Module
6
Superfinishing processes

Lesson
30
Superfinishing processes, Honing, Lapping and Superfinishing

Instructional Objectives

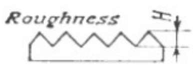
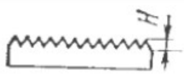
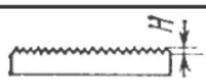
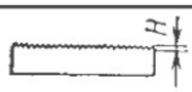
At the end of this lesson the students would be able to

(i) understand the significance of superfinishing process
(ii) state various applications of the superfinishing process
(iii) illustrate various techniques of superfinishing process

To ensure reliable performance and prolonged service life of modern machinery, its components require to be manufactured not only with high dimensional and geometrical accuracy but also with high surface finish. The surface finish has a vital role in influencing functional characteristics like wear resistance, fatigue strength, corrosion resistance and power loss due to friction. Unfortunately, normal machining methods like turning, milling or even classical grinding can not meet this stringent requirement.

Table 30.1 illustrates gradual improvement of surface roughness produced by various processes ranging from precision turning to superfinishing including lapping and honing.

Table 30.1

Process	Diagram of resulting surface	Height of micro irregularity (μm)
Precision Turning		1.25-12.50
Grinding		0.90-5.00
Honing		0.13-1.25
Lapping		0.08-0.25
Super Finishing		0.01-0.25

Therefore, superfinishing processes like lapping, honing, polishing, burnishing are being employed to achieve and improve the above-mentioned functional properties in the machine component.

30.1 Lapping

Lapping is regarded as the oldest method of obtaining a fine finish. Lapping is basically an abrasive process in which loose abrasives function as cutting points finding momentary support from the laps. Figure 30.1 schematically represents the lapping process. Material removal in lapping usually ranges from .003 to .03 mm but many reach 0.08 to 0.1mm in certain cases.

Characteristics of lapping process:

- Use of loose abrasive between lap and the workpiece
- Usually lap and workpiece are not positively driven but are guided in contact with each other
- Relative motion between the lap and the work should change continuously so that path of the abrasive grains of the lap is not repeated on the workpiece.

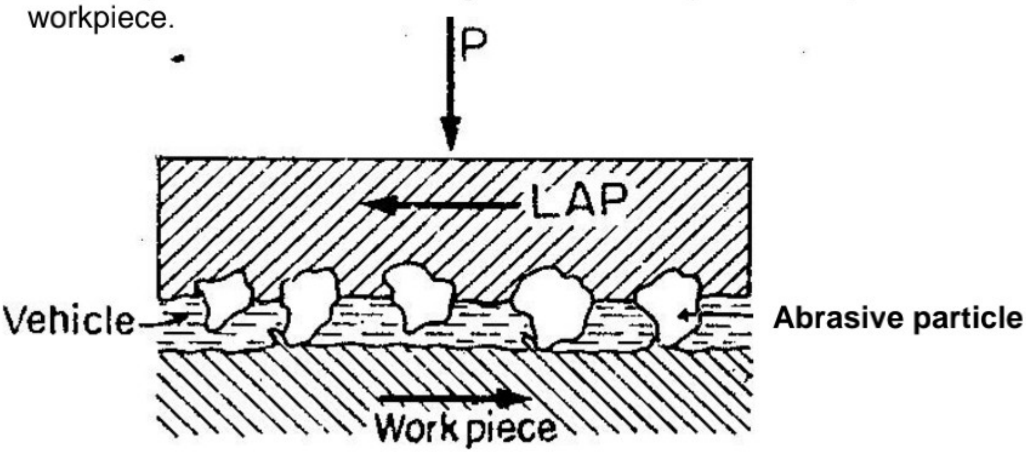


***Fig. 30.1** Scheme of lapping process*

Cast iron is the mostly used lap material. However, soft steel, copper, brass, hardwood as well as hardened steel and glass are also used.

Abrasives of lapping:

- Al_2O_3 and SiC, grain size 5~100μm
- Cr_2O_3, grain size 1~2 μm
- B_4C_3, grain size 5-60 μm
- Diamond, grain size 0.5~5 V

Vehicle materials for lapping

- Machine oil
- Rape oil
- grease

Technical parameters affecting lapping processes are:

- unit pressure
- the grain size of abrasive
- concentration of abrasive in the vehicle
- lapping speed

Lapping is performed either manually or by machine. Hand lapping is done with abrasive powder as lapping medium, whereas machine lapping is done either with abrasive powder or with bonded abrasive wheel.

30.1.1 Hand lapping

Hand lapping of flat surface is carried out by rubbing the component over accurately finished flat surface of master lap usually made of a thick soft close-grained cast iron block. Abrading action is accomplished by very fine abrasive powder held in a vehicle. Manual lapping requires high personal skill because the lapping pressure and speed have to be controlled manually.

Laps in the form of ring made of closed grain cast iron are used for manual lapping of external cylindrical surface. The bore of the ring is very close to size of the workpiece however, precision adjustment in size is possible with the use of a set screw as illustrated in Fig.30.2(a). To increase range of working, a single holder with interchangeable ring laps can also be used. Ring lapping is recommended for finishing plug gauges and machine spindles requiring high precision. External threads can be also lapped following this technique. In this case the lap is in the form of a bush having internal thread.

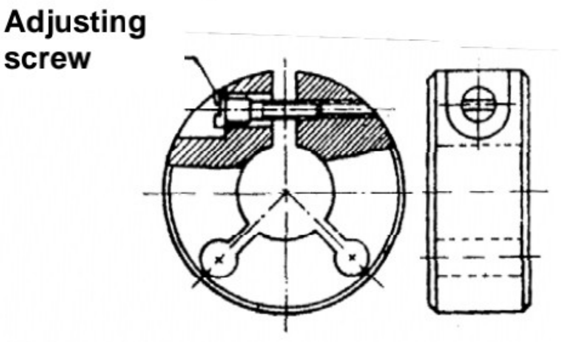


Fig. 30.2 *Manual Ring lapping of external cylindrical surface*

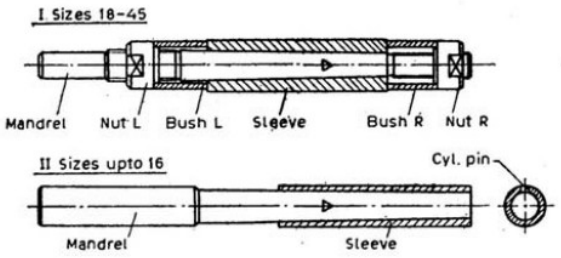


Fig. 30.2 *(b) Manual Lapping of internal cylindrical surfaces*

Solid or adjustable laps, which are ground straight and round, are used for lapping holes. For manual lapping, the lap is made to rotate either in a lathe or honing machine, while the workpiece is reciprocated over it by hand. Large size laps are made of cast iron, while those of small size are made of steel or brass. This process finds extensive use in finishing ring gauges.

30.1.2 Lapping Machine

Machine lapping is meant for economic lapping of batch qualities. In machine lapping, where high accuracy is demanded, metal laps and abrasive powder held in suitable vehicles are used. Bonded abrasives in the form wheel are chosen for commercial lapping. Machine lapping can also employ abrasive paper or abrasive cloth as the lapping medium. Production lapping of both flat and cylindrical surfaces are illustrated in Fig. 30.3 (a) and (b). In this case cast iron plate with loose abrasive carried in a vehicle can be used. Alternatively, bonded abrasive plates may also be used. Centreless roll lapping uses two cast iron rolls, one of which serves as the lapping roller twice in diameter than the other one known as the regulating roller. During lapping the abrasive compound is applied to the rolls rotating in the same direction while the workpiece is fed across the rolls. This process is suitable for lapping a single piece at a time and mostly used for lapping plug gauges, measuring wires and similar straight or tapered cylindrical parts.

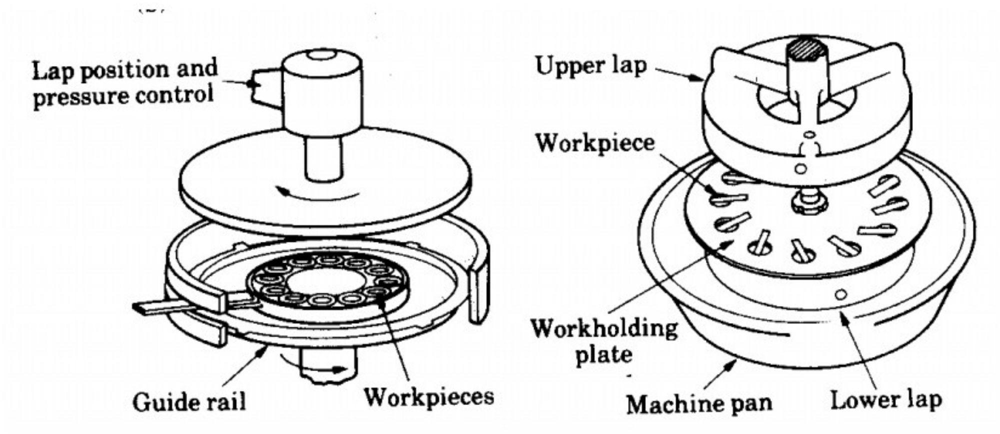


***Fig.30.3** Production lapping on (a) flat surface (b) cylindrical surface*

Centreless lapping is carried out in the same principle as that of centreless grinding. The bonded abrasive lapping wheel as well as the regulating wheel are much wider than those used in centreless grinding. This technique is used to produce high roundness accuracy and fine finish, the workpiece requires multi-pass lapping each with progressively finer lapping wheel. This is a high production operation and suitable for small amount of rectification on shape of workpiece. Therefore, parts are to be pre-ground to obtain substantial straightness and roundness. The process finds use in lapping piston rings, shafts and bearing races.

Machines used for lapping internal cylindrical surfaces resembles honing machines used with power stroke. These machines in addition to the rotation of the lap also provide reciprocation to the workpiece or to the lap. The lap made usually of cast iron either solid or adjustable type can be conveniently used.

Figure 30.4 shows that to maximize the MRR (material removal rate) an optimum lapping pressure and abrasive concentration in the vehicle have to be chosen.

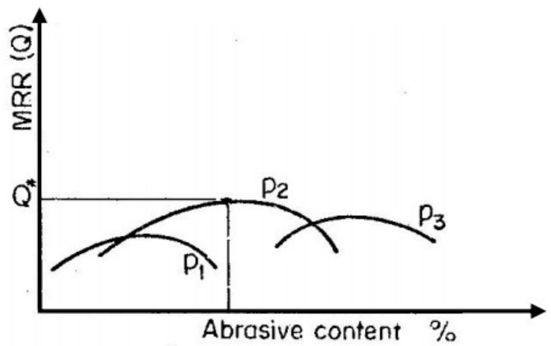


***Fig. 30.4** Effect of abrasive content on MRR*

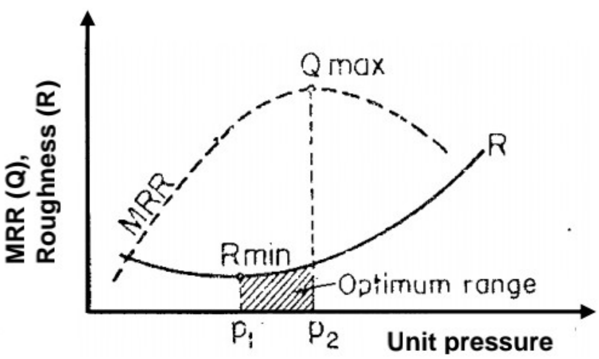


***Fig. 30.5** Effect of lapping pressure on surface roughness and MRR*

The effect of unit pressure on MRR and surface roughness is shown in Fig. 30.5. It is shown in the same figure that unit pressure in the range of p_1-p_2 gives the best values for MRR and roughness of the lapped surface.

The variation in MRR and surface roughness with grain size of abrasive are shown in Fig.30.6. It appears that grain size corresponding to permissible surface roughness and maximum MRR may be different. Primary consideration is made on the permissible surface roughness in selecting abrasive grain size.

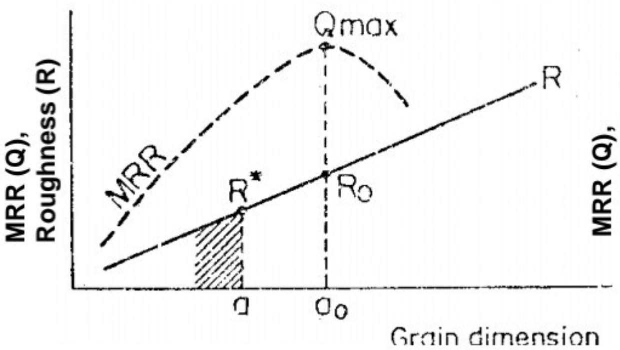


Fig. 30.6 *Effect of abrasive grain size on surface roughness and MRR*

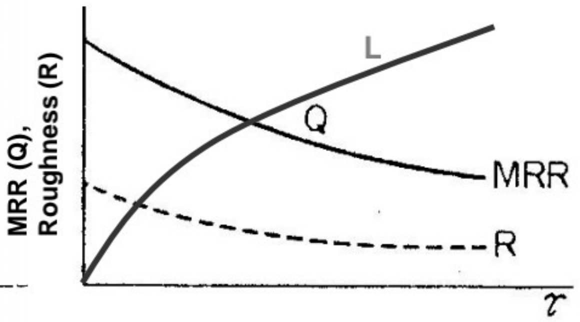


Fig. 30.7 *Effect of lapping time on surface roughness and MRR*

The dependence of MRR, surface roughness and linear loss (L) of workpiece dimension is shown in fig. 30.7. Lapping conditions are so chosen that designed surface finish is obtained with the permissible limit of linear loss of workpiece dimension as shown in Fig. 30.8.

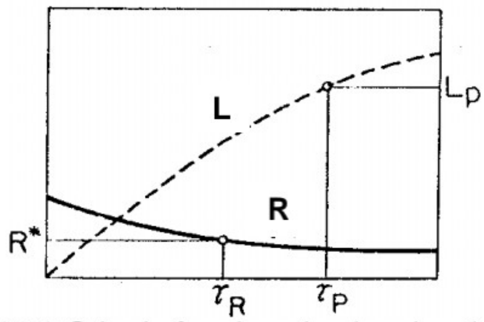


Fig. 30.8 *Criteria for choosing lapping time*

30.2 Honing

Honing is a finishing process, in which a tool called hone carries out a combined rotary and reciprocating motion while the workpiece does not perform any working motion. Most honing is done on internal cylindrical surface, such as automobile cylindrical walls. The honing stones are held against the workpiece with controlled light pressure. The honing head is not guided externally but, instead, floats in the hole, being guided by the work surface (Fig. 30.9). It is desired that

1. honing stones should not leave the work surface
2. stroke length must cover the entire work length.

In honing rotary and oscillatory motions are combined to produce a cross hatched lay pattern as illustrated in Fig. 30.10

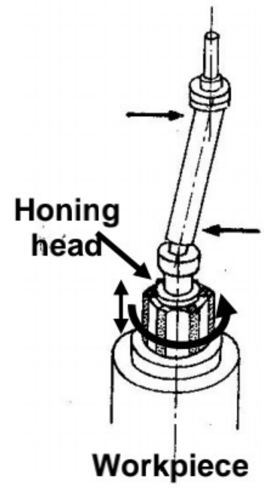


Fig. 30.9 *Honing tool*

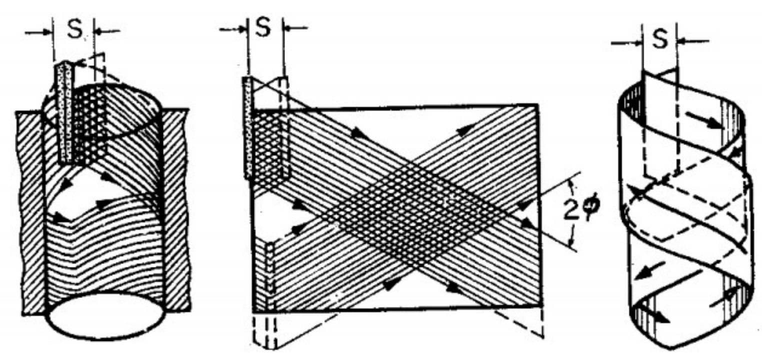


Fig. 30.10 *Lay pattern produced by combination of rotary and oscillatory motion*

The honing stones are given a complex motion so as to prevent every single grit from repeating its path over the work surface. The critical process parameters are:

1. rotation speed
2. oscillation speed
3. length and position of the stroke
4. honing stick pressure

With conventional abrasive honing stick, several strokes are necessary to obtain the desired finish on the work piece. However, with introduction of high performance diamond and cBN grits it is now possible to perform the honing operation in just one complete stroke. Advent of precisely engineered microcrystalline cBN grit has enhanced the capability further. Honing stick with microcrystalline cBN grit can maintain sharp cutting condition with consistent results over long duration.

