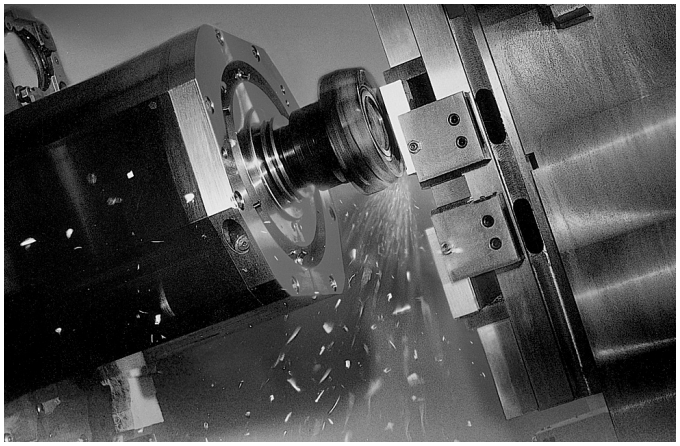


Chapter 17

The Milling Machine

LEARNING OBJECTIVES

After studying this chapter, students will be able to:

- Describe how milling machines operate.
- Identify the various types of milling machines.
- Select the proper cutter for the job to be done.
- Calculate cutting speeds and feeds.

INSTRUCTIONAL MATERIALS

Text: pages 285–316
Test Your Knowledge Questions, pages 314–316
Workbook: pages 91–98
Instructor's Resource: pages 223–238
Guide for Lesson Planning
Research and Development Ideas
Reproducible Masters:
17-1 Horizontal Milling Machine
17-2 Vertical Milling Machine
17-3 Cutter Hand (right and left)
17-4 Conventional and Climb Milling
17-5 Cutting Speeds and Feeds
17-6 Rules for Determining Speed and Feed
17-7 Cutting Speed and Feed Problems
17-8 Test Your Knowledge Questions
Color Transparency (Binder/CD only)

GUIDE FOR PLANNING LESSON

Due to the amount of material covered, it would be advisable to divide this chapter into several segments. Although it has been divided into six parts here, each classroom situation will dictate what division would work best.

Part I—Types of Milling Machines

Set up horizontal and vertical milling machines for demonstration purposes.

Have the class read and study pages 285–293. Review the assignment using Reproducible Masters 17-1 and 17-2 as overhead transparencies and/or handouts. Discuss and demonstrate the following:

- How milling machines work.
- Types of milling machines.
- Difference between plain-type horizontal milling machine and universal-type horizontal milling machine.
- Methods of milling machine control.
- How to adjust cutting speed and feed.
- Milling operations.
- Milling safety practices.

Briefly review the demonstrations. Provide students/trainees with the opportunity to ask questions.

Part II—Milling Cutters

Set up milling machines to demonstrate facing and peripheral milling operations. Be sure the

entire class is wearing approved eye protection as they view the demonstration. Also have a selection of milling cutters on hand for the class to examine. Explain how to handle milling cutters safely.

Have students/trainees read and study pages 293–304. Review the assignment, use Reproducible Master 17-3 as an overhead transparency and/or handout when discussing cutter hand. Discuss and demonstrate the following:

- Face milling and peripheral milling.
- Milling cutter classification.
- Milling cutter material.
- End mills.
- Face milling cutters.
- Fly cutters.
- Arbor milling cutters.
- Miscellaneous milling cutters.
- Care of milling cutters.
- Methods of milling.
- How to safely handle milling cutters.

Briefly review the demonstrations. Provide students/trainees with the opportunity to ask questions.

Part III—Holding and Driving Cutters

Have class read and study pages 304–308 paying particular attention to the illustrations. Review the assignment and discuss the following:

- Various types of arbors.
- Installing and removing cutter holding devices from the machines.
- Using collets.
- Care of cutter holding and driving devices.

Briefly review the demonstrations. Provide students/trainees with the opportunity to ask questions.

Part IV—Milling Cutting Speeds and Feeds

Have students/trainees read and study pages 308–310. Review the assignment emphasizing the importance of using the correct speeds and feeds. Use Reproducible Masters 17-5, 17-6, and 17-7 as overhead transparencies and/or handouts. Discuss the following:

- Calculating the correct cutting speeds and feeds.
- The purpose of cutting fluids and their importance in maintaining optimum cutting action.

