UNIT - I

THEORY OF METAL CUTTING

1.1 INTRODUCTION

In an industry, metal components are made into different shapes and dimensions by using various metal working processes.

Metal working processes are classified into two major groups. They are:

- Non-cutting shaping or chips less or metal forming process - forging, rolling, pressing, etc.
- Cutting shaping or metal cutting or chip forming process - turning, drilling, milling, etc.

1.2 MATERIAL REMOVAL PROCESSES

1.2.1 Definition of machining

Machining is an essential process of finishing by which work pieces are produced to the desired dimensions and surface finish by gradually removing the excess material from the preformed blank in the form of chips with the help of cutting tool(s) moved past the work surface(s).

1.2.2 Principle of machining

Fig. 1.1 typically illustrates the basic principle of machining. A metal rod of irregular shape, size and surface is converted into a finished product of desired dimension and surface finish by machining by proper relative motions of the tool-work pair.

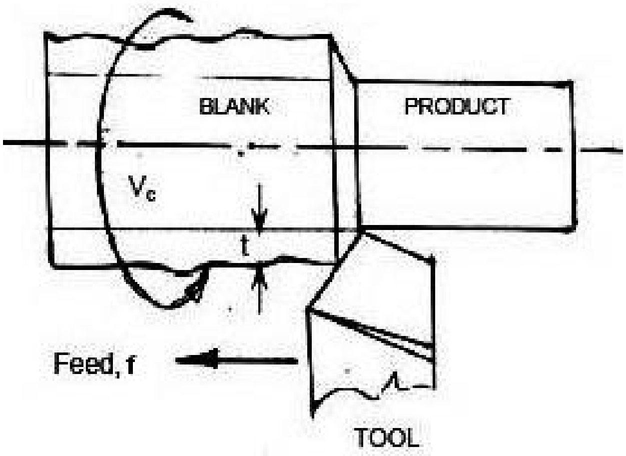


Fig. 1.1 Principle of machining (Turning)

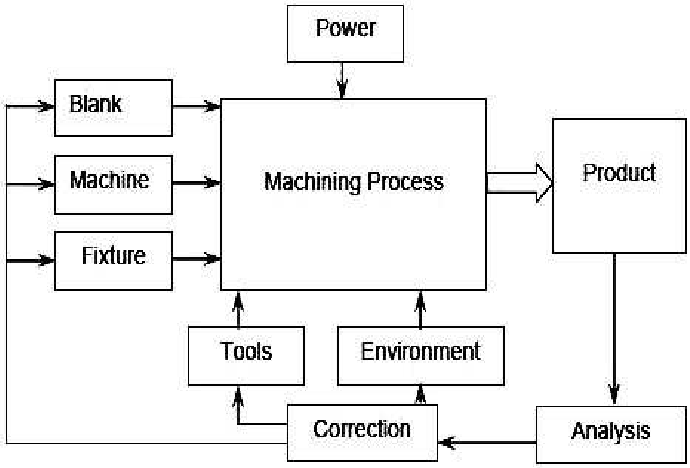


Fig. 1.2 Requirements for machining

1.2.3 Purpose of machining

Most of the engineering components such as gears, bearings, clutches, tools, screws and nuts etc. need dimensional and form accuracy and good surface finish for serving their purposes. Preforming like casting, forging etc. generally cannot provide the desired accuracy and finish. For that such preformed parts, called blanks, need semi-finishing and finishing and it is done by machining and grinding. Grinding is also basically a machining process.

Machining to high accuracy and finish essentially enables a product:

- Fulfill its functional requirements.
- Improve its performance.
- Prolong its service.

1.2.4 Requirements of machining

The essential basic requirements for machining a work are schematically illustrated in Fig. 1.2.

The blank and the cutting tool are properly mounted (in fixtures) and moved in a powerful device called machine tool enabling gradual removal of layer of material from the work surface resulting in its desired dimensions and surface finish. Additionally some environment called cutting fluid is generally used to ease machining by cooling and lubrication.

1.3 TYPES OF MACHINE TOOLS

1.3.1 Definition of machine tool

A machine tool is a non-portable power operated and reasonably valued device or system of devices in which energy is expended to produce jobs of desired size, shape and surface finish by removing excess material from the preformed blanks in the form of chips with the help of cutting tools moved past the work surface(s).

1.3.2 Basic functions of machine tools

Machine tools basically produce geometrical surfaces like flat, cylindrical or any contour on the preformed blanks by machining work with the help of cutting tools.

The physical functions of a machine tool in machining are:

- Firmly holding the blank and the tool.
- Transmit motions to the tool and the blank.
- Provide power to the tool-work pair for the machining action.
- Control of the machining parameters, i.e., speed, feed and depth of cut.

1.3.3 Classification of machine tools

Number of types of machine tools gradually increased till mid 20th century and after that started decreasing based on group technology.

However, machine tools are broadly classified as follows:

According to direction of major axis:

- Horizontal - center lathe, horizontal boring machine etc.
- Vertical - vertical lathe, vertical axis milling machine etc.
- Inclined - special (e.g. for transfer machines).

According to purpose of use:

- General purpose - e.g. center lathes, milling machines, drilling, machines etc.
- Single purpose - e.g. facing lathe, roll turning lathe etc.
- Special purpose - for mass production.

According to degree of automation:

- Non-automatic - e.g. center lathes, drilling machines etc.
- Semi-automatic - capstan lathe, turret lathe, hobbing machine etc.
- Automatic - e.g., single spindle automatic lathe, swiss type automatic lathe, CNC milling machine etc.

According to size:

- Heavy duty - e.g., heavy duty lathes (e.g. $\geq$ 55 kW), boring mills, planning machine, horizontal boring machine etc.
- Medium duty - e.g., lathes - 3.7 ~ 11 kW, column drilling machines, milling machines etc.
- Small duty - e.g., table top lathes, drilling machines, milling machines.
- Micro duty - e.g., micro-drilling machine etc.

According to blank type:

- Bar type (lathes).
- Chucking type (lathes).
- Housing type.

According to precision:

- Ordinary - e.g., automatic lathes.
- High precision - e.g., Swiss type automatic lathes.

According to number of spindles:

- Single spindle - center lathes, capstan lathes, milling machines etc.
- Multi spindle - multi spindle (2 to 8) lathes, gang drilling machines etc.

According to type of automation:

- Fixed automation - e.g., single spindle and multi spindle lathes.
- Flexible automation - e.g., CNC milling machine.

According to configuration:

- Stand alone type - most of the conventional machine tools.
- Machining system (more versatile) - e.g., transfer machine, machining center, FMS etc.

1.3.4 Specification of machine tools

A machine tool may have a large number of various features and characteristics. But only some specific salient features are used for specifying a machine tool. All the manufacturers, traders and users must know how machine tools are specified.

The methods of specification of some basic machine tools are as follows:

Centre lathe:

- Maximum diameter and length of the jobs that can be accommodated.
- Power of the main drive (motor).
- Range of spindle speeds and range of feeds.
- Space occupied by the machine.

Shaper:

- Length, breadth and depth of the bed.
- Maximum axial travel of the bed and vertical travel of the bed / tool.
- Maximum length of the stroke (of the ram / tool).
- Range of number of strokes per minute.
- Range of table feed.
- Power of the main drive.
- Space occupied by the machine.

Drilling machine (column type):

- Maximum drill size (diameter) that can be used.
- Size and taper of the hole in the spindle.
- Range of spindle speeds.
- Range of feeds.
- Power of the main drive.
- Range of the axial travel of the spindle / bed.
- Floor space occupied by the machine.

Milling machine (knee type and with arbor):

- Type; ordinary or swiveling bed type.
- Size of the work table.
- Range of travels of the table in X - Y - Z directions.
- Arbor size (diameter).
- Power of the main drive.
- Range of spindle speed.
- Range of table feeds in X - Y - Z directions.
- Floor space occupied.

1.4 THEORY OF METAL CUTTING

1.4.1 Types of cutting tools

Cutting tools may be classified according to the number of major cutting edges (points) involved as follows:

- Single point: e.g., turning tools, shaping, planning and slotting tools and boring tools.
- Double (two) point: e.g., drills.
- Multipoint (more than two): e.g., milling cutters, broaching tools, hobs, gear shaping cutters etc.

1.4.2 Geometry of single point cutting (turning) tools

Both material and geometry of the cutting tools play very important roles on their performances in achieving effectiveness, efficiency and overall economy of machining.

1.4.2.1 Concept of rake and clearance angles of cutting tools

The word tool geometry is basically referred to some specific angles or slope of the salient faces and edges of the tools at their cutting point. Rake angle and clearance angle are the most significant for all the cutting tools. The concept of rake angle and clearance angle will be clear from some simple operations *shown in Fig. 1.3.*

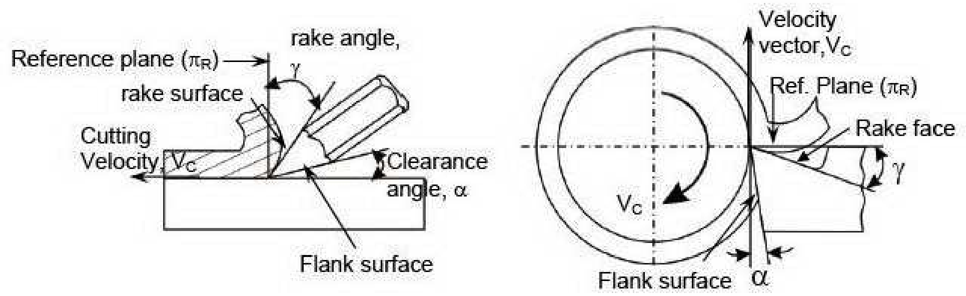
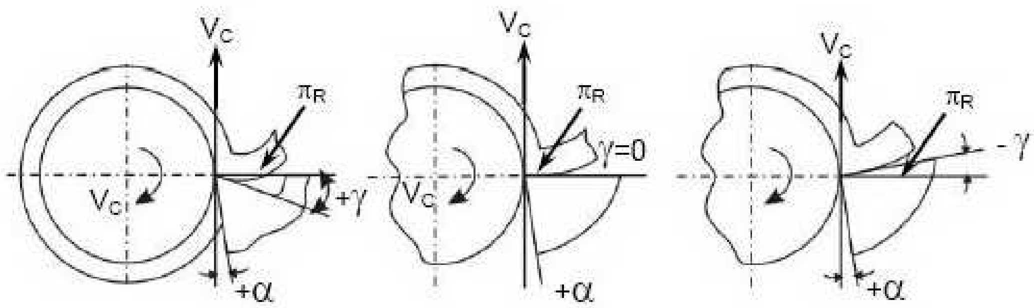


Fig. 1.3 Rake and clearance angles of cutting tools

Definition

- *Rake angle (γ):* Angle of inclination of rake surface from reference plane.
- *Clearance angle (α):* Angle of inclination of clearance or flank surface from the finished surface.

Rake angle is provided for ease of chip flow and overall machining. Rake angle may be positive, or negative or even zero *as shown in Fig. 1.4 (a, b and c).*



(a) Positive rake (b) Zero rake (c) Negative rake

Fig. 1.4 Three possible types of rake angles

Relative advantages of such rake angles are:

- Positive rake - helps reduce cutting force and thus cutting power requirement.
- Zero rake - to simplify design and manufacture of the form tools.
- Negative rake - to increase edge-strength and life of the tool.

Clearance angle is essentially provided to avoid rubbing of the tool (flank) with the machined surface which causes loss of energy and damages of both the tool and the job surface. Hence, clearance angle is a must and must be positive (3^0 ~ 15^0) depending upon tool-work materials and type of the machining operations like turning, drilling, boring etc.

1.4.2.2 Systems of description of tool geometry

- Tool-in-Hand System - where only the salient features of the cutting tool point are identified or visualized *as shown in Fig. 1.5 (a).* There is no quantitative information, i.e., value of the angles.
- Machine Reference System - ASA system.
- Tool Reference System - Orthogonal Rake System - ORS.
  - Normal Rake System - NRS.
- Work Reference System - WRS.

1.4.2.3 Description of tool geometry in Machine Reference System

This system is also called as ASA system; ASA stands for American Standards Association. Geometry of a cutting tool refers mainly to its several angles or slopes of its salient working surfaces and cutting edges. Those angles are expressed with respect to some planes of reference.

In Machine Reference System (ASA), the three planes of reference and the coordinates are chosen based on the configuration and axes of the machine tool concerned. The planes and axes used for expressing tool geometry in ASA system for turning operation *are shown in Fig. 1.5 (b).*

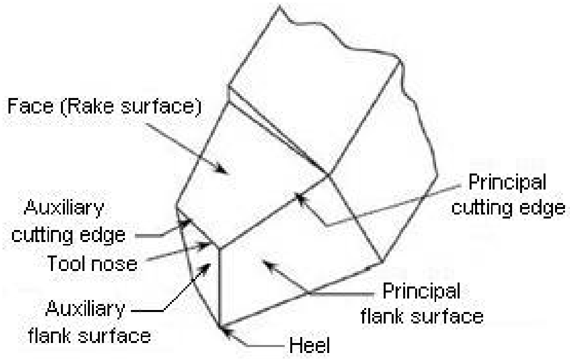


Fig 1.5 (a) Basic features of single point cutting (turning) tool

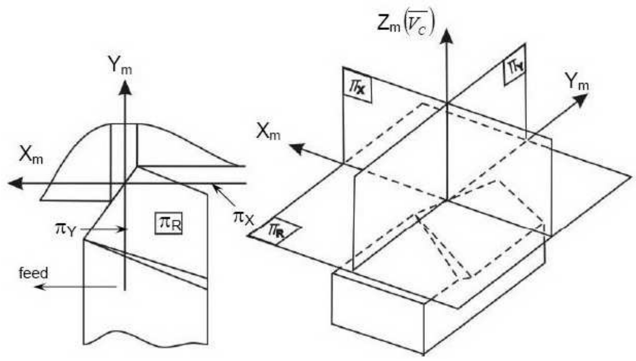


Fig. 1.5 (b) Planes and axes of reference in ASA system

The planes of reference and the coordinates used in ASA system for tool geometry are:

π_R - π_X - π_Y and X_m - Y_m - Z_m; where,

π_R = Reference plane; plane perpendicular to the velocity vector. Shown in Fig. 1.5 (b).

