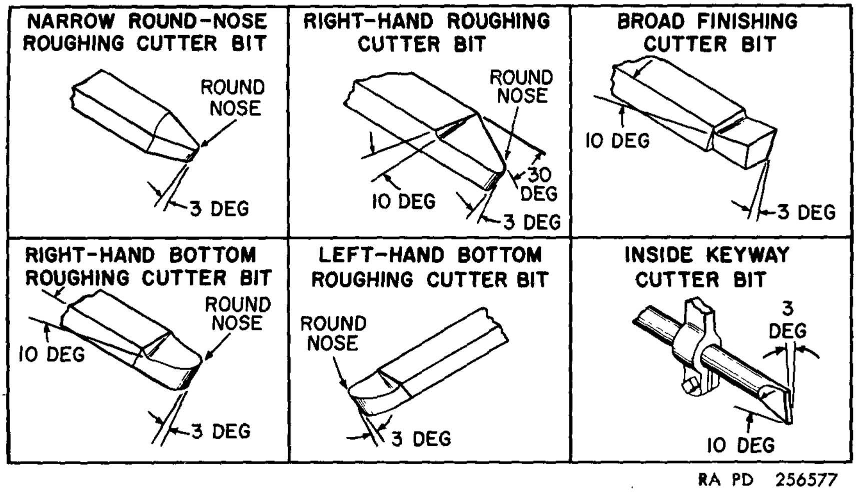


Figure 165. Shaper and planer cutter bits.

(2) *Left and right hand roughing cutter bits.*

(*a*) The left hand roughing cutter bit (fig. 164) is used for the majority of roughing operations on cast iron and steel workpieces. This cutter bit is capable of heavy feeds and deep cuts. The cutter bit is supported vertically in the cutting tool holder for surface cuts and is offset at an angle for down cutting operations. No back rake is given to the left hand roughing cutter bit but the side rake may be as great as 15° or 20° for soft metals so that the heavy chip produced will curl and break at short intervals.

(*b*) The right hand roughing cutter bit (fig. 165) is ground like the left hand roughing cutter bit ((*a*) above) only in reverse. This cutter bit is intended for roughing cuts from left to right when the normal right-to-left cutting procedure is impractical.

(3) *Left and right hand bottom roughing cutter bits.*

(*a*) The left hand bottom roughing cutter bit (fig. 165) is similar to the round-nose roughing cutter bit ((1) above) in shape, but is ground with about 10° of positive back rake and with varying amounts of side rake to direct the chips away from the workpiece surface. This cutter bit is designed primarily for very heavy roughing operations on machine steel workpieces.

(*b*) The right hand bottom roughing cutter bit (fig. 165) is ground like the left hand bottom roughing cutter bit ((*a*) above) only in reverse. This cutter bit is used in place of the left hand bottom roughing cutter bit when left-to-right feed is desired.

(4) *Angle roughing cutter bit* (fig. 164). The left and right hand angle roughing cutter bits are used to rough cut dovetails and similar conformations where the cutter bit must be fed into the workpiece at an angle. The left hand tool cuts to the left and the right hand tool cuts to the right. In the machining of dovetails, the shape is roughed out with this tool and followed with a left or right hand angle finishing cutter bit ((7) below).

(5) *Broad finishing cutter bit* (figs. 164 and 165). The broad finishing cutter bit has a flat tip and slightly recessed sides to provide necessary clearance. This cutter bit is used to finish flat surfaces, usually being operated with shallow depth of cut and heavy feed. The broad finishing cutter bit is well suited for finishing the bottom and sides of shoulder cuts, keyways, and wide grooves.

(6) *Side finishing cutter bit* (fig. 164). The side finishing cutter bit may be either right hand or left hand, and is used for finishing vertical cuts. Since this cutter bit has two cutting edges, small horizontal shoulders or surfaces may be finished with this cutter bit in order to avoid changing tools.

(7) *Angle finishing cutter bit* (fig. 164). The angle finishing cutter bit is supplied in both right hand and left hand types, and is used to finish dovetails or other similar shapes after roughing. Usually the tool is first fed laterally to finish the bottom of the cut, and then fed downward at an angle to finish the angular side of the cut.

(8) *Inside keyway cutter bit* (fig. 165). The inside keyway cutter bit differs basically from the cutter bits described above in that it is formed from a round shank rather than a square shank. Mounted in an appropriate cutting tool holder, this cutter bit may be used for cutting keyways and splines in workpiece bores. This cutter bit can be ground to various widths.

c. Clearance and Rake Angles. The nomenclature used for shaper and planer cutter bits is the same as that for lathe cutter bits (par. 62) and the elements of the cutter bit, such as clearance and rake angles, are in the same relative positions as shown in figure 46.

(1) Less end clearance (clearance at the heel of the cutter bit) is required for planer and shaper cutter bits than for lathe cutter bits.

(2) Cutter bits designed for roughing operations with the planer and shaper are often ground without back rake and with a large side rake angle. This design generally reduces the tendency of the cutter bit to chatter.

(3) Table XXXIV lists clearance and rake angles commonly used for the machining of different materials with the shaper and the planer.

Table XXXIV. Clearance and Rake Angles for Shaper and Planer Cutter Bits

Material	Operation	Side clearance angle (deg.)	End clearance angle (deg.)	Back rake angle (deg.)	Side rake angle (deg.)
Aluminum	Roughing	5–9	2–5	2–8	16–22
	Finishing	0	2–5	8	16–22
Brass	Roughing	5–9	2–5	2–8	4–10
	Finishing	0	2–5	14–22	0
Bronze	Roughing	5–9	2–5	2–8	4–10
	Finishing	0	2–5	14–22	0
Cast iron	Roughing	5–9	2–5	2–8	14
	Finishing	0	2–5	6–10	0
Copper	Roughing	5–9	2–5	2–10	16–20
	Finishing	0	2–5	8	16–20
Magnesium	Roughing	6–10	2–5	0–5	3–5
	Finishing	0	2–5	10–15	0
Monel metal	Roughing	5–9	2–5	0–4	10–14
	Finishing	0	2–5	14–22	0
Steel, hard	Roughing	5–9	2–5	0–6	10–14
	Finishing	0	2–5	8–14	0
Steel, soft	Roughing	5–9	2–5	0–8	14–22
	Finishing	0	2–5	14–22	0
Steel, very hard	Roughing	5–9	2–5	0–5	5–10
	Finishing	0	2–5	5–10	0

d. Grinding of Shaper and Planer Cutter Bits. As with all cutting tools used for machining, shaper and planer cutter bits should be kept sharp for efficiency of operation and quality of machined surfaces. A dull cutter bit overworks the machine tool, cuts slowly, and produces a poor finish. Shaper and planer cutter bits are ground offhand on utility grinding machines in the manner outlined for the grinding of lathe tools (par. 62*g*). It should be remembered that high-speed steel cutter bits must be ground dry; dipping these tools in water when hot will crack the cutting edge. After grinding, the cutting edge of the cutter bit should be carefully honed with an oilstone to produce a smooth edge. This practice will increase the life of the cutting edge as well as making possible a smoother cut.

e. Mounting of Shaper and Planer Cutter Bits. Cutter bits for shapers and planers are usually mounted in cutting tool holders which are secured to a tool post (fig. 163) on the clapper block of the machine. The cutting tool holders are made in different shapes, some designed to support the cutter bit in a vertical position, others designed to support the cutter bit at an offset angle, and others designed to hold the cutter bit at a variety of different angles (par. 162). Large cutter bits, especially those used on heavy-duty planers, are often mounted directly to the tool post on the clapper block of the machine where the cutting tool holder would normally mount.

161. Forged Shaper and Planer Cutting Tools

a. General. Forged cutting tools are often used in large shapers and planers instead of the smaller cutter bits. These tools are generally adaptable to heavier cuts than are cutter bits, and are mounted directly to the tool post on the planer or shaper clapper block.

b. Types of Forged Shaper and Planer Cutting Tools.

(1) *Gooseneck cutting tool* (fig. 166). The gooseneck cutting tool is intended primarily for the finishing of cast iron. This cutting tool is forged in the shape of a gooseneck so that the cutting edge is behind the back side of the tool shank. This feature allows the tool to spring away from the workpiece slightly, reducing the tendency for gouging or chattering. The cutting edge is usually flat with slightly rounded corners.

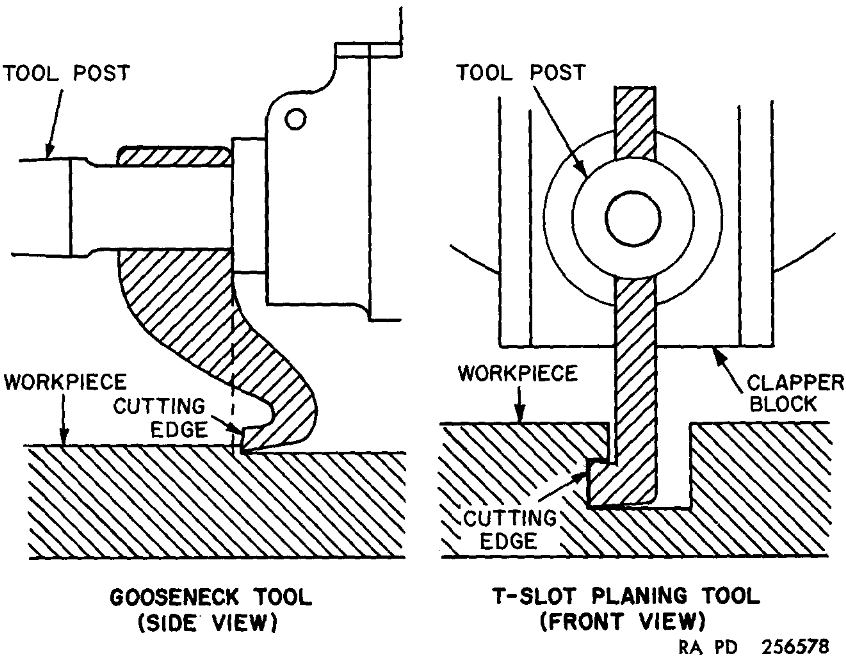


Figure 166. Forged shaper and planer cutting tools.

(2) *T-slot planing tool* (fig. 166). The T-slot planing tool illustrates the necessity for using forged cutting tools for special operations. This cutting tool has an offset cutting edge designed for planing or shaping undercuts. The T-slot planing tool is made in left and right hand models for cutting undercuts to the left or to the right.

c. Clearance and Rake Angles of Forged Cutting Tools. The clearance angles and the rake angles required for forged cutting tools are the same as those used for planer and shaper cutter bits (par. 160*c*).

d. Grinding of Forged Cutting Tools. Forged shaper and planer cutting tools are ground off-hand on utility grinding machines in the manner outlined for the grinding of lathe cutter bits (par. 62*g*). Refer to table XXXIV (par. 160*c*) for proper rake and clearance angles to be maintained.

162. Cutting Tool Holders

a. General.

(1) Various types of cutting tool holders are available for securing planer and shaper cutter bits to the machine tool. These cutting tool holders are usually forged steel bars containing an opening into which the cutter bit is positioned and locked in place by means of a setscrew or bolt.

(2) The cutting tool holder mounts to the tool post (fig. 163) projecting forward from the shaper or planer clapper block.

(3) The common types of cutting tool holders for shaper and planer use are the straight shank cutting tool holder, the right and left hand offset cutting tool holders, the swivel head cutting tool holder (fig. 167), and the extension bar cutting tool holder (fig. 167).

b. Straight-Shank Cutting Tool Holder. The straight-shank cutting tool holder is similar to the straight-shank cutting tool holder used with the lathe (par. 63*b*), the major difference being that this cutting tool holder is larger and supports the cutter bit on a line parallel to the axis of the shank, while the similar lathe cutting tool holder supports the bit at an upward angle. The straight-shank cutting tool holder is supplied in different sizes, each intended for supporting one size of cutter bit.

c. Offset Cutting Tool Holders. The offset cutting tool holders are supplied with right hand or left hand offset angles for supporting the cutter bit at an angle for different shaper and planer operations. These tool holders differ from the right and left hand offset cutting tool holders used with the lathe (par. 63*c*) in that they are generally larger and the cutter bit remains vertical although offset to the left or right. With the corresponding lathe tool holder, the cutter bit is offset vertically as well as laterally.

d. Swivel Head Cutting Tool Holder (fig. 167). The swivel head cutting holder is a popular tool holder because a cutter bit can be mounted in it in several different radial positions. This feature allows it to be used as a straight shank holder or a right hand or left hand offset holder, and also permits mounting of the cutter bit at right angles to the shank.

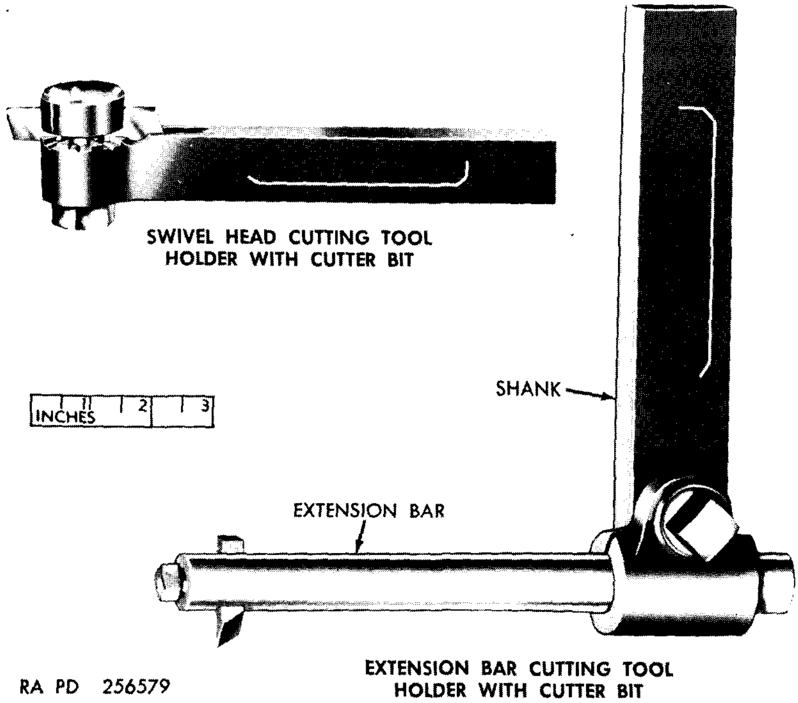


Figure 167. Shaper cutting tool holders.

e. Extension Bar Cutting Tool Holder (fig. 167). The extension bar cutting tool holder supports the cutter bit in an extension bar projecting forward from the shank of the holder. This cutting tool holder is adapted for cutting internal splines and keyways on the shaper. The extension bar may be adjusted in the shank for length or for radial position by releasing a setscrew. The cutter bit fits through a slot in one end of the extension bar and is clamped in place by a setscrew.

163. Swivel Vise

The swivel vise is the most common machine tool attachment used with the shaper. It is essentially the same as the swivel vise used for holding workpieces to the milling machine table (fig. 123) and usually attaches to the shaper table with T-slot bolts. The vise body can be swiveled 260° on a graduated base. The base is keyed to the shaper table to maintain alinement of the graduated scale.

164. Shaper Rotary Table

The shaper rotary table (fig. 168) consists chiefly of a circular table containing T-slots, a table base, and an indexing pin. The circular table has an engraved graduated scale and 12 index pin holes in its circumferential surface whereby the table can be fixed in any desired position of rotation. Workpieces are clamped to the circular table top, using T-slot bolts. Typical operations performed in conjunction with the shaper rotary table include slotting and angle cutting of workpieces which, due to their shape, cannot be mounted conveniently in the swivel vise.

165. Indexing Fixture

a. An indexing fixture (fig. 169) is provided as a machine tool attachment with some shapers to hold and index workpieces for keyway

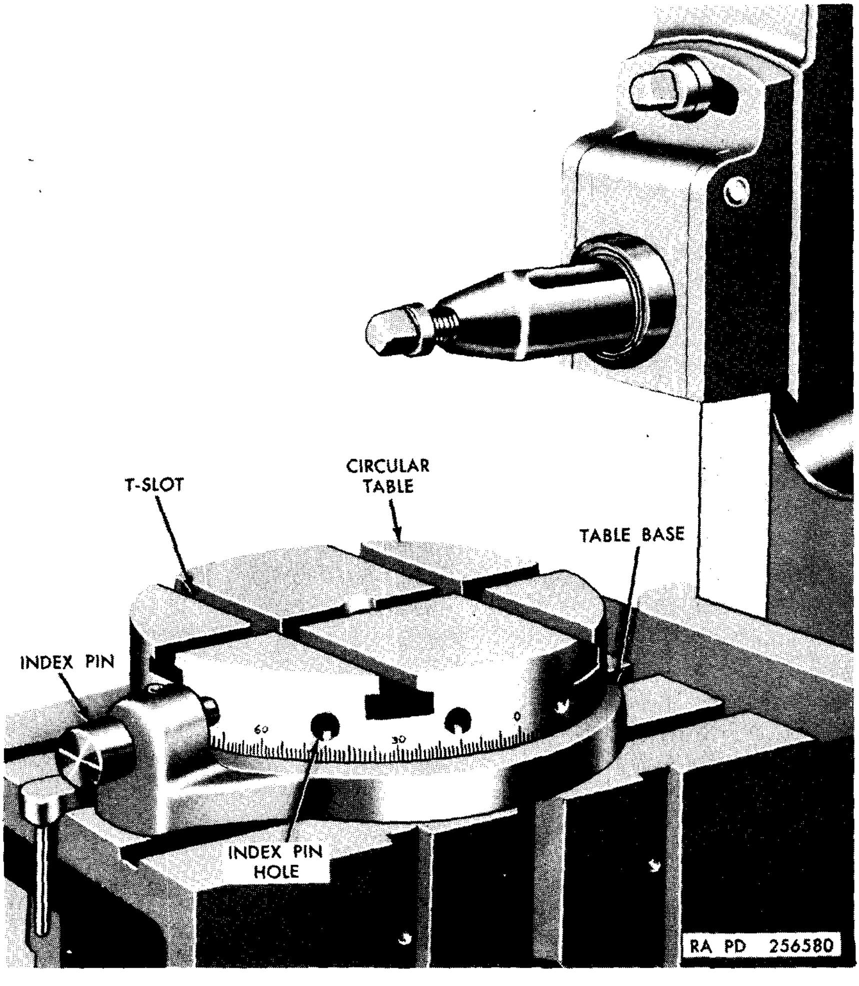


Figure 168. Shaper rotary table.

and spline cutting operations. This indexing fixture is generally much simpler than the indexing fixtures used with milling machines (par. 111) and the milling and grinding lathe attachment (par. 94).

(*b.*) The shaper indexing fixture usually consists of a base, an index head, one or more indexing plates, and centers. The workpiece must be drilled and countersunk at each end so that it can be mounted between the live center in the index head and the deadcenter in the base. A clamp dog is used to lock the workpiece to the index head spindle.

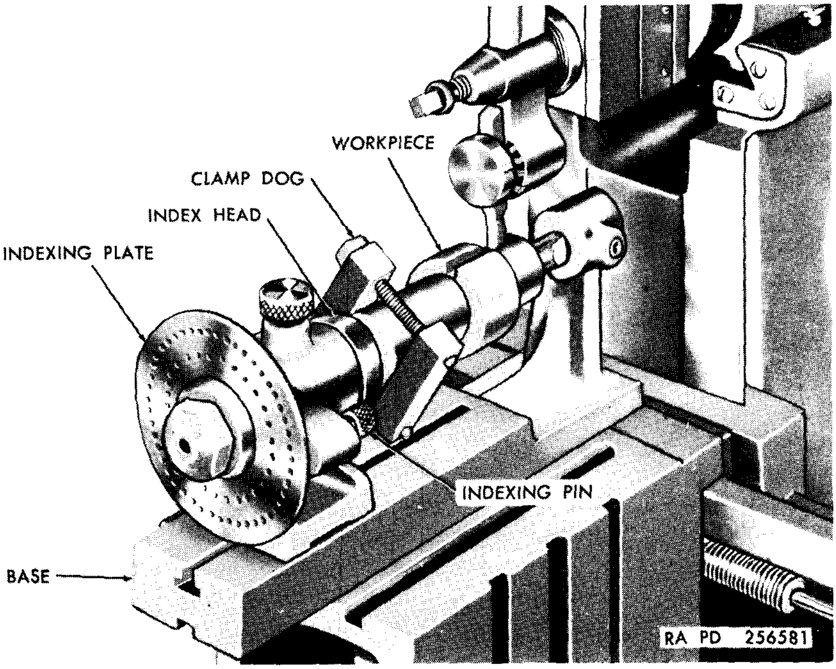


Figure 169. Indexing fixture for the shaper.

The indexing plate, containing equally spaced pin holes, is mounted to the forward end of the index head spindle where it contacts an indexing pin mounted at the side of the index head. Indexing is accomplished by moving the indexing plate a specified number of holes past the indexing pin to rotate the workpiece a desired distance. Unlike the indexing fixtures for the milling machine and milling and grinding lathe attachment, the indexing plates are coupled directly to the index head spindle. Indexing plates containing rings of different numbers of holes are furnished.

166. Miscellaneous Holding Devices

a. In addition to the basic machine tool attachments (pars. 163–165) a number of workpiece holding devices common to other machine tools are used for shaper and planer operation. These miscellaneous devices include T-slot bolts (par. 26*h*), parallels (par. 26*b*), V-blocks (par. 26*f*), hold-down straps (par. 110*f*(6)), machine strap clamps (par. 26*e*), step blocks (par. 26*d*), and angle plates (par. 26*g*).

b. These holding devices are used to mount workpieces directly to the shaper table or planer worktable, to secure workpieces to the surface of the shaper rotary table, and to provide additional support for vise mounted workpieces.

Section III. MOUNTING AND LAYING OUT WORK FOR SHAPER OPERATION

167. General

a. In machining operations on the shaper, the proper securing of workpieces and the positive alinement of the shaper table are of utmost importance.

b. Mounting of workpieces for shaper cutting requires that positive alinement of the table to the ram be maintained at all times. Periodically the shaper table should be checked for alinement, using a dial indicator mounted in the tool post. By manually operating the ram with the dial indicator point in contact with the shaper table, front to back alinement can be checked. By feeding the table manually from side to side past the ram, lateral alinement can be determined. Refer to the pertinent technical manual for adjustment procedure applicable to specific shapers.

c. Due to the variety of operations that may be performed on the shaper, many different problems arise in the mounting of workpieces, and care must be exercised in the selection of the proper mounting device for each case. The springing of the workpiece during clamping operations must be avoided if accuracy is to be obtained. Where relatively small amounts of metal are to be removed from heavy parts, the problem of springing is usually negligible; however with light or irregularly shaped workpieces, the springing of the workpiece is a factor that must be carefully considered. Springing may be caused by applying excessive pressure to the workpiece in clamping, by faulty application of clamping devices, or by relief of internal stresses in the material when the outer surface is removed. Springing resulting from the first two of these causes can be overcome by proper mounting of the workpiece. Springing caused by internal stresses in the workpiece can usually be minimized by roughing all external surfaces before finishing cuts are taken.

168. Mounting Workpieces in the Vise

a. The swivel vise (par. 163) is used for mounting small workpieces of regular shape to the shaper table.

b. The proper method of mounting a block in the vise for planing parallel and square surfaces is as follows:

(1) Aline the stationary vise jaw parallel to the direction of the ram movement.

(2) Set the workpiece to be planed in the vise and plane one of its largest surfaces (step 1, fig. 170). The workpiece should be clamped tightly and well supported against the bottom of the vise or on parallels. Plane the surface (par. 178).

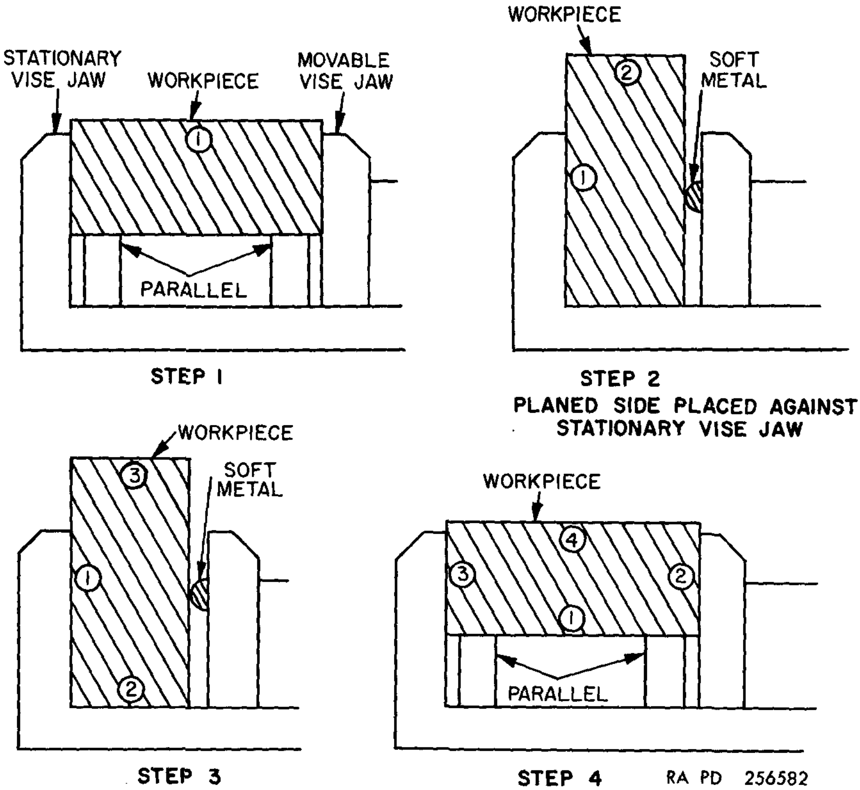


Figure 170. Sequence of steps for squaring a workpiece mounted in the vise.

(3) Remove the workpiece from the vise. Place the surface just planed against the stationary vise jaw (step 2, fig. 170). Insert a strip or rod of soft metal between the workpiece and the movable vise jaw to assure a tight fit of the first side planed with the stationary jaw. Tap the workpiece firmly in place before tightening the vise securely. Plane the second side of the workpiece (par. 178).

(4) Remove the workpiece from the vise and place the surface just planed against the bottom of the vise or on parallels. The first surface planed should still be positioned againts the stationary vise jaw (step 3, fig. 170). Place a strip or rod of soft metal between the workpiece and the movable

vise jaw. Tighten the vise and tap the workpiece firmly against the stationary vise jaw and vise bottom. Plane the third side of the workpiece (par. 178).

(5) Again remove the workpiece from the vise and place the first surface planed against the bottom of the vise or on parallels (step 4, fig. 170). Tighten the vise carefully while tapping the workpiece to assure that all planed surfaces are solidly in contact with the vise jaws and the vise bottom or parallels. It should not be necessary in this case to use a piece of soft metal next to the movable jaw since the three planed sides are known to be square or parallel. Plane the fourth side of the workpiece (par. 178).

(6) To square the ends of the workpiece, set one end against the bottom of the vise with one finished side against the stationary jaw. Use parallels beneath the workpiece if necessary. Use a machinist's square to aline one of the finished sides perpendicular to the bottom of the vise. Clamp the workpiece lightly in the vise and recheck the perpendicular alinement. Corrections should be made by tapping the workpiece lightly with a soft hammer. After a final check of the alinement, plane the end of the workpiece (par. 178). The piece may then be reversed and the opposite end planed after making sure the planed end is firmly in contact with the bottom of the vise and one planed side of the block is firmly in contact with the stationary jaw of the vise.

c. The method of mounting workpieces in the vise for horizontal planing of parallel surfaces without regard to square edges between these surfaces is as outlined in *b*(1), (2), and (5) above except that for *b*(5) above, soft metal strips or rods should be positioned between both vise jaws and the workpiece so that the sides of the workpiece, if not square, will not cause the workpiece to lift away from the vise bottom or parallels when clamped. An alternate method for supporting the workpiece when the second side is to be machined parallel to the first is to secure the workpiece in the vise using hold-down straps (par. 110*f*(6)).

d. If it is desired to plane an angular surface by horizontal planing in the shaper, the workpiece can be mounted in the vise as illustrated in figure 171.

(1) Degree parallels (fig. 171) may be placed between the workpiece and the vise jaws if degree parallels of the proper angle are available.

(2) The workpiece can be layed out with a line scribed on its surface to indicate the plane of the angular surface (fig. 171). The workpiece is then placed in the vise and alined with the aid of a surface gage to make the scribed line horizontal and parallel to the horizontal line of the vise and shaper table.

e. Angular surfaces can also be cut on vise mounted workpieces by mounting the workpiece squarely in the vise and down-cutting with the shaper using angular feed (par. 180).

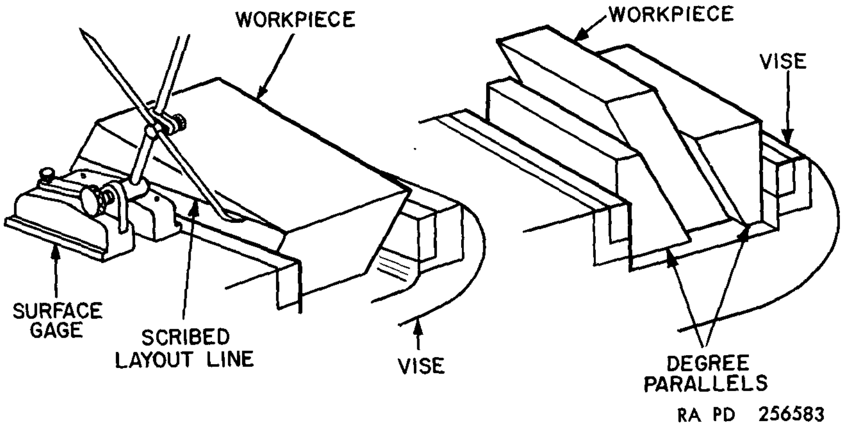


Figure 171. Positioning work in vise for horizontal planing of angular surfaces.

169. Mounting Workpieces Directly to the Shaper Table

a. Several types of shaper operations are performed with the workpieces mounted directly to the shaper table using T-slot bolts, machine strap clamps, step blocks, angle plates, and V-blocks.

b. Workpieces mounted directly to the shaper table must be well supported and braced to prevent their shifting under the force of the cutter bit. If the workpiece has a smooth under surface, it may be mounted flat against the table but if the workpiece has an uneven or rough under surface, a piece of soft material such as shim stock should be placed between it and the shaper table.

c. Cylindrical stock requiring end surfacing can be mounted to the side of some shaper tables. On these machines, a vertical V-groove is machined in the side of the shaper table, and cylindrical workpieces can be clamped in this groove by application of a simple strap secured by bolts to the table (fig. 172).

170. Mounting Workpieces to the Shaper Rotary Table

a. Slotting and grooving operations which require accurate indexing of cuts are performed with the workpiece mounted between centers in the indexing fixture or mounted to the shaper rotary table.

b. The shaper rotary table is used when slots are to be machined at various angles to the travel of the shaper ram (fig. 173).

c. The shaper rotary table is fastened to the shaper table in the same manner as the swivel vise. The workpiece is fastened to the rotary table, using T-slot bolts and clamps. It is necessary that the portion of the workpiece be accurately centered on the shaper rotary

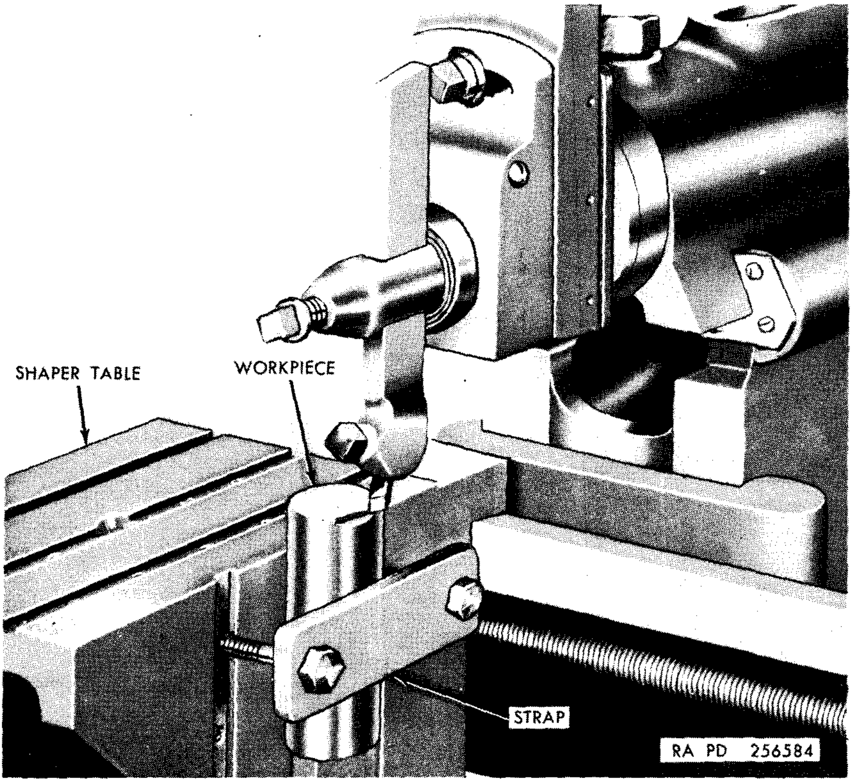


Figure 172. Mounting cylindrical stock to side of the shaper table.

table, since any eccentricity of the workpiece will require recentering of the cutter bit after each indexing of the shaper rotary table.

d. Figure 173 shows a workpiece properly mounted to the shaper rotary table. Note that the workpiece in this case has been fastened to the table using T-slot bolts. The workpiece also can be clamped to the table using machine strap clamps with the T-slot bolts, or an angle plate can be fastened to the table and the workpiece clamped to the angle plate.

