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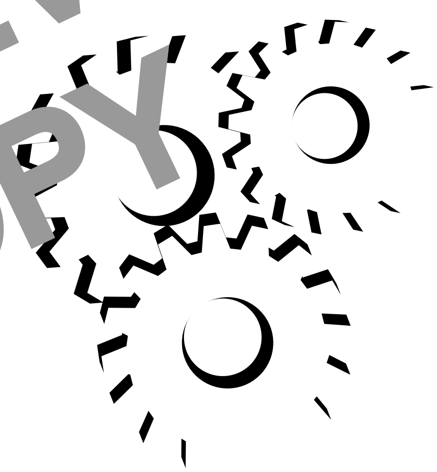
MACHINE SHOP SHAPING OPERATIONS

Lesson One

Milling Operations



TPC Training Systems

31701

Lesson

1 Milling Operations

TOPICS

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OBJECTIVES

After studying this Lesson, you should be able to…

- Explain the difference between peripheral milling and face milling.
- List the four types of knee-and-column milling machines.
- Explain how each of the knee-and-column machines works.
- Explain how a workpiece is held on a milling machine.
- Name and describe the three basic styles of arbor.
- Explain how the speed of a milling cutter is measured.
- Define indexing.

KEY TECHNICAL TERMS

Peripheral milling 1.01 uses teeth on the outer edge of the cutter body

Face milling 1.01 uses tooth on the end, as well as on the outer edge of the cutter body

Duplex milling machine 1.12 has two spindles, mounted on opposite sides of the bed

Indexing 1.45 moving and locating a workpiece in a series of positions

Index plate 1.48 plate punched with circles of holes; allows setting of the stopping points of the dividing head

Milling is the process of removing material using a rotating cutter. A properly equipped milling machine can do more operations than any other machine tool in the maintenance machine shop. A universal knee-and-column type milling machine, in particular, having the proper accessories, can do any machining operation that any other type of machine tool can do. Therefore, a milling machine is a valuable tool for you as a maintenance machinist.

This Lesson describes the types of milling, and the milling machines most used in the maintenance shop. It also describes and tells you how to use workholding and toolholding devices, and other accessories used for milling. You will also learn how to determine spindle speeds and feed rates using tables of general recommendations.

Types of Milling

1.01 You can divide milling operations into two general types by the location of the teeth on the milling machine's cutter. The two types are peripheral milling and face milling, as shown in Fig. 1-1. On a *Peripheral Milling* cutter, the teeth are on the periphery (or outer edge) of the cutter body. On a *Face Milling* cutter, the teeth are on the end, as well as on the outer edge of the cutter body. Within these two general types there are many kinds of milling, such as slab milling, side milling, end milling, profiling, and slotting.

Types of Milling Machines

1.02 Milling machines range in size from small bench models or attachments on lathes, to large bed-type machines equipped with multiple spindles. You will do most maintenance machining operations on one of four types of knee-and-column milling machines:

1. Ram and turret (sometimes called a tool-room type)
2. Plain (horizontal spindle)
3. Universal (horizontal spindle)
4. Vertical (vertical spindle)

1.03 Figure 1-2 on the following page shows a *ram-and-turret type knee-and-column milling machine*. You can set up this machine several ways, and many accessories are available for it. Therefore, it is an excellent machine for light-duty work. Both the knee and the quill, which is part of the spindle assembly, move up and down (vertical motion). The saddle moves in and out (crossfeed), and the table moves from side to side (longitudinal motion). Some of these machines have power feed to the knee, saddle, and table.

1.04 You can rotate the spindle head on a ram-and-turret machine in a plane parallel to the column face for angular cuts. Some machines of this type have a knuckle between the spindle head and the ram. Thus, you can tip the spindle head perpendicular to the column face to obtain additional angles. The ram slides in and out, and you can also rotate it on the turret. Some machines have a power head for small jobs, such as slotting.

1.05 *A plain-type knee-and-column milling machine* is more rigid than the ram-and-turret type milling machine. The plain-type machine has a horizontal spindle, and an overarm brace supports the arbor for the milling cutter at the end opposite the spindle. Therefore, it can take heavier cuts. But it does not have all the possible angle settings

Fig. 1-1. Two forces in balance

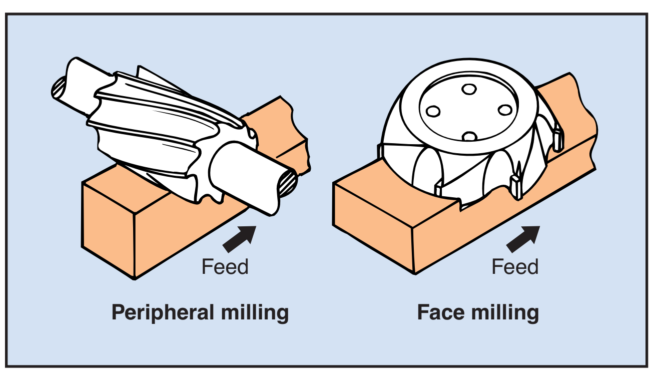
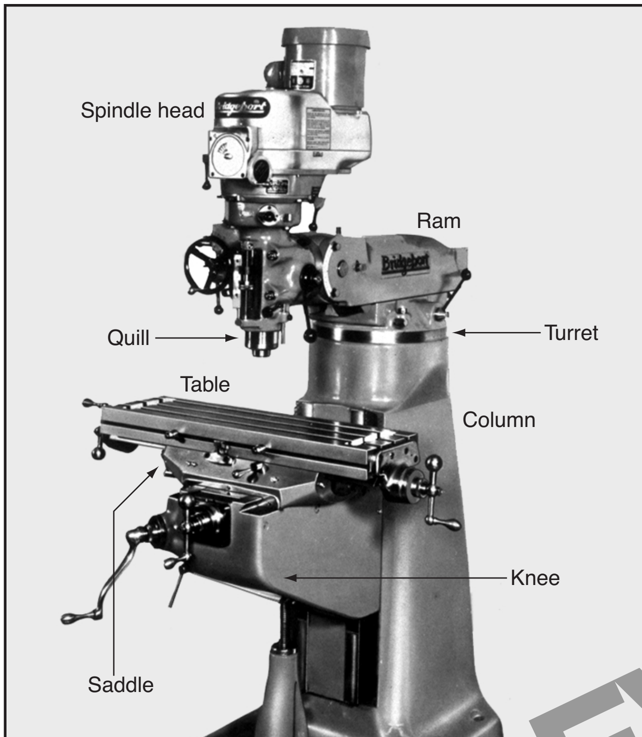


