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Subject Name: **Metal Cutting & machine Tools**

Subject Code: **ME-6004**

Semester: **6<sup>th</sup>**



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## INTRODUCTION

Milling machine is one of the important machining operations. In this operation the workpiece is fed against a rotating cylindrical tool. The rotating tool consists of multiple cutting edges (multipoint cutting tool). Normally axis of rotation of feed given to the workpiece. Milling operation is distinguished from other machining operations on the basis of orientation between the tool axis and the feed direction, however, in other operations like drilling, turning, etc. the tool is fed in the direction parallel to axis of rotation.

The cutting tool used in milling operation is called milling cutter, which consists of multiple edges called teeth. The machine tool that performs the milling operations by producing required relative motion between workpiece and tool is called milling machine. It provides the required relative motion under very controlled conditions. These conditions will be discussed later in this unit as milling speed, feed rate and depth of cut.

Normally, the milling operation creates plane surfaces. Other geometries can also be created by milling machine. Milling operation is considered an interrupted cutting operation teeth of milling cutter enter and exit the work during each revolution. This interrupted cutting action subjects the teeth to a cycle of impact force and thermal shock on every rotation. The tool material and cutter geometry must be designed to bear the above stated conditions. Depending upon the positioning of the tool and workpiece the milling operation can be classified into different types.

## Objectives

After studying this unit, you should be able to understand

- Introduction and working principle of milling machine,
- Different type of milling operations,
- Different type of milling machine and their main parts,
- Specifications of milling machines,
- Different cutting parameters as setting of a milling machine,
- Introduction and categorization of milling cutters,
- Different operations that can be performed on a milling machine, and
- Indexing, different methods of indexing.

## Types of Milling Machines

Milling operation is broadly classified as peripheral milling and face milling.

### Peripheral Milling

This operation is also called plain milling operation. In this operation axis of rotating tool is always kept parallel to the surface being machined. This operation is done by the cutting edges on outside periphery of the milling cutter. Different type of peripheral milling operations are possible as described below.

### Slab Milling

In this milling operation the cutter width extends beyond the workpiece on both sides.

### Slotting

It is also a type of milling operation, also called as slot milling operation. In this case width of the cutter is less than the width of workpiece. It is used to make slot in the workpiece. Thin slots can be made by using very

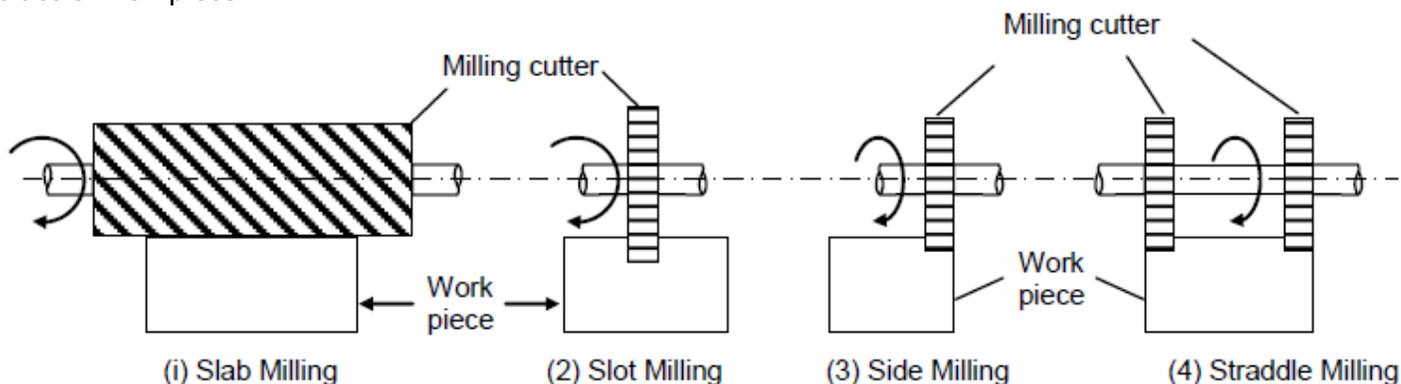
thin milling cutters. The workpiece can be cut into two pieces by making a very thin slot throughout the depth of workpiece. Cutting the workpiece this way by slot milling is called saw milling.

### Side Milling

The cutter is used for milling of sides of a workpiece.

### Straddle Milling

It is just like side milling with difference that cutting (milling operation) takes place simultaneously on both the sides of workpiece.



**Figure: Different Types of Peripheral Milling**

Peripheral milling is also classified on the basis of the rotational direction of cutter, as up milling and down milling.

