CHAPTER 10

PRECISION GRINDING MACHINES

CHAPTER LEARNING OBJECTIVES

Upon completing this chapter, you should be able to do the following:

- *Describe speeds, feeds, and coolants used while grinding.*
- *Describe and explain the use of surface grinders.*
- *Describe and explain the use of cylindrical grinders.*
- *Describe and explain the use of tool and cutter grinders.*

Modern grinding machines are versatile and are used to perform work of extreme accuracy. They are used primarily to finish surfaces that have been machined in other machine tool operations. Surface grinders, cylindrical grinders, and tool and cutter grinders can perform practically all of the grinding operations required in Navy repair work.

To perform these operations, you must know the construction and principles of operation of commonly used grinding machines. You gain proficiency in grinding through practical experience. Therefore, you should take every opportunity to watch or perform grinding operations from setup to completion.

There are several classes of each type of grinder. The **SURFACE** grinder may have either a rotary or a reciprocating table and either a horizontal or a vertical spindle. **CYLINDRICAL** grinders may be classified as plain, centerless, or internal grinders; the **TOOL AND CUTTER** grinder is basically a cylindrical grinder. Those generally found in Navy machine shops are the reciprocating table grinder, the horizontal spindle (planer type) surface grinder, the plain cylindrical grinder, and the tool and cutter grinder. Shops also may have a universal grinder, which is similar to a tool and cutter grinder except that it is designed for heavier work and usually has a power feed system and a coolant system.

Before operating a grinding machine, you must understand the underlying principles of grinding and the purpose and operation of the various controls and parts of the machine. You also must know how to set up the work in the machine. The setup procedures will vary with the different models and types of machines. Study the manufacturer’s technical manual to learn specific procedures for a particular model of machine.

As with any shop equipment you must observe all posted safety precautions. Review your equipment operators manual for safety precautions and any chapters of *Navy Occupational Safety and Health (NAVOSH) Program Manual for Forces Afloat,* OPNAV Instruction 5100.19B, that apply to the equipment.

GRAIN DEPTH OF CUT

On most ships, stowage space is limited. Consequently, the inventory of grinding wheels must be kept to a minimum. It would be impractical and unnecessary to keep on hand a wheel for every grinding job. With a knowledge of the theory of grain depth of cut you can vary the cutting action of the various wheels and with a small inventory can perform practically any grinding operation that may be necessary.

For ease in understanding this theory, assume that a grinding wheel has a single grain. When the grain reaches the point of contact with the work, the depth of cut is zero. As the wheel and the work revolve, the grain begins cutting into the work, increasing its depth of cut until it reaches a maximum depth at some point along the arc of contact. This greatest depth is called the grain depth of cut.

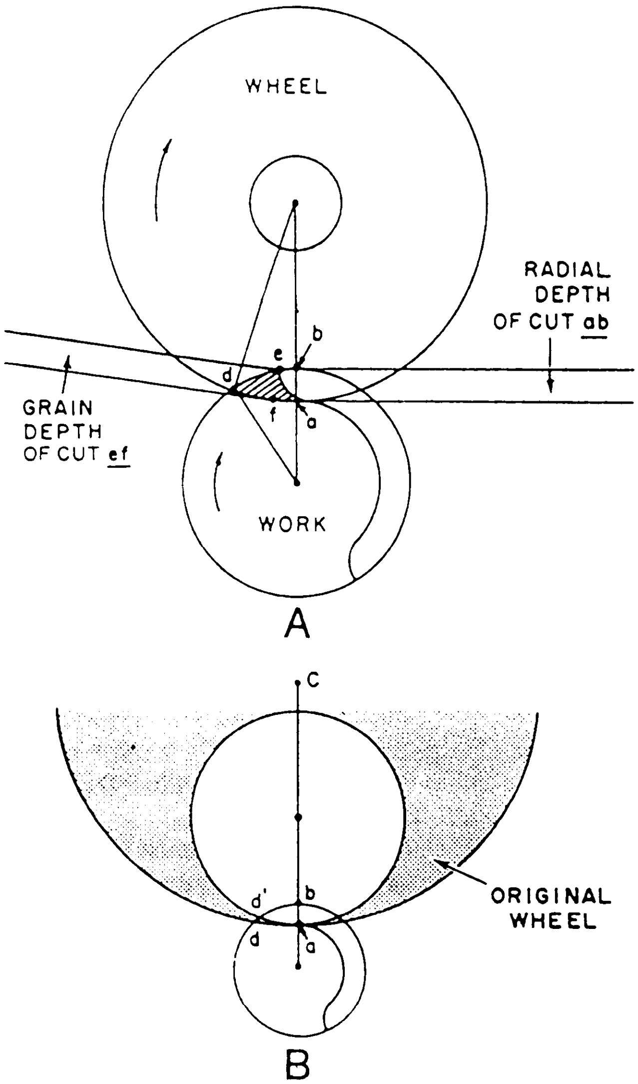

Figure 10-1.—Grain depth of cut; center-type machine.

To understand what part grain depth of cut plays in grinding, look at figure 10-1. View **A** illustrates a grinding wheel and a workpiece; ab is the radial depth of cut, ad is the arc of contact, and ef is the grain depth of cut. As the wheel rotates, the grain moves from the point of contact a to d in a given amount of time. During the same time, a point on the workpiece rotates from d to e, at a slower speed than that of the wheel. During this time the grain will remove an amount of material represented by the shaded area ade. Now refer to view **B** and assume that the wheel has worn down to a much smaller size, while the wheel and work speeds remain unchanged. The arc of contact ad' of the smaller wheel is shorter than the arc of contact ad of the original (larger) wheel. Since the width of the grains remains the same, decreasing the length of the arc of contact will decrease the surface (area = length × width) that a grain on the smaller wheel covers in the same time as a grain on the larger wheel. If the depth that each grain cuts into the workpiece remains the same, the grain on the smaller wheel will remove a smaller volume (volume = length × width × depth) of material in the same time as the grain on the larger wheel. However, for both grains to provide the same cutting action, they both have to remove the same volume of material in the same length of time. To make the volume of material the grain on the smaller wheel removes equal to that of the grain on the larger wheel, you have to either make the grain on the smaller wheel cut deeper into the workpiece or cover a larger workpiece surface area at its original depth of cut.

To make the grain cut deeper, you must increase the feed pressure on the grain. This increase of feed pressure will cause the grain to be torn from the wheel sooner, making the wheel act like a softer wheel. Thus, the grain depth of cut theory says that as a grinding wheel gets smaller, it will cut like a softer wheel because of the increase in feed pressure required to maintain its cutting action.

The opposite is true if the wheel diameter increases. For example, if you replace a wheel that is too small with a larger wheel, you must decrease feed pressure to maintain the same cutting action.

The other previously mentioned way to make a grain on a smaller wheel remove the same amount of material as a grain on a larger wheel is to keep the depth of cut the same (no increase in feed pressure) while you increase the surface area the grain contacts. Increasing the surface area requires lengthening the contact area, since the width remains the same. To lengthen the contact area, you can either speed up the workpiece rotation or slow down the wheel rotation. Either of these actions will cause a longer surface strip of the workpiece to come in contact with the grain on the wheel, thereby increasing the volume of material removed.

As mentioned earlier, the opposite is true if you increase the wheel diameter. To keep from removing a larger volume of material, you must decrease the surface of the workpiece with which the grain comes into contact. You can do this by either slowing down the workpiece rotation or speeding up the wheel rotation.

Keep in mind that all of these actions are based on the grain depth of cut theory. That is, making adjustments to the grinding procedure to make one wheel cut like another. The following summary shows the actions you can take to make a wheel act a certain way:

MAKE THE WHEEL ACT SOFTER (INCREASE THE GRAIN DEPTH OF CUT)

Increase the work speed.

Decrease the wheel speed.

Reduce the diameter of the wheel and increase feed pressure.

MAKE THE WHEEL ACT HARDER (DECREASE THE GRAIN DEPTH OF CUT)

Decrease the work speed.

Increase the wheel speed.

Increase the diameter of the wheel and decrease feed pressure.

SPEEDS, FEEDS, AND COOLANTS

As with other machine tools, the selection of the proper speed, feed, and depth of cut is an important factor in grinding. Also, coolants may be necessary for some operations. The definitions of the terms *speed, feed,* and *depth of cut,* as applied to grinding, are basically the same as those in other machining operations.

WHEEL SPEED, unless otherwise defined, means the surface speed of the grinding wheel in fpm. TRAVERSE (longitudinal or cross) is the rate that the work is moved across the working face of the grinding wheel. FEED is the depth of cut the wheel takes in each pass across the work. We'll explain each of these in the next paragraphs

WHEEL SPEED

Grinding wheel speeds commonly used in precision grinding vary from 5,500 to 9,500 fpm. You can change wheel speed by changing the spindle speed or by using a larger or smaller wheel. To find the wheel speed in fpm, multiply the spindle speed (rpm) by the wheel circumference (inches) and divide the product by 12.

$$fpm = \frac{(cir. \times rpm)}{12}$$

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

The maximum speed listed on a grinding wheel is not necessarily the speed at which it will cut best. The manufacturer decides the maximum speed based on the strength of the wheel. That speed provides a margin of safety and the wheel usually will cut better at a lower speed.

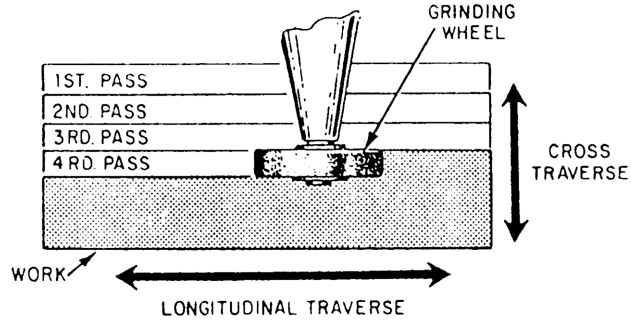

Figure 10-2.—Surface grinding a flat workpiece.

