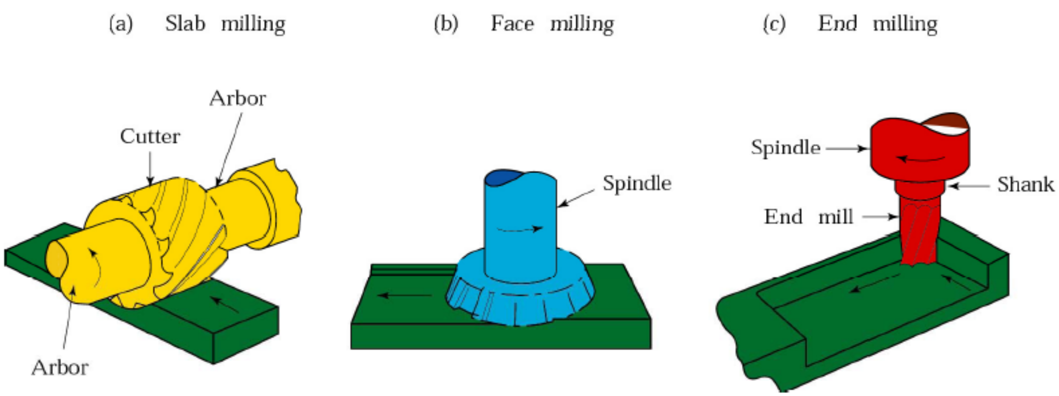
Milling operations
TA 102 Workshop Practice

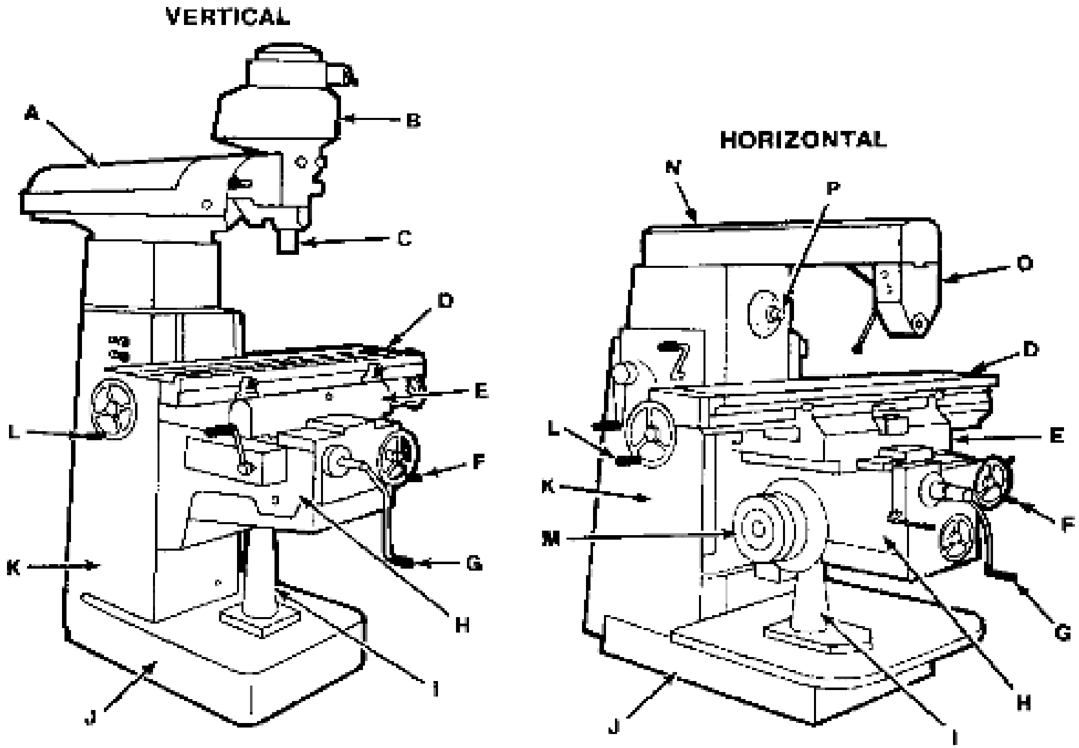
Milling



By Prof.A.chANDRASHEKHAR

Introduction

- Milling machines are used to produce parts having flat as well as curved shapes.
- Milling machines are capable of performing the usual flat, horizontal and vertical machining operations and can be used to do many other machining operations like gear teeth cutting, drilling, reaming, boring, slotting, tapping, keyway cutting, cam milling and so forth.
- In this process, the work piece is normally fed into a rotating cutting tool known as milling cutter. Equally spaced peripheral teeth on the cutter come in contact with the work piece intermittently and machine the work piece.



A RAM
B VERTICAL HEAD
C QUILL
D TABLE
E SADDLE
F CROSSFEED HANDLE
G VERTICAL FEED CRANK
H KNEE
I VERTICAL POSITIONING SCREW
J BASE
K COLUMN
L TABLE HANDWHEEL
M TABLE TRANSMISSION
N RAM TYPE OVERARM
O ARBOR SUPPORT
P SPINDLE

Figure 8-1. Milling machines.

Face Milling

- In conventional milling operation, metal is cut as the work piece is fed against a rotating multi point cutter.
- Different types of cutters are used in milling like end mill cutter, side and face cutter machine, form cutter and so forth.