Briefly review the demonstrations. Provide students/trainees with the opportunity to ask questions. Reproducible Master 17-7 contains problems that can be used as an in-class assignment of homework.

Part IV—Milling Work-Holding Attachments

An assortment of work-holding attachments should be available for class examination.

Have the class read and study pages 310–314. They should pay particular attention to the illustrations. Review the assignment and discuss the following:

- The advantages and disadvantages of the various types of vises.
- When a magnetic chuck should be used for milling operations.
- The use of the rotary and index tables.
- The dividing head and how it is set up and used.
- Safety procedures to be followed when handling heavy work-holding attachments.

Briefly review the demonstrations. Provide students/trainees with the opportunity to ask questions.

Technical Terms

Review the terms introduced in the chapter. New terms can be assigned as a quiz, homework, or extra credit. These terms are also listed at the beginning of the chapter.

arbor
climb milling
column and knee milling machine
face milling
horizontal spindle milling machine
peripheral milling
rate of feed
side milling cutters
traverse
vertical spindle milling machine

Review Questions

Assign *Test Your Knowledge* questions. Copy and distribute Reproducible Master 17-8 or have students use the questions on pages 314–316 and write their answers on a separate sheet of paper.

Workbook Assignment

Assign Chapter 17 of the ***Machining Fundamentals Workbook.***

Research and Development

Discuss the following topics in class or have students complete projects on their own.

1. Prepare a display panel that includes samples of the various types of milling cutters. Include manufacturers' catalogs and price lists.
2. Develop a bulletin board using illustrations of the various types of milling machines. If available, include how much each machine costs.
3. The milling machine and its inventor, Eli Whitney, played an important part in developing mass production techniques. Prepare a term paper on Whitney's project of producing 10,000 muskets with interchangeable parts for the federal government in 1798. Include information on how this project led to the invention of the milling machine.
4. Make a series of posters dealing with milling machine safety.
5. Cutting fluids play an important part in any machining operation. Secure samples of cutting fluids used by industry and conduct a series of experiments to show the quality of surfaces machined dry and with the various cutting compounds. Your experiment should include milling aluminum, brass, and steel.
6. Overhaul and paint a milling machine in your training facility.
7. Demonstrate how to use a dividing head.
8. Present a video on CNC milling machines. Lead the discussion on what was seen.
9. Milling machines were the first machine tools to be automated. Do a research project on automated milling machines. Include samples of the programs, tapes, and specialized drawings used.