171. Mounting Workpieces in the Indexing Fixture

a. Workpieces which require accurate indexing of slots, keyways, or grooves along their circumference are mounted in the indexing fixture attached to the shaper table.

b. It is necessary to drill and countersink center holes in each end of the workpiece before it can be mounted in the indexing fixture. The center holes should be countersunk to a 60° included angle as described for lathe work (par. 72*f*). The workpiece is then mounted between centers in the indexing fixture and a clamp dog applied to the indexing head end of the workpiece (fig. 169).

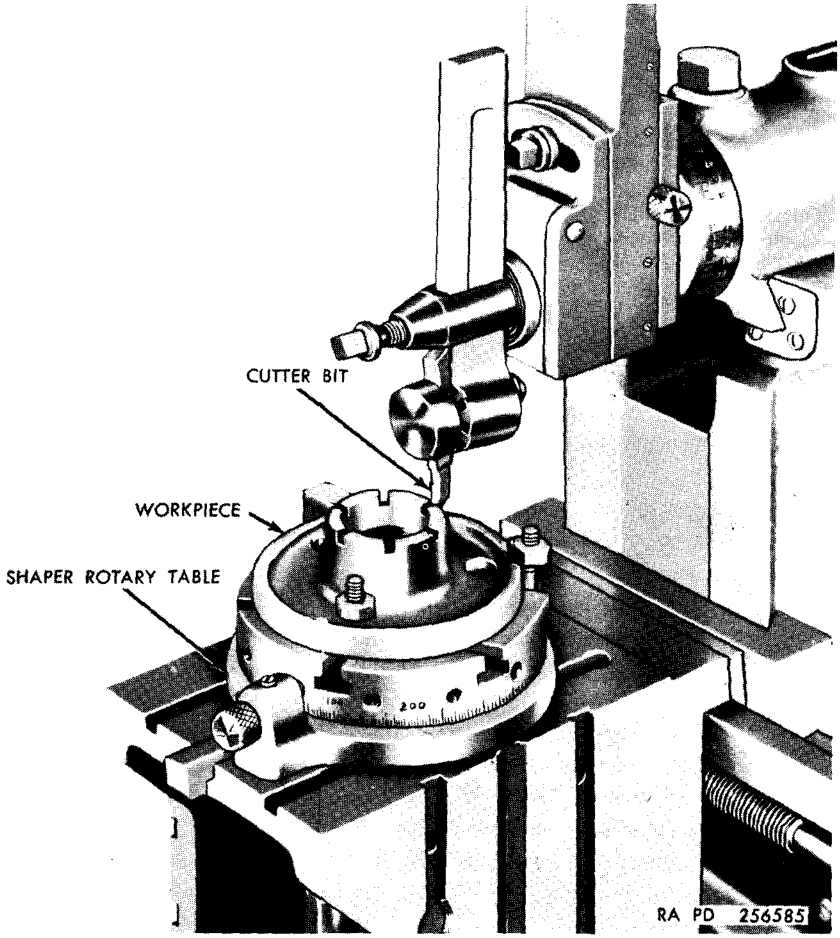


Figure 173. Slotting operation with workpiece mounted on shaper rotary table.

c. Indexing is accomplished as follows:

(1) Determine the number of equal divisions which are to be made about the circumference of the workpiece.

(2) Multiply the number of divisions by any number which will produce a product equal to the number of holes in a circle of the indexing plate (fig. 169). The number by which the divisions were multiplied is the number of holes in the indexing plate to be rotated past the indexing pin to move the workpiece the required distance between each cut. For example, if eight slots are to be equally spaced about the workpiece, the number 8 is multiplied by 3 giving a product of 24. If an indexing plate with 24 holes to a circle is available, the indexing plate should be rotated 3 holes for each slot. If an indexing plate having 24 holes is not available, multiply

8 by another number, say 5, giving a product of 40. If an indexing plate containing 40 holes to a circle is available, the indexing plate would be rotated 5 holes between each slot to produce 8 equally spaced slots.

(3) If the distance between divisions in degrees is known, divide 360 by the number of degrees in one division to obtain the number of equal divisions per circle. Then proceed as outlined in (2) above.

Section IV. GENERAL SHAPING AND PLANING OPERATIONS

172. General

Successful planing operations using the shaper require that the operator know the capabilities and limitations of his machine; that he know the speeds, feeds, and depths of cut which can be economically used; and that he know how to adjust the machine tool to produce accurate cuts and prevent unnecessary wear and breakage of the machine tool, cutting tool, and attachments.

173. Shaper and Planer Cutting Speeds

a. General. Shaper and planer cutting speed is designated as the rate in feet per minute the cutting tool passes over the workpiece or the workpiece passes under the cutting tool. This rate applies only to the cutting stroke and not to the return stroke.

b. Factors Governing Speed. The correct speed to be used for any given planer or shaper operation will depend on the size, shape, and material of the cutter bit or cutting tool, the type of material to be cut, the cutting oil used (if any), the feed and depth of cut selected, and the speed limitations of the particular shaper or planer. Generally, roughing and finishing operations are performed using the same speed except on cast iron workpieces where a slower speed is required for the finishing operation in order to produce a good surface. Wide finishing tools used for finish planing of large surfaces with a very coarse feed also require a slower speed to conserve the edge of the tool. Heavy round-nose cutter bits and cutting tools used for medium and heavy roughing can be operated safely at higher speeds than finishing tools having sharp corners on the cutting edge.

c. Selection of Cutting Speeds. Typical cutting speeds for various materials are listed in table XXXV. These speeds are approximate and should be readjusted if excessive tool wear is noted.

174. Setting Shaper Stroke

a. General. Knowledge of proper cutting speeds for the shaper is valueless without understanding the reciprocating action of the shaper ram and how cutting speeds are translated into strokes per minute of the ram.

Table XXXV. Shaper and Planer Cutting Speeds

Material	Operation [1]	Cutting speed for high-speed steel cutter bits (fpm)
Aluminum	Roughing and finishing	60 to 200
Brass	Roughing and finishing	50 to 100
Bronze	Roughing and finishing	30 to 80
Cast iron	Roughing	35 to 70
	Finishing	25 to 45
Copper	Roughing and finishing	30 to 80
Monel metal	Roughing and finishing	30 to 50
Steel, machine	Roughing and finishing	45 to 75
Steel, hard	Roughing and finishing	25 to 60
Steel castings	Roughing and finishing	30 to 60
Steel forgings:		
Soft	Roughing and finishing	40 to 60
Hard alloys	Roughing and finishing	12 to 30

[1] Except for cast iron, metals are roughed and finished at the same speed. However, when broad cutting tools are used with wide feeds for finishing large surfaces, a slower cutting speed is used to conserve the cutting tool.

b. Changing Cutting Speed to Strokes Per Minute. The ram of the shaper reciprocates, or moves forward and back to push the cutter bit across the workpiece and pull the cutter bit back again. The cutter bit cuts only on the forward movement which is designated the "cutting stroke," or simply "stroke." The back movement of the ram during which the cutter bit does not cut, is called the "return stroke."

(1) On all shapers, the "return stroke" is quicker than the "cutting stroke." On most shapers, the ratio of the time of the cutting stroke to the return stroke in any one cycle is three to two, or in other words, the cutting stroke consumes ⅗ of the cycle time and the return stroke consumes ⅖ of the time.

(2) To change a cutting speed given in feet per minute to cutting strokes per minute, it is necessary to apply a formula *based on the relationship of the cutting stroke time to the return stroke time* (*(1) above*). The formula is: Number of strokes per minute equals the cutting speed in feet per minute (fpm) divided by the product of 0.14 times the length of the stroke in inches, or:

$$\text{Number of strokes per minute} = \frac{\text{cutting speed (fpm)}}{0.14 \times \text{stroke length (inches)}}$$

For example, if it is desired to cut material at 70 feet per minute cutting speed, and the shaper ram is adjusted for a 5-inch stroke, the number of strokes per minute equals 70 divided by the product of 5 times 0.14, or 70 divided by 0.7, or 100 strokes per minute.

(3) If the number of strokes per minute and the length of the stroke is known and it is desired to calculate the cutting speed, multiply the number of strokes per minute by the length of the stroke in inches, and then multiply the product by 0.14, as:

$$\text{cutting speed (fpm)} = 0.14 \times \text{stroke length (in.)} \times \text{number of strokes per minute}$$

For example, if the shaper makes 100 strokes per minute, and the stroke is 5 inches long, the cutting speed equals 0.14 times 5 times 100, or 70 feet per minute.

c. *Adjusting Length of the Stroke*

(1) Since the length of the shaper stroke is a factor relating the cutting speed in feet per minute to the shaper ram speed in strokes per minute, it can be seen that excessive travel of the ram during each stroke will increase the time required to complete a job. For example, if a workpiece is 4 inches long and the stroke of the machine is adjusted to 10 inches, it will take twice as long to machine the workpiece at a given cutting speed than it will if the stroke were adjusted to 5 inches.

(2) For economical operation of the shaper, the stroke should be adjusted to equal the length of the workpiece plus an additional ⅝ inch for clearance (*d* below). The ⅝-inch clearance addition applies to most common shaper operations. Some specific operations will require a greater or lesser clearance.

d. Positioning the Stroke. After the stroke is adjusted to the proper length, it is necessary to position the ram so that the stroke is located over the workpiece as illustrated in figure 174. The ram should be positioned so that the cutter bit moves ¼ inch beyond the workpiece on the forward or cutting stroke, and ⅜ inch behind the workpiece on the return stroke. When positioning the stroke, the ram should be moved throughout a complete cycle by hand to make sure the ram was located at the extreme end of the stroke when the adjustment was made.

175. Feed and Depth of Cut

a. Feed. The feed of a shaper or planer cutter bit is the lateral distance the shaper table or the planer tool head moves after each cutting stroke. On most planers and shapers, the feed is automatic unless hand feed is desired for special jobs. The shaper table or planer tool head moves to the left or right during the return stroke to relocate the workpiece and cutter bit for the following cutting stroke. The amount of feed is determined by the type of operation being performed, the size and shape of the cutter bit, and the depth of cut being used.

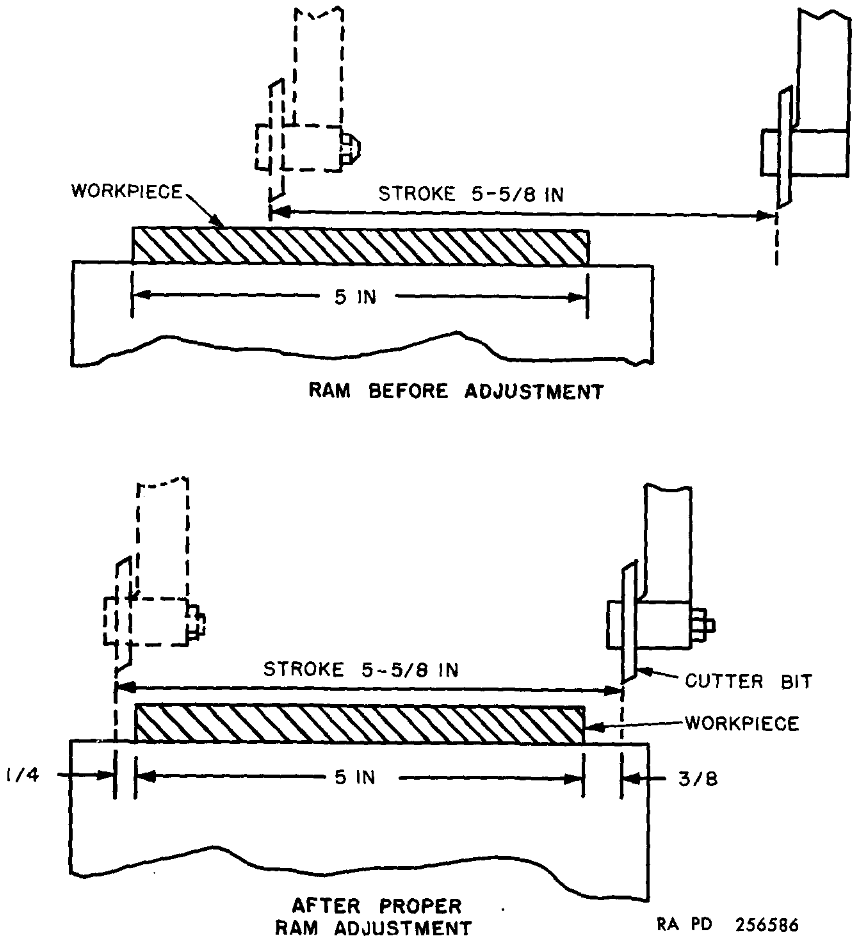


Figure 174. Locating ram stroke position.

b. Depth of Cut. The depth of cut is the amount of downward penetration of the cutter bit into the workpiece. The depth of cut is adjusted by manually turning the tool post crank located at the top of the tool slide which moves the cutter bit and cutting tool holder up or down in relation to the shaper or planer tool head. For horizontal planing operations, the depth of cut is increased after each complete traverse of the tool from right to left or from left to right. When vertical cuts or angular cuts are made, the depth of cut adjustment takes the place of feed and is made after each stroke. The depth of cut is determined by the type of operation, the size and shape of the cutter bit, and the amount of feed being used.

c. Selection of Feed and Depth of Cut. Feed and depth of cut are interrelated; if the feed is increased, the depth of cut generally must be decreased; and if the feed is decreased, the depth of cut can usually be increased.

(1) For roughing operations, the feed and depth of cut are usually held to a maximum since the primary objective of roughing is to remove excess material without regard to the finish produced. On small and medium size shapers, the depth of cut should be kept less than 1/8 inch and generally between 1/32 and 1/16 inch. On heavy-duty shapers and large planers, the depth of cut is often as heavy as 1/2 inch for heavy roughing operations. The feed for roughing should be equal to about one-fourth the depth of cut, and in no case should it be so wide as to leave uncut ridges between strokes.

(2) Finishing operations for the most part consist of coarse feeds and insignificant depths of cut, the purpose being to remove bumps and ridges left by the heavy roughing cuts. Often workpieces are roughed to within 0.001 inch and the finish cut is taken with a broad, square nose cutter bit set parallel to the surface using a feed almost equal to the width of the cutter bit nose. When very coarse feeds are used in this manner for finishing operations, it is necessary to decrease the cutting speed to prevent excess wear on the cutting tool. If instead, the finish cut is taken using a very fine feed and very little depth of cut, the cutting speed can be increased.

(3) For heavy planing operations, a third type of cut, a straightening cut, is sometimes taken after the roughing cut and before the finishing cut. For this procedure, the workpiece is roughed with one or two very heavy cuts down to about 0.006 inch oversize. A straightening cut is then taken to bring the workpiece within 0.001 inch, and the remainder of the material is removed using a very wide feed with a broad nose cutter bit.

176. Cutting Oils

Shaper and planer operation does not require a cutting oil or lubricant to any great extent, most operations being performed dry. The use of a cutting oil is, however, recommended during finishing operations on steel workpieces if a fine finish is desired. Since no recirculating lubricating system or drip can is supplied with most shapers and planers, the cutting oil, if used, should be applied to the point of tool contact with a hand oiler. The cutting oil should be the same for each material as prescribed for milling machines (table XXII).

177. Setting the Clapper Box

a. General. The clapper box (fig. 175) is a device located on the tool head of the shaper or planer which causes the cutter bit to lift from its cutting position on each return stroke, thereby protecting the cutting edge of the cutter bit from damage. The clapper box must be correctly adjusted for each operation or damage may occur to the workpiece, cutter bit, and machine tool.

b. Description. The clapper box attaches to the tool slide (fig. 175). A clapper block, hinging from the cupper part of the clapper box, supports the tool post to which the cutting tool holder is fastened. During each cutting stroke, the clapper block is seated in the clapper box but during the return stroke, the clapper block pivots outward to lift the cutter bit from the workpiece. The clapper box can be tilted to one side or another to provide lateral clearance for the cutter bit on the return stroke.

c. Clapper Box Adjustment.

(1) For horizontal planing, the clapper box is positioned either vertically or with the top pivoted slightly away from the direction of feed (fig. 175). The pivoting of the clapper box causes the cutter bit to swing both upward and outward on the return stroke, where if the clapper box is vertical. the cutter bit will only pivot upward.

(2) When taking vertical or angular cuts, the top of the clapper box should be pivoted away from the surface being cut, so that the cutter bit will clear the surface on the return stroke.

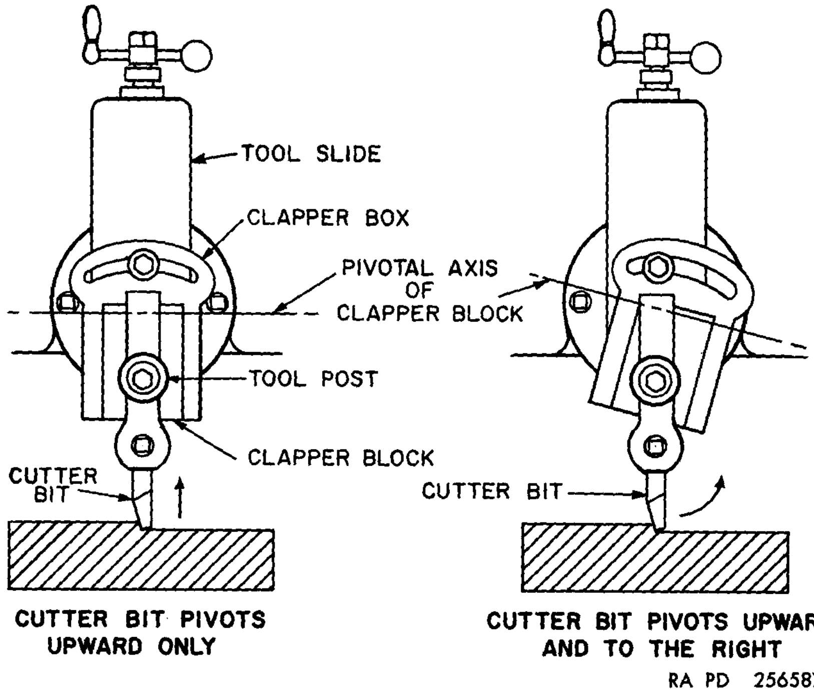


Figure 175. Clapper box adjustment.

(3) For slotting operations or internal slotting operations, the clapper box must be absolutely vertical so that the cutter bit will not catch on the sides of the slot during the return stroke.

178. Horizontal Planing

a. General. Much of the work done on the shaper, and practically all the work done on the planer, is the planing of flat surfaces on workpieces. The horizontal surface produced is the result of a series of cuts made with a single-point cutter bit.

b. Setting Up Workpiece. The workpiece to be horizontally planed is mounted in the swivel vise (par. 168), mounted on the shaper rotary table (par. 170), or mounted directly to the table of the shaper or planer (par. 169). The shaper or planer should be properly alined (par. 167), and the surface to be planed should be adjusted parallel to the table. The workpiece must be rigidly mounted to prevent possible shifting that would result in an inaccurate cut

c. Horizontal Planing Operation. Wherever possible, the cut is made from the right side of the workpiece to the left so that the operator can easily observe the cutting action from his position at the right side of the machine. In this case, a left hand cutter bit is used. The table is fed to the right for shapers, and the tool head is fed to the left for planers. The sequence of operation described below is for shaper operation, an example of which is shown in figure 176. The same principles can be applied to planer operation.

(1) With the workpiece mounted to the shaper table, select a cutter bit (par. 160*b*) and a cutting tool holder (par. 162), and mount the bit and holder to the tool post (fig. 163) of the machine. The cutter bit should project only as far as necessary from the cutting tool holder, and the cutting tool holder should be mounted in the tool post as high as is practical without causing interference of the ram with the workpiece. Unnecessary overhang produces excessive strain on the cutter bit and results in chatter and poor surface quality.

(2) Adjust the stroke of the shaper so that the stroke is ⅝ inch longer than the workpiece (par. 174*c*) and move the ram so that the stroke is positioned correctly over the workpiece (par. 174*d*).

(3) The clapper box should be either vertical or slightly pivoted (fig. 175) with its top set over to the right if the shaper table is to feed to the right, and its top set over to the left if the table is to feed to the left (par. 177*c*).

(4) Position the shaper table so that the cutter bit is over the edge of the workpiece and set the tool slide to position the

cutter bit for the proper depth of cut (par. 175). Set the desired feed per stroke on the machine (par. 175).

(5) Determine the proper cutting speed for the material to be cut (table XXXV), calculate the number of strokes per minute that will produce this speed (par. 174*b*), and select the shaper speed which most closely approximates this number.

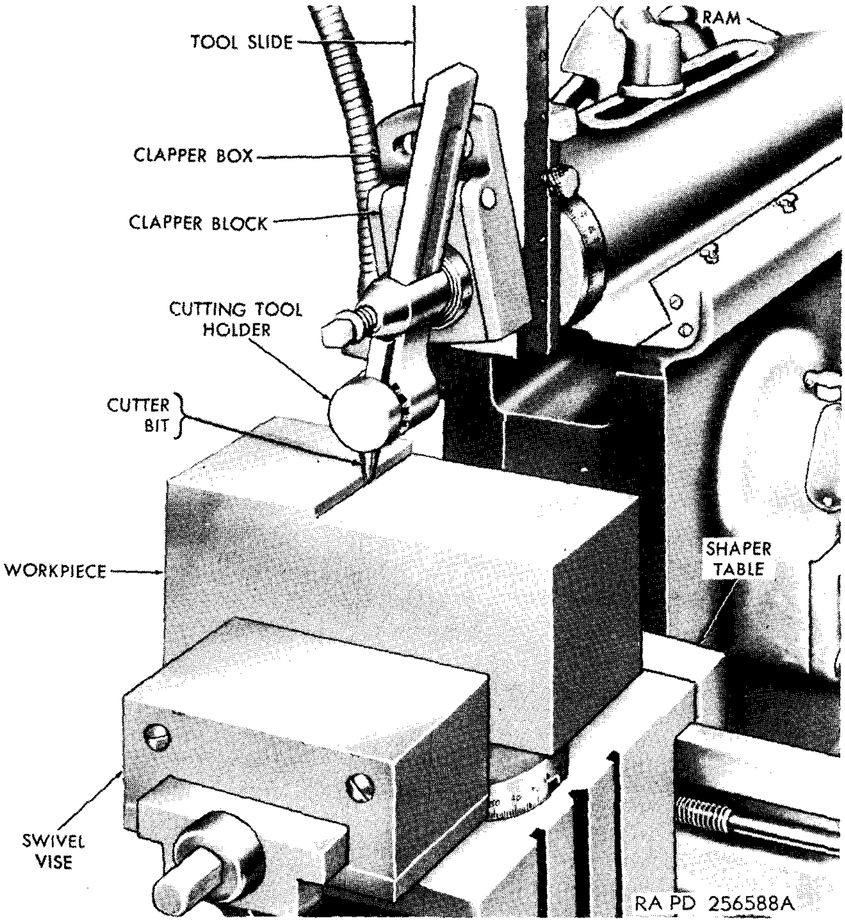


Figure 176. Horizontal planing operation.

(6) Start the shaper and carefully observe the operation. If the cutter bit overheats, stop the machine and change to a slower speed or a finer feed.

179. Vertical Planing

a. General. Vertical planing, or down planing, is the shaper operation in which the feed is controlled by the tool slide and the shaper table remains stationary. This operation is used to square edges and finish shoulders on the workpiece without remounting the workpiece for horizontal planing.

b. Setting Up Workpiece. The workpiece is firmly mounted in the swivel vise, shaper rotary table, or directly to the shaper table as described for horizontal planing (par. 178*b*).

c. Vertical Planing Operation.

(1) Select a cutter bit (par. 160*b*) and a cutting tool holder (par. 162). The cutting tool holder may be either straight or offset for vertical cuts. The closer the cutter bit is held in the tool holder, and the closer the tool end of the tool holder is held to the tool post, the more rigid the cutting edge.

(2) Pivot the clapper box away from the surface to be cut so that the cutter bit will not drag against the workpiece on the return stroke. The cutting tool holder should be positioned so that it will not touch the workpiece surface.

(3) Move the shaper table to position the cutter bit over the side of the workpiece and ascertain that the tool slide will not be extended any more than necessary when in the lowest cutting position. Adjust the height of the table if necessary.

(4) Adjust the stroke for length (par. 174*c*) and position the stroke correctly over the workpiece (par. 174*d*).

(5) Determine the proper cutting speed (par. 173*c*) and calculate the required number of strokes per minute (par. 174*b*). Select the shaper speed that most nearly approximates this number.

(6) Position the cutter bit over the workpiece and check the cross feed to see that it is disengaged.

(7) Start the shaper and feed the cutter bit downward by hand about 0.01 inch at the end of each return stroke.

Note. The work table may be fed-up (by means of a vertical adjusting handle or, on some shapers, by means of an automatic vertical feed), instead of feeding cutter bit downward by hand.

180. Angular Planing

a. General. Angular planing is the cutting of a surface on the shaper which is neither parallel nor perpendicular to the surface of the shaper worktable. This operation should not be confused with the cutting of angular surfaces by horizontal planing, with the workpiece mounted at an angle to the shaper table (par. 168*d*). Refer to paragraph 181 for the angular planing of dovetails.

b. Setting Up Workpiece. The workpiece should be mounted in the swivel vise (par. 168) or directly to the shaper table (par. 169). Clearance for the cutting tool holder and cutter bit must be taken into consideration if the angular surface is to be cut across one edge of the workpiece. This may necessitate mounting the workpiece higher than usual in the vise on parallels, or it may dictate a special arrangement of clamping devices if the workpiece is to be mounted directly to the shaper table.

c. Angular Planing Operation. Angular planing is performed in the same basic manner as vertical planing (par. 179) using the tool slide to feed the cutter bit across the workpiece surface. The angular movement, however, is achieved by rotating the tool head on the ram to set the tool slide parallel to the surface to be cut (fig. 177). Using the engraved scale on the ram, the tool head is set to the complement of the angle to be cut (90° minus the angle to be cut). After the adjustment has been made, proceed as described for vertical planing operation (par. 179*c*).

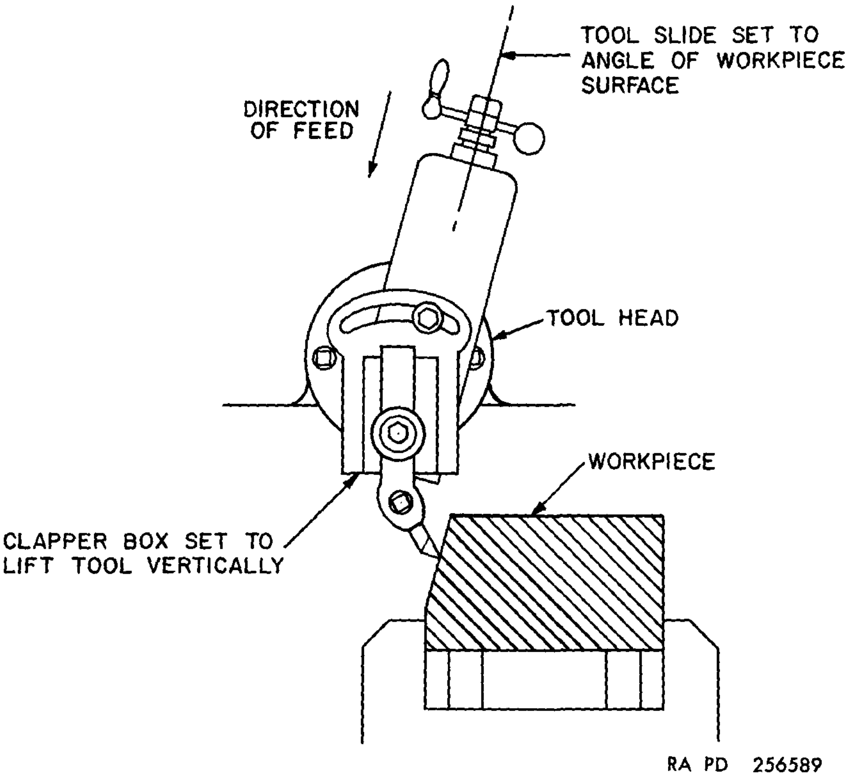


Figure 177. Angular planing operation.

181. Dovetail Planing

a. General. The planing of a dovetail involves horizontal planing and angular planing in its accomplishment. The angular surfaces of the dovetail are cut by angular down feeding of the cutter bit, and the flat between the angles is cut by horizontal planing.

b. Setting Up Workpiece.

(1) The workpiece is usually mounted in the swivel vise (par.

168) or directly to the shaper table (par. 169). However, if the workpiece is small, it may be advantageous to mount it to the shaper rotary table, so that the workpiece may be rotated 180° after one dovetail angle has been cut, thereby eliminating the necessity of repositioning the tool head and changing the cutting tool holder and cutter bit to cut the second angle.

(2) Before making the setup, the outline of the dovetail should be carefully laid out on a finished surface of the workpiece and prick punched to provide a better outline.

c. Dovetail Planing Operation.

(1) With the workpiece properly mounted to the shaper table, the workpiece should be planed by horizontal planing (par. 178) leaving near vertical shoulders where the dovetail angles are to be cut. The shoulders should be left oversize so that the angle cutting tool will cut the complete angular surface.

(2) Select an angle roughing cutter bit (par. 160*b*) ground for left hand or right hand cutting depending on the direction of the dovetail angle to be cut. The cutter bit should be mounted in an offset cutting tool holder, a swivel head cutting tool holder, or a straight cutting tool holder mounted to the tool post at an angle.

(3) Set the tool head and tool slide to the complement of the dovetail angle (par. 180*c*) and adjust the position of the cutting tool holder and cutter bit to provide necessary clearances with the workpiece.

(4) Rough out the dovetail in a series of parallel cuts, starting at the bottom of the shoulder, and progressing upward and inward. The clapper box should be set over to an angle at least equal to the angle of the tool slide to allow the cutter to swing away from the angular wall on the return stroke. The roughing operation should bring the dovetail to within 1/32 inch of the finished dimensions.

(5) After the dovetail is roughed out, the angle roughing cutter bit should be removed and an angle finishing cutter bit installed in the cutting tool holder (par. 160*b*). After carefully alining the cutter bit, feed the cutter bit down into the dovetail in one or more parallel cuts, carefully removing the fillet at the base of the angle. This same cutter bit can be then used to finish cut the bottom surface by engaging the table feed, and feeding the cutter bit away from the corner.

(6) Feeds, speeds, and depth of cut for the above operation should be the same as those recommended for horizontal and angular planing operations (pars. 178 and 180).

182. Slotting

a. General. Slotting operations are performed with inside keyway cutter bits (fig. 165) having clearance angles ground on both sides. The cutter bit is fed downward into the workpiece using the tool slide. Typical slotting operations for shapers include keyway planing and spline cutting.

b. Setting Up Workpiece.

(1) The workpiece can be vise mounted or mounted directly to the shaper table if the slot is to be cut in the surface of flat stock. For slotting operations requiring indexing of slots, the workpiece should be set up on the shaper rotary table (par. 170) or in the indexing fixture (par. 171).