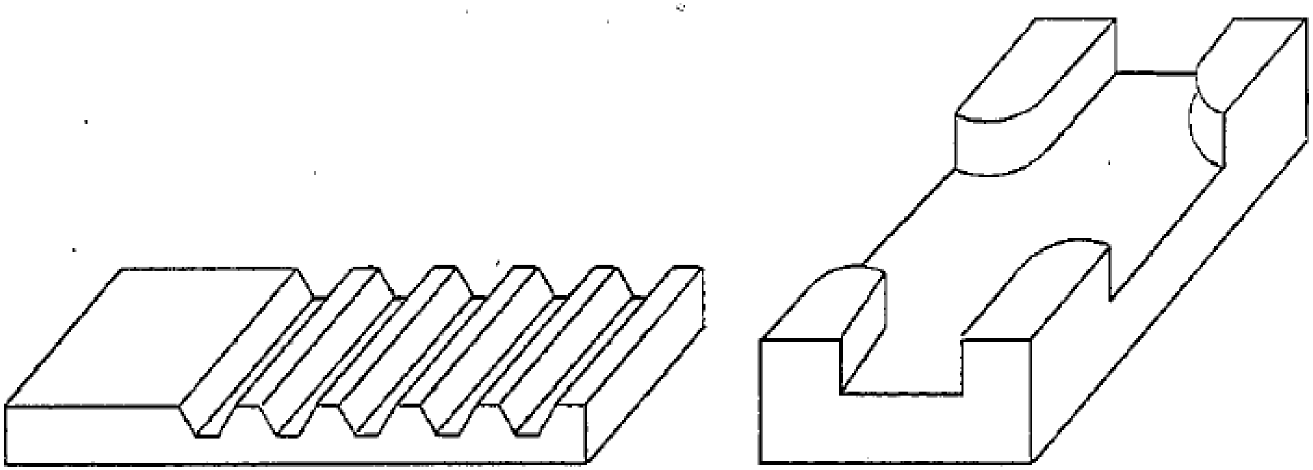


Figure 8.1 Typical components produced by milling machine.

The Milling Machine

- Two types of milling machines are common. They are distinguished by the orientation of the axis of rotation of the spindle of the cutter.
- In horizontal milling machine, the axis of the spindle in horizontal and
- In vertical milling machine the axis of the spindle is vertical.

Horizontal Knee and Column type milling machine

- Principal parts

i. Base
ii. Column
iii. Knee
iv. Saddle
v. Table
vi. Over arm
vii. Spindle, and
viii. arbor

