1. Milling Introduction

Milling machine is one of the most versatile conventional machine tools with a wide range of metal cutting capability. Many complicated operations such as indexing, gang milling, and straddle milling etc. can be carried out on a milling machine.

This training module is intended to give you a good appreciation on the type of milling machines and the various types of milling processes. Emphasis is placed on its industrial applications, operations, and the selection of appropriate cutting tools.

On completion of this module, you will acquire some of these techniques from the training exercises as illustrated in figure 1. However, to gain maximum benefit, you are strongly advised to make yourself familiar with the following notes before undertaking the training activities, and to have a good interaction between yourself and the staff in charge of your training.

Assessment of your training will be based on a combination of your skill and attitude in getting the work done.

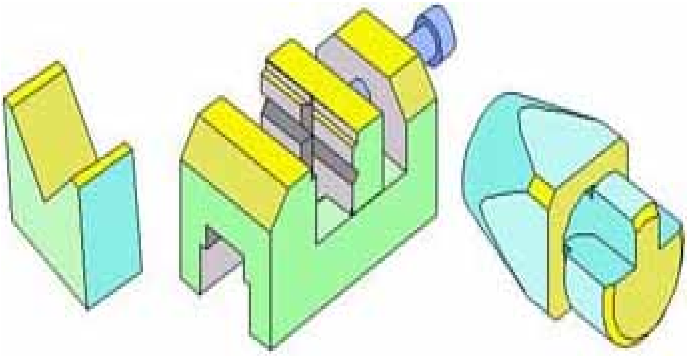


Figure 1. Milling Products

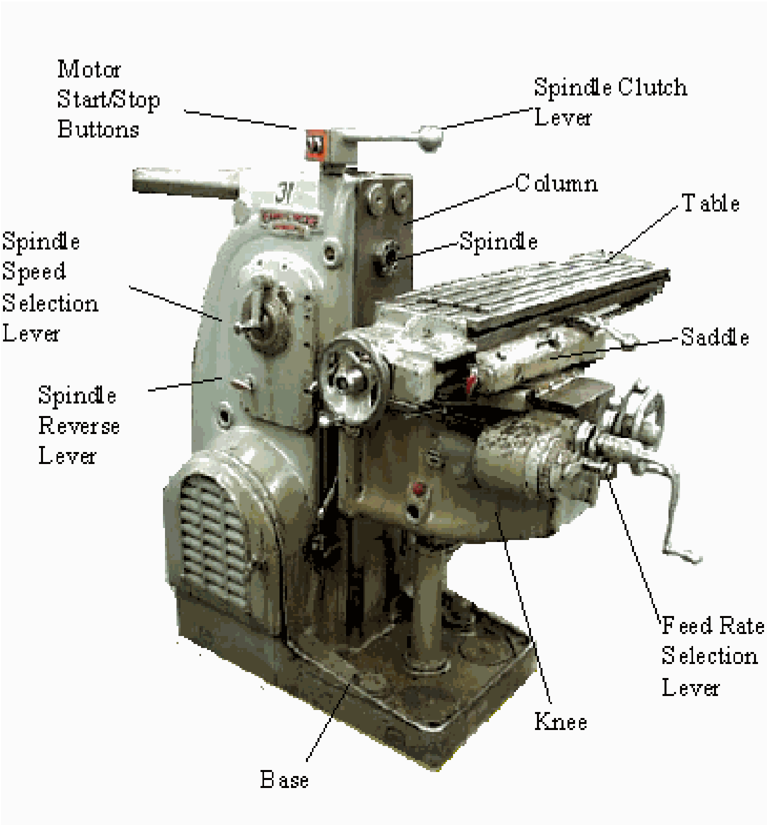
2. Types of Milling Machine

Most of the milling machine are constructed of ¡¥column and knee¡¦ structure and they are classified into two main types namely Horizontal Milling Machine and Vertical Milling Machine. The name Horizontal or Vertical is given to the machine by virtue of its spindle axis. Horizontal machines can be further classified into Plain Horizontal and Universal Milling Machine. The main difference between the two is that the table of an Universal Milling Machine can be set at an angle for helical milling while the table of a Plain Horizontal Milling Machine is not.

2.1. Horizontal Milling Machine

Figure 2 shows the main features of a Plain Horizontal Milling Machine.

Their functions are :-



a. Column
The column houses the spindle, the bearings, the gear box, the clutches, the shafts, the pumps, and the shifting mechanisms for transmitting power from the electric motor to the spindle at a selected speed.

b. Knee
The knee mounted in front of the column is for supporting the table and to provide an up or down motion along the Z axis.

c. Saddle
The saddle consists of two slideways, one on the top and one at the bottom located at 90º to each other, for providing motions in the X or Y axes by means of lead screws.

d. Table
The table is mounted on top of the saddle and can be moved along the X axis. On top of the table are some T-slots for the mounting of workpiece or clamping fixtures.

e. Arbor
The arbor is an extension of the spindle for mounting cutters. Usually, the thread end of an arbor is of left hand helix.

f. Base

The base of the milling machine, along with the column, are the major structural components. They hold, align, and support the rest of the machine.

g. Spindle

The spindle holds the tool and provides the actual tool rotation.

h. Spindle Reverse Lever

The position of this lever determines the spindle direction. The three positions of the handle are; In, Middle, and Out. The middle position is the neutral position. Never move the spindle reverse lever when the spindle is turning.