(2) When planing keyways that do not run the full length of the shaft, a hole must be drilled at the point where the cut will terminate. This hole (fig. 178) must be of the same width and depth as the keyway. It is drilled to prevent building up chips in front of the cutter bit, thereby allowing the keyway, to be cut to full size throughout its depth.

(3) Where the finished keyway will not extend to either end of the shaft, starting holes must be drilled at both ends of the keyway (fig. 178). Usually two adjacent holes are drilled at the starting point and the metal between the holes chipped out to give the cutter bit clearance to start the cut. This practice also provides sufficient clearance at the start of the cut for the cutter bit to drop back down into position for the next cut.

(4) Refer to paragraphs 122*b*, *c* and 127*c* for standard dimensions of keyways and splines.

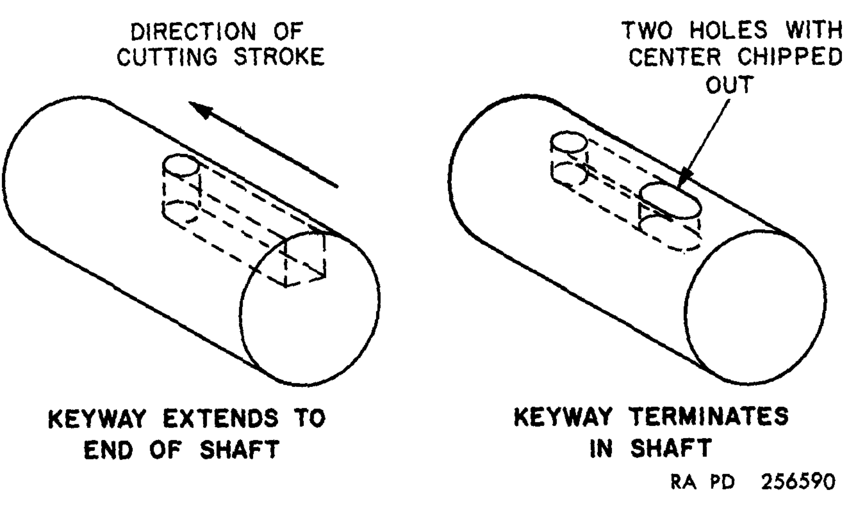


Figure 178. Starting holes for keyway cutting.

c. Slotting Operation.

(1) Select a cutter bit that has been ground with side clearance on both sides and that will produce the desired shape cut (par. 160).

(2) Set the tool head and tool slide vertical and adjust the clapper box to the vertical position. This adjustment is important because swinging of the cutter bit to either side will cause the cutter bit to bind against the sides of the slot.

(3) Whenever the cut must terminate within the metal (*b*(2) and (3) above), extreme accuracy is required in the adjusting and positioning of the stroke to prevent breaking the cutter bit. If the cutter bit is not equal in width to the desired width of the slot, the cross feed should be adjusted by hand after each return stroke. If this is not done, the cutter bit may bind on one wall of the slot when the shaper table shifts during the return stroke.

(4) Figure 169 illustrates a typical slotting operation performed on a workpiece mounted in the indexing fixture. The workpiece is alined perpendicular to the cutter bit by one of the methods described in paragraph 122*f* for alining the milling cutter for keyway cutting. Indexing procedure for cutting equally spaced slots about the shaft is described in paragraph 171.

(5) The slotting of a workpiece mounted to the shaper rotary table is shown in figure 173. The workpiece and cutter bit must be adjusted so that the cutter bit is centered on the axis line of the workpiece. The workpiece can then be indexed, and as long as the shaper table is not moved, each cut will pass through the workpiece axis.

183. Internal Slotting

a. General. Internal slotting is the operation of cutting slots in restricted areas of workpieces where a normal tool holder cannot enter, such as the cutting of keyways or internal splines in a bore. This operation is performed using an extension bar cutting tool holder (par. 162*e*) to permit entry of the cutter bit in the bore.

b. Setting Up Workpiece. The workpiece is mounted either directly to the shaper table or in the swivel vise. The workpiece must be firmly mounted and the vise jaws or clamping devices must not be positioned where interference to the tool holder or cutter bit may result. It is suggested that a radial line be scribed on the hub to assist in alining the cutter bit with the workpiece.

c. Internal Slotting Operation. A typical internal slotting operation is shown in figure 179.

(1) The cutter bit is ground in the same manner as for regular slotting operations, except that the shank must be short enough so that it will not interfere with the wall of the bore.

(2) The extension bar of the extension bar cutting tool holder (fig.167) should project forward from the tool holder shank only as far as required to permit the cutter bit to complete its cutting stroke. Excessive projection of the extension bar will increase the tendency for the cutter bit to chatter.

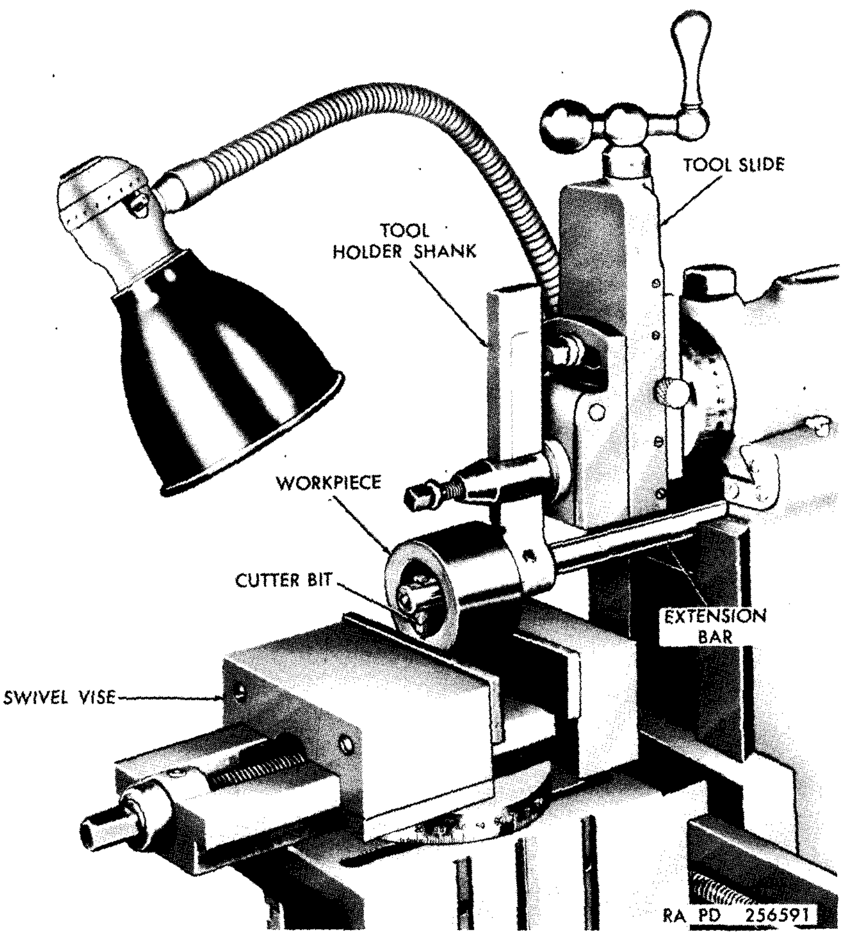


Figure 179. Internal slotting operation.

(3) After setting and positioning the shaper stroke, move the ram by hand through one cycle to determine that all clearances are sufficient. Particular attention should be given to the rear of the extension bar which might strike the shaper column if improperly positioned.

(4) The clapper box and the tool slide must both be positioned vertically to prevent binding of the cutter bit during the return stroke.

184. Planing Irregular Surfaces

a. Irregular surfaces are often planed on the shaper using either hand cross feed and hand down feed or using automatic table cross feed and hand down feed. In either case, the planing operation is one requiring constant attention of the operator and a fair degree of skill on his part.

b. The workpiece is mounted in a swivel vise or directly to the shaper table, and the outline of the cut is scribed on a finished surface of the workpiece.

c. The planing operating consists of a series of horizontal roughing cuts, the cutter bit and the workpiece being manipulated until the metal is cut to within 1/16 inch of the layout line. These roughing cuts may leave the surface rough and irregular.

d. A round-nose cutter bit is used to make two finishing cuts, each cut removing 1/32 inch of metal. It is recommended that final finishing of the surface be performed by hand filing to eliminate possible tearing of the edges caused by breaking of chips.

CHAPTER 8

MISCELLANEOUS MACHINE TOOLS

Section I. GENERAL

185. Purpose

a. This chapter describes and explains the function of several miscellaneous machine tools found in the Ordnance Corps. These machine tools in general perform operations often done by hand in machine shops or done on other machine tools as special operations.

b. The utility reamer drive and the horizontal honing machine are machine tools designed for accurate removal of small portions of metal from holes and bores. The utility reamer drive is used to support and rotate machine reamers which remove a controlled amount of metal from the hole or bore by a light cutting action. The horizontal honing machine supports and rotates an expanding mandrel which brings an abrasive stone in contact with the hole or bore, thus removing small amounts of metal by an abrading process.

c. The power-driven metal punching and shearing machine is used to cut bar, angle, tee, and flat steel stock to length, to punch holes in flat steel, angle stock, and thin sections of castings, and to notch or cope angles, tees, channels, I-beams, and flat stock. This machine tool functions by applying sufficient pressure upon the workpiece to cause shearing, or rupture of the metal structure by overcoming the tensile strength of the metal.

d. The vertical hammer forging machine and the coal burning forge are used for the hot working of metals. This process, called forging, consists of the plastic manipulation of metal by heating the metal to a point where it can be easily worked, and then reshaping the metal with a series of hammer blows. The coal burning forge is an open furnace in which the metal is heated to the proper temperature for forging. The vertical hammer forging machine pounds the metal between two dies to change the shape of the metal to conform to the shape of the dies. This machine can also be used to reshape soft, nonferrous metals when they are cold.

186. Bench-Mounted Utility Reamer Drive

(fig. 180)

The bench-mounted utility reamer drive is a machine tool used to support machine reamers and revolve them at selected speeds. The workpiece to be reamed on this machine is hand held by the operator who can start or stop the reamer drive by pressing a foot switch. A ⅓-horsepower electric motor is used to power the utility reamer drive through a belt and pulley arrangement. The transmission can be adjusted to provide variable speeds for the reamer. Reamers are supported in the spindles of the reamer drive by means of 2 chucks, a 3-jaw drill chuck with 3/16- to ⅝-inch capacity and a 5-inch, 2-jaw universal chuck with a capacity of 1⅝ inches for round shanks and 1 3/16 inches for square shanks.

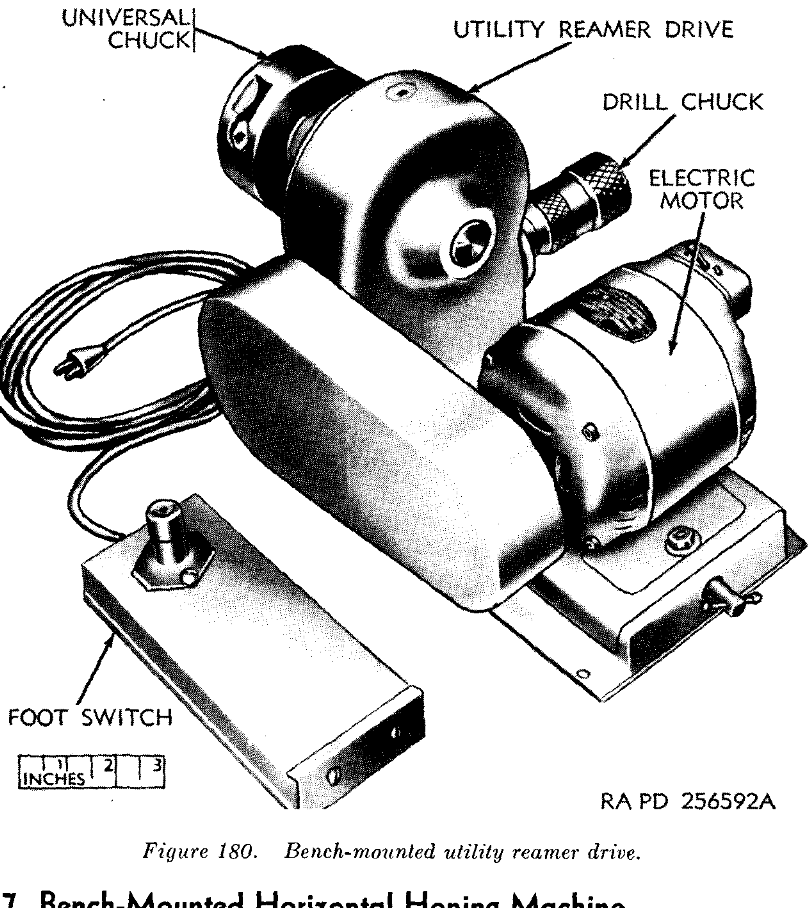


Figure 180. Bench-mounted utility reamer drive.

187. Bench-Mounted Horizontal Honing Machine
(fig. 181)

The bench-mounted horizontal honing machine is used to perform light grinding and honing operations which remove small amounts of metal from bores or holes. This machine tool is very accurate, typical jobs comprising the removal of 0.001 to 0.005 inch of metal from workpiece bores or holes. The typical horizontal honing machine is powered by an electric motor attached to the frame and connected to the spindle by a drive belt. A pulley idler controlled by a pedal is used to tighten and loosen the drive belt to start or stop the spindle without stopping the motor. Mandrels are supplied with the horizontal honing machine as equipment. Each mandrel, when mounted to the spindle, rotates and feeds an abrasive stone outward (away

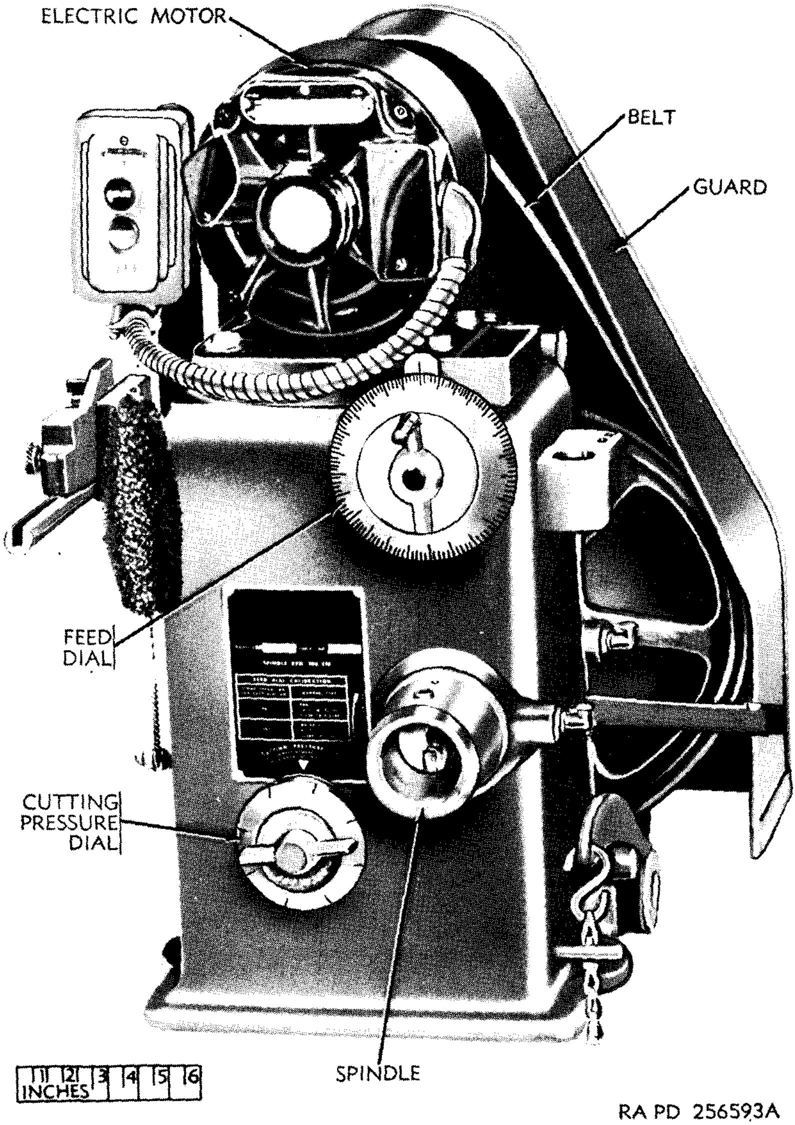


Figure 181. Bench-mounted horizontal honing machine.

from the mandrel axis) to bring the abrasive stone in contact with the wall of the bore. The amount of feed and the outward pressure applied to the stone is controlled, through the rotating spindle, by a mechanism within the honing machine, and dials on the front panel of the machine.

188. Power-Driven Metal Punching and Shearing Machine (fig. 182)

a. Power-driven metal punching and shearing machines are universal or combination-type machine tools with which a number of punching, shearing, notching, and coping operations can be performed.

b. The punch section is located at the front of the machine and is capable of punching holes in armor plate steel. A bar cutter section is located on the right side of the machine tool and is used for shearing rounds, squares, tees, and angle stock. The shear section, located at the right rear of the machine, is used for shearing flat plate stock or flat sections of angle stock, and the notcher and coper sections are used for shearing 90° V-notches or square notches in angle, channel, I-beam, and tee stock. The various sections of this machine can be used at the same time by several operators if necessary.

c. The power-driven metal punching and shearing machine is powered by a 3-horsepower electric motor and has a ram pressure of 50 tons. This type of machine tool is rated by the maximum size and thickness of a hole in armor plate which can be successfully punched, and by the throat depth of the punch section. This machine tool is rated ½ x 12, which indicates that it will punch a ½-inch hole in ½-inch thick armor plate, and that the throat of the punch section is 12 inches deep, so that a hole could be punched in the center of stock measuring 24 inches across. The capacity of the punch section for low carbon steel is about double that for armor plate, being capable of punching a 1-inch hole in ⅝-inch thick stock. The shear section of the punching and shearing machine is rated by the maximum thickness of soft steel plate that can be sheared which, in this case, is ½ inch. The bar cutter section will shear 1⅝-inch rounds 1½-inch squares, 4 x 4 x ½-inch angles, and 3 x 3 x ⅜-inch tees. The notcher section will cut V-notches 2¾ inches deep in ⅜-inch stock, while the coper section will shear 2-inch wide square notches in ⅜-inch plate.

189. Vertical Hammer Forging Machine (fig. 183)

The vertical hammer forging machine is a machine tool used for blacksmithing or forging of metal workpieces. It operates by lifting a hammer, or a ram, and then pounding it downward upon the

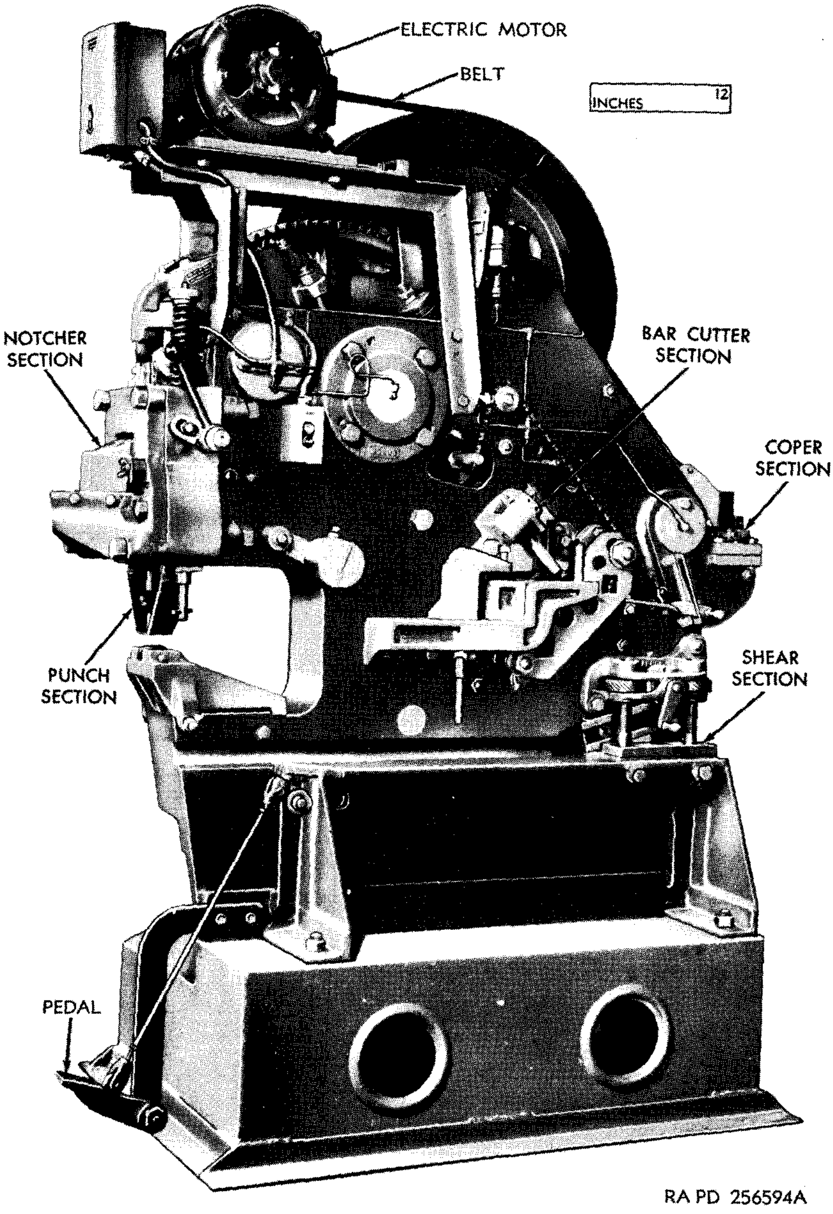


Figure 182. Power-driven metal punching and shearing machine.

workpiece which is supported upon a die block fixed to the frame of the machine. A 3-horsepower electric motor mounted to the frame base drives the crankshaft at the top of the frame through a flat belt. The crankshaft drives the ram up or down with a crankpin and plate in which the crankpin is mounted eccentrically to the plate.

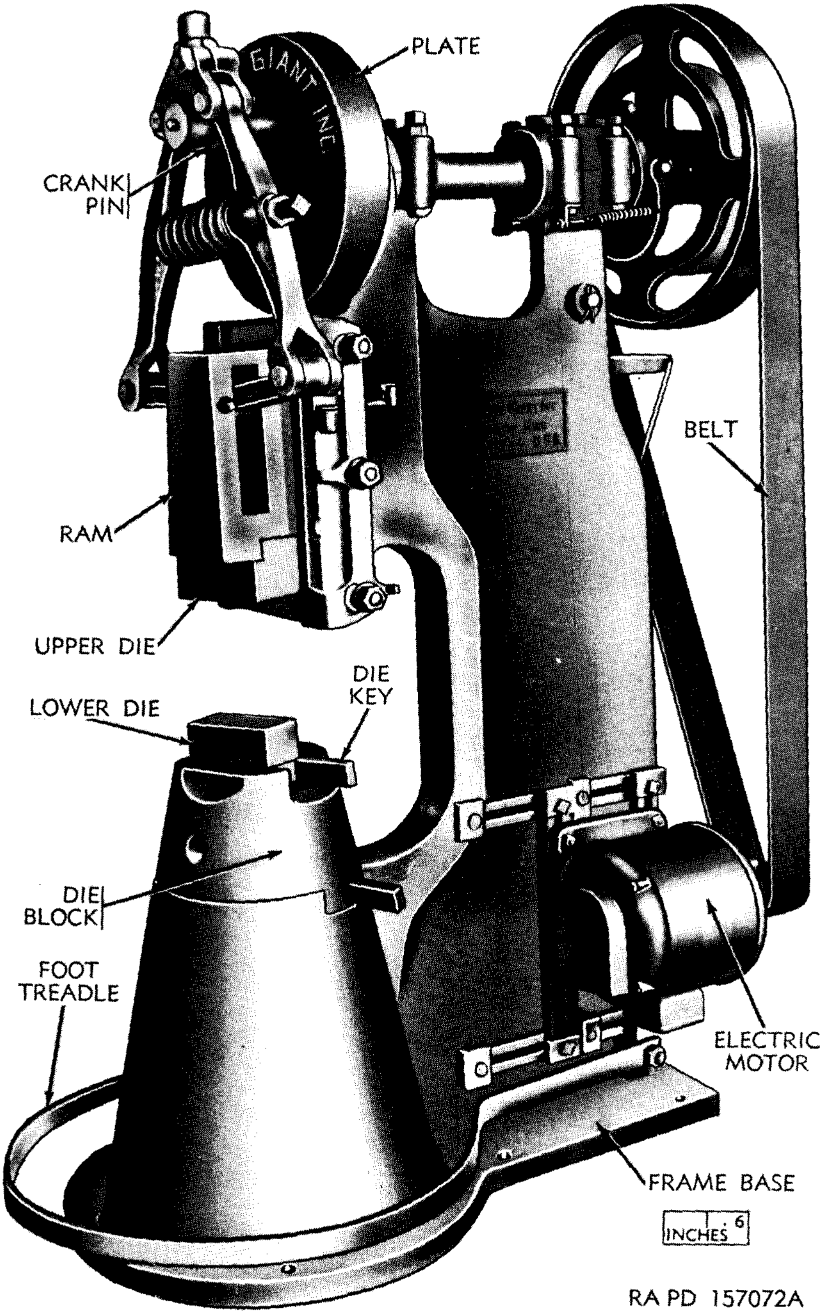


Figure 183. Vertical hammer forging machine.

Continuously variable control of the ram is obtained through a clutch at the crankshaft and spider. The clutch is engaged by pressing on a foot treadle at the base of the machine. A light pressure will produce a light blow, while a heavy pressure will fully engage the clutch causing the ram to deliver its heaviest blow. The vertical hammer forging machine is supplied with flat upper and lower die blocks. The upper die block can be replaced with a rounded die block if required for particular operations.

190. Coal Burning Forge

(fig. 184)

The coal burning forge is an open-type furnace intended for heating metal workpieces preparatory to forging or blacksmithing operations. The forge consists basically of a hearth and fire pot, a tuyere and ash pit assembly, a hand-operated blower, and a windshield. The coal fire is built in the fire pot, and the blower assembly is used to feed air to the fire. The tuyere is the opening at the bottom of the fire pot through which the air from the blower passes. A valve in the tuyere, controlled by a valve rod, is used to regulate the flow of air to the fire. A water tank is affixed to the edge of the hearth and is used for quenching hot metal and for controlling the fire.

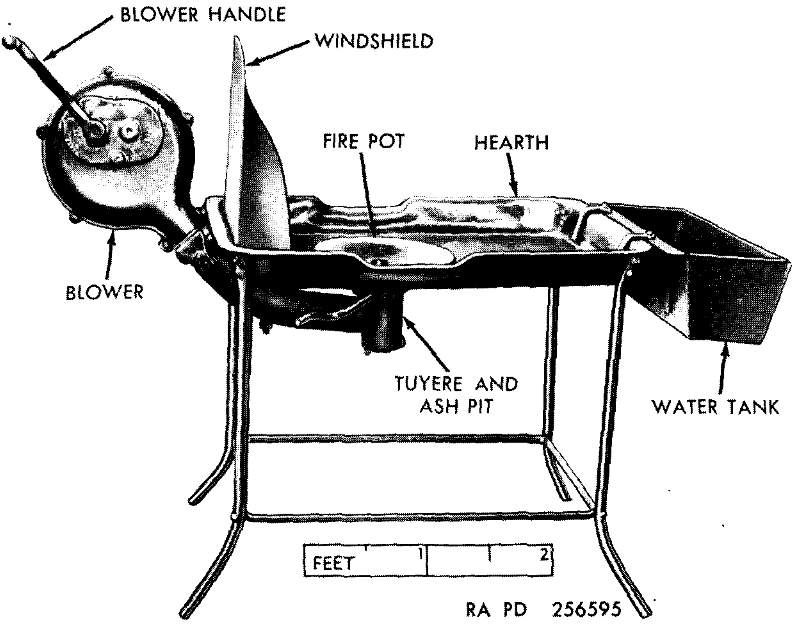


Figure 184. Coal burning forge.

Section II. TOOLS AND EQUIPMENT

191. Reamer Drive Tools and Equipment

a. General. Tools and equipment used with the bench-mounted utility reamer drive (par. 186) consist of straight-flute straight-shank chucking machine reamers, straight-fluted shell reamers, and straight-shank shell reamer arbors.

b. Straight-Flute Straight-Shank Chucking Machine Reamers (fig. 185). The straight-flute straight-shank chucking machine reamers are finishing tools for removing small quantities of metal from bores or holes. These reamers have a short-fluted section, usually one-fourth the length of the entire reamer, and are designed primarily to be used with machine tools whereby either the workpiece or the reamer is not held rigidly but allowed to float to seek alinement. Chucking machine reamers are supplied in sizes ranging from $\frac{3}{16}$- to $\frac{3}{4}$-inch diameter. These reamers mount directly in the chucks of the bench-mounted utility reamer drive for use.

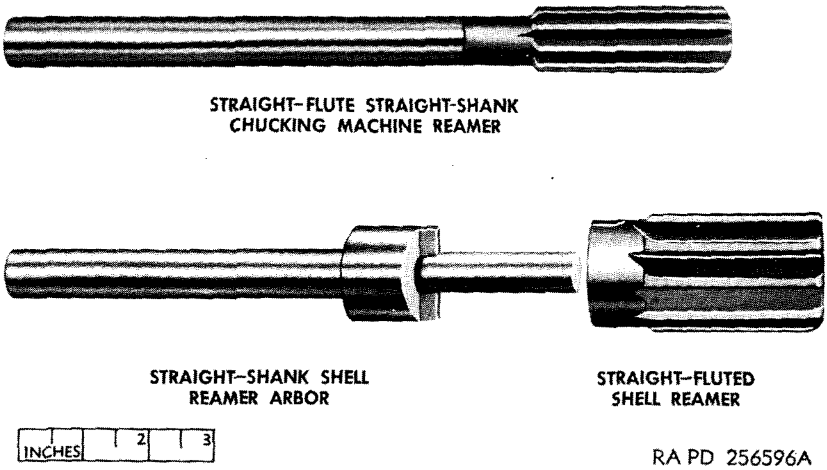


Figure 185. Reamers used with the bench-mounted utility reamer drive.

c. Straight-Fluted Shell Reamers (fig. 185). Straight-fluted shell reamers are identical in function to the straight-flute straight-shank chucking machine reamers (*b* above) but are supplied in larger diameter sizes. These reamers are made as shells for economy reasons and are intended for use mounted to a straight-shank shell reamer arbor. The hole of the shell reamer is tapered to provide a snug fit over the arbor, and radial notches are ground in the rear face of the reamer to mate and lock with keys on the arbor. Straight-fluted shell reamers are supplied in sizes ranging from $\frac{3}{4}$- to $1\frac{1}{2}$-inch diameter. Four sizes of arbors will accommodate the entire range of straight-fluted shell reamers (*d* below).

d. Straight-Shank Shell Reamer Arbor (fig. 185). The straight-shank shell reamer arbor is used to mount straight-fluted shell reamers in the chuck of the bench-mounted utility reamer drive (fig. 180). This arbor consists of a straight shank terminating in a collar which contains keys on its forward face to prevent the shell reamer from twisting. Projecting from the collar is a slightly tapered seat upon which the shell reamer fits. The straight-shank shell reamer arbor is supplied in four sizes, numbers 4, 5, 6, and 7, to accept various sizes of shell reamers. Number 4 arbor accepts shell reamers from $^{21}/_{32}$ to $^{25}/_{32}$ inch in diameter; number 5 arbor takes shell reamers from $^{13}/_{16}$ to $1\,^{1}/_{32}$ inches in diameter; number 6 arbor accepts shell reamers ranging from $1\,^{1}/_{6}$ to $1\,^{9}/_{32}$ inches in diameter; and number 7 arbor is used to mount reamers ranging from $1\,^{5}/_{16}$ to $1\,^{21}/_{32}$ inches in diameter.

e. Care and Maintenance of Reamers. Accuracy and surface quality of reamed work is only possible if the reamers used are kept in good condition and not mistreated. Several general precautions are listed below.

(1) A reamer should never be rotated backwards in a hole or bore, as this practice will injure the reamer's cutting edges.

(2) When not in use, reamers should be separated from each other with wood or another soft material to prevent nicking of the reamer teeth. A light coating of oil should be applied to the reamer before use as well as when in storage.

