circle. This permits the crank to be turned an accurate, fractional part of a complete circle as represented by the increment between any two holes of a given circle on the index plate. Utilizing the 40:1 gear ratio and the proper hole circle on the index plate, the spindle can be rotated a precise amount by the application of either of the following rules:

\[
\text{number of turns of crank} = \frac{40}{\text{cuts per revolution of work}}
\]

\[
\text{holes to be indexed} = \frac{40 \times \text{holes index circle}}{\text{cuts per revolution of work}}
\]

If the first rule is used, an index circle must be selected that has the proper number of holes to be divisible by the denominator of any resulting fractional portion of a turn of the crank. In using the second rule, the number of holes in the index circle must be such that the numerator of the fraction is an even multiple of the denominator. For example, if 24 cuts are to be taken about the circumference of a workpiece, the number of turns of the crank required would be \(24 \times \frac{40}{1} = 1200\) holes. An index circle having 12 holes could be used with one full turn plus eight additional holes. The second rule would give the same result. Adjustable sector arms are provided on the index plate that can be set to a desired number of holes, less than a full turn, so that fractional turns can be made readily without the necessity for counting holes each time. Dividing heads are made having ratios other than 40:1. The ratio should be checked before using.

Because each full turn of the crank on a standard dividing head represents 360/40, or 9° of rotation of the spindle, indexing to a fraction of a degree can be obtained. Indexing can be done in three ways. Plain indexing is done solely by the use of the 40:1 ratio in the dividing head. In compound indexing, the index plate is moved forward or backward a number of hole spaces each time the crank handle is advanced. For differential indexing the spindle and the index plate are connected by suitable gearing so that as the spindle is turned by means of the crank, the index plate is rotated a proportional amount.

The dividing head can also be connected to the feed screw of the milling machine table by means of gearing. This procedure is used to provide a definite rotation of the workpiece with respect to the longitudinal movement of the table, as in cutting helical gears. This procedure is illustrated in Chapter 29.

### Key Words

- climb (down) milling
- column-and-knee milling machine
- conventional (up) milling cutting time
- end milling
- face milling
- insert-tooth milling cutter
- interrupted cutting
- machining center
- metal removal rate
- milling
- milling cutters
- milling machines
- peripheral milling
- slab milling
- staggered-tooth milling cutter
- straddle milling
- Woodruff keyseat

### Review Questions

1. Suppose you wanted to machine a cast iron with BHN of 275. The process to be used is face milling and an HSS cutter is going to be used. What feed and speed values would you select?
2. Explain how table feed (ipm) and spindle rpm are specified or computed for a milling machine after speed and feed per tooth are selected.
3. Why must the number of teeth on the cutter be known when calculating milling machine table feed, in in./min?
4. Why is the question of up or down milling more critical in horizontal slab milling than in vertical-spindle (end or face) milling?
5. For producing flat surfaces in mass production machining, how does face milling differ basically from peripheral milling?
6. Milling has a higher metal removal rate than planing. Why?
7. Which type of milling (up or down) is being done in Figures 24-1, Figure 24-2, and 24-7?
8. Why does down milling dull the cutter more rapidly than up milling when machining sand castings?
9. What parameters do you need to specify in order to calculate MRR in milling?
10. In Figure 24-2b the tool material is carbide. What would you change in the process?
11. What is the advantage of a helical-tooth cutter over a straight-tooth cutter for slab milling?
12. What would the cutting force diagram for \( F_e \) look like if the cutter were performing climb milling?
13. Could the stub arbor-mounted face mill shown in Figure 24-9 be used to machine a T-slot? Why or why not?
14. In a typical solid arbor milling cutter shown in Figure 24-10, why are the teeth staggered? (Check in Chapter 19 for discussion of dynamics.)
15. Make some sketches to show how you would set up a plain column-and-knee milling machine to make it suitable for milling the top and sides of a large block.
16. Make some sketches to show how you would set up a horizontal milling machine to cut both sides of a block of metal simultaneously.
17. Explain how controlled movements of the work in three mutually perpendicular directions are obtained in column-and-knee-type milling machines.
18. What is the basic principle of a universal dividing head?
19. What is the purpose of the hole-circle plate on a universal dividing head?

**Problems**

1. You have selected a feed per tooth and a cutting speed for a face milling process. Reasonable values for feed and speed are 0.010 in. per tooth and 200 sfpm. The cutter is 8 in. in diameter, as shown in Figure 24-9. Compute the input values for the machine tool.
2. How much time will be required to face mill an AISI 1020 steel surface Bhn, 150, that is 12 in. long and 5 in. wide, using a 6-in.-diameter, eight-tooth tungsten carbide inserted-tooth face mill cutter? Select values of feed per tooth and cutting speed from Table 24-1.
3. If the depth of cut is 0.35 in., what is the metal removal rate in Problem 2?
4. Estimate the power required for the operation of Problem 3. Do not forget to consider Figure 24-7.
5. Examine the part shown in Figure 24-6. The slot on the left end must be machined by machining. Provide a process plan (a description [sketch] of how the part would set up in the machine for machining the slot and the details regarding cutting tools, such as material, sizes, and so on). Specify (select) the type of milling machine, the cutting parameters, and any other information needed to make this component.
6. A gray cast iron surface 6 in. wide and 18 in. long may be machined on either a vertical milling machine, using an 8-in.-diameter face mill having eight inserted HSS teeth, or on a horizontal milling machine using an HSS slab mill with eight teeth on a 4-in. diameter. Which machine has the faster cutting time?
7. An operation is to be performed to machine three grooves on a number of parts shown in Figure 24-11. Setup time is 20 minutes on a shaper (not shown) and 30 minutes on the horizontal milling machine. The direct time to machine each piece on the shaper is 14 min and on the miller is 6 min. Labor costs $10/hr. The charge for the use of the shaper is $10/hr and for the milling machine $20/hr. What is the breakeven quantity, below which the shaper is more economical than the mill?
8. In Figure 24-12, the feed is 0.006 in. per tooth. The cutter is rotating at an rpm that will produce the desired surface cutting speed of 125 sfpm. The cutter diameter is 5 in. The depth of cut is 0.5 in. The block is 2 in. wide.
   a. What is the feed, in inches per minute, of the milling machine table?
   b. What is the MRR for this situation?
   c. What is horsepower (HP) consumed by this process, assuming an 80% efficiency and a HP, value for this material of 1.8?
9. Suppose you want to do the job described in Problem 6 by slab milling. You have selected a 6-in.-diameter cutter with eight TiN-coated carbide teeth. The cutting speed will be 500 sfpm and the feed per tooth will be 0.010 in. per tooth. Determine the input parameters for the machine (rpm of arbor and table feed), then calculate the \( T_m \) and MRR. Compare these answers with what you got for face milling the block with HSS teeth.
10. The Bridgeport vertical-spindle milling machine is perhaps the single most popular machine tool. Virtually every factory (or shop) that does machining has one or more of these type machines. Go to your nearest machine shop and find a Bridgeport, make a sketch to show how it works, and explain what makes it so popular.