π_X = Machine longitudinal plane; plane perpendicular to π_R and taken in the direction of assumed longitudinal feed.

π_Y = Machine transverse plane; plane perpendicular to both π_R and π_X. [This plane is taken in the direction of assumed cross feed]

The axes X_m, Y_m and Z_m are in the direction of longitudinal feed, cross feed and cutting velocity (vector) respectively. The main geometrical features and angles of single point tools in ASA systems and their definitions will be clear *from Fig. 1.6.*

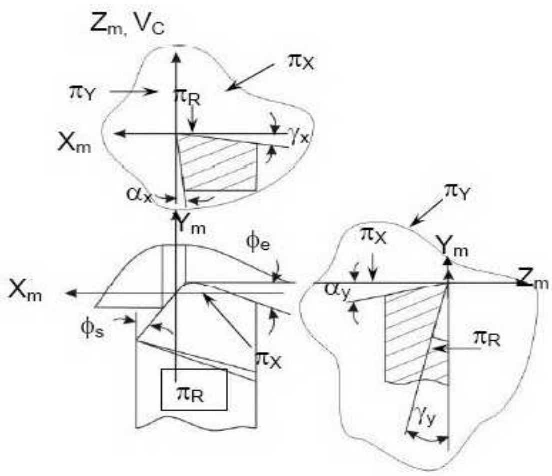


Fig. 1.6 Tool angles in ASA system

Definition of:

Shank: The portion of the tool bit which is not ground to form cutting edges and is rectangular in cross section. [Fig. 1.5 (a)]

Face: The surface against which the chip slides upward. [Fig. 1.5 (a)]

Flank: The surface which face the work piece. There are two flank surfaces in a single point cutting tool. One is principal flank and the other is auxiliary flank. [Fig. 1.5 (a)]

Heel: The lowest portion of the side cutting edges. [Fig. 1.5 (a)]

Nose radius: The conjunction of the side cutting edge and end cutting edge. It provides strengthening of the tool nose and better surface finish. [Fig. 1.5 (a)]

Base: The underside of the shank. [Fig. 1.5 (a)]

Rake angles: [Fig. 1.6]

γ_x = Side rake angle (axial rake): angle of inclination of the rake surface from the reference plane (π_R) and measured on machine reference plane, π_X.

γ_y = Back rake angle: angle of inclination of the rake surface from the reference plane and measured on machine transverse plane, π_Y.

Clearance angles: [Fig. 1.6]

α_x = Side clearance angle (Side relief angle): angle of inclination of the principal flank from the machined surface (or CV) and measured on π_X plane.

α_y = Back clearance angle (End relief angle): same as α_x but measured on π_Y plane.

Cutting angles: [Fig. 1.6]

φ_s = Side cutting edge angle (Approach angle): angle between the principal cutting edge (its projection on π_R) and π_Y and measured on π_R.

φ_e = End cutting edge angle: angle between the end cutting edge (its projection on π_R) from π_X and measured on π_R.

1.4.3 Designation of tool geometry

The geometry of a single point tool is designated or specified by a series of values of the salient angles and nose radius arranged in a definite sequence as follows:

Designation (Signature) of tool geometry in ASA System - $\boldsymbol{\gamma_y, \gamma_x, \alpha_y, \alpha_x, \varphi_e, \varphi_s, r}$ (in inch)

Example: A tool having 7, 8, 6, 7, 5, 6, 0.1 as designation (Signature) in ASA system will have the following angles and nose radius.

Back rack angle	=	7^0
Side rake angle	=	8^0
Back clearance angle	=	6^0
Side clearance angle	=	7^0
End cutting edge angle	=	5^0
Side cutting edge angle	=	6^0
Nose radius	=	0.1 inch

1.4.4 Types of metal cutting processes

The metal cutting process is mainly classified into two types. They are:

- ***Orthogonal cutting process*** (Two - dimensional cutting) - The cutting edge or face of the tool is 90^0 to the line of action or path of the tool or to the cutting velocity vector. This cutting involves only two forces and this makes the analysis simpler.
- ***Oblique cutting process*** (Three - dimensional cutting) - The cutting edge or face of the tool is inclined at an angle less than 90^0 to the line of action or path of the tool or to the cutting velocity vector. Its analysis is more difficult of its three dimensions.

1.4.4.1 Orthogonal and oblique cutting

It is appears from the diagram *shown in Fig. 1.7 (a and b)* that while turning ductile material by a sharp tool, the continuous chip would flow over the tool's rake surface and in the direction apparently perpendicular to the principal cutting edge, i.e., along orthogonal plane which is normal to the cutting plane containing the principal cutting edge. But practically, the chip may not flow along the orthogonal plane for several factors like presence of inclination angle, λ, etc.

The role of inclination angle, λ on the direction of chip flow is schematically shown in Fig. 1.8 which visualizes that:

- When $\lambda = 0^0$, the chip flows along orthogonal plane, i.e, $\rho_c = 0^0$.
- When $\lambda \neq 0^0$, the chip flow is deviated from π_o and $\rho_c = \lambda$ where ρ_c is chip flow deviation (from π_o) angle.

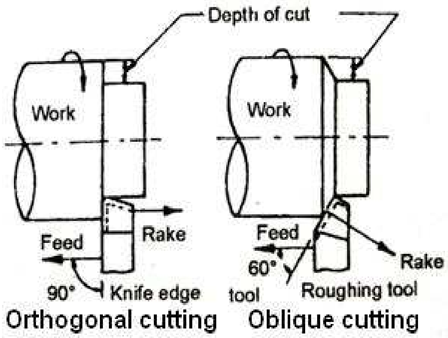


Fig. 1.7 (a) Setup of orthogonal and oblique cutting

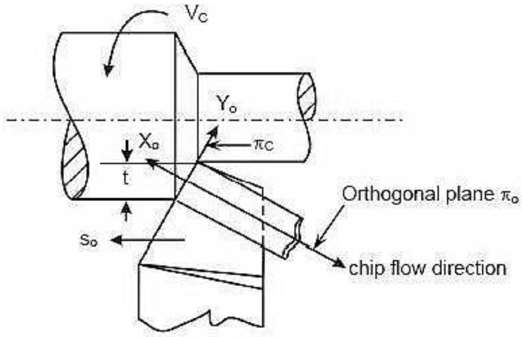


Fig. 1.7 (b) Ideal direction of chip flow in turning

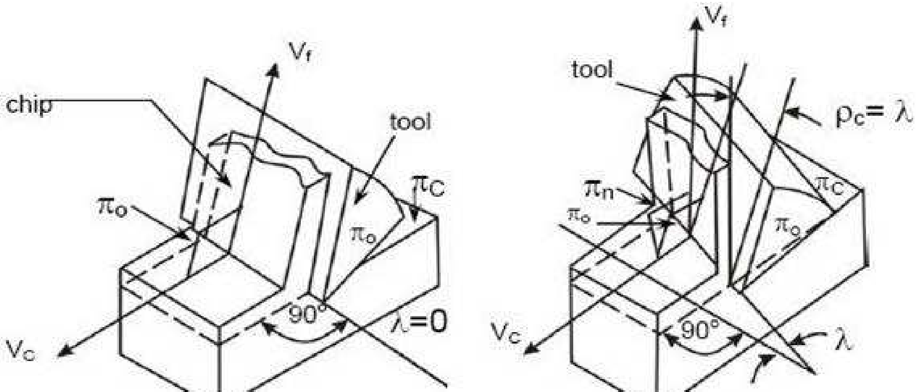


Fig. 1.8 Role of inclination angle, λ on chip flow direction

Orthogonal cutting: When chip flows along orthogonal plane, π_o, i.e., $\rho_c = 0^0$.

Oblique cutting: When chip flow deviates from orthogonal plane, i.e. $\rho_c \neq 0^0$.

But practically ρ_c may be zero even if $\lambda = 0^0$ and ρ_c may not be exactly equal to λ even if $\lambda \neq 0^0$. Because there is some other (than λ) factors also may cause chip flow deviation.

1.4.4.2 Pure orthogonal cutting

This refers to chip flow along π_o and $\varphi = 90^0$ *as typically shown in Fig. 1.9.* Where a pipe like job of uniform thickness is turned (reduced in length) in a center lathe by a turning tool of geometry; $\lambda = 0^0$ and $\varphi = 90^0$ resulting chip flow along π_o which is also π_x in this case.

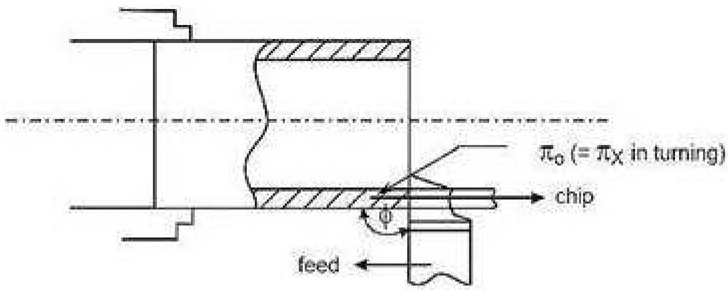


Fig. 1.9 Pure orthogonal cutting (pipe turning)

1.5 CHIP FORMATION

1.5.1 Mechanism of chip formation

Machining is a semi-finishing or finishing process essentially done to impart required or stipulated dimensional and form accuracy and surface finish to enable the product to:

- Fulfill its basic functional requirements.
- Provide better or improved performance.
- Render long service life.

Machining is a process of gradual removal of excess material from the preformed blanks in the form of chips. *The form of the chips is an important index of machining because it directly or indirectly indicates:*

- Nature and behavior of the work material under machining condition.
- Specific energy requirement (amount of energy required to remove unit volume of work material) in machining work.
- Nature and degree of interaction at the chip-tool interfaces.

The form of machined chips depends mainly upon:

- Work material.
- Material and geometry of the cutting tool.
- Levels of cutting velocity and feed and also to some extent on depth of cut.
- Machining environment or cutting fluid that affects temperature and friction at the chip-tool and work-tool interfaces.

Knowledge of basic mechanism(s) of chip formation helps to understand the characteristics of chips and to attain favorable chip forms.

1.5.1.1 Mechanism of chip formation in machining ductile materials

During continuous machining the uncut layer of the work material just ahead of the cutting tool (edge) is subjected to almost all sided compression *as indicated in Fig. 1.10.*

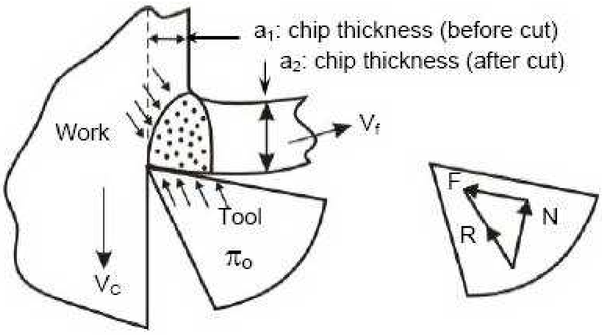
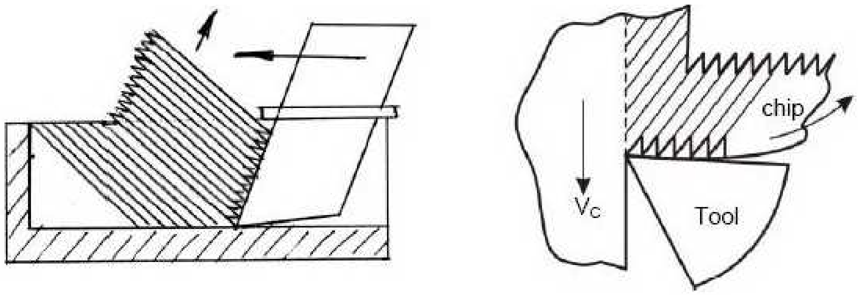


Fig. 1.10 Compression of work material (layer) ahead of the tool tip

The force exerted by the tool on the chip arises out of the normal force, N and frictional force, F as indicated in Fig. 1.10. Due to such compression, shear stress develops, within that compressed region, in different magnitude, in different directions and rapidly increases in magnitude. Whenever and wherever the value of the shear stress reaches or exceeds the shear strength of that work material in the deformation region, yielding or slip takes place resulting shear deformation in that region and the plane of maximum shear stress. But the forces causing the shear stresses in the region of the chip quickly diminishes and finally disappears while that region moves along the tool rake surface towards and then goes beyond the point of chip-tool engagement.

As a result the slip or shear stops propagating long before total separation takes place. In the mean time the succeeding portion of the chip starts undergoing compression followed by yielding and shear. This phenomenon repeats rapidly resulting in formation and removal of chips in thin layer by layer. *This phenomenon has been explained in a simple way by Piispannen[*1] using a card analogy as shown in Fig. 1.11 (a).*



(a) Shifting of the postcards by partial sliding against each other (b) Chip formation by shear in lamella

Fig. 1.11 Piispannen model of card analogy to explain chip formation in machining ductile materials

In actual machining chips also, such serrations are visible at their upper surface *as indicated in Fig. 1.11 (b).* The lower surface becomes smooth due to further plastic deformation due to intensive rubbing with the tool at high pressure and temperature. The pattern of shear deformation by lamellar sliding, indicated in the model, can also be seen in actual chips by proper mounting, etching and polishing the side surface of the machining chip and observing under microscope.

The pattern and extent of total deformation of the chips due to the primary and the secondary shear deformations of the chips ahead and along the tool face, *as indicated in Fig. 1.12,* depend upon:

- Work material.
- Tool; material and geometry.
- The machining speed (VC) and feed (so).
- Cutting fluid application.