(3) Do not attempt to remove too much metal with the reamer. If more than 0.012 inch of material must be removed, the workpiece should first be bored to within several thousandths of an inch.

(4) Do not rotate reamers at high speeds (par. 199). Excessive speed will hasten wear on the reamer teeth and will produce a poorer finish on the workpiece.

(5) Do not force a reamer to the side when in operation to correct a hole position. The reamer will only follow the existing hole and correct slight eccentricities and waves caused by boring or drilling.

(6) Do not use a dull reamer. Sharpen reamers when dull by grinding as explained in *f* below.

f. Grinding of Reamers. Reamers are ground in a manner similar to milling cutters (par. 97*d*) but require more care and accuracy.

(1) To grind the clearance angles on the reamer blades, the reamer should be mounted between centers on a lathe (par. 73*d*) and a tool post grinding machine set up for cylindrical grinding (par. 47*b*). Since the clearance angles of reamer blades are very slight, the clearance can be ground by cylindrical grinding (par. 53). However, in order to produce a clearance when grinding cylindrically, the reamer must be rotated so that the heel of the blade contacts the

grinding abrasive wheel before the cutting edge. The clearance is produced because the reamer springs slightly when the grinding abrasive wheel first contacts a blade. Care should be taken while grinding this angle to use a minimum amount of feed, generally 0.0005 to 0.001 inch with a fine grain grinding abrasive wheel, (fig. 33), to prevent decreasing the reamer diameter greatly. Generally, new reamers are a few ten-thousandths of an inch oversize to permit grinding without appreciable reduction in size.

(2) After the clearance angles are ground, each blade should be backed off to give the proper width to the land. Most reamers have very narrow lands, usually between 0.005 and 0.015 inch wide. The blades are backed off by mounting the reamer between centers in the center fixture of the bench type tool and cutter grinding machine (par. 97*d*), and grinding the heel of each blade using a cup grinding abrasive wheel (fig. 31). The wheel head should be offset about 10 degrees to prevent the rear face of the wheel from contacting the reamer when the front face is brought in contact with the reamer blade. The index finger is set beneath the reamer blade and adjusted to aline each blade properly with the grinding abrasive wheel. Remove only 0.0005 to 0.001 inch of metal in each cut to prevent possible over grinding, and repeat the grinding procedure until the lands are of the proper width.

(3) After grinding reamers, all edges should be carefully honed by light stoning to remove all burs or irregularities resulting from the grinding. Before performing any reaming operations with newly ground reamers, test the reamers by reaming a test hole in scrap stock and then carefully measuring the reamed hole.

192. Horizontal Honing Machine Tools and Equipment

a. General. The tools and equipment used with the horizontal honing machine (fig. 181) consist of the abrasive stones used for honing, the mandrels to which the abrasive stones mount, the stone truing sleeves used to shape new abrasive stones or reshape worn abrasive stones, and the gages furnished with the honing machine for determining the amount of metal to be removed by the honing process and for checking the accuracy of the honed workpiece.

b. Abrasive Stones. The abrasive stones used for honing with the horizontal honing machine are rectangular pieces of bonded abrasive mounted to stone holders which attach to the mandrel (fig. 190) for operation. Usually two abrasive grain sizes are used for honing machine abrasive stones, the coarser grain stone being used for heavy honing and the finer grain stone being suitable for light honing or finishing operations. The abrasive stones and stone holders are made in several different shapes and lengths to fit the different types of mandrels used for honing. The stones are usually impregnated with sulfur, resins, cutting oil, or wax to improve their cutting action.

c. Mandrels.

(1) Each horizontal honing machine is supplied with mandrels in two or three basic shapes and several size ranges in each shape.

(2) The horizontal honing machine illustrated in figure 181 comes equipped with three sizes of hydraulic brake master cylinder mandrels, all of which are used with abrasive stones to hone bores which permit access from one side only. On these mandrels the abrasive stone is mounted at the end so that the bore can be honed completely up to a shoulder or to the extreme depth of a hole.

(3) Five die cast mandrels are also provided for honing bushings and bores which pass completely through the workpiece. With these mandrels the abrasive stone is centrally located on the mandrel, and the stone is usually longer than the end-mounted stones of the other mandrels.

(4) The mandrels mentioned above are adjustable, each mandrel having specified size limitations to accommodate different size bores. By use of a wedge device, the mandrels feed the abrasive stone outward with a preselected pressure. The amount of feed and pressure is controlled within the honing machine and transferred to the mandrel through a feed rod within the honing machine spindle. Mandrel shoes are machined on the side of the mandrel opposite the seat for the abrasive stone. These shoes guide the abrasive stone and keep it in contact with the wall of the bore.

d. Stone Truing Sleeves. A stone truing sleeve is supplied for each mandrel size. It is used to true new abrasive stones, new mandrels, and worn abrasive stones to permit accurate honing. To true an abrasive stone and mandrel, the stone truing sleeve is slipped over the mandrel. The sleeve is then treated like a workpiece being honed except that instead of the abrasive stone honing the sleeve, the sleeve is grinding the abrasive stone and the mandrel shoes, thereby correcting for any uneven spots on the stone or mandrel shoes.

e. Gages.

(1) Gages of special design are usually supplied as special equipment with the horizontal honing machine. These gages are used for measuring the inside diameter of bores or holes prior to honing to determine the mandrel size required and the amount of metal to be removed. The gages are used after honing to check the accuracy of the honing operation. With practice on the part of the operator, these gages will

measure bores to within a few ten thousandths of an inch. However, care must be taken not to strike or chew the accurately ground surfaces of the gages, and they should be kept absolutely free of dirt or other foreign material.

(2) The special gages supplied with the horizontal honing machine illustrated in figure 181 are a bushing grinder mandrel selector gage which consists of a graduated wedge-shaped scale which can be inserted in the end of the bore or hole to determine what size mandrel should be used for honing. The other gage supplied with this machine is the bushing grinder piston pin fitting gage which uses accurately ground inclined surfaces to permit measuring workpiece bores between 0.720- and 1.750-inch inside diameter. This gage has a working range of from 0.006 inch under to 0.002 inch over the size of the piston pins being fitted. The gage is adaptable to other workpieces of similar size and shape.

193. Punching and Shearing Machine Tools and Equipment

a. General. Tools and equipment for the power driven metal punching and shearing machine (fig. 182) consist of different size punches and dies which are used in the punch section, and shear blades (fig. 186) which are used in the shear, bar cutter, and notcher sections of the machine. The shear blades are usually considered as parts of the machine, but since they fall into the category of cutting tools which require sharpening, they are described in this section.

b. Shear Blades.

(1) Shear blades function by pressing against the metal to stress it beyond its ultimate strength and cause it to break. A set of shear blades consists of two blades, a lower blade which is fixed to the shearing machine frame, and an upper blade which is powered by the punching and shearing machine.

(2) Each pair of shear blades is designed to do a specific type of shearing operation. Three types of shear blades are illustrated in figure 186, straight blades used for shearing flat stock, V-shaped blades used to shear angle stock, and specially shaped blades used to shear tee stock, Other shear blades are designed for shearing channel stock, I-beams, rounds, and square stock. Notching is done with two-sided shear blades that bite a triangular section from the workpiece (fig. 187). Coping is done with three-sided shear blades that bite a rectangular section from the piece.

(3) It is important that the workpiece be well supported against the lower or stationary shear blade to prevent lifting of the workpiece instead of shearing when the upper shear blade comes into contact with the workpiece. Therefore, the lower shear blades are shaped to support the workpiece primarily,

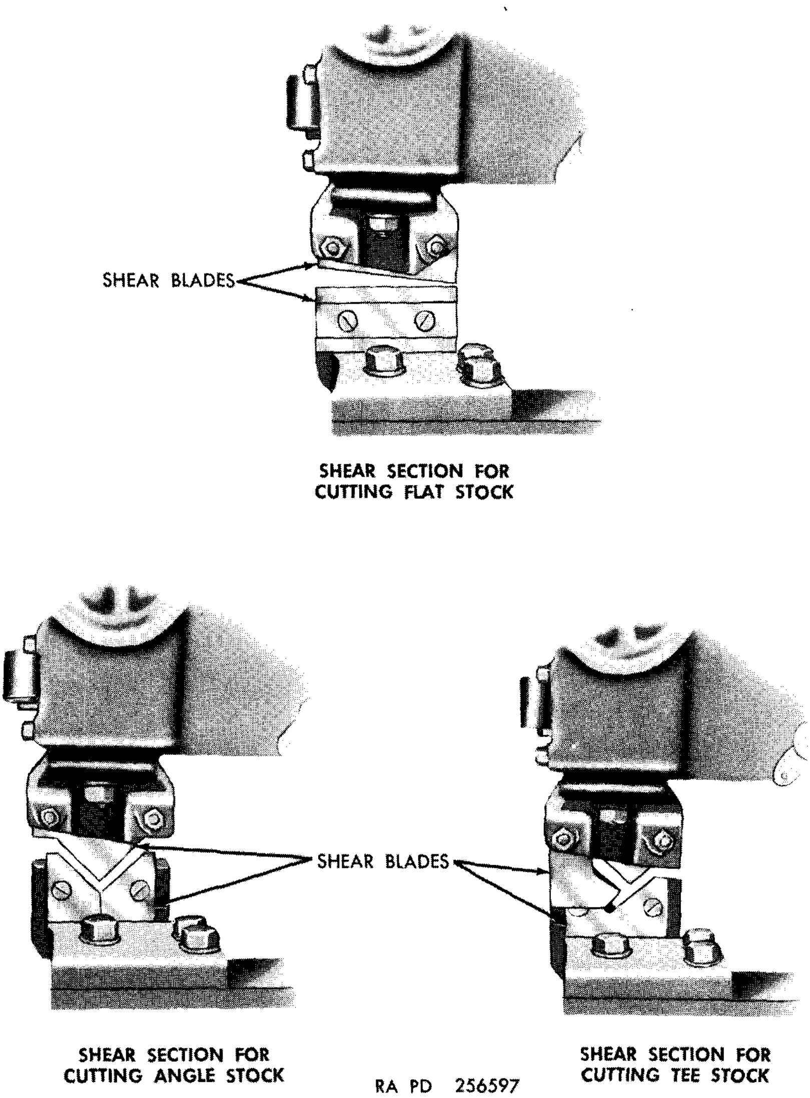


Figure 186. Types of shear blades.

and the upper shear blades are designed to press upon and stress the workpiece with a minimum amount pressure consistent with good results. For shearing of flat stock, the upper shear blade is set at an angle to the lower blade (fig. 186). This angle gives a good shearing action to the shear blades and permits shearing with less force than required by parallel shear blades.

(4) It is not necessary for the shear blades to penetrate the workpiece completely to cause shearing. Actually, after the upper and lower shear blades have pressed into the workpiece a

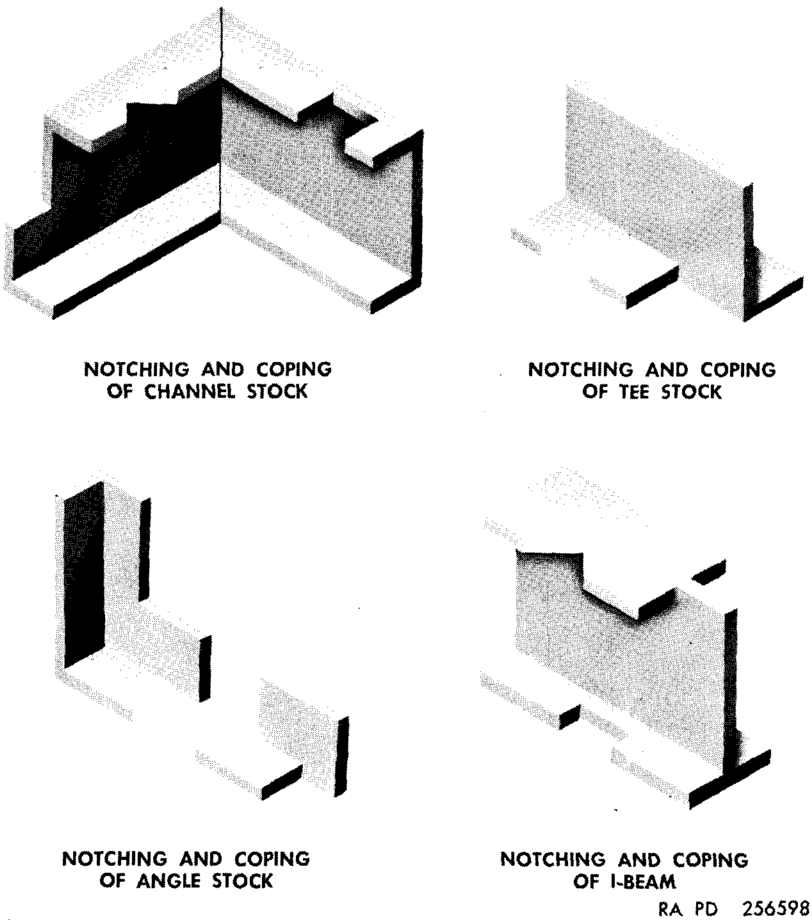


Figure 187. Types of notching and coping performed on the punching and shearing machine.

distance equal to about one-third its thickness, lines of fracture form at each cutting edge (fig. 188). If the clearance between the two shear blades is correct, the two lines of fracture, one extending from the upper blade edge and one from the lower blade edge, will meet and result in a clean sheared edge. If, however, the blades are set too close together (insufficient blade clearance, fig. 188), the lines of fracture will cross. Continued blade movement will cause the upper blade to make a secondary fracture which will result in a poor sheared edge. If the shear blades are set too far apart, the metal will be torn rather than cut, also resulting in poor quality edges on the workpieces.

(5) Proper blade clearances for shear blades vary with the hard-

ness and thickness of the metal. Soft metals and thin metals require less clearance than hard metals and thick metals. For mild steel, the clearance should be equal to about one-twentieth the metal thickness for metals ⅛ inch thick or less, about ¹⁄₁₆ inch for metals between ⅛ and ¼ inch thick, and about ¹⁄₃₂ inch for metals greater in thickness than ¼ inch. For hard metals, the clearance should be equal to about one-sixteenth the metal thickness for metals less than ⅛ inch thick.

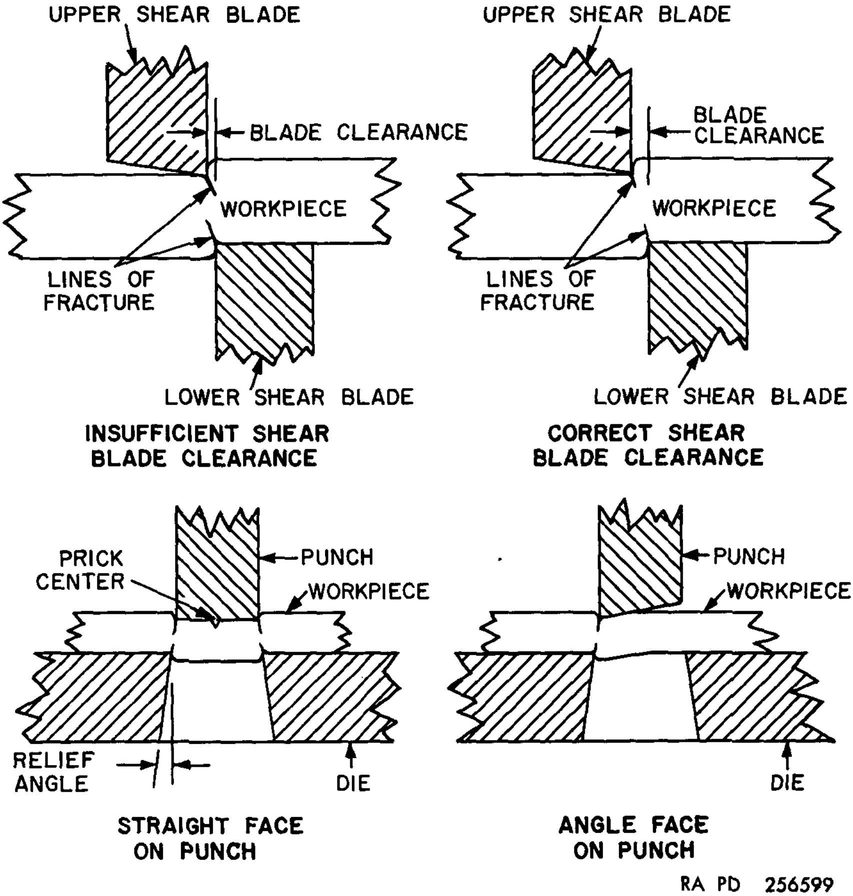


Figure 188. Shearing action of shear blades and punches and dies.

(6) Poor sheared edges will result when the cutting edges of the shear blades are dull as well as when blade clearances are incorrect. Dull shear blades should be sharpened by grinding on the bottom flat surface only, never on the sides of the blades. The edges should be ground to the same angle as before since these angles are determined by the manufacturer

of the machine to provide proper cutting qualities without overworking the machine. The upper shear blade of the shear section of the punching and shearing machine has four cutting edges so that the blade can be inverted or reversed when one edge becomes dull, thereby increasing the length of time the blade can be used between sharpening operations.

c. *Punches and Dies.*

(1) Punches and dies are used in the punch section (fig. 182) of the power driven metal punching and shearing machine to punch holes in metal workpieces and to punch shaped blanks from sheet stock. Punches and dies are comparable to shear blades, the punch being the equivalent of the upper or movable shear blade, and the die being the equivalent of the lower or fixed shear blade. Holes or blanks are produced by a shearing action as described in *b* above.

(2) Punches are made with either a straight face that will contact the workpiece evenly (fig. 188) or an angle face with which the workpiece will be contacted unevenly The advantage of the angle surface is that the pressure required on the punch to shear the workpiece will not be as great at any moment during the shearing operation as that required for a straight face punch. However, if the object of the punching operation is to produce blanks rather than to make holes, the straight face is required, since the angle face causes the blank or slug to bend as it is sheared from the workpiece. For punching blanks, the die is often angled slightly to improve the punching characteristics.

(3) A ½- x 12-inch power driven metal punching and shearing machine such as is described in paragraph 188 is capable of punching holes up to 3 inches in diameter provided the thickness of the steel plate is not excessive. Holes smaller than ½ inch in diameter in armor plate or ¾ inch in diameter in soft machine steel are limited by the proportion of hole diameter to the metal thickness that can be successfully punched without causing extreme pressure on the punch and possible breakage.

***Caution:* Holes having a diameter equal to less than the workpiece thickness should not be punched because extreme pressures will be applied to the punch causing possible breakage of the punch and injury to the operator.**

Table XXXVI lists the capacity of a ½- x 12-inch punching and shearing machine for different sizes of holes.

(4) Punches and dies require the same clearances described for shear blades (*b*(4) above) to function properly. These clearances are obtained by making the die diameter larger

Table XXXVI. Punching Capacity of a ½- x 12-inch Punching and Shearing Machine

Punch diameter (in.)	Maximum workpieces thickness (in.)		Punch diameter (in.)	Maximum workpieces thickness (in.)	
	Armor plate steel	Soft machine steel		Armor plate steel	Soft machine steel
½	0. 50	[1] 0. 50	1⅞	0. 133	0. 266
⅝	0. 40	[1] 0. 625	2	0. 125	0. 250
¾	0. 30	0. 60	2⅛	0. 117	0. 234
⅞	0. 286	0. 572	2¼	0. 111	0. 222
1	0. 25	0. 50	2⅜	0. 105	0. 210
1⅛	0. 222	0. 444	2½	0. 10	0. 20
1¼	0. 20	0. 40	2⅝	0. 095	0. 190
1⅜	0. 182	0. 364	2¾	0. 09	0. 18
1½	0. 166	0. 332	2⅞	0. 086	0. 172
1⅝	0. 153	0. 306	3	0. 083	0. 166
1¾	0. 143	0. 286			

[1] The maximum workpiece thickness for this size punch is not limited by the capacity of the machine but represents the safe limitation for ordinary punches to prevent punch breakage.

than the punch diameter. For mild steel, the clearances should be as follows: for workpieces under ⅛ inch thick, the die diameter should be equal to the punch diameter plus one-tenth the thickness of the material to be punched; for workpieces between ⅛ and ¼ inch thick, the die diameter should be equal to the punch diameter plus 1/64 inch; for workpieces thicker than ¼ inch, the die diameter should be equal to the punch diameter plus 1/32 inch. More clearance should be allowed when punching hard steel plate.

(5) Punches are usually made with a prick center (fig. 188) to facilitate locating the position on the workpiece where the hole is to be punched. Dies are made with relief under the cutting edge so that the slug or blank that is punched through the die will not jam the die opening.

(6) Punches and dies should be kept sharp for efficient shearing. Punches should be ground only on the face, never on the sides. If the face has an angle, the same angle should be maintained when grinding. Grind dies by surface grinding of the top surface until the sharp edges are restored. Never use a punch after its cutting edge has been chipped because of the possible hazard to the operator, and damage to the workpiece.

(7) Never use a circular punch and die to punch half holes on an edge. If this practice is attempted, the punch will move in the direction of least resistance (away from material) and will break.

194. Vertical Hammer Forging Machine Tools and Equipment

a. General. The only equipment supplied with the vertical hammer forging machine (fig. 183) consists of upper and lower dies which are fastened to the die block on the frame and the ram for operation.

b. Dies. Three dies are supplied with this machine, a lower flat-face die, an upper flat-face die, and a round-face die (fig. 189). Each of these dies is a specially hardened tool steel block with a dovetail cut on one side for mounting to the forging machine. The lower flat-face die is mounted to the die block located on the frame using a key which is driven between one angle of the dovetail and the corresponding angle of the die block. Either the upper flat-face die or the round-face die can be mounted to the ram of the forging machine. Both dies are fastened to the ram by driving a die key (fig. 183) between one angle of the dovetail and the corresponding dovetail groove angle of the ram.

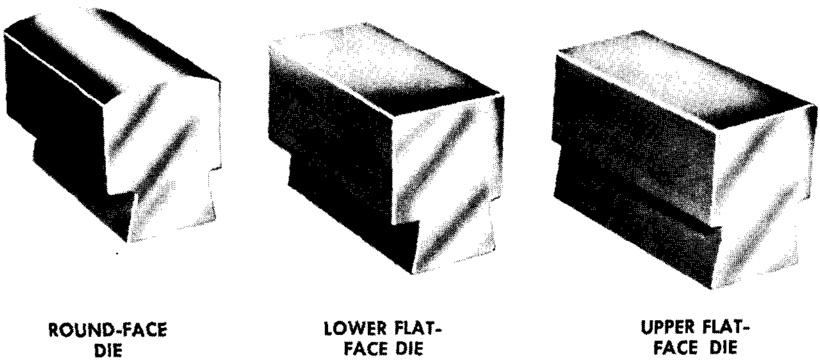


Figure 189. Dies used with the vertical hammer forging machine.

Section III. LAYING OUT AND MOUNTING WORK

195. Preparation for Reaming and Honing Operations

a. General. Preparation for reaming and honing operations consists of determining how much metal is to be removed, whether the metal can be removed successfully by reaming or honing, and selecting the proper reamer or honing mandrel and abrasive stone for the job.

b. Measuring Hole or Bore Prior to Reaming or Honing. The hole or bore can be measured accurately with one of the special gages supplied with the horizontal honing machine (par. 192*e*) or with an inside micrometer caliper. The caliper or gage should be rocked gently while setting to make sure that it does not clamp but finds a snug natural seat in the bore. After measuring, rotate the workpiece bore 90° and repeat the procedure to check the first measurement.

Measure at several points along the bore to determine whether any taper is present in the hole. If the bore is tapered slightly, the minimum inside diameter must be considered when figuring how much metal is to be removed.

c. When To Ream. For best results, reaming should be limited to the removal of from 0.004 to 0.012 inch from the diameter of the workpiece bore. If more than 0.012-inch diameter of metal is to be removed, the hole or bore should first be redrilled or bored to within 0.004- to 0.008-inch diameter of the finished size. Reaming cannot be used to correct a hole that has been drilled or bored slightly off center or at a slight angle. Since the workpiece or the reamer is permitted to float and seek alinement with the hole, the reaming operation serves only to enlarge and improve the accuracy and finish of the hole or bore.

d. When To Hone. Honing is used primarily to remove tool marks, tapers, high spots, and slight cases of out-of-roundness. Normally, honing should be restricted to removal of less than 0.010 inch of material, although up to 0.030 inch can be removed if necessary. As with reaming, the abrasive stone and the mandrel or the workpiece is permitted to float so that the stone seeks alinement with the hole or bore, and this process cannot correct or change the hole location or angle. Unlike reaming, honing is an abrading process and produces a fine cross-hatched finish which is generally desirable for lubrication. Therefore, honing is used primarily for bearings and bushings where good lubrication characteristics are desirable.

e. Selection of Reamers. Reamers are precisely ground to the size hole to be produced and should be selected accordingly. A new reamer may cut one or two ten-thousandths of an inch oversize to provide a longer accurate life. For holes or bores ¾ inch in diameter or less, a straight-flute straight-shank chucking machine reamer (par. 191*b*) should be used in the bench-mounted utility reamer drive (fig. 180). For holes larger than ¾ inch in diameter, select a straight-fluted shell reamer (par. 191*c*) of the proper size and mount this reamer to a straight-shank shell reamer arbor (par. 191*d*) for use.

f. Selection of Mandrels and Abrasive Stones for Honing.

(1) The selection of a mandrel for honing with the bench-mounted horizontal honing machine (fig. 181) depends upon the diameter of the bore to be honed and whether the bore passes completely through the workpiece, stops at a shoulder, or ends within the workpiece. The mandrel used for honing bores which pass completely through the workpiece mounts a long abrasive stone midway along the cylinder of the mandrel (fig. 190). The stone is generally from two-thirds to twice the length of the average workpiece bore. When honing workpiece bores which end within the workpiece or are stopped at a shoulder, a mandrel with the abrasive

stone mounted at the end is required. These mandrels usually mount shorter stones and are designed so that the bore can be honed up to the end or shoulder without interference from the mandrel. Each type of mandrel (par. 192*c*) is provided in several size ranges according to the minimum and maximum diameters of the unfinished and finished bores.

(2) The abrasive stones used for honing differ in shape for each type of mandrel, but are interchangeable among different size ranges of mandrels of one type. Generally at least two abrasive stones of different coarseness are supplied with each mandrel type. The coarser grit abrasive stone should be used where more than 0.001 inch of metal is to be removed. The finer grit abrasive stone is used where less than 0.001 inch is to be removed. The bench-mounted horizontal honing machine (fig. 181) also has a roughing cutter containing a steel blade which can be interchanged with either abrasive stone used in the die cast mandrel. This cutter should be used only on soft metal such as aluminum to remove metal in excess of 0.005 inch, thereby saving undue wear of the coarser abrasive stone.

196. Preparation for Punching and Shearing Operations

a. General. The preparatory steps for punching and shearing operations consist of locating and marking the position on the workpiece of the desired cut, and adjusting the strippers of the punch section, shear section, bar cutter section, notcher section, or coper section for the various operations.

b. Locating Work Centers for Punching Operations. Punches generally have prick centers (fig. 188) located on their faces that permit workpieces to be accurately located under the punch. If a punch being used does not have a prick center, centering can be facilitated by use of a wooden or metal template.

(1) To prepare workpieces for punching when the punch has a prick center, locate the position of the hole to be punched on the workpiece. Scribe intersecting lines where the hole center should be, and mark this point with a prick punch. When positioning the workpiece beneath the punch, the punch is lowered into contact with the workpiece and the workpiece is alined by feeling the prick center of the punch enter the punched center mark on the workpiece.

(2) To prepare a wooden or metal template for punching, cut a piece of wood or metal to the shape of the workpiece surface to be punched. Lay out the holes to be punched on the template and drill or bore them to the diameter of the punched holes desired plus a small amount for clearance.

In operation, the template is placed over the workpiece and the punch is lowered into the template hole to aline the punch correctly with the workpiece.

c. *Adjusting the Punch Section Stripper.* The stripper of the punch section (fig. 182) of the punching and shearing machine consists of two stationary projections, one at each side of the punch, that serve to separate the punch from the workpiece after the hole is punched. The strippers serve to hold the workpiece stationary while the punch is withdrawn from its tight position within the workpiece. The stripper should be adjusted so that the punch raises at least 1/16 inch above the stripper when in its upper position. When punching workpieces close to the edge of the material, a forked tool should be placed around the punch under the stripper to give an even bearing against the full stripper face thereby preventing tipping of the material and breaking of the punch.

d. *Adjusting the Shear Section Stripper.* It is necessary to support a workpiece being sheared firmly against the lower or stationary shear blade to prevent its lifting due to the pressure applied by the upper shear blade to the workpiece. A wide stripper plate is located close to the shear blades of the shear section. The stripper plate can be adjusted to clamp thin plate stock or one edge of a section of angle stock. The stripper can be quickly raised or lowered by a screw and gear arrangement operated by a handcrank. If the stripper plate is not adjusted to the plate being sheared, serious damage to the machine will result.

e. *Adjusting the Strippers for the Bar Cutter Section.* The bar cutter section (fig. 182) contains three strippers, one of which is used for each operation performed with this section of the power driven metal punching and shearing machine.

(1) The stripper for round and square bars is a fixed vertical plate containing cutout holes to fit each size of bar stock that may be sheared on the machine. The plate is alined with the lower or fixed shear blade. When round or square bar stock is sheared, the stripper prevents the bar from lifting or pivoting on the fixed shear blade when the movable shear blade strikes the bar.

(2) The angle stripper for 90° cuts consists of an adjustable bolt set at a 45° angle and positioned above and to the outside of the angle and tee shearing blades. The stripper is set firmly into the angle of the angle or tee stock where it holds the stock against the machine supports to prevent movement of the stock when it is sheared. The stripper hinges back and out of the way when not in use.

(3) The stripper for mitering of angles consists of a movable bracket containing an adjustable bolt set vertically which can be applied to angle stock that is positioned between the

shear blades for mitering cuts. This stripper prevents upward movement of the workpiece only.

197. Preparation for Forging Operations

Preparation for forging operations includes selection of a forgeable metal and heating the workpiece to the forging temperature.

a. Forgeable Metals. Successful forging depends upon the resistance or lack of resistance to deformation of the workpiece. Low-carbon steels of 0.20- to 0.40-percent carbon are best suited to forging because they can be heated without damage to a high temperature (up to 2,400° F.) where they can be easily forged. High-carbon steels tend to resist forging more than low-carbon steels and cannot be brought to as high temperatures. Low-carbon alloy steels are easily forged but have a greater resistance to deformation than plain steel with the same carbon content. Stainless steels and irons of similar carbon content are harder to forge than commercial alloy steels. Aluminum, brass, bronze, and copper can be forged easily and are similar in plastic flow to low-carbon steel when properly heated.

b. Heating Workpieces for Forging. The heating of workpieces to the forging temperature is discussed with the operation of the coal burning forge (par. 205).

Section IV. GENERAL OPERATION

198. General

This section describes the operational procedure for reaming with the bench-mounted utility reamer drive (par. 186), honing with the bench-mounted horizontal honing machine (par. 187), punching and shearing with the power-driven metal punching and shearing machine (par. 188), and forging using the vertical hammer forging machine (par. 189) and the coal burning forge (par. 190). Where important, cutting speeds, feeds, and temperatures are given.

199. Reaming Feeds, Speeds, and Cutting Oils

a. In general, reaming must be performed using low speeds and relatively high feeds to obtain good finishes. Excessive speed will cause unnecessary wear of the reamer blades and shorten the life of the reamer.

b. As a rule, the correct speed for reaming is about one-half the recommended speed for drilling (table V). The reaming feed should be about 300 or 400 percent of drilling feeds when using fluted chucking machine reamers or fluted shell reamers.

c. Cast iron should always be reamed dry but for other metals a cutting oil should be used to preserve the edge on the reamer blades and produce a better finish. Cutting oils recommended for drilling can be used (table VI), and should be applied generously from a hand oiler to the workpiece and reamer.