ı. Spindle Speed Selection Lever

The spindle speed selection lever is used to change the spindle R.P.M. setting. This type of machine has a geared head so the spindle speed can only be changed when the spindle is stopped.

j. Spindle Clutch Lever

The spindle clutch lever engages the spindle clutch to the motor. By manipulating the spindle clutch lever the operator can start and stop the spindle.

k. Feed Rate Selection Lever

The feed rate selection lever is used to change the feed rate setting. The feed rate settings are expressed in inches per minute.

m. Motor Start and Stop Buttons-

The motor start and stop buttons control the power to the main motor for the machine

2.2. Vertical Milling Machine

Figure 3 shows a vertical milling machine which is of similar construction to a horizontal milling machine except that the spindle is mounted in the vertical position.

Its additional features are :-

a.Milling head
The milling head consisting the spindle, the motor, and the feed control unit is mounted on a swivel base such that it can be set at any angle to the table.

b. Ram
The ram on which the milling head is attached can be positioned forward and backward along the slideway on the top of the column.

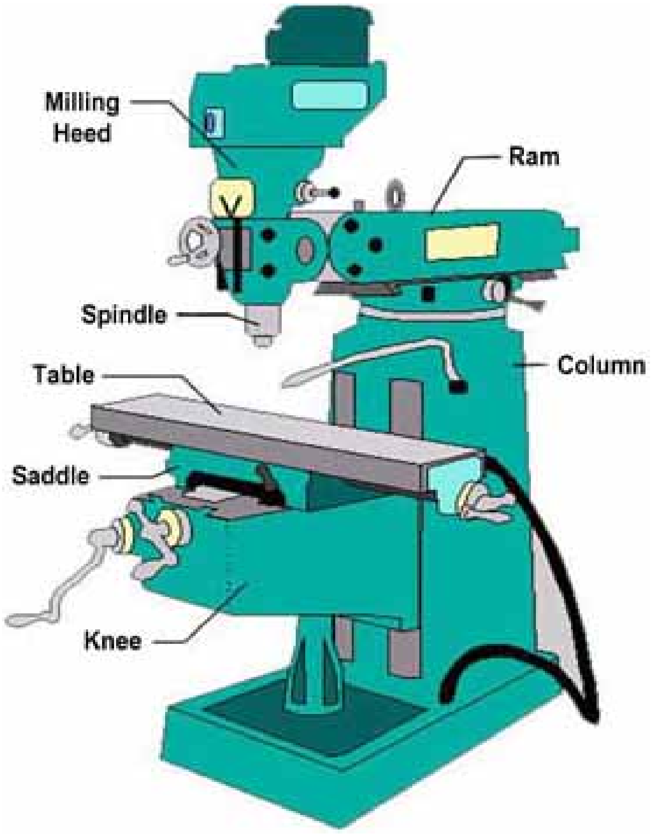


Figure 3. Vertical Milling Machine

3. Cutting Tools

3.1. Cutting Tools for Horizontal Milling

a. Slab Mills
For heavy cutting of large and flat surfaces.

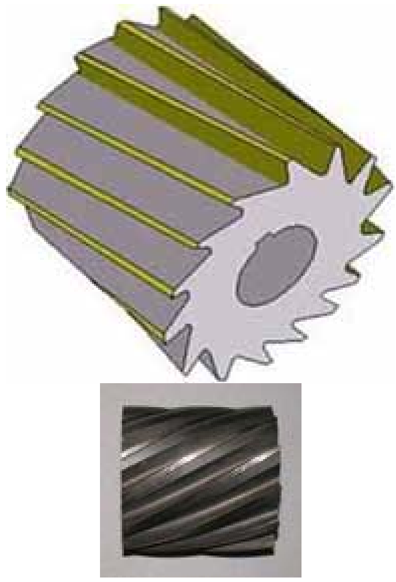


Figure 4. Slab Mill

b. Side and Face Cutters
This type of cutters has cutting edges on the periphery and sides of the teeth for cutting shoulders and slots.

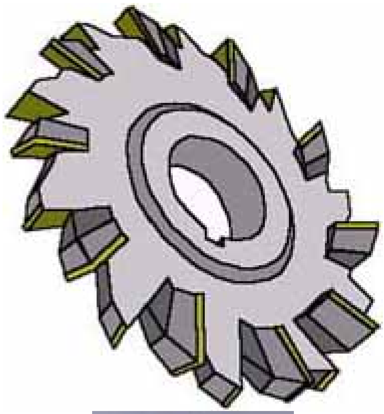


Figure 5. Side and Face Cutter

c. Slitting Saws
For cutting deep slots or for parting off.

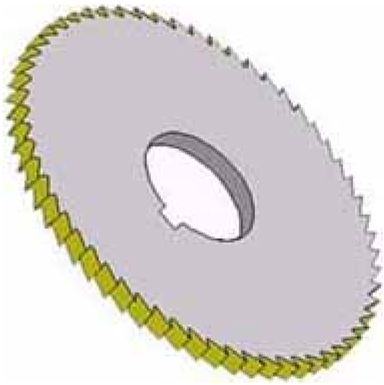


Figure 6. Slitting Saw

3.2. Cutting tools for Vertical Milling
a. End Mills
Commonly used for facing, slotting and profile milling.

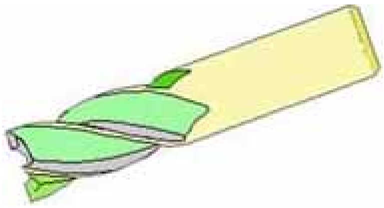


Figure 7. End Mill

b. Rough Cut End Mills
For rapid metal removal.