Fig. 1-2. Ram-and-turret type knee-and-column milling machine



that a ram-and-turret type machine has. To make angular cuts, you need a vertical head attachment, or you have to use fixturing. The spindle will rotate clockwise or counterclockwise. Be sure to set it to rotate in the proper direction before starting a cut.

1.06 The knee, saddle, and table have power feeds. The table moves from side to side for longitudinal motion. The saddle moves in and out for crossfeed, and the knee moves up and down for vertical motion. Although you can power feed all three axes at the same time, this is not advisable unless you are thoroughly familiar with the machine. The feed selector will allow you to select a feed speed in inches per minute. Usually, the knee or vertical feed speed is only one-half that of the table and saddle. But be sure to check this ratio on the particular machine you are using.

1.07 The plain-type knee-and-column milling machine also has a rapid traverse for fast work positioning. It also works on all three axes. Be sure that no other feed levers are engaged before using the rapid traverse, however.

1.08 Fixed and adjustable trip dogs on the machine shut off the feed. Fixed dogs, permanently set at the end of travel, stop the table, saddle, or knee from overtraveling. You set the adjustable dogs to shut off the feed at a desired position.

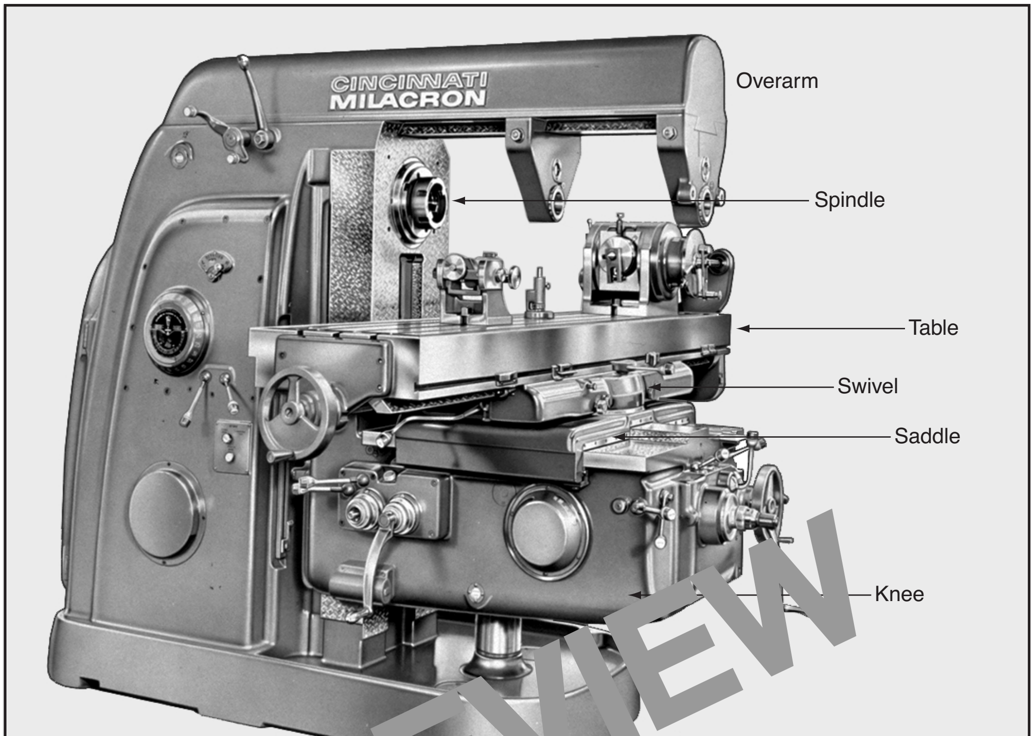
1.09 Figure 1-3 shows a *universal-type knee-and-column milling machine*. With the proper attachments this machine can perform any machine operation. A universal milling machine is basically a plain milling machine with a swivel mounted on top of the saddle. Therefore, you can rotate the table horizontally so it will feed past the cutter at an angle. You can use this feature to cut flutes in twist drills and milling cutters, and teeth on helical gears.

1.10 *A vertical-type knee-and-column milling machine* has a vertical spindle for holding face milling cutters, end mills, and boring type tools. Knee, saddle, and table motion are the same as for the plain milling machine. You can also feed the spindle by hand or power. This is called quill feed. Note that there are depth stops and a dial indicator on the vertical head for feeding the cutter to a precise depth. Some vertical milling machines have a swivel on the head for angular cuts. Others feed the entire vertical head assembly rather than the quill.

1.11 A numbering system designates the sizes of plain, universal, and vertical knee-and-column milling machines. A Number 2 machine is usually the smallest, but there are a few Number I machines. A Number 6 machine is the largest. Table 1-1 lists the maximum travel available for each size of machine.