200. Reaming Operation

Reaming operations performed on the drilling machine and on the engine lathe are described in paragraphs 37 and 92 respectively. Reaming with the bench-mounted utility reamer drive is described below.

a. Select a straight-flute straight-shank chucking machine reamer or a straight-fluted shell reamer and straight-shank shell reamer arbor (fig. 185) of the proper diameter and mount in one of the chucks (fig. 180) of the reamer drive.

b. Set the speed of the reamer drive to one-half the recommended speed for drilling (table V).

c. Start the electric motor of the reamer drive and check to see that the reamer is rotating on center. Adjust the reamer in the chuck if any wobble or eccentricity of motion is noted.

d. Apply a cutting oil to the reamer and workpiece (par. 199*c*).

e. Support the workpiece by hand in front of the reamer, aline the hole to be reamed with the revolving reamer, and feed the workpiece over the reamer. Feed the workpiece steadily over the reamer at a feed of about 3 or 4 times the feed used for drilling of the same type of metal (par. 31). After the reamer has passed through the workpiece, carefully pull back on the workpiece to withdraw the reamer. This should be done while the reamer is still rotating.

201. Honing Feeds and Speeds

a. For best results, honing should be performed with the mandrel and abrasive stone revolving at a speed of from 15 to 20 feet per minute. The bench-mounted horizontal honing machine (par. 187) has a fixed spindle speed, and when using this machine it will not be necessary to calculate cutting speed. If the speed is variable on some machines, use care not to rotate the stone at too high a speed as this will cause undesirable burnishing of the workpiece.

b. The workpiece is placed over the honing mandrel and abrasive stone (fig. 190) and fed by stroking the workpiece back and forth at a rate of about 100 strokes per minute. The abrasive stone should run from ¼ to ½ its length out of the bore at the end of each stroke so that the entire bore will be honed evenly.

202. Honing Operation

The procedure for honing using the bench-mounted horizontal honing machine (fig. 181) is outlined below. If honing is to be performed using other equipment, the following information should be used for general reference purposes.

a. Select a mandrel and an abrasive stone of the proper size and type for the specific operation (par. 195*f*).

b. Rotate the feed dial (fig. 181) on the honing machine to its minimum setting and install the mandrel to the spindle of the machine.

c. If the abrasive stone being used is new or has been worn unevenly, use a stone truing sleeve (par. 192*d*) to true the stone and mandrel before honing the workpiece. The truing procedure is the same as regular honing except the truing sleeve is "honed" instead of a workpiece.

d. Before honing, adjust the feed pressure dial (fig. 181) on the honing machine to regulate the amount of pressure that will be applied against the workpiece bore by the abrasive stone. For the bench-mounted horizontal honing machine (par. 187), the proper pressure setting is at "4" for roughing operations and at "2" for finishing operations. With experience, the operator can increase or decrease the pressure from these suggested settings to obtain best results with individual workpieces.

e. Position the workpiece over the mandrel and press the pedal to engage the motor drive. Slowly advance the feed dial with one hand until the abrasive stone begins to tighten on the workpiece bore. Advance the feed dial one graduation for each one-thousandth inch of material that is to be removed, and hone by stroking the workpiece rapidly back and forth over the revolving abrasive stone (fig. 190).

f. Apply a stone treating compound to the abrasive stone before and, if necessary, during the honing operation to improve the cutting efficiency of the stone. A new abrasive stone will require treatment more often than a used stone because as the stone is repeatedly treated it becomes saturated with the cutting oil compound of the stone treating stick.

g. Occasionally reverse the workpiece so that the abrasive stone will not wear unevenly. To do so, release the pedal and allow the mandrel to stop before removing the workpiece. Reverse the workpiece (if possible) and restart the machine by depressing the pedal. Do not position the workpiece over the abrasive stone and mandrel or remove the workpiece from the mandrel when the spindle is rotating, but wait until the spindle has stopped rotating.

h. The workpiece is honed to size when the pressure of the abrasive stone can no longer be felt on the workpiece. Remove the workpiece from the mandrel and measure the bore (par. 195*b*). If the workpiece is still oversize, repeat the honing operation.

203. Punching Operation

Punching operations consist of properly alining the workpiece between the punch and the die and tripping a control to cause the punch to drive into the workpiece and die.

a. The punch and die should have suitable clearance for the thickness of metal being punched (par. 193*c*).

b. The punch section of the power-driven metal punching and shearing machine is energized by pressing of the pedal (fig. 182) which moves a sliding block between a reciprocating ram and the punch plunger, causing the ram to drive the punch downward. The punch and stripper are also mounted to a floating head which can be raised from the workpiece to provide clearance between the punch and die for ease in positioning the workpiece. Prior to punching, the floating head is lowered to bring the punch in contact with the workpiece so that the prick center of the punch can be alined with the workpiece prick punch mark.

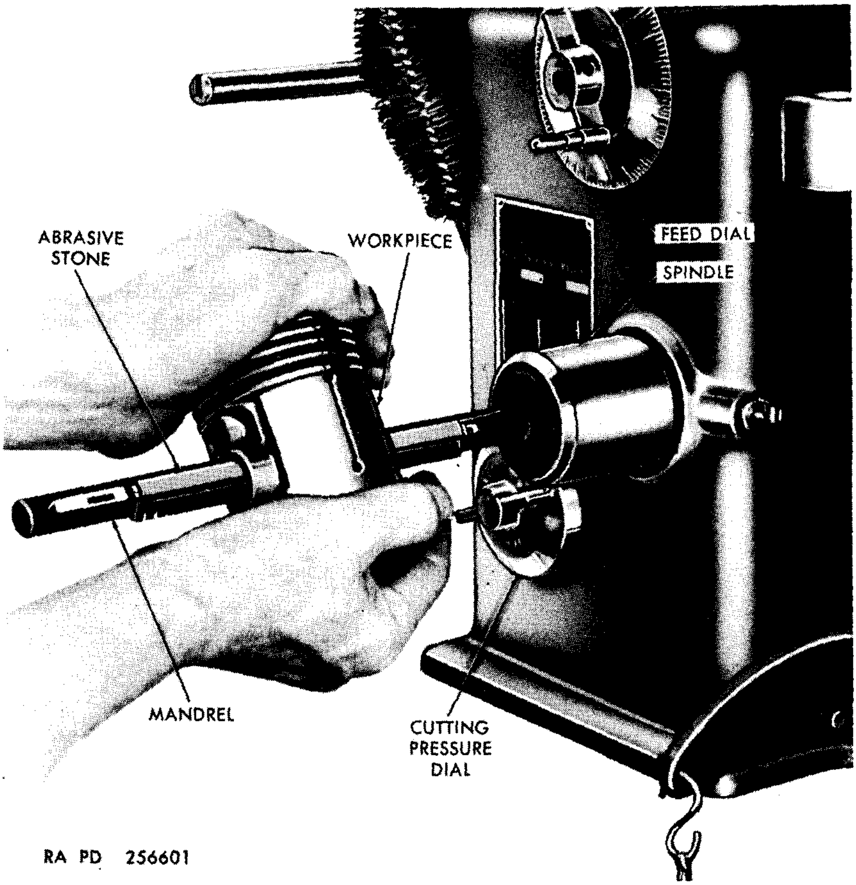


Figure 190. Honing operation.

c. With the workpiece in position and the punch in contact with the workpiece, the workpiece is punched by stepping on the pedal. If the pedal is kept down, the punch will continue to trip at a rate of 30 strokes per minute.

d. Before operation, apply a light coat of oil to the punch and the die using a small swab. This practice will aid the shearing action and extraction of the punch from the die, and will help preserve sharp edges on both the punch and die.

204. Shearing Operation

a. Clean and lightly lubricate the shear blades (fig. 186) before operation. The blade clearance should be checked and adjusted, if necessary, to agree with the workpiece thickness (par. 193*b*).

b. The workpiece is inserted into the shear section (fig. 182) of the power-driven metal punching and shearing machine and positioned so that the lower shear blade alines with the scribed line on the workpiece. The workpiece is then retained in position with the stripper, and the upper shear blade is actuated to shear the metal by tripping the hand lever at the right rear of the machine. If variable speeds should be available on the machine tool, the speed that will produce the fastest knife action should be used. A fast knife action, up to 100 strokes per minute, will produce squarer cuts than a slow knife action.

c. For shearing round or square bar stock with the power-driven metal punching and shearing machine, insert the bar stock into the appropriate size stripper hole of the bar cutter section (fig. 182) and aline the mark of the cut with the inner edge of the fixed shear blade. The movable shear blade is tripped using the same control provided for shearing flat stock with the shear section.

d. To shear angle or tee stock in the bar cutter section (fig. 182) of the power-driven metal punching and shearing machine, insert the angle or tee stock between the shear blades and against the supports on the machine frame. Adjust the angle stripper for 90° cuts or the stripper for mitering angles to prevent the stock from lifting during the shearing operation. Trip the shear blade with the same control used for shearing stock mounted in the shear section.

e. To shear 90° V-notches with the notcher section (fig. 182) lift the protective cover from the notching shear blades and position the workpiece between the shear blades. A depth gage screw is provided to restrict the size notch that can be cut. With the workpiece alined between the blades, trip the upper blade by pressing on the pedal used for punching.

f. To use the coper section (fig. 182) of the power-driven metal punching and shearing machine, lift the protective cover from the upper coper shear blade. Adjust the depth of the rectangular notch to be cut by turning the adjustable depth gage screw in or out. Position the workpiece between the shear blades of the coper section and trip the upper blade with the same control used for shearing with the shear section and the bar cutter section.

205. Operation of the Coal Burning Forge

a. General. The coal burning forge (par. 190) is used to heat metal workpieces to a temperature at which they can be successfully forged, or reshaped while in a plastic state. It can also be used for hardening and tempering tool steel. The operation of the coal burning forge (fig. 184) consists of building and maintaining a fire of the proper characteristics, and heating workpieces in the live coals (fig. 191).

b. Building and Maintaining a Forge Fire.

(1) Fuel for the forge fire should be a good grade of smithing coal, coke, or charcoal. Smithing coal is a soft type of bituminous coal that is lustrous in appearance and relatively free of impurities. It will crumble easily and should not split in layers. Good smithing coal will turn to coke very readily and will form few clinkers. Coke and charcoal are used for forge fires where an exceptionally clean, even heat is required such as when heating tool steel.

(2) The fire is started by placing a piece of paper and a handful of wood shavings or oily waste over the tuyere in the bottom of the fire pot (fig. 191). Ignite the paper or waste, and as the shavings or waste begin to burn, add some small pieces of coke to the fire and apply a small amount of blast by turning the blower handle (fig. 184).

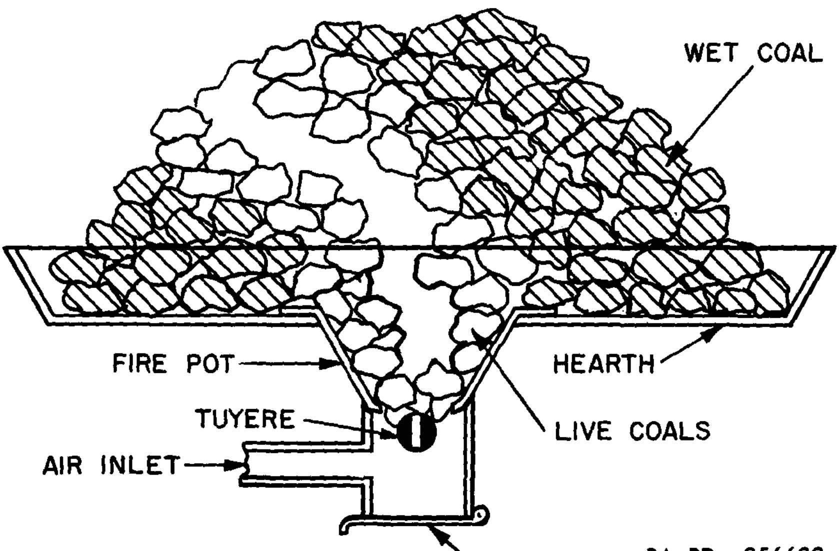


Figure 191. Building a fire in the coal burning forge.

(3) Add more coke until a fire of the desired size is built and then bank the outer edges of the fire with wet coal (fig. 191), leaving the side toward the operator open. As the wet coal becomes heated, some of the gases are driven off, and this coal changes to coke. As the hot bed of coal is used up, break away some of the newly formed coke from the walls

of the fire to restock the fire, and rake more wet coal from the hearth in place about the fire so that the process of forming coke around the edges of the hot coals will continue.

(4) If the fire tends to become too big, add wet coals around the sides or pour water on the coke surrounding the fire.

(5) After the fire has been used for a while, cinders and slag will form on the bottom, over the tuyere. This deposit should be broken up and pushed past the tuyere to the ash pit where it can be removed by flipping open the ash door (fig. 191).

(6) When the fire is to be left unused for a short time, bank wet coal around it.

c. *Heating Workpieces in the Forge Fire.*

(1) The forge fire must be supplied the proper amount of air from the blower (fig. 184) to be effective for heating workpieces. If more air than is needed for the combustion of the fuel is supplied, the fire is called an oxidizing fire. The excess oxygen in this fire tends to unite with the steel being heated and forms a hard scale on the steel. If tool steel or high-carbon steel is being heated, this excess oxygen will unite with the carbon to decarbonize or soften the steel. An oxidizing fire is characterized by a rim of live coals about a hollow core, and a very thin layer of cinder over the tuyere. The proper amount of air for the forge fire will produce a reducing fire: a fire in which all the oxygen supplied is consumed by the fire. In this fire, all the air supplied serves to make the fire hotter and produces a solid bank of live coals over the tuyere. It is better to apply too little air than too much.

(2) The workpiece to be heated should be inserted horizontally into the center of the fire, not on top of the fire and not too close to the tuyere (fig. 191). The workpiece will be heated faster and more evenly if it is surrounded by live coals. Do not permit the workpiece to remain in the fire without any blast, or the oxygen in the metal will feed the fire and change the composition of the metal. Do not permit the blast to come directly in contact with the workpiece.

(3) Table XXXVII lists forging temperatures for several types of steel and other metals. A pyrometer should be used to test the temperature of the metal at intervals during heating. The forging temperature for low-carbon steels will occur when the steel is heated to a bright red color. This visual method of determining temperature is not accurate, however, and varies with different alloys having the same carbon content.

Table XXXVII. Forging Temperatures for Metals

Metal	Carbon content (percent)	Maximum forging temperature (degrees Fahrenheit)
Brass		1, 120–1, 380
Bronze		1, 120–1, 470
Copper		1, 300–1, 470
Monel metal		2, 100
Nickel		1, 300–1, 600
Steel, carbon (plain)	0. 10–0. 25	2, 350–2, 400
	0. 30–0. 40	2, 300–2, 320
	0. 45–0. 60	2, 160–2, 280
	0. 65–0. 75	2, 100–2, 160
	0. 80–0. 95	2, 020–2, 050
Steel, manganese	0. 30–0. 40	2, 260–2, 300
	0. 50	2, 200
Steel, molybdenum	0. 15–0. 50	2, 200
Steel, nickel	0. 12–0. 50	2, 180–2, 220

206. Forging Operation

a. General. The forging operation consists of heating metal workpieces to a temperature at which they become plastic, and then reshaping them by pressure or hammer blows. Forging operations are performed using the coal burning forge (par. 205) to heat the workpieces, and using blacksmith tools or the vertical hammer forging machine (fig. 183) to manipulate the hot metal.

b. Heating Workpieces. The portion of the workpiece to be reshaped should be thoroughly heated to a forging temperature in the coal burning forge (par. 205). If only one end of a workpiece is to be reshaped, the workpiece is placed in the fire so that only that portion becomes heated. For good results, the fire should be a reducing fire (par. 205*c*(1)) and the blast should be kept to a minimum consistent with keeping the fire hot. While in the fire, rotate or turn over the workpiece at intervals, and allow the metal to heat through evenly before removing.

c. Forging. After removing the workpiece from the fire, it is hammered into shape with the vertical hammer forging machine. The workpiece is held by tongs and is positioned over the lower die where a hammer blow is desired. When the foot treadle (fig. 183) is pressed, the ram and upper die pound down upon the workpiece. By holding the foot treadle down, the machine will continue to hammer. When the foot treadle is released, the ram will stop in its normal (upper) position. A light pressure on the foot treadle will cause a light blow to be delivered while a heavy pressure will cause a hard blow. The workpiece is manipulated between the two dies until the desired shape is attained. If the workpiece cools off while working, it should be replaced in the forge fire and reheated to forging temperature before continuing.

207. Annealing, Hardening, and Tempering

a. General. Annealing, hardening, and tempering are processes by which metal workpieces are changed in structure to become softer, harder, or tougher. These characteristics are brought about by heating the metal to a critical temperature and then cooling the metal. Annealing, hardening, and tempering can be performed using the coal burning forge.

b. Annealing. Annealing is the process of removing or reducing internal stresses in metal caused by unequal heating, or manipulation of the metal. Workpieces that have been forged or welded often require annealing, and tool steel that has been hardened or tempered may require annealing to make it soft so that it can be machined. The annealing process for steel is described below.

(1) Place the workpiece in the forge fire (par. 205) and heat evenly to a uniform temperature of 1,200° to 1,500° F. The workpiece should be heated thoroughly and should have the same cherry red color throughout.

(2) If the workpiece is tool steel, it should be heated to a very dull red color, but heated thoroughly to this color. The edges should not be permitted to overheat.

(3) After the workpiece has reached this uniform temperature, it should be quickly removed from the fire and allowed to cool slowly. A good way to control the cooling is to bury the workpiece in a pile of warm dry ashes at the side of the hearth and leave it there until entirely cold. Workpieces are also cooled by placing them in an annealing box containing air slaked lime or powdered charcoal, and allowing them to remain there until cold.

(4) Tool steel that has been annealed as outlined above will cut very soft and will respond well to hardening and tempering treatments.

(5) Alloy steels are harder to anneal than plain carbon steel, and manufacturers' recommendations should be followed. In general, alloy steel requires much slower cooling than plain carbon steel.

c. Hardening. Hardening of steel is accomplished by heating the steel to its critical temperature and then cooling it rapidly.

(1) Carbon steel should be heated in the forge fire until the area to be hardened is a bright cherry red in color. The workpiece is then removed from the fire and plunged quickly into cold water to cool it rapidly.

(2) Care should be taken not to overheat the workpiece. If too high a heat is used, the metal will assume a very coarse,

crystalline structure which will be unsuitable for most applications. If the workpiece is overheated by mistake, its fine grain may be restored by allowing it to cool below red heat and then reheating it to about 1,350° F. and then annealing the workpiece.

(3) When cooling the workpiece, move it back and forth rapidly in the water to prevent formation of oxygen bubbles on its side, and to prevent the water immediately surrounding the workpiece to warm up and slow down the cooling action.

d. Tempering. Tempering is the process of softening and toughening tool steel to give it the hardness necessary to do the work for which it was intended. The steel is first hardened (*c* above) and then softened by reheating to a relatively low temperature and quenched in oil or water.

(1) Table XXXVIII indicates the temperature to which hardened tool steel should be heated in tempering to provide the proper hardness for various types of tools. When steel is heated in an oxidizing atmosphere, the oxide which forms on the steel gives off different colors at different temperatures. The colors of steel at various temperatures are listed in table XXXIX.

(2) When the workpiece is thoroughly heated to the proper temperature, plunge it quickly into water for cooling. After

Table XXXVIII. Tempering Temperatures for Steel Tools

Type of tool	Temperature for tempering (degrees Fahrenheit)	Type of tool	Temperature for tempering (degrees Fahrenheit)
Counterbores	460	Milling cutters	435–440
Countersinks	460	Punches	470–530
Cutter bits, lathe	430–450	Reamers	430–440
Cutter bits, shaper and planer	450–470	Springs	570–800
Formed milling cutters	430	Taps, over ½ inch dia	490–500
Knurls	485	Taps, under ½ inch dia	500–520
Lathe centers	450	Thread dies	495–530
		Twist drills	450–500

Table XXXIX. Color of Steel at Tempering Temperatures

Temperature of steel (degrees Fahrenheit)	Color of steel	Temperature of steel (degrees Fahrenheit)	Color of steel
430	Very pale yellow.	510	Spotted red-brown.
440	Light yellow.	520	Brown-purple.
450	Pale straw yellow.	530	Light purple.
460	Straw yellow.	540	Purple.
470	Deep straw yellow.	550	Dark purple.
480	Dark yellow.	560	Blue.
490	Yellow-brown.	570	Dark blue.
500	Brown-yellow.		

the workpiece is cool, use an abrasive cloth to remove scale that has formed on the metal.

(3) When the tool workpiece thus tempered is used for the purpose for which it was intended, look for signs of improper tempering. If the tool chips or breaks, the tool was tempered too hard. In this case, retemper the tool by heating it to a temperature slightly higher than used before and then cool. If the tool bends when used, the tool was tempered too soft. In this case, harden the tool again (*c* above) and retemper to a lower temperature than used previously.

(4) When it is desired to harden and temper only one end or portion of a tool workpiece, the hardening and tempering operation can be combined as follows.

(*a*) Heat the end of the workpiece in the forge fire to a cherry-red heat. Remove the workpiece from the fire and plunge perpendicularly about 1 inch of the tool into the cooling bath. Keep the tool moving in the bath to speed the cooling action. When the end of the tool is cold, remove it from the bath and remove the scale from the cooled portion by polishing with an abrasive cloth.

(*b*) Notice the heat from the unscaled portion of the workpiece will begin moving toward the tip very quickly after the tool has been removed from the bath. A band of color, straw yellow on the leading edge and ranging to blue on the trailing edge, will be seen moving toward the end of the tool. Each color represents a different heat and therefore a different degree of hardness. When the color representing the desired degree of hardness (table XXXIX) reaches the tip of the tool, quickly plunge the entire tool into the cooling bath, and move it about until cool.

(5) There are other methods of tempering besides that described so far. One method consists of heating the workpiece in special baths of oil, molten salts, lead, or sand to provide more accurate control of temperatures. Another method combines hardening and tempering by first heating the workpiece to a red heat and then plunging it into an oil bath having a controlled cooling capacity. By this method, the degrees of hardness are controlled by changing the composition of the oil which changes its cooling efficiency.

208. Cold Forging

Workpieces made of soft or malleable nonferrous metals such as aluminum, copper, brass, tin, or lead often are worked on the vertical hammer forging machine (fig. 183) when cold. Typical cold forging operations include swaging and riveting. More pressure and harder dies are generally required for cold forging than for hot forging.

CHAPTER 9

PORTABLE MACHINE TOOLS

Section I. GENERAL

209. Purpose

The portable machine tools identified and described in this chapter are used in place of hand tools, when available, to facilitate metal and woodworking operations outside the machine shop, and to take the place of nonportable machine tools when their use cannot be justified, or when the workpiece cannot be moved to the machine tool. The portable machine tools are all lightweight, easily transportable tools which are powered by self-contained electric motors or by compressed air from an outside source.

210. Types of Portable Machine Tools

Portable machine tools can be conveniently categorized by function as cutting tools, finishing tools, and driving tools.

a. The cutting tools consist of portable electric (fig. 192) and pneumatic (fig. 193) drills, portable hack sawing machines (fig. 205), and portable electric metal cutting shears (fig. 213).

b. The finishing tools include portable electric (figs. 198–200) and pneumatic (fig. 201) grinders, portable electric (fig. 202) and pneumatic (fig. 203) sanders, and portable electric polishers (fig. 204).

c. The driving tools include portable electric and pneumatic wrenches (fig. 207), portable pneumatic riveting (fig. 210) and chipping (fig. 208) hammers, and the powder-actuated projectile unit driver (fig. 212).

d. Another portable machine tool described in this chapter, the portable coolant attachment (fig. 214), does not fit into one of the three categories above. It is used in conjunction with nonportable machine tools such as drilling machines, lathes, grinding machines, milling machines, and sawing machines to apply cutting oils when required.

Section II. PORTABLE DRILLS

211. General

A portable drill is a hand-supported, power-driven machine tool that mounts and rotates twist drills, reamers, counterbores, and similar cutting tools. The portable drill may be electrically powered by means of an internal electric motor, or may be pneumatically powered, operated by compressed air supplied by an external source. Portable drills are rated by the maximum size hole that can be drilled in steel without overtaxing the portable drill. Therefore, a ¼-inch capacity drill is capable of drilling in steel a hole ¼ inch in diameter or smaller, although such a drill may be capable of drilling a hole ½ inch in diameter in a softer material such as wood. Portable electric and pneumatic drills rated at ¼- and ½-inch capacities are usually equipped with geared drill chucks for mounting straight, round-shank twist drills. Heavier portable drills having 1- or 1¼-inch capacities use taper sockets to mount twist drills having taper shanks and tangs.

212. Portable Electric Drills

a. General. The portable electric drills in the Ordnance Corps have the following characteristics in common. Each drill is powered by a universal (ac/dc) electric motor built into the drill case. The motor drives the chuck spindle and chuck through an arrangement of gears which reduces the spindle speed from that of the motor shaft and increases the rotational power. Each portable electric drill has a button device by which the trigger switch can be locked in the operating position when required, although under normal operation, the drill stops when the switch is released. Portable electric drills with capacities other than those described in *b* through *d* below are also available in the Ordnance Corps.

b. ¼-Inch Capacity Portable Electric Drill (fig. 192). The ¼-inch capacity portable electric drill is a heavy-duty drill capable of drilling ¼-inch holes in steel or ½-inch holes in hard wood. The drill is equipped with a geared drill chuck which will mount any straight shank twist drill or similar tool having a shank diameter of ¼ inch or less. The chuck spindle rotates freely at a speed of 1,900 revolutions per minute, although under full load the speed will be reduced to 1,000 to 1,200 revolutions per minute. The electric drill may have a spade-type or pistol grip handle with a trigger switch so that the drill can be supported and operated by one hand. A vertical stand (par. 214*b*) may be supplied to convert the drill to a drilling machine.

c. ½-Inch Capacity Portable Electric Drill (fig. 192). The ½-inch capacity portable electric drill is a heavy-duty drill with geared chuck in which straight-shank twist drills or similar shanked tools ½ inch in diameter or smaller can be mounted. This drill is driven by a universal-type (ac/dc) electric motor and has a rated capacity of ½-inch holes in steel plate and 1-inch holes in hard wood. The drill is geared to rotate the chuck spindle at 550 revolutions per minute without a load and at 360 revolutions per minute with full load. Three handles are present on this drill, the rear handle, the switch handle, and the pipe handle. The rear handle and switch

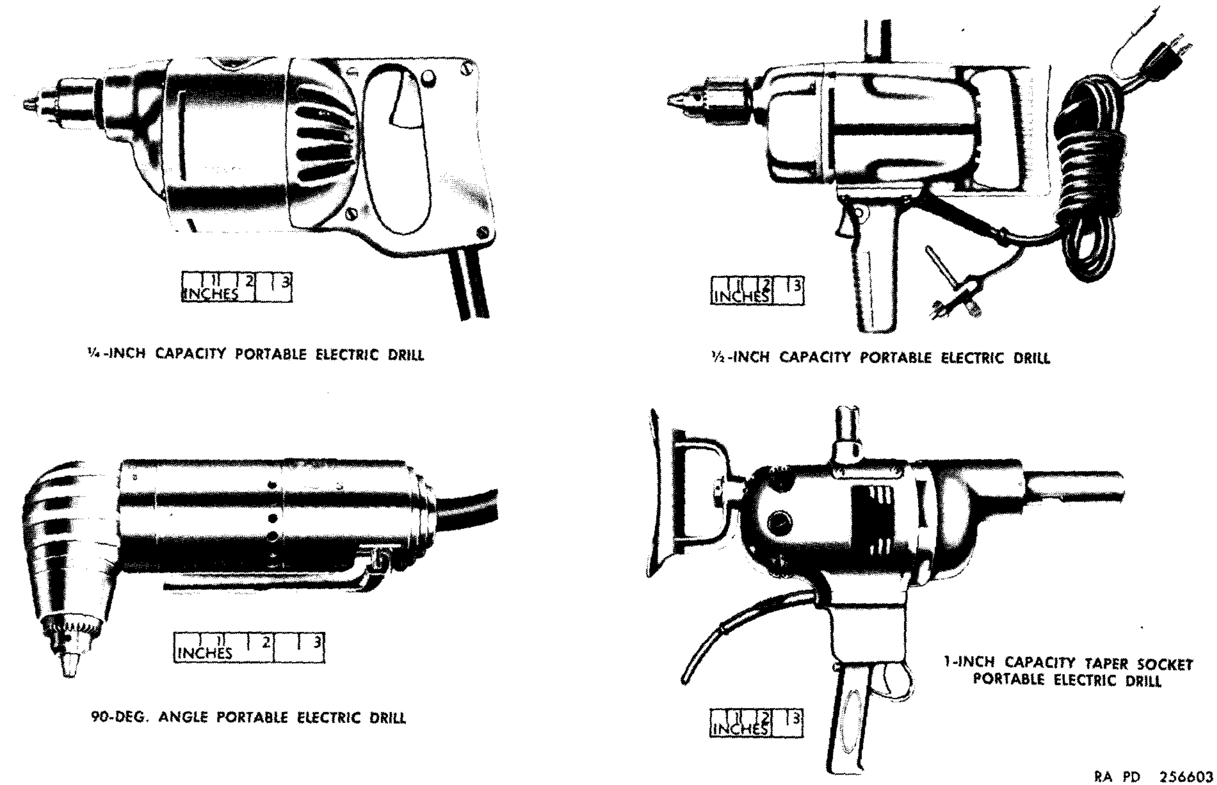


Figure 192. Portable electric drills.

handle are extensions of the drill housing and are not removable, but the pipe handle screws into a socket opposite the switch handle and can be removed and replaced by a stand if desired. The stand for this drill consists of a section of pipe with a flange on the end by which the drill can be bolted to a surface.

d. 1-Inch Capacity Taper Socket Portable Electric Drill (fig. 192). The 1-inch capacity taper socket portable electric drill is a larger and heavier version of the two drills previously described, being capable of drilling a hole 1 inch in diameter in steel. Instead of mounting drills in a geared drill chuck, this portable electric drill has a No. 2 or No. 3 taper socket for chucking twist drills and similar tools having taper shanks with tangs. This socket is similar to the drilling machine spindle (par. 24*a*) which requires a drill drift for removing drills. Drill sockets, drill sleeves, and drill chucks (par. 24) can be mounted to the taper socket of this drill to permit chucking of larger or smaller taper-shank tools and straight-shank twist drills and tools. A removable pipe handle is located opposite the switch handle. The spade-type handle at the rear of the machine can be removed and replaced by a feed screw attachment if required. The drill rotates at 275 revolutions per minute under full load and 350 revolutions per minute with no load.

e. 90° Angle Portable Electric Drill (fig. 192). The 90° angle portable electric drill is designed for working in confined places where a standard shape drill will not have sufficient clearance. This drill has a ¼-inch capacity in steel, and will drill up to a ½-inch hole in hard wood. Drilling speed is 1,600 revolutions per minute under full load and 2,500 revolutions per minute without a load. The universal-type (ac/dc) electric motor is controlled by a paddle-type trigger switch which is operated by squeezing with the fingers as the hand encircles and supports the case of the drill. A geared chuck mounts straight-shank twist drills with ¼-inch shank diameters or less.