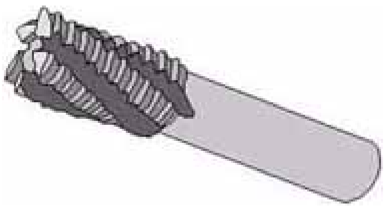


Figure 8. Rough Cut End Mill

c. Slot Drills
For producing pockets without drilling a hole before hand.

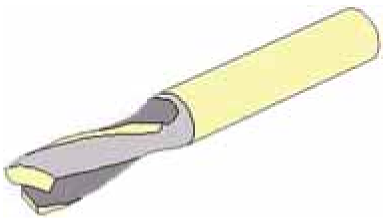


Figure 9. Slot Drill

d. Face Milling Cutters
For heavy cutting.

Figure 10. Face Milling Cutter

Involute gear cutter

Involute gear cutter - No. 4

The image shows a *Number 4* cutter from an involute gear cutting set. There are 7 cutters (excluding the rare half sizes) that will cut gears from 12 teeth through to a rack (infinite diameter). The cutter shown has markings that show it is a

- 10 DP (diametrical pitch) cutter
- That it is No. 4 in the set
- that it cuts gears from 26 through to 34 teeth
- It has a 14.5 degree pressure angle

Hobbing cutter

Fig. Hobbing cutter

These cutters are a type of form tool and are used in hobbing machines to generate gears. A cross section of the cutters tooth will generate the required shape on the workpiece, once set to the appropriate conditions (blank size). A hobbing machine is a specialised milling machine.

4. Industrial Applications

Milling machines are widely used in the tool and die making industry and are commonly used in the manufacturing industry for the production of a wide range of components as shown in figure 11. Typical examples are the milling of flat surface, indexing, gear cutting, as well as the cutting of slots and key-ways.

5. Milling Processes

Milling is a metal removal process by means of using a rotating cutter having one or more cutting teeth as illustrated in figure 13.

Cutting action is carried out by feeding the workpiece against the rotating cutter. Thus, the spindle speed, the table feed, the depth of cut, and the rotating direction of the cutter become the main parameters of the process. Good results can only be achieved with a well balanced settings of these parameters.

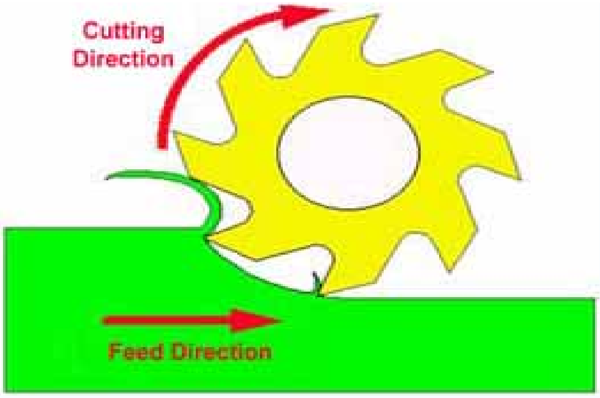


Figure 13. Milling Process

5.1. Spindle Speed

Spindle speed in revolution per minute (R.P.M.) for the cutter can be calculated from the equation :-

$$N = \frac{CS \times 1000}{\pi d}$$

where -- **N** = R.P.M. of the cutter
CS = Linear Cutting Speed of the material in m/min. (see table 1)
d = Diameter of cutter in mm

5.2. Feed Rate

Feed rate (F) is defined as the rate of travel of the workpiece in mm/min. But most tool suppliers recommend it as the movement per tooth of the cutter (f). Thus,

$$\mathbf{F = f \cdot u \cdot N}$$

where -- **F** = table feed in mm/min
f = movement per tooth of cutter in mm (see table 1)
u = number of teeth of cutter
N = R.P.M. of the cutter

where

C.S. and feed rate for some common material :-

Tool Material	**High Speed Steel**		**Carbide**	
Material	Cutting Speed	Feed (f)	Cutting Speed	Feed (f)
Mild Steel	25	0.08	100	0.15
Aluminium	100	0.15	500	0.3
Hardened Steel	---	---	50	0.1

Table 1

5.3. Depth of Cut

Depth of cut is directly related to the efficiency of the cutting process. The deeper the cut the faster will be the production rate. Yet, it still depends on the strength of the cutter and the material to be cut.

For a certain type of cutter, a typical range of cut will be recommended by the supplier. Nevertheless, it should be noted that a finer cut is usually associated with a better surface finish as well as a long tool life.

5.4. Direction of Cutter Rotation

a. Up Cut Milling

In up cut milling, the cutter rotates in a direction opposite to the table feed as illustrated in figure 14. It is conventionally used in most milling operations because the backlash between the leadscrew and the nut of the machine table can be eliminated.

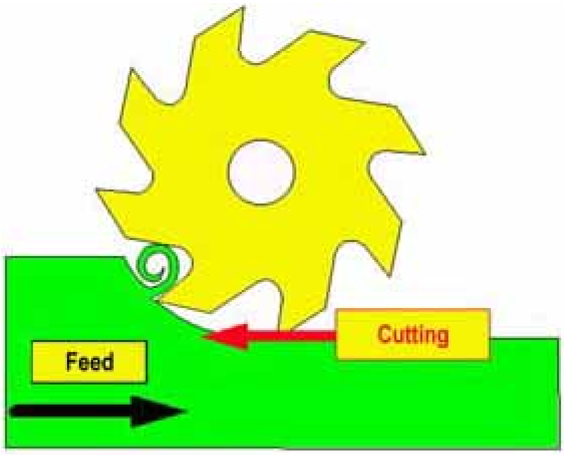


Figure 14. Up Cut Milling

b. Down Cut Milling

In down cut milling, the cutter rotates in the same direction as the table feed as illustrated in figure 15. This method is also known as Climb Milling and can only be used on machines equipped with a backlash eliminator or on a CNC milling machine. This method, when properly treated, will require less power in feeding the table and give a better surface finish on the workpiece