### Up Milling

It is also called conventional milling in this case movement of cutter teeth is opposite to the direction of feed motion.

### Down Milling

It is also called climb milling. In this case direction of cutter motion is the same so that of direction of feed motion.

### Face Milling

In the operation of face milling, axis of the milling cutter remains perpendicular to the surface being milled. In this case cutting action is done by cutting edges of both sides (end and out side) periphery of the milling cutter. Depending upon the relative geometry of workpiece and milling cutter face milling is different types as described below.

### Conventional Face Milling

In this case diameter of milling cutter is greater than the width of workpiece. The milling cutter remains overhanging on both sides of workpiece.

### Partial Face Milling

In this case the milling cutter overhangs on the workpiece on one side only.

### End Milling

In case of end milling thin (low diameter) cutter are used as compared to workpiece width. It is used to make slot in the workpiece.

### Profile Milling

This is just like end milling in which the outer side periphery of a flat part is machined (milled).

### Pocket Milling

This is a selective portion milling on the flat surface of workpiece used to make shallow packets there.

### Surface Contouring

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In this operation a ball nose cutter if feed back and forth across the workpiece along a curvilinear path at short intervals. This creates the required contours on the surface of workpiece. This operation is used to make contours of molds and dies and this time the operation is named as die sinking.

All the above described operations are indicated in Figure at their respective number.

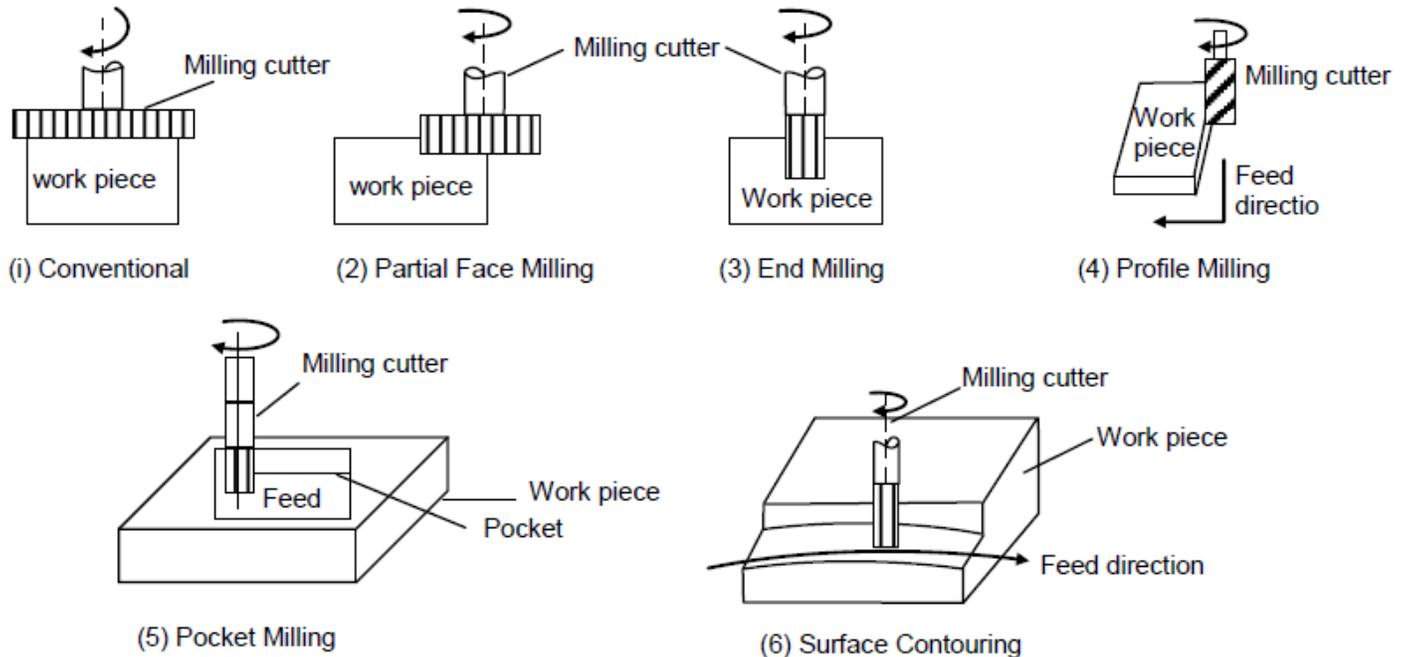


Figure: Different Types of Face Milling

### Working Principle Of Milling Machine

Working of a milling machine is based on the fact that milling cutter is fed against workpiece. This is achieved by developing relative motion with precise control between workpiece and rotating milling cutter. Feed motion is generally given to the workpiece through its holding device. Cutting mechanism of the workpiece in milling operations is same as that in turning operation on lathe. This cutting takes place due to plastic deformation of metal by the cutting tool. Milling machine can also hold more than one cutter at a time. The holding device is supported by mechanism that can offer a selective portion of the workpiece to milling cutter for its processing. Indexing is one of the examples of this type of processing.