213. Portable Pneumatic Drills

a. General. The portable pneumatic drills require an outside source of compressed air and connecting flexible hoses for operation. Basically, these drills operate by introduction of compressed air into an air cylinder where the air forces against rotor blades to impart a rotary motion to the rotor. The rotor is connected to a gear system which reduces the speed and increases the rotational force applied to the chuck spindle. The trigger of the pneumatic drill operates a valve which starts and stops the supply of compressed air to the air cylinder of the drill. Governors are built into the drill mechanism to maintain a regulated speed by metering the air admitted to the rotor blades. The portable pneumatic drills are rated by the maximum size hole the drill is capable of drilling in steel. Hence, a portable pneumatic drill rated at ½-inch capacity can successfully drill a hole ½ inch in diameter in steel without overburdening the mechanism.

b. Portable Pneumatic Drill With Geared Chuck (fig. 193). The portable pneumatic drill with geared chuck is intended for drilling, tapping, and reaming operations. The drilling capacities of a ½-inch drill of this type are ½-inch diameter holes in steel plate, ¾-inch holes in iron castings, and 1½-inch holes in hard wood. This drill can also be used to ream bores and tap holes up to $\frac{5}{16}$ inch in diameter. The pistol-grip type handle houses a trigger that controls the flow of air to the drill air rotor. A trigger lock pin can be depressed when desired to lock the trigger in the operating position. Three chucking devices are used for securing drills and other tools to the chuck spindle. These are a geared drill chuck for mounting straight-shank twist drills or similar tools; a Morse taper chucking socket for mounting twist drills and similar tools having tapered shanks with tangs; and a Morse taper "use-em-up" chucking socket for holding tapered-shank tools which have nonstandard shank lengths. The

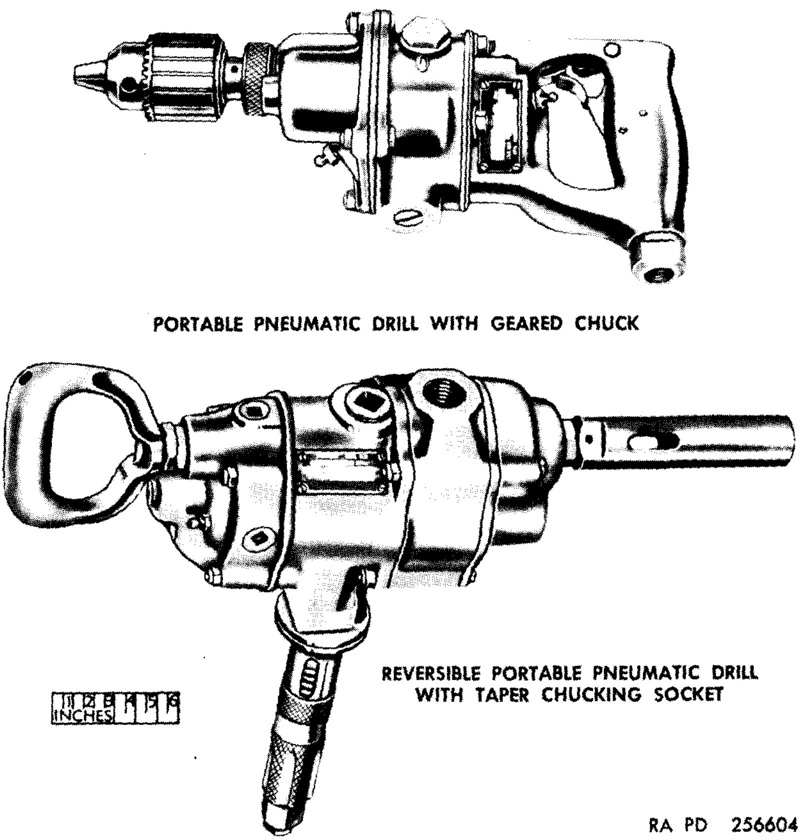


Figure 193. Portable pneumatic drills.

portable pneumatic drill generally has a governed no-load speed of 925 revolutions per minute. For proper operation, an air pressure of from 70 to 90 pounds per square inch is required.

c. Reversible Portable Pneumatic Drill With Taper Chucking Socket (fig. 193). The reversible portable pneumatic drill with taper chucking socket is a heavy-duty pneumatic drill capable of drilling a hole 1¼ inches in diameter in steel. It is equipped with a Morse taper chucking socket for mounting twist drills, reamers, taps, and similar tools having tapered shanks. The typical drill of this type has a maximum governed speed of 100 revolutions per minute and can be reversed by moving a throttle lock to indicate the desired direction of rotation, and rotating the throttle. The reversible feature makes this drill especially suited to tapping operations. A spade-type handle at the rear of the drill can be removed and replaced by a feed screw to apply pressure other than by hand. A removable pipe handle can be screwed to the side of the drill housing opposite the throttle handle. This drill requires an air pressure of 70 to 90 pounds per square inch for proper operation.

d. 360° Angle Head Portable Pneumatic Drill (fig. 194). The 360° angle head portable pneumatic drill is designed for drilling in hard-to-reach corners or tight spots where a standard shape drill would not have sufficient clearance. The drill has an all-angle drilling head which can be swiveled to any desired angle and locked in that position. Primarily intended for light drilling operations, the 360° angle head portable pneumatic drill operates on 90 pounds per square inch air pressure, and has a maximum speed of 3,000 revolutions per minute. The actual speed is regulated by the pressure applied to the throttle of the drill; a light pressure will produce a slow speed, and a heavy pressure will produce a faster speed. The throttle lever is a paddle-type lever operated by squeezing it against cylindrical drill housing with the fingers while holding the drill with both hands. A straight-shank twist drill or similar tool mounts in a ¼-inch capacity three-jaw chuck fixed to the drill spindle. The chuck is loosened and tightened with a spanner wrench.

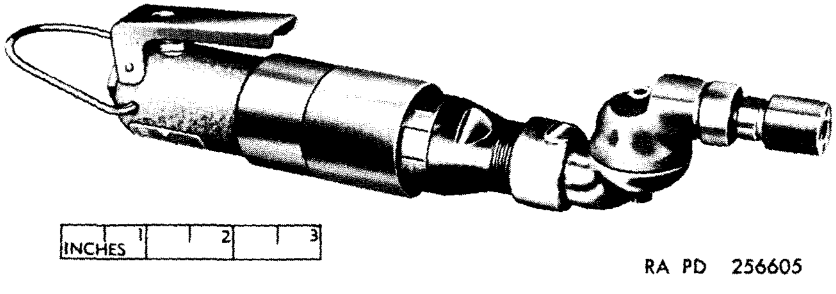


Figure 194. 360° Angle head portable pneumatic drill.

214. Special Equipment for Portable Drills

a. General. The equipment used in conjunction with portable drills consists of vertical stands which are used to convert portable electric drills to sensitive-type drilling machines (fig. 195), and feed screws (fig. 196) which attach to the rear of large portable drills for applying pressure to the drill when hand pressure cannot be applied easily. The tools and equipment described in paragraphs 26 and 36 can also be applied to portable drills when operations require their use. These tools and equipment include the tapping attachment, machine table vise, and various work holding devices.

b. Vertical Stand (fig. 195). A vertical stand may be supplied with the portable electric drills. The combination of the portable electric drill and the vertical stand forms a lightweight, sensitive-type drilling machine that can perform all standard drilling machine operations consistent with the rated capacity of the portable electric drill. The vertical stands are built in different sizes. A vertical stand for mounting a 1-inch capacity portable electric drill, for example, is larger and more heavily constructed than a stand for mounting ½-inch capacity drills, and that stand would be larger and stronger than a stand intended for ¼-inch capacity drills. These stands consist basically of a base, vertical post, and cradle. The drill clamps to the cradle which is adjustable on the vertical post and controlled by the drill stand handle. Pulling the drill stand handle downward causes the portable electric drill to lower and feed into the workpiece which is positioned on the base of the stand. By releasing the drill stand handle, the cradle and drill will return to its upper position through action of a coil spring. A stop screw clamps to the vertical post beneath the cradle, and can be adjusted vertically to limit the depth to which the drill can be lowered. The base contains mounting holes on its four corners for attachment to a work bench. On some vertical stands, the workpiece must be supported against the base by hand or positioned beneath the drill in a vise. Other vertical stands have T-bolt slots machined in the base so that workpieces can be mounted directly to the base.

c. Feed Screw (fig. 196). A feed screw may be supplied with the larger capacity portable electric and pneumatic drills that have removable rear handles. The feed screw is a device consisting essentially of a screw, a threaded sleeve, and a handwheel affixed to the screw. This device functions to apply pressure against the drill and feed it into the workpiece by running the screw out of the sleeve. The sleeve of the feed screw threads into the socket at the rear of the drill housing; and in operation, the screw bears against a support to the rear of the drill. The feed screw is intended for use where an obstruction to the rear of the workpiece prevents the operator from applying sufficient pressure to the drill by hand. The feed screw

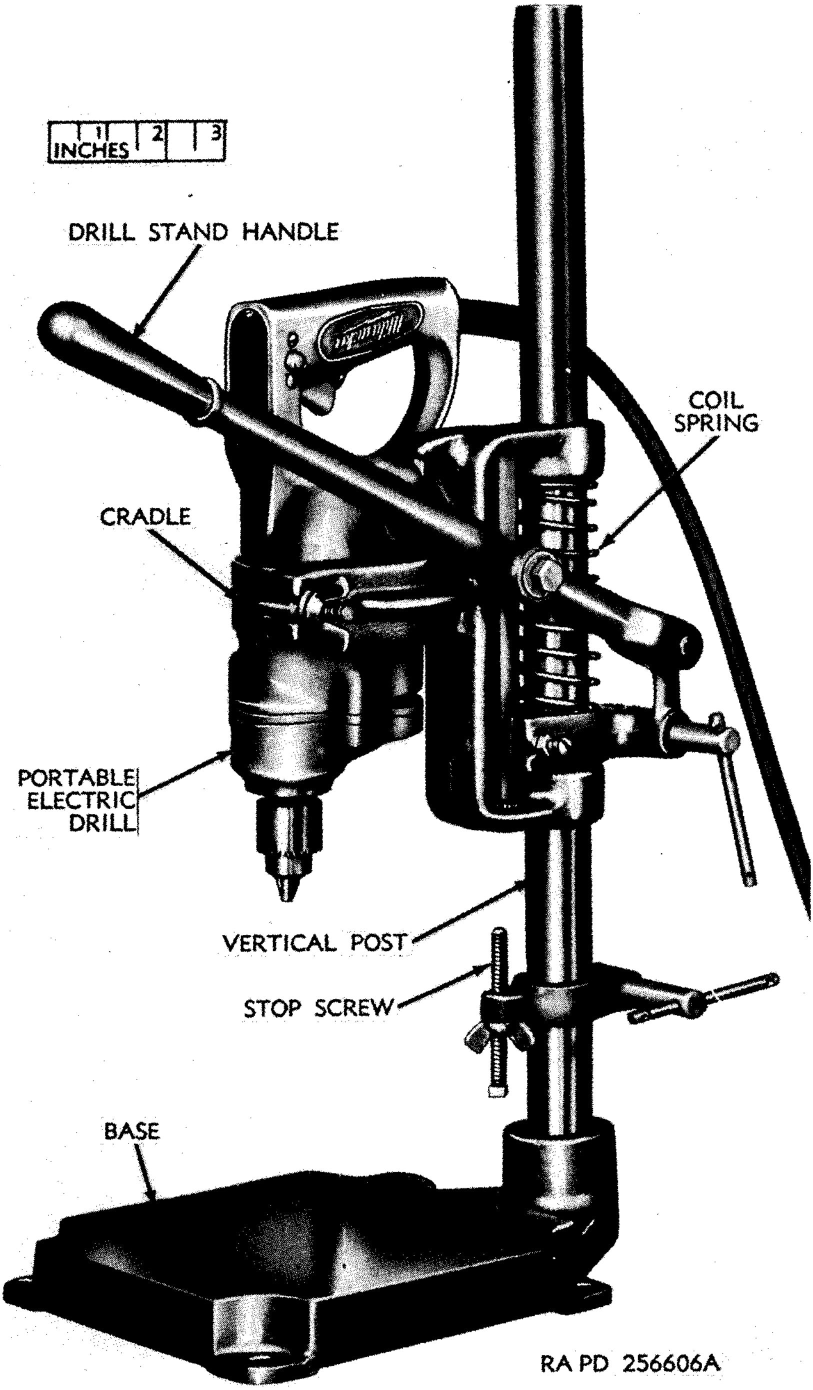


Figure 195. Portable electric drill with vertical stand.

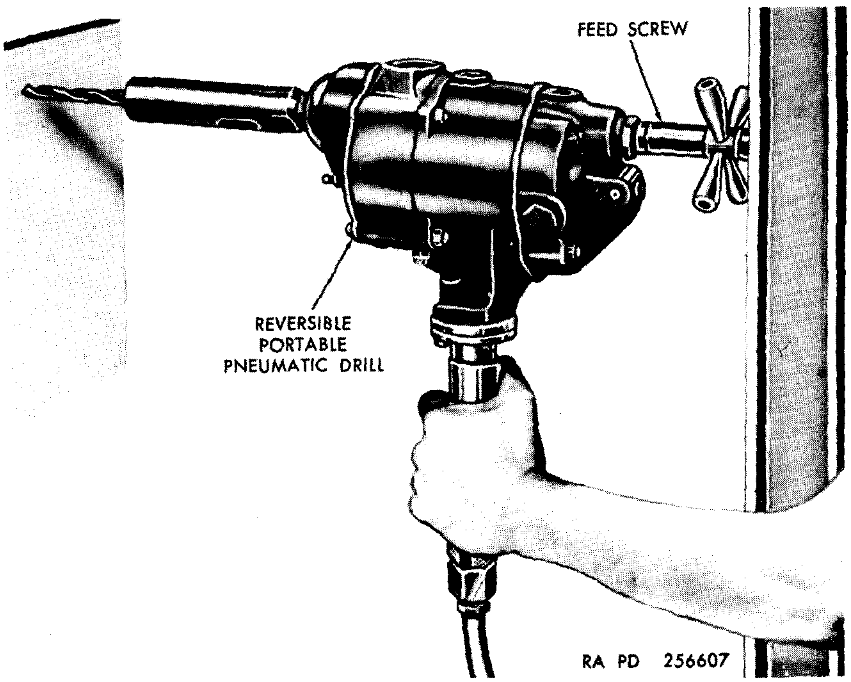


Figure 196. Operation of portable drill showing use of feed screw.

cannot be conveniently used when the area is clear to the rear of the workpiece.

215. Portable Drill Operation

a. General. Operation of the portable electric and pneumatic drills differs from recommended operating procedures for the drilling machine (pars. 30–39) in that the portable drill is hand supported for most operations, and the cutting speed of the drill is fixed. Being hand supported, the drill must be carefully alined with the workpiece and this alinement must be maintained throughout the drilling operation. Care must be taken not to lose control of the portable drill and allow it to be wrenched from the operator's hands. Since cutting speeds are fixed, the operator must learn to control the feed of the portable drill by applying sufficient pressure for the drill to cut, but not so much pressure as to cause overheating of the twist drill or stalling of the portable drill motor.

b. Preparation for Drilling Operation.

(1) When metal is to be drilled with the portable electric or pneumatic drill, the workpiece must be prepared as described for drilling machine operation (par. 27) by locating the center position of the potential hole and marking the

location with a center punch. When a large drill is to be used, it will be necessary first to drill a pilot hole equal in diameter to the width of the drill's chisel edge (par. 21*c*) so that the drill may cut properly.

(2) Portable pneumatic drills require special attention to lubrication levels, and should be checked before operation and after every 4 hours of operation. Refer to the pertinent lubrication order or lubrication chart before operating a portable pneumatic drill.

(3) For drilling by hand, the workpiece must be mounted securely. Thin workpieces should be backed up with wood or metal.

(4) When using a portable electric drill with vertical stand (par. 214*b*), mount the workpiece securely in a machine table vise, or fasten the workpiece directly to the base of the vertical stand with work holding devices. Do not attempt to hold the workpiece by hand unless the material is wood or very soft metal, and workpiece can be easily controlled in this manner. Adjust the stop screw on the vertical post to limit the downward travel of the drill as desired.

c. Hand Drilling Operation (fig. 197).

(1) Select a twist drill of the proper size for the diameter hole desired, and of the proper shank type for the geared drill chuck or chucking socket of the portable drill. Twist drills must be sharp. Sharpen dull twist drills by grinding on a bench-type drill grinding machine (par. 21*d*).

(2) Mount the twist drill securely in the geared drill chuck or chucking socket.

(3) Connect the portable electric drill to a proper power source as prescribed in the pertinent technical manual, or as stated on the motor data plate on the portable electric drill. If the portable electric drill is to be used in a location far removed from a power source, select a 3-conductor extension cord of the proper cable size and length (refer to pertinent technical manual).

(4) Connect the portable pneumatic drill to a source of regulated compressed air. The source should have adequate moisture traps and filters, and the regulated air pressure (psi) should be as prescribed for the particular portable pneumatic drill.

(5) Position the portable drill over the workpiece and center the chisel point of the drill in the punched center hole of the workpiece. Aline the drill perpendicular to the workpiece (fig. 197), and while applying firm but not heavy

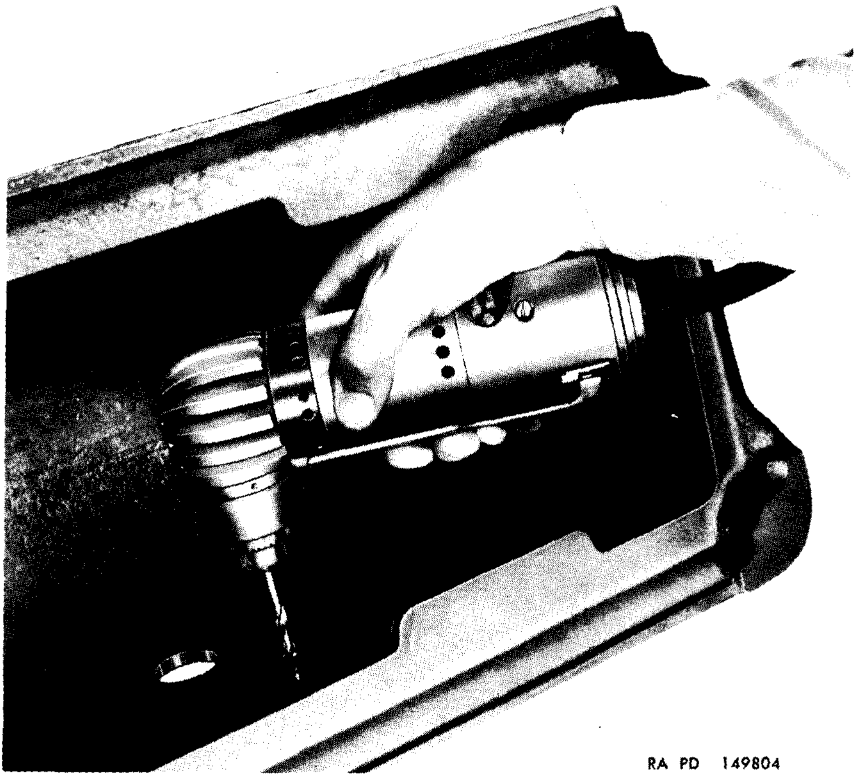


Figure 197. Hand drilling operation in confined space.

pressure upon the portable drill, actuate the trigger or throttle gently to start the drill.

(6) When the hole has been started, stop and remove the portable drill. Examine the hole to determine if it is properly centered. If the started hole is off center, draw the drill back to the correct center as described in paragraph 33.

(7) Apply a few drops of cutting oil as prescribed for drilling machine operation (par. 34) to the twist drill and hole to improve the cutting action and prevent overheating of the twist drill. For long drilling operations, stop the drill at intervals and apply additional cutting oil.

(8) Continue drilling the hole while applying enough pressure to produce a clean chip but not so much pressure as to cause the motor to strain or the drill to bind. The drill must be held firmly at all times to prevent the drill from being wrenched from the hands of the operator if the flutes of the drill should snag on a metal projection in the hole. For

lengthy cutting operations, the lock pin on the trigger switch can be engaged.

(9) As the twist drill nears the back wall of the workpiece, take the portable drill off the lock pin for the trigger, so that the drill can be stopped immediately if required. Lighten the feed pressure as the drill breaks through, and cautiously feed the drill through the wall of the workpiece.

(10) If the drill should snag, stop the portable drill immediately, and withdraw it from the hole. Carefully feed the drill back into the hole with the drill running to cut through the obstruction.

d. Operation of Drill With Vertical Stand. When a portable electric drill is mounted to a vertical stand (fig. 195) for operation, the operating procedure is identical to that of the drilling machine (pars. 29–39). The portable drill is started by pulling the trigger switch and pushing in the lock pin to hold the trigger switch depressed. The lock pin is disengaged after the drilling operation has been completed.

Section III. PORTABLE GRINDERS

216. General

The portable grinder is a versatile machine tool used for grinding excess metal from castings and weldments, cleaning rust, scale, or corrosion from workpieces, and performing miscellaneous finishing operations around the machine shop. Both portable electric grinders and portable pneumatic grinders are used in the Ordnance Corps.

217. Portable Electric Grinders

a. General. Three basic types of portable electric grinders are the portable electric grinder (chuck type), the portable electric grinder (wheel type), and the flexible-shaft portable electric grinder.

b. Portable Electric Grinder (Chuck Type) (fig. 198). The portable electric grinder (chuck type), often called a portable die grinder, has a high-speed universal (ac/dc) electric motor which drives a ¼-inch collet chuck. This grinder comes equipped with a number of accessories such as rotary files, small circular saws, shaped grinding abrasive wheels, sanding and polishing disks and belts, wire brushes, and router bits, each of which are mounted to straight-shanked arbors which fit into the collet chuck of the grinder. Reduction collets are provided so that smaller diameter arbors or shanks can be mounted in the chuck. Operations performed with this portable grinder include shaping and smoothing of dies and intricate castings, removing burs from bores and surfaces, cleaning and repairing threaded parts, repairing keyways and splines, grinding bevels, countersinking holes, and repairing scored or mutilated surfaces.

c. Portable Electric Grinder (Wheel Type) (fig. 199). The portable electric grinder (wheel type) is a heavy-duty portable grinder capable of mounting and rotating 6-inch diameter grinding abrasive wheels and 6-inch diameter wire brushes and polishing wheels. This grinder is used as a hand grinder for removing rust, corrosion, and paint from large workpieces, and when mounted to a grinder stand (par. 219) it becomes a bench-mounted utility grinding machine for sharpening tools and performing miscellaneous grinding operations about the machine shop. Powered by a ½-horsepower universal (ac/dc) electric motor, the portable electric grinder has a controlled speed of 3,300 or 3,800 revolutions per minute depending upon the model designation. Three grinding abrasive wheels of different grain size are provided for performing roughing, finishing, and general purpose

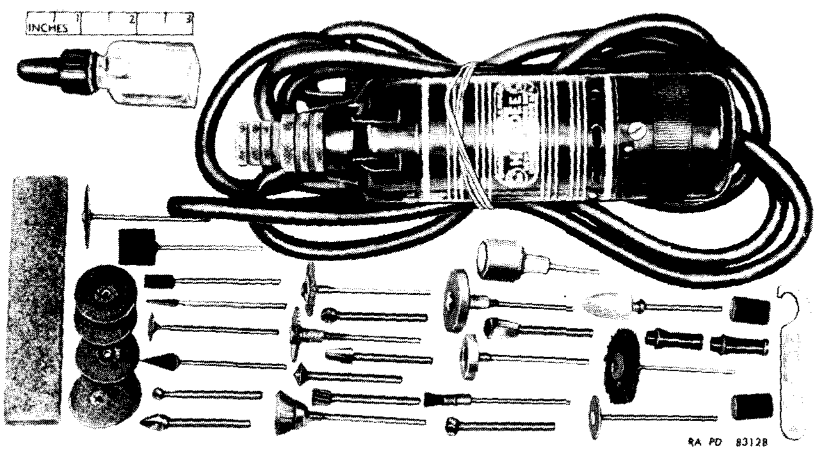
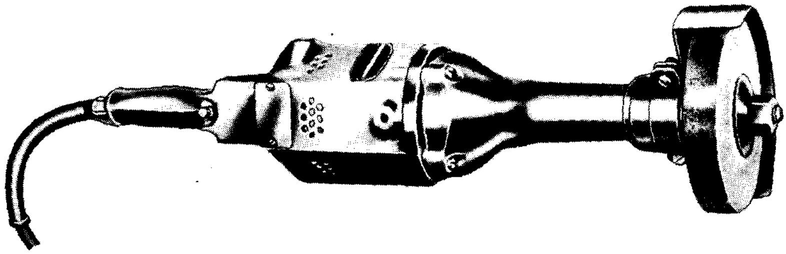


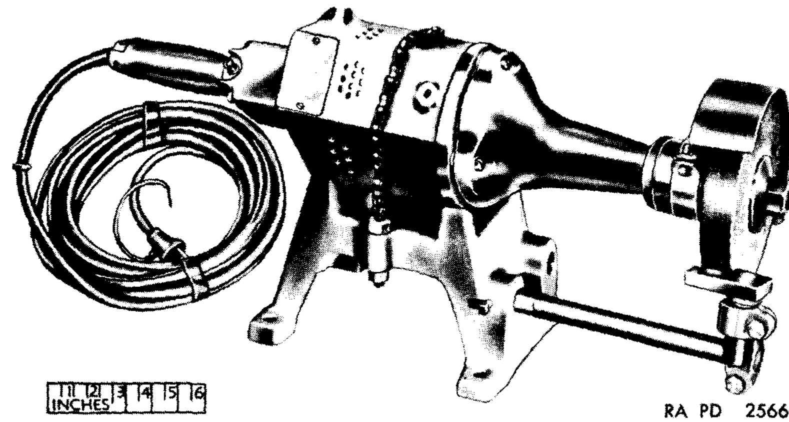
Figure 198. Portable electric grinder (chuck type) with accessories.

grinding operations. A wheel guard extends over the mounted grinding abrasive wheel to protect the operator from flying sparks and metal particles during operation.

d. Flexible-Shaft Portable Electric Grinder (fig. 200). The flexible-shaft portable electric grinder consists of a flexible shaft in a protective sheath that is connected to and rotated by an electric motor mounted to a three-legged floor stand. A belt and pulley transmission between the jackshaft (which drives the flexible shaft) and the motor spindle provides three rotational speeds ranging, generally, from 2,500 to 5,000 revolutions per minute. A handpiece assembly is located at the extreme end of the flexible shaft, and mounts attachments for grinding, buffing, wire brushing, and filing operations. The floor stand upon which the motor is mounted, rides upon casters so that it can be wheeled close to the workpiece.



PORTABLE ELECTRIC GRINDER (WHEEL TYPE)



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PORTABLE ELECTRIC GRINDER (WHEEL TYPE)
WITH GRINDER STAND

Figure 199. Portable electric grinder (wheel type) with and without grinder stand.

218. Portable Pneumatic Grinders

a. General. The portable pneumatic grinder is similar in appearance and identical in function to the portable electric grinder (par. 217*c*). This grinder can be used in shops having compressed air sources.

b. Portable Pneumatic Grinder (fig. 201). The portable pneumatic grinder is used for cleaning rust and scale from large metal objects, for removing excess metal from heavy castings or forgings, and for smoothing welds. The air motor operates on 80 to 90 pounds per square inch of compressed air to rotate a 6- or 8-inch grinding abrasive wheel at a maximum speed of 4,500 revolutions per minute. A built-in governor controls the maximum speed of the portable pneumatic grinder.

219. Special Equipment for Portable Grinders

a. General. The equipment used with the portable electric and pneumatic grinders consists of grinding abrasive wheels, wire brushes,

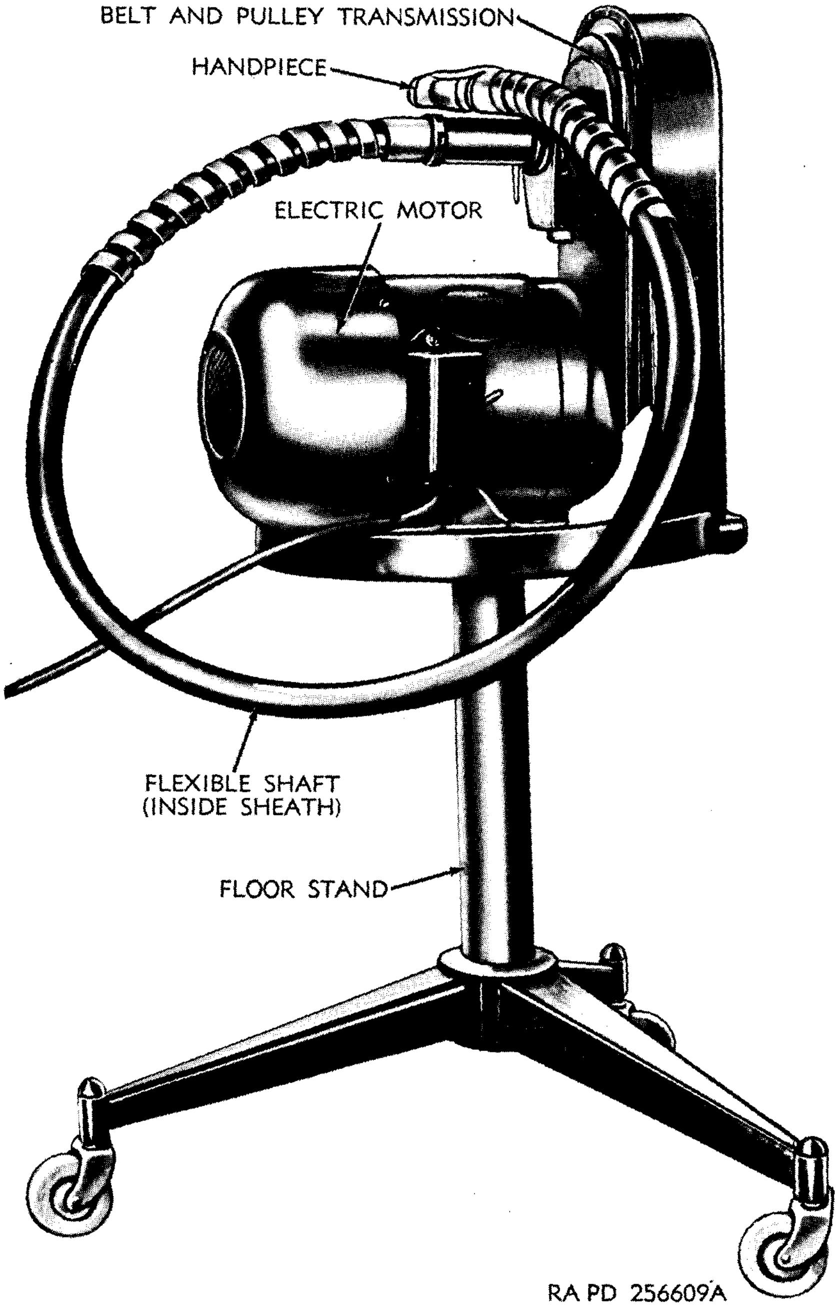


Figure 200. Flexible-shaft portable electric grinder.

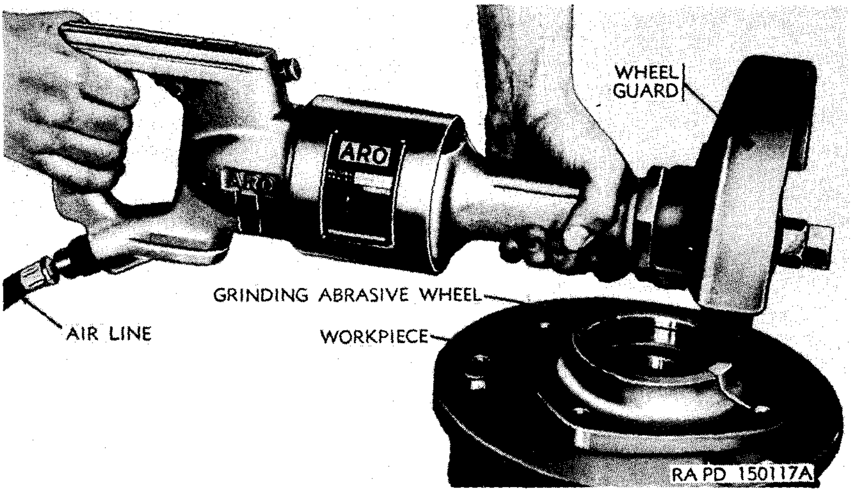


Figure 201. Operation of the portable pneumatic grinder.

and grinder stands. Grinding abrasive wheels used with these portable grinders are the same as those grinding abrasive wheels used with grinding machines (par. 42) except for size and mounting details. Wire wheels (par. 43) can be used with the portable electric grinder, the flexible-shaft portable electric grinder, and the portable pneumatic grinder in place of the standard grinding abrasive wheels. Do not mount wheels or brushes larger in diameter than the rated wheel size on any portable grinder.

b. Grinder Stand (fig. 199). A grinder stand may be supplied with the portable electric grinder (wheel type) so that the grinder may be bench mounted for use as a utility grinding machine. The grinder stand consists of a base to which the grinder is secured in a horizontal position, and an adjustable tool rest positioned in front of the grinding abrasive wheel. The portable electric grinder with grinder stand can be used for grinding lathe and shaper cutter bits, for sharpening hand tools such as chisels, knives, and screwdrivers, and for performing odd grinding jobs around the shop.

220. Portable Grinder Operation

a. Operation as a Portable Grinder (fig. 201).

(1) The wheel guard of the portable grinder should be positioned between the grinding abrasive wheel and the operator's face at all times for protection from abrasive and metal particles. Goggles should be worn by the operator at all times when performing grinding operations.