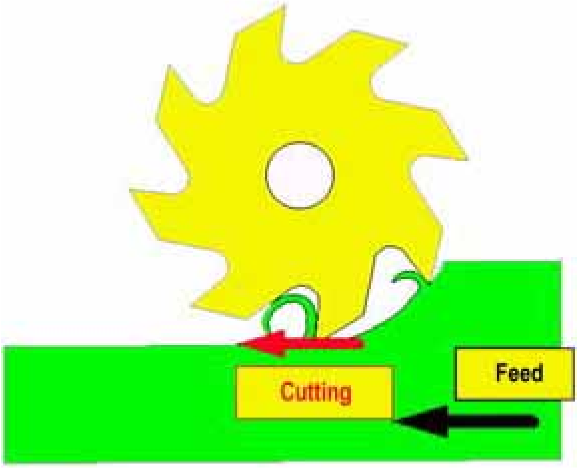


Figure 15. Down Cut Milling

6. Typical Milling Operations

6.1. Plain Milling

Plain milling is the milling of a flat surface with the axis of the cutter parallel to the machining surface. It can be carried out either on a horizontal machine or a vertical machine as shown in figure 16.

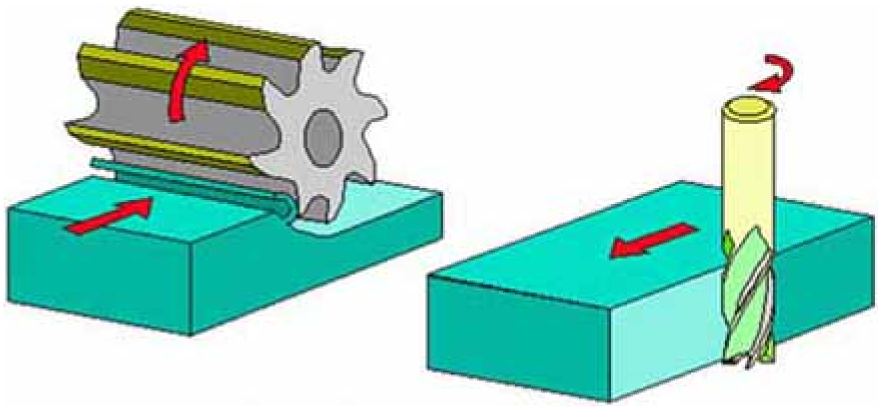


Figure 16. Plain Milling

6.2. End Milling

End Milling is the milling of a flat surface with the axis of the cutter perpendicular to the machining surface as shown in figure 17.

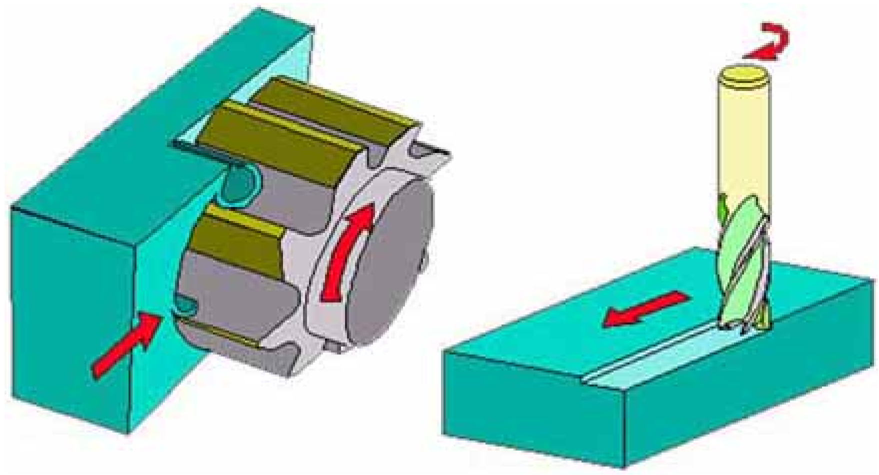


Figure 17. End Milling

6.3. Gang Milling

Gang milling is a horizontal milling operation that utilises three or more milling cutters grouped together for the milling of a complex surface in one pass. As illustrated in figure 18, different type and size of cutters should be selected for achieving the desire profile on the workpiece.

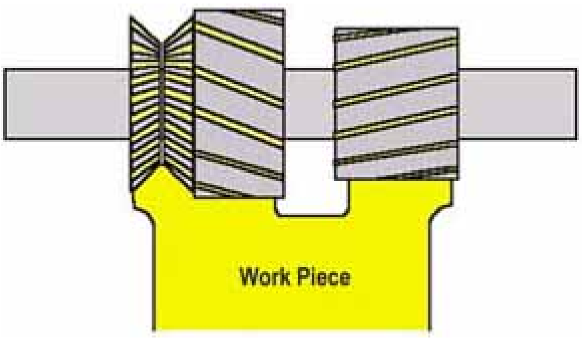


Figure 18. Gang Milling

6.4. Straddle Milling

In straddle milling, a group of spacers is mounted in between two side and face milling cutters on the spindle arbor as shown in figure 19. for the milling of two surfaces parallel to each other at a given distance.