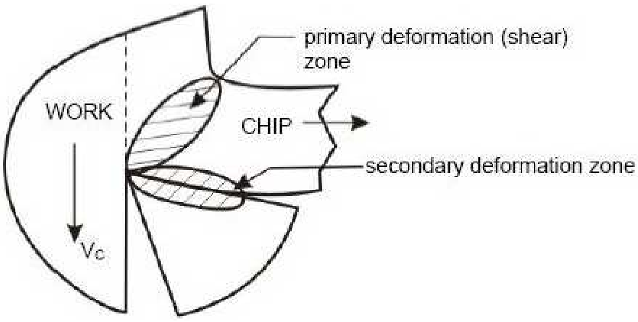
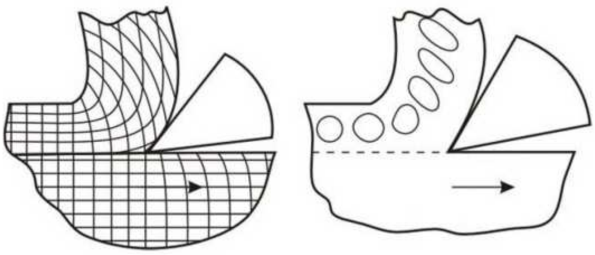


Fig. 1.12 Primary and secondary deformation zones in the chip

The overall deformation process causing chip formation is quite complex and hence needs thorough experimental studies for clear understanding the phenomena and its dependence on the affecting parameters. The feasible and popular experimental methods*2 for this purpose are:

- Study of deformation of rectangular or circular grids marked on side surface *as shown in Fig. 1.13 (a and b).*
- Microscopic study of chips frozen by drop tool or quick stop apparatus.
- Study of running chips by high speed camera fitted with low magnification microscope.

It has been established by several analytical and experimental methods including circular grid deformation that though the chips are initially compressed ahead of the tool tip, the final deformation is accomplished mostly by shear in machining ductile materials. *However, machining of ductile materials generally produces flat, curved or coiled continuous chips.*



(a) Rectangular grids (b) Circular grids

Fig. 1.13 Pattern of grid deformation during chip formation

1.5.1.2 Mechanism of chip formation in machining brittle materials

The basic two mechanisms involved in chip formation are:

- Yielding - generally for ductile materials.
- Brittle fracture - generally for brittle materials.

During machining, first a small crack develops at the tool tip as shown in Fig. 1.14 due to wedging action of the cutting edge. At the sharp crack-tip stress concentration takes place. In case of ductile materials immediately yielding takes place at the crack-tip and reduces the effect of stress concentration and prevents its propagation as crack. But in case of brittle materials the initiated crack quickly propagates, under stressing action, and total separation takes place from the parent work piece through the minimum resistance path *as indicated in Fig. 1.14.*

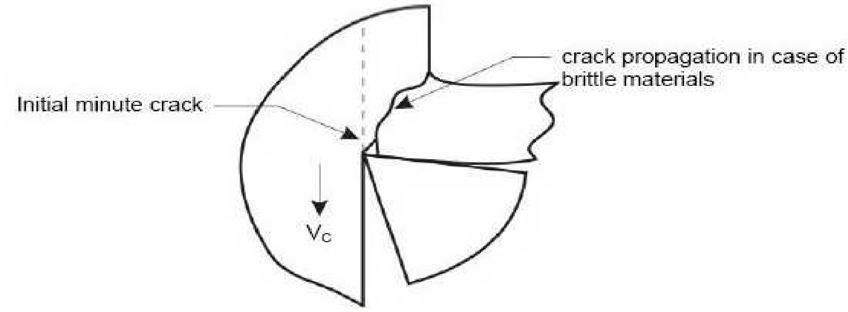
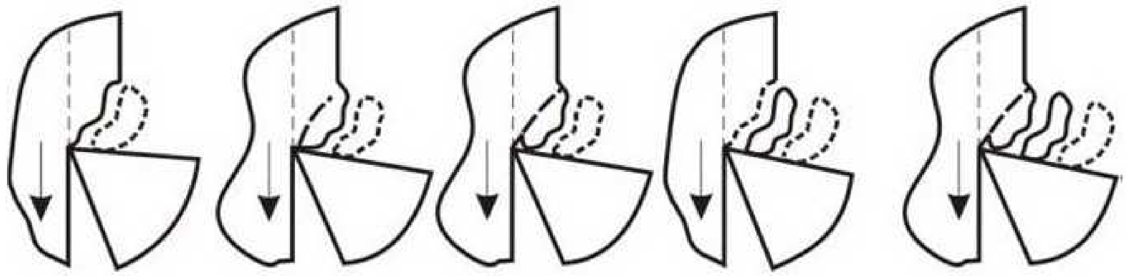


Fig. 1.14 Development and propagation of crack causing chip separation.

Machining of brittle material produces discontinuous chips and mostly of irregular size and shape. The process of forming such chips *is schematically shown in Fig. 1.15 (a, b, c, d and e).*



(a) Separation (b) Swelling (c) Further swelling (d) Separation (e) Swelling again

Fig. 1.15 Schematic view of chip formation in machining brittle materials

1.5.2 Chip thickness ratio

Geometry and characteristics of chip forms

The geometry of the chips being formed at the cutting zone follow a particular pattern especially in machining ductile materials. The major sections of the engineering materials being machined are ductile in nature; even some semi-ductile or semi-brittle materials behave ductile under the compressive forces at the cutting zone during machining.

The pattern and degree of deformation during chip formation are quantitatively assessed and expressed by some factors, the values of which indicate about the forces and energy required for a particular machining work.

Chip reduction coefficient or cutting ratio

The usual geometrical features of formation of continuous chips are schematically shown in Fig. 1.16. The chip thickness (a_2) usually becomes larger than the uncut chip thickness (a_1). *The reason can be attributed to:*

- Compression of the chip ahead of the tool.
- Frictional resistance to chip flow.
- Lamellar sliding according to Piispannen.

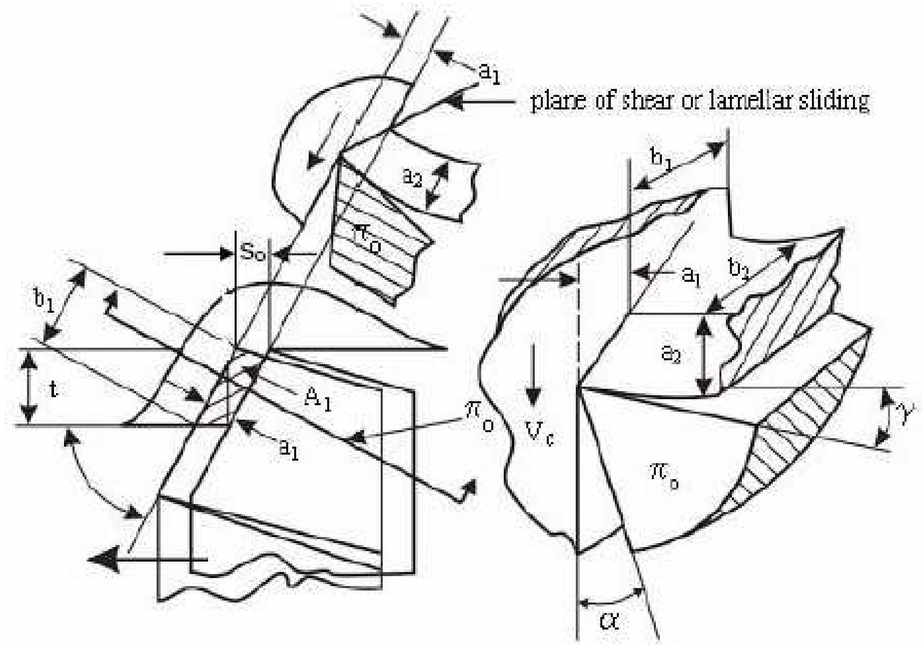


Fig. 1.16 Geometrical features of continuous chip formation.

The significant geometrical parameters involved in chip formation *are shown in Fig. 1.16* and those parameters are defined (in respect of straight turning) as:

t = depth of cut (mm) - perpendicular penetration of the cutting tool tip in work surface.

f = feed (mm/rev) - axial travel of the tool per revolution of the job.

b_1 = width (mm) of chip before cut.

b_2 = width (mm) of chip after cut.

a_1 = thickness (mm) of uncut layer (or chip before cut).

a_2 = chip thickness (mm) - thickness of chip after cut.

A_1 = cross section (area, mm2) of chip before cut.

The degree of thickening of the chip is expressed by

$$\mathbf{r_c = a_2 / a_1 > 1.00} \quad \text{(since } a_2 > a_1\text{)} \qquad 1.1$$

where, r_c = chip reduction coefficient.

$$\mathbf{a_1 = f \sin\varphi} \qquad 1.2$$

where φ = principal cutting edge angle.

Larger value of r_c means more thickening i.e., more effort in terms of forces or energy required to accomplish the machining work. Therefore it is always desirable to reduce a_2 or r_c without sacrificing productivity, i.e. metal removal rate (MRR).

Chip thickening is also often expressed by the reciprocal of r_c as,

$$\mathbf{1 / r_c = r = a_1 / a_2} \qquad 1.3$$

where r = cutting ratio.

The value of chip reduction coefficient, r_c (and hence cutting ratio) depends mainly upon

⟶ Tool rake angle, γ ⟶ Chip-tool interaction, mainly friction, μ

Roughly in the following way,[*3]

$$\mathbf{r_c} = e^{\mu(\frac{\pi}{2} - \gamma)} \text{ (for orthogonal cutting)} \qquad 1.4$$

$\frac{\pi}{2}$ and γ are in radians.

The simple but very significant expression 1.4 clearly depicts that the value of r_c can be desirably reduced by

- Using tool having larger positive rake.
- Reducing friction by using lubricant.

The role of rake angle and friction at the chip-tool interface on chip reduction coefficient are also schematically shown in Fig. 1.17.

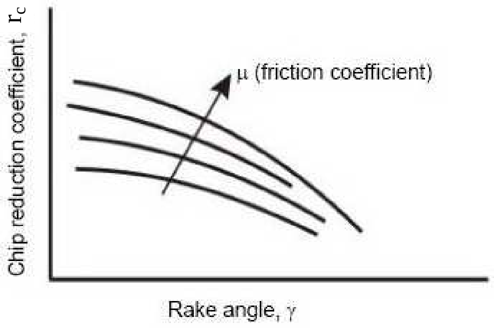


Fig. 1.17 Role of rake angle and friction on chip reduction coefficient

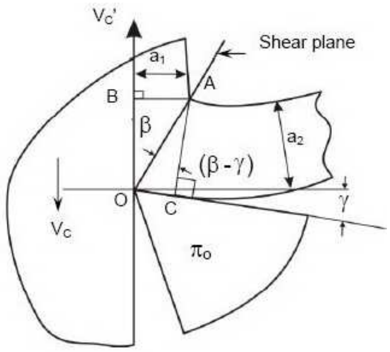


Fig. 1.18 Shear plane and shear angle in chip formation

Chip reduction coefficient, r_c is generally assessed and expressed by the ratio of the chip thickness, after cut (a_2) and before cut (a_1) as in equation 1.1. *But r_c can also be expressed or assessed by the ratio of:*

- Total length of the chip before cut (L_1) and after cut (L_2).
- Cutting velocity, V_C and chip velocity, V_f.

Considering total volume of chip produced in a given time,

$$\mathbf{a_1b_1L_1 = a_2b_2L_2} \quad 1.5$$

The width of chip, b generally does not change significantly during machining unless there is side flow for some adverse situation. Therefore assuming, b1=b2 in equation 1.5, r_c comes up to be,

$$\mathbf{r_c = a_2 / a_1 = L_1 / L_2} \quad 1.6$$

Again considering unchanged material flow (volume) ratio, Q

$$Q = \mathbf{(a_1b_1)V_C = (a_2b_2)V_f} \quad 1.7$$

Taking $b_1=b_2$,

$$\mathbf{r_c = a_2 / a_1 = V_C / V_f} \quad 1.8$$

Equation 5.8 reveals that the chip velocity, V_f will be lesser than the cutting velocity, V_C and the ratio is equal to the cutting ratio, $\mathbf{r = 1 / r_c}$

Shear angle

It has been observed that during machining, particularly ductile materials, the chip sharply changes its direction of flow (relative to the tool) from the direction of the cutting velocity, VC to that along the tool rake surface after thickening by shear deformation or slip or lamellar sliding along a plane. *This plane is called shear plane and is schematically shown in Fig. 1.18.*

Shear plane

Shear plane is the plane of separation of work material layer in the form of chip from the parent body due to shear along that plane.

Shear angle

Angle of inclination of the shear plane from the direction of cutting velocity as shown in Fig. 1.18.

The value of shear angle, denoted by β (taken in orthogonal plane) depends upon:

- Chip thickness before cut and after cut i.e. r_c.
- Rake angle, γ (in orthogonal plane).

From Fig. 1.18,

$$\mathbf{AC = a_2 = OA\cos(\beta - \gamma)} \text{ and } \mathbf{AB = a_1 = OA\sin\beta} \qquad \text{dividing } a_2 \text{ by } a_1$$

$$\mathbf{a_2 / a_1 = r_c = \cos(\beta - \gamma) / \sin\beta} \quad 1.9$$

or $$\tan\mathbf{\beta = \cos\gamma / r_c - \sin\gamma} \quad 1.10$$

Replacing chip reduction coefficient, r_c by cutting ratio, r, the equation 1.10 changes to,

$$\tan\boldsymbol{\beta} = \mathbf{r\cos\gamma / 1 - r\sin\gamma} \qquad 1.11$$

Equation 1.10 depicts that with the increase in r_c, shear angle decreases and vice-versa. It is also evident from equation 1.10 as well as equation 1.4 that shear angle increases both directly and indirectly with the increase in tool rake angle. Increase in shear angle means more favorable machining condition requiring lesser specific energy.