TEST YOUR KNOWLEDGE ANSWERS, Pages 314–316

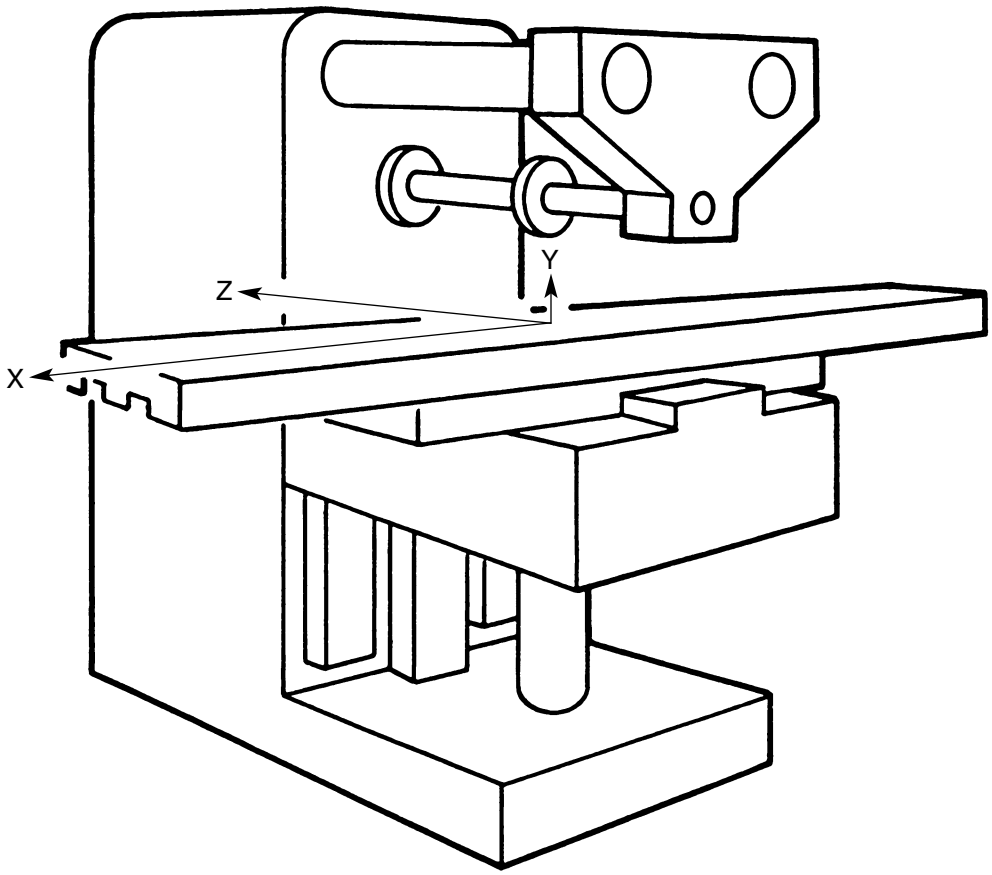
1. fixed bed, knee and column
2. a. plain
   b. universal
   c. vertical
3. Any order: manual, semi-automatic, fully automatic, computerized. Evaluate description of each individually. Refer to Section 17.1.6.
4. measurements, adjustments
5. hand, brush
6. d. All of the above.
7. cloth, gloves
8. a. Face
   b. Peripheral
9. Solid cutter and inserted-tooth cutter.
10. Direction of rotation and helix of flutes.
11. d. Can be fed into work like a drill.
12. f. Recommended for conventional milling where plunge cutting (going into work like a drill) is *not* required.
13. c. A facing mill with a single-point cutting tool.
14. i. Mounts on a stub arbor.
15. g. Intended for machining large flat surfaces parallel to the cutter face.
16. e. Cutter with teeth located around the circumference.
17. b. Cutter with helical teeth designed to cut with a shearing action.
18. a. Has cutting teeth on the circumference and on one or both sides.
19. j. Has alternate right-hand and left-hand helical teeth.
20. h. Thin milling cutter designed for machining narrow slots and for cutoff operations.
21. fly, inserted
22. Evaluate individually. Refer to Figure 17-60.
23. Evaluate individually. Refer to Figure 17-60.
24. b. The work moves in the same direction as the rotation of the cutter.
25. a. The work is fed into the rotation of the cutter.
26. Threaded metal rod that fits through the spindle. It screws into the arbor or collet and holds it firmly in the spindle.
27. Cutting speed, feet, meters, one minute
28. Feed
29. 485 rpm, 10 ipm
30. 840 rpm, 67 ipm
31. 350 rpm
32. 190 rpm, 15 ipm
33. 380 rpm, 18 ipm
34. Any three of the following: dissipate heat; lubricate; prevent chips from sticking or fusing with the cutter teeth; flush away chips; influence the finish quality of the machined surface.

35. b. Can only be mounted parallel to or at right angles on worktable.
36. e. Has circular base graduated in degrees.
37. h. Permits compound angles (angles on two planes) to be machined without complex or multiple setups.
38. c. Needed when cutting segments of circles, circular slots, and irregular shaped slots.
39. g. Used to divide circumference of round work into equally spaced divisions.
40. f. Permits rapid positioning of circular work in 15° increments and can be locked at any angular setting.
41. d. Can only be used with ferrous metals.
42. a. Keys vise to a slot in worktable.