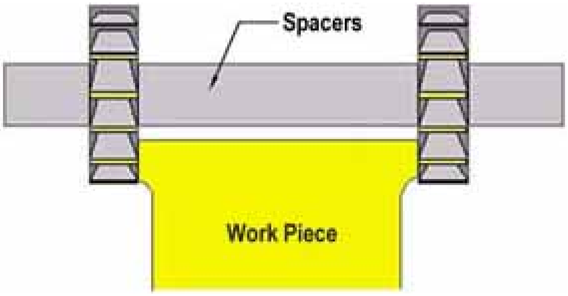


Figure 19. Straddle Milling

7. Milling machine vices

The milling machine vise is the most common type of work holding devise used on the milling machine (Figure 1).

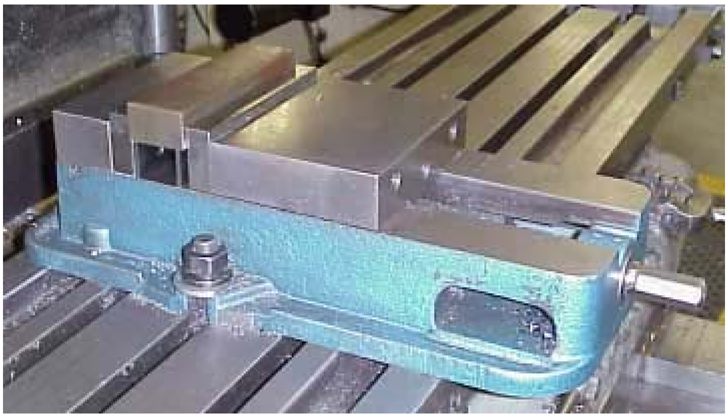


Figure 1: Plain Milling Machine Vise

The plain milling machine vise is used for holding work which has parallel sides. The vise is bolted directly to the table using the T-slots in the machine table. The plain vise can be accompanied by a swivel base (Figure 2).

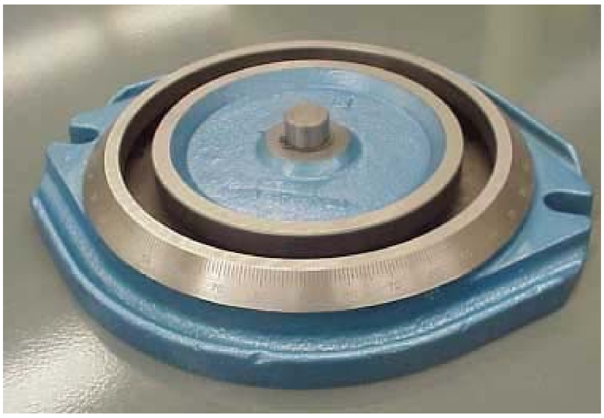


Figure 2: Swivel Base

Figure 3: Swivel Base and Vise

The swivel base is graduated in degrees and allows the vise to swivel in the horizontal plane. The swivel base gives the vise a greater degree of versatility, but should be avoided when doing heavy rough cutting operations because it reduces the rigidity of the setup.

For machining operations involving compound angles, a universal vise is commonly used (Figure 4).

Figure 4: Universal Angle Milling Vise

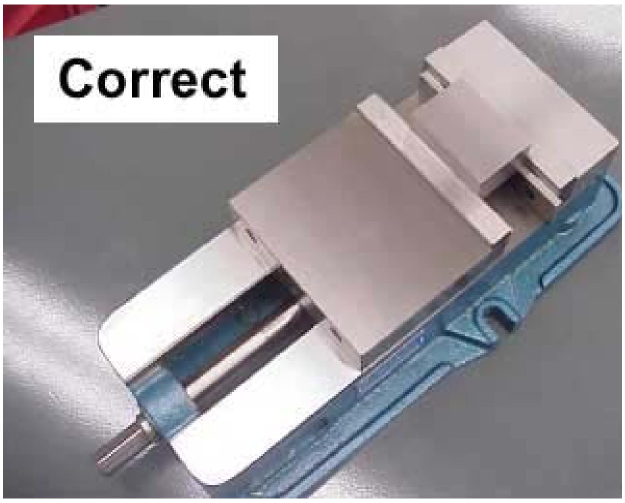
The universal vise allows the operator to tilt the workpiece 90 degrees in the vertical plane as well as swivel it 360 degrees in the horizontal plane.

In high production situations an air or hydraulically actuated vise may be used. These types of vises are quick acting. They also maintain consistent clamping pressures from one part to the next. However, on most manual type milling machines the vise is opened or closed using a handle. When tightening a plain type milling machine vise it is **not** necessary to strike the handle of the vise (Figure 5).

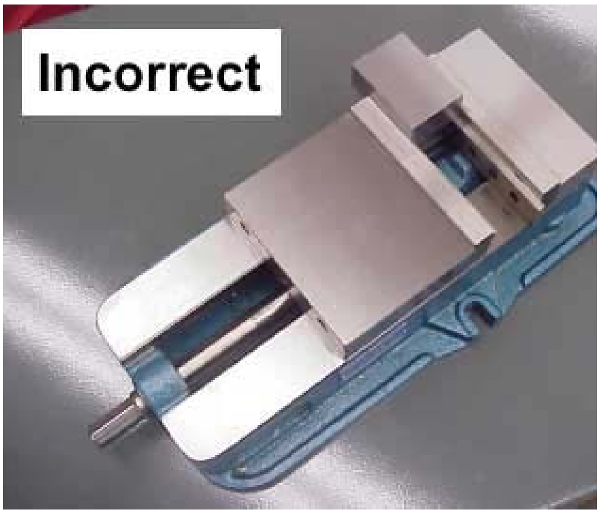
Figure 5

Striking the vise handle with a hammer can either cause the vise to become over-tightened or cause the vise handle to break. If it becomes apparent that the vise is not holding properly, check with your instructor for other possible causes to the problem.