Cutting strain

The magnitude of strain, that develops along the shear plane due to machining action, is called cutting strain (shear). *The relationship of this cutting strain, ε with the governing parameters can be derived from Fig. 1.19.*

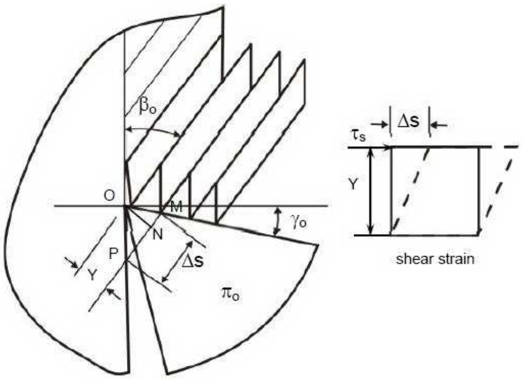


Fig. 1.19 Cutting strain in machining

Due to presence of the tool as an obstruction the layer 1 has been shifted to position 2 by sliding along the shear plane. From Fig. 1.19,

Cutting strain (average), $\boldsymbol{\varepsilon = \Delta s / Y = PM / ON}$ or $\boldsymbol{\varepsilon = PN + NM / ON}$

$$\boldsymbol{\varepsilon = PN / ON + NM / ON} \quad \text{or} \quad \boldsymbol{\varepsilon = \cot\beta + \tan(\beta - \gamma)} \qquad 1.12$$

1.5.3 Built-up-Edge (BUE) formation

Causes of formation

In machining ductile metals like steels with long chip-tool contact length, lot of stress and temperature develops in the secondary deformation zone at the chip-tool interface. Under such high stress and temperature in between two clean surfaces of metals, strong bonding may locally take place due to adhesion similar to welding. Such bonding will be encouraged and accelerated if the chip tool materials have mutual affinity or solubility.

The weldment starts forming as an embryo at the most favorable location and thus gradually grows as schematically shown in Fig. 1.20.

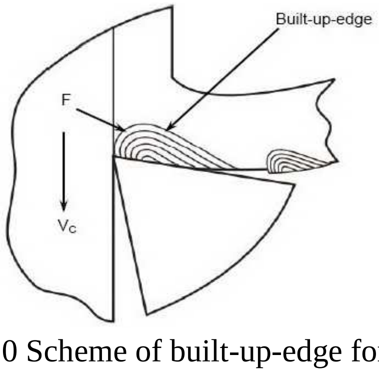


Fig. 1.20 Scheme of built-up-edge formation

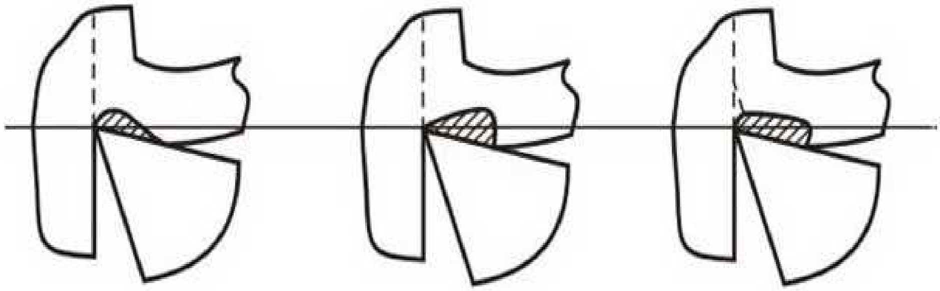
With the growth of the BUE, the force, F (shown in Fig. 1.20) also gradually increases due to wedging action of the tool tip along with the BUE formed on it. Whenever the force, F exceeds the bonding force of the BUE, the BUE is broken or sheared off and taken away by the flowing chip. Then again BUE starts forming and growing. This goes on repeatedly.

Characteristics of BUE

Built-up-edges are characterized by its shape, size and bond strength, which depend upon:

- Work tool materials.
- Stress and temperature, i.e., cutting velocity and feed.
- Cutting fluid application governing cooling and lubrication.

BUE may develop basically in three different shapes as schematically shown in Fig. 1.21 (a, b and c).



(a) Positive wedge (b) Negative wedge (c) Flat type

Fig. 1.21 Different forms of built-up-edge.

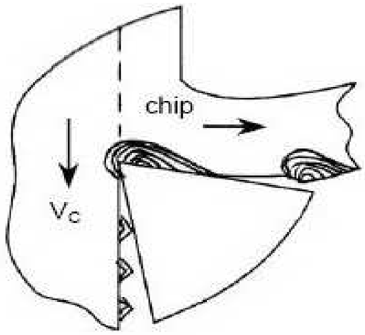


Fig. 1.22 Overgrowing and overflowing of BUE causing surface roughness

In machining too soft and ductile metals by tools like high speed steel or uncoated carbide the BUE may grow larger and overflow towards the finished surface through the flank *as shown in Fig. 1.22.* While the major part of the detached BUE goes away along the flowing chip, a small part of the BUE may remain stuck on the machined surface and spoils the surface finish. BUE formation needs certain level of temperature at the interface depending upon the mutual affinity of the work-tool materials. With the increase in V_C and so the cutting temperature rises and favors BUE formation.

But if V_C is raised too high beyond certain limit, BUE will be squashed out by the flowing chip before the BUE grows. *Fig. 1.23 shows schematically the role of increasing V_C and so on BUE formation (size).* But sometime the BUE may adhere so strongly that it remains strongly bonded at the tool tip and does not break or shear off even after reasonably long time of machining. Such harmful situation occurs in case of certain tool-work materials and at speed-feed conditions which strongly favor adhesion and welding.

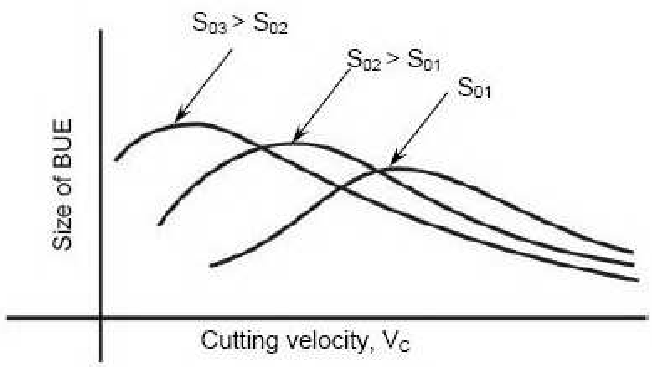


Fig. 1.23 Role of cutting velocity and feed on BUE formation

Effects of BUE formation

Formation of BUE causes several harmful effects, such as:

- It unfavorably changes the rake angle at the tool tip causing increase in cutting forces and power consumption.
- Repeated formation and dislodgement of the BUE causes fluctuation in cutting forces and thus induces vibration which is harmful for the tool, job and the machine tool.
- Surface finish gets deteriorated.
- May reduce tool life by accelerating tool-wear at its rake surface by adhesion and flaking occasionally, formation of thin flat type stable BUE may reduce tool wear at the rake face.

1.5.4 Types of chips

Different types of chips of various shape, size, colour etc. are produced by machining depending upon:

- Type of cut, i.e., continuous (turning, boring etc.) or intermittent cut (milling).
- Work material (brittle or ductile etc.).
- Cutting tool geometry (rake, cutting angles etc.).
- Levels of the cutting velocity and feed (low, medium or high).
- Cutting fluid (type of fluid and method of application).

The basic major types of chips and the conditions generally under which such types of chips form are given below:

Continuous chips without BUE

When the cutting tool moves towards the work piece, there occurs a plastic deformation of the work piece and the metal is separated without any discontinuity and it moves like a ribbon. The chip moves along the face of the tool. This mostly occurs while cutting a ductile material. It is desirable to have smaller chip thickness and higher cutting speed in order to get continuous chips. Lesser power is consumed while continuous chips are produced. Total life is also mortised in this process. *The formation of continuous chips is schematically shown in Fig. 1.24.*

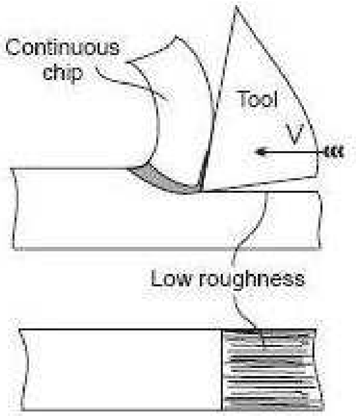


Fig. 1.24 Formation of continuous chips

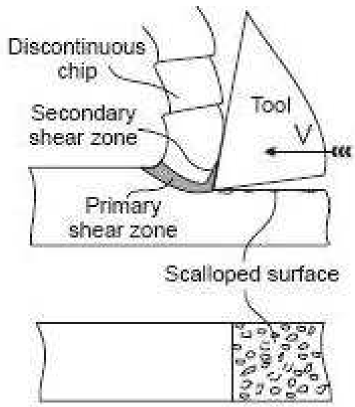


Fig. 1.25 Formation of discontinuous chips

The following condition favors the formation of continuous chips without BUE chips:

- Work material - ductile.
- Cutting velocity - high.
- Feed - low.
- Rake angle - positive and large.
- Cutting fluid - both cooling and lubricating.

Discontinuous chips

This is also called as segmental chips. This mostly occurs while cutting brittle material such as cast iron or low ductile materials. Instead of shearing the metal as it happens in the previous process, the metal is being fractured like segments of fragments and they pass over the tool faces. Tool life can also be more in this process. Power consumption as in the previous case is also low. *The formation of continuous chips is schematically shown in Fig. 1.25.*

The following condition favors the formation of discontinuous chips:

- Of irregular size and shape: - work material - brittle like grey cast iron.
- Of regular size and shape: - work material ductile but hard and work hardenable.
- Feed rate - large.
- Tool rake - negative.
- Cutting fluid - absent or inadequate.

Continuous chips with BUE

When cutting a ductile metal, the compression of the metal is followed by the high heat at tool face. This in turns enables part of the removed metal to be welded into the tool. This is known as built up edge, a very hardened layer of work material attached to the tool face, which tends to act as a cutting edge itself replacing the real cutting tool edge.

The built-up edge tends to grow until it reaches a critical size (~0.3 mm) and then passes off with the chip, leaving small fragments on the machining surface. Chip will break free and cutting forces are smaller, but the effect is a rough machined surface. The built-up edge disappears at high cutting speeds.

The weld metal is work hardened or strain hardened. While the cutting process is continued, some of built up edge may be combined with the chip and pass along the tool face. Some of the built up edge may be permanently fixed on the tool face. This produces a rough surface finish and the tool life may be reduced. *The formation of continuous chips with BUE is schematically shown in Fig. 1.26.*

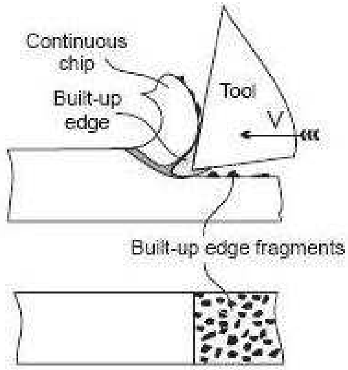


Fig. 1.26 Formation of continuous chips with BUE

The following condition favors the formation of continuous chips with BUE chips:

- Work material - ductile.
- Cutting velocity - low (~0.5 m/s,).
- Small or negative rake angles.
- Feed - medium or large.
- Cutting fluid - inadequate or absent.

Often in machining ductile metals at high speed, the chips are deliberately broken into small segments of regular size and shape by using chip breakers mainly for convenience and reduction of chip-tool contact length.

1.5.5 Chip breakers

1.5.5.1 Need and purpose of chip-breaking

Continuous machining like turning of ductile metals, unlike brittle metals like grey cast iron, produce continuous chips, which leads to their handling and disposal problems. The problems become acute when ductile but strong metals like steels are machined at high cutting velocity for high MRR by flat rake face type carbide or ceramic inserts. *The sharp edged hot continuous chip that comes out at very high speed:*

- Becomes dangerous to the operator and the other people working in the vicinity.
- May impair the finished surface by entangling with the rotating job.
- Creates difficulties in chip disposal.

Therefore it is essentially needed to break such continuous chips into small regular pieces for:

- Safety of the working people.
- Prevention of damage of the product.
- Easy collection and disposal of chips.

Chip breaking is done in proper way also for the additional purpose of improving machinability by reducing the chip-tool contact area, cutting forces and crater wear of the cutting tool.

1.5.5.2 Principles of chip-breaking

In respect of convenience and safety, closed coil type chips of short length and 'coma' shaped broken-to-half turn chips are ideal in machining of ductile metals and alloys at high speed.

The principles and methods of chip breaking are generally classified as follows:

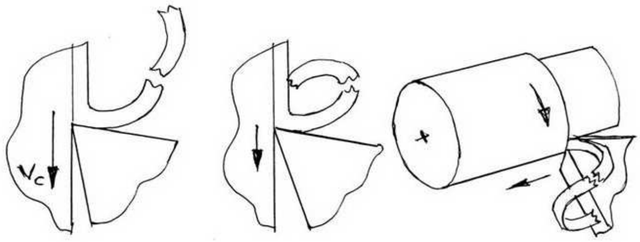
- ***Self chip breaking*** - This is accomplished without using a separate chip-breaker either as an attachment or an additional geometrical modification of the tool.
- ***Forced chip breaking*** - This is accomplished by additional tool geometrical features or devices.

a) Self breaking of chips

Ductile chips usually become curled or tend to curl (like clock spring) even in machining by tools with flat rake surface due to unequal speed of flow of the chip at its free and generated (rubbed) surfaces and unequal temperature and cooling rate at those two surfaces. With the increase in cutting velocity and rake angle (positive) the radius of curvature increases, which is more dangerous.

In case of oblique cutting due to presence of inclination angle, restricted cutting effect etc. the curled chips deviate laterally resulting helical coiling of the chips. *The curled chips may self break:*

- By natural fracturing of the strain hardened outgoing chip after sufficient cooling and spring back *as indicated in Fig. 1.27 (a).* This kind of chip breaking is generally observed under the condition close to that which favors formation of jointed or segmented chips.
- By striking against the cutting surface of the job, *as shown in Fig. 1.27 (b),* mostly under pure orthogonal cutting.
- By striking against the tool flank after each half to full turn *as indicated in Fig. 1.27 (c).*



(a) Natural (b) Striking on job (c) Striking at tool flank

Fig. 1.27 Principles of self breaking of chips

The possibility and pattern of self chip-breaking depend upon the work material, tool material and tool geometry (γ, λ, φ and r), levels of the process parameters (V_C and f_o) and the machining environment (cutting fluid application) which are generally selected keeping in view the overall machinability.

b) Forced chip-breaking

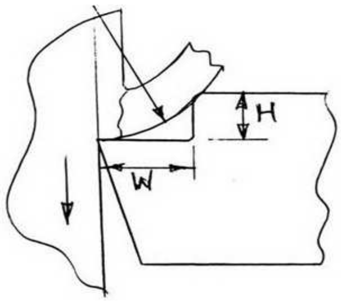
The hot continuous chip becomes hard and brittle at a distance from its origin due to work hardening and cooling. If the running chip does not become enough curled and work hardened, it may not break. In that case the running chip is forced to bend or closely curl so that it breaks into pieces at regular intervals. Such broken chips are of regular size and shape depending upon the configuration of the chip breaker. *Chip breakers are basically of two types:*

- In-built type.
- Clamped or attachment type.