### Type of Milling Machines

Milling machines can be classified into different categories depending upon their construction, specification and operations. The choice of any particular machine is primarily determined by nature of the work to be done, its size, geometry and operations to be performed. The typical classification of milling machines on the basis of its construction is given below.

The broader classification has three categories and each category has its sub-classifications given below :

### Column and Knee Type Milling Machine

- (a) Head milling machine
- (b) Plain milling machine
- (c) Universal milling machine
- (d) Omniversal milling machine
- (e) Vertical milling machine

### Fixed Bed Type Milling Machine

- (a) Simplex milling
- (b) Duplex milling
- (c) Triplex milling

### Special Type Milling Machine

- (a) Rotary table milling
- (b) Drum milling
- (c) Planetary milling
- (d) Tracer controlled milling

In addition to above three types there is one more type of milling machine named as planner type milling machine which is rarely used.

### Column and Knee Type Milling Machine

Main shape of column knee type of milling machine is shown in Figure; this milling machine consists of a base having different control mechanisms housed there in. The base consists of a vertical column at one of its end. There is one more base above the main base and attached to the column that serves as worktable equipped with different attachments to hold the workpiece. This base having worktable is identified as "knee" of the milling machine. At the top of the column and knee type milling machines are classified according to the various methods of supplying power to the table, different movements of the table and different axis of rotation of the main spindle. These are described in brief as below.

### Head Milling Machine

In case of head milling machine feed motion is given by hand and movements of the machine are provided by motor. This is simple and light duty milling machine meant for basic operations.

### Plain Milling Machine

Plain milling machine is similar to hand milling machine but feed movement can be powered controlled in addition to manual control.

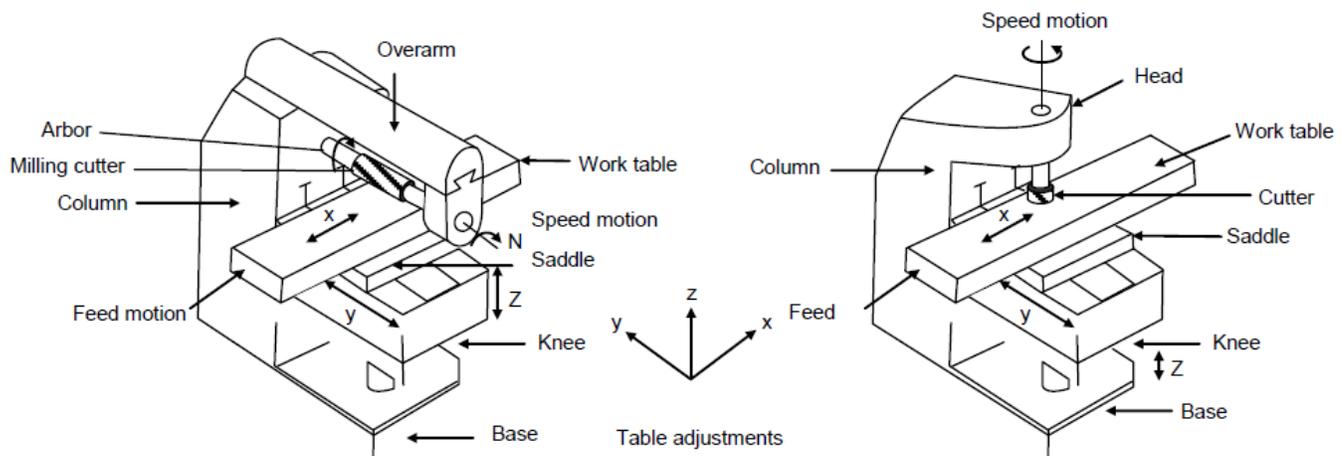


Figure: Column and Knee Type Milling Machine

**Universal Milling Machine**

A universal milling machine is named so as it is used to do a large variety of operations. The distinguishing feature of this milling machine is its table which is mounted on a circular swiveling base which has degree graduations. The table can be swiveled to any angle upto  $45^\circ$  on either side of normal position. Helical milling operation is possible on universal milling machine as its table can be fed to cutter at an angle. Provision of large number of auxiliaries like dividing head, vertical milling attachments, rotary table, etc. Make it suitable for wide variety of operations.