In Figure 6 please study the correct and incorrect vise clamping practices.

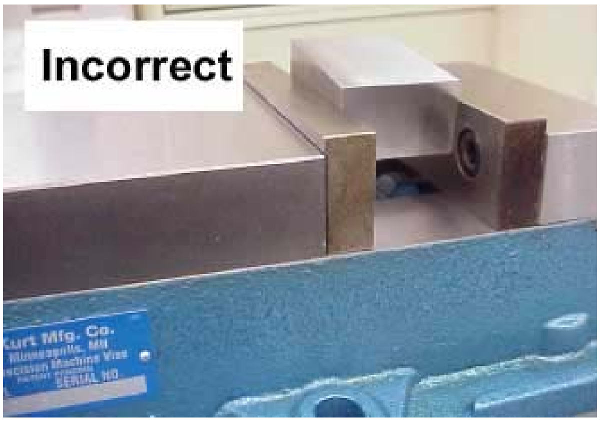


Locate the part in the center of the vise. This equalizes the pressure on the vise jaws.

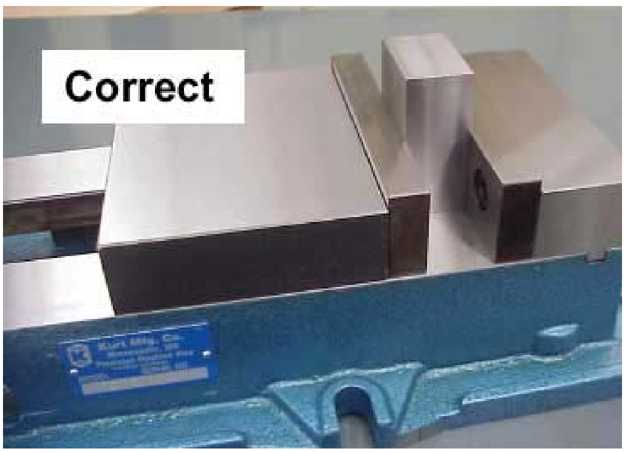


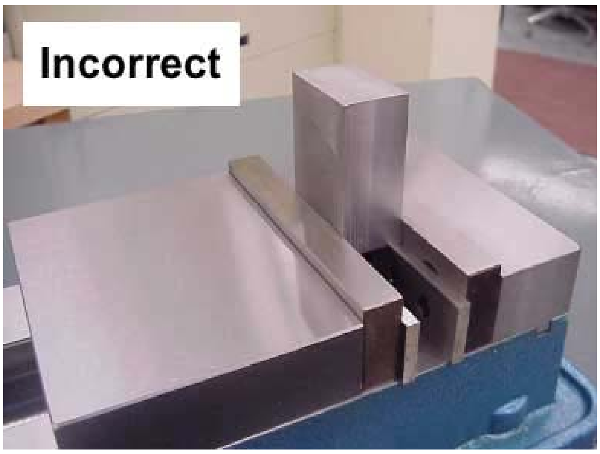
Holding the workpiece off center puts unequal pressure on the vise jaws. This can cause the piece to loosen up.

The workpiece should always be supported by the bottom of the vise or by parallels.



Work pieces that are not supported will move under the pressure of the cutting forces.





Keep the workpiece as low in the vise as possible.

Work that extends out of the vise has a greater chance of loosening up under cutting conditions.

Figure 6: Vise Clamping Principles For Milling

V - Blocks

V-Blocks hold and support round work for milling or drilling (Figure 7). V-Blocks come in many different sizes. On milling machines, V-Blocks are typically clamped directly to the table (Figure 8).

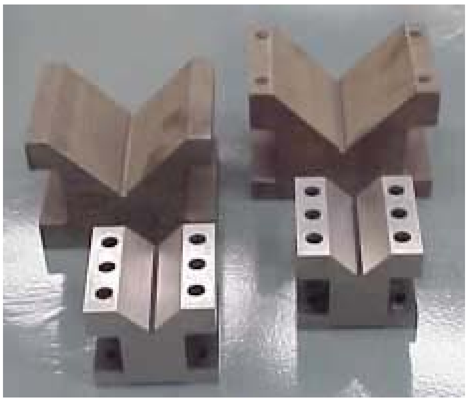


Figure 7: V-Blocks

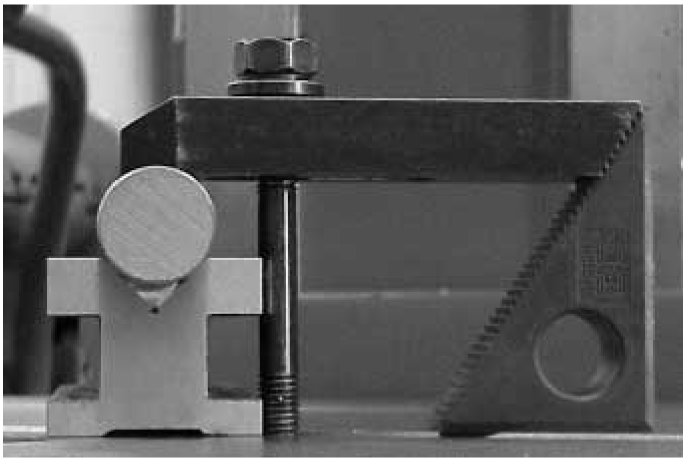


Figure 8: A V-Block and a strap clamp being used to clamp a round part to the table.

Angel plates

An angle plate is an L shaped piece of Cast Iron or Steel that has tapped holes or slots to facilitate the clamping of the workpiece(Figure 9).Angle plates are used when parts need to have machining operations performed at a 90 degree angle to the axis of the table(Figure 10).