In-built breakers are in the form of step or groove at the rake surface near the cutting edges of the tools. Such chip breakers are provided either:

- After their manufacture - in case of HSS tools like drills, milling cutters, broaches etc and brazed type carbide inserts.
- During their manufacture by powder metallurgical process - e.g., throw away type inserts of carbides, ceramics and cermets.

The basic principle of forced chip breaking is schematically shown in Fig. 1.28. When the strain hardened and brittle running chip strikes the heel, the cantilever chip gets forcibly bent and then breaks.



W = width, H = height, β = shear angle

Fig. 1.28 Principle of forced chip breaking

Fig. 1.29 (a, b, c and d) schematically shows some commonly used step type chip breakers:

- Parallel step.
- Angular step; positive and negative type.
- Parallel step with nose radius - for heavy cuts.

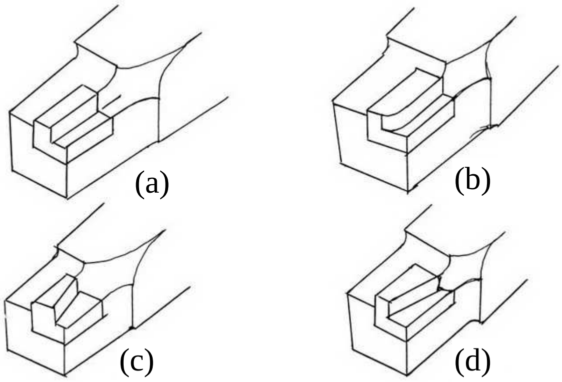
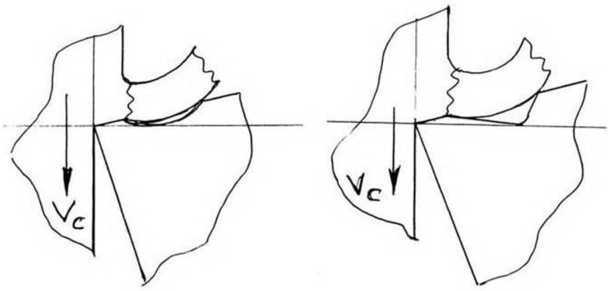


Fig. 1.29 Step type in-built chip breaker (a) Parallel step
(b) Parallel and radiused (c) Positive angular (d) Negative angular

Fig. 1.30 (a and b) schematically shows some commonly used groove type in-built chip breakers:

- Circular groove.
- Tilted Vee groove.



(a) Circular groove (b) Tilted Vee groove

Fig. 1.30 Groove type in-built chip breaker

The unique characteristics of in-built chip breakers are:

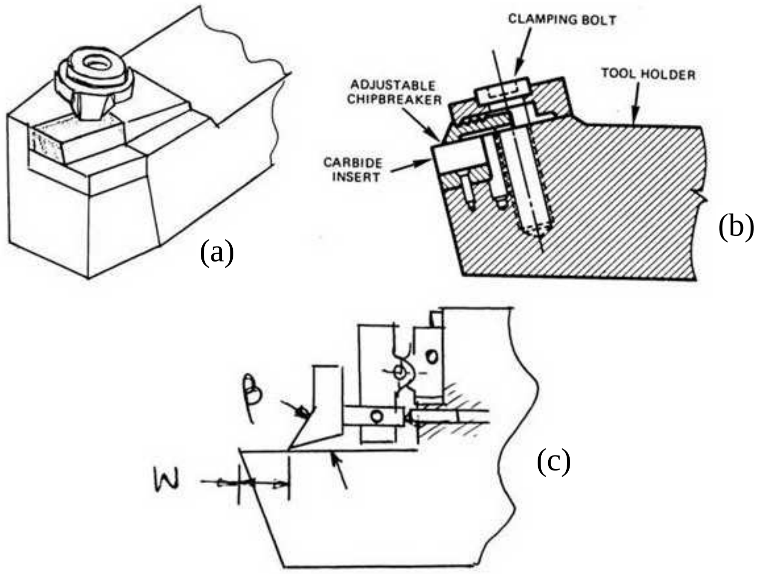
- The outer end of the step or groove acts as the heel that forcibly bends and fractures the running chip.
- Simple in configuration, easy manufacture and inexpensive.
- The geometry of the chip-breaking features is fixed once made. (i.e., cannot be controlled)
- Effective only for fixed range of speed and feed for any given tool-work combination.

(c) Clamped type chip-breaker

Clamped type chip breakers work basically in the principle of stepped type chip-breaker but have the provision of varying the width of the step and / or the angle of the heel.

Fig. 1.31 (a, b and c) schematically shows three such chip breakers of common use:

- With fixed distance and angle of the additional strip - effective only for a limited domain of parametric combination.
- With variable width (W) only - little versatile.
- With variable width (W), height (H) and angle (β) - quite versatile but less rugged and more expensive.



(a) Fixed geometry (b) Variable width (c) Variable width and angle
Fig. 1.31 Clamped type chip breakers

(d) Chip breakers in solid HSS tools

Despite advent of several modern cutting tool materials, HSS is still used for its excellent TRS (transverse rupture strength) and toughness, formability, grindability and low cost. The cutting tools made of solid HSS blanks, such as form tools, twist drills, slab milling cutters, broaches etc, are also often used with suitable chip breakers for breaking the long or wide continuous chips.

The handling of wide and long chips often becomes difficult particularly while drilling large diameter and deep holes. Grooves, either on the rake faces or on the flanks *as shown in Fig. 1.32* help to break the chips both along the length and breadth in drilling ductile metals. The locations of the grooves are offset in the two cutting edges.

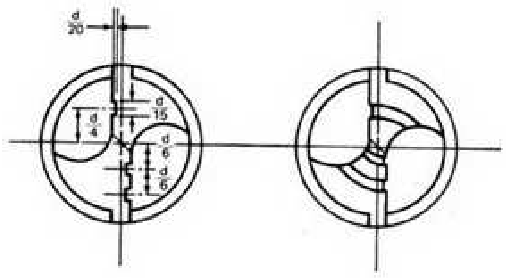
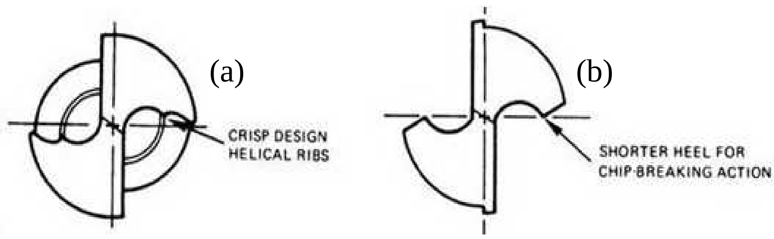


Fig. 1.32 Chip breaking grooves.



(a) Crisp design of chip-breaking drill
(b) US industrial design of chip-breaking drill
Fig. 1.33 Designs of chip-breaking drill

Fig. 1.33 (a and b) schematically shows another principle of chip-breaking when the drilling chips are forced to tighter curling followed by breaking of the strain hardened chips into pieces.

Plain milling and end milling inherently produces discontinuous 'coma' shaped chips of favorably shorter length. But the chips become very wide while milling wide surfaces and may offer problem of chip disposal. To reduce this problem, the milling cutters are provided with small peripheral grooves on the cutting edges *as shown in Fig. 1.34.* Such in-built type chip breakers break the wide chips into a number of chips of much shorter width. Similar groove type chip-breakers are also often provided along the teeth of broaches, for breaking the chips to shorter width and ease of disposal.

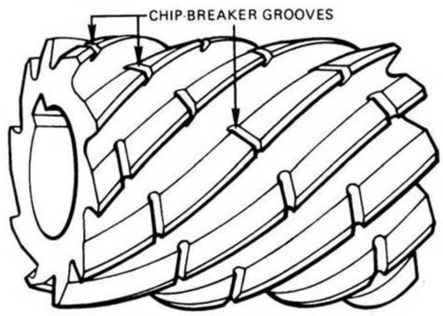


Fig. 1.34 Chip breaking grooves on a plain helical milling cutter

(e) Dynamic chip breaker

Dynamic turning is a special technique, where the cutting tool is deliberately vibrated along the direction of feed *as indicated in Fig. 1.35* at suitable frequency and amplitude. Such additional controlled tool oscillation caused by mechanical, hydraulic or electro-magnetic (solenoid) shaker improves surface finish. This also reduces the cutting forces and enhances the tool life due to more effective cooling and lubrication at the chip tool and work tool interfaces for intermittent break of the tool-work contact. Such technique, if further slightly adjusted, can also help breaking the chips. When the two surfaces of the chip will be waved by phase difference of about 90^0, the chip will either break immediately or will come out in the form of bids, which will also break with slight bending or pressure *as indicated in Fig. 1.35.* This technique of chip breaking can also be accomplished in dynamic drilling and dynamic boring. *Fig. 1.36 schematically shows another possible dynamic chip-breaking device suitable for radially fed type lathe operations, e.g., facing, grooving and parting.*

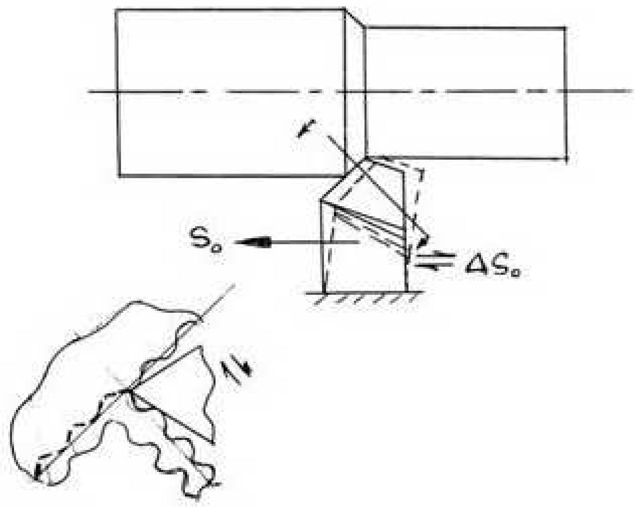


Fig 1.35 Self chip breaking in dynamic turning

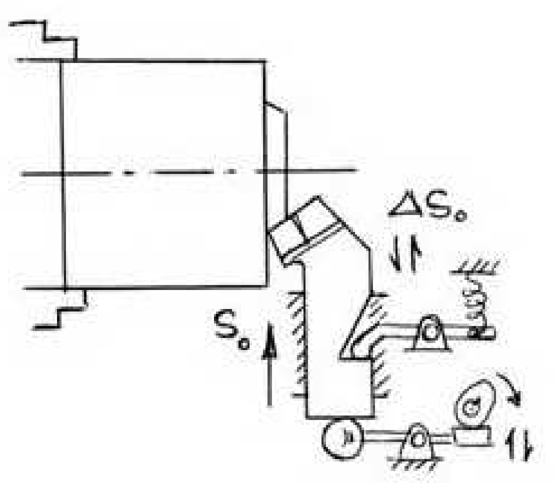


Fig 1.36 Dynamic chip breaking in radial operations in lathe

1.5.5.3 Overall effects of chip breaking

Favorable effects:

- Safety of the operator(s) from the hot, sharp continuous chip flowing out at high speed.
- Convenience of collection and disposal of chips.
- A chance of damage of the finished surface by entangling or rubbing with the chip is eliminated.
- More effective cutting fluid action due to shorter and varying chip tool contact length.

Unfavorable effects:

- Chances of harmful vibration due to frequent chip breaking and hitting at the heel or flank of the tool bit.
- More heat and stress concentration near the sharp cutting edge and hence chances of its rapid failure.
- Surface finish may deteriorate.

1.6 ORTHOGONAL METAL CUTTING

1.6.1 Benefit of knowing and purpose of determining cutting forces

The aspects of the cutting forces concerned:

- Magnitude of the cutting forces and their components.
- Directions and locations of action of those forces.
- Pattern of the forces: static and / or dynamic.

Knowing or determination of the cutting forces facilitate or are required for:

- Estimation of cutting power consumption, which also enables selection of the power source(s) during design of the machine tools.
- Structural design of the machine - fixture - tool system.
- Evaluation of role of the various machining parameters (process - V_C, f_o, t, tool - material and geometry, environment - cutting fluid) on cutting forces.
- Study of behaviour and machinability characterization of the work materials.
- Condition monitoring of the cutting tools and machine tools.

1.6.2 Cutting force components and their significances

The single point cutting tools being used for turning, shaping, planing, slotting, boring etc. are characterized by having only one cutting force during machining. But that force is resolved into two or three components for ease of analysis and exploitation. Fig. 1.37 visualizes how the single cutting force in turning is resolved into three components along the three orthogonal directions; X, Y and Z.

The resolution of the force components in turning can be more conveniently understood from their display in 2-D as shown in Fig. 1.38.