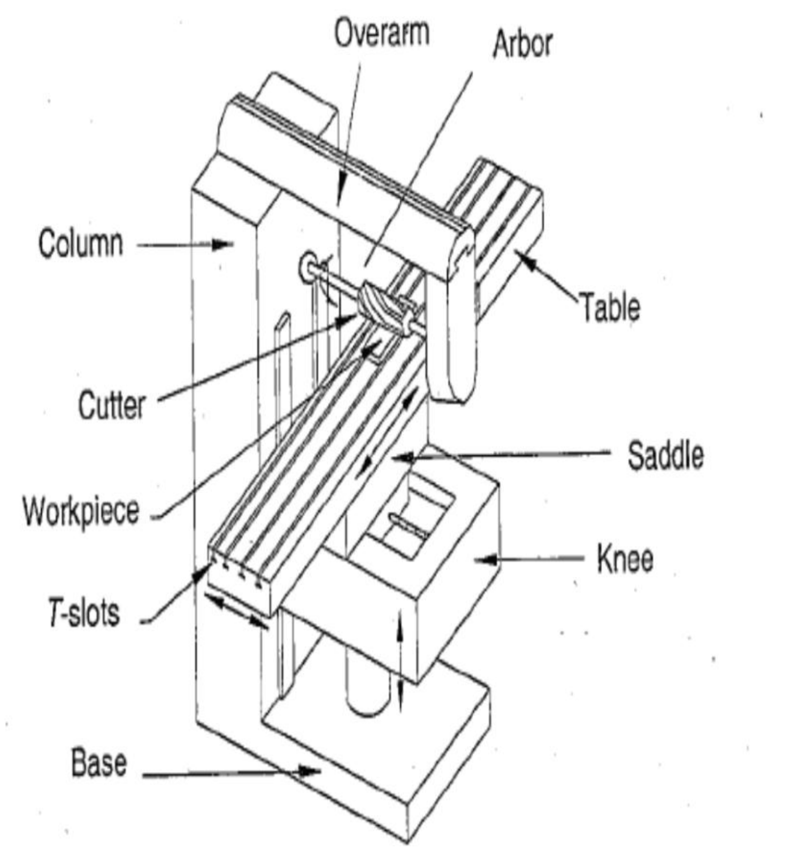
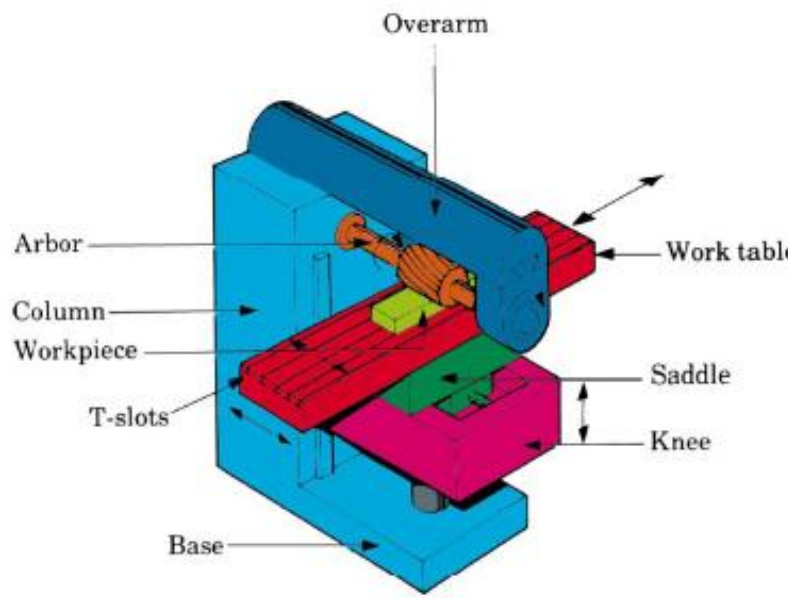
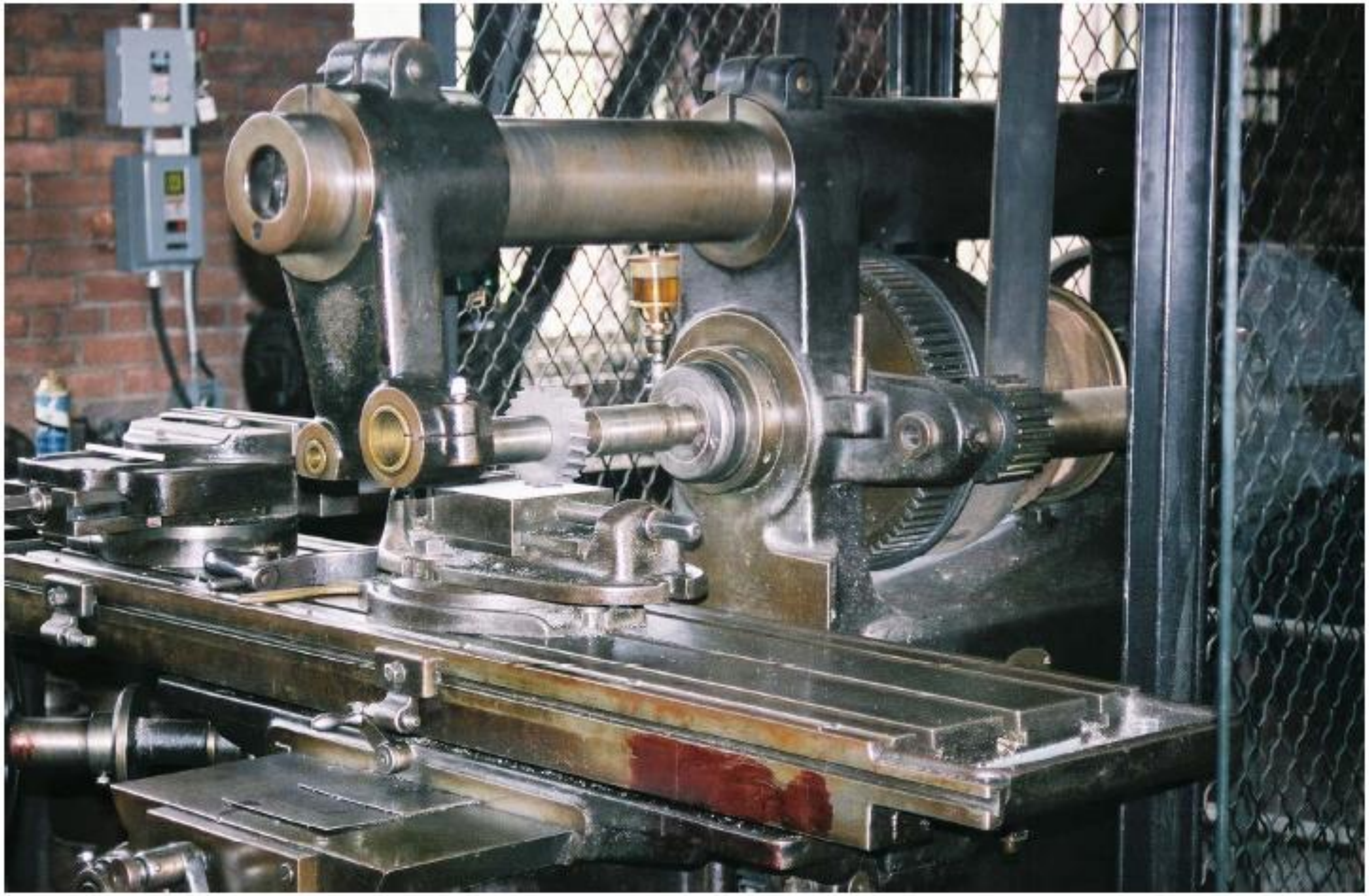


Figure 8.2 Horizontal knee and column type milling machine.