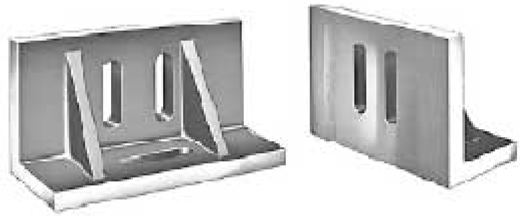


Figure 9: Angle Plates

Figure 10: Angle plate being used to machine the end of a long part.

Mounting to the table

Work that is too large or has an odd configuration is usually bolted directly to the table (Figure 11). This method of work holding takes the most ingenuity and expertise.

There are a number of accessories that can be used to help you set up the workpiece.

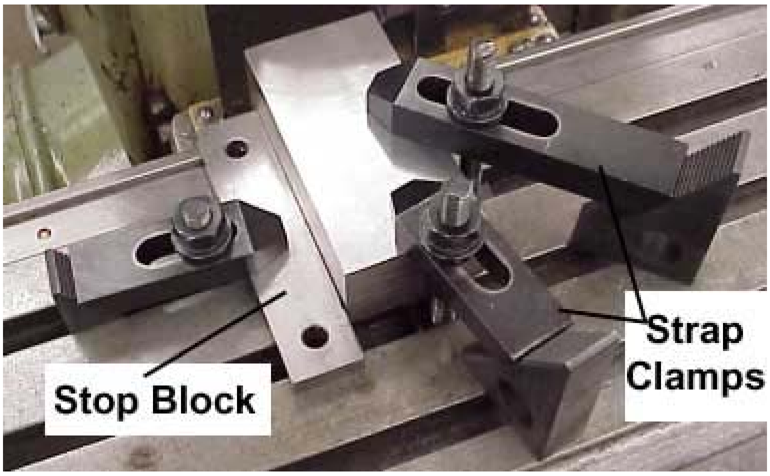


Figure 11: Direct Clamping using strap clamps-Notice the stop block. It is used to align the work as well as prevent the part from slipping.

A variety of commercially available clamp sets are available for directly mounting workpieces (Figure 12).

Figure 12: Clamping Sets

Parallels are pieces of steel bar stock accurately machines so that the opposing sides are parallel to each other (Figure 13). Parallels are provided in sets of two with identical dimensions.

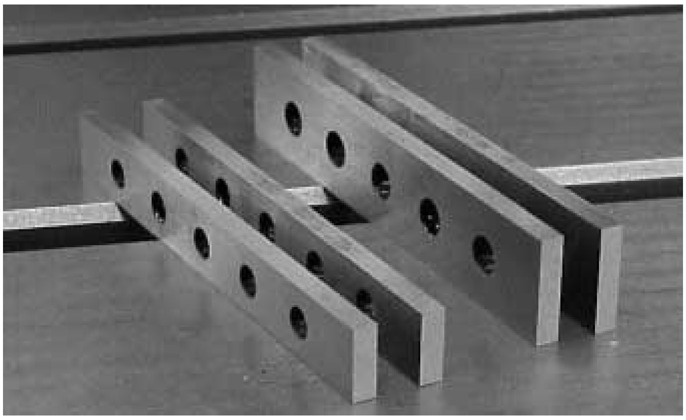


Figure 13: Parallels come in sets of two.

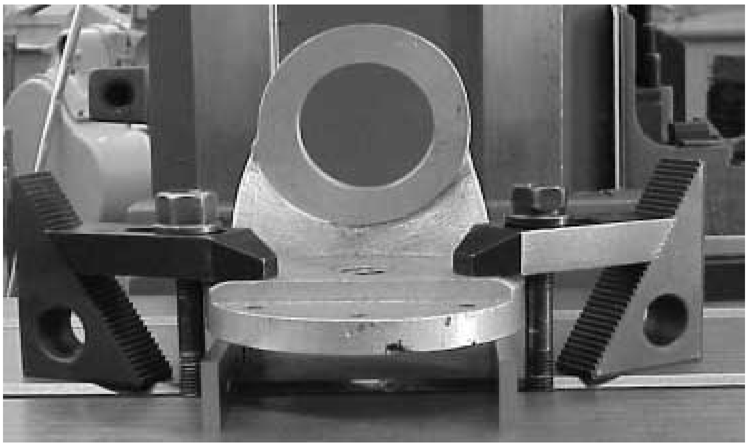
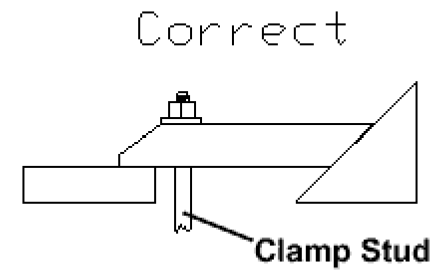


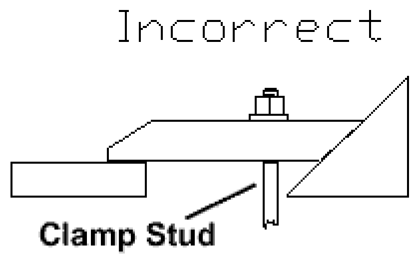
Figure 14: Parallels being used to raise the workpiece above the table surface**.**

Parallels are used in order to provide clearance under the work so the cutting tool does not damage the machine table or the vise base (see Figure 14).

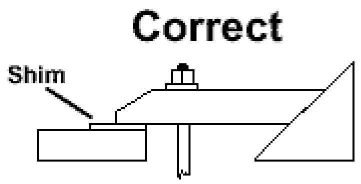
In Figure 15 please study the correct and incorrect direct clamping practices.