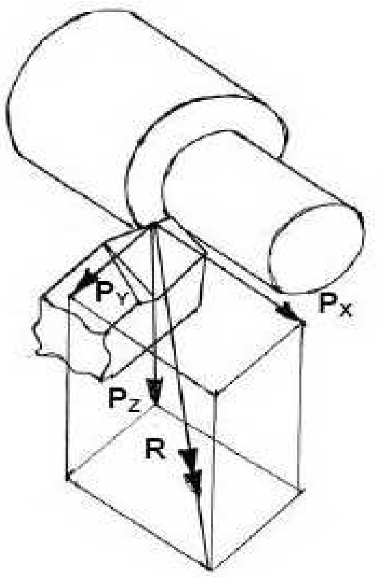


Fig. 1.37 Cutting force R resolved into P_X, P_Y and P_Z

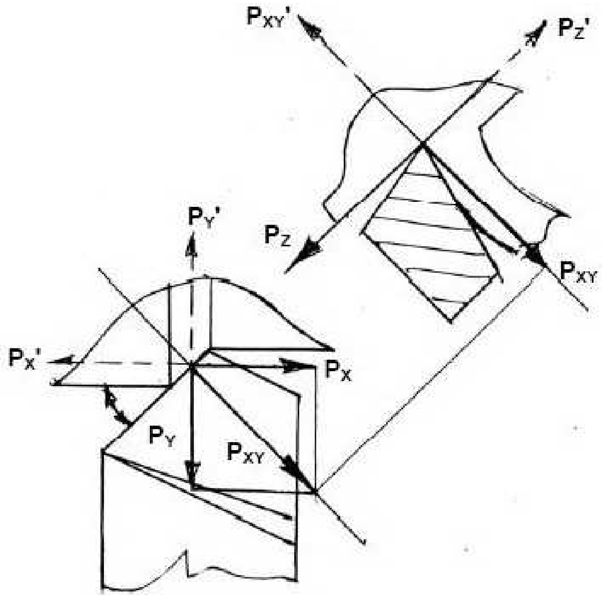


Fig. 1.38 turning force resolved into P_Z, P_X and P_Y

The resultant cutting force, R is resolved as,

$$\mathbf{R = P_Z + P_{XY}} \quad 1.13$$

and $$\mathbf{P_{XY} = P_X + P_Y} \quad 1.14$$

where, $$\mathbf{P_X = P_{XY} \sin\varphi} \quad 1.15$$

and $$\mathbf{P_Y = P_{XY} \cos\varphi} \quad 1.16$$

P_Z - Tangential component taken in the direction of Z_m axis.

P_X - Axial component taken in the direction of longitudinal feed or X_m axis.

P_Y - Radial or transverse component taken along Y_m axis.

In Fig. 1.37 and Fig. 1.38 the force components are shown to be acting on the tool. A similar set of forces also act on the job at the cutting point but in opposite directions *as indicated by P_Z', P_{XY}', P_X' and P_Y' in Fig. 1.38.*

Significance of P_Z, P_X and P_Y

- P_Z: Called the main or major component as it is the largest in magnitude. It is also called power component as it being acting along and being multiplied by V_C decides cutting power ($P_Z.V_C$) consumption.
- P_Y: May not be that large in magnitude but is responsible for causing dimensional inaccuracy and vibration.
- P_X: It, even if larger than PY, is least harmful and hence least significant.

1.6.3 Merchant's Circle Diagram and its use

In orthogonal cutting when the chip flows along the orthogonal plane, π_0, the cutting force (resultant) and its components P_Z and P_{XY} remain in the orthogonal plane. *Fig. 1.39 is schematically showing the forces acting on a piece of continuous chip coming out from the shear zone at a constant speed.* That chip is apparently in a state of equilibrium.

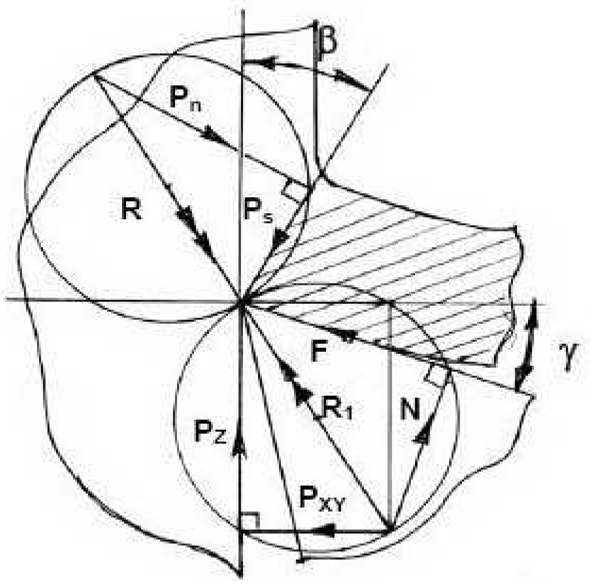


Fig 1.39 Development of Merchant's circle diagram

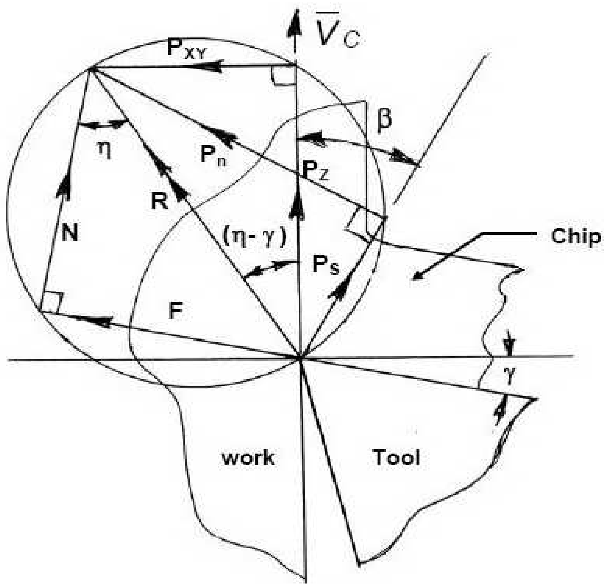


Fig. 1.40 Merchant's Circle Diagram with cutting forces

The forces in the chip segment are:

- From job-side:
  - P_s - Shear force.
  - P_n - force normal to the shear force.
- From the tool side:
  - $R_1 = R$ (in state of equilibrium) where, $R_1 = F + N$
    N - Force normal to rake face.
    F - Friction force at chip tool interface.

The resulting cutting force R or R_1 can be resolved further as,

$R_1 = P_Z + P_{XY}$ where, P_Z - Force along the velocity vector.
P_{XY} - force along orthogonal plane.

The circle(s) drawn taking R or R_1 as diameter is called Merchant's circle which contains all the force components concerned as intercepts. The two circles with their forces are combined into one circle having all the forces contained in that *as shown by the diagram called Merchant's Circle Diagram (MCD) in Fig. 1.40.*

The significance of the forces displayed in the Merchant's Circle Diagram is:

P_s - The shear force essentially required to produce or separate the chip from the parent body by shear.
P_n - Inherently exists along with P_s.
F - Friction force at the chip tool interface.

N - Force acting normal to the rake surface.

$P_Z = P_{XY} – P_X + P_Y$ = main force or power component acting in the direction of cutting velocity.

The magnitude of P_S provides the yield shear strength of the work material under the cutting action. The values of F and the ratio of F and N indicate the nature and degree of interaction like friction at the chip tool interface. The force components P_X, P_Y, P_Z are generally obtained by direct measurement. Again P_Z helps in determining cutting power and specific energy requirement. The force components are also required to design the cutting tool and the machine tool.

1.6.4 Advantageous use of Merchant's circle diagram

Proper use of MCD enables the followings:

- Easy, quick and reasonably accurate determination of several other forces from a few known forces involved in machining.
- Friction at chip tool interface and dynamic yield shear strength can be easily determined.
- Equations relating the different forces are easily developed.

Some limitations of use of MCD:

- Merchant's circle diagram (MCD) is only valid for orthogonal cutting.
- By the ratio, F/N, the MCD gives apparent (not actual) coefficient of friction.
- It is based on single shear plane theory.

1.6.5 Development of equations for estimation of cutting forces

The two basic methods of determination of cutting forces and their characteristics are:

(a) Analytical method: Enables estimation of cutting forces.

Characteristics:

- Easy, quick and inexpensive.
- Very approximate and average.
- Effect of several factors like cutting velocity, cutting fluid action etc. are not revealed.
- Unable to depict the dynamic characteristics of the forces.

(b) Experimental methods: Direct measurement.

Characteristics:

- Quite accurate and provides true picture.
- Can reveal effect of variation of any parameter on the forces.
- Depicts both static and dynamic parts of the forces.
- Needs measuring facilities, expertise and hence expensive.

The equations for analytical estimation of the salient cutting force components are conveniently developed using Merchant's Circle Diagram (MCD) when it is orthogonal cutting by any single point cutting tool like, in turning, shaping, planing, boring etc.

1.6.6 Development of mathematical expressions for cutting forces

Tangential or main component, P_Z

This can be very conveniently done by using Merchant's Circle Diagram, as shown in Fig. 1.40.

From the MCD shown in Fig. 1.40,

$$P_Z = R\cos(\eta – \gamma) \quad 1.17$$

$$P_s = R\cos(\beta + \eta – \gamma) \quad 1.18$$

Dividing Eqn. 1.17 by Eqn. 1.18,

$$P_Z = P_s \cos(\eta – \gamma) / \cos(\beta + \eta – \gamma) \quad 1.19$$

It was already shown that, $P_s = t.f.\, \tau_s / \sin\beta$ 1.20

where, τ_s - Dynamic yield shear strength of the work material.

Thus, $P_Z = t.f.\, \tau_s \cos(\eta – \gamma) / \sin\beta \cos(\beta + \eta – \gamma)$ 1.21

For brittle work materials, like grey cast iron, usually, $2\beta + \eta - \gamma = 90^0$ and τ_s remains almost unchanged.

Then for turning brittle material,

$P_Z = t.f.\ \tau_s \cos(90^0 - 2\beta) / \sin\beta \cos(90^0 - \beta)$ 1.22

or $P_Z = 2\ t.f.\ \tau_s \cot\beta$ 1.23

Where, $\cot\beta = r_c - \tan\gamma$

$r_c = a_2 / a_1 = a_2 / f \sin\varphi$

It is difficult to measure chip thickness and evaluate the values of ζ while machining brittle materials and the value of τ_s is roughly estimated from

$\tau_s = 0.175$ BHN 1.24

where, BHN - Brinnel's Hardness number.

But most of the engineering materials are ductile in nature and even some semi-brittle materials behave ductile under the cutting condition. The angle relationship reasonably accurately applicable for ductile metals is

$\beta + \eta - \gamma = 45^0$ 1.25

and the value of τ_s is obtained from,

$\tau_s = 0.186$ BHN (approximate) 1.26

or $\tau_s = 0.74\sigma_u\varepsilon^{0.6\Delta}$ (more suitable and accurate) 1.27

where, σ_u - Ultimate tensile strength of the work material

ε - Cutting strain, $\varepsilon \cong r_c - \tan\gamma$

Δ - % elongation

Substituting Eqn. 1.25 in Eqn. 1.21,

$P_Z = t.f.\ \tau_s(\cot\beta + 1)$ 1.28

Again $\cot\beta \cong r_c - \tan\gamma$

So, $\mathbf{P_Z = t.f.\tau_s(r_c - \tan\gamma + 1)}$ 1.29

Axial force, P_X and transverse force, P_Y

From the MCD shown in Fig. 1.40,

$P_{XY} = P_Z \tan(\eta - \gamma)$ 1.30

Combining Eqn. 1.21 and Eqn. 1.30,

$P_{XY} = t.f.\tau_s \sin(\eta - \gamma) / \sin\beta \cos(\beta + \eta - \gamma)$ 1.31

Again, using the angle relationship $\beta + \eta - \gamma = 45^0$, for ductile material

$P_{XY} = t.f.\tau_s(\cot\beta - 1)$ 1.32

or $\mathbf{P_{XY} = t.f.\tau_s(r_c - \tan\gamma - 1)}$ 1.33

where, $\tau_s = 0.74\sigma_u\varepsilon^{0.6\Delta}$ or $\tau_s = 0.186$ BHN

It is already known,

$P_X = P_{XY}\sin\varphi$ and $P_Y = P_{XY}\cos\varphi$

Therefore, $\mathbf{P_X = t.f.\tau_s(r_c - \tan\gamma - 1)\sin\varphi}$ 1.34

and $\mathbf{P_Y = t.f.\tau_s(r_c - \tan\gamma - 1)\cos\varphi}$ 1.35

Friction force, F, normal force, N and apparent coefficient of friction μ_a

From the MCD shown in Fig. 1.40,

$F = P_Z \sin\gamma + P_{XY} \cos\gamma$ 1.36

and $N = P_Z \cos\gamma - P_{XY} \sin\gamma$ 1.37

$\mu_a = F / N = P_Z \sin\gamma + P_{XY} \cos\gamma / P_Z \cos\gamma - P_{XY} \sin\gamma$ 1.38

or $\mathbf{\mu_a = P_Z \tan\gamma + P_{XY} / P_Z - P_{XY} \tan\gamma}$ 1.39

Therefore, if P_Z and P_{XY} are known or determined either analytically or experimentally the values of F, N and μ_a can be determined using equations only.

Shear force P_s and P_n

From the MCD shown in Fig. 1.40,

$$\mathbf{P_s = P_Z \cos\beta - P_{XY} \sin\beta} \quad 1.40$$

and $$\mathbf{P_n = P_Z \sin\beta + P_{XY} \cos\beta} \quad 1.41$$

From P_s, the dynamic yield shear strength of the work material, τ_s can be determined by using the relation,

$$\mathbf{P_s = A_s \tau_s}$$

where, A_s = t.f / sinβ = Shear area

Therefore, $\tau_s = P_s \sin\beta / t.f$

$$\mathbf{\tau_s = (P_Z \cos\beta - P_{XY} \sin\beta)\sin\beta / t.f} \quad 1.42$$

1.6.7 Metal cutting theories

1.6.7.1 Earnst - Merchant theory

Earnst and Merchant have developed a relationship between the shear angle β, the cutting rake angle γ, and the angle of friction η as follows:

$\mathbf{2\beta + \eta - \gamma = C}$ where C is a *machining constant* for the work material dependent on the rate of change of the shear strength of the metal with applied compressive stress, besides taking the internal coefficient of friction into account.

1.6.7.2 Modified - Merchant theory

According to this theory the relation between the shear angle β, the cutting rake angle γ, and the angle of friction η as follows:

$$\boldsymbol{\beta = \frac{\pi}{4} - \frac{\eta}{2} + \frac{\gamma}{2}}$$

- Shear will take place in a direction in which energy required for shearing is minimum.
- Shear stress is maximum at the shear plane and it remains constant.