WORKBOOK ANSWERS, Pages 91–98

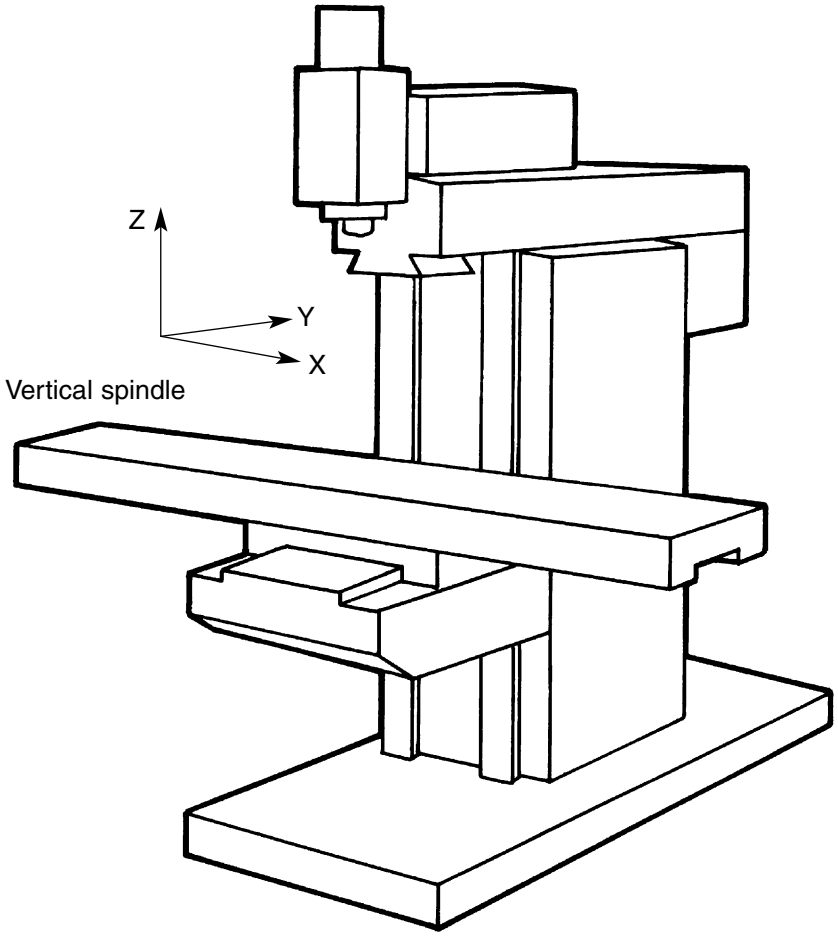
1. e. All of the above.
2. cutter head
3. a. permits work to be positioned at several times the fastest rate indicated on the feed chart
4. d. All of the above.
5. Evaluate individually. Refer to Section 17.2.
6. Cutting speed refers to the distance, measured in feet or meters, a point (tooth) on the cutter's circumference will travel in one minute.
7. feet, meters
8. d. All of the above.
9. d. All of the above.
10. b. 3–10 times faster
11. c. Both of the above.
12. A single-point (cutting tool) face mill.
13. fed, drill
14. conventional, plunge
15. stub, end
16. c. plain milling
17. e. slab milling
18. b. side milling
19. d. staggered-tooth side
20. a. metal slitting saw
21. Feed is the rate at which the work moves into the cutter.
22. d. All of the above.
23. b. semicircular keyseats
24. d. All of the above.
25. shortest
26. Feed per tooth per revolution.
27. collars
28. Drive keys
29. Evaluate individually. Refer to section 17.7.1.
30. 250 rpm
31. 460 rpm
32. 350 rpm
33. 17800 rpm
34. 16 ipm
35. 39.6 ipm
36. is not
37. First move the workpiece clear of the cutter. Disengage the crank by withdrawing the pin from the index plate and rotating it clockwise through the section marked by the sector arms. Drop the pin into the hole at the position of the second sector arm and lock the dividing head mechanism. Next, move the sector arms in the same direction as crank rotation to catch up with the pin in the index crank. For each cut, repeat the operation.
38. d. All of the above.
39. dividing head
40. A. Vertical movement crank
    B. Saddle
    C. Longitudinal feed handwheel
    D. Swivel
    E. Overarm
    F. Motor
    G. Quill feed lever
    H. Quill feed handwheel
    I. Quill
    J. Spindle
    K. Worktable
    L. Cross traverse handwheel
    M. Base