Superabrasive honing stick with monolayer configuration (Fig. 30.11), where a layer of cBN grits are attached to stick by a galvanically deposited metal layer, is typically found in single stroke honing application.

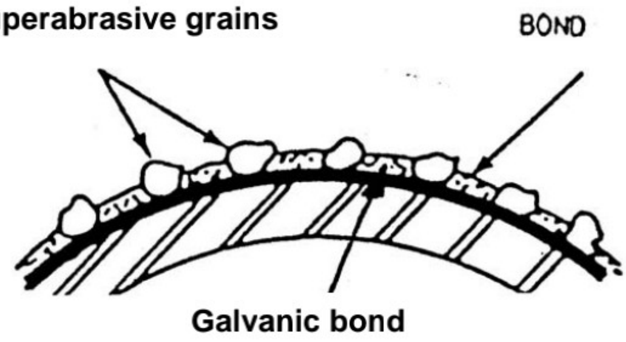


Fig.30.11 *Superabrasive honing stick with single layer configuration*

With the advent of precision brazing technique, efforts can be made to manufacture honing stick with single layer configuration with a brazed metal bond. Like brazed grinding wheel such single layer brazed honing stick are expected to provide controlled grit density, larger grit protrusion leading to higher material removal rate and longer life compared to what can be obtained with a galvanically bonded counterpart.

The important parameters that affect material removal rate (MRR) and surface roughness (R) are:

(i) unit pressure, p
(ii) peripheral honing speed, Vc
(iii) honing time, T

The variation of MRR (Q) and R with unit pressure is shown in Fig. 30.12. It is evident from the graph that the unit pressure should be selected so as to get minimum surface roughness with highest possible MRR.

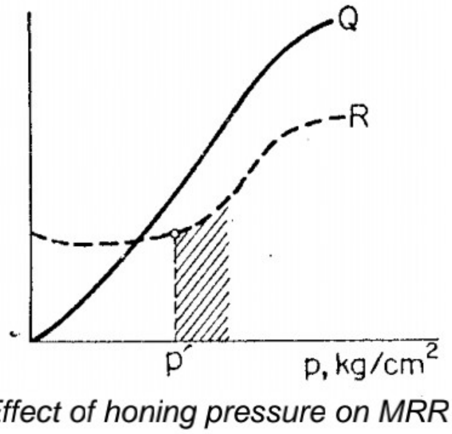


Fig. 30.12*: Effect of honing pressure on MRR and surface finish*

Figure 30.13 shows that an increase of peripheral honing speed leads to enhancement of material removal rate and decrease in surface roughness.

Figure 30.14 shows that with honing time T, MRR decreases. On the other hand, surface roughness decreases and after attaining a minimum value again rises. The selection of honing time depends very much on the permissible surface roughness.

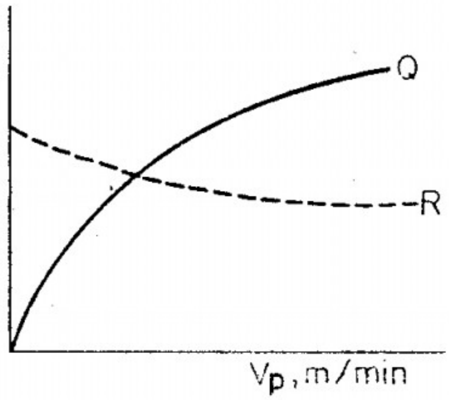


Fig. 30.13 *Effect of peripheral honing speed*

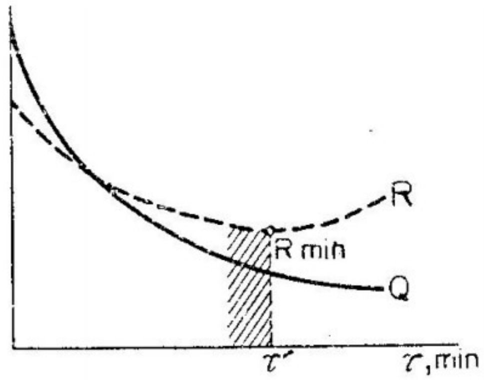


Fig. 30.14 *Effect of honing time on material removal rate and surface roughness*

30.3 Superfinishing

Figure 30.15 illustrates superfinishing end-face of a cylindrical workpiece. In this both feeding and oscillation of the superfinishing stone is given in the radial direction.

Figure 30.16 shows the superfinishing operation in plunge mode. In this case the abrasive stone covers the section of the workpiece requiring superfinish. The abrasive stone is slowly fed in radial direction while its oscillation is imparted in the axial direction.

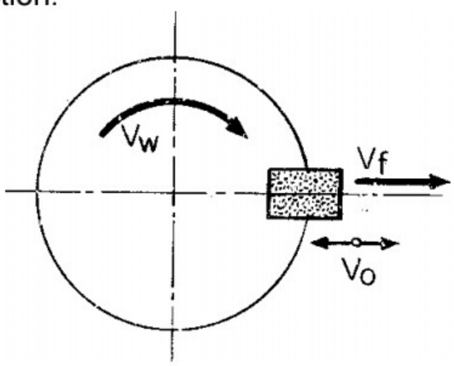


Fig. 30.15 *superfinishing of end face of a cylindrical work piece in radial mode*

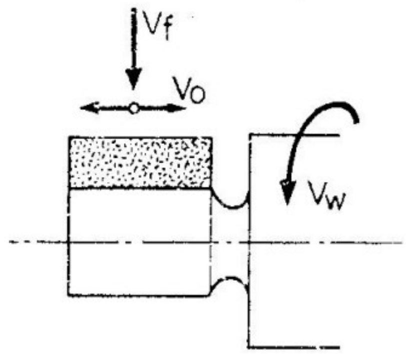


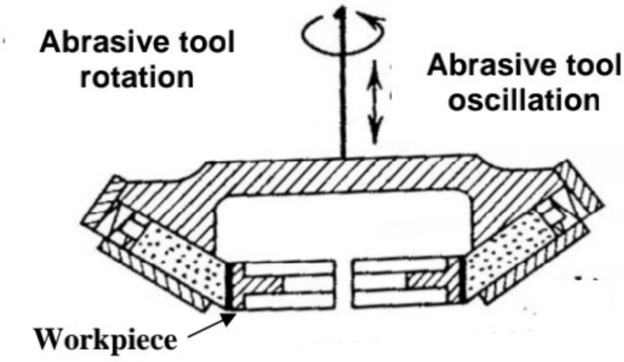
Fig. 30.16 *superfinishing operation in plunge mode*

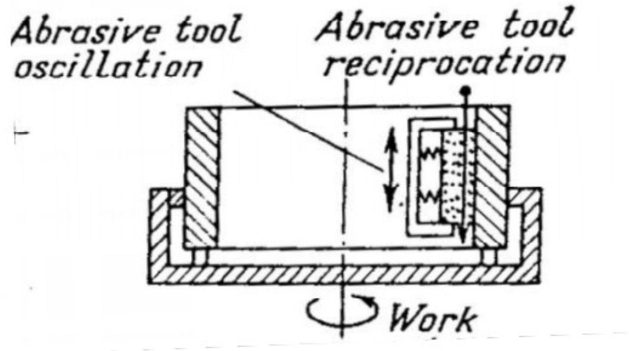
Superfinishing can be effectively done on a stationary workpiece as shown in Fig. 30.17. In this the abrasive stones are held in a disc which oscillates and rotates about the axis of the workpiece.

Fig. 30.18 shows that internal cylindrical surfaces can also be superfinished by axially oscillating and reciprocating the stones on a rotating workpiece.

Abrasive tool oscillation

Abrasive tool reciprocation





Abrasive tool oscillation

Workpiece

Fig. 30.17 *Abrasive tool rotating and oscillating about a stationary workpiece*

Fig. 30.18 *Superfinishing of internal surface*

30.3.1 Burnishing

The burnishing process consists of pressing hardened steel rolls or balls into the surface of the workpiece and imparting a feed motion to the same. Ball burnishing of a cylindrical surface is illustrated in Fig. 30.19.

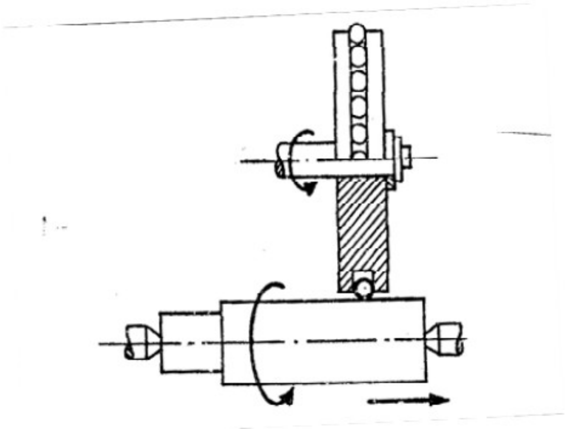


Fig. 30.19 *Scheme of ball burnishing*

During burnishing considerable residual compressive stress is induced in the surface of the workpiece and thereby fatigue strength and wear resistance of the surface layer increase.

30.3.2 Magnetic float polishing

Magnetic float polishing (Fig.30.20) finds use in precision polishing of ceramic balls. A magnetic fluid is used for this purpose. The fluid is composed of water or kerosene carrying fine ferro-magnetic particles along with the abrasive grains. Ceramic balls are confined between a rotating shaft and a floating platform. Abrasive grains ceramic ball and the floating platform can remain in suspension under the action of magnetic force. The balls are pressed against the rotating shaft by the float and are polished by their abrasive action. Fine polishing action can be made possible through precise control of the force exerted by the abrasive particles on the ceramic ball.

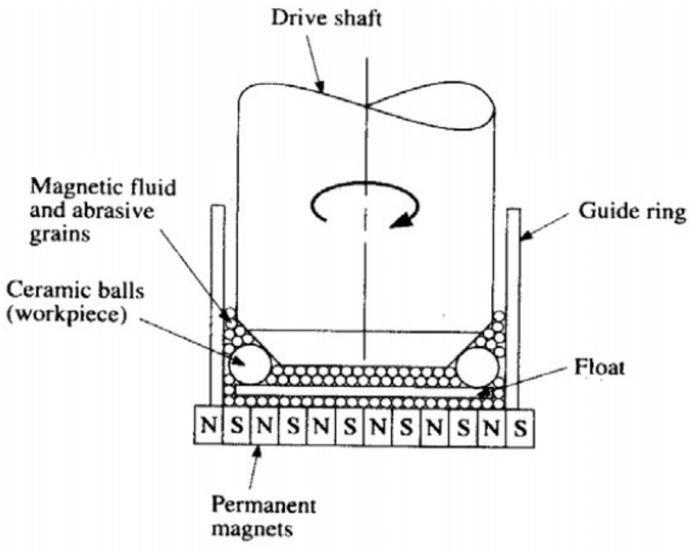


Fig. 30.20 *Scheme of magnetic float polishing*

30.3.3 Magnetic field assisted polishing

Magnetic field assisted polishing is particularly suitable for polishing of steel or ceramic roller. The process is illustrated schematically in Fig. 30.21. A ceramic or a steel roller is mounted on a rotating spindle. Magnetic poles are subjected to oscillation, thereby, introducing a vibratory motion to the magnetic fluid containing this magnetic and abrasive particles. This action causes polishing of the cylindrical roller surface. In this technique, the material removal rate increases with the field strength, rotational speed of the shaft and mesh number of the abrasive. But the surface finish decreases with the increase of material removal rate.

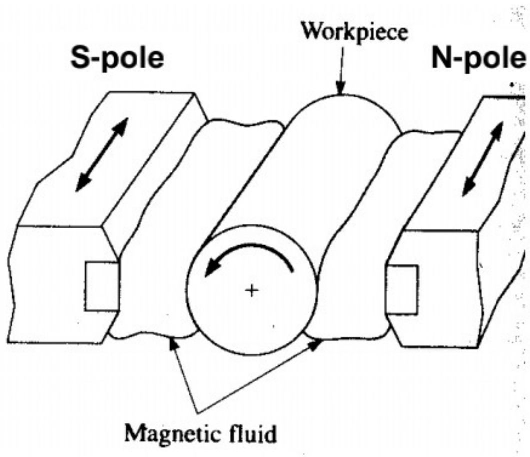


Fig. 30.21 *scheme of magnetic field assisted polishing*

30.3.4 Electropolishing

Electropolishing is the reverse of electroplating. Here, the workpiece acts as anode and the material is removed from the workpiece by electrochemical dissolution. The process is particularly suitable for polishing irregular surface since there is no mechanical contact between workpiece and polishing medium. The electrolyte electrochemically etches projections on the workpiece surface at a faster rate than the rest, thus producing a smooth surface. This process is also suitable for deburring operation.

Exercise 30

Q1: How is the size of the abrasive grain chosen?

Q2: Can cBN be used in honing stick in single layer configuration?

Q3: How does superfinishing differ from honing?

Q4: State the advantage of electro polishing over mechanical polishing.

Q5: How is the surface quality improved in ball burnishing?

Ans1:
Size of the abrasive grain is chosen keeping in view, the permissible roughness of the workpiece and maximum material removal rate attainable.

Ans2:
cBN grits in single layer configuration embedded in galvanic bond can be effectively used as honing stick. Such honing stick is preferred in production honing with just a single stroke operation.

Ans3:
Superfinishing, in a way, is similar to honing but with very low cutting pressure and different kinematic tool-work interactions like

- oscillatory motion of the abrasive stick with short stroke but with high frequency.
- rotation of workpiece is usually kept low.
- feed motion of the tool or the work piece.

Ans4:
Electropolishing has clear advantage in polishing irregular surfaces. The electrolyte attacks high points at a faster rate than rest of the surface resulting in production of a smooth surface.

Ans5:
In this process, a hardened steel ball presses the workpiece surface. The surface finish is markedly improved. In addition, a residual compressive stress is developed on the surface, which in turn improves the fatigue resistance. The work hardening effect, as a result of burnishing, also enhances wear resistance of the surface. Therefore, by ball burnishing the overall quality of the workpiece surface is significantly improved.

UNIT 1 MILLING

Structure

1.1 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.

1.2 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 be 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.

All the above types of milling operations are also demonstrated in Figure 1.1 as per their respective article number.

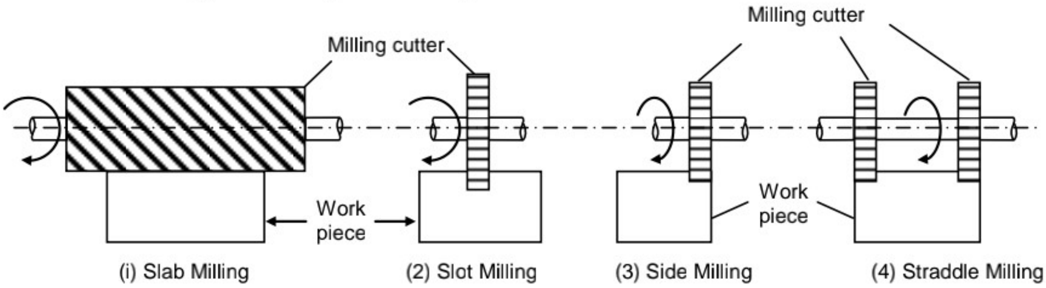


Figure 1.1 : Different Types of Peripheral Milling

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 over hanging 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

In this operation a ball nose cutter if feedback 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 1.2 at their respective number.

