Basic functions and purposes of using milling machines

The basic function of milling machines is to produce flat surfaces in any orientation as well as surfaces of revolution, helical surfaces and contoured surfaces of various configurations.

Such functions are accomplished by slowly feeding the workpiece into the equispaced multiedge circular cutting tool rotating at moderately high speed.

Upmilling needs stronger holding of the job and downmilling needs backlash free screw-nut systems for feeding.
Fig. 4.3.1  Schematic views of conventional up and down milling
Milling machines of various type are widely used for following purposes using proper cutting tools called milling cutters:

- Flat surface in vertical, horizontal and inclined planes
- Making slots or ribs of various sections
- Slitting or parting
- Often producing surfaces of revolution
- Making helical grooves like flutes of the drills.
- Long thread milling on large lead screws, power screws, worms etc and short thread milling for small size fastening screws.
• 2-D contouring like cam profiles, clutches etc and 3-D contouring like die or mould cavities

• Cutting teeth in piece or batch production of spur gears, straight toothed bevel gears, worm wheels, sprockets, clutches etc.

• Producing some salient features like grooves, flutes, gushing and profiles in various cutting tools, e.g., drills, taps, reamers, hobs, gear shaping cutters etc.
Broad classifications of milling cutters

(a) Profile sharpened cutters – where the geometry of the machined surfaces are not related with the tool shape, viz;

i. Slab or plain milling cutter – straight or helical fluted

ii. side milling cutters – single side or both sided type

iii. slotting cutter

iv. slitting or parting tools

v. end milling cutters – with straight or taper shank

vi. face milling cutters
(b) Form relieved cutters – where the job profile becomes the replica of the tool-form, e.g., viz.;

i. Form cutters

ii. gear (teeth) milling cutters

iii. spline shaft cutters

iv. tool form cutters

v. T-slot cutters

vi. Thread milling cutter
Uses of different milling cutters and milling machines

Use of profile sharpened cutters

The profile sharpened cutters are inherently used for making flat surfaces or surface bounded by a number of flat surfaces only.

- **Slab or Plain milling cutters**: -

Plain milling cutters are hollow straight HSS cylinder of 40 to 80 mm outer diameter having 4 to 16 straight or helical equi-spaced flutes or cutting edges and are used in horizontal arbour to machine flat surface as shown in Fig.
Fig. 4.3.14  Machining flat surface by slab milling.
• **Side and slot milling cutters**

These arbour mounted disc type cutters have a large number of cutting teeth at equal spacing on the periphery.

Each tooth has a peripheral cutting edge and another cutting edge on one face in case of single side cutter and two more cutting edges on both the faces leading to double sided cutter.

One sided cutters are used to produce one flat surface or steps comprising two flat surfaces at right angle as shown in Fig.
(a) parallel facing by two side (single) cutter

(b) slotting by side (double sided) milling cutter
Both sided cutters are used for making rectangular slots bounded by three flat surfaces.

Slotting is also done by another similar cutter having only one straight peripheral cutting on each tooth. These cutters may be made from a single piece of HSS or its teeth may be of carbide blades brazed on the periphery or clamped type uncoated or coated carbide inserts for high production machining.
• Slitting saw or parting tool

These milling cutters are very similar to the slotting cutters having only one peripheral cutting edge on each tooth. However, the slitting saws
– are larger in diameter and much thin
– possess large number of cutting teeth but of small size
– used only for slitting or parting
End milling cutters or End mills

The shape and the common applications of end milling cutters (profile sharpened type) are shown in Fig on next.

The common characteristics of such cutters are:

- mostly made of HSS
- 4 to 12 straight or helical teeth on the periphery and face
- diameter ranges from about 1 mm to 40 mm
- widely used in vertical spindle type milling machines
- end milling cutters requiring larger diameter are made as a separate cutter body which is fitted in the spindle through a taper shank arbour as shown in the same figure.
(a) face milling

(b) angular milling

(c) slotting

(d) shell milling

Fig. 4.3.16 Use of end milling cutters and shell mill
**Face milling cutters**

The shape, geometry and typical use of face milling cutters are shown in Fig on next slide.