Horizontal Milling Machine



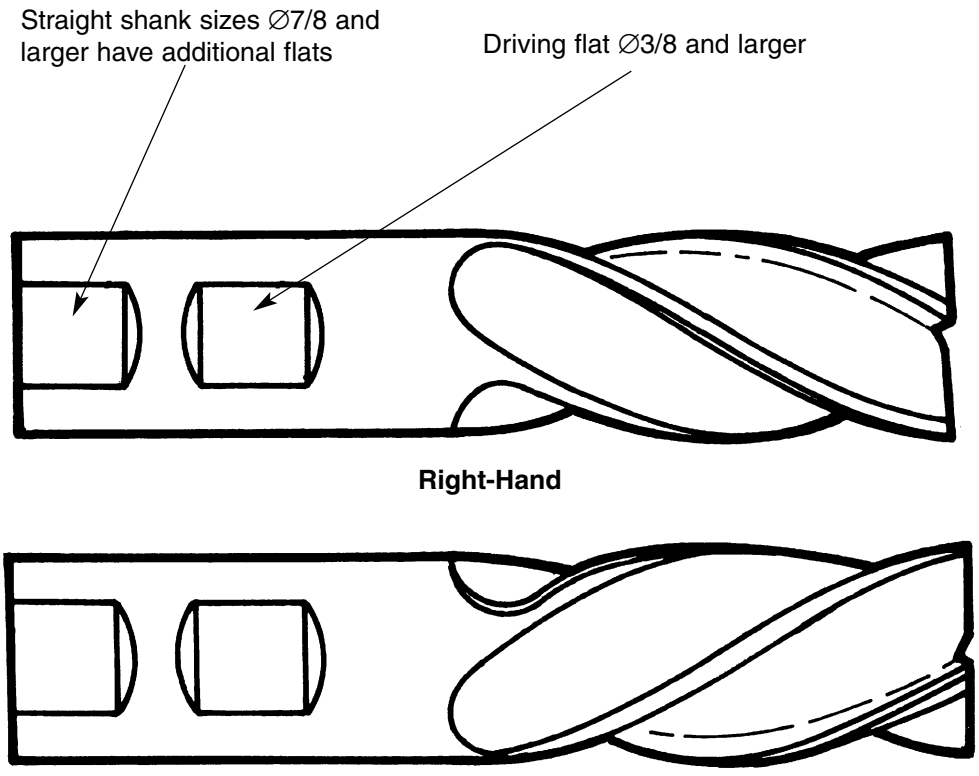
Spindle motion is assigned Z axis.

Vertical Milling Machine



Spindle motion is assigned Z axis.