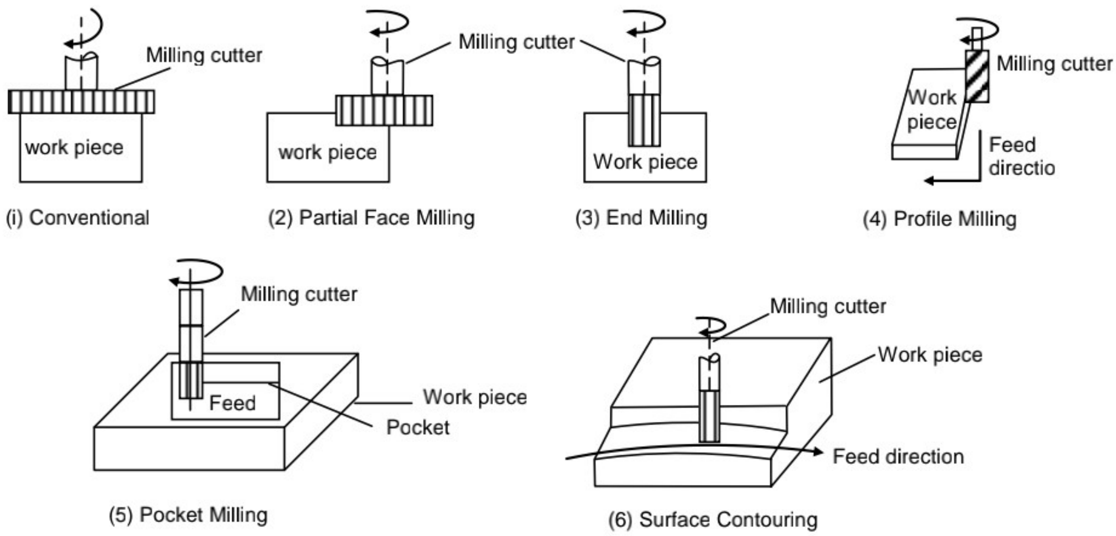


Figure 1.2 : Different Types of Face Milling

1.3 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.

1.3.1 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 1.3. 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.

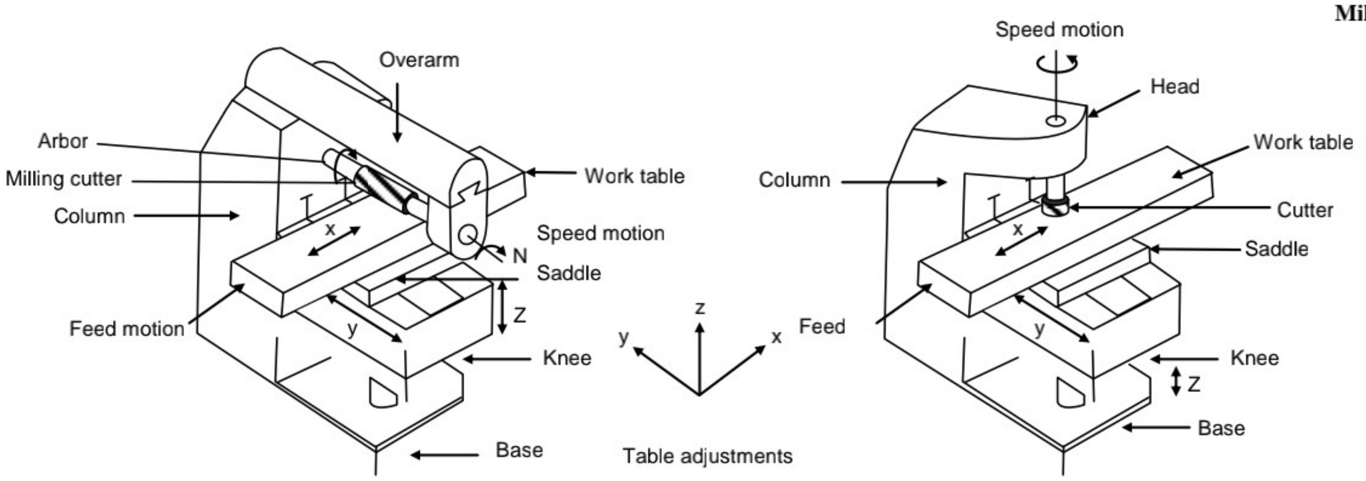


Figure 1.3 : Column and Knee Type Milling Machine

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 it table which is mounted on a circular swiveling base which has degree graduations. The table can be swiveled to any angle upto 45^o 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 1.4.

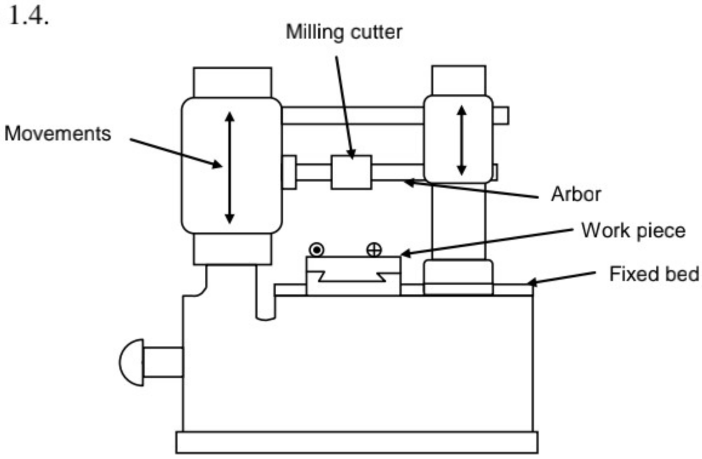


Figure 1.4 : Fixed Bed Type Milling Machine

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 workpieces 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.

1.5 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 be 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.

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.

1.6 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 × table width as 900 × 275 mm.

Table movements : Longitudinal travel × Cross × Vertical as 600 × 200 × 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.

1.7 CUTTING PARAMETERS

There are three major cutting parameters to be controlled in any milling operation. These three parameters are cutting, speed, feed rate and depth of cut. These parameters are described below.

Cutting Speed

Cutting speed of a milling cutter is its peripheral linear speed resulting from operation. It is expressed in meters per minute. The cutting speed can be derived from the above formula.

$$V = \frac{\pi\, d\, n}{1000}$$

where d = Diameter of milling cutter in mm,

V = Cutting speed (linear) in meter per minute, and

n = Cutter speed in revolution per minute.

Spindle speed of a milling machine is selected to give the desired peripheral speed of cutter.

Feed Rate

It is the rate with which the workpiece under process advances under the revolving milling cutter. It is known that revolving cutter remains stationary and feed is given to the workpiece through worktable. Generally feed is expressed in three ways.

Feed per Tooth

It is the distance traveled by the workpiece (its advance) between engagement by the two successive teeth. It is expressed as mm/tooth (f_t).

Feed per Revolution

Travel of workpiece during one revolution of milling cutter. It is expressed as mm/rev. and denoted by $f_{(rev)}$.

Feed per Unit of Time

Feed can also be expressed as feed/minute or feed/sec. It is the distance advances by the workpiece in unit time (f_m).

Above described three feed rates are mutually convertible.

$$f_m = n \times f_{rev}$$

where n = rpm of cutter.

It can be extended further as

$$f_m = n \times f_{rev} = z \times n \times f_t$$

where z = Number of teeth in milling cutter.

Depth of Cut

Depth of cut in milling operation is the measure of penetration of cutter into the workpiece. It is thickness of the material removed in one pairs of cutter under process. One pairs of cutter means when cutter completes the milling operation from one end of the workpiece to another end. In other words, it is the perpendicular distance measured between the original and final surface of workpiece. It is measured in mm.

1.8 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 angle. 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 1.5. Depending upon the size and applications plain milling cutters are categorized as light duty, heavy duty and helical plain milling cutters.

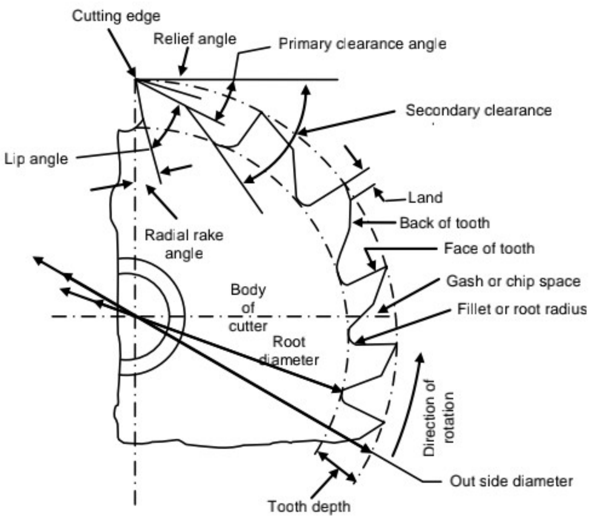


Figure 1.5 : Plain Milling Cutter and its Elements

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.

Interlocking side milling cutter has teeth of two half side milling cutter which are made to interlock to form one unit.

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.

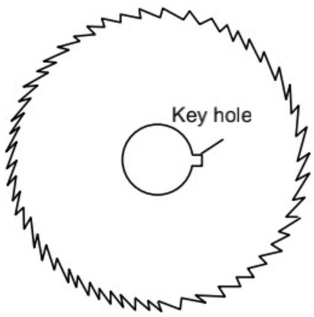


Figure 1.6 : Metal Slitting Saw

Angle Milling Cutter

These cutters have conical surfaces with cutting edges over them. These are used to machine angles other than 90^o. 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

These cutters have teeth curved inwards. These milling cutters are used to form contours of quarter circle. These are main 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 cutter have shape of the teeth which are to be reproduced on the gear blank.

Different gear cutters are used to make teeth with invalute 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 of 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.

1.9 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 pairs of plain milling operation.

Face Milling Operation

This operation produces flat surface at the face o 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 opration. Angular milling is shown in Figure 1.7.

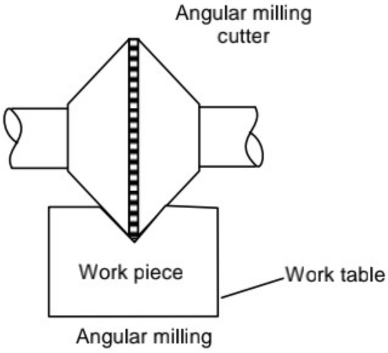


Figure 1.7 : Angular Milling Operation

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 1.8.

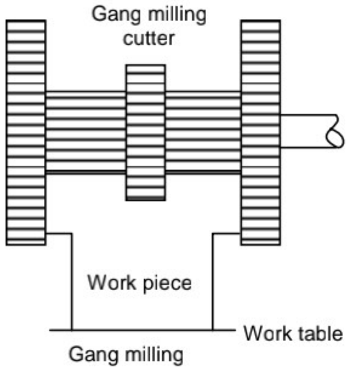


Figure 1.8 : Gang Milling Operation

Form Milling Operation

Form milling operation is illustrated in Figure 1.9. 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.

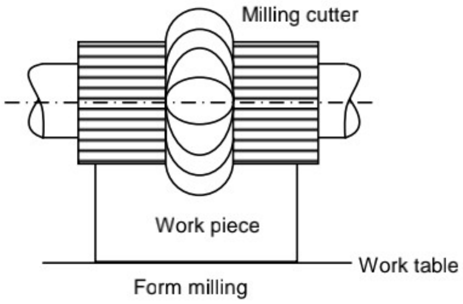


Figure 1.9 : Form Milling Operation

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 1.10.

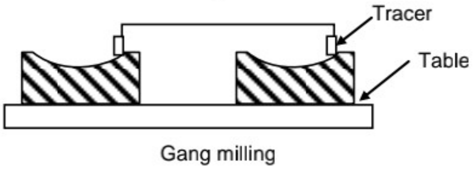


Figure 1.10 : Profile Milling Operation

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 1.11.

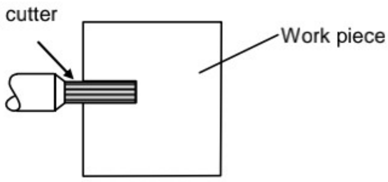


Figure 1.11 : End Milling Operation

Saw Milling Operation

Saw milling operation produces narrow slots or grooves into the workpiece using saw milling cutter. This operation is also used to cut the workpiece into two equal or unequal pieces which cut is also known as "parting off". In case of parting off operation cutter and workpiece are set in a manner so that the cutter is directly placed over one of the 'T' slot of the worktable as illustrated in Figure 1.12.

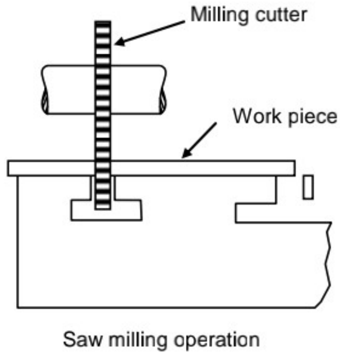


Figure 1.12 : Saw Milling Operation

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 1.13.

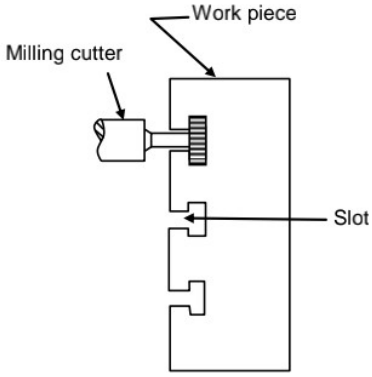


Figure 1.13 : Slot Milling Operation

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 1.14. Indexing is explained in detail later in this unit.

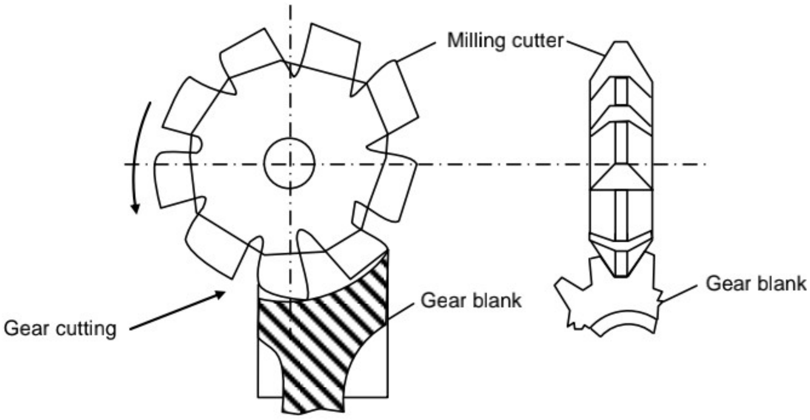


Figure 1.14 : Gear Cutting Operation

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.

1.10 INDEXING

Indexing is the operation of dividing the periphery of a workpiece into any number of equal parts. For example if we want to make a hexagonal bolt. Head of the bolt is given hexagonal shape. We do indexing to divide circular workpiece into six equal parts and then all the six parts are milled to an identical flat surface. If we want to cut 'n' number of teeth in a gear blank. The circumference of gear blank is divided into 'n' number of equal parts and teeth are made by milling operation one by one. The main component used in indexing operation is universal dividing head.

Universal Dividing Head

It is most popular and common type of indexing arrangement. As indicated by its name "universal", it can be used to do all types of indexing on a milling machine. Universal dividing head can set the workpiece in vertical, horizontal, or in inclined position relative to the worktable in addition to working principle is explained below with the help of illustration in Figure 1.15. The worm gear has 40 teeth and the worm has simple thread. Crank is directly attached with the worm. If we revolve crank by 40 revolutions the spindle attached with worm gear will revolve by only one revolution and one complete turn of the crank will revolve the spindle only by 1/40^th^ revolution (turn). In order to turn the crank precisely a fraction of a revolution, an indexing plate is used. An indexing plate is like a circular disc having concentric rings of different number of equally spaced holes. Normally indexing plate is kept stationary by a lock pin. A spring loaded pin is fixed to the crank which can be fixed into any hole of indexing plate. The turning movement of the workpiece is stably controlled by the movement of crank as explained below.