1.12 Two other types of milling machines occasionally used in maintenance operations are production and planer-type milling machines. A *production or fixed-bed type milling machine* does not have a knee or saddle. The table moves horizontally only on a fixed bed. The spindle head moves up and down on a vertical column, while the spindle quill moves horizontally. If the machine has two spindles mounted on columns on opposite sides of the bed, it is called a duplex machine. These machines often have automatic cycle controls, and can be fitted with rise and fall tracer control. A planer-type milling machine is used for very large work. It usually has two, three, or more spindle heads mounted on a bridge over the table.

Fig. 1-3. Universal-type knee-and-column milling machine



Holding the Workpiece

1.13 You can hold and locate the workpiece on the milling machine table using a vise, special clamping devices, or fixtures. Figure 1-4 on the following page shows a milling vise mounted on a swivel base graduated in degrees. You can remove the swivel base to make it a plain vise. You can also remove the hardened and ground vise jaws, and install special jaws to fit a particular workpiece. Keys on the base of the vise allow you to accurately locate it in T-slots on the machine table. You can mount it either parallel or at right angles to the milling machine spindle.

1.14 You can also use the T-slots to locate and bolt the workpiece or fixtures. (Fixtures are special holders designed for a specific workpiece.) T-slot dimensions are standard, but the spacing between the slots differs between makes of machines. Be sure you use the right size T-bolt for the T-slots on your machine.

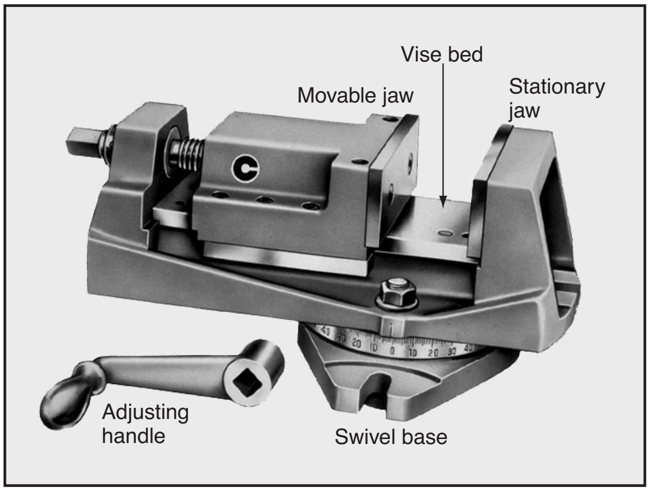
1.15 Figure 1-5 on the following page shows some typical clamping devices. Always be sure that you have enough clamps properly tightened to hold a workpiece in position. Be sure the T-bolt is closer to the work than the riser or step block. Use a "kicker" or stop to keep the workpiece from shifting under the cutting forces. You can clamp round workpieces on a V-block or mount them between centers.

1.16 If the workpiece requires milling on more than one surface, you must remount it after each cut. Or you can set it up for indexing. Indexing methods are described later in this Lesson and also in Lesson Four.

Table 1-1. Maximum table travel for plain, universal, and vertical knee-and-column milling machines

Size designation	Maximum feed (in.)		
	Longitudinal	Cross	Vertical
1	22	8	17
2	28	10	17
3	34	12	17
4	42	14	18
5	50	16	21
6	60	16	21

Fig. 1-4. A table-mounted milling machine vise



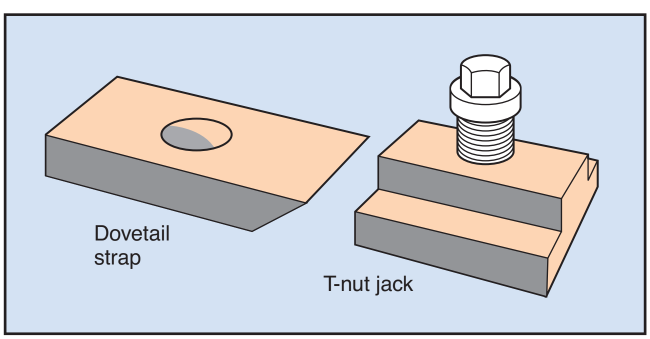
Spindles

1.17 The spindle on a milling machine is hollow. The front end of the hole is tapered to match the taper on the milling arbor or other toolholder. Milling machines use several types of spindle noses.

1.18 The most common spindle nose is called either the American Standard steep taper for milling machines, or ISO (International Standards Organization) taper. The four sizes, identified as Numbers 30, 40, 50, and 60, have the same 3.500 in. per ft taper, but different diameters. The most common size is Number 50, which has a hole diameter of $2^3/_4$ in. at the face.

1.19 The draw-in bolt, inserted from the back side of the spindle, screws into the arbor or toolholder to hold it in place. Keys on the face of the spindle fit into slots on the flange of the arbor to drive the arbor. The face of the spindle nose also has threaded boltholes to mount large (above 6 in. diameter) face milling cutters. You use a centering plug in the spindle hole to center the cutter on the spindle nose.

Fig. 1-5. Common types of workpiece clamps



1.20 Many ram-and-turret type milling machines have an R-8 type spindle nose. The back of an R-8 spindle nose hole has a straight section with a key. The shank of an R-8 toolholder has a straight section with a keyway that fits over the key in the spindle nose. A drawbolt pulls and locks the shank into the spindle nose.

1.21 Many older milling machines, and some bench type and profiling machines, have spindles with self-holding tapers, such as:

1. Morse tapers—approximately $^5/_8$ in. per ft.
2. Brown and Sharpe taper—$^1/_2$ in. per ft.
3. Jarno taper—0.600 in. per ft.

Other machines have a spindle similar to a drill press spindle. You remove the arbor from this type of spindle with a drift.