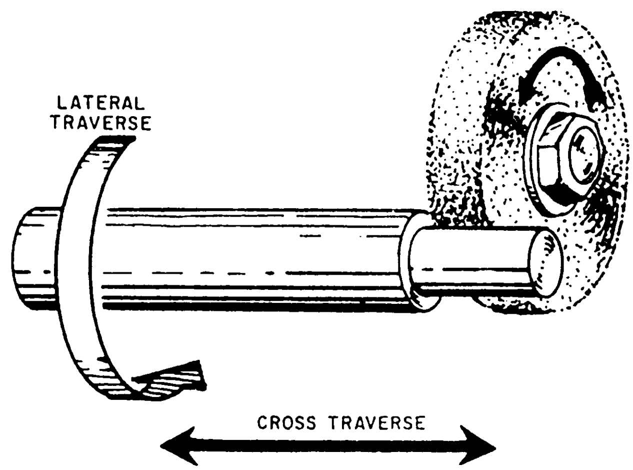

Figure 10-3.—Surface grinding a cylindrical workpiece.

One method used to determine the proper wheel speed is to set the speed between the minimum and maximum recommended by the manufacturer. Take a trial cut. If the wheel acts too soft, increase the speed. If it acts too hard, decrease the speed.

TRAVERSE (WORK SPEED)

During the surface grinding process, the work moves in two directions. As a flat workpiece is being ground (fig. 10-2), it moves under the grinding wheel from left to right (longitudinal traverse). This longitudinal speed is called work speed. The work also moves gradually from front to rear (cross traverse), but this movement occurs at the end of each stroke and does not affect the work speed. We'll explain how to set cross traverse later in this chapter.

You should grind a cylindrical workpiece in a manner similar to the finishing process used on a lathe (fig. 10-3). As the surface of the cylinder rotates under the grinding wheel (lateral traverse), the work moves from left to right (cross traverse).

To select the proper work speed, take a cut with the work speed set at 50 fpm. If the wheel acts too soft, decrease the work speed. If the wheel acts too hard, increase the work speed.

Wheel speed and work speed are closely related. Usually, you can adjust one or both to get the most suitable combination.

DEPTH OF CUT

The depth of cut depends on such factors as the material from which the work is made, heat treatment, wheel and work speed, and condition of the machine. Roughing cuts should be as heavy as the machine can take; finishing cuts are usually 0.0005 inch or less. For rough grinding, you might use a 0.003-inch depth of cut as a trial. Then, adjust the machine until you get the best cutting action.

COOLANTS

The cutting fluids used in grinding operations are the same as hose used in other machine tool operations. Synthetic coolants are the best, but you also may use a mixture of soluble oil and water. As in most machining operations, the coolant helps to maintain a uniform temperature between the tool and the work to prevent extreme localized heating. Excessive heat will damage the edges of cutters, cause warpage, and may cause inaccurate measurements.

In other machine tool operations, the chips will fall aside and present no great problem; this is not true in grinding work. If you have no way to remove chips, they can become embedded in the face of the wheel. This embedding, or loading, will cause unsatisfactory grinding and you will need to dress the wheel frequently. A sufficient volume of cutting fluid will help prevent loading. The fluid also helps to reduce friction between the wheel and the work and to produce a good finish. When you select a cutting fluid for a grinding operation, it should have the following characteristics:

- Have a high cooling capacity to reduce cutting temperature
- Prevent chips from sticking to the work
- Be suitable for a variety of machine operations on different materials, reducing the number of cutting fluids needed in the shop
- Have long life and not emit obnoxious odors or vapors harmful to personnel

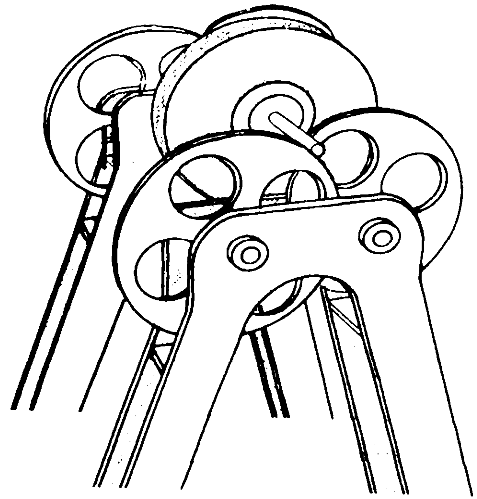

Figure 10-4.—Overlapping disk balancing ways (roller type).

- Not cause rust or corrosion
- Have a low viscosity to permit gravity separation of impurities and chips as it is circulated in the cooling system
- Not oxidize or form gummy deposits that will clog the circulating system
- Be transparent, allowing a clear view of the work
- Be safe, particularly in regard to fire and accident hazards
- Not cause skin irritation

The principles discussed above are basic to precision grinding machines. Keep them in mind as you study about the machines in the remainder of this chapter.

WHEEL BALANCING

You may need to balance wheels larger than 14 inches, but usually not smaller ones. A wheel that is slightly out of balance may cause chatter marks in the workpiece finish. One that is drastically out of balance may damage the grinder or fly apart and injure the operator.

You should balance grinding wheels on either the overlapping disk balancing ways (roller type) (fig. 10-4) or on parallel ways (knife edge) (fig. 10-5). Set these stands as level as possible, mount the wheel on a balancing arbor, and place it on the rollers or ways. The heavy side will rotate to the lowest position. Adjust

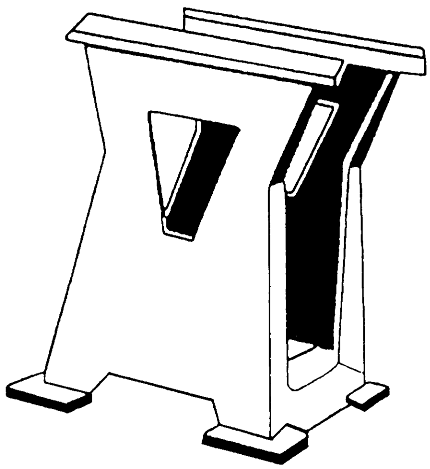

Figure 10-5.—Parallel ways (knife edge).

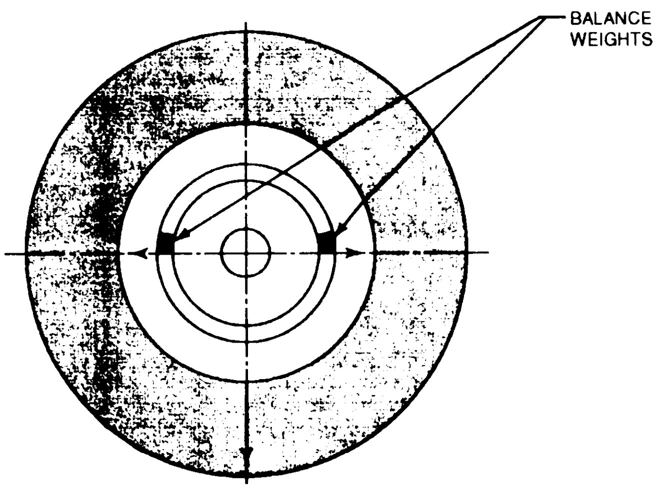

Figure 10-6.—Balance weights.

weights in the flanges (fig. 10-6) to get the correct balance.

SURFACE GRINDER

Most of the features shown in figure 10-7 are common to all planer-type surface grinders. The basic components of this machine are a base, a cross traverse table, a sliding worktable, and a wheelhead. Various controls and handwheels control the movement of the machine during the grinding operation.

The base is a heavy casting that houses the wheelhead motor, the hydraulic power feed unit, and the coolant system. Use the ways on top of the base to mount the cross traverse table. Use the vertical ways on the back of the base to mount the wheelhead unit.

The hydraulic power unit includes a motor, a pump, and piping. These provide hydraulic pressure to the power feed mechanisms on the cross traverse and

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Figure 10-7.—Surface grinder (planer type).

sliding tables. This smooth, direct power is very advantageous in grinding. The piping from this unit is usually connected to power cylinders under the traverse table. When the machine is operating automatically, control valves divert pressurized hydraulic fluid to the proper cylinder, causing the table to move in the desired direction. Suitable bypass and control valves in the hydraulic system let you stop the traverse table in any position and regulate the speed of movement of the table within limits. These valves provide a constant pressure in the hydraulic system, allowing you to stop the feed without securing the system.

CROSS TRAVERSE TABLE

The cross traverse table is mounted on ways that are parallel to the spindle of the wheelhead unit. This allows the entire width of the workpiece to be traversed under the grinding wheel.