(2) Hold the portable electric or pneumatic grinder securely with both hands. Turn the portable grinder on and move the grinding abrasive wheel slowly across the workpiece

surface. Do not permit the wheel to remain stationary over one spot of the workpiece. A light, even pressure must be applied, and the metal removed by several light passes rather than one or two heavy passes.

b. Operation as a Bench-Mounted Utility Grinding Machine. The operation of the portable electric grinder with the grinder stand is the same as the operation of the utility grinding machine (par. 51) used for off-hand grinding.

Section IV. PORTABLE SANDERS AND POLISHERS

221. General

Portable sanders and polishers are used for surface finishing of all materials—metal, wood, and plastic. Portable sanders are used to remove paint and rust and to produce surfaces smooth enough for finishing. The portable polisher is used to rub down surfaces that have been finished to produce a super-finish or shine to the workpiece surface. Portable polishers are generally more powerful than portable sanders since they encounter a greater frictional resistance when in operation. Portable polishers operate at a lower speed than portable sanders.

222. Portable Sanders

a. General. There are two basic types of portable sanders, the disk type and the oscillating pad type. The disk-type sander is generally driven by an electric motor, while the oscillating pad type may be either electrically or pneumatically operated.

b. Disk-Type Portable Electric Sander (fig. 202). The disk-type portable electric sander is used to remove paint and rust from broad workpiece surfaces, and to prepare rough surfaces for finishing operations. The sander is powered by a universal (ac/dc) electric motor which drives the sanding disk spindle at a speed of 4,200 revolutions per minute. Sanding disks are secured to a flexible sanding pad which mounts to the sanding disk spindle. The spindle can be locked by depressing a lock button while sanding disks are being installed and removed. A side handle is screwed to the sander case near the sanding disk. The handle can be attached to either side of the housing for either right or left hand operation.

c. Oscillating Pad Portable Pneumatic Sander (fig. 203). The oscillating pad portable pneumatic sander is used for dry and wet sanding, rubbing down, and polishing operations. This sander has two sanding pads that oscillate separately, each pad reciprocating 2,500 times per minute yet moving only seven-sixteenth of an inch per stroke. For operation, a sheet of abrasive paper is fitted over each pad and is held in place by a paper clamp assembly. The oscillating pad portable pneumatic sander is operated by 65 to 90 pounds per

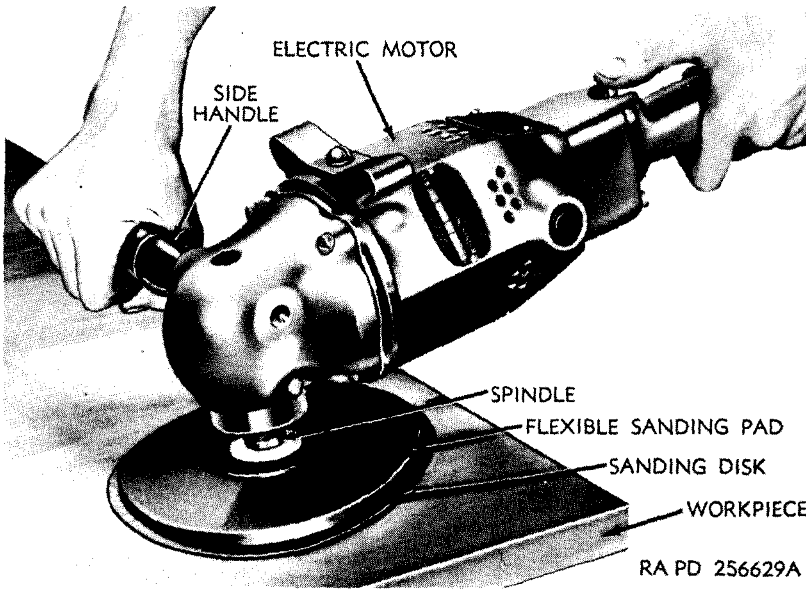


Figure 202. Operation of the disk-type portable electric sander.

square inch of air pressure. A palm lever controls both the air and water.

223. Portable Polishers

a. General. The portable polishers in the Ordnance Corps are all electrically operated although pneumatic models are available commercially. The portable electric polisher is essentially the same as the disk-type portable electric sander (par. 222*b*) but is designed to rotate at a slower speed and with more torque than required for sanding.

b. Portable Electric Polisher (fig. 204). The portable electric polisher is used for polishing and rubbing down bare metal, painted, or finished surfaces to improve the surface quality. The polisher is powered by a universal-type (ac/dc) electric motor which drives the polishing head spindle at a 90° angle to the motor shaft. A 7-inch diameter rubber cushion pad is fixed to the spindle and polishing is performed by a lambswool polishing bonnet that fits over the cushion. A side handle on the polisher housing is used for support of the polisher during operation. This handle can be removed and screwed into the opposite side of the housing when left hand operation is desired.

224. Special Equipment for Portable Sanders and Polishers

a. General. Special equipment required for the operation of the portable electric and pneumatic sanders consists of abrasive disks for

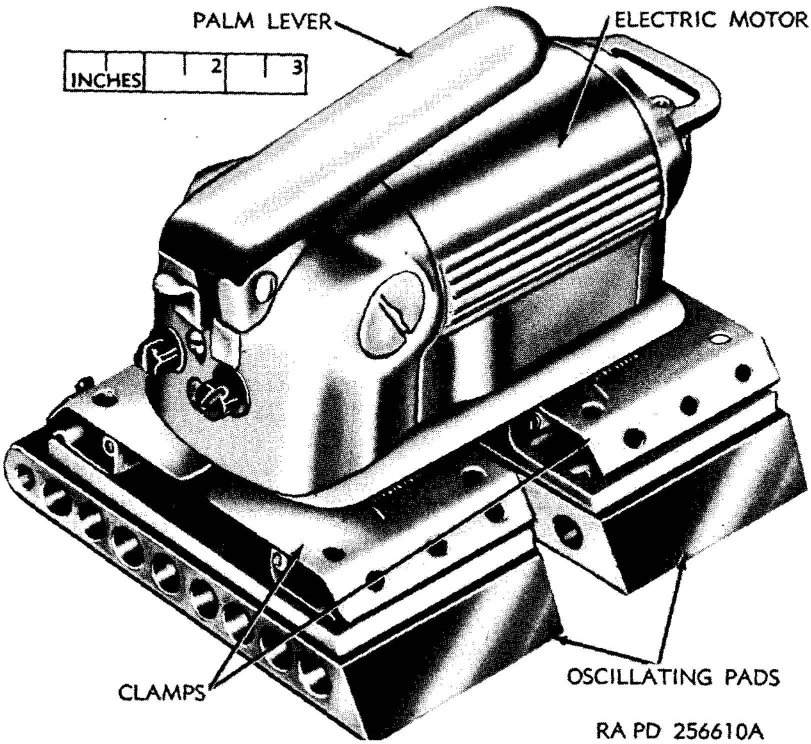


Figure 203. Oscillating pad portable pneumatic sander.

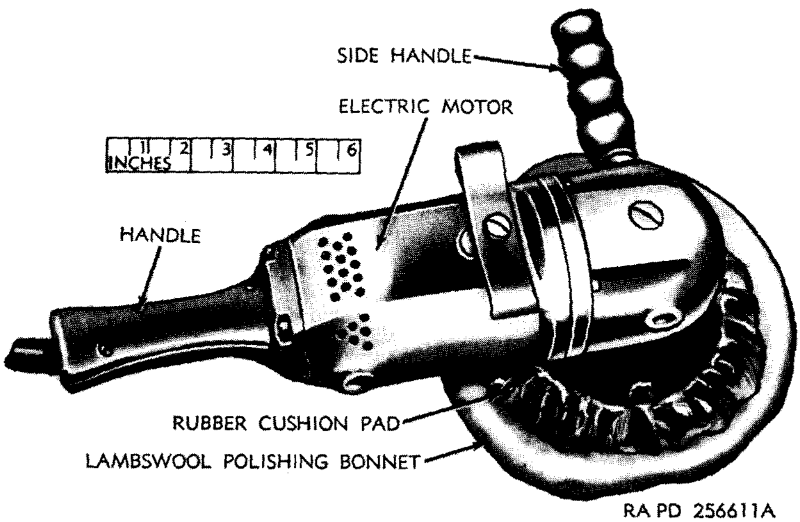


Figure 204. Portable electric polisher.

the disk-type portable electric sander, and abrasive paper for the oscillating pad portable pneumatic sander. Equipment for the portable electric polisher consists of the lambswool polishing bonnets used on the cushion pad of the polisher.

b. Abrasive Disks

(1) *Description.* The abrasive disks used for sanding with the disk-type portable electric sander consist of abrasive grain bonded to one side of a flexible cloth or paper disk. The backing is of a tough vulcanized fiber construction that will withstand flexing of the disk during use. The abrasive grain bonded to the face of the disk is usually aluminum oxide, and the bonding agent is either glue or a synthetic resin.

(2) *Open and closed coats.* Depending on the use of the abrasive disk, an open coat abrasive disk or a closed coat abrasive disk may be selected. The closed coat disk has the abrasive grains bonded close together, while the open coat disk has the abrasive grains spaced apart from each other. Open coat abrasive disks are used for sanding materials that would tend to load up a closed coat abrasive disk quickly, reducing the disk's efficiency and requiring constant cleaning. Open coat abrasive disk operations include all wood sanding, removal of paint from metal and wood surfaces, and removal of rust from metal surfaces. Closed coat abrasive disks are used for sanding metal, rough sanding as well as smooth finishing cuts.

(3) *Selection of abrasive disks.*

(*a*) Select abrasive disks for use with the disk-type portable electric sander in accordance with the particular sanding operation to be performed. Table XL indicates suitable grain sizes of abrasive disks for different operations. A closed coat disk should be selected for sanding metal, and

Table XL. Selection of Abrasive Disks

Operation	Abrasive disk	
	Grain No.	Type of coat
Removing rust	16 to 30	Open.
Removing paint	16 to 36	Open.
Sanding metal (rough cuts)	24 to 36	Closed.
Sanding metal (medium cuts)	36 to 60	Closed.
Sanding metal (finishing cuts)	80 to 180	Closed.
Sanding wood (rough cuts)	16 to 24	Open.
Sanding wood (medium cuts)	24 to 50	Open.
Sanding wood (finishing cuts)	60 to 120	Open.

an open coat disk selected for sanding wood and removing rust and paint.

(*b*) The size of abrasive grit used to produce different degrees of coarseness in abrasive disks and abrasive paper is identified by two basic methods: the grain number (number of grains per linear inch) and the grit symbol. The grain number is more commonly used than the earlier grit symbol identification. Table XLI lists comparative coarsenesses for abrasive disks and abrasive paper used with the oscillating pad portable pneumatic sander (*c* below).

Table XLI. Relative Coarseness of Abrasive Disks and Abrasive Paper

Relative coarseness		Grain No.	Grit symbol
Abrasive disks	Abrasive paper		
		16	4
Coarse		24	3
		30	2½
Medium	Very coarse	36	2
		40	1½
	Coarse	50	1
		60	1/2
Fine	Medium	80	1/0
		100	2/0
	Fine	120	3/0
		150	4/0
		180	5/0
	Very fine	220	6/0
		240	7/0
		280	8/0
	Extra fine	320	9/0
	Super fine	400	10/0
		500	11/0
		600	12/0

c. Abrasive Paper.

(1) *Description.* Abrasive paper identical to that used for hand sanding is used with the oscillating pad portable pneumatic sander (fig. 203). This abrasive paper is supplied in standard size sheets 9 x 11 in size. The abrasive materials commonly used in making abrasive paper are aluminum oxide, silicon carbide, flint, emery, and garnet. The abrasive grain is bonded to a heavy paper backing fortified with rope or wood fibers.

(2) *Selection of abrasive paper.* A finer abrasive than required for abrasive disks can be used for sanding with the oscillating

pad portable pneumatic sander. For rough sanding of wood, a No. 40 or 60 grain paper should be used. Use a No. 120 or 150 grain abrasive paper for finishing wood. For sanding metals, use a No. 36 or 40 grain paper for rough cuts and progress to finer grain papers to produce a smoother finish. Relative coarseness of abrasive papers is given in table XLI.

d. Lambswool Polishing Bonnet. The lambswool polishing bonnet is a hood of soft lambswool that fastens over the rubber cushion pad (fig. 204) of the portable electric polisher and is held in place by a drawstring. The bonnet is charged with a polishing abrasive, liquid glaze, or wax before use, depending upon the surface quality desired.

225. Sanding Operation

a. Operation of the Disk-Type Portable Electric Sander (fig. 202). Hold the portable electric sander so that the abrasive disk forms an angle of approximately 15° to the workpiece surface. Apply just enough pressure against the sander to bend the sanding pad and abrasive disk so that about 2 inches of the disk contact the surface. Move the sander from side to side, overlapping each path with the next. If the sander cuts irregularly or is hard to control, the sander is most likely at an angle smaller than 15° to the workpiece. If the sander gouges or leaves rough edges, the angle formed by the sander is most likely too great. When the sander is operating, keep it moving or lift it from the workpiece. Holding the sander stationary will cause overheating of the workpiece and abrasive disk and will cause burning if the workpiece is wood.

b. Operation of the Oscillating Pad Portable Pneumatic Sander. To operate the oscillating pad portable pneumatic sander (fig. 203), fix half of a 9 x 11 sheet of abrasive paper to each pad of the sander, and place the sander on the surface to be sanded. Connect the water supply if wet sanding of metal or finished surfaces is to be performed. Start the sander and move it slowly from side to side or back and forth. When sanding wood, the sander can be moved with the grain, across the grain, or against the grain successfully without producing patterns on the wood. The sander can also remain stationary without causing overheating or burning of the workpiece. Apply very little downward pressure to the sander during operation; the weight of the sander is usually sufficient. Replace abrasive paper as soon as the sanding performance drops.

226. Polishing Operation

The portable electric polisher (fig. 204) is built with the correct speed and torque for polishing. The polishing operation is performed by placing the spinning lambswool polishing bonnet lightly against the workpiece and moving the polisher slowly back and forth while maintaining a light pressure on the workpiece. Recharge the polishing bonnet as necessary during the polishing operation. Do not press down hard on the polisher at any time while in contact with the work surface. Use separate polishing bonnets for different polishing abrasives, glazes, or waxes.

Section V. PORTABLE HACKSAWING MACHINE

227. General

The portable hacksawing machine (fig. 205) is similar in most respects to the horizontal hacksawing machine (par. 132). The major difference is that the portable machine can be moved about conveniently and can be carried to the workpiece rather than carrying the workpiece to it.

228. Portable Horizontal Hacksawing Machine.

The portable horizontal hacksawing machine (fig. 205) has a built-in electric motor that causes the hacksaw blade to reciprocate at a fixed speed of 115 strokes per minute. The machine is capable of square cutting solid steel 3 inches square and cutting 1½ x 3 steel at a 45° angle. This saw can be used in a horizontal, angular, or vertical position successfully, having an adjustable counterbalance to compensate for operating the sawing machine in a vertical position. A 10-inch hacksaw blade is used with this machine producing a 4-inch stroke. A tension screw permits increasing or decreasing the blade pressure with each cut. The portable horizontal hacksawing machine will support itself when fastened rigidly to a stationary workpiece.

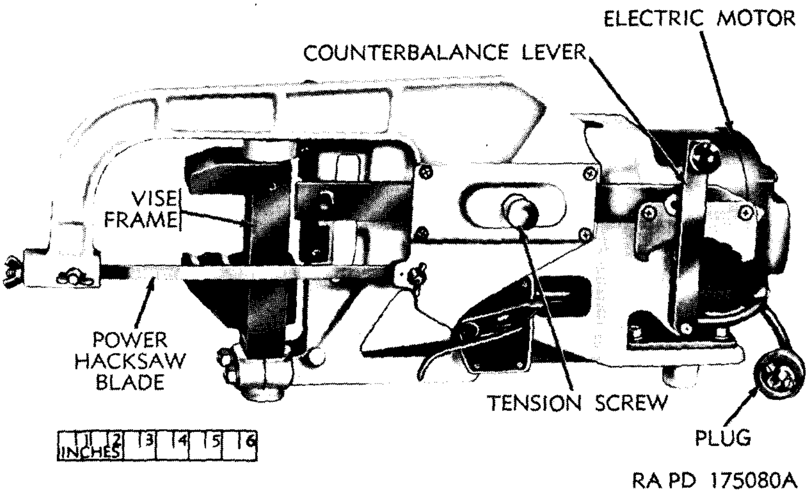


Figure 205. Portable horizontal hacksawing machine.

229. Tools and Equipment for the Portable Hacksawing Machine

a. General. The only equipment used with the portable horizontal hacksawing machine consists of power hacksaw blades.

b. Power Hacksaw Blades. The power hacksaw blades for this machine are 10 inches long, ½ inch wide, and 0.025 inch thick. The blades recommended for the machine come in three pitches of 18, 24, and 32 teeth per inch. The 18-tooth power hacksaw blade is used to cut solid steel and heavy-walled steel or iron pipes. The 24-tooth blade is recommended for general purpose sawing operations and for cutting conduit and structural shapes of steel. The 32-tooth power hacksaw blade is used to cut thin wall aluminum, bronze, and copper tubing. For additional information on power hacksaw blades and their selection, refer to paragraph 134.

230. Portable Hacksawing Machine Operation

a. General. Two adjustments are important when using the portable horizontal hacksawing machine; the proper adjustment of the tension screw and the proper adjustment of the counterbalance lever (fig. 205). The tension screw when turned clockwise will increase the amount of lift the hacksaw blade makes on each return stroke, and will increase the downward pressure of the blade on each cutting stroke. Counterclockwise rotation of the tension screw will decrease the lift and pressure. This control should be adjusted to cause the hacksaw blade to lift ⅛ inch on each return stroke to provide maximum cutting speed and efficiency. The counterbalance lever controls the downward pressure exerted upon the hacksaw blade by the weight of the saw frame. By moving the counterbalance lever to the left, the pressure is decreased. Moving the lever to the right increases the pressure.

b. Square Sawing in the Horizontal Position. The vise frame (fig. 205) should be positioned to support the workpiece perpendicular to the hacksaw blade. This position can be determined by alining one of the engraved lines on the top surface of the vise frame with the engraved index mark on the main hacksaw frame. The workpiece is then mounted squarely in the vise. For normal sawing operations, move the counterbalance lever to the middle notch in the guide bar ratchet to produce a nominal amount of sawing pressure. Decrease the pressure for sawing wood, plastics, or thin wall tubing by moving the counterbalance lever one or two notches left of the middle notch. Start the sawing machine and observe the sawing action. If the machine strains, the blade pressure may be too heavy. If the machine cuts very slowly increase the pressure. Check the power hacksaw blade for sharpness. If the blade is dull, it should be replaced. When the portable horizontal hacksawing machine cuts completely through the workpiece, the saw frame will trip the motor switch and stop the sawing action.

c. Angular Sawing in the Horizontal Position. The vise of the portable horizontal hacksawing machine can be pivoted about the hacksaw frame for supporting workpieces at 22½°, 30°, and 45° angles to the power hacksaw blade. Engraved marks on the top of the main hacksaw frame and vise frame (fig. 205) indicate each of these positions so that the vise may be alined without measuring the angle. With the vise frame firmly secured at the desired angle, mount the workpiece in the vise flat against the stationary and movable jaws and the bottom of the vise frame. The workpiece size limit is 1½ inches wide for 45° angle cuts, 2⅝ inches wide for 30° angle cuts, and 3 inches wide for 22½° angle cuts. Proceed to saw in the same manner described for square sawing (*b* above).

d. Sawing in the Vertical Position (fig. 206). When the sawing machine is used in the vertical position, the counterbalance lever must be positioned in the farthest right notch of the guide bar ratchet to compensate for the lack of gravitational pressure normally applied to the blade by the saw frame. The portable horizontal hacksawing machine in figure 206 is shown hanging from the workpiece clamped in the vise of the machine. This practice should be attempted only if the workpiece can be clamped very securely in the vise and is not likely to wrench loose.

Section VI. PORTABLE WRENCHES

231. General

Portable wrenches are power-operated hand tools designed to install and remove threaded fastening devices. These tools operate by spinning the screw, nut, or bolt when little resistance to movement is encountered, and by impacting, or imparting a number of rapid hits, when resistance is encountered. Portable wrenches are supplied with numerous socket wrenches and driver bits to perform different operations. The portable wrenches are actuated either by an electric motor or by compressed air.

232. Types of Portable Wrenches

a. General. The portable wrenches (fig. 207) used in the Ordnance Corps are either electrically or pneumatically powered and are selected according to the more convenient power source available. Portable electric wrenches are operated by a universal-type (ac/dc) electric motor, and portable pneumatic wrenches are powered by an air turbine requiring 60 to 90 pounds per square inch air pressure. Both portable wrenches are reversible so that they can be used for both loosening and tightening of threaded fastening devices.

b. Reversible Impact Portable Electric Wrench (fig. 207). The reversible impact portable electric wrench is used for applying and removing nuts, cap screws, socket head screws, cross-recess head

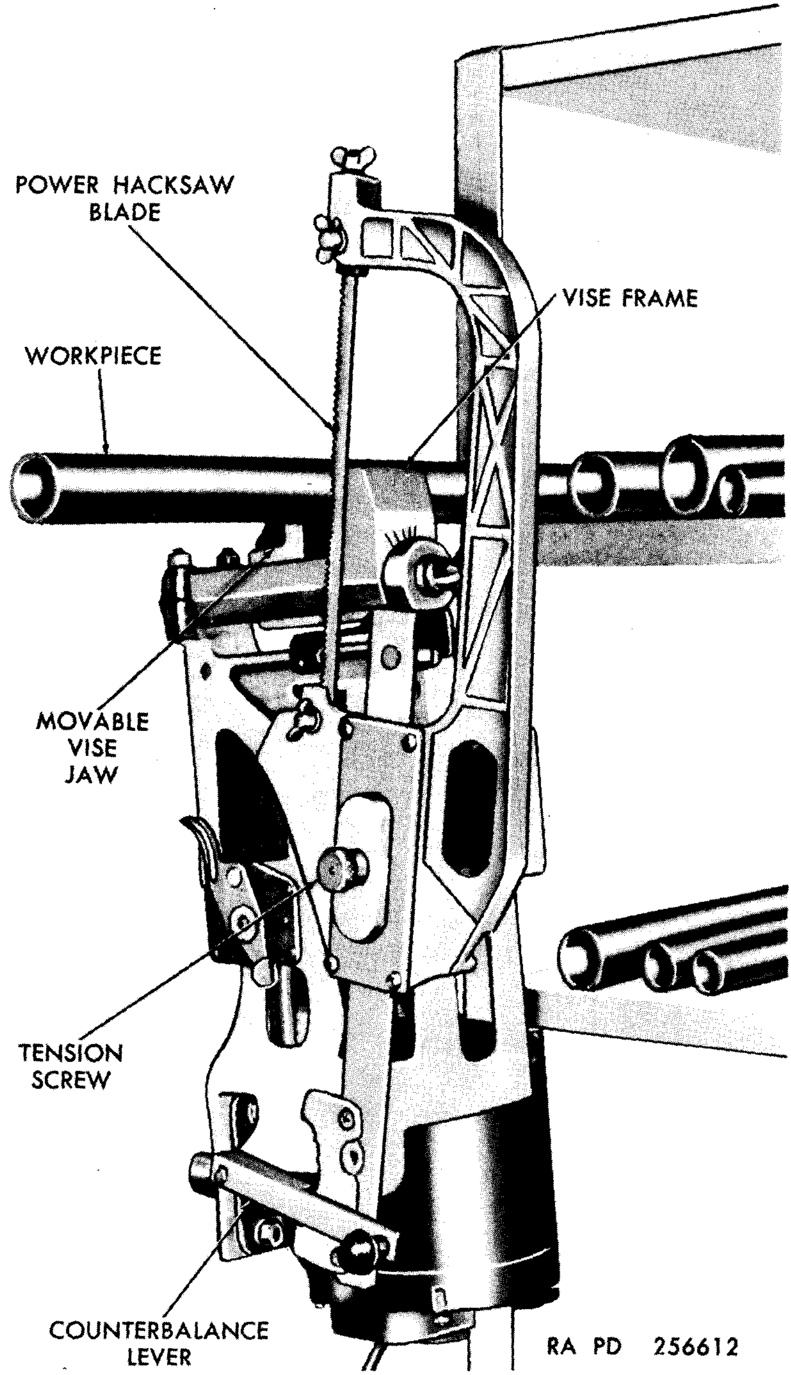


Figure 206. Portable hacksawing operation in the vertical position.

screws, slotted screws, and bolts, and for drilling and tapping operations in metal and wood. The wrench has an electric motor that is reversed by rotating the cap at the rear of the wrench housing. Socket wrenches, driver bits, sockets, and chucks are mounted to a ½-inch square driver at the front of the wrench. A ball detent located on one side of the square driver slips into recesses on the equipment to hold it in place for operation. When little or no resistance is encountered by the portable electric wrench, the square driver will rotate at a speed of up to 1,900 revolutions per minute. As resistance to movement is encountered, the driver will stop rotating freely and start impacting at a speed of 1,900 impacts per minute. This series of rapid hits will loosen tight or rusted nuts and bolts, and will tighten loose bolts easily. Equipment supplied with this wrench includes socket wrenches in sizes from ⅜ to 1 inch, slotted screwdriver bits, cross-recess screwdriver bits, socket head screwdriver bits in sizes from 3/16 to ⅝ inch, a bit holder, a taper socket for chucking tools having No. 2 Morse taper shanks, a collet-type chuck, extension bars, and a universal joint to permit access to tight spaces.

c. Torque-Type Reversible Impact Portable Pneumatic Wrench (fig. 207). The torque-type reversible impact portable pneumatic wrench operates on from 60 to 90 pounds per square inch of air pressure. The reversing mechanism is easily engaged to change the operation from clockwise to counterclockwise, and vice versa. The wrench has a ½-inch square driver which will accommodate the same equipment used with the reversible impact portable electric wrench (*b* above). A major difference between this wrench and the reversible impact portable electric wrench is the addition of an adjustable torque mechanism with which threaded fastening devices can be tightened to a predetermined degree of tightness.

233. Operation of the Portable Wrench

a. General. The operation procedures for the reversible impact portable electric wrench (par. 232*b*) and the torque-type reversible impact portable pneumatic wrench (par. 232*c*) are essentially the same. When either wrench is impacting, care must be taken not to overtighten fastening devices. Only when the torque is properly adjusted on the torque-type reversible impact portable pneumatic wrench can the wrench be left on the bolt, nut, or screw for more than a few seconds after the device seats.

b. Operation With the Socket Wrench. Install a socket wrench of the proper size to the square driver of the portable wrench. Pull the trigger and run the nut or cap screw head down until it seats. The wrench will then start impacting to tighten the screw or nut. Different size bolts or screws will affect the length of time the wrench should be operated after impacting begins. For a ⅜-inch bolt, an average of 2 or 3 seconds of impacting will tighten the bolt. If a

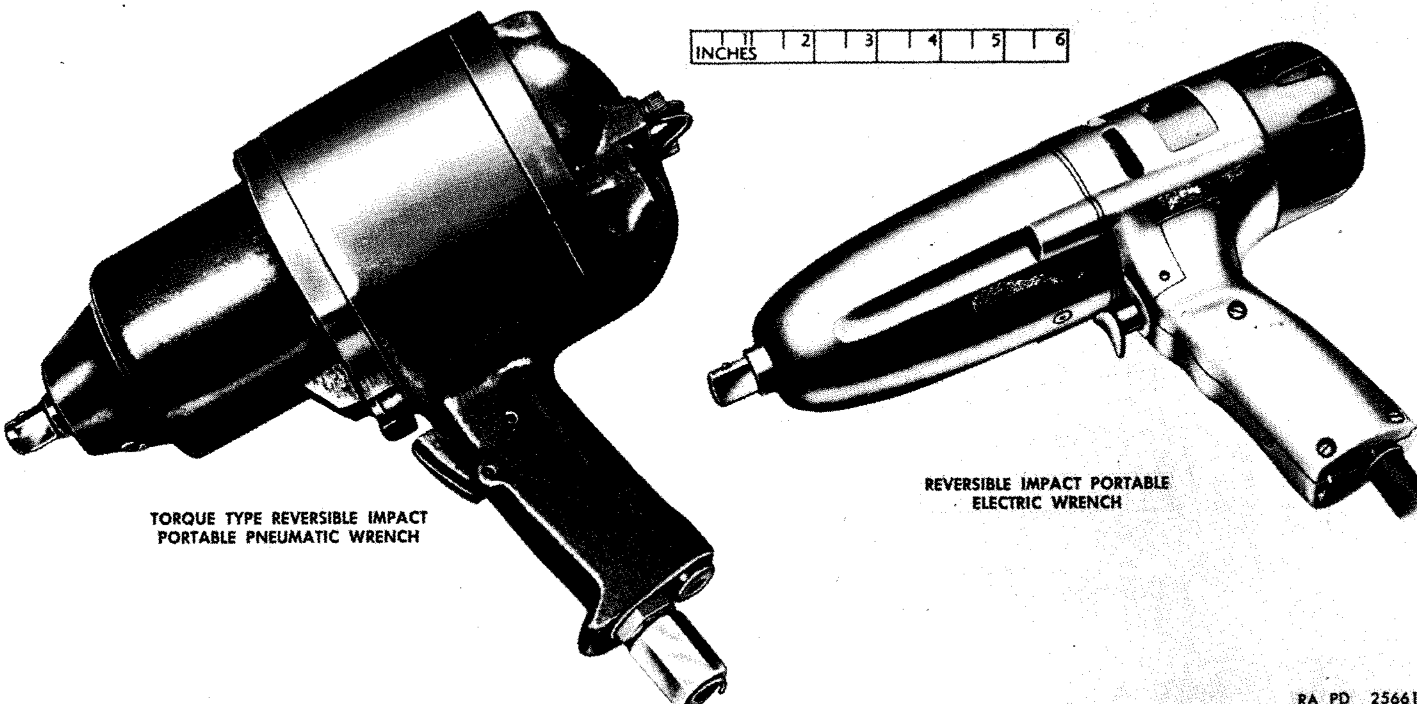


Figure 207. Portable wrenches.

lockwasher is beneath the screw head or nut, or if two plates are being drawn together by the fastening device, up to 5 seconds of impacting may be required. To loosen bolts, screws, or nuts, reverse the direction of the wrench, and let the wrench impact to loosen the device. If after 10 seconds of impacting, the screw or nut does not loosen, reverse the direction of the wrench for a few seconds, and then repeat the loosening operation. This step will most likely break any seals present, permitting loosening of the nut or screw.

c. Operation With the Screwdriver Bits. Select a slotted screwdriver bit, a cross-recess screwdriver bit, or a socket-head screwdriver bit of the proper size for the screw and mount the bit to the square driver using a bit holder. Proceed to install or remove the screw in the same manner described in *b* above. Avoid stripping of the screw, nut, or threaded hole by too much impact. Apply suitable pressure when seating slotted or cross-recess screws to prevent the bit from slipping out of the slot and chewing up the screw head.

d. Operation Using the Universal Joint and Extension Bars. The universal joint and the extension bars are provided so that wrenching and screw driving operations can be performed in inaccessible places. These pieces of equipment attach to the square driver on the wrench and have similar square drivers on their other ends so that any wrench, chuck, or driver bit that can be attached directly to the portable wrench can be similarly attached to the extension bar or universal joint. For operation, proceed as described for other operations of the portable wrenches.

e. Drilling, Reaming, and Tapping Operations With the Portable Wrench. Twist drills, reamers, taps, countersinks, and other tools can be mounted to the wrench using the taper socket for those tools having tapered shanks with tangs, and using the collet-type chuck for those tools having straight round shanks. Both the taper socket and the collet-type chuck mount to the square driver of the wrench. When using drills, reamers, taps, and similar tools, the feed pressure applied to the wrench should not be enough to cause continuous impacting.

Section VII. PORTABLE HAMMERS

234. General

The portable hammers in the Ordnance Corps are pneumatic tools which deliver a rapid series of heavy blows when energized. Two basic forms of the portable pneumatic hammer are the portable chipping pneumatic hammer (fig. 208) used to break and separate hard materials, and the portable riveting pneumatic hammer (fig. 210) used to upset metal as in riveting.

235. Portable Chipping Pneumatic Hammer

a. General. The portable chipping pneumatic hammer (fig. 208) is used for chiseling, beveling, cutting, and beading metal, for calking workpieces, and for chipping, drilling, and demolishing brick and masonry. This hammer must be used only for working with solid, hard materials. If used on soft or poorly supported materials, the hammer may be damaged and personnel in the vicinity of the hammer may be injured.