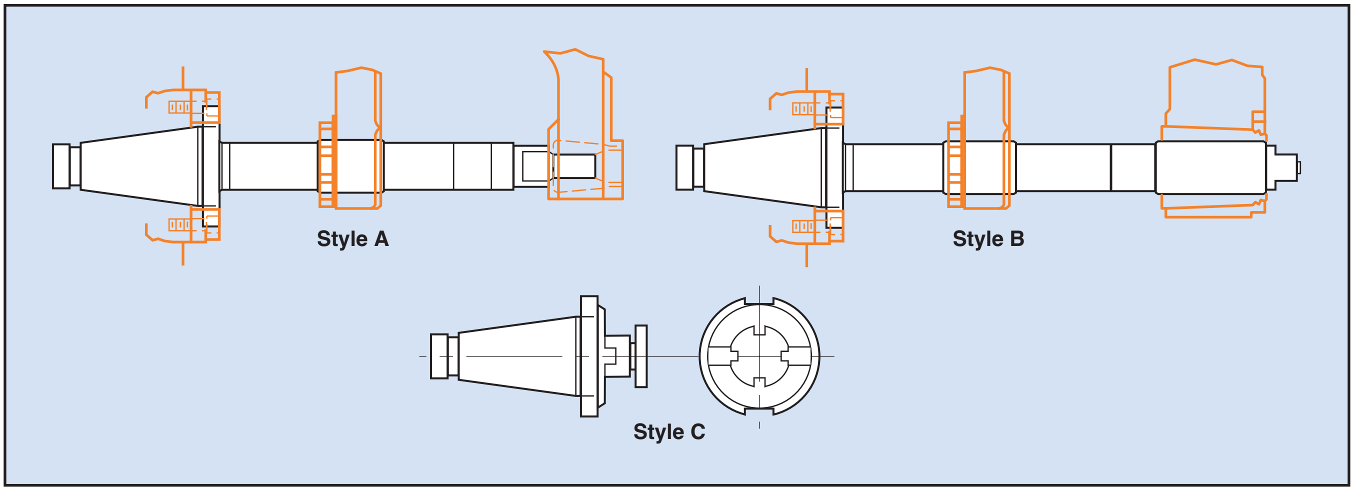
1.22 Before mounting a cutter, arbor, or toolholder on a spindle, wipe all mating surfaces with a clean, lint-free rag. This removes any dirt or other foreign matter. Carefully feel all mating surfaces for nicks or burrs, and remove them before mounting. Place a shop rag in the spindle hole when the machine is not in use to keep dirt out. Keep all machined surfaces on the spindle nose oiled to prevent rust.

Arbors, Styles A and B

1.23 There are three basic styles of arbors, as shown in Fig. 1-6. Style A arbors fit into a small pilot fitting in an arbor support-at the end opposite the spindle. You use this style for small diameter cutters when you need arbor support clearance to pass over fixtures or vises.

1.24 A Style B arbor has larger diameter bearings than a Style A arbor, and you can place the arbor supports close to the cutter for maximum support. Therefore, you should use a Style B arbor whenever possible to hold the cutter as rigidly as possible.

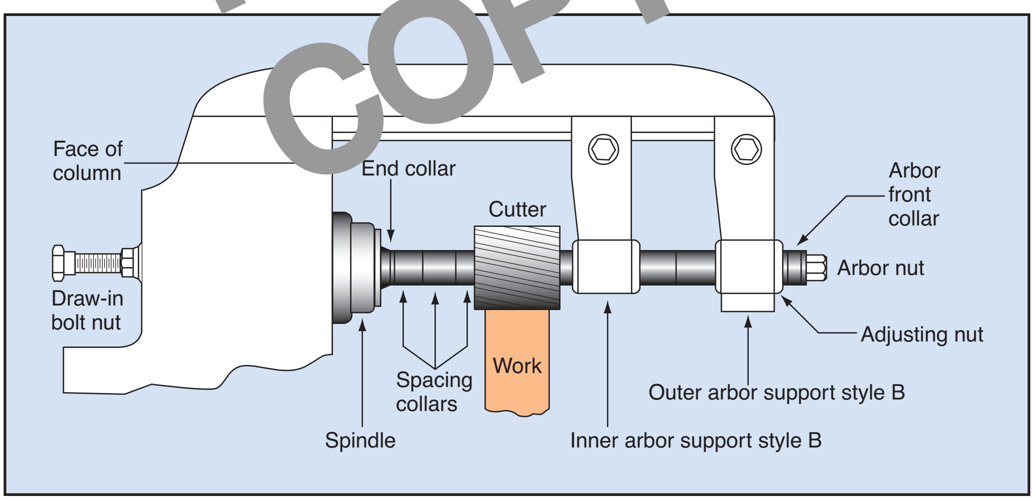
Fig. 1-6. Styles of milling machine arbors



1.25 Figure 1-7 shows a cutter mounted on a Style B arbor. Spacing collars locate the cutter on the arbor. The arbor drives the cutter through a cutter drive key. Use soft steel keys to drive cutters and running bushings. If overloaded, a soft steel key will shear without damaging the arbor. The shear keys are easy to remove.

The Programmed Exercises on the next page will tell you how well you understand the material you have just read. Before starting the exercises, remove the REVEAL KEY from the back of your Book. Read the instructions printed on the Reveal Key. Follow these instructions as you work through the Programmed Exercises.