Cutter Hand

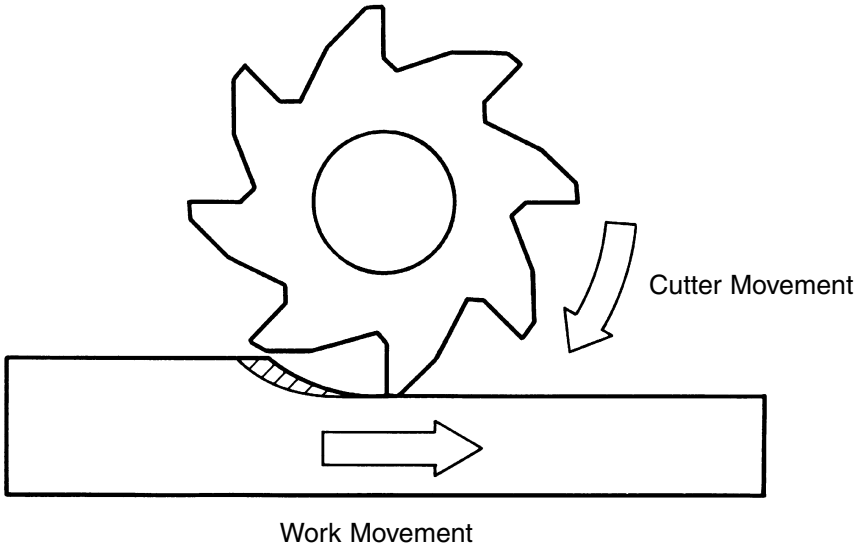


Right-Hand

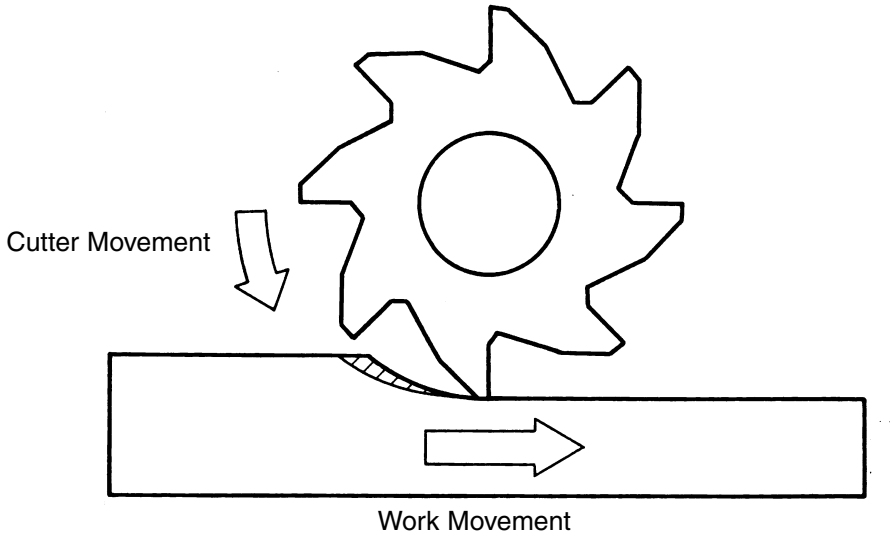
Left-Hand

Cutter is right-hand if it rotates counterclockwise when viewed from cutting end. It is left-hand if rotation is clockwise.

Conventional and Climb Milling



Conventional (up) Milling



Climb (down) Milling

Cutting Speeds and Feeds

Material	High-speed steel cutter		Carbide cutter	
	Feet per minute	Meters per minute*	Feet per minute	Meters per minute*
Aluminum	550–1000	170–300	2200–4000	670–1200
Brass	250–650	75–200	1000–2600	300–800
Low carbon steel	100–325	30–100	400–1300	120–400
Free cutting steel	150–250	45–75	600–1000	180–300
Alloy steel	70–175	20–50	280–700	85–210
Cast iron	45–60	15–20	180–240	55–75

Reduce speeds for hard materials, abrasive materials, deep cuts, and high alloy materials. Increase speeds for soft materials, better finishes, light cuts, frail work, and setups. Start at midpoint on the range and increase or decrease speed until best results are obtained.
*Figures rounded off.

Recommended cutting speeds for milling. Speed is given in surface feet per minute (fpm) and in surface meters per minute (mpm).

	Material				
Type of cutter	**Aluminum**	**Brass**	**Cast iron**	**Free cutting steel**	**Alloy steel**
End mill	0.009 (0.22) 0.022 (0.55)	0.007 (0.18) 0.015 (0.38)	0.004 (0.10) 0.009 (0.22)	0.005 (0.13) 0.010 (0.25)	0.003 (0.08) 0.007 (0.18)
Face mill	0.016 (0.40) 0.040 (1.02)	0.012 (0.30) 0.030 (0.75)	0.007 (0.18) 0.018 (0.45)	0.008 (0.20) 0.020 (0.50)	0.005 (0.13) 0.012 (0.30)
Shell end mill	0.012 (0.30) 0.030 (0.75)	0.010 (0.25) 0.022 (0.55)	0.005 (0.13) 0.013 (0.33)	0.007 (0.18) 0.015 (0.38)	0.004 (0.10) 0.009 (0.22)
Slab mill	0.008 (0.20) 0.017 (0.43)	0.006 (0.15) 0.012 (0.30)	0.003 (0.08) 0.007 (0.18)	0.004 (0.10) 0.008 (0.20)	0.001 (0.03) 0.004 (0.10)
Side cutter	0.010 (0.25) 0.020 (0.50)	0.008 (0.20) 0.016 (0.40)	0.004 (0.10) 0.010 (0.25)	0.005 (0.13) 0.011 (0.28)	0.003 (0.08) 0.007 (0.18)
Saw	0.006 (0.15) 0.010 (0.25)	0.004 (0.10) 0.007 (0.18)	0.001 (0.03) 0.003 (0.08)	0.003 (0.08) 0.005 (0.13)	0.001 (0.03) 0.003 (0.08)

Increase or decrease feed until the desired surface finish is obtained.
Feeds may be increased 100 percent or more depending upon the rigity of the machine and the power available, if carbide tipped cutters are used.

Recommended feed rates in inches per tooth and millimeters (shown in parentheses) per tooth for high speed steel (HSS) milling cutters.