1.6.7.3 Lee and Shaffer's theory

This theory analysis the process of orthogonal metal cutting by applying the theory of plasticity for an ideal rigid plastic material. The principle assumptions are:

- The work piece material ahead of the cutting tool behaves like an ideal plastic material.
- The deformation of the metal occurs on a single shear plane.
- This is a stress field within the produced chip which transmits the cutting force from the shear plane to the tool face and therefore, the chip does not get hardened.
- The chip separates from the parent material at the shear plane.

Based on this, they developed a slip line field for stress zone, in which no deformation would occur even if it is stressed to its yield point. From this, they derived the following relationship.

$$\boldsymbol{\beta = \frac{\pi}{4} - \eta + \gamma}$$

1.6.8 Velocity relationship

The velocity relationships for orthogonal cutting are illustrated in fig. 2.7 where V_C is the cutting velocity, V_s is the velocity of shear and V_f is the velocity of chip flow up the tool face.

$$V_s = V_C \cos\gamma / \cos(\beta - \gamma) \quad 1.43$$

and $$V_f = \sin\beta / \cos(\beta - \gamma) \quad 1.44$$

From equation $V_f = V_C / r_c$

It can be inferred from the principle of kinematics that the relative velocity of two bodies (here tool and the chip) is equal to the vector difference between their velocities relative to the reference body (the workpiece). So, $\mathbf{V_C = V_s + V_f}$ 1.45

1.6.9 Metal removal rate

It is defined as the volume of metal removed in unit time. It is used to calculate the time required to remove specified quantity of material from the work piece.

Metal removal rate (**MRR**) = **t. f.V_C** 1.46

where, t - Depth of cut (mm), f - Feed (mm / rev) and V_C - Cutting speed (mm / sec).

If the MRR is optimum, we can reduce the machining cost. To achieve this:

- The cutting tool material should be proper.
- Cutting tool should be properly ground.
- Tool should be supported rigidly and therefore, there should be any vibration.

For turning operation, **MRR = t.f.V_C** 1.47

For facing and spot milling operation, **MRR = B.t.T** 1.48

where B - Width of cut (mm) and T- Table travel (mm /sec).

For planing and shaping, **MRR = t.f.L.S** 1.49

where L - length of workpiece (mm) and S - Strokes per minute.

1.6.10 Evaluation of cutting power consumption and specific energy requirement

Cutting power consumption is a quite important issue and it should always be tried to be reduced but without sacrificing MRR.

Cutting power consumption **(P_C)** can be determined from, $P_C = P_Z.V_C + P_X.V_f$ 1.50

where, V_f = feed velocity = **Nf / 1000** m/min [N = rpm]

Since both P_X and V_f, specially V_f are very small, $P_X.V_f$ can be neglected and then $P_C \cong P_Z.V_C$ 1.51

Specific energy requirement **(U_s)** which means amount of energy required to remove unit volume of material, is an important machinability characteristics of the work material. Specific energy requirement, U_s, which should be tried to be reduced as far as possible, depends not only on the work material but also the process of the machining, such as turning, drilling, grinding etc. and the machining condition, i.e., V_C, f, tool material and geometry and cutting fluid application.

Compared to turning, drilling requires higher specific energy for the same work-tool materials and grinding requires very large amount of specific energy for adverse cutting edge geometry (large negative rake). Specific energy, U_s, is determined from,

$U_s = P_Z.V_C / MRR = P_Z / t.f$ 1.52

1.7 CUTTING TOOL MATERIALS

1.7.1 Essential properties of cutting tool materials

The cutting tools need to be capable to meet the growing demands for higher productivity and economy as well as to machine the exotic materials which are coming up with the rapid progress in science and technology. *The cutting tool material of the day and future essentially require the following properties to resist or retard the phenomena leading to random or early tool failure:*

- High mechanical strength; compressive, tensile, and TRA.
- Fracture toughness - high or at least adequate.
- High hardness for abrasion resistance.
- High hot hardness to resist plastic deformation and reduce wear rate at elevated temperature.
- Chemical stability or inertness against work material, atmospheric gases and cutting fluids.
- Resistance to adhesion and diffusion.
- Thermal conductivity - low at the surface to resist incoming of heat and high at the core to quickly dissipate the heat entered.
- High heat resistance and stiffness.
- Manufacturability, availability and low cost.

1.7.2 Needs and chronological development of cutting tool materials

With the progress of the industrial world it has been needed to continuously develop and improve the cutting tool materials and geometry:

- To meet the growing demands for high productivity, quality and economy of machining.
- To enable effective and efficient machining of the exotic materials those are coming up with the rapid and vast progress of science and technology.
- For precision and ultra-precision machining.
- For micro and even nano machining demanded by the day and future.

It is already stated that the capability and overall performance of the cutting tools depend upon:

- The cutting tool materials.
- The cutting tool geometry.
- Proper selection and use of those tools.
- The machining conditions and the environments.

Out of which the tool material plays the most vital role. The relative contribution of the cutting tool materials on productivity, for instance, can be roughly assessed from Fig. 1.41.

The chronological development of cutting tool materials is briefly indicated in Fig. 1.42.

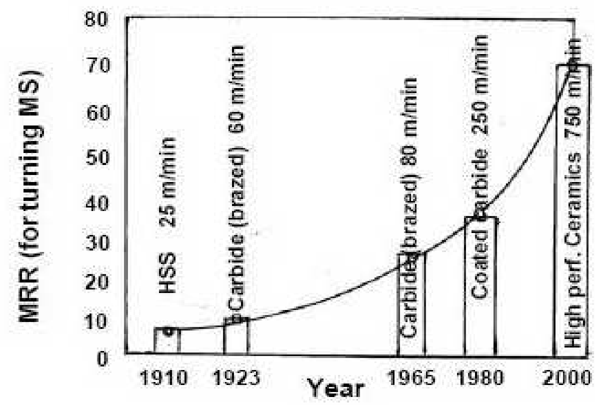


Fig. 1.41 Productivity raised by cutting tool materials

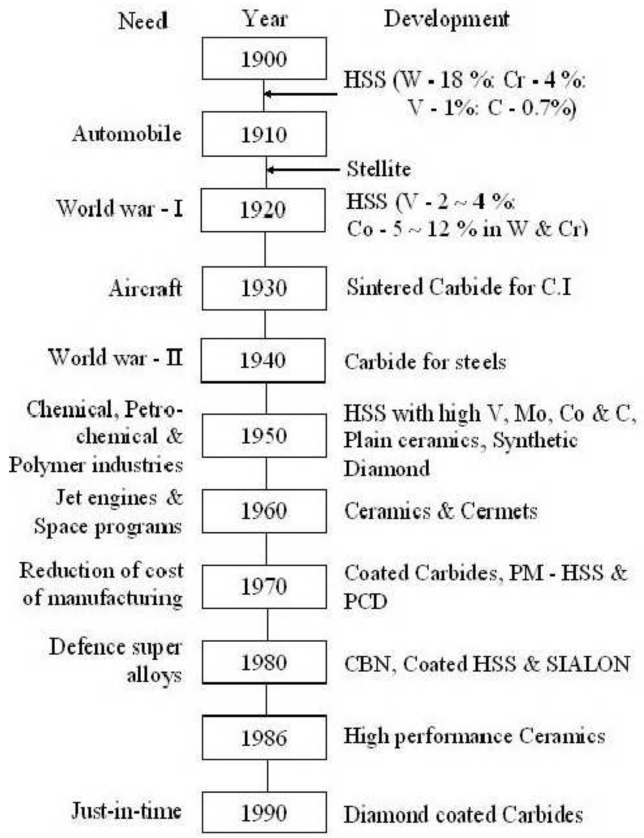


Fig 1.42 Chronological development of cutting tool materials

1.7.3 Characteristics and applications of cutting tool materials

a) High Speed Steel (HSS)

Advent of HSS in around 1905 made a break through at that time in the history of cutting tool materials though got later superseded by many other novel tool materials like cemented carbides and ceramics which could machine much faster than the HSS tools.

The basic composition of HSS is 18% W, 4% Cr, 1% V, 0.7% C and rest Fe. Such HSS tool could machine (turn) mild steel jobs at speed only up to 20 ~ 30 m/min (which was quite substantial those days)

However, HSS is still used as cutting tool material where:

- The tool geometry and mechanics of chip formation are complex, such as helical twist drills, reamers, gear shaping cutters, hobs, form tools, broaches etc.
- Brittle tools like carbides, ceramics etc. are not suitable under shock loading.
- The small scale industries cannot afford costlier tools.
- The old or low powered small machine tools cannot accept high speed and feed.
- The tool is to be used number of times by resharpening.

With time the effectiveness and efficiency of HSS (tools) and their application range were gradually enhanced by improving its properties and surface condition through:

- Refinement of microstructure.
- Addition of large amount of cobalt and Vanadium to increase hot hardness and wear resistance respectively.
- Manufacture by powder metallurgical process.
- Surface coating with heat and wear resistive materials like TiC, TiN, etc. by Chemical Vapour Deposition (CVD) or Physical Vapour Deposition (PVD).

The commonly used grades of HSS are given in Table 1.1.

Table 1.1 Compositions and types of popular high speed steels

Type	C	W	Mo	Cr	V	Co	RC
T - 1	0.70	18		4	1		
T - 4	0.75	18		4	1	5	
T - 6	0.80	20		4	2	12	
M - 2	0.80	6	5	4	2		64.7
M - 4	1.30	6	5	4	4		
M - 15	1.55	6	3	5	5	5	
M - 42	1.08	1.5	9.5	4	1.1	8	62.4

Addition of large amount of Co and V, refinement of microstructure and coating increased strength and wear resistance and thus enhanced productivity and life of the HSS tools remarkably.

b) Stellite

This is a cast alloy of Co (40 to 50%), Cr (27 to 32%), W (14 to 19%) and C (2%). Stellite is quite tough and more heat and wear resistive than the basic HSS (18 - 4 - 1) But such stellite as cutting tool material became obsolete for its poor grindability and especially after the arrival of cemented carbides.

c) Sintered Tungsten carbides

The advent of sintered carbides made another breakthrough in the history of cutting tool materials.

i) Straight or single carbide

First the straight or single carbide tools or inserts were powder metallurgically produced by mixing, compacting and sintering 90 to 95% WC powder with cobalt. The hot, hard and wear resistant WC grains are held by the binder Co which provides the necessary strength and toughness. Such tools are suitable for machining grey cast iron, brass, bronze etc. which produce short discontinuous chips and at cutting velocities two to three times of that possible for HSS tools.

ii) Composite carbides

The single carbide is not suitable for machining steels because of rapid growth of wear, particularly crater wear, by diffusion of Co and carbon from the tool to the chip under the high stress and temperature bulk (plastic) contact between the continuous chip and the tool surfaces.

For machining steels successfully, another type called composite carbide have been developed by adding (8 to 20%) a gamma phase to WC and Co mix. The gamma phase is a mix of TiC, TiN, TaC, NiC etc. which are more diffusion resistant than WC due to their more stability and less wettability by steel.

iii) Mixed carbides

Titanium carbide (TiC) is not only more stable but also much harder than WC. So for machining ferritic steels causing intensive diffusion and adhesion wear a large quantity (5 to 25%) of TiC is added with WC and Co to produce another grade called mixed carbide. But increase in TiC content reduces the toughness of the tools. Therefore, for finishing with light cut but high speed, the harder grades containing up to 25% TiC are used and for heavy roughing work at lower speeds lesser amount (5 to 10%) of TiC is suitable.

Gradation of cemented carbides and their applications

The standards developed by ISO for grouping of carbide tools and their application ranges are given in Table 1.2.

Table 1.2 Broad classifications of carbide tools

ISO Code	Colour Code	Application
P	Sky blue	For machining long chip forming common materials like plain carbon and low alloy steels.
M	Yellow	For machining long or short chip forming ferrous materials like Stainless steel.
K	Red	For machining short chipping, ferrous and non-ferrous material and non-metals like Cast Iron, Brass etc.

K-group is suitable for machining short chip producing ferrous and non-ferrous metals and also some non metals.

P-group is suitably used for machining long chipping ferrous metals i.e. plain carbon and low alloy steels.

M-group is generally recommended for machining more difficult-to-machine materials like strain hardening austenitic steel and manganese steel etc.

Each group again is divided into some subgroups like P10, P20 etc., as shown in Table 1.3 depending upon their properties and applications.

Table 1.3 Detail grouping of cemented carbide tools

ISO App. group	Material	Process
P01	Steel, Steel castings	Precision and finish machining, high speed
P10	Steel, steel castings	Turning, threading and milling high speed, small chips
P20	Steel, steel castings, malleable cast iron	Turning, milling, medium speed with small chip section
P30	Steel, steel castings, malleable cast iron forming long chips	Turning, milling, low cutting speed, large chip section
P40	Steel and steel casting with sand inclusions	Turning, planning, low cutting speed, large chip section
P50	Steel and steel castings of medium or low tensile strength	Operations requiring high toughness turning, planning, shaping at low cutting speeds
K01	Hard grey C.I., chilled casting, Al. alloys with high silicon	Turning, precision turning and boring, milling, scraping
K10	Grey C.I. hardness > 220 HB. Malleable C.I., Al. alloys containing Si	Turning, milling, boring, reaming, broaching, scraping
K20	Grey C.I. hardness up to 220 HB	Turning, milling, broaching, requiring high toughness
K30	Soft grey C.I. Low tensile strength steel	Turning, reaming under favourable conditions
K40	Soft non-ferrous metals	Turning milling etc.
M10	Steel, steel castings, manganese steel, grey C.I.	Turning at medium or high cutting speed, medium chip section
M20	Steel casting, austenitic steel, manganese steel, spherodized C.I., Malleable C.I.	Turning, milling, medium cutting speed and medium chip section
M30	Steel, austenitic steel, spherodized C.I. heat resisting alloys	Turning, milling, planning, medium cutting speed, medium or large chip section
M40	Free cutting steel, low tensile strength steel, brass and light alloy	Turning, profile turning, especially in automatic machines.