Horizontal Mill



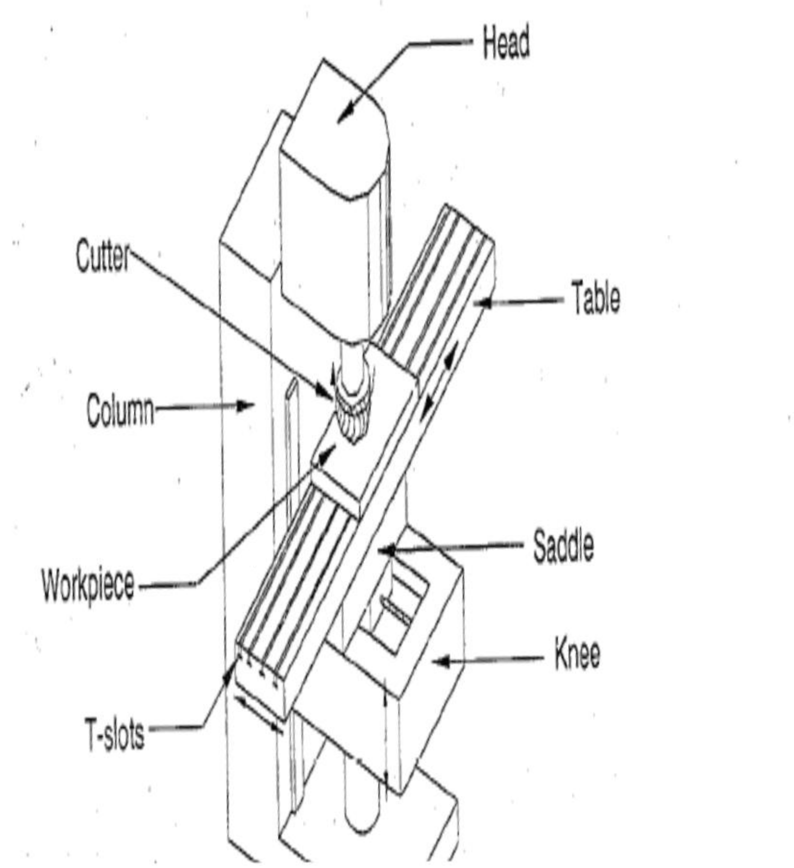
Old Horizontal Mill



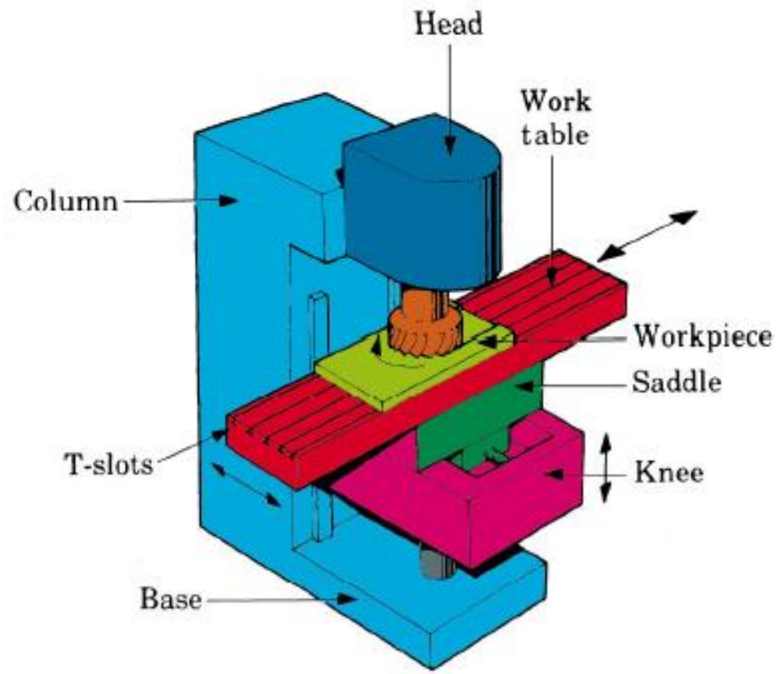
Vertical Knee and column type milling machine

- A horizontal milling machine can be converted in to a vertical milling machine by removing the arbor and attaching a vertical milling attachment to the spindle.

Figure 8.3 illustrates the features of a vertical knee and column type

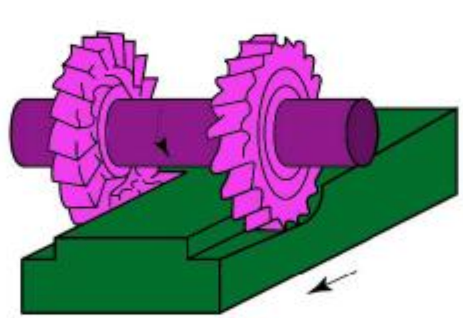


Vertical Mill

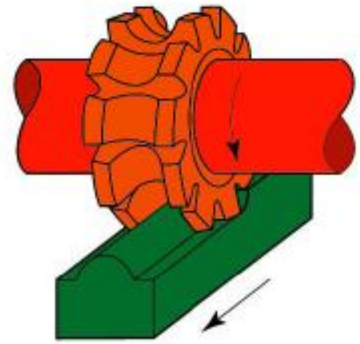


Milling Types

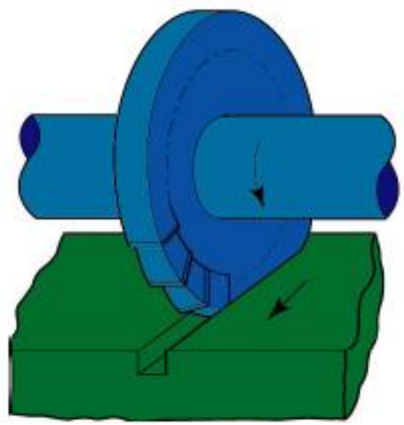
(a) Straddle milling



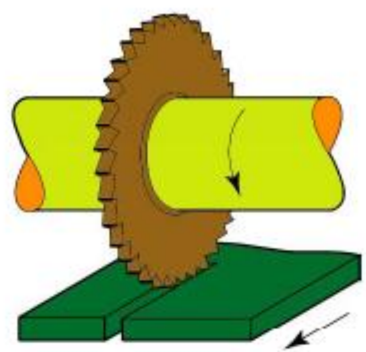
(b) Form milling



(c) Slotting



(d) Slitting



The Milling Process

- Milling is a machining process for producing flat, countered and helical surfaces by means of multiple- cutting-edged rotating tools called milling cutters.
- There are two different methods of metal cutting in the milling operation

  - up milling and

  - down milling

  The difference between these two types of operations lies in the direction along which the work piece is fed in to the rotating milling cutter and the direction of rotation of cutter.

UP Milling

- In up milling or conventional milling, the feed direction of the work piece is opposite to that of the cutter rotation.
- Each tooth of the cutter starts the cut with zero depth of cut, which gradually increases and reaches the maximum value as the tooth leaves the cut.
- The chip thickness at the start is zero and increases to the maximum at the end of the cut.
- The surface becomes slightly wavy, as the cut does not begin as soon as the cutter touches the work piece.