The main features are:

- Usually large in diameter (80 to 800 mm) and heavy
- Used only for machining flat surfaces
- Mounted directly in the vertical and horizontal spindles
- Coated or uncoated carbide inserts are clamped at the outer edge of the carbon steel body
- Generally used for high production machining of large jobs.
Fig. 4.3.17 Face milling cutters and their working
• Form cutters

Such disc type HSS cutters are generally used for making grooves or slots of various profiles as indicated in Fig. Form cutters may be also end mill type like T-slot cutter as shown in Fig.
Gear milling cutters

Gear milling cutters are made like slot milling cutters and also in the form of end mill for producing teeth of large module gears.

The form of these tools conform to the shape of the gear tooth-gaps bounded by two involutes.

Such form relieved cutters can be used for producing teeth of straight and helical toothed external spur gears and worm wheels as well as straight toothed bevel gears.
Fig. 4.3.20  Gear milling cutters and their use
• Spline shaft cutters
These disc type HSS of external spline shafts having 4 to 8 straight axial teeth.
Fig typically shows such application.
- **Straddle milling**

For faster and accurate machining two parallel vertical surfaces at a definite distance, two separate side milling cutters are mounted at appropriate distance on the horizontal milling arbour as shown in Fig. 4.3.25.

*Fig. 4.3.25 Straddle milling*
Gang milling

In gang milling, being employed, where feasible, for quick production of complex contours comprising a number of parallel flat or curved surfaces, a proper combination of several cutters are mounted tightly on the same horizontal milling arbour as indicated in Fig. 4.3.26.
• **Turning by rotary tools (milling cutters)**

During turning like operations in large heavy and odd shaped jobs, its speed (rpm) is essentially kept low. For enhancing productivity and better cutting fluid action rotary tools like milling cutters are used as shown in Fig. 4.3.27.

![Diagram of turning by rotary milling cutters](image)

**Fig. 4.3.27** Turning by rotary milling cutters
- **Ball-nose end mill**

Small HSS end mill with ball like hemispherical end, as shown in Fig. 4.3.28, is often used in CNC milling machines for machining free form 3-D or 2-D contoured surfaces.

*Fig. 4.3.28  Ball nose end mills*
Machining time in Milling operations

There are different types of milling operations done by different types of milling cutters:

- Plain milling by slab milling cutter mounted on arbour
- End milling by solid but small end mill cutters being mounted in the spindle through collet
- Face milling by large face milling cutters being directly fitted in the spindle.
Fig. 4.9.4  Plain milling operation.
\[ T_C = \frac{L_C}{s_m} \] (for job width < cutter length) \hspace{1cm} (4.9.13)

Where,
- \( L_C = \) total length of travel of the job
  - \( = L_w + A + O + D_c/2 \)
- \( L_w = \) length of the workpiece
- \( A, O = \) approach and over run (5 to 10 mm)
- \( D_c = \) diameter of the cutter, mm
- \( S_m = \) table feed, mm/min
  - \( = s_o Z_c N \)

where,
- \( s_o = \) feed per tooth, mm/tooth
- \( Z_c = \) number of teeth of the cutter
- \( N = \) cutter speed, rpm.