A piston in a power cylinder is fastened to the cross traverse table to provide power feed. A handwheel attached to a feed screw provides manual feed. The thickness (width) of the grinding wheel determines the amount of cross traverse feed per stroke of the reciprocating sliding table. During roughing cuts, the work should traverse slightly less than the thickness of the wheel each time it passes under the wheel. For finish cuts, decrease the rate until you obtain the desired finish. When you engage the power feed mechanism, the cross traverse table feeds only at each end of the stroke of the

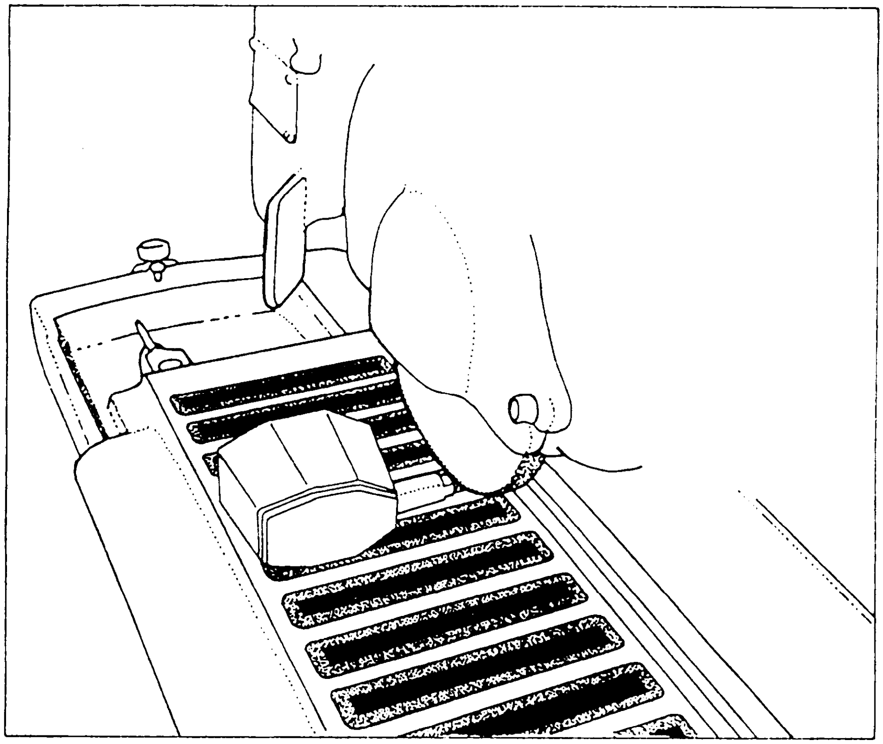

Figure 10-8.—Magnetic chuck used for holding a tool grinding fixture.

sliding table (discussed in the next paragraphs). The grinding wheel clears the ends of the workpiece before cross-feed is made; this decreases side thrust on the grinding wheel and prevents a poor surface finish on the ends of the workpiece.

Grinding machines in shipboard shops usually have 12 inches or less of cross traverse. It isn't necessary to traverse the full limit for each job. To limit the cross traverse to the width of the work being ground, use the adjustable cross traverse stop dogs that actuate the power cross traverse control valves.

SLIDING TABLE

The sliding table is mounted on ways on the top of the cross traverse table. Recall that the sliding table moves from left to right, carrying the workpiece under the grinding wheel.

The top of the sliding table has T-slots machined in it so you can clamp work or workholding devices like magnetic chucks or vises onto the table. You can traverse the sliding table manually or by power.

The power feed of the table is similar to that of the cross traverse table. During manual traverse, a pinion turned by a handwheel engages a rack attached to the bottom of the sliding table.

During manual operation of the sliding table, table stop dogs limit the length of stroke. When power feed is used, table reverse dogs reverse the direction of movement of the table at each end of the stroke. The reverse dogs actuate the control valve to shift the hydraulic feed pressure from one end of the power cylinder to the other.

You can usually adjust the speed (fpm) of the sliding table within a wide range to give the most suitable speed.

WHEELHEAD

The wheelhead carries the motor-driven grinding wheel spindle. You can adjust the wheelhead vertically to feed the grinding wheel into the work by turning a lead screw type of mechanism similar to that used on the cross traverse table. A graduated collar on the handwhcel lets you keep track of the depth of cut.

The wheelhead movement is not usually power fed because the depth of cut is quite small and you need large movement only to set up the machine. The adjusting mechanism is quite sensitive; you can adjust the depth of cut in amounts as small as 0.0001 inch.

WORKHOLDING DEVICES

In most surface grinding operations, you will use one of two workholding devices, either a magnetic

chuck or a universal vise. We will discuss each of them in the next paragraphs.

Magnetic Chucks

Since most surface grinding is done on flat workpieces, most surface grinders have magnetic chucks. These chucks are simple to use. You can mount the work directly on the chuck or on angle plates, parallels, or other devices mounted on the chuck You cannot hold nonmagnetic materials in a chuck unless you use special setups.

The top of a magnetic chuck (see fig. 10-8) is a series of magnetic poles separated by nonmagnetic materials. The magnetism of the chuck may be induced by permanent magnets or by electricity. In a permanent-type magnetic chuck, the chuck control lever positions a series of small magnets inside the chuck to hold the work In an electromagnetic chuck, electric current induces magnetism in the chuck; the control lever is an electric switch. For either chuck, work will not remain in place unless it contacts at least two poles of the chuck.

Work held in a magnetic chuck may become magnetized during the grinding operation. This is not usually desirable and the work should be demagnetized. Most modern magnetic chucks are equipped with demagnetizers.

A magnetic chuck will become worn and scratched after repeated use and will not produce the accurate results normally required of a grinder. You can remove small burrs by hand stoning with a fine grade oilstone. But, you must regrind the chuck to remove deep scratches and low spots caused by wear. If you remove the chuck from the grinder, be sure to regrind the chuck table when you replace the chuck to make sure the table is parallel with the grinder table. To grind the table, use a soft grade wheel with a grit size of about 46. Feed the chuck slowly with a depth of cut that does not exceed 0.002 inch. Use enough coolant to help reduce heat and flush away the grinding chips.

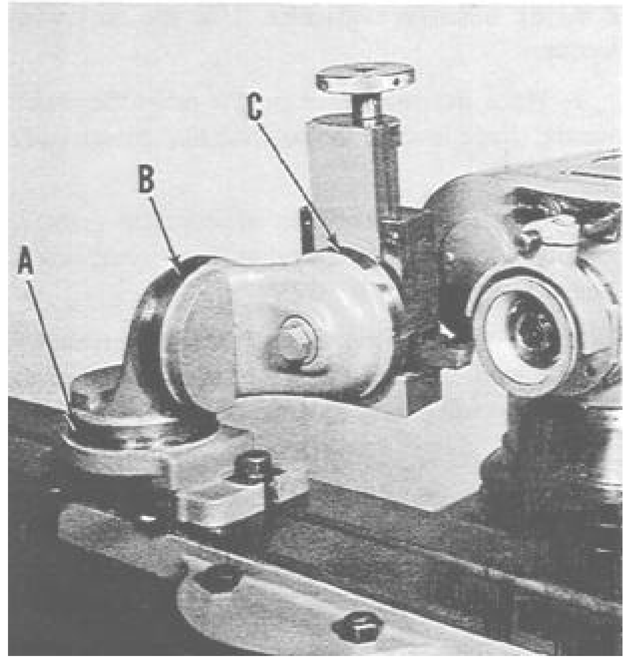

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Figure 10-9.—Universal vise (mounted on a tool and cutter grinder). A. Base swivel. B. Intermediate swivel. C. Vise swivel.

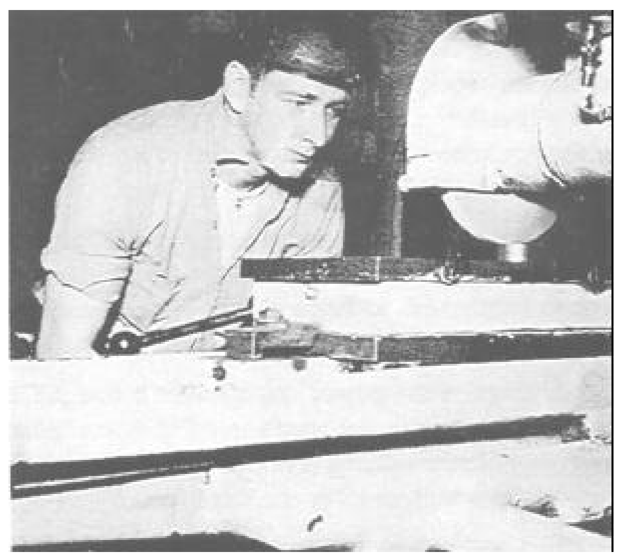

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Figure 10-10.—Grinding a spacer on a surface grinder.

Universal Vise

You will usually use the universal vise (fig. 10-9) when you need to grind complex angles on a workpiece. You can mount the vise directly on the worktable of the grinder or on the magnetic chuck.

You can use the universal vise to set up work, such as lathe tools, so you can position the surface to be ground at any angle. The swivels rotate through 360°. You can rotate the base swivel (A, fig. 10-9) in a horizontal plane; the intermediate swivel (B, fig. 10-9) in a vertical plane; and the vise swivel (C, fig. 10-9) in either a vertical or a horizontal plane, depending on the position of the intermediate swivel.

SURFACE GRINDER OPERATION

We will use a hardened steel spacer similar to the one shown in figure 10-10 as an example of work you

can do on a surface grinder. Use the following procedures:

1. Place the workpiece on the magnetic chuck. Move the chuck lever to the position that energizes the magnetic field.

2. Select and mount an appropriate grinding wheel. This job requires a straight-type wheel with a designation similar to A60F12V.

3. Set the table stop dogs so the sliding table will move the work clear of the wheel at each end of the stroke. If you use power traverse, set the table reverse dogs.

4. Set the longitudinal traverse speed of the worktable. To rough grind hardened steel, use a speed of about 25 fpm; to finish the piece, use 40 fpm.

5. Set the cross traverse mechanism so the table moves under the wheel a distance slightly less than the width of the wheel after each pass. (Refer to the manufacturer's technical manual for specific procedures for steps 4 and 5.)

6. Start the spindle motor, let the machine run for a few minutes, and then dress the wheel.

7. Feed the moving wheel down until it just touches the work surface; then use the manual cross traverse handwheel to move the work clear of the wheel. Set the graduated feed collar on zero to keep track of how much you feed the wheel into the work.

8. Feed the wheel down about 0.002 inch and engage the longitudinal power traverse. Use the cross traverse handwheel to bring the grinding wheel into contact with the edge of the workpiece.

9. Engage the power cross traverse and let the wheel grind across the surface of the workpiece. Carefully note the cutting action to decide if you need to adjust the wheel speed or the work speed.