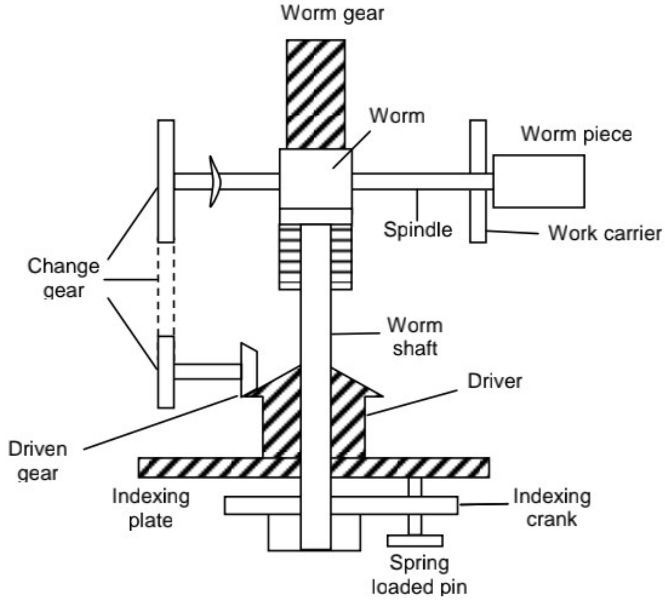


Figure 1.15 : Working Principle of Indexing Mechanism

If the pin is moved by one hole on the indexing plate in the circle of 20 holes, the spindle will revolve by $\frac{1}{40} \times \frac{1}{20} = \frac{1}{600}$ th turn of one revolution.

1.11 INDEXING METHOD

There are different indexing methods in popularity. These are :

(a) Direct indexing

(b) Simple indexing

(c) Compound indexing

(d) Differential indexing

Direct Indexing

It is also named as rapid indexing. For this direct indexing plate is used which has 24 equally spaced holes in a circle. It is possible to divide the surface of workpiece into any number of equal divisions out of 2, 3, 4, 56, 8, 12, 24 parts. These all numbers are the factors of 24.

In this case fist of all worm and worm wheel is disengaged. We find number of holes by which spring loaded pin is to be moved. If we want to divide the surface into 6 parts than number of holes by which pin is to be moved $= \frac{24}{N}$ for 6 parts

$N = 6$.

So number of holes $= \frac{26}{6} = 4$ holes that is after completing one pair of milling whole surface of workpiece we have to move the pin by 4 holes before next milling operation, that is to be done for 5 number of times for making hexagonal bolt.

Simple Indexing

It is also named as plain indexing. It over comes the major limitation of direct indexing that is possibility of dividing circumference of workpiece into some fixed number of divisions. In this case worm and worm gear is first engaged. So one complete turn of indexing crank revolves the workpiece by $\frac{1}{40}$ th revolution.

Three indexing plates are used. These plates have concentric circles of holes with their different numbers as described below :

Plate No. 1	15	16	17	18	19	20
Plate No. 2	21	23	27	29	31	33
Plate No. 3	37	39	41	43	47	49

These are the standard indexing plates followed by all machine tool manufacturers.

Indexing Procedure

(a) Divide 40 by the number of divisions to be done on the circumference of workpiece. This gives movement of indexing crank.

$$\text{Indexing crank movement} = \frac{40}{N}$$

N is the number of divisions to be made on the circumference of workpiece.

(b) If the above number is a whole number, then crank is rotated by that much number of revolutions after each milling operations, till the completion of the work.

For example, if we want to divide the circumference into 10 number of parts.

$$\text{Indexing crank movement} = \frac{40}{10} = 4 \text{ revolutions.}$$

That is the indexing crank is given 4 revolutions after each of milling operation for 9 more milling operations.

(c) If indexing crank movement calculated by $\frac{40}{N}$ is not whole number, it is simplified and then expressed as a whole number and a fraction.

(d) The fractional part of the above number is further processed by multiplying its denominator and numerator by a suitable common number so that the denominator will turn to a number equal to any number of holes available on the any of indexing plates.

(e) That particular holes circle is selected for the movement of crank pin.

(f) The numerator of the process fraction stands for the number of holes to be moved by the indexing crank in the selected hole circle in addition to complete turns of indexing crank equal to whole number part of $\frac{40}{N}$.

Let us do the indexing to cut 30 teeth on a spur gear blank that means we need to divide the circumference of gear blank into 30 identical, parts. Crank movement is calculated s given below.

$$\text{Crank movement} = \frac{40}{N} = \frac{40}{30}$$

Here, $N = 30$.

$$= 1\frac{10}{30} = 1\frac{1}{3}$$

Let us multiply both numerator and denominator by 5.

$$= 1\frac{5}{15}$$

Denominator becomes '15' so we will select 15 hole circle of plate 1.

Action 1

After each milling operation we will rotate indexing crank by one complete turn and 5 holes in 15 holes circle. This way we do milling total 30 times.

In this case we can multiply numerator and denominator by '7' a the place of '5' as described below.

$$\text{Indexing crank movement } = \frac{40}{N} \quad (N = 30 \text{ teeth})$$

$$= \frac{40}{30} = 1\frac{10}{30} = 1\frac{1}{3} \times \frac{7}{7} = 1\frac{7}{21}$$

Action 2

We will select the hole circle of 21 holes. After each milling operation indexing crank will be rotated by 1 complete circle and 7 holes in 21 holes circle. This way milling operation will be done by total 30 times.

Both the answers determined in the above problem are correct and substitute of each other.

Limitations

This method can used for indexing upto 50 for any number of divisions after 50 this method is not capable for some numbers like 96, etc. Compound indexing overcomes the limitations.

Compound Indexing

The word compound indexing is an indicative of compound movements of indexing crank and then plate along with crank. In this case indexing plate is normally held stationary by a lock pin, first we rotate the indexing crank through a required number of holes in a selected hole circle, then crank is fixed through pin. It is followed by another movement by disengaging the rear lock pin, the indexing plate along with indexing crank is rotated in forward or backward direction through predetermined holes in a selected hole circle, then lock pin is reengaged.

Following steps are to be followed for compound indexing operation. The procedure is explained with the help of numerical example.

Example 1.1

Let us make 69 divisions of workpiece circumference by indexing method. (Using compound indexing)

Solution

Follow the steps given below :

(a) Factor the divisions to be make ($69 = 3 \times 23$) $N = 69$.

(b) Select two hole circles at random (These are 27 and 33 in this case, both of the hole circles should be from same plate).

(c) Subtract smaller number of holes from larger number and factor it as ($33 - 27 = 6 = 2 \times 3$).

(d) Factor the number of turns of the crank required for one revolution of the spindle (40). Also factorize the selected hole circles.

(e) Place the factors of N and difference above the horizontal line and factors of 40 and selected both the hole circles below the horizontal line as given below. Cancel the common values.

$$69 = 23 \times 3$$
$$6 = 2 \times 3$$
$$\overline{}$$
$$40 = 2 \times 2 \times 2 \times 5$$
$$27 = 3 \times 3 \times 3$$
$$33 = 3 \times 11$$

(f) If all the factors above the line are cancelled by those which are below the line, then the selected hole circles can be used for indexing otherwise select another two hole circles. In this case there is need to select another hole circles. Let us select 23 and 33 this time and repeat the step 5 as indicated below.

$$69 = 23 \times 3$$
$$10 = 2 \times 5$$
$$\overline{}$$
$$40 = 2 \times \textcircled{2} \times \textcircled{2} \times 5$$
$$22 = 23 \times 1$$
$$33 = \textcircled{11} \times 3$$

(Difference of hole circle values)

Encircled numbers below the line are the left out numbers after canceling the common factors. All the factors above the horizontal line are cancelled so selected hole circles with 22 and 33 holes can used for indexing.

(g) Following formula is used for indexing :

$$\frac{40}{69} = \frac{n_1}{N_1} \pm \frac{n_2}{N_2}$$

In this formula $N_1 = 23$ and $N_2 = 33$ (N_1 is always given smaller value out of two).

(h) Multiply all the remaining factors below the line as $2 \times 2 \times 11 = 44$. The formula above will turn to

$$\frac{40}{69} = \frac{44}{23} - \frac{44}{33}$$

We will neglect the +ve sign.

$$= 1\frac{21}{23} - 1\frac{11}{33}$$

The –ve sign indicates backward movement.

Action

For indexing of 69 divisions, the indexing crank should be moved by 21 holes circle in forward direction and then crank along with the plate are moved by 11 holes in 33 hole circle is reversed (backward) direction.

1.12 SUMMARY

The unit is focused of milling machine study. Complete description and categorization of milling machine to different categories on the basis of its construction is covered. Milling machines are available in different sizes, its size depends on the dimension of is bed and other machines is capabilities to do the processing work. All the main part of a milling machine work in coordination with each other. Cutting speed, feed rate and depth of cut are important parameters that are to be set before starting an operation. Different operations can be performed on milling machine, these operations are named on the basis of their machining characteristics. Depending upon the operations different milling cutters are used to carryout these operations. Different types of milling cutters are described in the unit. The operation gear cutting is one of the complex operations. There is a need to divide whole circumference of workpiece into identical divisions equal to number of teeth to be made in the gear blank. The operation, divide the circumference into identical divisions is named as indexing. Different types of indexing can be done like direct, simple, differential and compound indexing. These indexing methods have their own advantages and limitations. These methods are described in detail in this unit.

1.13 ANSWERS TO SAQs

Refer the preceding text for all the Answers to SAQs.

Module
4
General purpose machine tools

Lesson
20
Construction, working principle and applications of shaping, planing and slotting machines.

Instructional objectives

At the end of this lesson, the students will be able to;

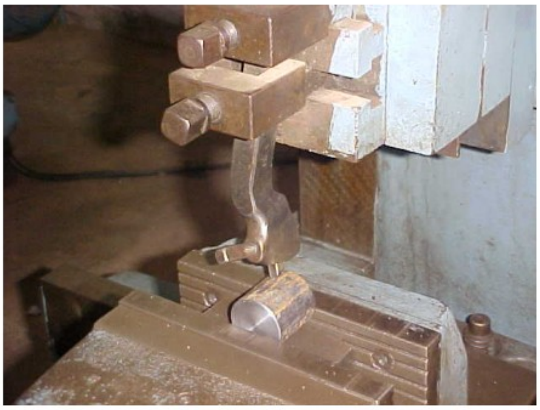
(i) Demonstrate the configurations and functions of shaping machine, planing machine and slotting machine
(ii) Illustrate the kinematic systems and explain the working principles of shaping machine, planing machine and slotting machine
(iii) Show and describe the various machining applications of shaping, planing and slotting machines.

(i) Configurations and basic functions of

- **Shaping machines**
- **Planing machines**
- **Slotting machines**

- **Shaping machine**

A photographic view of general configuration of shaping machine is shown in Fig. 4.4.1. The main functions of shaping machines are to produce flat surfaces in different planes. Fig. 4.4.2 shows the basic principle of generation of flat surface by shaping machine. The cutting motion provided by the linear forward motion of the reciprocating tool and the intermittent feed motion provided by the slow transverse motion of the job along with the bed result in producing a flat surface by gradual removal of excess material layer by layer in the form of chips. The vertical infeed is given either by descending the tool holder or raising the bed or both. Straight grooves of various curved sections are also made in shaping machines by using specific form tools. The single point straight or form tool is clamped in the vertical slide which is mounted at the front face of the reciprocating ram whereas the workpiece is directly or indirectly through a vice is mounted on the bed.



Cutting tool in action

Fig. 4.4.1 *Photographic view of a shaping machine*

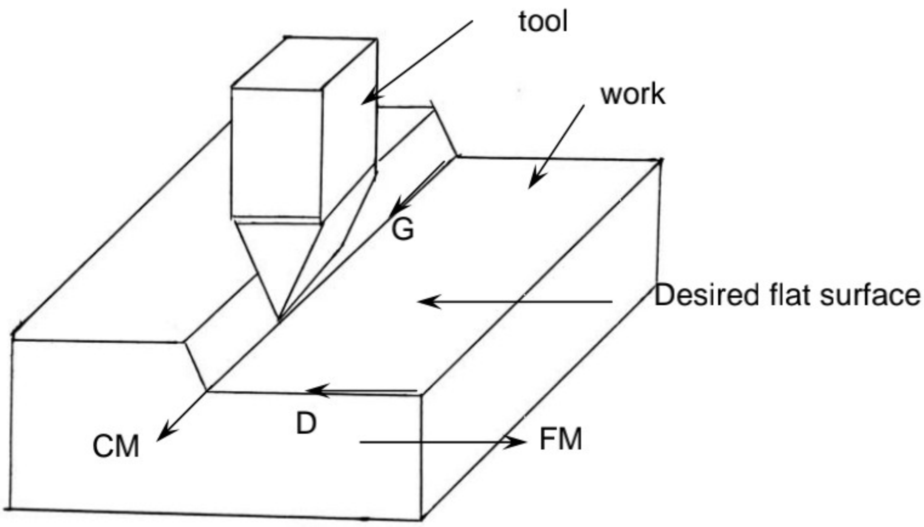


Fig. 4.4.2 *Principle of producing flat surface in shaping machine*

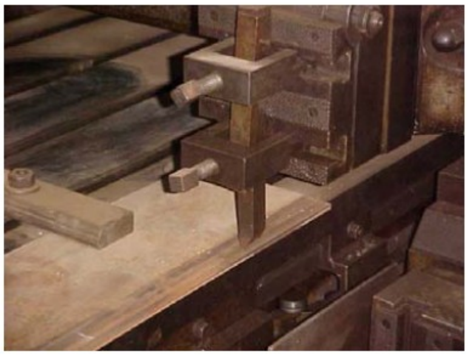
- **Planing machine**

The photographic view in Fig. 4.4.3 typically shows the general configuration of planing machine. Like shaping machines, planing machines are also basically used for producing flat surfaces in different planes. However, the major differences between planing machines from shaping machines are :

- o Though in principle both shaping and planing machines produce flat surface in the same way by the combined actions of the Generatrix and Directrix but in planing machine, instead of the tool, the workpiece reciprocates giving the fast cutting motion and instead of the job, the tool(s) is given the slow feed motion(s).
- o Compared to shaping machines, planing machines are much larger and more rugged and generally used for large jobs with longer stroke length and heavy cuts. In planing machine, the workpiece is mounted on the reciprocating table and the tool is mounted on the horizontal rail which, again, can move vertically up and down along the vertical rails.
- o Planing machines are more productive (than shaping machines) for longer and faster stroke, heavy cuts (high feed and depth of cut) possible and simultaneous use of a number of tools.

As in shaping machines, in planing machines also;

- Δ The length and position of stroke can be adjusted
- Δ Only single point tools are used
- Δ The quick return persists
- Δ Form tools are often used for machining grooves of curved section
- Δ Both shaping and planing machines can also produce large curved surfaces by using suitable attachments.

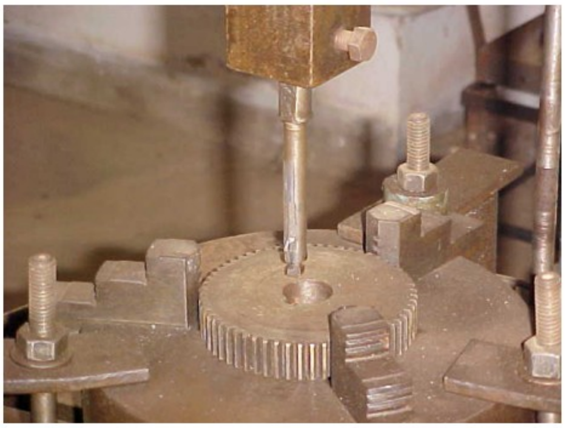


Cutting tool in action

Fig. 4.4.3 *Photographic view of a planing machine*

- **Slotting machine**

Slotting machines can simply be considered as vertical shaping machine where the single point (straight or formed) reciprocates vertically (but without quick return effect) and the workpiece, being mounted on the table, is given slow longitudinal and / or rotary feed as can be seen in Fig. 4.4.4. In this machine also the length and position of stroke can be adjusted. Only light cuts are taken due to lack of rigidity of the tool holding ram for cantilever mode of action. Unlike shaping and planing machines, slotting machines are generally used to machine internal surfaces (flat, formed grooves and cylindrical).
Shaping machines and slotting machines, for their low productivity, are generally used, instead of general production, for piece production required for repair and maintenance. Like shaping and slotting machines, planing machines, as such are also becoming obsolete and getting replaced by plano-millers where instead of single point tools a large number of large size and high speed milling cutters are used.



Cutting tool in action

Fig. 4.4.4 *Photographic view of a slotting machine*

(ii) Kinematic system and working principles of

- **Shaping machine**
- **Planing machine**
- **Slotting machine**

- **Shaping machine**

The usual kinematic system provided in shaping machine for transmitting power and motion from the motor to the tool and job at desired speeds and feeds is schematically shown in Fig. 4.4.5.