**Omniversal Milling Machine**

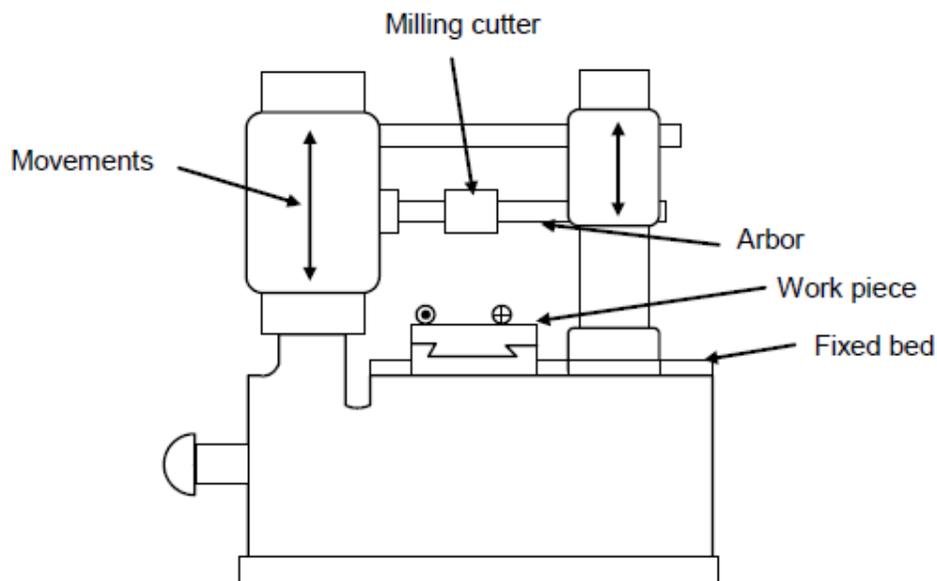
Omniversal milling machine is like a universal milling machine with additional feature that its table can be tilted in a vertical plane by providing a swivel arrangement at the knee. This enables it to make taper spiral grooves in reamers, bevel gears, etc.

**Vertical Milling Machine**

Position of spindle is kept vertical or perpendicular to the worktable in case of vertical milling machine.

**Fixed Bed Type Milling Machine**

It is also known as manufacturing type milling machine. Its table is mounted directly on the ways of fixed bed. Table movement is restricted to reciprocation only. Cutter is mounted on the spindle head which can move vertically on the column. Duplex milling machine has double spindle heads, one on each side of the table. Triplex milling machine has three spindle heads one each side of the table and third one is mounted on the cross rail. Bed type milling machine is shown in Figure.



**Figure 1.4: Fixed Bed Type Milling Machine**

**Planer Type Milling Machine**

It is a heavy duty milling machine, its spindle head is adjustable in vertical and transverse directions. It is different from planner as feed is given to the worktable. This can accommodate a number of independent spindles carrying milling cutters on the rail. Independent driving of the different spindles is possible so multiple operations are possible simultaneously.

**Special Type Milling Machines**

These are the special purpose milling machines, entirely different in design and construction from the conventional milling machines. In case of rotary table milling machine face milling cutters are mounted on two or more vertical spindles and a number of workpiece are clamped on the horizontal surface of a circular table which rotates about a vertical axis. Different milling cutters are mounted at different heights. Loading and unloading are possible while milling is in progress. In case of drum milling machine the worktable rotates about a horizontal axis and is called drum. In a planetary milling machine, the work is held stationary while the revolving cutters in a planetary path. It is used to finish cylindrical surface of a workpiece internally or externally or both. Pantograph milling machine reproduced the workpiece at any desired scale of pre-decided model. Profiling machine duplicates full size of the template attached to the machine. Tracer milling machine can produce any pre-decided irregular or complex shapes of dies, moulds by synchronizing movements of the cutter and tracing elements.

**PRINCIPAL PARTS OF A MILLING MACHINE**

Generally columns and knee type milling machine is considered as typical milling machine. Principal parts of a typical milling machine are described as below.

**Base**

It provides rest for all parts of milling machine including column. It is made of grey iron by casting.

**Column**

It is a type of rigid vertical long box. It houses driving mechanism of spindle, table knee is also fixed to the guide ways of column.

**Knee**

Knee can be adjusted at a height on the column. It houses the feed mechanism of the table and other controls.

**Saddle**

Saddle is placed at the top of the knee. Saddle provides guide ways for the movement of the table.

**Table**

Table rests on the saddle. It consists of „T“ shaped slots for clamping the workpiece. Movements of the table (feed motions) are given in very controlled manner by lead screw.