Fig. 1-7. Milling cutter mounted on a style B arbor



1-1. The two types of milling are peripheral milling and __________ milling.	1-1. FACE Ref: 1.01, Fig. 1-1
1-2. In a ram-and-turret type milling machine, the knee and __________ move vertically.	1-2. QUILL Ref: 1.03
1-3. For fast work positioning, the knee-and-column milling machine has a(n) __________ traverse.	1-3. RAPID Ref: 1.07
1-4. A Number 6 milling machine is __________ than a No. 2 machine.	1-4. LARGER Ref: 1.11
1-5. A holder designed to hold a specific workpiece is called a(n)__________.	1-5. FIXTURE Ref: 1.14
1-6. To match the milling machine arbor or toolholder, the spindle hole is __________.	1-6. TAPERED Ref: 1.17, 1.18
1-7. The arbor is driven by __________ on the spindle face that fit into __________ in the arbor flange.	1-7. KEYS; SLOTS Ref: 1.19
1-8. A milling cutter is positioned or located on the arbor by spacing __________.	1-8. COLLARS Ref: 1.25

Arbors, Style C

1.26 The Style C arbor (see Fig. 1-6) is used for mounting shell end mills. A locking screw holds the cutter in place, while keys on the arbor drive the cutter. Make sure the shell end mill is tightly locked in place, and that the screw does not vibrate loose during cutting.

1.27 You must have the right size arbor to match the cutter. Standard arbors range from 7/8 in. to 2 1/2 in. diameter. Flange mounted arbors used on large bed type milling machines come in larger sizes. Two types of arbors are available for using arbor mounting cutters on vertical spindle machines. One type mounts directly to the spindle nose taper. The other type has an end mill type shank for mounting in end mill holders.

1.28 Do not store a milling machine arbor lying on its side. It can sag from its own weight. A sprung arbor will not mill accurately, and cutter life will be poor. Store arbors vertically, hanging them from the flange with the taper mounting end up. Keep all machined surfaces on arbors oiled to prevent rusting.

End Mill Holders and Collets

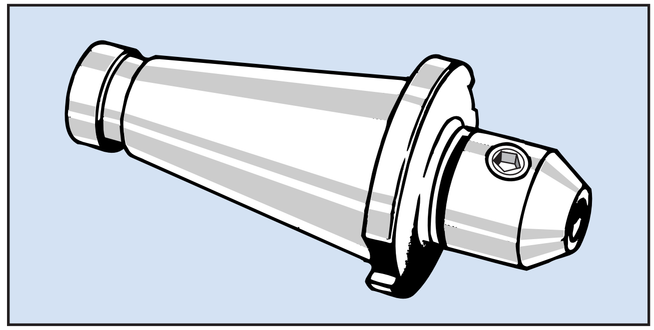
1.29 End mills and other shank mounted tools are the types you will probably use most for maintenance work. Figure 1-8 shows an end mill holder. A setscrew in the holder locks on the flat of the end mill shank. End Mills 7/8 in. diameter and larger have two flats, and the holders have two setscrews. Some holders have a pin drive shank. Shanks 1 1/2 in. diameter and larger have both setscrew flats and a pin drive.

1.30 A collet holder has a locking collar that compresses the collet around the end mill shank. You can adjust the stop screw to maintain a desired length. The knurled collar on the spindle nose will release the collet holder with a 1/4 turn. This not only makes it easier to change toolholders, but also eliminates the need for a draw-in bolt.

Locating the Cutter

1.31 When using a vertical milling machine with a swivel head, you must locate the cutter with reference to the workpiece. Do this after you set up the cutter and workpiece, and align the spindle.

Fig. 1-8. An end mill holder



1.32 The most common way is to use a strip of paper. First measure the thickness of the paper with a micrometer. Most notebook paper is about 0.003 in. thick. Some machinists prefer to use cigarette paper. Be sure the paper is long enough so that you can keep your fingers away from the cutter. Start the machine spindle, making sure the cutter is rotating in the proper direction. Hold the paper between the cutter and workpiece. Move the paper slightly, and bring the cutter and work together until you just feel the cutter grab the paper. When you feel the cutter grab the paper, it is exactly the paper thickness away from the edge.

1.33 You can also use a wiggler (center finder) or an edge finder to locate the cutter and workpiece. You can use a dial indicator to locate holes in a workpiece.

1.34 Once you have located the cutter and workpiece, set the machine dials, allowing for the paper thickness or edge finder body diameter. This is usually done in two axes. You now can position the cutter for the first cut.

Determining Spindle Speed

1.35 You set the spindle speed on a milling machine in revolutions per minute (rpm). But the cutting speed recommendations for milling cutters are in surface feet per minute (sfpm), as shown in Table 1-2 on the following page. Sfpm is the speed on the outer surface of the cutter. Therefore you must convert the cutting speed recommendation from sfpm to rpm before you can set the spindle speed. Use the formula:

$$\text{Spindle speed (rpm)} = \frac{12V}{\pi D} \text{ or } \frac{3.82V}{D}$$

Table 1-2. Starting cutting speeds for milling cutters

Material	Cutting speed (sfpm), Tool material: High-speed steel	Cutting speed (sfpm), Tool material: Cemented carbide	Material	Cutting speed (sfpm), Tool material: High-speed steel	Cutting speed (sfpm), Tool material: Cemented carbide
Magnesium	600 up	1000 up	Titaniu		
Aluminum	600 up	1000 up	Under 100,000 psi	35 to 55	150 to 180
Coppper	300 up	1000 up	100,000 to 135,000 psi	25 to 35	120 to 150
Brass	300	800	135,00 psi and over	15 to 25	80 to 120
Bronze	200	400	High-tensile steels		
Malleable iron	100	350	180,000 to 220,000 psi	25 to 40	200 to 250
Cast iron	100	300	220,000 to 260,000 psi	10 to 25	110 to 200
Cast steel	70	200	260,000 to 300,000 psi	6 to 10	90 to 180
Steel—100 Bhn	150	450	High-temperature alloys		
200 Bhn	70	350	Ferritic low alloys	40 to 60	150 to 300
300 Bhn	40	200	Austenitic alloys	20 to 30	100 to 235
400 Bhn	20	100	Nickel base alloys	5 to 20	50 to 150
500 Bhn	10	75	Cobalt base alloys	5 to 10	50 to 100
Stainless steel:					
Free machining	70	400			
Other	40	300			

where V = recommended cutting speed, sfpm; π = 3.1416; D = outside cutter diameter, in.; and 12 = conversion factor from inches to feet.