10. Stop the longitudinal and cross traverses and check the workpiece.

Figure 10-9 shows a universal vise being used on a tool and cutter grinder to grind a lathe tool bit. For this job, set the base swivel (A) to the required side cutting edge angle, the intermediate swivel (B) to the side clearance angle, and the vise swivel (C) so the vise jaws are parallel to the table. Then, use a cup-type wheel to grind the side of the tool. Reset the universal vise to cut the end and top of the tool after the side is ground.

You can use the universal vise on a surface grinder for very accurate grinding of lathe cutting tools such as threading tools. For example, to grind an Acme threading tool, set the vise swivel at 14 1/2° from parallel to the table. Set the intermediate swivel to the clearance angle. Set the base swivel so the tool blank (held in the vise jaws) is parallel to the spindle of the grinder. Remember to leave the tool blank extending far enough out of the end of the vise jaws to prevent the grinding wheel from hitting the vise. After grinding one side of the tool bit, turn it one-half turn in the vise and set the intermediate swivel to an equal but opposite angle to the angle set for the first side. This setting will result in a clearance equal to the clearance of the first side.

Another method for grinding single-point tools is to hold the tool in a special fixture, as shown in figure 10-8. The fixture surfaces are cut at the angles necessary to hold the tool so the angles of the tool bit are formed properly.

When you use either method to grind tool bits, check the bit occasionally with an appropriate gauge until you have the correct dimensions. To save time, rough grind the bit to approximate size on a bench grinder before you set it in the jig.

CYLINDRICAL GRINDER

The cylindrical grinder is used to grind work such as round shafts. Although many of the construction features of the cylindrical grinder are similar to those of the surface grinder, there is a considerable difference in the functions of the components. Cylindrical grinders have no cross traverse table. An additional piece of equipment (the workhead) is mounted on the sliding table, and the wheelhead spindle is parallel to the sliding table. See figure 10-11.

As in the surface grinder, the base of this machine contains a hydraulic power unit and a coolant system. Longitudinal ways support the sliding table. Horizontal ways (at right angles to the longitudinal ways) permit the wheelhead to move toward or away from the workpiece. You will use this horizontal movement to feed the grinding wheel into the work for a depth of cut.

SLIDING TABLE

The sliding table of the cylindrical grinder is mounted directly on the longitudinal ways. This table moves back and forth to traverse the work longitudinally along the width of the grinding wheel.

An adjustable taper table, located on top of the sliding table is used to grind long (small angle) tapers

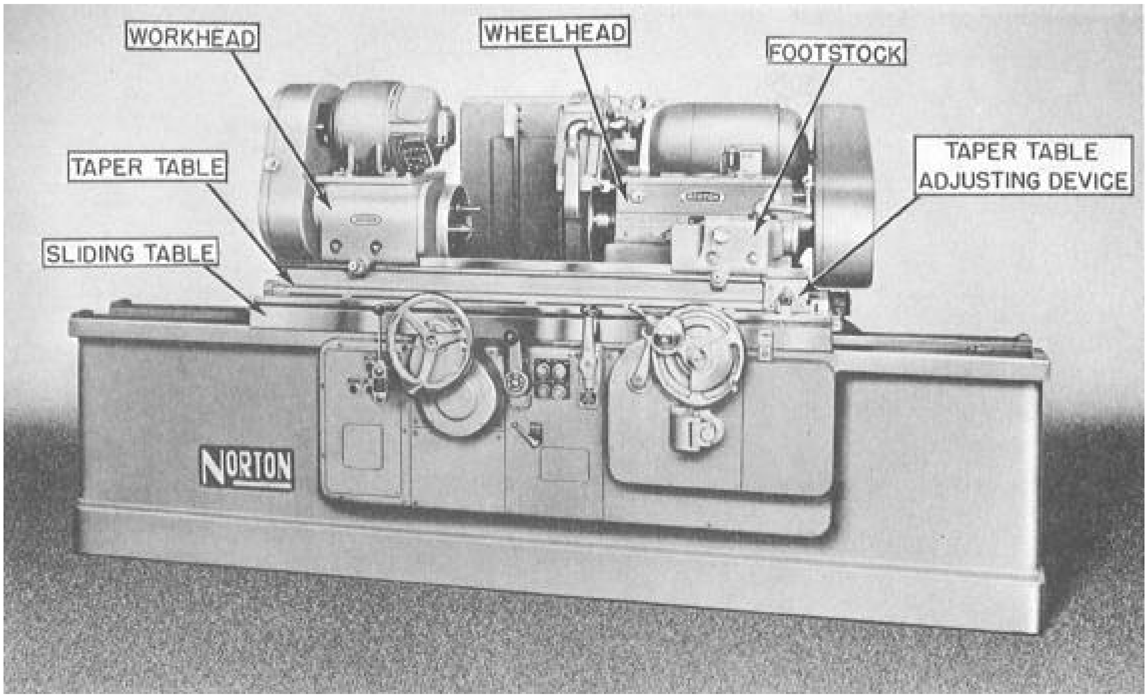

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Figure 10-11.—Cylindrical grinder (with workhead and footstock mounted).

on the workpiece. Adjust the taper table like the taper attachment on a lathe. Clamp workholding devices on top of the taper table.

The motor-driven workhead is mounted on the taper table. This component holds and rotates the work during the grinding cut. To meet the requirements of a job, you may need to change the speed at which the workpiece rotates. The workhead has variable-speed drive motors or step pulleys for this purpose.

You may use a chuck, a center, or a faceplate to mount work on the workhead. You also may use center rests and steady rests in conjunction with the workhead to mount long workpieces for cylindrical grinding.

On most cylindrical grinders used by the Navy, the workhead is mounted on a swivel base. This allows you to set the work to grind relatively large taper angles.

WHEELHEAD

The wheelhead of a cylindrical grinder moves on the horizontal ways (platen). Since cylindrical grinding is done with the axis of the spindle level with the center of the work, there is no need for vertical movement of the wheelhead. Some wheelheads are mounted on swivel bases to provide versatility in taper and angle grinding setups.

CYLINDRICAL GRINDER OPERATION

The methods used to set up stock in a cylindrical grinder are similar to the methods used to set up lathes. If you plan to grind work between centers, you will usually machine it to approximate size between centers on a lathe. Then, you will use the same center holes for the grinding setup. Use center rests or steady rests (as applicable) to support long work or overhanging ends. You can hold short workpieces in chucks. If you need to do internal grinding (on machines that have an internal grinding spindle), hold the work in a chuck and use steady rests for any necessary support.

When you set up a workpiece to grind between centers, use the following procedures:

1. Be sure the centers in the workhead and footstock and the center holes in the workpiece are in good condition.

2. Clamp a driving dog onto the workpiece.

3. Position the workhead and footstock and set the traverse stop dogs so that when the workpiece is in place, the table will traverse (longitudinally) the proper distance to grind the surface.

4. Make sure the workhead swivel, the taper table attachment, and the wheelhead swivel are set properly

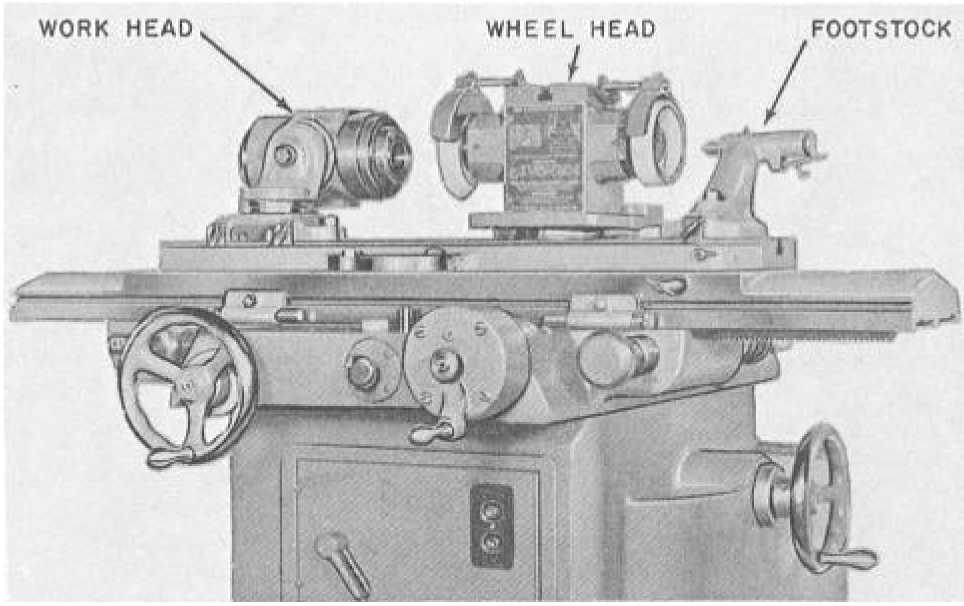

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Figure 10-12.—Tool and cutter grinder (workhead and footstock).

for straight cylindrical grinding or for the correct taper or angle, depending on the job.

5. Adjust the workhead speed mechanism to get the proper rotational speed. Normally, you should use a slow speed for roughing and a high speed for finishing.

6. Set the longitudinal traverse speed so the work advances from two-thirds to three-fourths the thickness of the wheel during each revolution of the workpiece. Use a fast traverse feed for roughing and a slow feed for finishing.

7. Set the workpiece in place and clamp the footstock spindle after making sure that both centers are seated properly and that the driving dog is not binding.

8. Select and mount the grinding wheel.

9. Start the spindle motor, hydraulic power pump, and coolant pump. After the machine has run for a few minutes, start the coolant flow and dress the wheel.

10. Using the cross traverse mechanism, bring the wheel up to the workpiece and traverse the table longitudinally by hand to see that the wheel will travel through the cycle without hitting any projections. (About one-half of the wheel width should remain on the work at each end of the longitudinal traverse stroke.) Clamp the table dogs in the correct positions to limit longitudinal traverse.