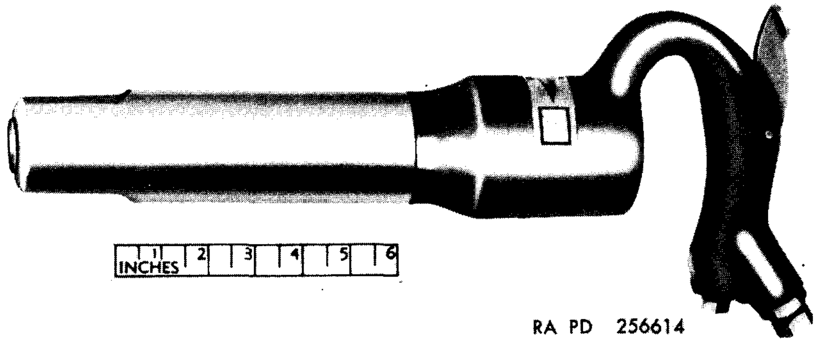


Figure 208. Portable chipping pneumatic hammer.

b. Description. The portable chipping pneumatic hammer operates on 85 to 95 pounds per square inch air pressure, and consumes 29 cubic feet of air per minute during operation. The compressed air enters a cylinder within the hammer and forces a steel piston forward. On the return stroke, the piston is cushioned by air to prevent metal-to-metal contact with the rear of the cylinder. In operation, the hammer delivers 1,480 forward strokes or blows per minute. Tools such as chisels (fig. 209), star dillls, calking tools, and beading tools fit into the hexagon-shaped nozzle of the hammer barrel. Any suitable tool having a $\frac{9}{16}$-inch hexagon shank can be used with the portable chipping pneumatic hammer. The tool fits loosely in the hexagon nozzle of the hammer and is struck by the reciprocating steel piston during operation of the hammer. The portable chipping pneumatic hammer cannot be used without a tool inserted in the nozzle.

c. Tools and Equipment. Tools and equipment for the portable chipping pneumatic hammer consist of power hammer chisels and power hammer star drills (fig. 209) having $\frac{9}{16}$-inch hexagon shanks to fit the nozzle of the hammer. The power hammer chisels are further identified by their size and shape.

(1) *Flat power hammer chisel* (fig. 209). The flat power hammer chisel is used for general purpose work and is the most common of chisel shapes. The chisel edge is slightly wider

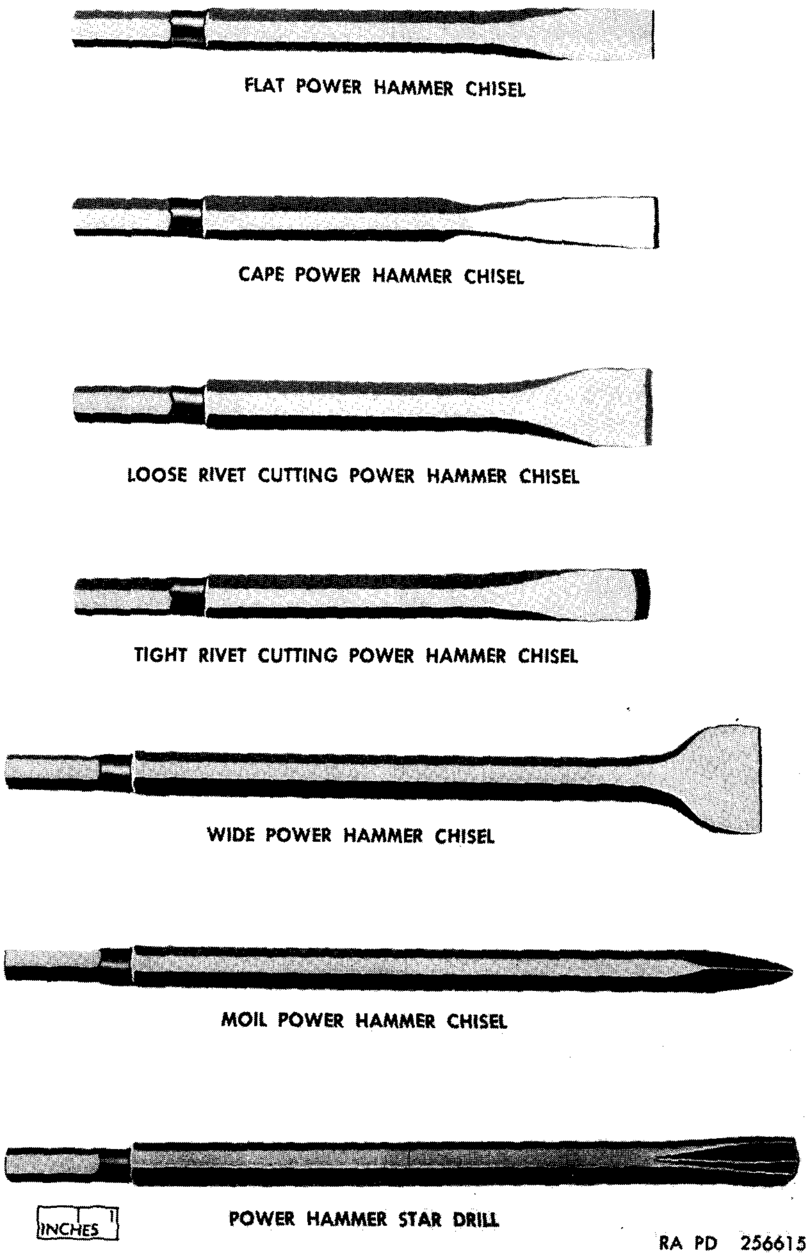


Figure 209. Power hammer chisels and star drill.

than the stock from which the chisel if forged, and the edge is usually ground to an included angle of 70°. This chisel can be used for beveling and grooving metal workpieces, for trimming edges of metal plate, and for chipping and edging of brick and masonry.

(2) *Cape power hammer chisel* (fig. 209). The cape power hammer chisel is used for cutting keyways in shafts and chipping narrow grooves and channels in metal. The chisel has a narrow cutting edge and recessed sides.

(3) *Wide power hammer chisel* (fig. 209). The wide power hammer chisel is characterized by a wide straight cutting edge. This chisel is well suited for removing scale from metal, for removing thin strips from metal, and for general surfacing operations.

(4) *Moil power hammer chisel* (fig. 209). The moil power hammer chisel is used for light demolition work on brick and masonry. It has a blunt point that breaks up the material by a wedging action.

(5) *Rivet cutting power hammer chisel* (fig. 209). The rivet cutting power hammer chisels are designed for shearing rivet heads so that the riveted pieces of metal can be separated. These chisels are made in different shapes, one for cutting loose rivets and one for cutting tight rivets.

(6) *Power hammer star drill* (fig. 209). The power hammer star drill is a four-pointed, straight-fluted chisel used to drill holes in brick, concrete, and masonry.

236. Portable Riveting Pneumatic Hammer

a. General. The portable riveting pneumatic hammer (fig. 210) is used for riveting operations accomplished by upsetting the metal rivet body to fill the hole in which the rivet is inserted and form a head on both ends of the rivet. The operation generally requires the services of two personnel, one to operate the portable riveting pneumatic hammer and one to back up the rivet to prevent its being forced out of the hole.

b. Description. The portable riveting pneumatic hammer is similar in appearance and function to the portable chipping pneumatic hammer (par. 235*b*). The hammer operates on 85 to 95 pounds per square inch air pressure to drive the reciprocating steel piston. Pneumatic rivet sets (fig. 210) having standard diameter straight shanks fit into the nozzle of the hammer. In operation, the steel piston of the portable riveting pneumatic hammer strikes the shank of the rivet set on each forward stroke to impart a blow upon the rivet in contact with the rivet set. The portable hammer is capable of driving ½-inch diameter hot rivets. Care must be taken not to operate the portable riveting pneumatic hammer without a workpiece or rivet

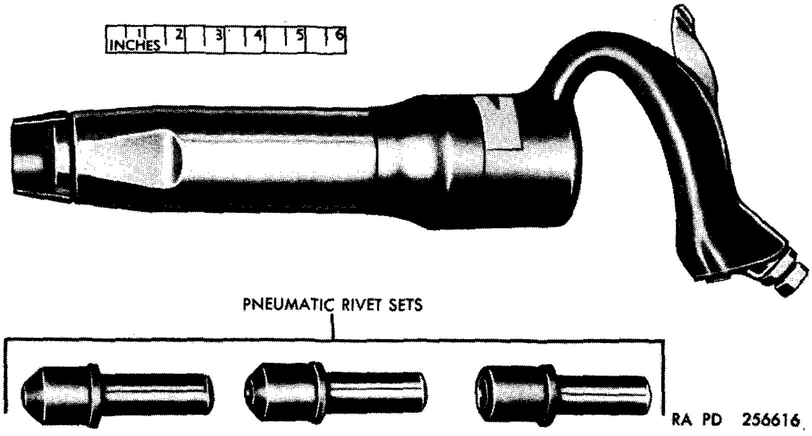


Figure 210. Portable riveting pneumatic hammer.

to bear upon, because the steel piston, traveling freely, will strike the forward end of its cylinder or bore, and may damage the hammer. Also, if the hammer is operated freely and a rivet set is positioned in the nozzle, the rivet set will be ejected from the hammer, resulting in possible injury to personnel in the area.

c. Tools and Equipment. Pneumatic rivet sets (fig. 210) are made in several shapes and sizes. The most common rivet head shape is the button-head which is similar to the shape of round-head machine screws. Pneumatic rivet sets for producing button-heads on rivets have ends recessed to form the button-head shape for one size of rivet. Different sets are required to produce this shape on other sizes of rivets, and several pneumatic rivet sets are usually available so that different size rivets can be upset using the portable riveting pneumatic hammer.

237. Portable Hammer Operation

a. General. Portable hammer operation consists of two general classes of work: chipping and related operations, and riveting. The portable hammer is operated in the same basic manner for all of these operations. The operator of the hammer and any personnel in the immediate vicinity must wear protective goggles when the hammer is operating. Tools such as chisels and rivet sets should be removed from the nozzle of the hammer immediately after use for safety. The operator should be well instructed in the use of the hammer. Both the portable chipping pneumatic hammer and the portable riveting pneumatic hammer have exhaust deflectors on the barrel that can be rotated to one of four positions. The exhaust of air pressure from the cylinder of the hammer is violent, and should be directed away from the operator by rotating the exhaust deflector using special pliers supplied with the hammer. Follow instructions in the pertinent technical manual for lubrication of the hammer immediately before and during operation. Adequate lubrication is vital for maintaining these hammers in serviceable condition.

b. Chipping Operation (fig. 211).

(1) Select a power hammer chisel or a power hammer star drill (fig. 209) suitable in shape and size for the intended operation.

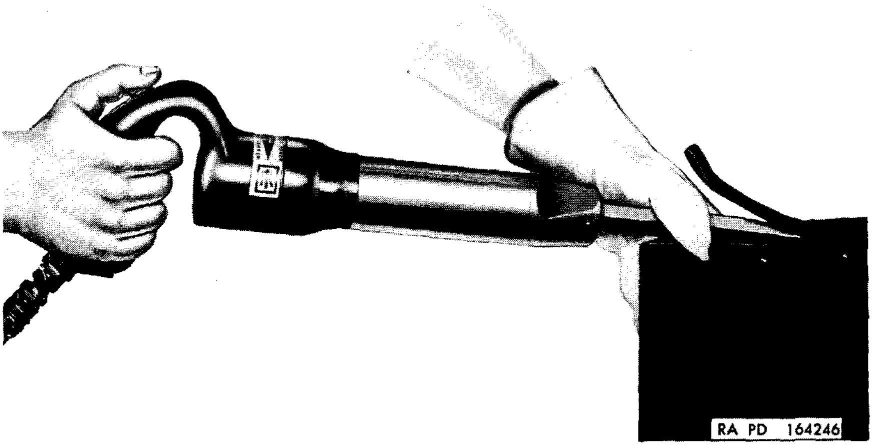


Figure 211. Operation of the portable chipping pneumatic hammer.

(2) Check the direction of the exhaust deflector. Adjust the deflector (*a* above) so that it is pointing away from the operator.

(3) Insert the chisel or star drill in the nozzle of the hammer, and position the hammer against the workpiece.

(4) Depress the throttle trigger slowly, and as the hammer starts to strike, decrease or increase the forward pressure applied to the hammer to obtain a "play off" of the hammer and chisel of $\frac{3}{8}$ to $\frac{5}{8}$ inch. To increase the "play off" distance, decrease the pressure applied to the hammer. To decrease the "play off" distance, increase the pressure applied to the hammer. If more than $\frac{5}{8}$ inch of "play off" is permitted, the steel piston of the hammer will strike the forward stop of its bore and cause damage to the hammer. Therefore, the operator must carefully control the "play off" for best results. If excessive "play off" is permitted and the piston strikes the forward stop in the bore, the operator will recognize this condition by feeling a violent shock on the hammer.

(5) When chipping or chiseling alloy steel or heavy metal workpieces, the chisel should be dipped in heavy engine oil at intervals to improve the action of the tool and keep its edge sharp.

(6) When nearing the edge of the workpiece when chipping, ease off on the throttle trigger to avoid having the chip or the chisel fly forward when the chisel breaks through. Immediately after use, remove the chisel or star drill from the hammer to prevent accidents if the hammer should be accidentally started when not in use.

c. Riveting Operation. Most riveting operations in steel are performed using hot rivets. Hot rivets upset much more easily than cold rivets, and a portable riveting pneumatic hammer capable of upsetting a ½-inch diameter rivet when hot, will be able to upset only a ¼-inch cold rivet. Before riveting, the two workpieces to be fastened together are clamped into position and the rivet holes alined. For good results, the two holes should be drilled and reamed together to a size slightly larger than the cold rivet diameter. A typical riveting operation using the portable riveting pneumatic hammer is described below.

(1) Drive or "plug" the rivet into the hole. Have the person who is to back up the rivet, hold a rivet bucking bar of suitable shape over the headed end of the rivet.

(2) Place the portable riveting pneumatic hammer with pneumatic rivet set installed over the projecting rivet body. Start the hammer slowly by lightly squeezing down on the throttle trigger. A light starting pressure will prevent bending of the rivet body to one side before a head can be formed.

(3) Maintain a great enough pressure on the hammer to upset the rivet but not so much as to make it difficult for the person backing up the rivet to hold the rivet tightly. Excessive pressure can also cause dimpling or distortion of the plates being fastened. The rivet head should form evenly after the hole has been filled by the expanding rivet metal. When a perfect head has been formed, stop riveting; the joint can be weakened by over-riveting.

(4) Tighter joints will be formed when the rivet is hot, because when the rivet cools it will contract, and this contraction will pull the riveted plates closer together and hold them tighter.

Section VIII. PROJECTILE UNIT DRIVER

238. General

The projectile unit driver (fig. 212) is, in effect, a gun from which a projectile is fired. In this case, the projectile is a fastening device used to attach wood to concrete or steel, and steel to steel. This tool must not be used to fasten lightweight or soft materials together. The projectile unit driver can be operated successfully under water.

239. Magazine-Type Powder-Actuated Projectile Unit Driver

The magazine-type powder-actuated projectile unit driver (fig. 212) uses an explosive propellent cartridge to fire a special fastener into heavy wood, steel, or concrete in the same manner used to propel a bullet. The unit driver which resembles a pistol, is hand operated and air cooled. It has a trigger-operated, spring-actuated firing pin that is cocked before firing by depressing the barrel of the unit driver against the workpiece. An adjustable shield covers the muzzle of the barrel to confine the blast and prevent fragments of the workpiece or fastener to ricochet when firing the tool. A magazine containing 10 fastener units clips onto the barrel and feeds fasteners into the chamber automatically. By withdrawing the tool quickly from the workpiece after firing, the fired cartridge case will be automatically ejected. Disks are supplied with the fasteners to retard the speed and distance of penetration of the fasteners when used on thinner and softer materials.

204. Tools and Equipment

a. General. The tools and equipment used with the magazine-type powder-actuated projectile unit driver consist of the fastener unit composed of cartridge case, sabot, and fastener (fig. 212); the disks which are used to retard the speed and penetration of the fastener; and the cocking handle which is used to facilitate cocking of the unit driver under water.

b. Fastener Unit (fig. 212). The fastener unit is composed of three sections, the cartridge case, the sabot, and the fastener. The cartridge case is a caliber .38 case specially wadded to give the desired propellent qualities to the fastener. The sabot is a tubular device that is threaded internally to accept the threaded end of the fastener, and has an external groove to which the cartridge case is crimped. The sabot has two purposes: to secure the cartridge case to the fastener, and to contact the walls of the barrel and carry the fastener through the barrel in a straight line when fired. The fastener has a pointed nose, a coarsely knurled body, and a threaded rear section. The knurled body grips and holds when the fastener is fired into wood, steel, and concrete.

c. Disk (fig. 212). The disk is a washer-like piece of metal approximately 3/16 inch thick and 5/8 inch in diameter. The disk is placed in the muzzle of the magazine-type-powder-actuated projectile unit driver when the material being fastened requires retarding of the fastener. When fired, the fastener enters the hole in the disk and is slowed down by the additional resistance of the disk. The disk need not be used when fastening into steel plate 3/8 inch thick or over, or solid concrete. It should be used whenever fastening into wood of any thickness, concrete or cinder block, and steel plate less than ⅜ inch thick. If in doubt about whether to use a disk or not, use the disk. If the knurled section of the fastener grips into the workpiece in this case, the disk should be used for successive fastenings. If the knurled section of the fastener does not pass through the disk, do not use the disk for successive fastenings. Ten disks are held in a spring dispenser in the tool handle where they can be easily removed one by one.

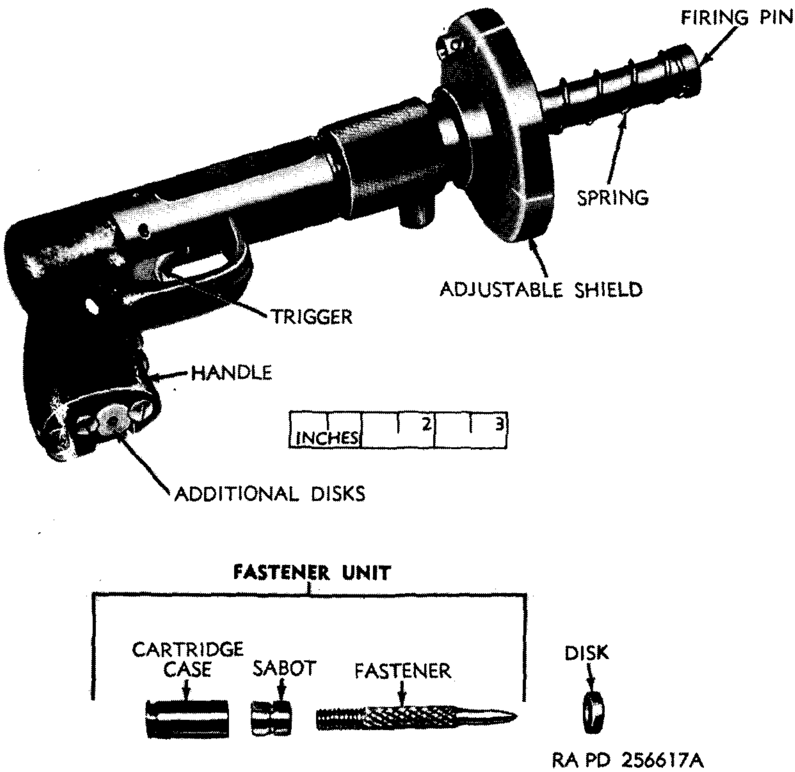


Figure 212. Magazine-type powder-actuated projectile unit driver and fastener unit.

d. Cocking Handle. The cocking handle is a threaded shaft with a knob on one end. It is inserted into a hole at the rear of the driver unit in place of the firing pin indicator plug and is threaded into a hole in the firing pin. The cocking handle is drawn to the rear to cock the firing pin. The cocking handle should be used only for underwater operation, and is supplied for this purpose because of the difficulty experienced in applying suitable pressure against the unit driver while underwater to cock the firing pin in the normal manner.

241. Fastening Operation

***Caution:* The magazine-type powder-actuated projectile unit driver is a dangerous tool when handled carelessly. The same precautions taken when handling a loaded pistol should be observed with this tool.**

a. Preparation for Operation.

(1) Load the ten-round magazines with fastener units (fig. 212). Make sure that all fastener units are inserted in the same direction and that the extraction grooves on the cartridge cases are engaged by the cartridge groove rib in the magazine.

(2) Load the disk dispenser with disks by inserting them one by one into the hole at the bottom of the tool handle (fig. 212).

(3) Adjust the shield to the full-shield or half-shield position as dictated by the nature of the operation. Whenever possible, the shield should be used in the full-shield position as this position offers more protection from ricochet and powder blast. The shield is opened by loosening a lock screw on its rear surface which permits rotating of the inner shield half.

(4) Lay out the positions for the fasteners on the workpieces by marking or scribing perpendicular lines that intersect at the desired point for the fastener.

b. Operation.

(1) Pointing the muzzle of the unit driver away from the body and any other personnel in sight, load a magazine into the slot at the side of the tool. Fully seat the magazine by pressing inward until the magazine lock clicks.

(2) Insert a disk into the muzzle if a disk is required (par. 240*c*) or if the need of a disk is in doubt. Hold one hand securely around the barrel while inserting the disk in the barrel to prevent the barrel from moving back into the housing. Do not move the hand or head over the muzzle while inserting the disk.

(3) Locate the barrel over the fastening point. Do not squeeze the trigger.

(4) Depress the tool squarely and tightly against the workpiece surface. The intersecting lines drawn or scribed on the surface should coincide with the four scribed marks on the shield for accurate centering. With the tool fully depressed, pull the trigger to fire the fastener.

(5) After firing, quickly withdraw the magazine-type powder-actuated projectile unit driver from the workpiece surface. This will cause the fired cartridge case to be automatically ejected from the tool.

c. After Operation. To insure safe handling after operation, the magazine-type powder-actuated projectile unit driver should be unloaded and inspected. The unit driver should be cleaned after use in the same manner as prescribed for cleaning pistols after firing.

Section IX. PORTABLE METAL CUTTING SHEARS

242. General

The portable metal cutting shears (fig. 213) are a power-operated tool used to cut through sheet metal by controlled stressing of the metal to cause it to break along a desired line. An upper, movable shear blade is caused to reciprocate rapidly over a lower, fixed shear blade so that a continuous shearing action is obtained as the portable metal cutting shears are moved through the metal.

243. Portable Electric Metal Cutting Shears

The portable electric metal cutting shears (fig. 213) are powered by a universal-type (ac/dc) electric motor to drive the movable shear blade up and down at a working speed of 1,500 to 2,000 strokes per minute. These shears are capable of cutting through 18 gage sheet steel or 20 gage cold rolled steel, monel metal, or stainless steel. Fifty percent thicker sheets of copper, aluminum, lead, and other soft materials can also be cut successfully with the portable electric metal cutting shears. The shear blade clearance is easily adjusted so that optimum clearance can be obtained for each type and thickness of

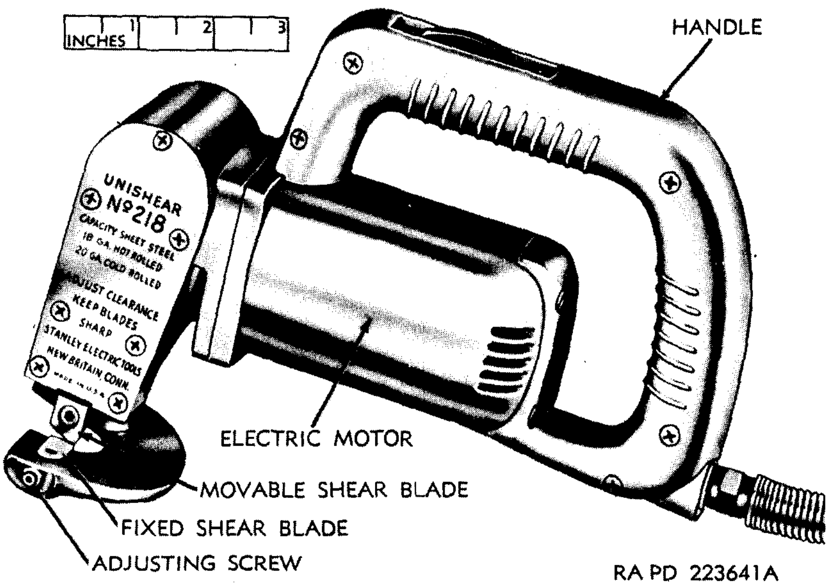


Figure 213. Portable electric metal cutting shears.

metal. A straight line or an irregular pattern layed out on the sheet metal can be followed easily with the shears.

244. Portable Metal Cutting Shear Operation

a. General. Successful operation of the portable electric metal cutting shears depends upon two major factors: sharp shear blades and correct blade clearance. The shear blades of the portable electric metal cutting shears are easily removed so that they may be taken off for sharpening, and may be easily replaced when they become unserviceable.

b. Sharpening Shear Blades. The shear blades should be ground only on the bottom or top edges never on the side surfaces. When grinding the edges, keep the same angle present on new blades since this angle was determined by the manufacturer of the shears to produce best shearing qualities for the particular tool. When properly ground, the cutting edge should be sharp and not rough or burred. Stone the edges after grinding to remove any burs caused by grinding. If either or both shear blades become badly nicked or defaced, replace either or both shear blades.

c. Blade Clearance Adjustment. Proper shear blade clearance is equal to one-twentieth the metal thickness for mild steel and one-sixteenth the metal thickness for hard steels. The fixed shear blade (fig. 213) of the portable electric metal cutting shears may be moved laterally closer to or away from the movable shear blade by means of an adjusting screw on the shoe. If the metal being cut twists or jams between the blades, the blade clearance is most likely excessive. If the shears bind or stall when cutting through the metal, or if the blades tend to double shear and produce a burred edge, the blade clearance is probably too small.

d. Shearing Operation. A scribed or marked line should be layed out on the sheet metal before shearing. Holding the portable electric metal cutting shears in one hand, start cutting from the edge of the sheet metal, keeping the scribed line alongside the reciprocating upper shear blade. Only a light forward pressure is required to guide the shears through the metal. Irregular contours can be followed easily and closely because the upper blade is always visible to the operator. If the shear blades should bind and stop in the metal, stop the shears and withdraw them from the spot of binding. Investigate the cause of binding which will most likely be either incorrect blade clearance or dull shear blades.

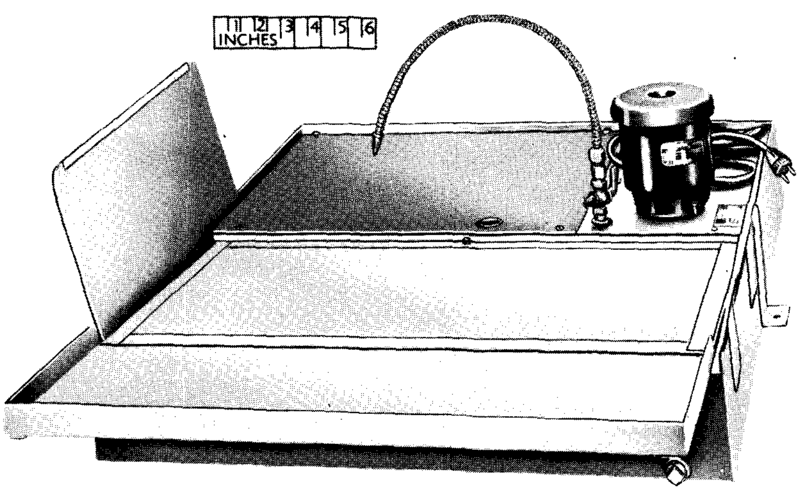
Section X. PORTABLE COOLANT ATTACHMENT

245. General

The portable coolant attachment (fig. 214) is a device for supplying coolants and cutting oils for cutting operations with machine tools when continuous application of a coolant or cutting oil is desired. The portable coolant attachment consists of a container to hold the coolant or cutting oil, a pump to force the coolant through a flexible hose directed at the cutting tool and workpiece, and a pan arrangement beneath the machine tool to catch the coolant or cutting oil, filter it, and return it to the container.

246. Portable Coolant Attachment

The portable coolant attachment (fig. 214) is designed to provide automatic application of a coolant or cutting oil to grinding machines, lathes, milling machines, drilling machines, sawing machines, and miscellaneous machine tools when particular operations require the use of a coolant or cutting oil and the machine tool is not equipped with a built-in attachment. The portable coolant attachment is self contained, powered by an electric motor. The coolant container and pans are attached to the bed or frame of the machine tool beneath the work area, and a flexible metal hose is positioned where the stream of coolant or cutting oil from the pump will flood the workpiece and cutting tool at their point of contact. A valve at the base of the flexible hose controls the flow of the coolant. The pans beneath the workpiece catch the coolant as it splashes from the workpiece, and strain the coolant as it flows back to the container for recirculation. A pipe plug is provided at the base of the container for draining of the coolant or cutting oil after use. The portable coolant attachment will serve the needs of a machine shop containing several different types of machine tools, since it can be moved from one machine tool to another as the need arises. The size of the container and pans



RA PD 256618

Figure 214. Portable coolant attachment.

positioned for operation is approximately 24 inches long, 25 inches wide, and 4 inches high.

247. Operation of the Portable Coolant Attachment

a. The portable coolant attachment should be set up on the bed or frame of the machine tool in a horizontal position where the flexible metal hose can conveniently reach the work area of the machine tool. The pans should be arranged to catch all of the coolant as it splashes and drips from the workpiece.

b. Fill the container of the portable coolant attachment with coolant or cutting oil. The coolant or cutting oil mixture should be selected in accordance with the tables of recommended coolants and cutting oils for each machine tool and material (pars. 34, 50, 79, and 115).

c. Position the flexible hose so that it directs a stream of coolant to the point of contact between the cutting tool and the workpiece. If the cutting tool moves along the workpiece, clip the hose end to the cutting tool carriage so that the hose will move with the tool.

d. Start the pump motor of the portable coolant attachment before starting the machine tool. Adjust the stream of coolant so that the desired intensity of flow is obtained.

e. Start the machine tool and perform the desired machining operation. At the conclusion of the operation, stop the pump motor of the portable coolant attachment. Drain the coolant or cutting oil from the container by removing the pipe plug near the bottom of the container. Clean out the container, pump, and hose before using a different cutting oil or coolant in the attachment.

APPENDIX
REFERENCES

1. Publication Indexes

The following indexes should be consulted frequently for latest changes or revisions of references given in this appendix and for new publications relating to materiel covered in this manual.

Index of Army Motion Pictures, Film Strips, Slides, and Phono-Recordings	DA Pam 108-1
Index of Administrative Publications	DA Pam 310-1
Index of Blank Forms	DA Pam 310-2
Index of Graphic Training Aids and Devices	DA Pam 310-5
Index of Supply Manuals—Ordnance Corps	DA Pam 310-29
Index of Technical Manuals, Technical Bulletins, Supply Bulletins, Lubrication Orders, and Modification Work Orders	DA Pam 310-4
Index of Training Publications	DA Pam 310-3

2. Supply Manuals

Abrasives, Adhesives, Cleaners, Preservatives, Recoil Fluids, Special Oils, and Related Items	ORD 3 SNL K-1
Common Hand Tools	ORD 3 SNL J-17
FSC Group 34 Metalworking Machinery	SM 9-5-3413, 15, 16, 17, 19, 55, 60, 70
FSC Group 34 Metalworking Machinery	SM 9-5-3424, 32, 41, 44, 45, 46
FSC Group 51 Hand Tools	SM 9-5-5100
Tool Set, General Mechanic's (41-T-3534-30)	ORD 6 SNL J-10, Section 4
Tool Set, Machinist's	ORD 6 SNL J-10, Section 9

3. Other Publications

Logistics (General): Unsatisfactory Equipment Report	AR 700-38
Military Symbols	FM 21-30 AFM 55-3
Military Terms, Abbreviations, and Symbols:	
Authorized Abbreviations	AR 320-50
Dictionary of United States Army Terms	AR 320-5
Military Training	FM 21-5
Safety: Accident Reporting	SR 385-40
Techniques of Military Instruction	FM 21-6

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[AG 413.1 (20 Oct 58)]

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USAR: None.

For explanation of abbreviations used, see AR 320–50.

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