Rules for Determining Speed and Feed

To find	Having	Rule	Formula
Speed of cutter in feet per minute (fpm)	Diameter of cutter and revolutions per minute	Diameter of cutter (in inches) multiplied by 3.1416 (π) multiplied by revolutions per minute, divided by 12	$fpm = \frac{\pi D \times rpm}{12}$
Speed of cutter in meters per minute	Diameter of cutter and revolutions per minute	Diameter of cutter multiplied by by 3.1416 (π) multiplied by revolutions per minute, divided by 1000	$mpm = \frac{D(mm) \times \pi \times rpm}{1000}$
Revolutions per minute (rpm)	Feet per minute and diameter of cutter	Feet per minute, multiplied by 12, divided by circumference of cutter (πD)	$rpm = \frac{fpm \times 12}{\pi D}$
Revolutions per minute (rpm)	Meters per minute and diameter of cutter in millimeters (mm)	Meters per minute multiplied by 1000, divided by the circumference of cutter (D)	$rpm = \frac{mpm \times 1000}{\pi D}$
Feed per revolution (FR)	Feed per minute and revolutions per minute	Feed per minute, divided by revolutions per minute	$FR = \frac{F}{rpm}$
Feed per tooth per revolution (ftr)	Feed per minute and number of teeth in cutter	Feed per minute (in inches or millimeters) divided by number of teeth in cutter $\times$ revolutions per minute	$ftr = \frac{F}{T \times rpm}$
Feed per minute (F)	Feed per tooth per revolution, number of teeth in cutter, and rpm	Feed per tooth per revolution multiplied by number of teeth in cutter, multiplied by revolutions per minute	$F = ftr \times T \times rpm$
Feed per minute (F)	Feed per revolution and revolutions per minute	Feed per revolution multiplied by revolutions per minute	$F = FR \times rpm$
Number of teeth per minute (TM)	Number of teeth in cutter and revolutions per minute	Number of teeth in cutter multiplied by revolutions per minute	$TM = T \times rpm$

rpm = Revolutions per minute
T = Teeth in cutter
D = Diameter of cutter
π = 3.1416 (pi)
frm = Speed of cutter in feet per minute
TM = Teeth per minute
F = Feed per minute
FR = Feed per revolution
ftr = Feed per tooth per revolution
mpm = Speed of cutter in meters per minute

Cutting Speed and Feed

Name: _____ Date: _____ Score: _____

Refer to the *Rules for determining cutting speeds and feeds* to calculate the cutting speed and feed for specific materials.

1. Determine the proper speed and feed for a 5″ diameter HSS side milling cutter with 22 teeth, milling aluminum. Answer the following: 1. _____

   Recommended cutting speed for aluminum (midpoint on range) = _____

   Recommended feed per tooth (midpoint on range) = _____

   Cutter diameter = 5″

   Number of teeth on cutter = 22

2. Determine the proper speed and feed for a 4″ diameter HSS helical slab cutter with 6 teeth, milling low-carbon steel. Answer the following: 2. _____

   Recommended cutting speed for low-carbon steel (midpoint on range) = _____

   Recommended feed per tooth (midpoint on range) = _____

   Cutter diameter = 4″

   Number of teeth on cutter = 6

The Milling Machine

Name: _____ Date: _____ Score: _____

1. Milling machines fall into two broad classifications: _____ and _____ types.
   1. _____
      _____
2. There are three basic types of milling machines.
   a. A _____ type has a horizontal spindle and the worktable has three movements.
   b. A _____ type is similar to the above machine but a fourth movement has been added to the worktable to permit it to cut helical shapes.
   c. A _____ type has the spindle perpendicular or at right angles to the worktable.
   2. a. _____
      b. _____
      c. _____
3. List the four methods of machine control. Briefly describe each of them.

   _____

   _____

   _____

   _____

4. Stop the machine before making _____ and _____.
   4. _____
      _____
5. Metal chips must never be removed with your _____. Use a _____.
   5. _____
      _____
6. Treat all small cuts and skin punctures as potential sources of infection. The following should be done:
   a. Clean them thoroughly.
   b. Apply antiseptic and cover with a bandage.
   c. Promptly report the injury to your instructor.
   d. All of the above.
   e. None of the above.
   6. _____
7. Milling cutters are sharp. Protect your hands with a _____ or _____ when handling them.
   7. _____
      _____
8. Milling operations fall into two main categories:
   a. _____ milling, in which the surface being machined is parallel with the cutter face.
   b. _____ milling, in which the surface being machined is parallel with the periphery of the cutter.
   8. a. _____
      b. _____
9. What are two general types of milling cutters?_____

   _____

Name: _____

10. What is the term *"hand"* used to describe, in reference to an end mill? _____

_____

_____

- Match each term on the left with the correct description on the right.