1.36 For example, use a 1/2 in. diameter end mill to make a profile cut on steel of 200 Bhn hardness. From Table 1-2, the recommended speed is 70 sfpm for a high-speed steel cutter. Therefore,

$$\text{Spindle speed (rpm)} = \frac{3.82 \times 70}{0.500} = 535 \text{ rpm}$$

Table 1-3. Starting feed rates for milling machines

Type of cut	Feed per tooth (in.)
Face milling	.007
Straddle milling	.005
Slot milling (side mills)	.003
Slab milling	
light-duty	.001
heavy-duty	.003
End milling:	
1/2 in. diameter and over	.002 to .003
Under 1/2 in. diameter	.0002 to .002
Sawing	.0005 to .001
Thread milling	.0005 to .001

Note: Use these feeds as a starting point only. You will have to modify them for the best results, depending on factors such as workpiece material and shape, and condition and power of the machine.

Now make a second cut using a 6 in. diameter shell end mill:

$$\text{Spindle speed (rpm)} = \frac{3.82 \times 70}{6} = 45 \text{ rpm}$$

Switch to a 6 in. carbide face mill:

$$\text{Spindle speed (rpm)} = \frac{3.82 \times 350}{6} = 223 \text{ rpm}$$

Note the large differences in rpm between different size cutters, and between high-speed steel and cemented carbide.

Determining Feed Rates

1.37 You set the feed rates on a milling machine in inches per minute (ipm). But the recommendations for feeds are given in inches per tooth (ipt), as shown in Table 1-3. Ipt is how much chip load you can put on one tooth. For example, if you use a cutter with one tooth, the distance the workpiece moves in one revolution of the cutter equals the chip load. If you use a cutter with two teeth at the same feed rate, the chip load per tooth would be one-half that of the one-tooth cutter.

1.38 To convert recommended feeds from ipt to ipm, use the formula:

$$F_m = F_t \times t \times rpm$$

where F_m = feed rate, ipm; F_t = feed, ipt; t = number of teeth in cutter; and rpm = rotational speed of cutter in revolutions per minute. From the previous example, assume that the $^1/_2$ in. diameter end mill has 4 teeth, the shell end mill has 16 teeth, and the carbide face mill has 12 teeth. Therefore, for the $^1/_2$ in. end mill (using 0.002 ipt from Table 1-3):

$$F_m = 0.002 \times 4 \times 535 = 4.3 \text{ ipm}$$

For the 6 in. shell end mill (using 0.007 ipt):

$$F_m = 0.007 \times 16 \times 46 = 5.2 \text{ ipm}$$

For the 6 in. carbide tipped face mill (using 0.007 ipt):

$$F_m = 0.007 \times 14 \times 223 = 21.9 \text{ ipm}$$

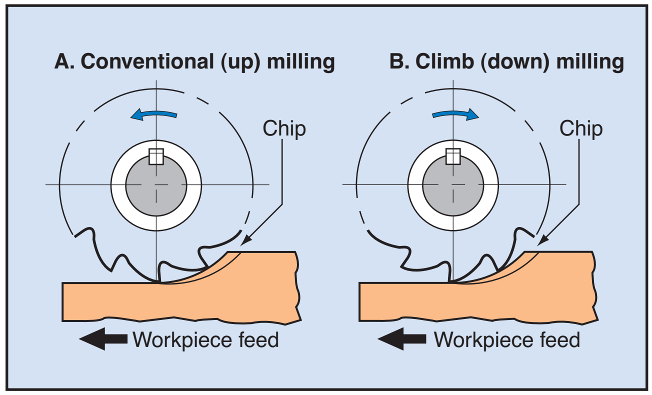
1.39 Note the much higher feed rate using the carbide cutter. Usually more teeth in a cutter allows greater feed and production rates. But you must be sure that the milling machine you are using has sufficient power, and that the cutter has sufficient flute space to work properly under the conditions selected. Also be careful not to feed at too low a rate. Do not feed carbide cutters lower than 0.005 ipt. Too low a feed causes rubbing rather than clean cutting.

Determining Direction of Feed

1.40 Next, determine which way to feed the cutter into the work. You can use conventional (up) milling, or you can use climb (down) milling. Figure 1-9 shows the difference.

1.41 In conventional milling feed, the cutter tends to hold the workpiece back. In climb milling feed, however, the cutter tends to pull the work into it. Climb milling gives a better surface finish than conventional milling and, in general, is more efficient than conventional milling. Therefore, try to use climb milling whenever possible. Climb milling, however, requires more power and a more rigid machine than conventional milling. Thus you may have to use conventional milling on light-duty ram-and-turret machines, or older milling machines. Do not use climb milling on castings or forgings with a hard scale on the surface. The hard scale dulls the cutter rapidly as the teeth dig down through it.

Fig. 1-9. Conventional milling and climb milling



Cutting Fluids

1.42 Cutting fluids are necessary in many milling operations. Spray mist is often the best way to apply cutting fluid, because flooding can be messy. The shape of the knee-and-column type milling machine makes it hard to keep cutting fluids from dripping off the table and knee onto the floor.

1.43 When you do have to apply cutting fluids by flooding, however, use the largest nozzle possible to avoid too much splashing. Direct the cutting fluid at the point where the cutting tooth enters the cut. But avoid quenching the cutter as the heated cutting edge leaves the cut.

1.44 For general purpose milling, use general purpose oil-water mixtures. However, many machinists prefer cutting oils when milling tough steels such as die or mold tool steels, and quenched and tempered alloy steels. Avoid a cutting fluid that will wash the lubricating oil from the machine ways. Do not use cutting fluids with carbide cutters. The fluid's quenching action can crack the carbide tips.