**Overhanging Arm**

Overhanging arm is mounted on the column and serves a bearing support for the arbor. This arm is adjustable so that the bearing support may be provided near to the milling cutter. There can be more than one bearing supports to the arbor.

**Arbor**

It holds rotating milling cutters rigidly and mounted on the spindle. Sometimes arbor is supported at maximum distance from support of overhanging arm like a cantilever, it is called stub arbor. Locking provisions are provided in the arbor assembly to ensure its reliability.

**Milling Front Brace**

Front base is used to adjust the relative position of knee and overhanging arm. It is also an extra support fixed between the knee and overhanging arm for rigidity.

**Spindle**

Spindle is projected from the column face and provided with a tapered hole to accommodate the arbor. Performance of a milling machine depends on the accuracy, strength and rigidity of the spindle. Spindle also transfer the motive power to arbor through belt or gear from column.

**SPECIFICATIONS OF A MILLING MACHINE**

Along with the type of a milling machine, it has to be specified by its size. Generally size of a typical milling machine is designated as given below:

(a) Size (dimensions) of the worktable and its movement range table length  $\times$  table width as 900  $\times$  275 mm.

Table movements: Longitudinal travel  $\times$  Cross  $\times$  Vertical as 600  $\times$  200  $\times$  400 mm.

Above travels indicate maximum movement in a direction.

(b) Number of feeds available (specify their values).

(c) Number of spindle speeds (specify their values).

(d) Total power available.

(e) Spindle nose taper.

(f) Floor space required.

(g) Net weight.

**Milling Cutters**

Milling cutters are classified into different categories depending on different criteria as described below :

**According to the Construction of Milling Cutter**

(a) Solid milling cutter

(b) Inserted teeth cutter

(c) Tipped solid cutter

Solid cutter consists of teeth integral with the cutter body, in tipped cutter, teeth are made of cemented carbide or satellite, teeth are brazed to steel cutter body called shank. Inserted teeth cutter are larger in diameter, teeth of hard material are inserted and secured in the shank.

**According to Relief Characteristics of the Cutter Teeth**

(a) Profile relieved cutter

(b) Form relieved cutter

In case of profile relieved cutter, a relief to cutting edges is provided by grinding a narrow land at their back. In case of form relieved cutters a curved relief is provided at the back of the cutting edges.

**According to Method of Mounting the Cutters**

(a) Arbor type

(b) Facing cutter

(c) Shank cutter

Arbor type cutters have a central hole and keyways for their mounting on arbor. Shank type cutters are provided with straight or tapered shanks inserted into the spindle nose and clamped there. Facing type milling cutter are used to produce flat surfaces. These are balled or attached to the spindle nose or the face of a short arbor (stub arbor).

**According to Direction of Rotation of the Cutter**

(a) Right hand rotational cutter

(b) Left hand rotational cutter

A right hand rotational cutter rotates in an anticlockwise direction when viewed from end of the spindle while left hand rotational cutter rotates in a clockwise direction.

**According to the Direction of Helix of the Cutter Teeth**

(a) Parallel straight teeth

(b) Right hand helical

(c) Left hand helical

(d) Alternate helical teeth

Parallel or straight teeth cutter consists of teeth parallel to axis of rotation of the cutter with zero helix angles. In case of right hand and left hand helical teeth cutters, teeth cut at an angle to the axis of rotation of the cutter. Teeth have opposite inclination in both the cutters. Alternate helical teeth cutter has alternate teeth of right hand and left hand helical teeth cutters.

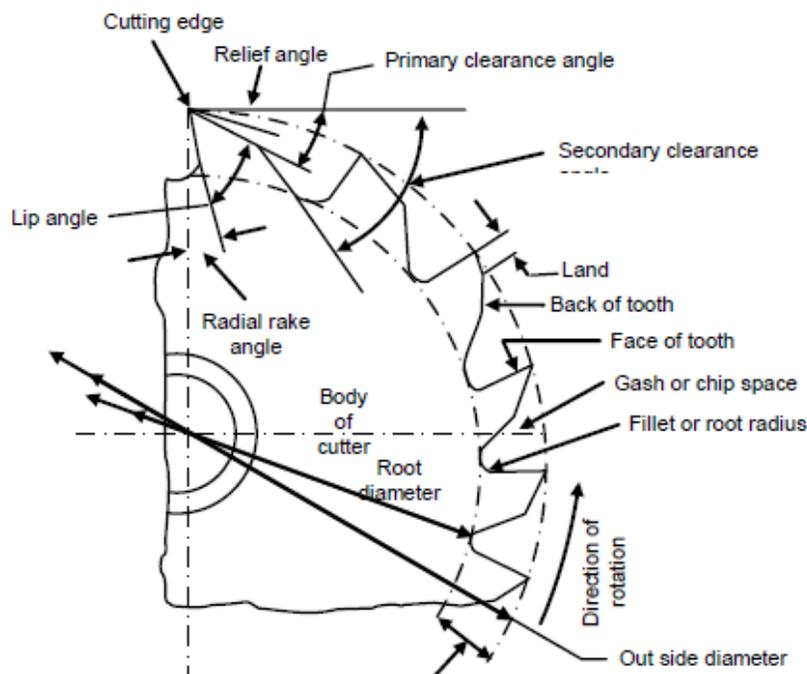
#### **According to Purpose of Use of the Cutter**