UP Milling

- The resultant cutting force are directed upward and tend to lift the work piece upward from the table, and therefore, more secured clamping of the work piece is required.

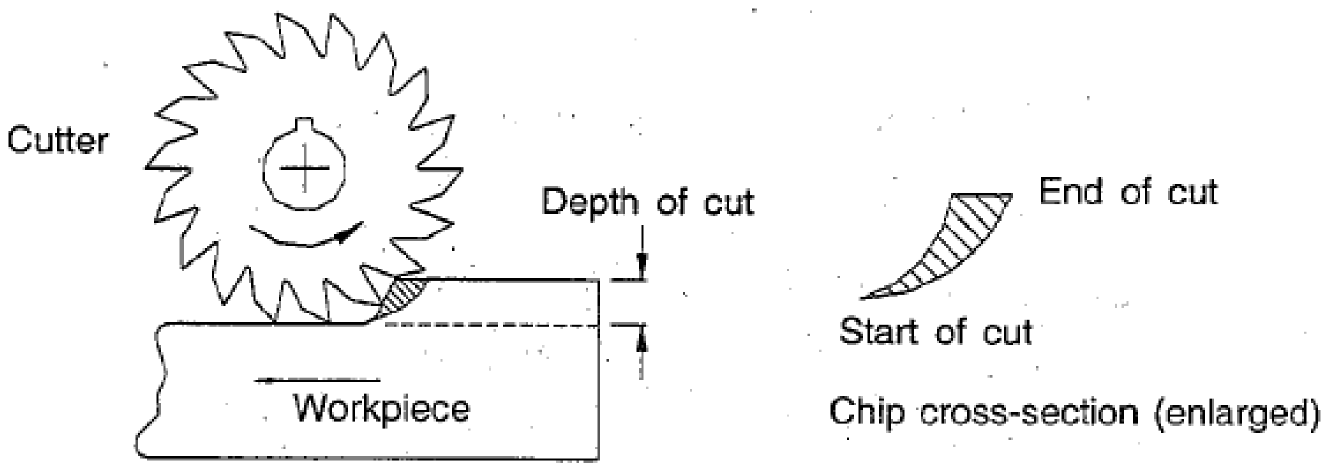


Figure 8.4 Up milling operation and the chip cut by a cutter tooth.

Down Milling

- Also called as Climb milling.
- The feed direction of the work piece is same as that of the cutter rotation.
- The maximum thickness of the chip at the start of the cut and decreases to zero thickness at the end of the cut.
- The resultant cutting forces in the down milling are directed downward in to the machine and tend to drag the work piece in to the cutter.
- This type of milling produces better surface finish and dimensional accuracy.

DOWN MILLING

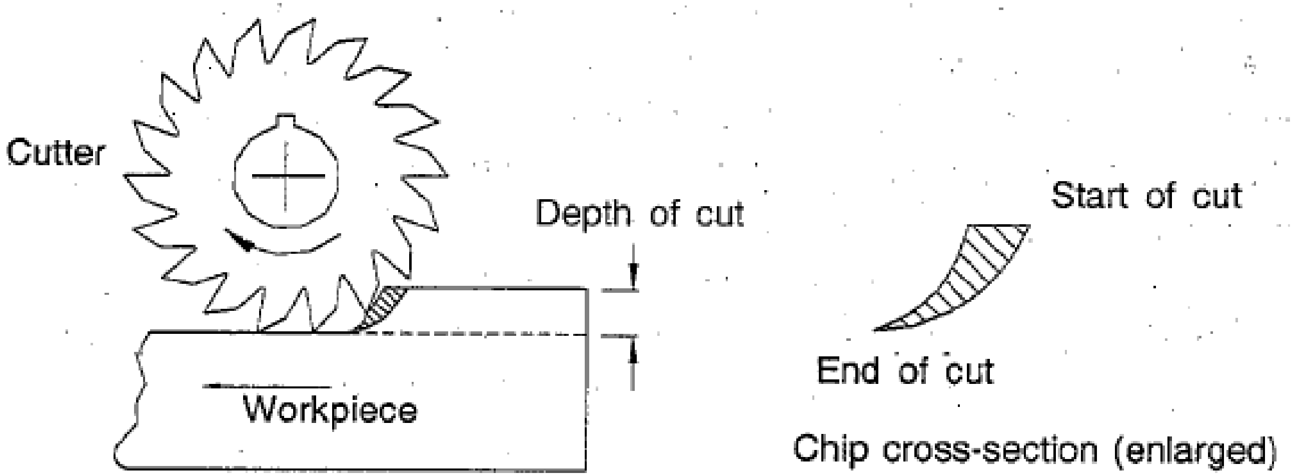
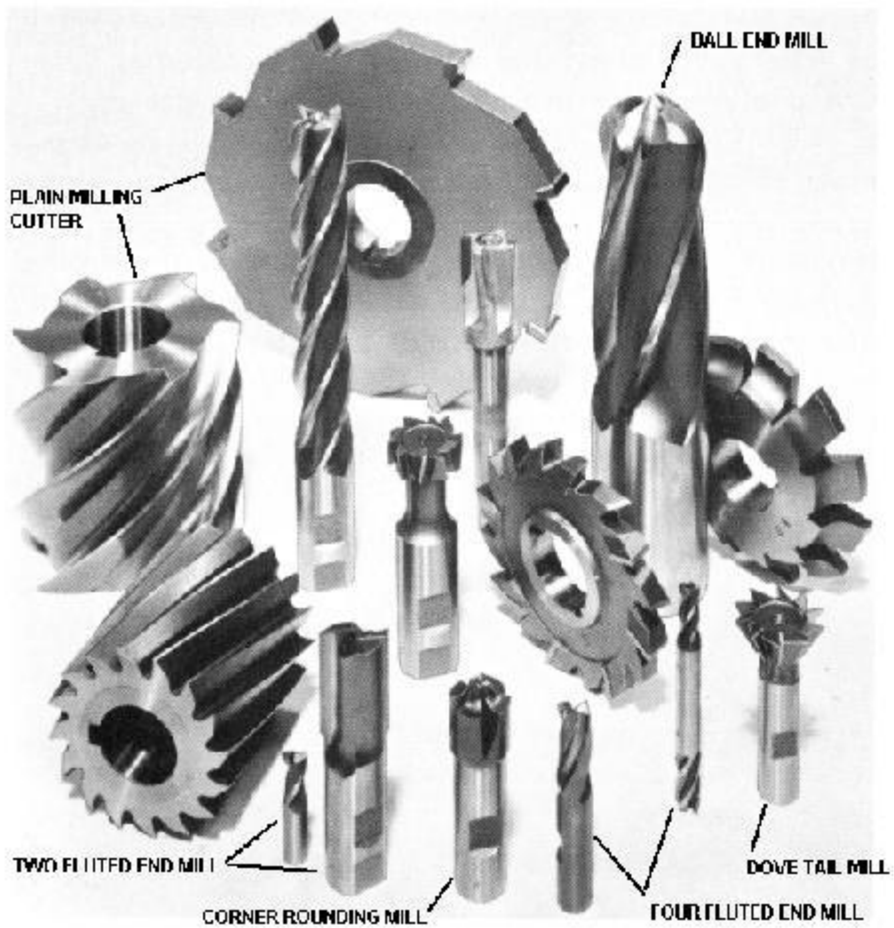