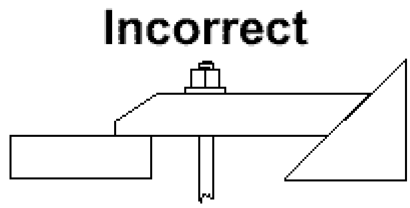
Place clamp stud close to the workpiece.



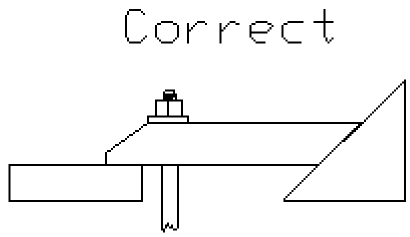
Do not place clamp stud closer to the support



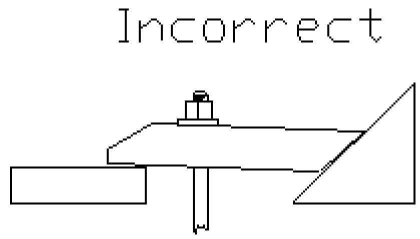
Use shims between finished surfaces and clamps



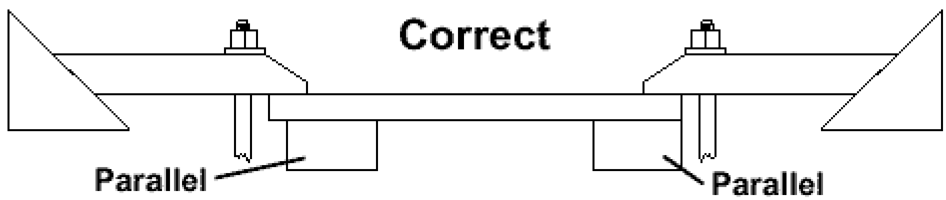
Clamps in contact with finished surfaces will mar the workpiece.



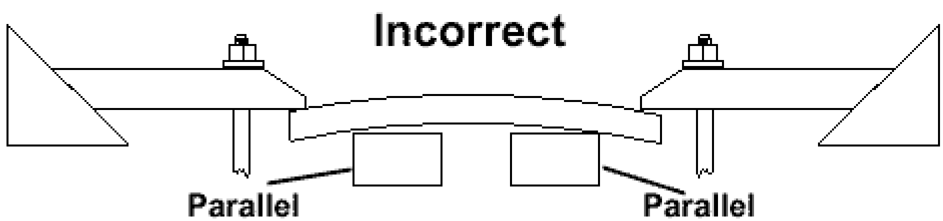
Clamps that are level or with a slight decline toward the workpiece will equalize the clamping pressure.



Angling clamps incorrectly puts pressure on the support, not the workpiece.



Place support parallels directly under clamps.



The spring caused by improper parallel placement will cause the part to bow.

Figure 15: Correct and Incorrect Clamping Practices

7.1. Vice Alignment

In the setting up of the vice onto the machine table, the fix jaw of the vice must be set parallel to the machine table using a Parallel Bar and a Dial Indicator. Adjustments can only be made by using a hide face hammer to correct its position such that a near zero indicator movement is achieved at all positions along the parallel bar.

7.2. Work Holding Method

In the machining of a complex component, it is usually started off with the milling of a rectangular block. To ensure that each surface of the rectangular block is perpendicular to its neighbouring surfaces, the following points should be noted:-

- The vice jaws and the workpiece must be free from burrs, chips, and cutting fluid.
- Smaller workpiece should be supported by parallel bars to provide the supporting datum.
- Round bar must be placed between the workpiece and the movable jaw to ensure that the workpiece is in perfect contact with the fix jaw.
- The vice handle should be tightened by hand to avoid over clamping of the workpiece as well as the vice. Hide face hammer should be used to assure that the workpiece is in perfect contact with the supporting base.
- On completion of the milling of the first face, the workpiece should be unloaded, deburred, and cleaned before the next operation.
- To machine the second and the third faces, the workpiece should be clamped with its preceding machined surface facing against the fix jaw of the vice.
- Similar clamping method can be applied in the machining of the fourth face.
- Yet it can also be clamped on the vice without the round bar.
- Both ends of the workpiece can be machined with the periphery flutes of the cutter using up cut milling as shown in figure below.

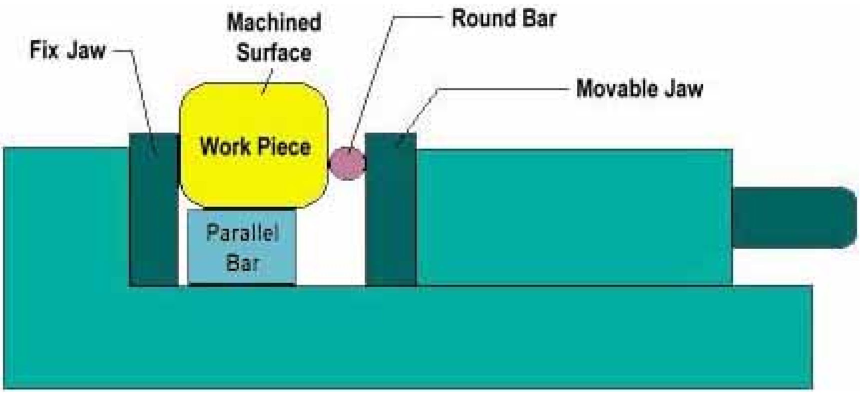


Figure . Holding Method by Using a Machine Vice