- (a) Standard milling cutter
- (b) Special milling cutter

Special milling cutters are designed to perform special operations which may be combination of several conventional operations. Standard milling cutters are the conventional cutters which are classified as given below.

#### **Plain Milling Cutters**

These cutters are cylindrical in shape having teeth on their circumference. These are used to produce flat surfaces parallel to axis of rotation. Plain milling cutter is shown in Figure; Depending upon the size and applications plain milling cutters are categorized as light duty, heavy duty and helical plain milling cutters.



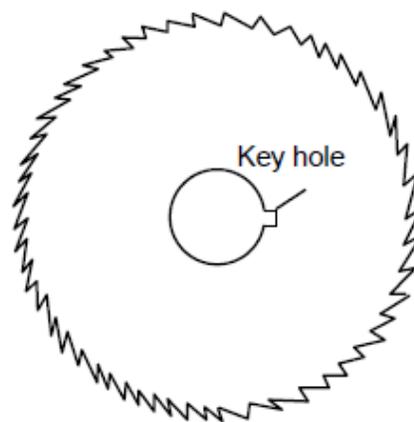
**Figure: Plain Milling Cutter and its Elements**

#### **Side Milling Cutters**

Side milling cutters are used to remove metals from the side of workpiece. These cutters have teeth on the periphery and on its sides. These are further categorized as plain side milling cutters having straight circumferential teeth. Staggered teeth side milling cutters having alternate teeth with opposite helix angle providing more chip space. Half side milling cutters have straight or helical teeth on its circumference and on its one side only. Circumferential teeth do the actual cutting of metal while side teeth do the finishing work.

#### **Metal Slitting Saw**

These cutters are like plain or side milling cutters having very small width. These are used for parting off or slotting operations. Metal slitting saw is shown in Figure 1.6. It is of two types. If teeth of this saw resembles with plain milling cutter, it is called plain milling slitting saw. If its teeth matches with staggered teeth side milling cutter, it is called staggered teeth slitting saw.



**Figure: Metal Slitting Saw**

### Angle Milling Cutter

These cutters have conical surfaces with cutting edges over them. These are used to machine angles other than 90°. Two types of angle milling cutters are available single angle milling cutter and double angle milling cutter.

### End Mill

End mills are used for cutting slots, small holes and light milling operations. These cutters have teeth on their end as well as an periphery. The cutting teeth may be straight or helical. Depending upon the shape of their shank, these are categorized as discussed below.

### Taper Shank Mill

Taper shank mill have tapered shank.

### Straight Shank Mill

Straight shank mill having straight shank.

### Shell End Mills

These are normally used for face milling operation. Cutters of different sizes can be accommodated on a single common shank.

### 'T' Slot Milling Cutters

These are the special form of milling cutters used to produce „T“ shaped slots in the workpiece. These have cutting edges on their periphery and both sides.

### Fly Cutter

Fly cutters are the simplest form of cutters used to make contoured surfaces. These cutters are the single cutting point cutting tools.

### Formed Cutters

Formed cutters may have different types of profile on their cutting edges which can generate different types of profile on the workpieces. Depending upon tooth profile and their capabilities formed cutters are categorized as given below.

### Convex Milling Cutters

These cutters have profile outwards at their circumference and used to generate concave semicircular surface on the workpiece.

### Concave Milling Cutters

These milling cutters have teeth profile curve in words on their circumference. These are used to generate convex semicircular surfaces.

### Corner Rounding Milling Cutters

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These cutters have teeth curved inwards. These milling cutters are used to form contours of quarter circle. These are mainly used in making round corners and round edges of the workpiece.

**Gear Cutter**

These cutters are used in making gears on milling machine. Gear cutting is an operation which cannot be done otherwise. These cutters have shape of the teeth which are to be reproduced on the gear blank.

Different gear cutters are used to make teeth with involute profile or cycloidal profile. A gear cutter is used to cut a range of gear size with a fixed tooth profile.