11. Start the workhead motor and feed the grinding wheel in sufficiently to make a cleanup cut (a light cut the entire length of the surface to be ground).

12. Using power longitudinal traverse, take a cut. Then, disengage the power traverse, stop the workhead motor and wheelhead rotation, and check the workpiece for taper. Make any changes required. (If you are using the taper table attachment and you need to make an adjustment at this point, dress the wheel again.)

We have not provided specific information on how to set the various controls and speeds because there are variations for each machine. Look for this information in the manufacturer's technical manual for your machine.

TOOL AND CUTTER GRINDER

The tool and cutter grinder (fig. 10-12) has a combination of the features of the plain cylindrical grinder and the planer-type surface grinder. A tool and cutter grinder is used primarily to grind multiedged cutting tools, such as milling cutters, reamers, and taps. The worktable has the same basic construction features as the surface grinder, but a taper table is mounted on the sliding table so you can grind tools that have small tapers, such as tapered reamers.

You can adjust the wheelhead in two directions. You can move it vertically on its support column through 360°. If you need to change the rotational direction of the grinding wheel, simply rotate the wheelhead 180°.

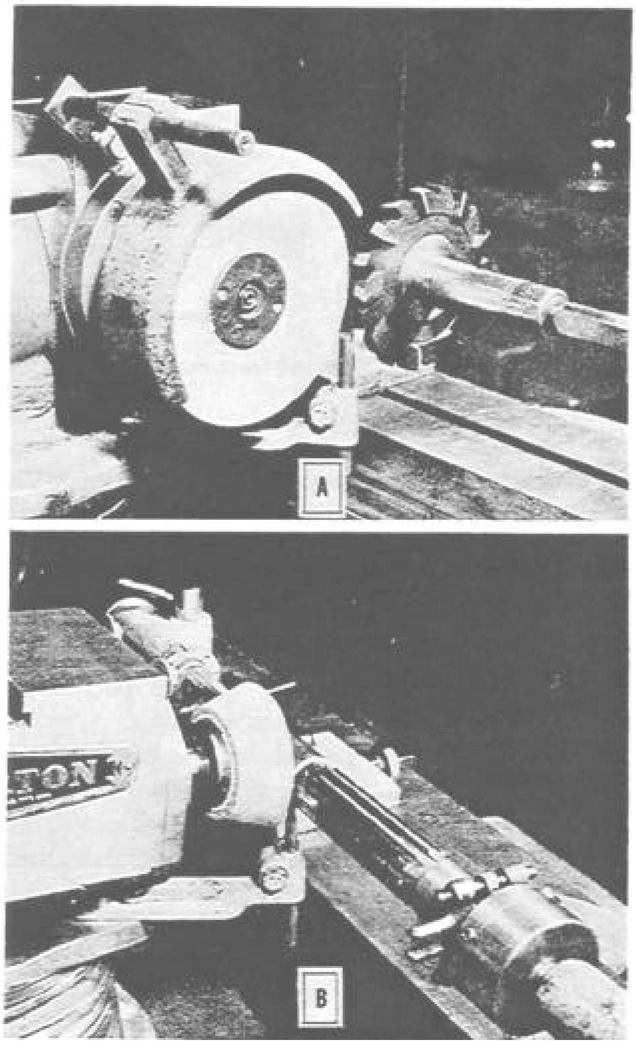

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Figure 10-13.—Tool grinding setups on a tool and cutter grinder. A. Straight wheel grinding a milling cutter. B. Cup wheel grinding a reamer.

Also, the spindle is double ended, allowing you to mount two wheels on the wheelhead.

The basic workholding devices used on the tool and cutter grinder are the workhead and the footstock (fig. 10-12). When there is no workhead, you can use a left-hand footstock similar to the right-hand footstock shown mounted on the table in figure 10-12. Also, you will have a variety of tooth rests to support and guide the teeth of a cutter being sharpened.

Most tool and cutter grinders have control handwheels at both the back and the front of the machine. These dual controls permit you to stand in the most convenient position to view the work while you operate the machine. You can usually disengage the sliding table handwheel to push the table back and forth by hand. Graduated collars on the handwheels offer a quick visible guide to show you the amount of movement of the various feed components.

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Figure 10-14.—Direction of wheel rotation. A. Toward the cutting edge. B. Away from the cutting edge.

CUTTER SHARPENING

The working efficiency of a cutter is largely determined by the keenness of its cutting edge. Therefore, you should sharpen a cutter at the first sign of dullness; this practice is both economical and a sign of good workmanship. A dull cutter not only leaves a poorly finished surface, but also may be damaged beyond repair if you continue to use it in that condition. Here is a good rule to help you decide when to sharpen a cutter; sharpen it when the wear land on the cutting edge is between 0.010 and 0.035 inch.

Cutters to be sharpened may be divided into two groups: (1) those that are sharpened on the relief and (2) those that are sharpened on the face. The first group includes cutters such as plain milling, side milling, stagger tooth, angle, and end nulls. The second group includes the various form cutters such as involute gear cutters and taps. The manufacturer provides the relief on the second type of cutter by grinding the faces of the teeth to sharpen them.

Figure 10-13 shows two methods used to grind cylindrical cutting tools on a tool and cutter grinder. View A shows a setup to grind a staggered tooth cutter using a straight wheel. View B shows a setup to grind a reamer using a cup type wheel. You can use either type of wheel; the cup-type produces a straight clearance angle; the straight wheel produces a hollow ground clearance angle.

When you use the straight wheel, set the spindle parallel to the table. When you use a flaring cup wheel, turn the spindle at an angle of 89° to the table. This provides the necessary clearance for the trailing edge of the grinding wheel as it is traversed along the cutter.

When you grind a cutter, you should have the grinding wheel rotating as shown in view B of figure 10-14. This method tends to keep the tooth of the cutter

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Figure 10-15.—Typical tooth rest blades.

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Figure 10-16.—L-shaped tooth rest blade.

firmly against the tooth rest, ensuring a correct cutting edge. If this method causes too much burring on the cutting edge, you may reverse the direction of wheel rotation as shown in view A. If you use the latter method, be sure the tooth being ground rests firmly on the tooth rest during the cut.

Dressing and Truing

You will usually need a soft grade wheel to sharpen a high-speed steel cutter or reamer. A soft grade wheel breaks down easily and is less likely to burn the cutter. True and dress the wheel before you start the sharpening operation and then redress as necessary, depending on the amount of wheel wear. As you grind each cutter tooth, the grinding wheel diameter decreases because of wear. As a result, you will remove less metal and the teeth will gradually increase in size.

To compensate for wheel wear and to be sure all the teeth are the same size, rotate the cutter 180° and grind all the teeth again. Be careful not to grind the cutter undersize.

To ensure a good cutting edge on the cutter, there must be a good finish on the clearance angle; therefore, you will occasionally need to dress the grinding wheel. Use the wheel truing attachment for this operation and for the initial truing and dressing operation on the wheel.

Tooth Rest Blades and Holders

Tooth rest blades are not carried in stock, so you must make them in the shop. Once you understand the requirements for the blades, you can fabricate various shapes to suit the types of cutters you will sharpen. Normally, these blades should be made of spring steel.

Use a plain (straight) tooth rest blade (view A, fig. 10-15) to sharpen side milling cutters, end mills, straight-fluted reamers, or any straight-fluted cutter. Use a rounded tooth rest blade (view B, fig. 10-15) for helix cutters, shell end mills, and small end mills. The offset tooth rest blade (view C, fig. 10-15) is a universal blade and you can use it for most applications. Figure 10-16 shows an L-shaped tooth rest blade used to sharpen metal slitting saws and straight tooth plain milling cutters with closely spaced teeth. You can make other shapes of tooth rest blades to fit the specific type of cutter or the cutter grinder you are using.

Holders for the tooth rest blades may be either plain or universal. Figure 10-17, view A, shows a tooth rest blade in a plain holder and view B shows a tooth rest blade in a universal-type holder. The universal tooth rest holder has a micrometer adjustment at its bottom to help you make precise up and down movements in the final positioning of the blade.

Setting the Clearance Angle

It is essential that the back of the cutting edge of any cutter have correct clearance. If it has too little clearance, the teeth will drag, causing friction and slow cutting. Too much clearance produces chatter and dulls the teeth rapidly. The cutting edge must have strength, and the correct clearance will provide this strength. Figure 10-18 shows a typical cutter tooth and the angles produced by grinding.

The primary clearance angle is the angle you grind when you sharpen a cutter. The number of degrees in the primary clearance angle vary according to the diameter of the cutter and the material being cut. A large diameter cutter requires less clearance than a small cutter. Cutters used to cut hard materials such as alloy and tool steels require less clearance than cutters used to cut softer materials such as brass and aluminum.

The primary clearance angles range from 4° for a large cutter to 13° for a smaller cutter. Some manufacturers of tool and cutter grinders have charts that can help you determine the correct clearance angle. The width of the primary land (the surface created when you

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Figure 10-17.—A. Tooth rest blade in a plain holder. B. Tooth rest blade in a universal holder.

grind the primary clearance angle) varies according to the size of the cutter. Primary land widths range from 0.0005 to 0.015 inch for a small cutter to 0.030 to 0.062 inch for a large cutter. You should grind the lands very carefully. A land that is too narrow will allow the cutting edge to chip or wear rapidly. A land that is too wide will cause the trailing side (heel) of the land to rub the work.

When the width of the primary land becomes excessive due to repeated grindings, you must grind the secondary clearance angle to reduce it. The secondary clearance angle is normally 3° to 5° greater than the primary clearance angle.

You get the desired clearance angle by the positioning of the grinding wheel, the cutter, and the tooth rest. The general procedure is to position the center of the wheel, the center of the work, and the tooth rest all in the same plane and then raise or lower the wheelhead the proper distance to give the desired clearance angle.