Figure 8.5 Down milling operation and the chip cut by a cutter tooth.

Types of Milling Cutters



Operating Conditions in Milling

- Cutting Speed is defined as the peripheral speed of the cutter.

$$= \pi DN/1000 \text{ m/min}$$

Where,

D = Diameter of the cutter in mm

N = Rotational Speed of the cutter in rpm

- Both N and D refer to the milling cutter in milling
- The selection of the cutting speed depends on the properties of the material being cut, diameter and life of cutter, number of cutter teeth, feed, depth of cut as well as width of cut and coolant used.

FEED

- Feed is defined as the movement of work piece relative to the cutter axis.
- In milling, the feed can be defined in three ways

1. Feed per tooth is defined as the distance advanced by the work piece between the time interval when two teeth come into cutting action.

$$F_1 = f / zN \text{ mm/tooth}$$

Where,

f = feed rate in mm

Z= number of teeth on the cutter periphery

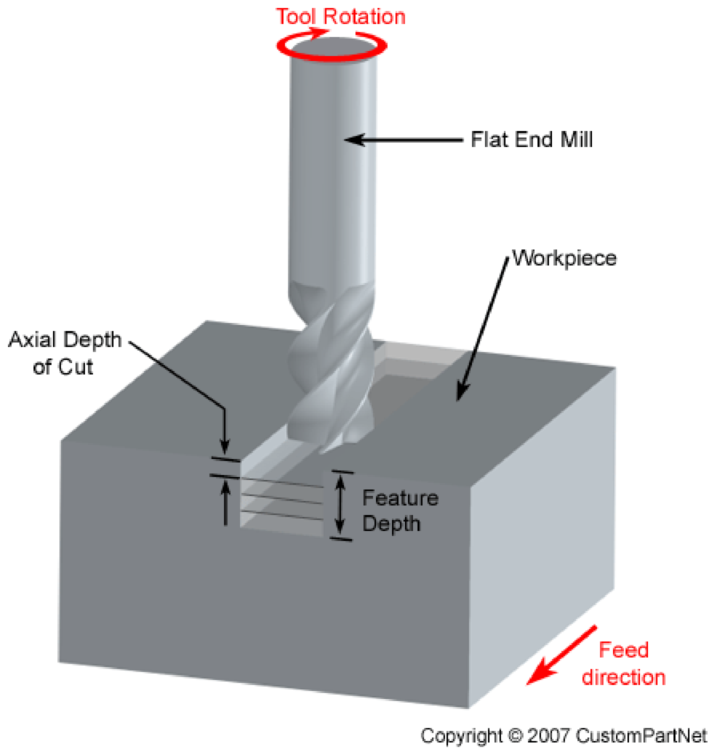
N = rpm of the cutter.

2. Feed per cutter revolution F_2 is defined as the distance advanced by the work piece in the time interval when cutter goes through one complete revolution.

$$F_2 = F_1 z \text{ mm/rev}$$

3. Feed per minute is the distance advanced by the work piece in on minute f.

$$f = F_2 N = F_1 z N$$



Depth of cut

- It is defined as the thickness of the layer of material removed in one pass of the work piece under cutter. It is expressed in mm.

Width of cut

- The width of cut ω is the width of work piece surface contacting the cutter in a direction perpendicular to the feed.

Material removal rate

- It is the volume of material removed in unit time.

For milling

MRR in mm^3/min

$$\mathbf{MRR = \omega\, d\, f}$$

or $$\mathbf{MRR = \omega\, d\, F_2\, N}$$

or $$\mathbf{MRR = \omega\, d\, F_1 z\, N}$$

where

w = width of cut in mm

d = depth of cut in mm

f = feed rate in mm/min

F_1 = feed rate in mm/tooth

F_2 = feed rate in mm/rev

z = number of cutter teeth

N = rpm of the cutter.