**Thread Milling Cutter**

These cutters are designated to mill threads of specific form and size on the workpiece. These cutters may be with parallel shank or tapered shank and mainly used to make worms.

**Top and Reamer Cutter**

Top and reamer cutters are the cutters of double angle type, these are normally used to make grooves and flutes in taps or reamers. Taps and reamers are used as thread cutting tools for softer material workpieces.

**MILLING MACHINE OPERATIONS**

Milling operations described earlier were based on major categorization of milling. These were differentiated on the basis of relative position of milling cutter and workpiece. Their detailed description is given below.

Following different operations can be performed on a milling machine:

- (a) Plain milling operation
- (b) Face milling operation
- (c) Side milling operation
- (d) Straddle milling operation
- (e) Angular milling operation
- (f) Gang milling operation
- (g) Form milling operation
- (h) Profile milling operation
- (i) End milling operation
- (j) Saw milling operation
- (k) Slot milling operation
- (l) Gear cutting operation
- (m) Helical milling operation
- (n) Cam milling operation
- (o) Thread milling operation

**Plain Milling Operation**

This is also called slab milling. This operation produces flat surfaces on the workpiece. Feed and depth of cut are selected, rotating milling cutter is moved from one end of the workpiece to other end to complete the one pair of plain milling operation.

**Face Milling Operation**

This operation produces flat surface at the face of the workpiece. This surface is perpendicular to the surface prepared in plain milling operation. This operation is performed by face milling cutter mounted on stub arbor of milling machine. Depth of cut is set according to the need and cross feed is given to the work table.

**Side Milling Operation**

This operation produces flat and vertical surfaces at the sides of the workpiece. In this operation depth of cut is adjusted by adjusting vertical feed screw of the workpiece.

### Straddle Milling Operation

This is similar to the side milling operation. Two side milling cutters are mounted on the same arbor. Distance between them is so adjusted that both sides of the workpiece can be milled simultaneously. Hexagonal bolt can be produced by this operation by rotating the workpiece only two times as this operation produces two parallel faces of bolt simultaneously.

### Angular Milling Operation

Angular milling operation is used to produce angular surface on the workpiece. The produced surface makes an angle with the axis of spindle which is not right angle. Production of „V“ shaped groove is the example of angular milling operation. Angular milling is shown in Figure

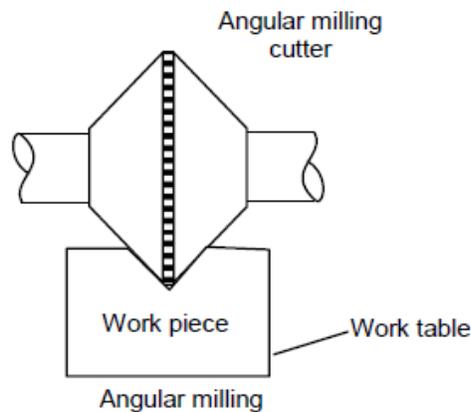


Figure: Angular Milling Operation

### Gang Milling Operation

As the name indicates, this operation produces several surfaces of a workpiece simultaneously using a gang of milling cutters. During this operation, the workpiece mounted on the table is fed against the revolving milling cutters. This operation is illustrated in Figure

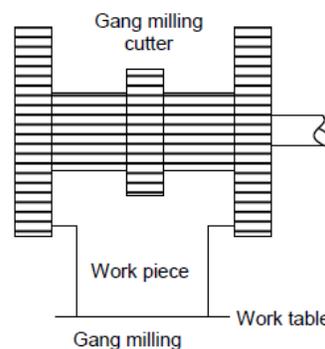


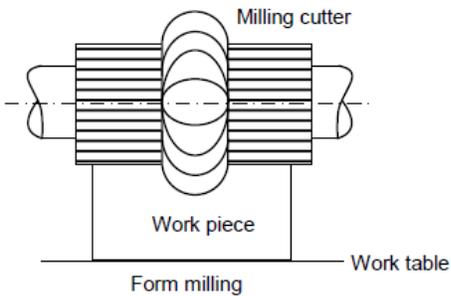
Figure: Gang Milling Operation

### Form Milling Operation

Form milling operation is illustrated in Figure this operation produces irregular contours on the work surface. These irregular contours may be convex, concave, or of any other shape. This operation is done comparatively at very low cutter speed than plain milling operation.