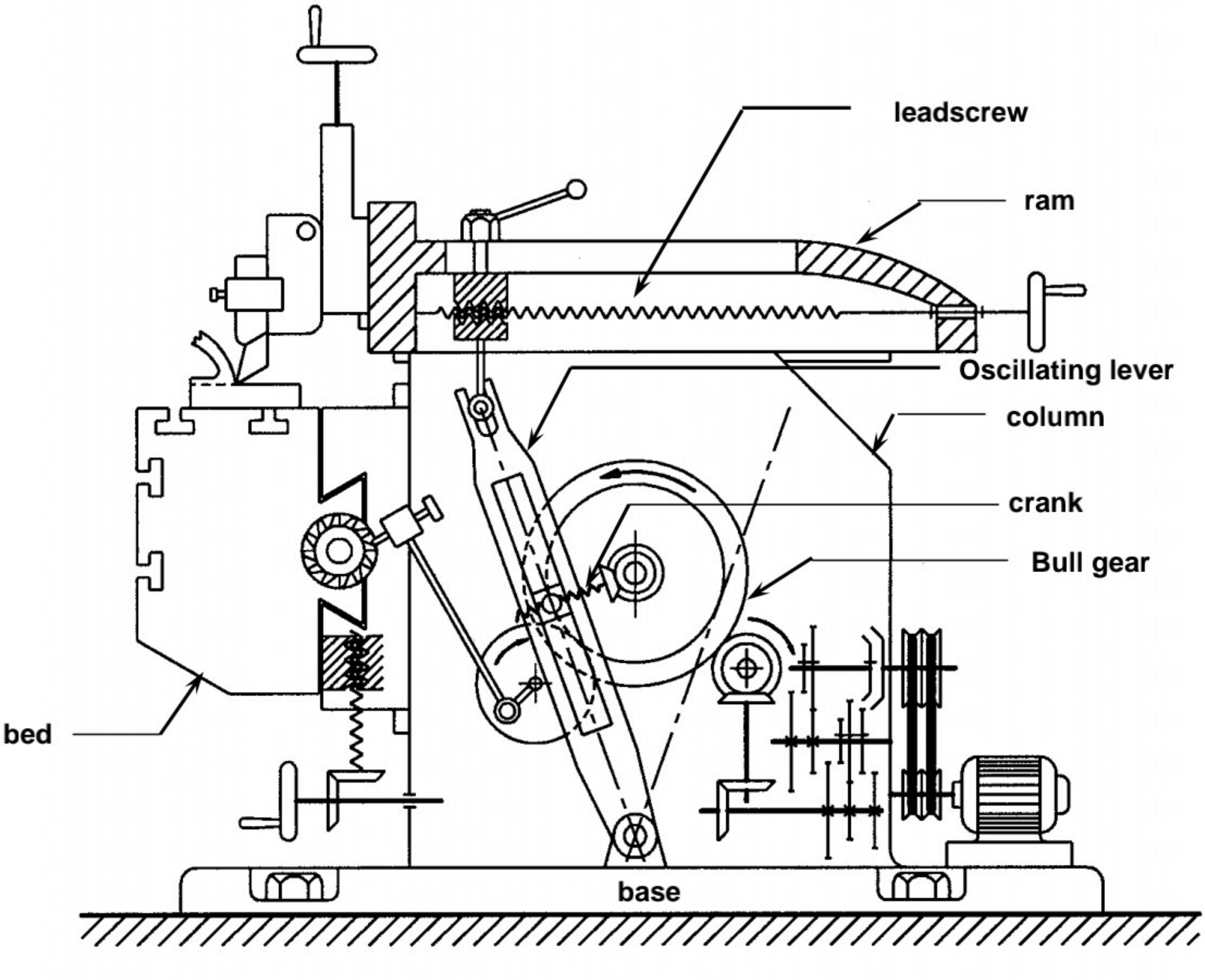


Fig. 4.4.5 *Kinematic diagram of a shaping machine.*

The central large bull gear receives its rotation from the motor through the belt-pulley, clutch, speed gear box and then the pinion. The rotation of the crank causes oscillation of the link and thereby reciprocation of the ram and hence the tool in straight path. Cutting velocity which needs to be varied depending upon the tool-work materials, depends upon

- o The stroke length, S mm
- o Number of strokes per min., N_s and
- o The Quick return ratio, QRR (ratio of the durations of the forward stroke and the return stroke)

As, $$V_C = \frac{sxN_s}{1000}\left(1+\frac{1}{QRR}\right) m/\min \quad (4.5.1)$$

To reduce idle time, return stroke is made faster and hence QRR > 1.0 (4.5.2)

Since $$QRR = \frac{2L+s}{2L-s} \quad (4.5.3)$$

where, L = length (fixed) of the oscillating lever
and s = stroke length

The benefit of quick return decreases when S becomes less.

The changes in length of stroke and position of the stroke required for different machining are accomplished respectively by

- ∆ Adjusting the crank length by rotating the bevel gear mounted coaxially with the bull gear
- ∆ Shifting the nut by rotating the leadscrew as shown in Fig. 4.4.5.

The value of N_s is varied by operating the speed gear box.

The main (horizontal) feed motion of the work table is provided at different rate by using the ratchet – paul systen as shown in Fig. 4.4.5. The vertical feed or change in height of the tool tip from the bed can be obtained either by lowering the tool or raising the bed by rotating the respective wheel as indicated in Fig. 4.4.5.

- **Planing machine**

The simple kinematic system of the planing machine enables transmission and transformation of rotation of the main motor into reciprocating motion of the large work table and the slow transverse feed motions (horizontal and vertical) of the tools. The reciprocation of the table, which imparts cutting motion to the job, is attained by rack-pinion mechanism. The rack is fitted with the table at its bottom surface and the pinion is fitted on the output shaft of the speed gear box which not only enables change in the number of stroke per minute but also quick return of the table.

The blocks holding the cutting tools are moved horizontally along the rail by screw-nut system and the rail is again moved up and down by another screw-nut pair as indicated in Fig. 4.4.3.

- **Slotting machine**

The schematic view of slotting machine is typically shown in Fig. 4.4.6

The vertical slide holding the cutting tool is reciprocated by a crank and connecting rod mechanism, so here quick return effect is absent. The job, to be machined, is mounted directly or in a vice on the work table. Like shaping machine, in slotting machine also the fast cutting motion is imparted to the tool and the feed motions to the job. In slotting machine, in addition to the longitudinal and cross feeds, a rotary feed motion is also provided in the work table.

The intermittent rotation of the feed rod is derived from the driving shaft with the help of a four bar linkage as shown in the kinematic diagram.

It is also indicated in Fig. 4.4.6 how the intermittent rotation of the feed rod is transmitted to the leadsrews for the two linear feeds and to the worm – worm wheel for rotating the work table. The working speed, i.e., number of strokes per minute, N_s may be changed, if necessary by changing the belt-pulley ratio or using an additional "speed gear box", whereas, the feed values are changed mainly by changing the amount of angular rotation of the feed rod per stroke of the tool. This is done by adjusting the amount of angle of oscillation of the paul as shown in Fig. 4.4.6. The directions of the feeds are reversed simply by rotating the tapered paul by 180^o as done in shaping machines.

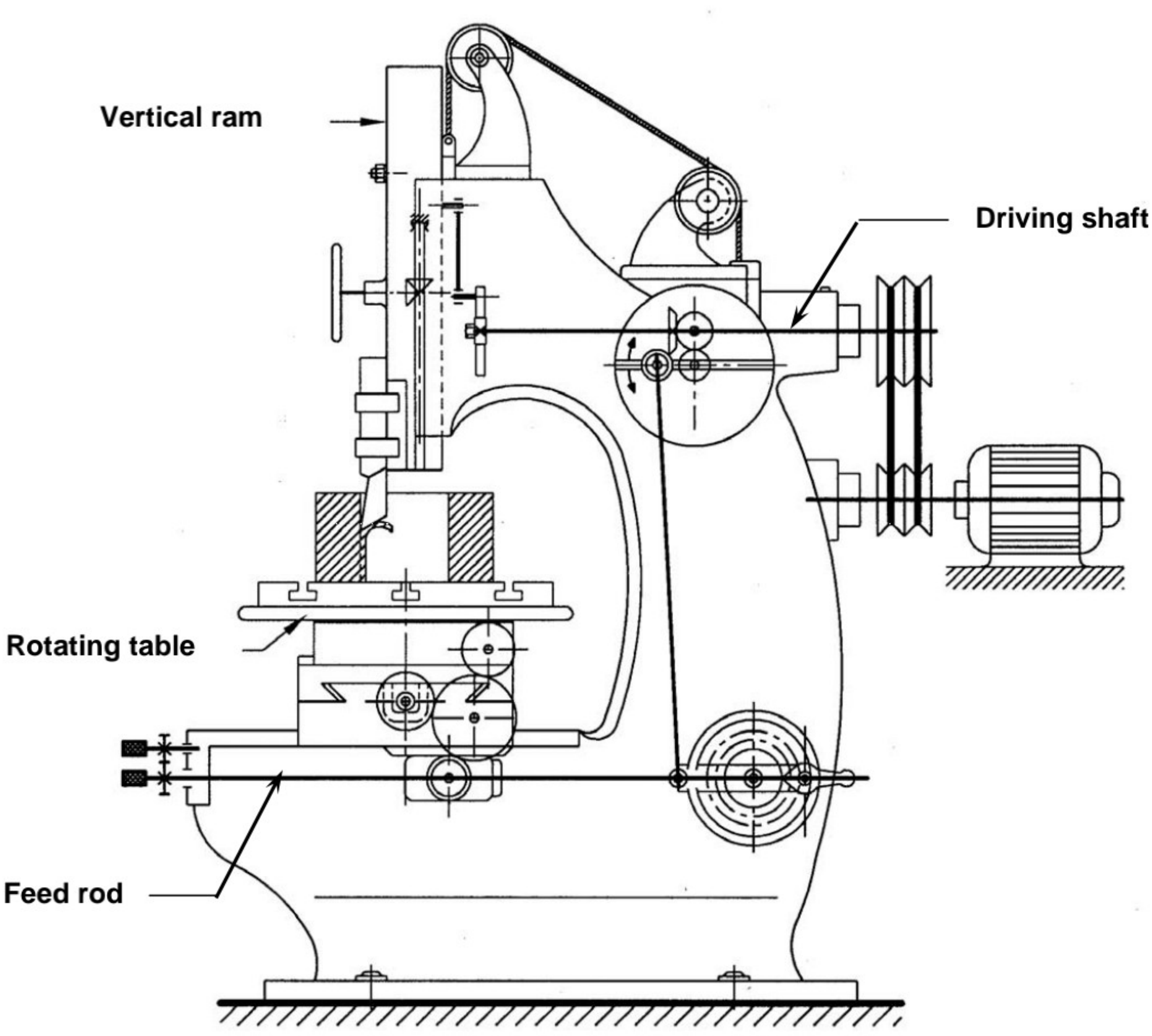


Fig. 4.4.6 *Kinematic system of a slotting machine.*

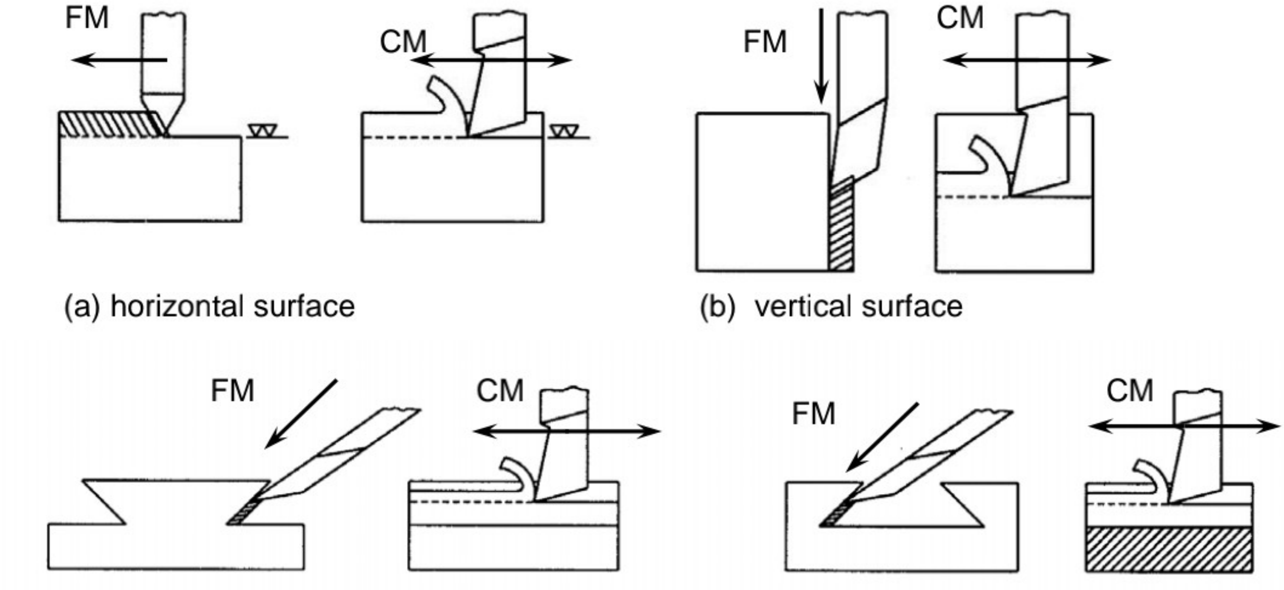
(iii) Various applications of

- **Shaping machine**
- **Planing machines**
- **Slotting machines**

- **Shaping machines**

It is already mentioned that shaping machines are neither productive nor versatile.
However, its limited applications include :

Δ Machining flat surfaces in different planes. Fig. 4.4.7 shows how flat surfaces are produced in shaping machines by single point cutting tools in (a) horizontal, (b) vertical and (c) inclined planes.



(c) inclined surfaces (dovetail slides and guides)

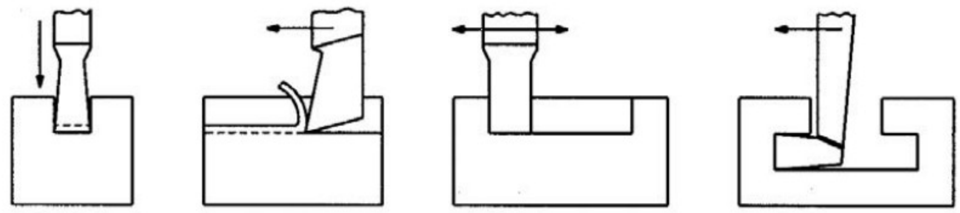
Fig. 4.4.7 *Machining of flat surfaces in shaping machines*

Δ Making features like slots, steps etc. which are also bounded by flat surfaces. Fig. 4.4.8 visualises the methods of machining (a) slot, (b) pocket (c) T-slot and (d) Vee-block in shaping machine by single point tools.

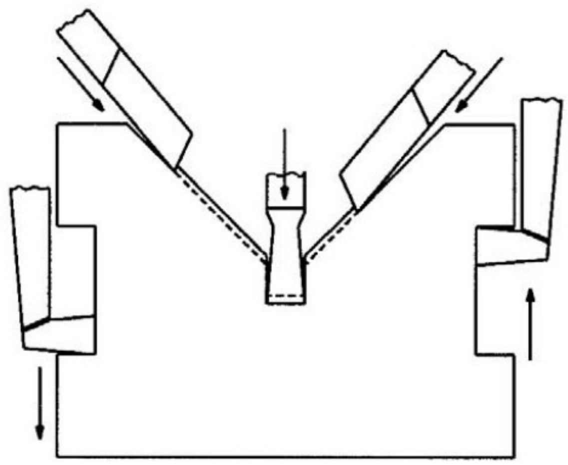
Δ Forming grooves bounded by short width curved surfaces by using single point but form tools. Fig. 4.4.9 typically shows how (a) oil grooves and (b) straight tooth of spur gears can be made in shaping machine

Δ Some other machining applications of shaping machines are cutting external keyway and splines, smooth slitting or parting, cutting teeth

of rack for repair etc. using simple or form type single point cutting tools.
Some unusual work can also be done, if needed, by developing and using special attachments.