_____11. Two-flute end mill.

_____12. Multiflute end mill.

_____13. Fly cutter.

_____14. Shell end mill.

_____15. Face milling cutter.

_____16. Plain milling cutter.

_____17. Slab cutter.

_____18. Side milling cutter.

_____19. Staggered-tooth side cutter.

_____20. Metal slitting saw.

a. Has cutting teeth on the circumference and on one or both sides.
b. Cutter with helical teeth designed to cut with a shearing action.
c. A facing mill with a single-point cutting tool.
d. Can be fed into work like a drill.
e. Cutter with teeth located around the circumference.
f. Recommended for conventional milling where plunge cutting (going into work like a drill) is *not* required.
g. Intended for machining large flat surfaces parallel to the cutter face.
h. Thin milling cutter designed for machining narrow slots and for cutoff operations.
i. Mounts on a stub arbor.
j. Has alternate right-hand and left-hand helical teeth.

21. Flat surfaces are machined with _____ or _____ tooth milling cutters. 21. _____

_____

22. Make a sketch that illustrates climb milling. *Draw your sketch below.*

23. Make a sketch illustrating conventional milling. *Draw your sketch below.*

Name: _____

24. In climb milling: 24. _____
    a. The work is fed into the rotation of the cutter.
    b. The work moves in the same direction as the rotation of the cutter.
    c. Neither of the above.
25. In conventional milling: 25. _____
    a. The work is fed into the rotation of the cutter.
    b. The work moves in the same direction as the rotation of the cutter.
    c. Neither of the above.
26. What is a draw-in bar, and how is it used? _____

    _____

    _____
27. _____ refers to the distance, measured in _____ or _____, that a point (tooth) on the circumference of a cutter moves in _____. 27. _____

    _____

    _____

    _____
28. _____ is the rate at which the work moves into the cutter. 28. _____

- Using the formulas below, find the answers for problems 29–33. Use the space provided to show your calculations.

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

$$F = ftr \times T \times rpm$$

29. Calculate machine speed (rpm) and feed (F) for a 1.5″ diameter tungsten carbide 5 tooth (T) end mill when machining cast iron. Recommended cutting speed is 190 fpm. Feed per tooth (ftr) is 0.004″.

30. Determine machine speed (rpm) and feed (F) for a 2.5″ diameter HSS shell end mill with 8 teeth (T), machining aluminum. Recommended cutting speed is 550 fpm. Feed per tooth (ftr) is 0.010″.

Name: _____

31. Calculate machine speed (rpm) for machining aluminum with a 6″ diameter HSS side milling cutter. Recommended cutting speed is 550 fpm.

32. Determine machine speed (rpm) and feed (F) for a 4″ diameter HSS side milling cutter with 16 teeth (T) milling free cutting steel. Recommended cutting speed is 200 fpm. Feed per tooth (ftr) is 0.005″.

33. Calculate machine speed (rpm) and feed (F) for a 2.5″ diameter HSS slab milling cutter with 8 teeth (T) machining brass. Recommended cutting speed is 250 fpm. Feed per tooth (ftr) is 0.006″.

34. Cutting fluids serve several purposes. List at least three of them.

_____

_____

_____

_____

_____

- Match each term on the left with the correct description on the right.

_____35. Flanged vise.

_____36. Swivel vise.

_____37. Universal vise.

_____38. Rotary table.

_____39. Dividing head.

_____40. Indexing table.

_____41. Magnetic chuck.

_____42. Vise lug.

a. Keys vise to a slot in worktable.
b. Can only be mounted parallel to or at right angles on worktable.
c. Needed when cutting segments of circles, circular slots, and irregular shaped slots.
d. Can only be used with ferrous metals.
e. Has a circular base graduated in degrees.
f. Permits rapid positioning of circular work in 15° increments and can be locked at any angular setting.
g. Used to divide circumference of round work into equally spaced divisions.
h. Permits compound angles (angles on two planes) to be machined without complex or multiple setups.