Indexing

1.45 Many milling operations require indexing the workpiece. Indexing means to move and accurately locate a workpiece in a series of positions for the same milling operation at different points on the workpiece.

1.46 Use linear indexing to make several cuts along a straight line on a workpiece. You can usually use the machine dials for linear indexing. Some machines have a rack indexing attachment mounted on the table screw for linear indexing. You can also use a universal dividing head geared to the table screw for linear indexing.

1.47 Figure 1-10 shows a dividing or indexing head. You can mount centers or workholding devices in the dividing head spindle which has a standard taper. You can rotate the spindle block between the horizontal and vertical positions. The crank handle, mounted in an assembly with the index pin plunger, is geared to the spindle with a ratio of 5:1. In other words, five revolutions of the index handle turns the spindle one revolution. Or, one revolution of the crank turns the spindle 72 degree. Some dividing heads have a 40:1 ratio between the crank and the spindle. Be sure you know which ratio your dividing head has.

1.48 The plate punched with circles of holes is called an index plate. Each circle of holes has a different number of holes. The index plate allows you to set the stopping points of the dividing head spindle where you need them. You adjust the length of the crank so the plunger will enter the circular row of holes desired, and adjust the index sector to the division required. To determine how many holes to move the crank, use the formula:

$$n = \frac{RH}{N}$$

where n = number of holes to be advanced, R = number of crank turns to turn the spindle one revolution (either 5 or 40), H = number of holes in the index plate circle, and N =number of divisions required.

1.49 For example, you are to mill the splines on an eight spline shaft. The dividing head has a 5:1 ratio. Try a 98 hole circle:

$$n = \frac{5 \times 98}{8} = 61.25 \text{ holes per index}$$

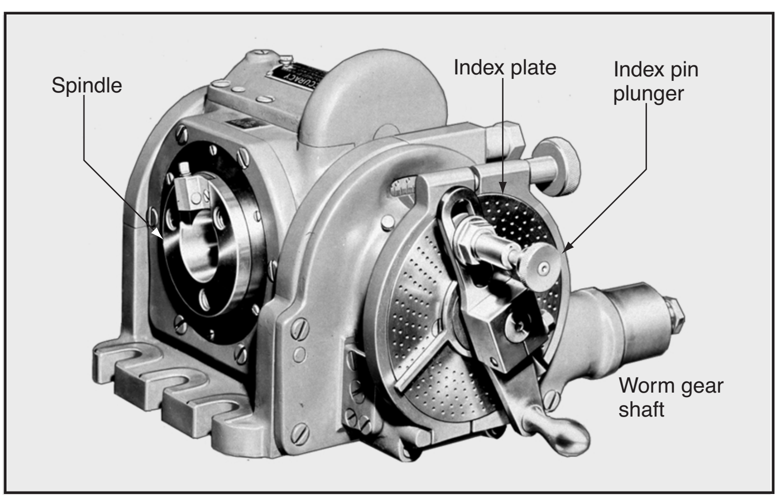
$$n = \frac{5H}{N} = \frac{5H}{8}$$

You find that you cannot use the 98 hole circle because the answer is not a whole number.

Then try an 88 hole circle:

$$n = \frac{5(88)}{8} = 55 \text{ holes per index}$$

Fig. 1-10. An indexing type dividing head



1.50 You can also use a 96 hole circle at 66 holes, a 64 hole circle at 40 holes, or a 56 hole circle at 35 holes. This method is known as plain indexing.

1.51 You can also use the worm gear shaft on the back of the dividing head shown in Fig. 1-10 for indexing. Attach a crank to the shaft or connect it through gears to the table screw. One turn of the crank gives $^1/_{40}$ of a turn to the dividing head spindle.

1.52 When you connect the dividing head to the table screw using gears, the workpiece rotates as the machine table moves. You can use this setup for helical milling of parts such as drum cams, helical fluted milling cutters, and twist drills. You can fit a gear box on the end of the machine table, and select different gear ratios for the indexing desired.

1.53 You can use a dividing head in other ways to index a workpiece. In angular indexing, you use degrees instead of the number of indexes. For example, when set up at a 5:1 ratio, each turn of the crank turns the workpiece 72° or $^1/_5$ of a circle. Compound indexing is using two index pins. Therefore you can use two rows of holes on an index plate. Differential indexing requires a separate set of gears between the dividing head spindle and the index plate. The gear ratio between the spindle and index plate determines the actual angular displacement of the workpiece. Setting up compound and differential indexing are beyond the scope of this lesson.

Safety Precautions for Milling Machine Operation

1.54 Always use *extreme caution* when working on a milling machine or any other machine tool. Read the operator's manual for the machine carefully. Learn how to operate the machine properly. Observe the safety precautions in the operator's manual. Also observe the following precautions.

1. *Always wear safety equipment*, including safety glasses, shoes, and a hard hat.

2. *Do not wear* loose clothing or jewelry that can get caught in the moving parts of the machine.

3. *Clamp the workpiece, tool-holder, and cutter securely*. Tighten the toolholder and cutter carefully so they cannot work loose when the machine is running. Make sure you have the workpiece clamped securely to the table so it cannot move or come loose during milling.

4. *Keep tools out of the machine*. Always make sure you have removed all wrenches and other tools from the machine before turning on the machine.

5. *Keep the work area clean*. Be sure that there are no tools, parts, oil or grease on the floor that could cause you to trip or

6. *Keep all machine guards in place*. Check all guards regularly to be sure they are operating properly.

7. *Keep the machine in top condition*. Keep the machine clean. Follow the machine manufacturer's recommendations for lubricating and preventive maintenance.