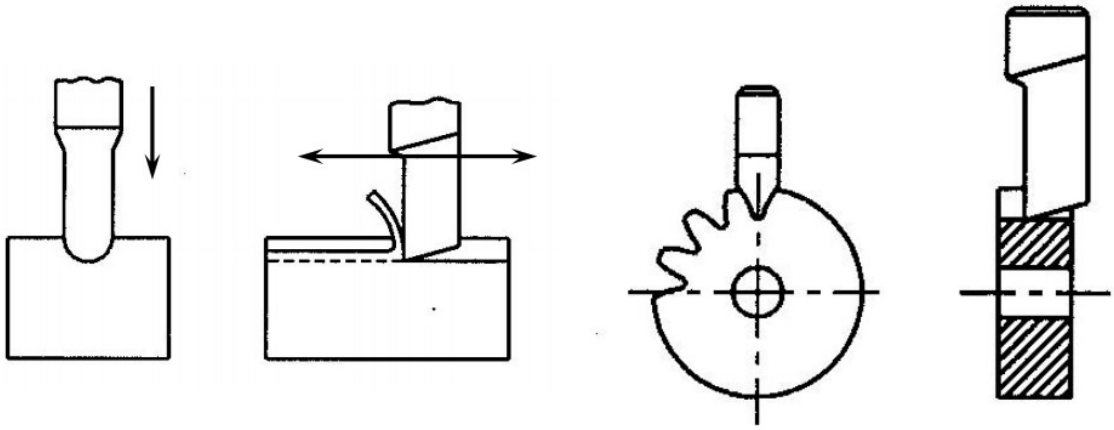


(a) slotting (b) pocketing (c) T-slot cutting



(d) Vee-block

Fig. 4.4.8 *Machining (a) slot, (b) pocket (c) T-slot and (d) Vee block in shaping machine*



(a) grooving (b) straight tooth cutting for spur gears

***Fig. 4.4.9** Making grooves and gear teeth cutting in shaping machine by form tools.*

However, due to very low productivity, less versatility and poor process capability, shaping machines are not employed for lot and even batch production. Such low cost primitive machine tools may be reasonably used only for little or few machining work on one or few pieces required for repair and maintenance work in small machine shops.

- **Planing machines**

The basic principles of machining by relative tool-work motions are quite similar in shaping machine and planing machine. The fast straight path cutting motion is provided by reciprocation of the tool or job and the slow, intermittent transverse feed motions are imparted to the job or tool. In respect of machining applications also these two machine tools are very close. All the operations done in shaping machine can be done in planing machine. But large size and stroke length and higher rigidity enable the planing machines do more heavy duty work on large jobs and their long surfaces. Simultaneous use of number of tools further enhances the production capacity of planing machines.
The usual and possible machining applications of planing machines are

- ∆ The common machining work shown in Fig. 4.4.7, Fig. 4.4.8 and Fig. 4.4.9 which are also done in shaping machines
- ∆ Machining the salient features like the principal surfaces and guideways of beds and tables of various machines like lathes, milling machines, grinding machines and planing machines itself, broaching machines etc. are the common applications of planing machine as indicated in Fig. 4.4.10 where the several parallel surfaces of typical machine bed and guideway are surfaced by a number of single point HSS or carbide tools. Besides that the long parallel T-slots, Vee and inverted Vee type guideways are also machined in planing machines.

Δ Besides the general machining work, some other critical work like helical grooving on large rods, long and wide 2-D curved surfaces, repetitive oil grooves etc. can also be made, if needed, by using suitable special attachments.

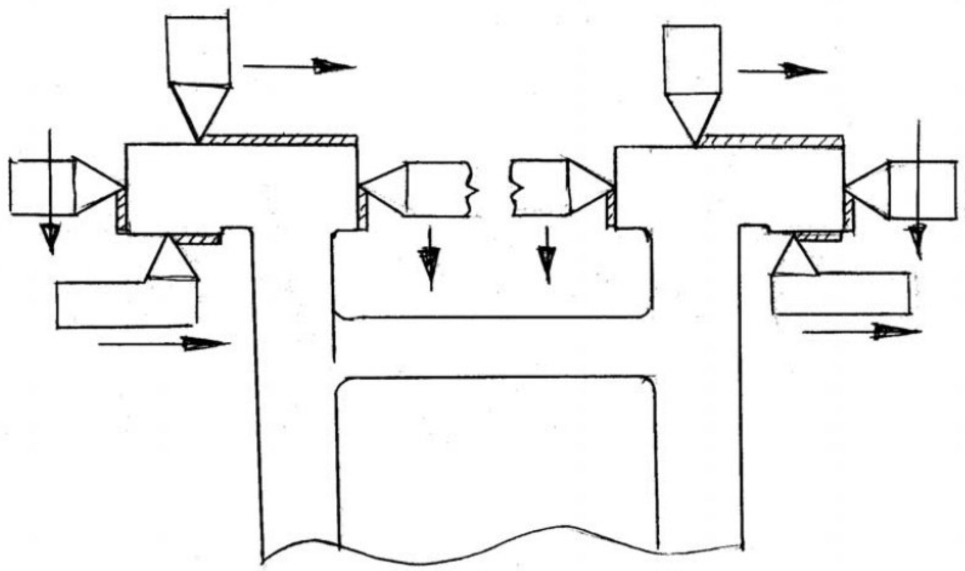


Fig. 4.4.10 *Machining of a machine bed in planing machine*

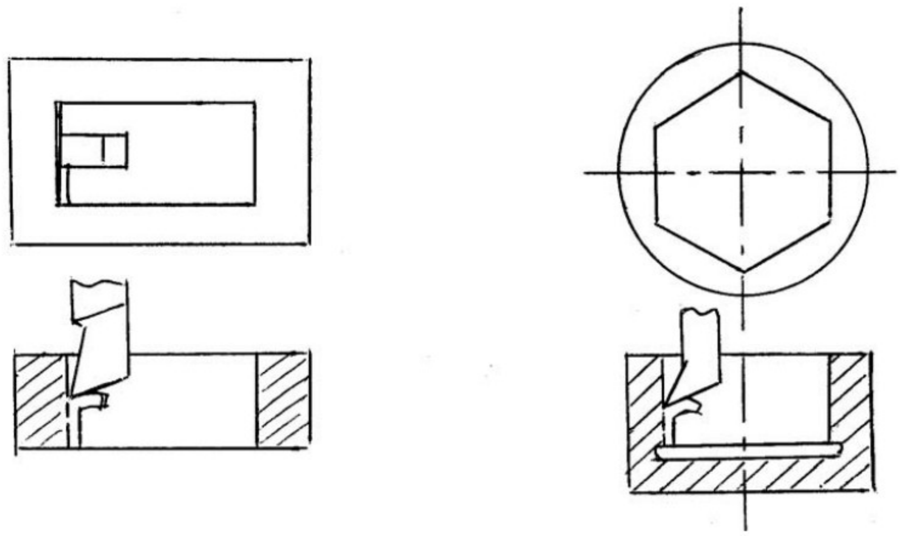
- **Slotting machine**

Slotting machines are very similar to shaping machines in respect of machining principle, tool-work motions and general applications. However, relative to shaping machine, slotting machines are characterised by :

Δ Vertical tool reciprocation with down stroke acting
Δ Longer stroke length
Δ Less strong and rigid
Δ An additional rotary feed motion of the work table
Δ Used mostly for machining internal surfaces.

The usual and possible machining applications of slotting machines are :

o Internal flat surfaces
o Enlargement and / or finishing non-circular holes bounded by a number of flat surfaces as shown in Fig. 4.4.11 (a)
o Blind geometrical holes like hexagonal socket as shown in Fig. 4.4.11 (b)
o Internal grooves and slots of rectangular and curved sections.
o Internal keyways and splines, straight tooth of internal spur gears, internal curved surface of circular section, internal oil grooves etc. which are not possible in shaping machines.



(a) through rectangular hole (b) hexagonal socket

***Fig. 4.4.11** Typical machining application of slotting machine.*

However, it has to be borne in mind that productivity and process capability of slotting machines are very poor and hence used mostly for piece production required by maintenance and repair in small industries. Scope of use of slotting machine for production has been further reduced by more and regular use of broaching machines.

Exercise

Identify the correct answer from the given four options.

1. Reciprocation of the cutting tool in shaping machines is accomplished by
    a. Rack pinion mechanism
    b. Crank and connecting rod mechanism
    c. Cam and cam follower mechanism
    d. Oscillating lever mechanism
2. Internal keyway in gears can be cut in
    a. Shaping machine
    b. Planing machine
    c. Slotting machine
    d. None of the above
3. The job reciprocates in
    a. Shaping machine
    b. Planing machine
    c. slotting machine
    d. All of the above
4. The T-slots in the table of planing machines are cut in
    a. Shaping machine
    b. Planing machine
    c. Slotting machine
    d. None of the above
5. Flat surface can be produced in
    a. Shaping machine only
    b. Planing machine only
    c. Slotting machine only
    d. All of the above
6. Large number of cutting tools can be simultaneously used in
    a. Shaping machine
    b. Planing machine
    c. Slotting machine
    d. None of the above

7. Heavy cuts can be given during machining in
    a. Shaping machine
    b. Planing machine
    c. Slotting machine
    d. None of the above
8. Slotting machines are used to cut internal gear teeth for
    a. Batch production
    b. Lot production
    c. Mass production
    d. None of the above
9. The work-table can rotate in
    a. Shaping machine
    b. Planing machine
    c. Slotting machine
    d. None of the above

10. Length of the stroke can be varied in
    a. Shaping machine
    b. Planing machine
    c. Slotting machine
    d. All of the above

Answers

Q.No	Answers
1	d
2	c
3	b
4	b
5	d
6	b
7	b
8	a
9	c
10	b

Module
4
General Purpose Machine Tools

Lesson
26
Broaching – Principles, Systems and Applications

Instructional objectives

This lesson will enable the students,

(i) State and visualise the basic principle of broaching
(ii) Describe constructional features and functioning of broaching tools
(iii) Illustrate different broaching tools and their applications
(iv) Classify broaching machines w.r.t. configuration and use
(v) Identify the advantages and limitations of broaching.

(i) BASIC PRINCIPLES OF BROACHINING

Broaching is a machining process for removal of a layer of material of desired width and depth usually in one stroke by a slender rod or bar type cutter having a series of cutting edges with gradually increased protrusion as indicated in Fig. 4.10.1. In shaping, attaining full depth requires a number of strokes to remove the material in thin layers step – by – step by gradually infeeding the single point tool (Fig. 4.10.1).. Whereas, broaching enables remove the whole material in one stroke only by the gradually rising teeth of the cutter called broach. The amount of tooth rise between the successive teeth of the broach is equivalent to the infeed given in shaping.

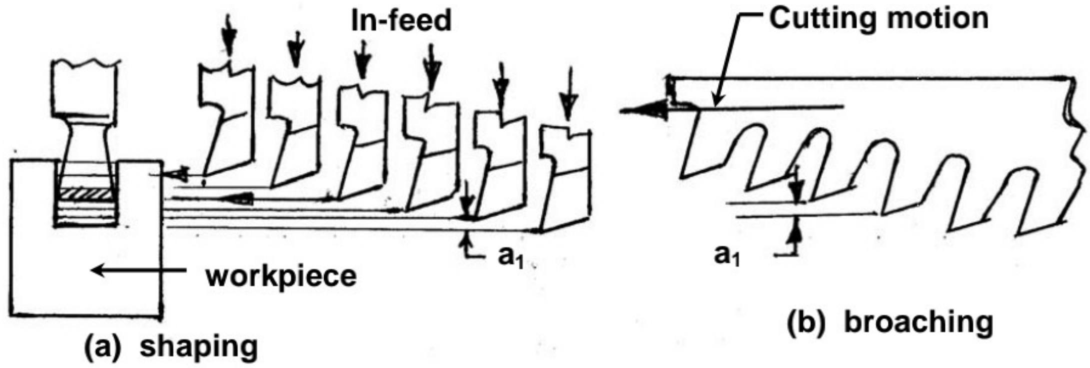


Fig. 4.10.1 *Basic principle of broaching.*

Machining by broaching is preferably used for making straight through holes of various forms and sizes of section, internal and external through straight or helical slots or grooves, external surfaces of different shapes, teeth of external and internal splines and small spur gears etc. Fig. 4.10.2 schematically shows how a through hole is enlarged and finished by broaching.

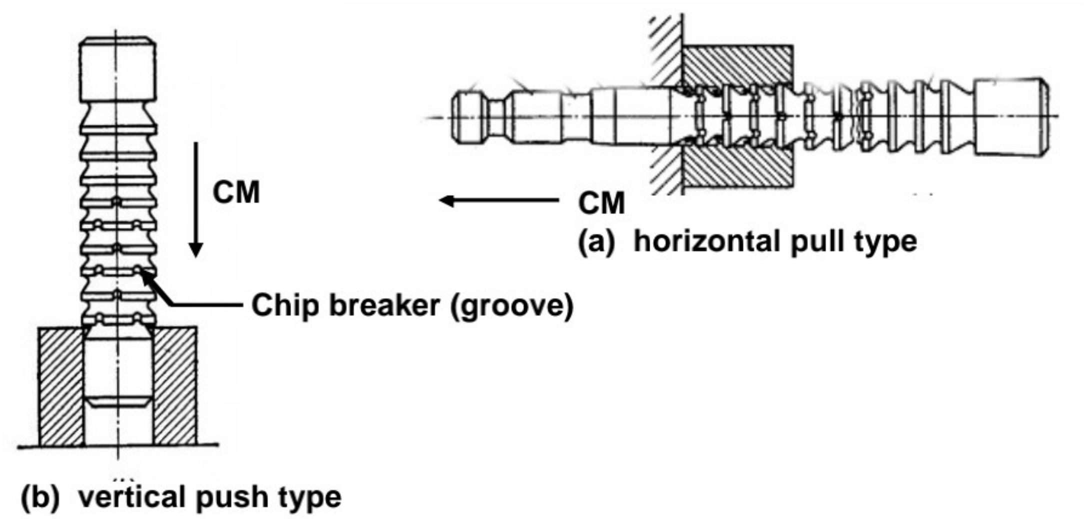


Fig. 4.10.2 *Schematic views of finishing hole by broaching.*

(ii) Construction And Operation Of Broaching

- **Construction of broaching tools**

Construction of any cutting tool is characterised mainly by

- Configuration
- Material and
- Cutting edge geometry

- **Configuration of broaching tool**

Both pull and push type broaches are made in the form of slender rods or bars of varying section having along its length one or more rows of cutting teeth with increasing height (and width occasionally). Push type broaches are subjected to compressive load and hence are made shorter in length to avoid buckling.

The general configuration of pull type broaches, which are widely used for enlarging and finishing preformed holes, is schematically shown in Fig. 4.10.3.

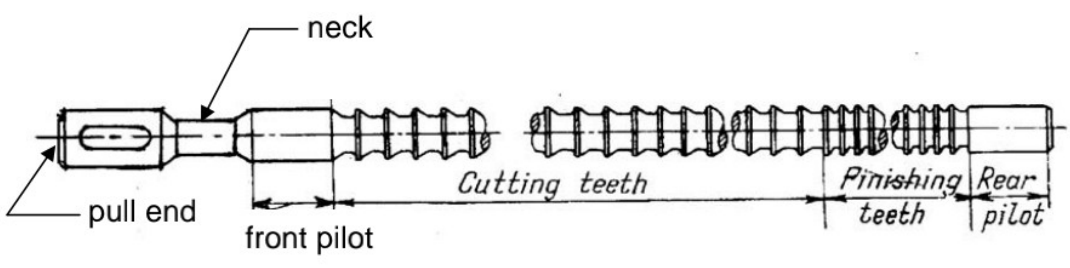


Fig. 4.10.3 *Configuration of a pull type broach used for finishing holes.*

The essential elements of the broach (Fig. 4.10.3) are :

- Pull end for engaging the broach in the machine

- Neck of shorter diameter and length, where the broach is allowed to fail, if at all, under overloading
- Front pilot for initial locating the broach in the hole
- Roughing and finishing teeth for metal removal
- Finishing and burnishing teeth
- Rear pilot and follower rest or retriever

Broaches are designed mostly pull type to facilitate alignment and avoid buckling. The length of the broach is governed by;

- Type of the broach; pull or push type
- Number of cutting edges and their pitch depending upon the work material and maximum thickness of the material layer to be removed
- Nature and extent of finish required.