Machining time

- It is defined as the time required for one pass of width of cut ω for milling or machining a surface and is expressed in minutes.

$$t = \frac{\text{Length of cut}}{\text{Feed rate}} = \frac{L}{f} = \frac{L}{F_2 N} = \frac{L}{F_1 z N} \text{ min}$$

- Where L is the length of cut includes length of job + length of approach + length of over travel distance

Length of cut

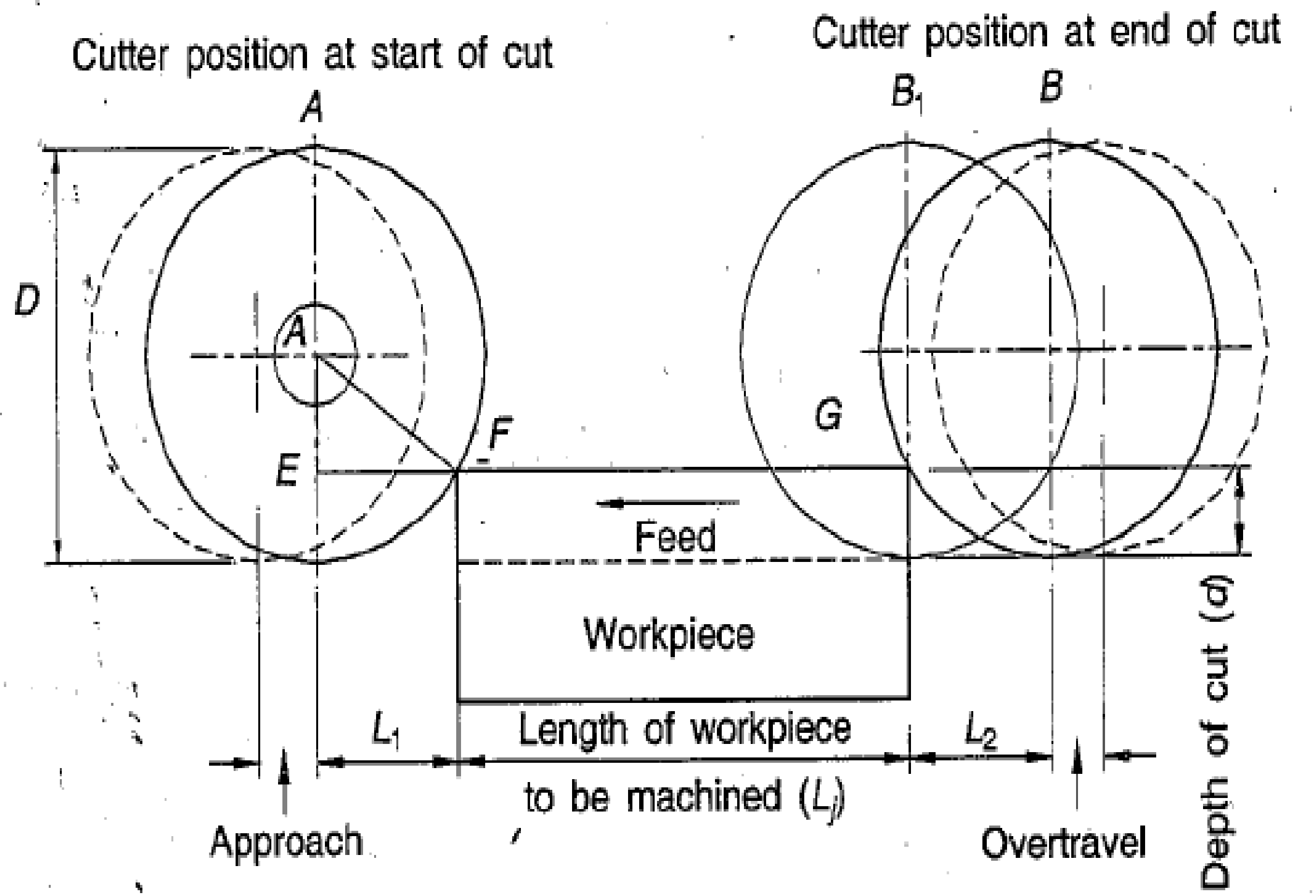


Figure 8.6 Workpiece length and length of cut in milling.

$$L = L_1 + L_j + L_2$$

From the figure note that $L_1 = L_2$, Hence, the length of cut is

$$L = 2L_1 + L_j \tag{8.10}$$

However, the cutting at the rear end is finished when the cutter axis is in position B_1, and, we may take length of cut L as:

$$L = L_1 + L_j \tag{8.11}$$

The distance L_1 can be computed geometrically from triangle AEF as:

$$L_1 = L_2 = \sqrt{d(D - d)} \tag{8.12}$$

where

D = diameter of the cutter
d = depth of cut

Similar to turning or other metal cutting operations, certain extra travel for the tool, called approach and overtravel, is desirable. These are also shown in Fig. 8.6 and length of cut is

$$L = L_1 + L_i + \text{approach} + \text{overtravel} \tag{8.13}$$

For the milling operations, sometimes, to simplify calculations sum of distance L_1, L_2, approach and overtravel is taken to be equal to the diameter of the cutter. Thus,

$$L = D + L_j \tag{8.14}$$

It should be noted here that the value of L_1 depends on the diameter of the cutter and depth of cut used.

In other milling operations like face milling, end milling etc., L_1, L_2 can be similarly computed from geometry.

Problem 1

- Determine the time required to mill a slot of 300 X 25 mm in a work piece of 300 mm length with a side and face milling cutter of 100 mm diameter, 25 mm wide and having 18 teeth. The depth of cut is 5 mm, the feed per tooth is 0.1 mm and cutting speed is 30 m/min. assume approach and over travel distance of 50 mm.