8. *Use sharp milling cutters*. Worn cutters put excess strain on the machine, workpiece, and the cutter itself. The result can be damage to the machine, a ruined workpiece, or personal injury.

9. *Stop the machine to work on it*. Make sure the power is off, and no one else can turn it on while you are adjusting or servicing the machine.

1-9. To keep arbors from springing, store them vertically and hang them from their __________.	1-9. FLANGES Ref: 1.28
1-10. To locate and line up a milling cutter with reference to the workpiece, use a strip of __________.	1-10. PAPER Ref: 1.31, 1.32
1-11. The milling machine spindle speed is measured in revolutions per __________.	1-11. MINUTE Ref: 1.35
1-12. To find the feed rate, multiply the feed per cutter tooth by the number of __________.	1-12. TEETH Ref: 1.38
1-13. The best way to apply cutting fluid for milling is the __________.	1-13. SPRAY MIST Ref: 1.42
1-14. Moving a workpiece through a series of positions to repeat a milling operation is called __________.	1-14. INDEXING Ref: 1.45
1-15. For linear indexing, you can use the machine, a rack indexing attachment, or a(n)__________ head.	1-15. DIVIDING Ref: 1.46
1-16. In angular indexing with a 5:1 ratio, each turn of the crank rotates the workpiece __________ degree.	1-16. 72 degree Ref: 1.53

Answer the following questions by marking an "X" in the box next to the best answer.

1-1. On a face milling cutter, the teeth are located

- ☐ a. around the arbor bore
- ☐ b. on the end only
- ☐ c. on the end and outer edge
- ☐ d. on the outer edge only

1-2. The milling machine that is sometimes called the toolroom type is the

- ☐ a. ram-and-turret type
- ☐ b. universal-type
- ☐ c. vertical-type
- ☐ d. plain-type

1-3. What milling machine attachment should you use for small jobs like slotting?

- ☐ a. The ram head
- ☐ b. The power head
- ☐ c. The retractable turret
- ☐ d. The overarm attachment

1-4. On a plain-type milling machine, which of the following has a power feed?

- ☐ a. The saddle
- ☐ b. The table
- ☐ c. The knee
- ☐ d. All of the above

1-5. The smallest size of milling machine in the shop is usually the

- ☐ a. No. 1
- ☐ b. No. 2
- ☐ c. No. 3
- ☐ d. No. 4

1-6. What holds a milling machine arbor securely in the spindle?

- ☐ a. The keys in the slots
- ☐ b. The steep taper fit
- ☐ c. The draw-in bolt
- ☐ d. All of the above

1-7. You should store milling machine arbors properly by

- ☐ a. hanging them, taper end up
- ☐ b. hanging them, taper end down
- ☐ c. standing them on end
- ☐ d. laying them on their sides

1-8. To locate a milling cutter with reference to the workpiece, use a

- ☐ a. washer
- ☐ b. feeler gauge
- ☐ c. shim
- ☐ d. strip of paper

1-9. Which of the following statements about climb milling is true?

- ☐ a. It gives a better finish
- ☐ b. It requires less power
- ☐ c. The cutter tends to hold the workpiece back
- ☐ d. All of the above

1-10. Often the best way to apply cutting fluids for milling is the

- ☐ a. pressurized stream
- ☐ b. spray mist
- ☐ c. flood
- ☐ d. lubricant stick

SUMMARY

Milling operations can be divided into two general types based on the location of the teeth on the machine's cutter. In peripheral milling, the teeth are on the outer edge of the cutter body. In face milling, the teeth are on the end of the cutter as well as on the outside edge. Milling machines come in all sizes. Most maintenance machining operations are done on one of four types of knee-and-column machines—ram and turret, plain, universal, or vertical.

You can hold and locate the workpiece on the milling machine table using a vise, special clamping devices, or fixtures. The spindle of a milling machine is hollow. The front end of the hole is tapered to match the taper on the milling arbor or other toolholder. Before mounting a cutter, arbor, or toolholder on a spindle, wipe all mating surfaces with a clean rag to remove dirt. There are three basic styles of arbors used for different types of milling procedures. End mills and other shank mounted tools are the types most often used for maintenance work.

You set the spindle speed on a milling machine in revolutions per minute (rpm). However, cutting speed recommendations for milling cutters are in surface feet per minute (sfpm). Sfpm is the speed on the outer surface of the cutter. Therefore you must convert the cutting speed recommendation from sfpm to rpm before you can set the spindle speed. You set the feed rate on a milling machine in inches per minute (ipm). Recommendations for feeds are given in inches per tooth (ipt), so once again you must convert. Next you must determine the direction of feed and kind of cutting fluid. Often a milling job will involve indexing—moving and accurately locating a workpiece in a series of positions. You might use, linear, angular, compound, or differential indexing.

Always use extreme caution when operating a milling machine. Wear protective safety equipment, never loose clothing or jewelry. Clamp all parts securely and keep all machine guards in place. Keep the work area clean, and always stop the machine while you are adjusting or servicing it.

Answers to Self-Check Quiz

1-1. c. On the end and outer edge. Ref: 1.01

1-2. a. Ram-and-turret type. Ref: 1.02(1)

1-3. b. The power head. Ref: 1.04

1-4. d. All of the above. Ref: 1.06

1-5. b. No. 2. Ref: 1.11

1-6. c. The draw-in bold. Ref: 1.19

1-7. a. Hanging them, taper end up. Ref: 1.28

1-8. d. Strip of paper. Ref: 1.31, 1.32

1-9. a. It gives a better finish. Ref: 1.41

1-10. b. Spray mist. Ref: 1.42

Contributions from the following sources are appreciated:

Figure 1-2. Bridgeport Machine Works, Inc.
Figure 1-3. Cincinnati Milacron
Figure 1-4. Clausing Corporation
Figure 1-10. Kearney and Trecker, Inc.