When you use the straight wheel, use a centering gauge (fig. 10-19) or a height gauge to bring the center of the wheel and the center of the work into the same plane. Then, fasten the tooth rest to the machine table and adjust the tooth rest to the same height as the center

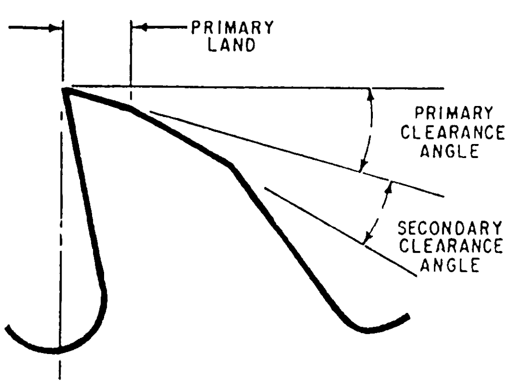

Figure 10-18.—Cutter clearance angles.

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Figure 10-19.—Centering gauge.

of the work. Raise or lower the wheelhead a predetermined amount to give the correct clearance angle. To determine the amount to raise or lower the wheelhead, multiply the clearance angle (in degrees) by the diameter of the wheel (inches) and then multiply this product by the constant 0.0087.

When you use a cup wheel, mount the tooth rest on the wheelhead. Position the center of the cutter in the same plane as the tooth rest. Then, raise or lower the wheelhead the proper amount to give the desired clearance. To determine the amount to raise or lower the wheelhead, multiply the clearance angle (in degrees) by the diameter of the cutter (in inches) and then multiply this product by the constant 0.0087.

Some tool and cutter grinders have a tilting wheelhead or a clearance setting device. Where you use a tilting wheelhead, simply tilt the wheelhead to the desired clearance angle. If you use a clearance setting device, follow the steps listed here.

1. Clamp a dog to the mandrel on which the cutter is mounted.

2. Insert the pin on the side of the dog into the hole in the clearance setting plate that is mounted on the footstock.

3. Loosen the setscrew in the clearance setting plate and rotate the cutter to the desired setting (graduations found on the clearance setting plate).

4. Tighten the setscrew.

5. Remove the dog.

When you grind the teeth of end mills, side milling cutters, or stagger tooth cutters, use the graduated dials on the workhead to set the clearance angle.

CUTTER SHARPENING SETUPS

Tool and cutter grinders vary in design and in the type of accessory equipment; however, most tool and cutter grinders operate in the same way. By using only the standard workhead, footstocks, and tooth rest blade holders, you can sharpen practically any cutter. In fact, you can sharpen most cutters by using essentially the same method. Study the following sections, use a little ingenuity and forethought, and you will be able to sharpen any cutter that may be sent to your shop.

The following sections cover the sharpening of various types of cutters in various depths of detail. We have provided more detail in the explanation of how to sharpen a plain milling cutter with helical teeth because this method is basically used to sharpen many other cutters.

Plain Milling Cutters (Helical Teeth)

Follow the steps listed here to sharpen plain milling cutters with helical teeth:

1. Remove all accessory equipment from the machine table.

2. Clean the table and the bottoms of the footstocks.

3. Mount the footstocks on the table. Allow just enough space between them to accommodate the mandrel with a slight amount of tension on the spring-loaded center.

4. Swivel the wheelhead to 89°. (This allows the end of the cutter to clear the opposite cutting face when you use a cup-type wheel.)

5. Mount the wheel and the wheel guard.

6. Use a dressing stick to thin the cutting face of the wheel to not more than 1/8 inch. Use a diamond truing device to true the wheel.

7. Use the centering gauge to bring the wheelhead axis into the same horizontal plane as the axis of the footstock centers.

8. Mount the cutter on a mandrel. (A knurled sleeve on the end of the mandrel will help the mandrel maintain an even, effective grip while you grind the cutter.)

9. Mount the mandrel between the footstock centers, preferably in a position so that the grinding wheel cuts onto the cutting edge of the teeth.

10. Mount the plain tooth rest holder (with a rounded tooth rest blade) on the wheelhead.

11. Place the centering gauge on top of the wheelhead and the tip of the gauge directly in front of the cutting face of the wheel, and then adjust the tooth rest blade to gauge height. (This brings the blade into the same horizontal plane as the footstock centers.)

12. Traverse the saddle toward the wheelhead until one tooth rests on the tooth rest blade; then lock the table into position.

13. Let a cutter tooth rest on the tooth rest, and then lower the wheelhead until the desired clearance is shown on the clearance setting plate. If you have no clearance setting device, calculate the distance to lower the wheelhead using the method described earlier in this chapter.

Figure 10-20.—Grinding the side teeth of a side milling cutter.

Before you start the sharpening operation, run through it without the machine running. This will let you get the feel of the machine and assure you that there is nothing to obstruct the grinding operation. Traverse the table with one hand and use the other hand to hold the cutter against the tooth rest blade. On the return movement, the tooth rest blade will cause the mandrel to turn in your hand; this eliminates the need to move the table away from the wheel on the return traverse.

To sharpen the teeth of any milling cutter, grind one tooth; then rotate the cutter 180° and grind another tooth. Check the teeth with a micrometer to be sure you are not grinding a taper. If there is taper, you must remove it by swiveling the swivel table of the machine.

As the width of the land increases with repeated sharpening, you will need to grind a secondary land on the cutter. Never allow the primary land to become greater than 1/16 inch wide, because the heel of the tooth may drag on the work To control the width of the primary land, double the clearance angle and grind a secondary land.

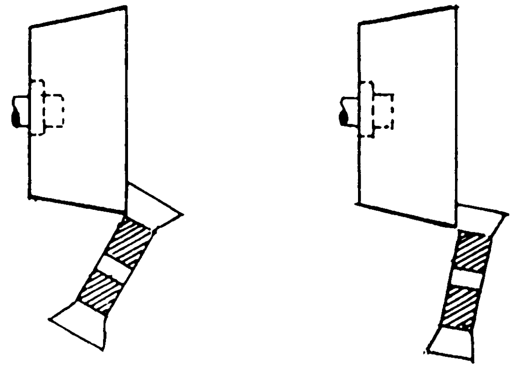

Figure 10-21.—Changing clearance angle by swiveling the cutter in a vertical plane.

Side Milling Cutters

The peripheral teeth of a side milling cutter are ground in exactly the same manner as the teeth of a plain milling cutter, with the exception that you will use a plain tooth rest blade.

To sharpen the side teeth, mount the cutter on a stub arbor and clamp the arbor in a universal workhead. Then, mount a universal tooth rest holder onto the workhead so that when the workhead is tilted the tooth rest holder moves with it (fig. 10-20).

The procedure used to grind clearance angles varies, depending on the type of grinding wheel used. If you are using a cup wheel, swivel the workhead vertically to move the tooth toward or away from the wheel. The clearance angle increases as the tooth is swivelled away from the wheel (fig. 10-21). If you use a straight wheel, set the cutter arbor horizontally and raise or lower the wheel to change the clearance angle. The clearance angle increases as the wheel is raised (fig. 10-22).

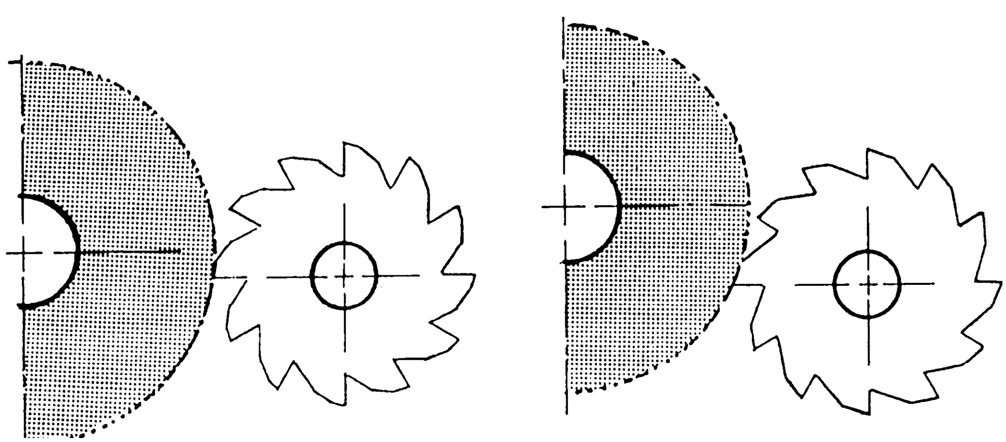

Figure 10-22.—Changing the clearance angle by raising the grinding wheel.

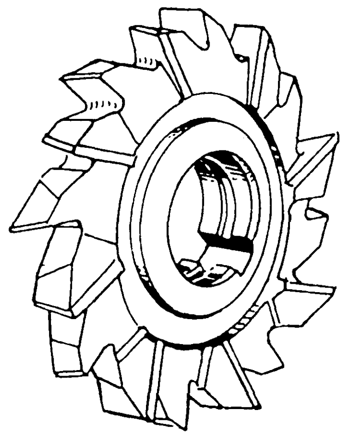

Figure 10-23.—Staggered-tooth side milling cutter.

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Figure 10-24.—Tooth rest mounted on the wheelhead in grinding a helical-tooth cutter.

Staggered Tooth Cutters

You can sharpen staggered tooth milling cutters (fig. 10-23) in exactly the same manner as plain milling cutters with helical teeth (fig. 10-24). If you use this method, grind all of the teeth on one side of the cutter. Then, turn the cutter over and grind all of the teeth on the other side.

There is, however, a method you can use to sharpen all of the cutter's teeth in one setting (see setup, fig. 10-13, view A). Follow the steps listed here:

1. Mount the cutter on a mandrel held between centers.
2. Fasten the tooth rest holder to the wheelhead.
3. Grind the tool rest blade to the helix angle of the cutter teeth on each side of the blade (fig. 10-25).