- Given

$L_j = 300$ mm, $D = 100$ mm, $w = 25$ mm,

$z = 18$, $d = 5$ mm, $F_1 = 0.1$ mm/tooth

$v = 30$ m/min

$N = 1000\, v / \Pi D$

$= 100$ rpm

Feed rate = feed per tooth X number of teeth on cutter X rpm

$f = F_1 z N = 0.1 \times 18 \times 100$

$= 180$ mm/min

- $L1 = L2 = \sqrt{d(D - d)}$

  $= 22$ mm

Length of cut $L = L_j + L_1 +$ approach $+$ Over travel

$= 300 + 22 + 50$

$= 372$ mm

$t =$ Length of cut/feed rate $= L/f = 372/180$

$= 2.067$ min

$= 2$ min (app)

Problem 2

- Determine the cutting time for cutting a 125 mm long keyway using HSS end-mill of 20 mm diameter having four cutting teeth. The depth of keyway is 4.5mm. Feed per tooth is 0.1mm and the cutting speed is 40 m/min. assume approach and over travel distances half of the diameter of the cutter and a depth of 4.5 mm can be cut in one pass.

- Given

$Lj = 125$ mm, $D = 20$ mm, $z = 4$

$d = 4.5$ mm, $F_1 = 0.1$ mm/tooth,

$v = 40$ m/min

$N = 1000\,v / \Pi D = 636$ rpm

Feed per minute = feed per tooth X no. of teeth X rpm

= 0.1 X 4 X 636

= 254.4 mm/min

Length of cut L = 125 + 10 = 135 mm

Cutting time = t = 135/254.4 = 0.53 min.

Problem 3

- For a given milling operation, it was decided to switch from HSS cutter to carbide cutter, changing the cutting speed from 35 m/min to 110 m/min. the other parameters of the cutting operation in the two cases are:

	carbide cutter	HSS Cutter
Cutter dia (mm)	150	125
Feed (mm/tooth)	0.0425	0.0375
Number of teeth	12	10

- Calculate the following for each of the cutting tools

a) Cutter rpm,

b) Feed in mm/min,

c) Time required to take 200-mm long cut including approach and over travel, and

d) Percentage saving in time by changing from HSS to Carbide tool.

Problem 3 Solution

- For HSS Cutter:

A) $N = 1000 \text{ X } 35/ (\Pi \text{ X } 125) = 89$ rpm

B) $f = F_1 zN = 0.0375 \text{ X } 10 \text{ X } 89 = 33.375$ mm/min

C) $t = L/f = 200 / 33.375 = 6$ min

- For Carbide Cutter:

A) $N = 233$ rpm

B) $f = F_1 zN = 118.8$ mm/min

C) $t = L/f = 1.68$ min

- Percentage saving in time = 6 – 1.68 /6 X100
  = 72 %

Problem 4

- Write down a possible sequence of operations for manufacturing the component shown in figure. From the stock having a length of 140 mm and 60 mm diameter.

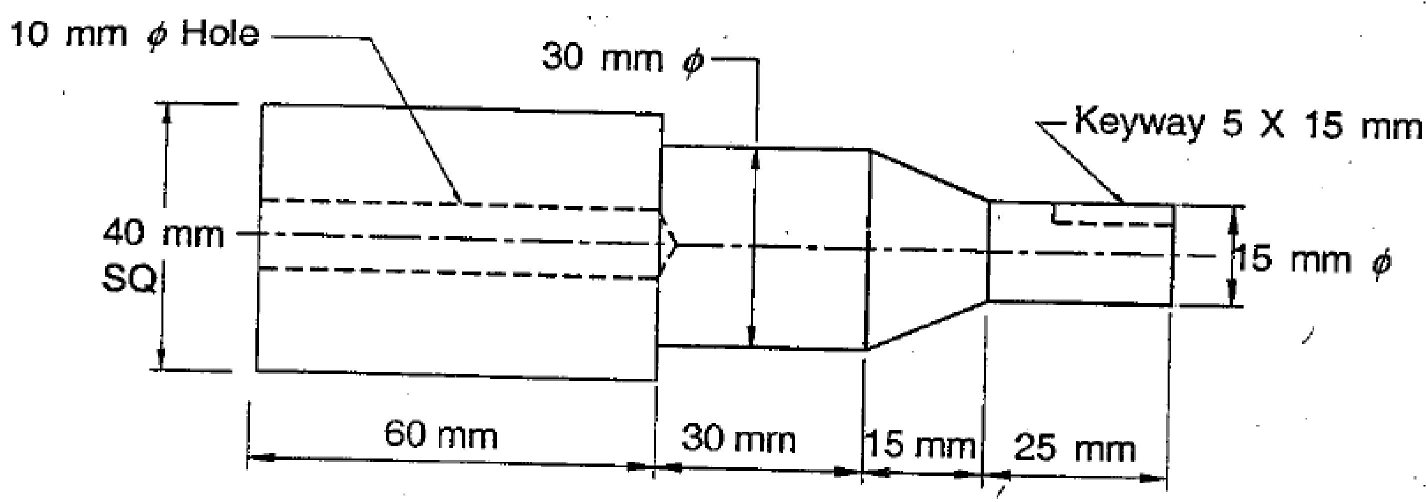


Figure 8.10 Part to be manufactured.

1. Hold job in 3-jaw chuck from one end. Face the other end.
2. Drill the 10 mm dia., 60 mm deep hole by fixing the drill in tailstock.
3. Hold job from other side in 3-jaw chuck and face to 130 mm length.
4. Turn 70 mm length from free end to 30 mm dia.
5. Turn 25 mm length from free end to 15 mm dia.
6. Taper turn the 15 mm length using compound slide.
7. Make 60 mm long 40 mm square on a shaper or milling machine.
8. Cut 5 × 15 mm keyway on a milling machine using end mill.