Keeping in view that around 4 to 8 teeth remain engaged in machining at any instant, the pitch (or gap), p, of teeth is simply decided from

$$\boldsymbol{p} = 1.25\sqrt{\boldsymbol{L}} \text{ to } 1.5\sqrt{\boldsymbol{L}}$$

where, L = length of the hole or job.

The total number of cutting teeth for a broach is estimated from,

$T_n \geq$ (total depth of material) / tooth rise, a_1 (which is decided based on the tool – work materials and geometry).

Broaches are generally made from solid rod or bar. Broaches of large section and complex shape are often made by assembling replaceable separate sections or inserting separate teeth for ease of manufacture and maintenance.

- **Material of broach**

Being a cutting tool, broaches are also made of materials having the usual cutting tool material properties, i.e., high strength, hardness, toughness and good heat and wear resistance.

For ease of manufacture and resharpening the complex shape and cutting edges, broaches are mostly made of HSS (high speed steel). To enhance cutting speed, productivity and product quality, now-a-days cemented carbide segments (assembled) or replaceable inserts are also used specially for stronger and harder work materials like cast irons and steels. TiN coated carbides provide much longer tool life in broaching. Since broaching speed (velocity) is usually quite low, ceramic tools are not used.

- **Geometry of broaching teeth and their cutting edges**

Fig. 4.10.4 shows the general configuration of the broaching teeth and their geometry. The cutting teeth of HSS broaches are provided with positive radial or orthogonal rake (5^o to 15^o) and sufficient primary and secondary clearance angles (2^o to 5^o and 5^o to 20^o respectively) as indicated in Fig. 4.10.4.

Small in-built chip breakers are alternately provided on the roughing teeth of the broach as can be seen in Fig. 4.10.2 to break up the wide curling chips

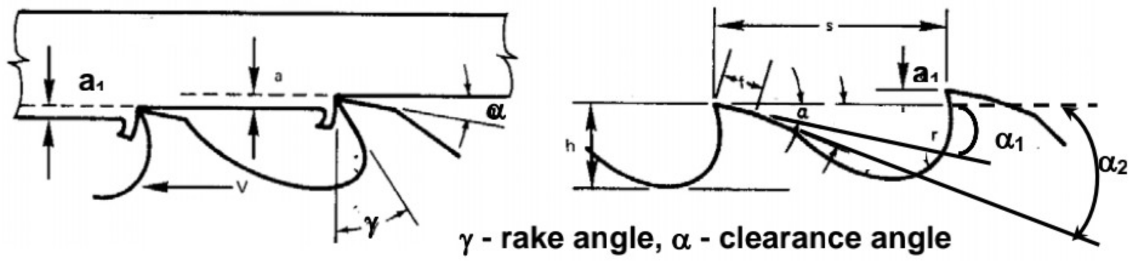


Fig. 4.10.4 *Geometry of teeth of broaching tools.*

and thus preventing them from clogging the chip spaces and increasing forces and tool wear. More ductile materials need wider and frequent chip breakers.

- **Broaching operation**

Like any other machining, broaching is also accomplished through a series of following sequential steps :

- Selection of broach and broaching machine
- Mounting and clamping the broach in the broaching machine
- Fixing workpiece in the machine
- Planning tool - work motions
- Selection of the levels of the process parameters and their setting
- Conducting machining by the broach.

- **Selection of broach and broaching machine**

There are various types of broaches available. The appropriate one has to be selected based on

- type of the job; size, shape and material
- geometry and volume of work material to be removed from the job
- desired length of stroke and the broach
- type of the broaching machines available or to be used

Broaching machine has to be selected based on

- The type, size and method of clamping of the broach to be used
- Size, shape and material of the workpiece
- Strength, power and rigidity required for the broaching machine to provide the desired productivity and process capability.

- **Mounting and clamping broach in the machine**

The broach needs to be mounted, clamped and moved very carefully and perfectly in the tool holding device of the broaching machine which are used for huge lot or mass production with high accuracy and surface finish.
Pull type and push type broaches are mounted in different ways.

Fig. 4.10.5 typically shows a broach pull head commonly used for holding, clamping and pulling pull type broach. Just before fitting in or removing the broach from the broach pull head (Fig. 4.10.5 (a)), the sliding outer socket is

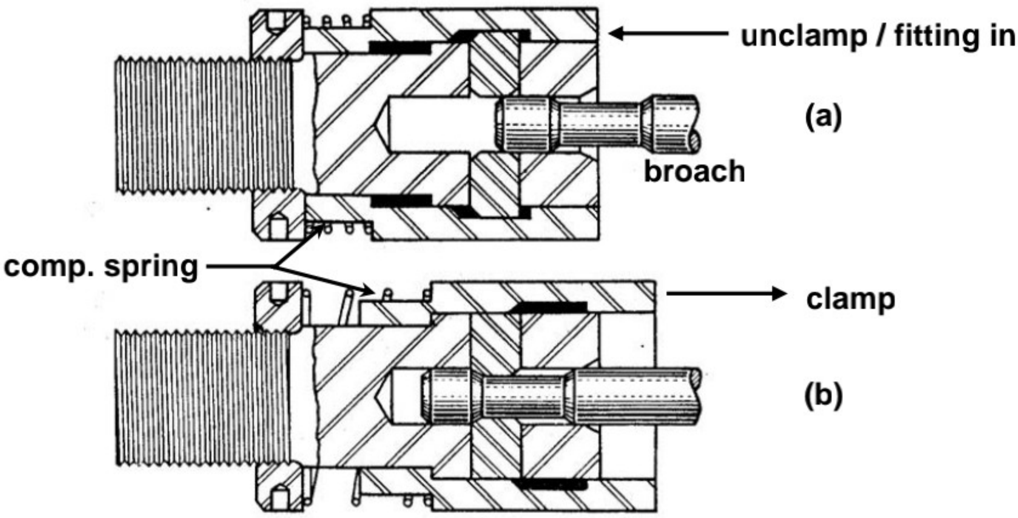


Fig. 4.10.5 *Mounting and clamping pull type broach.*

pushed back against the compression spring. After full entry of the pull end of the broach in the head the socket is brought forward which causes locking of the broach by the radially moving strips as shown in Fig. 4.10.5 (b).

Pull type broaches are also often simply and slight flexibly fitted by a suitable adapter and pin as can be seen in Fig. 4.10.6.

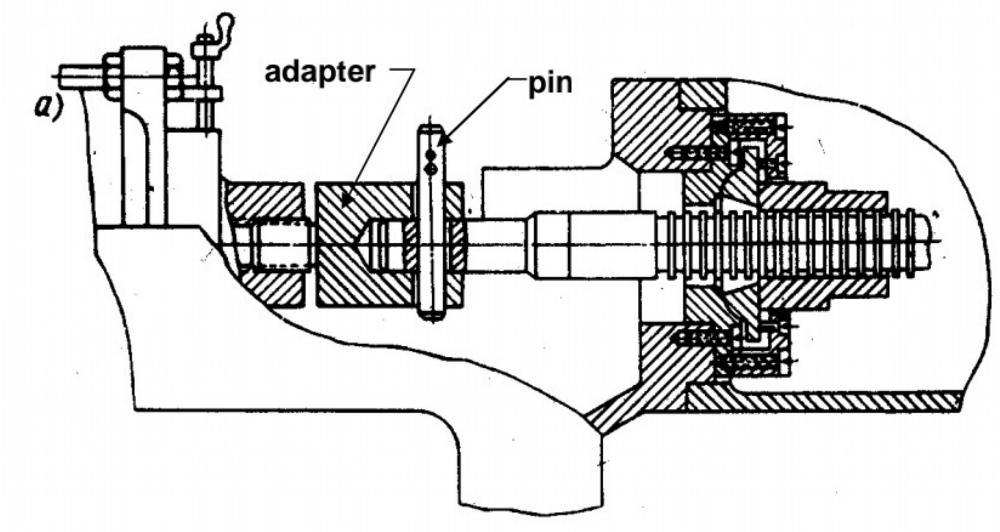


Fig. 4.10.6 *Fitting pull type broach by an adapter and a pin.*

- **Mounting of workpiece or blank in broaching machine**

Broaching is used for mass production and at fast rate. The blanks are repeatedly mounted one after another in an appropriate fixture where the blanks can be easily, quickly and accurately located, supported and clamped.

In broaching, generally the job remains fixed and the broach travels providing cutting velocity.

Fig. 4.10.7 schematically shows a typical method of mounting push or pull type external broach for through surfacing, slotting or contouring.

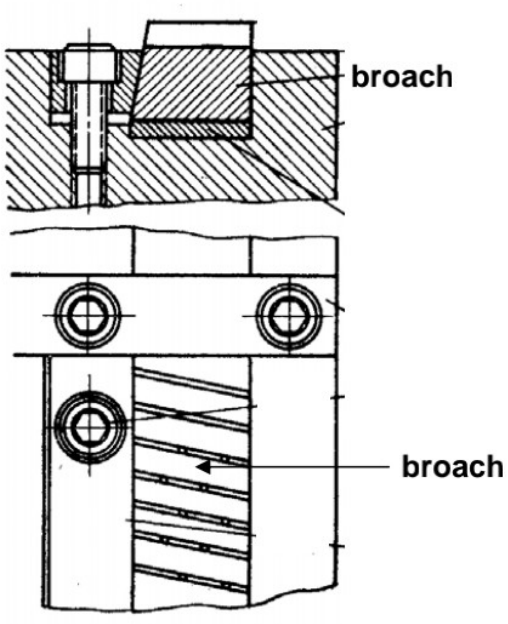


Fig. 4.10.7 *Mounting external broach for surfacing and slotting.*

- **Tool – work motions and process variables**

Any machining is associated with 2 to 5 tool – work motions as well as cutting velocity, feed and depth of cut as process variables. But broaching operation / machine needs only one motion which is cutting motion and is mostly imparted to the tool. In broaching feed is provided as tooth rise. The magnitude of cutting velocity, V_C is decided based on the tool – work materials and the capability of the broaching machine. In broaching metals and alloys, HSS broaches are used at cutting velocity of 10 to 20 m/min and carbide broaches at 20 to 40 m/min. The value of tooth rise varies within 0.05 mm to 0.2 mm for roughing and 0.01 to 0.04 mm for finishing teeth. Some cutting fluids are preferably used mainly for lubrication and cooling at the chip – tool interfaces.

Fig. 4.10.8 typically shows mounting of blank in fixture. But occasionally the job is travelled against the stationary broach as in continuous working type broaching machine.

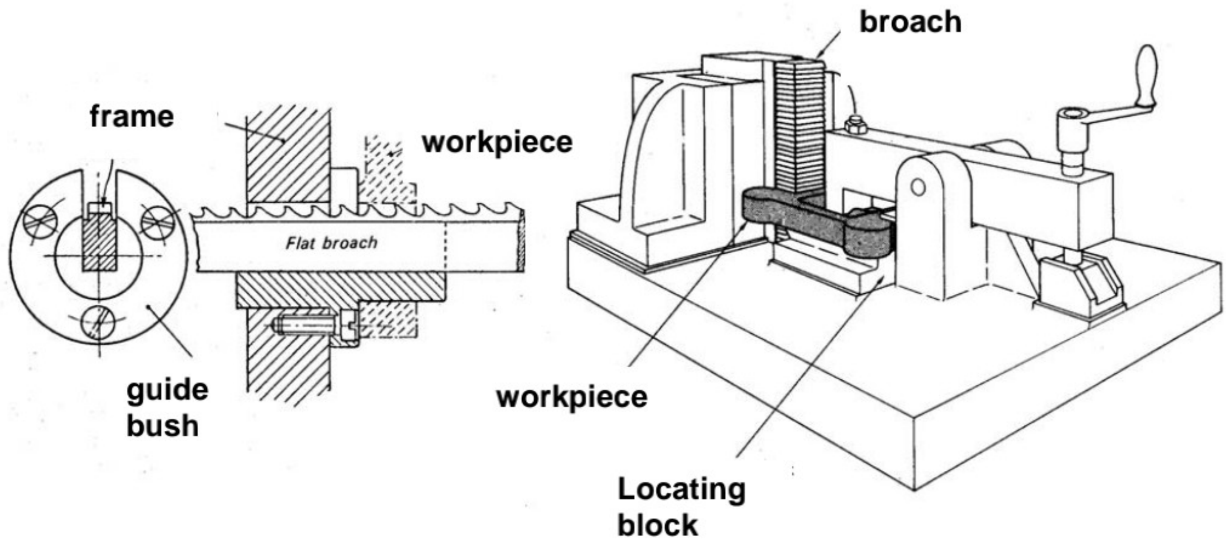


Fig. 4.10.8 *Mounting blank in broaching machine.*

(iv) Different Types Of Broaches And Their Applications

Broaching is getting more and more widely used, wherever feasible, for high productivity as well as product quality. Various types of broaches have been developed and are used for wide range of applications.
Broaches can be broadly classified in several aspects such as,

- Internal broaching or External broaching
- Pull type or Push type
- Ordinary cut or Progressive type
- Solid, Sectional or Modular type
- Profile sharpened or form relieved type

- **Internal and external broaching (tool)**

  - **Internal broaching and broaches**

Internal broaching tools are used to enlarge and finish various contours in through holes preformed by casting, forging, rolling, drilling, punching etc. Internal broaching tools are mostly pull type but may be push type also for lighter work. Pull type internal broaching tools are generally provided with a set of roughing teeth followed by few semi-finishing teeth and then some finishing teeth which may also include a few burnishing teeth at the end. The wide range of internal broaching tools and their applications include;

- through holes of different form and dimensions as indicated in fig. 4.10.9
- non-circular holes and internal slots (fig. 4.10.9)
- internal keyway and splines
- teeth of straight and helical fluted internal spur gears as indicated in fig. 4.10.9

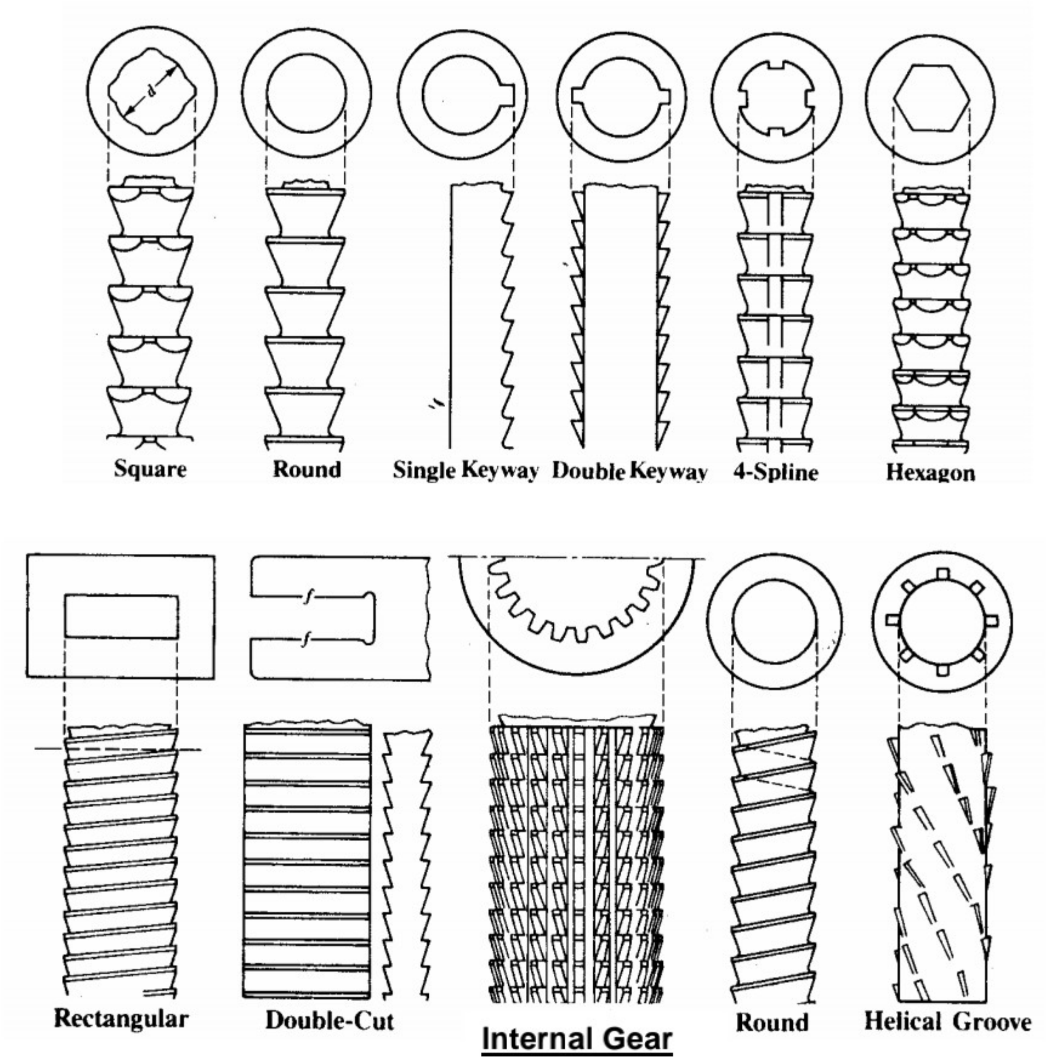


Fig. 4.10.9 Internal broaching – tools and applications.