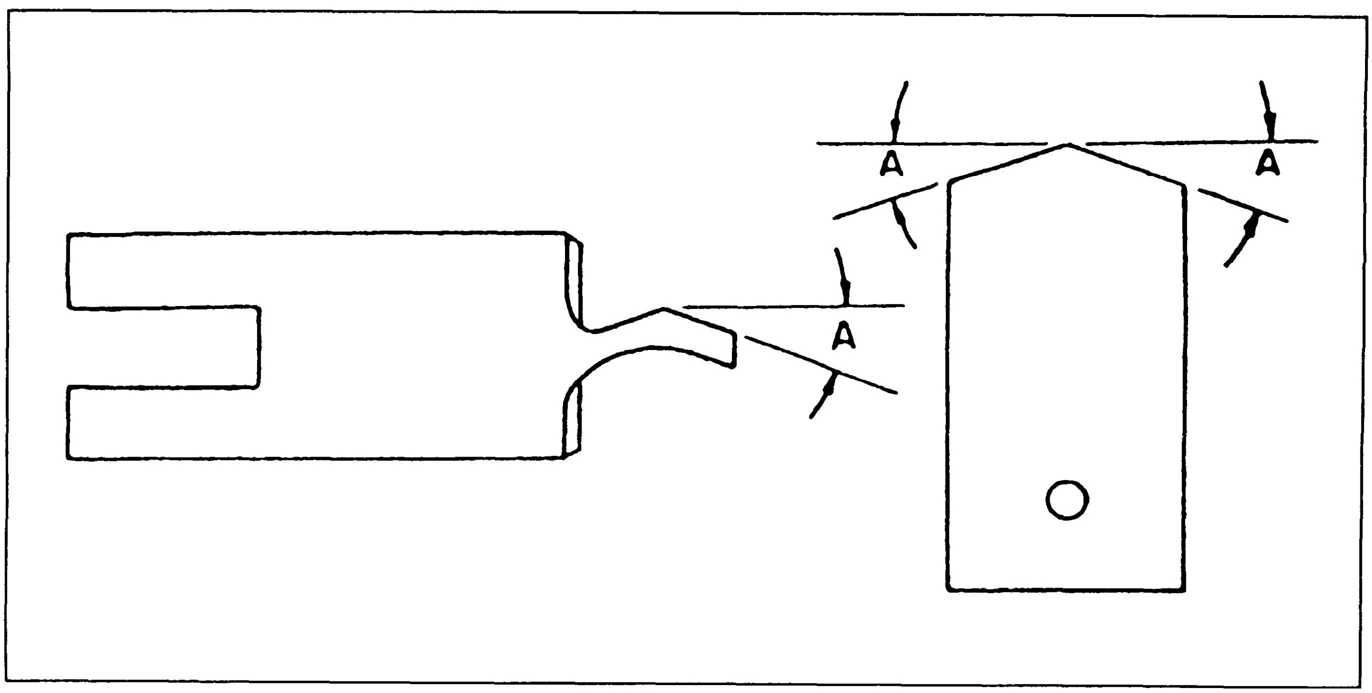

Figure 10-25.—Tooth rest blades for staggered tooth cutters.

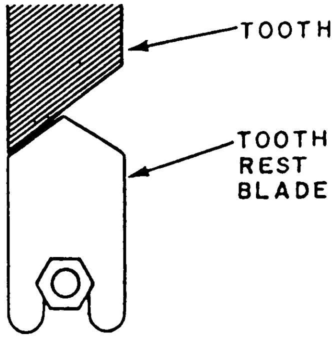

Figure 10-26.—Resting the face of a tooth on its corresponding side of the tooth rest blade.

4. Position the high point of the tooth rest blade in the center of the cutting face of the wheel.

5. Align the wheelhead shaft center line, the footstock centers, and the high point of the tooth rest blade in the same horizontal plane.

6. Raise or lower the wheelhead to give the desired clearance angle.

7. Rest the face of a tooth on its corresponding side of the tooth rest blade (fig. 10-26).

8. Move the cutting edge of the tooth across the face of the wheel. On the return cut, rest the next tooth on the opposite angle of the tooth rest. Continue alternating teeth on each pass until you have sharpened all the teeth.

Angular Cutters

To sharpen an angular cutter, mount the cutter on a stub arbor and mount the arbor in a universal workhead. Then, swivel the workhead on its base to the angle of the cutter. If the cutter has helical teeth, mount the tooth rest on the wheelhead. But, if the cutter has straight teeth, mount the tooth rest on the table or on the workhead. To set the clearance angle for both types of teeth, tilt the workhead the required number of degrees toward or away from the grinding wheel. Then, use a centering gauge to align the cutting edge of one tooth parallel with the cutting face of the wheel. Take a light cut to check your settings, and make fine adjustments until you get the desired clearance angle.

End Mills

You may salvage a damaged end mill by cutting off the damaged portion with a cylindrical grinding attachment, as shown in figure 10-27. Use a coolant if

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Figure 10-27.—Cutting off the damaged end of a helical end mill.

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Figure 10-28.—Grinding the peripheral teeth of an end mill.

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Figure 10-29.—Grinding the end teeth of a shell end mill.

possible to avoid removing the temper at the end of the cutter. Be sure to relieve the center of the end in the same way as on the original cutter.

Generally, it will not be necessary to sharpen the peripheral teeth. However, if you must grind them, use the same procedure that you would use to sharpen a plain milling cutter except for the method of mounting the cutter. Mount the end mill in a universal workhead (fig. 10-28) instead of between centers. You must remember that whenever you grind the peripheral teeth

of an end mill, you change the size (diameter) of the cutter. Therefore, you must show that the cutter size has been changed. Either mark the new size on the cutter or grind off the old size and leave the cutter unmarked.

Use the following steps to sharpen the end teeth:

1. Mount the end mill in a universal workhead.

2. Swivel the wheelhead to 89°.

3. Use a centering gauge to bring the cutting edge of a tooth into the same horizontal plane as the wheelhead spindle axis. Place the gauge on top of the wheelhead and raise or lower the wheelhead enough to place the blade of the gauge on the tooth's cutting edge. This also will align the cutting edge with the centerline of the wheel.

4. Lock the workhead spindle in place to prevent the cutter from moving.

5. Clamp the tooth rest blade onto the workhead so that its supporting edge rests against the underside of the tooth to be ground.

6. Swivel the workhead downward to the desired clearance angle and clamp it in position. At this point, make sure the tooth next to the one being ground will clear the wheel. If it does not, raise or lower the wheelhead until the tooth does clear the wheel.

7. Unclamp the workhead spindle and begin grinding the mill.

8. After you have ground all of the primary lands, tilt the workhead to the secondary clearance angle and grind all the secondary lands.

On end mills with large diameter wheels, it is often a good idea to back off the faces of the teeth toward the center of the cutter, similar to the teeth of a face mill. An angle of about 3° is enough, allowing a land of 3/16 to 5/16 inch long.

You must use as much care when you grind the comers of the teeth as when you grind the faces of the peripheral teeth. If not, the cutting edges will dull rapidly, and they will produce a poor finish. The comers of the teeth are usually chamfered 45° by swiveling the workhead or table and are left 1/6 to 1/8 inch wide.

To sharpen the end teeth of a shell end mill (fig. 10-29), mount the cutter on an arbor set in a taper shank mill bushing. Then, insert the bushing into the taper shank mill bushing sleeve held in the universal workhead. To get the desired clearance angle, swivel the workhead in the vertical plane and swivel it slightly in the horizontal plane to grind the teeth low in the center of the cutter. Turn the cutter until one of the teeth is horizontal; then raise the wheel until that tooth can be ground without interference.

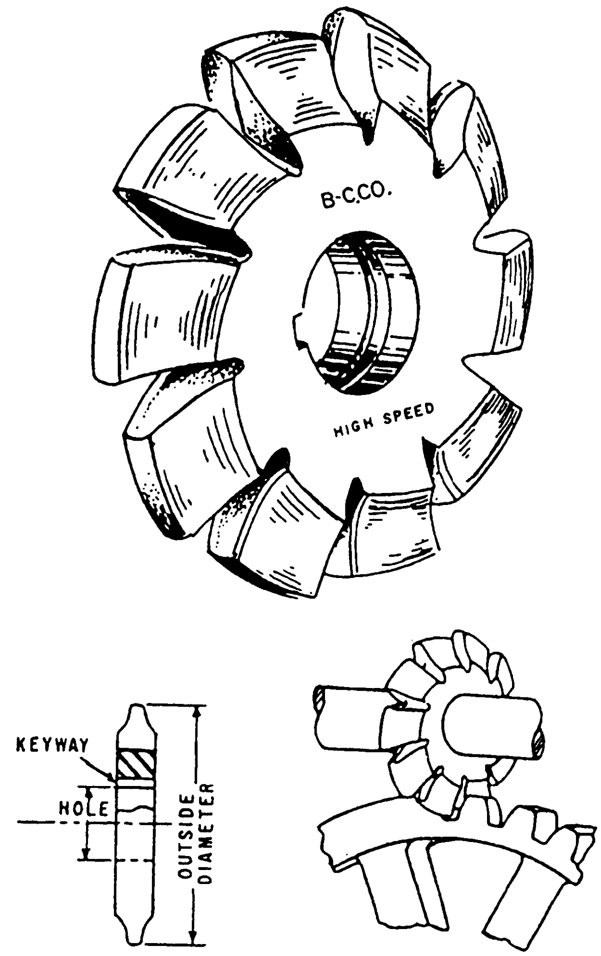

Figure 10-30.—Involute gear cutter.

Formed Cutters

Two methods are commonly used to sharpen formed milling cutters. The first method uses a formed cutter sharpening attachment and is by far the most convenient. In the second, set up the cutter on a mandrel, grind the backs of the teeth, and then reverse the cutter to sharpen the cutting faces.