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**Profile Milling Operation**

In this operation a template of complex shape or master die is used. A tracer and milling cutter are synchronized together with respect to their movements. Tracer reads the template or master die and milling cutter generates the same shape on the workpiece. Profile milling is an operation used to generate shape of a template or die. This operation is demonstrated in Figure

**End Milling Operation**

End milling operation produces flat vertical surfaces, flat horizontal surfaces and other flat surfaces making an angle from table surface using milling cutter named as end mill. This operation is preferably carried out on vertical milling machine. This operation is illustrated in Figure

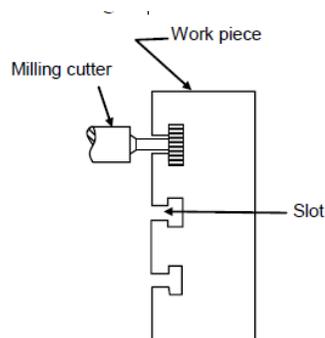


End Milling Operation

Saw Milling Operation

**Slot Milling Operation**

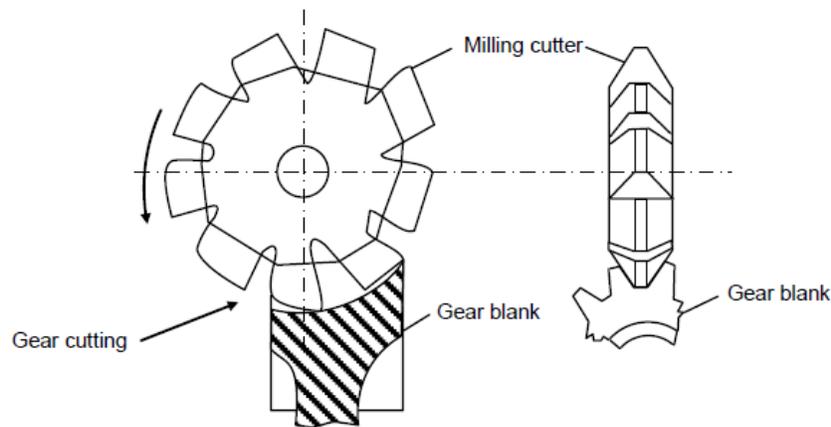
The operation of producing keyways, grooves, slots of varying shapes and sizes is called slot milling operation. Slot milling operation can use any type of milling cutter like plain milling cutter, metal slitting saw or side milling cutter. Selection of a cutter depends upon type and size of slot or groove to be produced. Right placement of milling cutter is very important in this operation as axis of cutter should be at the middle of geometry of slot or groove to be produced. The operation is illustrated in Figure



Slot Milling Operation

**Gear Cutting Operation**

The operation of gear cutting is cutting of equally spaced, identical gear teeth on a gear blank by handling it on a universal dividing head and then indexing it. The cutter used for this operation is cylindrical type or end mill type. The cutter selection also depends upon tooth profile and their spacing. Gear cutting operation is illustrated in Figure



**Figure: Gear Cutting Operation**

**Helical Milling Operation**

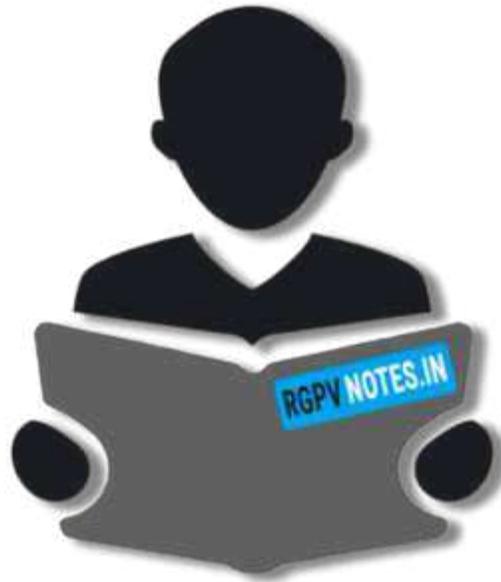
Helical milling produces helical flutes or grooves on the periphery of a cylindrical or conical workpiece. This is performed by swiveling the table to the required helix angle, then rotating and feeding the workpiece against revolving cutting edges of milling cutter. Helical gears and drills and reamers are made by this operation.

**Cam Milling Operation**

The operation cam milling is used to produce the cam on milling machine. In this operation cam blank is mounted at the end of the dividing head spindle and the end mill is held in the vertical milling attachment.

**Thread Milling Operation**

The operation thread milling produces threads using thread milling centres. This operation needs three simultaneous movements revolving movement of cutter, simultaneous longitudinal movement of cutter, feed movement to the workpiece through table. For each thread, the revolving cutter is fed longitudinal by a distance equal to pitch of the thread. Depth of cut is normally adjusted equal to the full depth of threads.



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