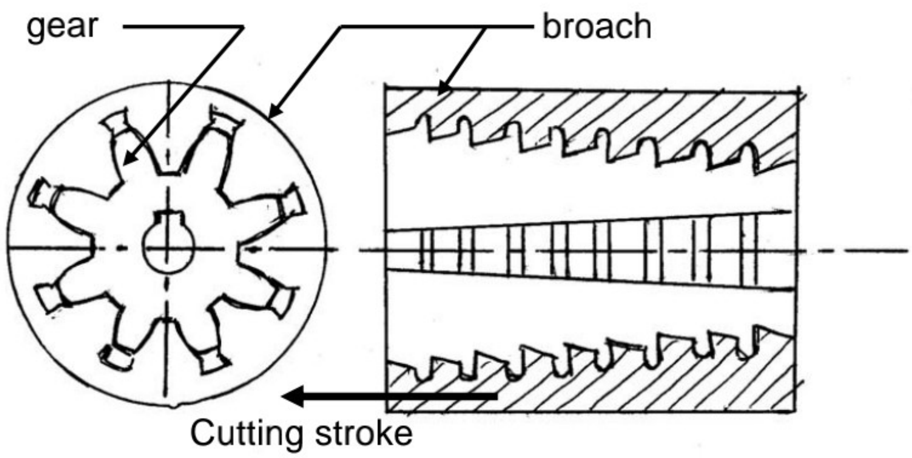


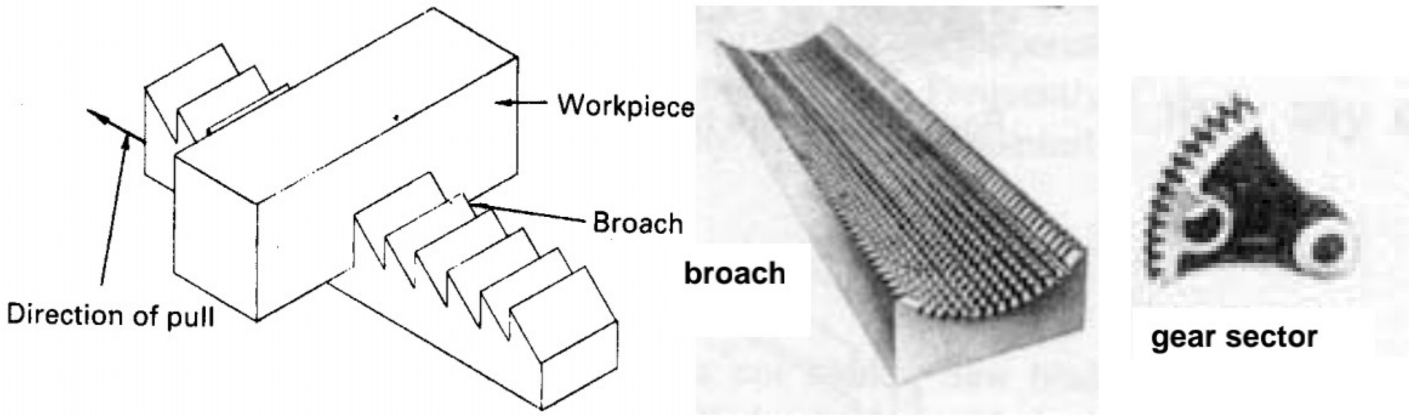
Fig. 4.10.10 Machining external gear teeth by broaching.

External broaching

External surface broaching competes with milling, shaping and planing and, wherever feasible, outperforms those processes in respect of productivity and product quality. External broaching tools may be both pull and push type.
Major applications of external broaching are :

- un-obstructed outside surfacing; flat, peripheral and contour surfaces (fig. 4.10.11 (a))
- grooves, slots, keyways etc. on through outer surfaces of objects (Fig. 4.10.8)
- external splines of different forms
- teeth of external spur gears or gear sectors as shown in Fig. 4.10.10 and Fig. 4.10.11 (b)

External broaching tools are often made in segments which are clamped in fixtures for operation.



(a) (b)

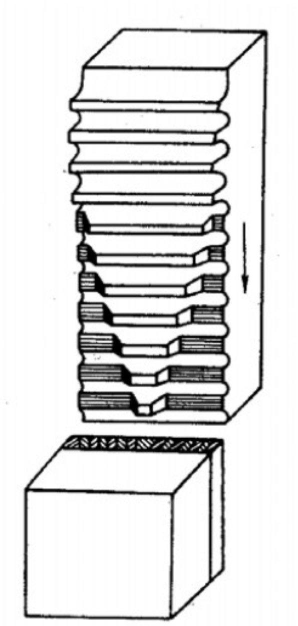
Fig. 4.10.11 *Typical external broaching (a) making slot (b) teeth of gear sector*

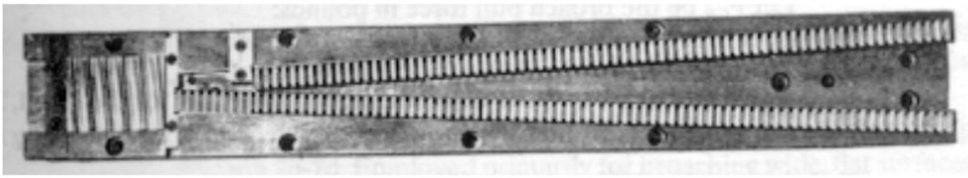
Pull type and push type broaches

During operation a pull type broach is subjected to tensile force, which helps in maintaining alignment and prevents buckling.
Pull type broaches are generally made as a long single piece and are more widely used, for internal broaching in particular. Push type broaches are essentially shorter in length (to avoid buckling) and may be made in segments. Push type broaches are generally used for external broaching, preferably, requiring light cuts and small depth of material removal.

Ordinary – cut and Progressive type broach

Most of the broaches fall under the category of Ordinary – cut type where the teeth increase in height or protrusion gradually from tooth to tooth along the length of the broach. By such broaches, work material is removed in thin layers over the complete form. Whereas, Progressive – cut type broaches have their teeth increasing in width instead of height. Fig. 4.10.12 shows the working principle and configuration of such broach.





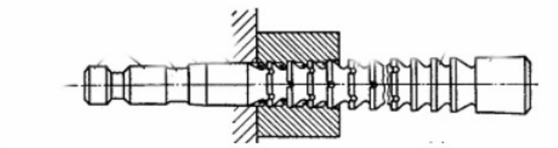
(b) double strip type

(a) single strip

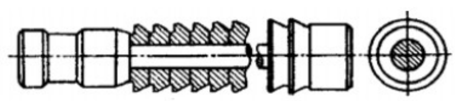
Fig. 4.10.12 *Progressive – cut type broaches; (a) single bar and (b) double bar type*

- **Solid, Sectional and module type broaches**

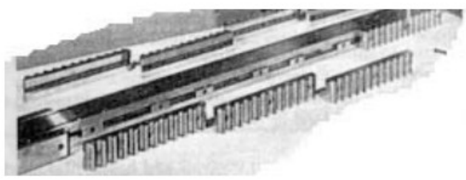
Broaches are mostly made in single pieces specially those used for pull type internal broaching. But some broaches called sectional broaches, are made by assemblying several sections or cutter-pieces in series for convenience in manufacturing and resharpening and also for having little flexibility required by production in batches having interbatch slight job variation. External broaches are often made by combining a number of modules or segments for ease of manufacturing and handling. Fig. 4.10.13 typically shows solid, sectional and segmented (module) type broaches.



(a) solid



(b) sectional



(c)segmented

Fig. 4.10.13 *(a) Solid, (b) Sectional and (c) Segmented broaches.*

- **Profile sharpened and form relieved type broaches**

Like milling cutters, broaches can also be classified as

- **Profile sharpened type broaches;**

  Such cutters have teeth of simple geometry with same rake and clearance angles all over the cutting edge. These broaches are generally designed and used for machining flat surface(s) or circular holes.

- **Form relieved type broaches**

  These broaches, being used for non-uniform profiles like gear teeth etc., have teeth where the cutting edge geometry is more complex and varies point – to – point along the cutting edges. Here the job profile becomes the replica of the tool form. Such broaches are sharpened and resharpened by grinding at their rake faces unlike the profile sharpened broaches which are ground at the flank surfaces.

(iv) Broaching Machines

The unique characteristics of broaching operation are

- For producing any surface, the form of the tool (broach) always provides the Generatrix and the cutting motion (of the broach relative to the job surface) provides the Directrix.
- So far as tool – work motions, broaching needs only one motion and that is the cutting motion (velocity) preferably being imparted to the broach.

Hence design, construction and operation of broaching machines, requiring only one such linear motion, are very simple. Only alignments, rigidity and reduction of friction and wear of slides and guides are to be additionally considered for higher productivity, accuracy and surface finish.
Broaching machines are generally specified by

- Type; horizontal, vertical etc.
- Maximum stroke length
- Maximum working force (pull or push)
- Maximum cutting velocity possible
- Power
- Foot print

Most of the broaching machines have hydraulic drive for the cutting motion. Electro-mechanical drives are also used preferably for high speed of work but light cuts.

There are different types of broaching machines which are broadly classified

- According to purpose of use
  - Δ general purpose
  - Δ single purpose
  - Δ special purpose

- According to nature of work
  - Δ internal broaching
  - Δ external (surface) broaching

- According to configuration
  - Δ horizontal
  - Δ vertical

- According to number of slides or stations
  - Δ single station type
  - Δ multiple station type
  - Δ indexing type

- According to tool / work motion
  - Δ intermittent (one job at a time) type
  - Δ continuous type

Some of the broaching machines of common use have been discussed here.

o **Horizontal broaching machine**

Horizontal broaching machines, typically shown in Fig. 4.10.14, are the most versatile in application and performance and hence are most widely employed for various types of production. These are used for internal broaching but external broaching work are also possible. The horizontal broaching machines are usually hydraulically driven and occupies large floor space.

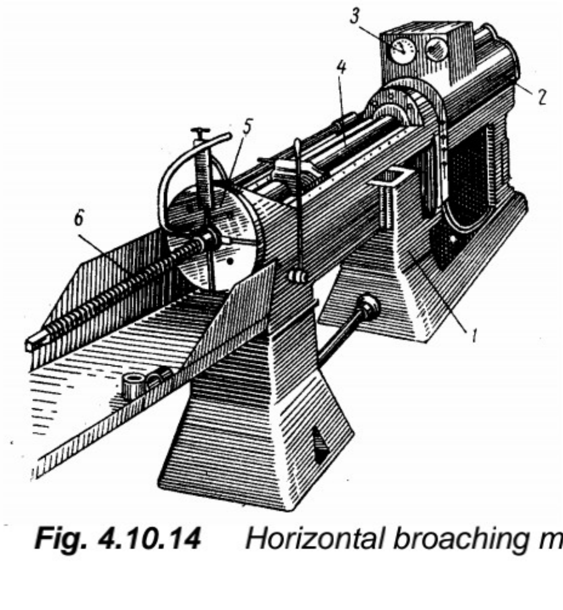


Fig. 4.10.14 *Horizontal broaching machine.*

- **Vertical broaching machine**

Vertical broaching machines, typically shown in Fig. 4.10.15,

- Δ occupies less floor space
- Δ are more rigid as the ram is supported by base
- Δ mostly used for external or surface broaching though internal broaching is also possible and occasionally done.

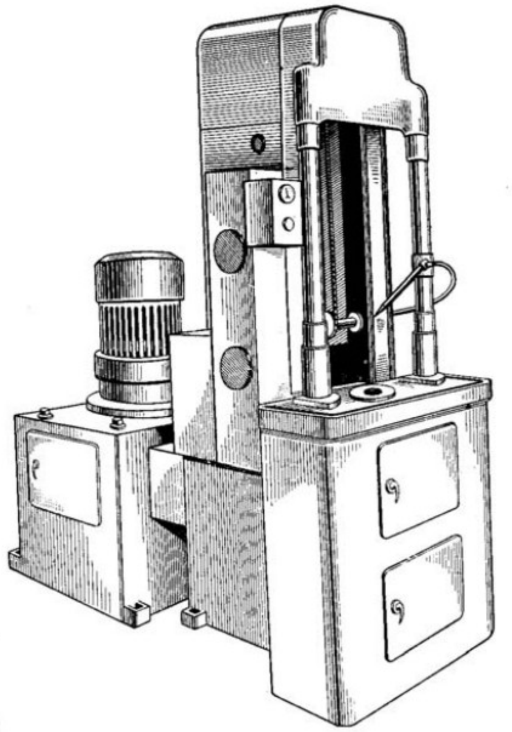


Fig. 4.10.15 *Vertical broaching machine.*

- **High production broaching machines**

Broaching operation and broaching machines are as such high productive but its speed of production is further enhanced by;

- Δ incorporating automation in tool – job mounting and releasing
- Δ increasing number of workstations or slides for simultaneous multiple production
- Δ quick changing the broach by turret indexing
- Δ continuity of working

Fig. 4.10.16 schematically shows the principle and methods of continuous broaching, which is used for fast production of large number of pieces by surface broaching.

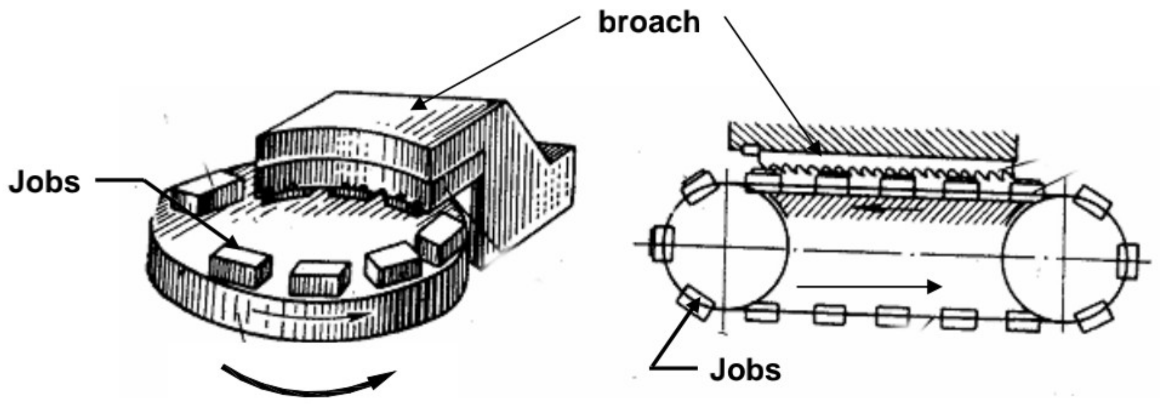


Fig. 4.10.16 Continuous broaching.

(v) ADVANTAGES AND LIMITATIONS OF BROACHING

 Major advantages

- Very high production rate (much higher than milling, planing, boring etc.)
- High dimensional and form accuracy and surface finish of the product
- Roughing and finishing in single stroke of the same cutter
- Needs only one motion (cutting), so design, construction, operation and control are simpler
- Extremely suitable and economic for mass production

 Limitations

- Only through holes and surfaces can be machined
- Usable only for light cuts, i.e. low chip load and unhard materials
- Cutting speed cannot be high
- Defects or damages in the broach (cutting edges) severely affect product quality
- Design, manufacture and restoration of the broaches are difficult and expensive
- Separate broach has to be procured and used whenever size, shape and geometry of the job changes
- Economic only when the production volume is large.