Again, \( N \) has to be determined from \( V_C \) as

\[ V_C = \frac{\pi D_c N}{1000} \] m/min

\( V_C \) and \( s_o \) have to be selected in the usual way considering the factors stated previously. Since milling is an intermittent cutting process, \( V_C \) should be taken lower (20 ~ 40%) of that recommended for continuous machining like turning. \( S_o \) should be taken reasonably low (within 0.10 to 0.5 mm) depending upon the tooth – size, work material and surface finish desired.
Basic purposes of use of drilling machines

Drilling machines are generally or mainly used to originate through or blind straight cylindrical holes in solid rigid bodies or enlarge (coaxially) existing (premachined) holes:

- of different diameter ranging from 1 mm to 40 mm
- of varying length depending upon the requirement and the diameter of the drill
- in different materials excepting very hard or very soft materials like rubber, polythene etc.
Classification of drilling machines.
(a) General purpose drilling machines of common use
- Table top small sensitive drilling machine

These small capacity ($\leq 0.5$ kW) upright (vertical) single spindle drilling machines are mounted (bolted) on rigid table and manually operated using usually small size ($\phi \leq 10$ mm) drills.
• Pillar drilling machine
Are quite similar to the table top drilling machines but of little larger size and higher capacity and are grouted on the floor (foundation). Here also, the drill-feed and the work table movement are done manually. These low cost drilling machines have tall tubular columns and are generally used for small jobs and light drilling.
Column drilling machine

These box shaped column type drilling machines are much more strong, rigid and powerful than the pillar drills. In column drills the feed gear box enables automatic and power feed of the rotating drill at different feed rates as desired.

Blanks of various size and shape are rigidly clamped on the bed or table or in the vice fitted on that. Such drilling machines are most widely used and over wide range (light to heavy) work.
• Radial drilling machine

This usually large drilling machine possesses a radial arm which along with the drilling head can swing and move vertically up and down.

The radial, vertical and swing movement of the drilling head enables locating the drill spindle at any point within a very large space required by large and odd shaped jobs.

There are some more versatile radial drilling machines where the drill spindle can be additionally swivelled and/or tilted.
(b) General purpose drilling machines with specific use.

- Hand drills

Unlike the grouted stationary drilling machines, the hand drill is a portable drilling device which is mostly held in hand and used at the locations where holes have to be drilled. The small and reasonably light hand drills are run by a high speed electric motor. In fire hazardous areas the drill is often rotated by compressed air.
• Gang drilling machine

In this almost single purpose and more productive machine a number (2 to 6) of spindles with drills (of same or different size) in a row are made to produce number of holes progressively or simultaneously through the jig.
• **Turret (type) drilling machine**

Turret drilling machines are structurally rigid column type but are more productive like gang drill by having a hexagon turret. The turret bearing a number of drills and similar tools is indexed and moved up and down to perform quickly the desired series of operations progressively.
• Multispindle drilling machine

In these high production machine tools a large number of drills work simultaneously on a blank through a jig specially made for the particular job. The entire drilling head works repeatedly using the same jig for batch or lot production of a particular job.
• Micro (or mini) drilling machine

This type of tiny drilling machine of height within around 200 mm is placed or clamped on a table. Operated manually for drilling small holes of around 1 to 3 mm diameter in small workpieces.
Types of Drills
Centre drills: for small axial hole with $\text{60}^\circ$ taper end to accommodate lathe centre for support
Step drill and subland drills:
for small holes with two or three steps
Half round drill, gun drill and crank shaft drill (for making oil holes)

Fig. 4.2.13 Schematic views of (a) half round drill, (b) gun drill and (c) crank shaft drill
Trepanning tool: for large holes in soft materials
Machining time estimation in drilling
The machining time, $T_C$ is estimated from,

$$T_C = \frac{L'_C}{N s_o} \quad (4.9.8)$$

where,

$L'_C = L_h + A + O + C$

$A, O =$ approach and over run

and $C = \frac{D}{2 \cot \rho}$

$D =$ diameter of the hole, i.e., drill

$\rho =$ half of the drill point angle.

Speed, $N$ and feed $s_o$ are selected in the same way as it is done in case of turning.

Therefore, the drilling time can be determined from,

$$T_C = \frac{\pi D (L_h + A + O + C)}{1000 V_c s_o} \quad (4.9.9)$$

In the same way $T_C$ is determined or estimated in boring also. Only the portion ‘C’ is not included.

For blind hole, only over run, ‘O’ is excluded.