The involute cutter (fig. 10-30) will serve as an example. Since the teeth of these cutters have a specific shape, the only correct way to sharpen them is to grind their faces. It is most important that the teeth are ground uniformly and that they all have the same thickness from the back face to the cutting face. To get this uniformity, grind the back faces of all new cutters before you use them. Grind only the back faces, since the cutting faces are already sharp and ready to use.

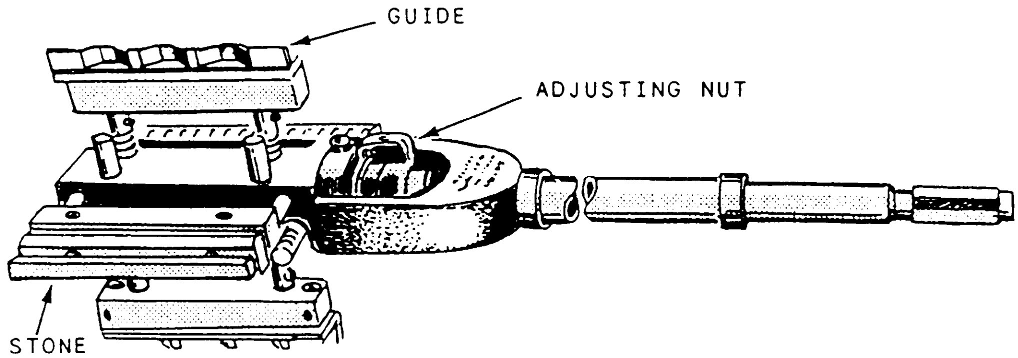

Figure 10-31.—Portable hone.

Once the teeth are uniform, they should remain uniform through repeated sharpening because you will be taking identical cuts on the cutting faces whenever you sharpen the cutter.

To sharpen a formed cutter using the formed cutter sharpening attachment, attach the wheelhead shaft extension to the shaft and mount a dish-shaped wheel on the extension. With the wheelhead swiveled to 90°, clamp the attachment to the table with the paw1 side of the attachment away from the wheel. Place the cutter on a stud and line up the cutting face of a tooth with the attachment centering gauge. Loosen the paw1 locking knob and adjust the paw1 to the back of the tooth. Then, adjust the saddle to bring the face of the tooth in line with the face of the grinding wheel. Once you have made this adjustment, do not readjust the saddle except to compensate for wheel wear. Grind one tooth, move the saddle away from the wheel, index to the next tooth, and grind that one. If you grind all of the teeth once and they have not been ground enough, rotate the tooth face toward the wheel and make a second cut on each tooth.

If a cutter has been initially provided with a radial rake angle, this angle must be retained or the cutter will not cut the correct form. To sharpen this type of cutter, line up the point of one cutter tooth with the attachment gauge, swivel the table to the degree of undercut, adjust the saddle to bring the face of the tooth in line with the face of the wheel, and grind.

If you don't have a formed cutter sharpening attachment, you can sharpen formed cutters by using a setup similar to that used to sharpen a plain milling cutter—between centers on a mandrel. In this method, the setup used to grind a radial tooth formed milling cutter is essentially the same as that used to grind a tap.

HONING EQUIPMENT

In honing, abrasive action does the cutting. You can use honing to remove stock from a drilled, bored, reamed, or ground hole to correct taper, out-of-roundness, or bow (bell-mouthed, barrel shape or misalignment). You can also use honing to develop a highly smooth finish while accurately controlling the size of the hole.

You may do cylindrical honing on a honing machine or on some other machine tool by attaching the honing device to the machine spindle, or you may do it by hand. Regardless of the method, either the hone or the work must rotate, and the honing tool must move back and forth along the axis of rotation.

PORTABLE HONING EQUIPMENT

The portable hone shown in figure 10-31 is similar to the type used in most Navy machine shops. It is normally available in sizes ranging from 1 3/4 to 36 inches, and each hone set is adjustable to cover a certain range within those sizes. The hone in figure 10-31 has two honing stones and two soft metal guides. The stones and the guides advance outward together to maintain a firm cutting action. An adjusting nut just above the stone and guide assembly is used to regulate the size of the honed bore. You can achieve accuracy to within 0.0001 inch when you follow the operating procedures.

To use the portable hone, follow these basic steps:

1. Clamp the hone shaft in the drill press chuck.

2. Clamp the workpiece to the drill press table.

3. Put the hone into the hole to be polished. Use honing compound as required.

4. Turn on the drill press and use the drill press feed handle to move the rotating hone up and down in the hole.

When you use a lathe (vertical or horizontal) to hone, you can mount the work in a chuck or on a faceplate and rotate it. In this arrangement, you will hold the honing tool in the tailstock with a chuck and use the tailstock spindle to move it back and forth in the workpiece bore.

When you use a milling machine or a horizontal boring mill, mount the workpiece on the table and the honing tool in the spindle. Move the machine table to pass the hone back and forth in the workpiece bore.

You also can use a hand-held power drill to rotate the hone in the workpiece. Move the rotating hone in and out of the hole by hand.

Each of these methods requires that the hone be allowed to self-align with the workpiece bore. To help this process, place one or two universals between the hone shaft and the device or spindle that will hold or drive the hone. Hone manufacturers can usually furnish these universals and shaft extensions.

When you hone large bores, use a device that attaches to the hone and lends support to the stones and guides to ensure a rigid setup.

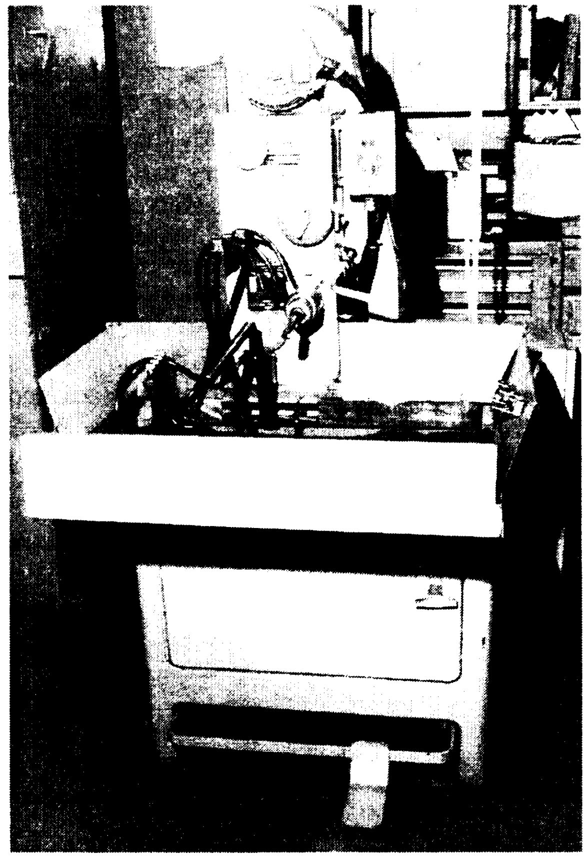

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Figure 10-32.—Stationary honing machine.

STATIONARY HONING MACHINE

Most large machine shops have a stationary honing machine such as the one shown in figure 10-32. These machines are usually self-contained hones with a built-in honing oil pump and reservoir, a workholding device, and a spindle to rotate and stroke the honing stones. They usually have standard controls to adjust the rpm, the rate of stroke, and the pressure feeding the stones to the desired size. Most models have a zero setting dial indicator that lets you know when the desired bore size is reached. Follow your machine manufacturer's operating manual.

STONE SELECTION

The honing stone is made somewhat like a grinding wheel, with grit, a bond, and air voids. The grit is the cutting edge of the tool. It must be tough enough to withstand the pressure needed to make it penetrate the surface, but not so tough that it cannot fracture and sharpen itself. The bond must be strong enough to hold the grit, but not so strong that it rubs on the bore and interferes with the cutting action of the grit. Air voids in the structure of the stone help the coolant or honing oil clear chips and dissipate heat.

Honing stones have either aluminum oxide grit for ferrous metals or silicon carbide grit for nonferrous metals and glass. Grit sizes range from 150 to 400. If you need to remove a large amount of metal, use a coarse grit stone such as a 150-grit to bring the base to within 0.0002 to 0.001 inch of the finish size. Then, use a finer grit stone to get a smooth finish. The hone manufacturer will recommend stones needed for specific jobs.

HONING HINTS

Honing does not change the axial location of a hole. The center line of the honing tool aligns itself with the center line of the bore. Either the tool or the part floats to ensure that the tool and the base align. Floating allows the tool to exert equal pressure on all sides of the bore.

As the honing tool is stroked through the bore, the pressure of the grit is greatest at the tight spots. Therefore, the hone takes out all taper and out-of-roundness before it removes any stock from the larger section of the bore. It also takes out any bow. Since the honing stones are rigid throughout their length, they cannot follow a bow—they bridge the low spots and cut deeper on the high spots, tending to straighten out a bow.

After you have honed out the inaccuracies, you must abrade every section of the bore equally. To be sure this happens, maintain both the rotating and reciprocating motions so that every part of the bore is covered before any grit repeats its path of travel.

If a bore will require honing to correct taper or out-of-roundness, leave about twice as much stock for honing as there is error in the bore. It is sometimes practical and economical to perform two honing operations: (1) rough honing to remove stock and (2) finish honing to develop the desired finish. We said earlier that you should leave from 0.0002 to 0.001 inch for finish honing.

If a machined bore must be heat-treated, rough hone it before heat treating to produce an accurately sized, round, and straight bore. After heat-treating the work-piece, finish hone to correct any minor distortion and to produce the desired finish.

Honing produces a crosshatch finish. The depth of cut depends on the abrasive, speed, pressure, and coolant or honing oil used. To produce a finer finish, you can do one or all of the following:

1. Use a finer grit stone.
2. Increase the rotating speed.
3. Decrease the stroking speed.
4. Decrease the feed pressure
5. Increase the coolant flow.