The smaller number refers to the operations which need more wear resistance and the larger numbers to those requiring higher toughness for the tool.

d) Plain ceramics

Inherently high compressive strength, chemical stability and hot hardness of the ceramics led to powder metallurgical production of indexable ceramic tool inserts since 1950. *Table 1.4 shows the advantages and limitations of alumina ceramics in contrast to sintered carbide.* Alumina (Al_2O_3) is preferred to silicon nitride (Si_3N_4) for higher hardness and chemical stability. Si_3N_4 is tougher but again more difficult to process. The plain ceramic tools are brittle in nature and hence had limited applications.

Table 1.4 Cutting tool properties of alumina ceramics

Advantages	**Shortcoming**
Very high hardness	Poor toughness
Very high hot hardness	Poor tensile strength
Chemical stability	Poor TRS
Antiwelding	Low thermal conductivity
Less diffusivity	Less density
High abrasion resistance	
High melting point	
Very low thermal conductivity*	
Very low thermal expansion coefficient	

* ***Cutting tool should resist penetration of heat but should disperse the heat throughout the core.***

Basically three types of ceramic tool bits are available in the market:

- Plain alumina with traces of additives - these white or pink sintered inserts are cold pressed and are used mainly for machining cast iron and similar materials at speeds 200 to 250 m/min.
- Alumina; with or without additives - hot pressed, black colour, hard and strong - used for machining steels and cast iron at VC = 150 to 250 m/min.
- Carbide ceramic (Al_2O_3 + 30% TiC) cold or hot pressed, black colour, quite strong and enough tough - used for machining hard cast irons and plain and alloy steels at 150 to 200 m/min.

The plain ceramic outperformed the existing tool materials in some application areas like high speed machining of softer steels mainly for higher hot hardness as indicated in Fig. 1.43.

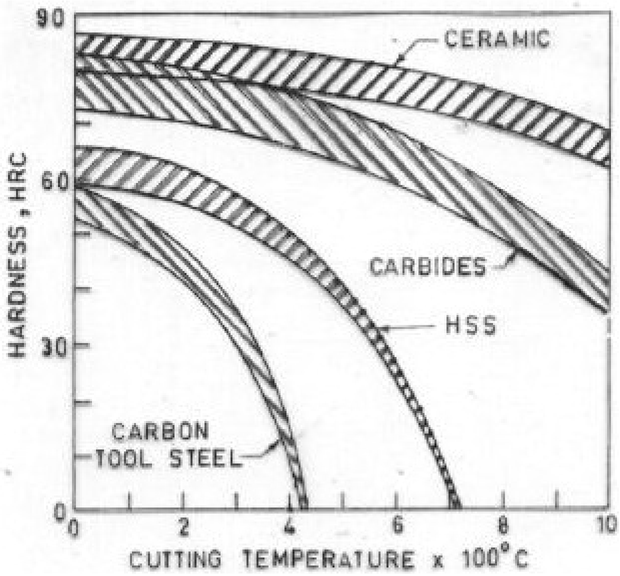


Fig. 1.43 Hot hardness of the different commonly used tool materials (Ref. Book by A. Bhattacharya)

However, the use of those brittle plain ceramic tools, until their strength and toughness could be substantially improved since 1970, gradually decreased for being restricted to:

- Uninterrupted machining of soft cast irons and steels only
- Relatively high cutting velocity but only in a narrow range (200 ~ 300 m/min)
- Requiring very rigid machine tools

Advent of coated carbide capable of machining cast iron and steels at high velocity made the ceramics almost obsolete.

1.7.4 Development and applications of advanced tool materials

a) Coated carbides

The properties and performance of carbide tools could be substantially improved by:

- Refining microstructure.
- Manufacturing by casting - expensive and uncommon.
- Surface coating - made remarkable contribution.

Thin but hard coating of single or multilayer of more stable and heat and wear resistive materials like TiC, TiCN, TiOCN, TiN, Al_2O_3 etc on the tough carbide inserts (substrate) ***(Fig. 1.44)*** by processes like chemical Vapour Deposition (CVD), Physical Vapour Deposition (PVD) etc at controlled pressure and temperature enhanced MRR and overall machining economy remarkably enabling:

- Reduction of cutting forces and power consumption.
- Increase in tool life (by 200 to 500 %) for same V_C or increase in V_C (by 50 to 150 %) for same tool life.
- Improvement in product quality.
- Effective and efficient machining of wide range of work materials.
- Pollution control by less or no use of cutting fluid, *through* -
    - Reduction of abrasion, adhesion and diffusion wear.
    - Reduction of friction and BUE formation.
    - Heat resistance and reduction of thermal cracking and plastic deformation.

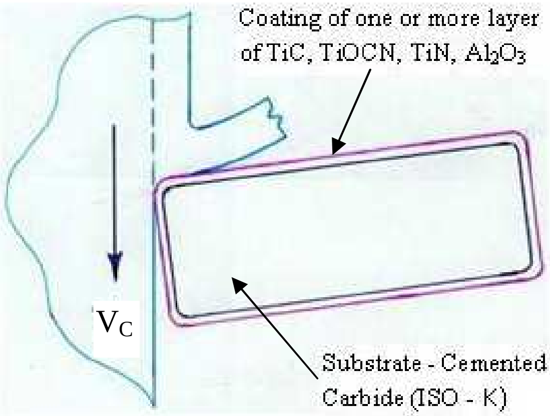


Fig. 1.44 Machining by coated carbide insert.

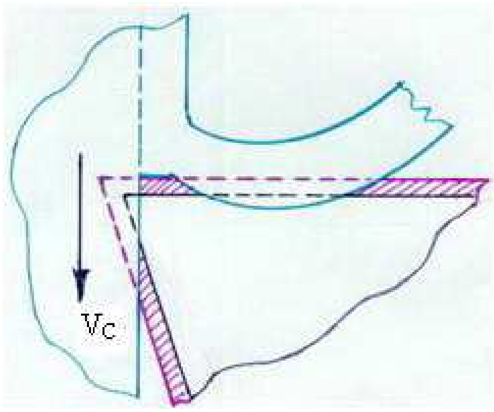


Fig. 1.45 Role of coating even after its wear and rupture

The contribution of the coating continues even after rupture of the coating as indicated in Fig. 1.45.

The cutting velocity range in machining mild steel could be enhanced from 120 ~ 150 m/min to 300 ~ 350 m/min by properly coating the suitable carbide inserts.

About 50% of the carbide tools being used at present are coated carbides which are obviously to some extent costlier than the uncoated tools.

Different varieties of coated tools are available. The appropriate one is selected depending upon the type of the cutting tool, work material and the desired productivity and product quality.

The properties and performances of coated inserts and tools are getting further improved by:

- Refining the microstructure of the coating.
- Multilayering (already up to 13 layers within 12 ~ 16 μm).
- Direct coating by TiN instead of TiC, if feasible.
- Using better coating materials.

b) Cermets

These sintered hard inserts are made by combining ‘cer’ from ceramics like TiC, TiN or TiCN and ‘met’ from metal (binder) like Ni, Ni-Co, Fe etc. Since around 1980, the modern cermets providing much better performance are being made by TiCN which is consistently more wear resistant, less porous and easier to make.

The characteristic features of such cermets, in contrast to sintered tungsten carbides, are:

- The grains are made of TiCN (in place of WC) and Ni or Ni-Co and Fe as binder (in place of Co)
- Harder, more chemically stable and hence more wear resistant.
- More brittle and less thermal shock resistant.
- Wt% of binder metal varies from 10 to 20%.
- Cutting edge sharpness is retained unlike in coated carbide inserts.
- Can machine steels at higher cutting velocity than that used for tungsten carbide, even coated carbides in case of light cuts.

Application wise, the modern TiCN based cermets with beveled or slightly rounded cutting edges are suitable for finishing and semi-finishing of steels at higher speeds, stainless steels but are not suitable for jerky interrupted machining and machining of aluminium and similar materials. Research and development are still going on for further improvement in the properties and performance of cermets.

c) Coronite

It is already mentioned earlier that the properties and performance of HSS tools could have been sizably improved by refinement of microstructure, powder metallurgical process of making and surface coating. Recently a unique tool material, namely Coronite has been developed for making the tools like small and medium size drills and milling cutters etc. which were earlier essentially made of HSS.

Coronite is made basically by combining HSS for strength and toughness and tungsten carbides for heat and wear resistance. Micro fine TiCN particles are uniformly dispersed into the matrix.

Unlike solid carbide, the coronite based tool is made of three layers:

- The central HSS or spring steel core.
- A layer of coronite of thickness around 15% of the tool diameter.
- A thin (2 to 5 μm) PVD coating of TiCN.

Such tools are not only more productive but also provide better product quality. The coronite tools made by hot extrusion followed by PVD-coating of TiN or TiCN outperformed HSS tools in respect of cutting forces, tool life and surface finish.

d) High Performance ceramics (HPC)

Ceramic tools as such are much superior to sintered carbides in respect of hot hardness, chemical stability and resistance to heat and wear but lack in fracture toughness and strength *as indicated in Fig. 1.46.*

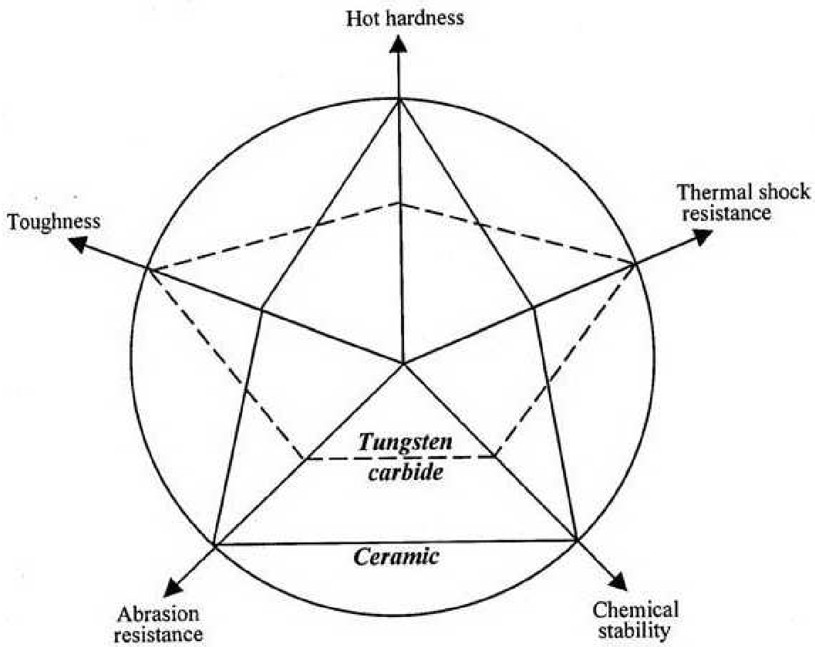


Fig. 1.46 Comparison of important properties of ceramic and tungsten carbide tools

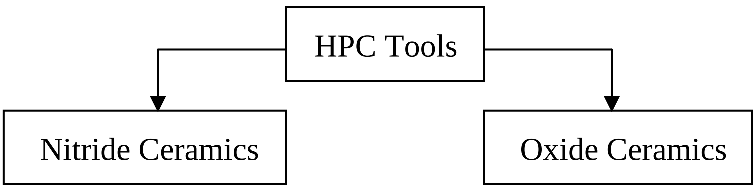
Through last few years' remarkable improvements in strength and toughness and hence overall performance of ceramic tools could have been possible by several means which include:

- Sinterability, microstructure, strength and toughness of Al_2O_3 ceramics were improved to some extent by adding TiO_2 and MgO.
- Transformation toughening by adding appropriate amount of partially or fully stabilized zirconia in Al_2O_3 powder.
- Isostatic and hot isostatic pressing (HIP) - these are very effective but expensive route.
- Introducing nitride ceramic (Si3N4) with proper sintering technique - this material is very tough but prone to built-up-edge formation in machining steels.
- Developing SIALON - deriving beneficial effects of Al_2O_3 and Si_3N_4.
- Adding carbide like TiC (5 ~ 15%) in Al_2O_3 powder - to impart toughness and thermal conductivity.
- Reinforcing oxide or nitride ceramics by SiC whiskers, which enhanced strength, toughness and life of the tool and thus productivity spectacularly. But manufacture and use of this unique tool need especially careful handling.
- Toughening Al_2O_3 ceramic by adding suitable metal like silver which also impart thermal conductivity and self lubricating property; this novel and inexpensive tool is still in experimental stage.

The enhanced qualities of the unique high performance ceramic tools, specially the whisker and zirconia based types enabled them machine structural steels at speed even beyond 500 m/min and also intermittent cutting at reasonably high speeds, feeds and depth of cut. Such tools are also found to machine relatively harder and stronger steels quite effectively and economically.

The successful and commonly used high performance ceramic tools have been discussed here:

The HPC tools can be broadly classified into two groups as:



Silicon Nitride	Alumina toughened by
(i) Plain	(i) Zirconia
(ii) SIALON	(ii) SiC whiskers
(iii) Whisker toughened	(iii) Metal (Silver, etc.)

Nitride based ceramic tools

i) Plain nitride ceramics tools

Compared to plain alumina ceramics, Nitride (Si_3N_4) ceramic tools exhibit more resistance to fracturing by mechanical and thermal shocks due to higher bending strength, toughness and higher conductivity. Hence such tool seems to be more suitable for rough and interrupted cutting of various material excepting steels, which cause rapid diffusion wear and BUE formation. The fracture toughness and wear resistance of nitride ceramic tools could be further increased by adding zirconia and coating the finished tools with high hardness alumina and titanium compound.

Nitride ceramics cannot be easily compacted and sintered to high density. Sintering with the aid of 'reaction bonding' and 'hot pressing' may reduce this problem to some extent.

ii) SIALON tools

Hot pressing and sintering of an appropriate mix of Al_2O_3 and Si_3N_4 powders yielded an excellent composite ceramic tool called SIALON which are very hot hard, quite tough and wear resistant.

These tools can machine steel and cast irons at high speeds (250 - 300 m/min). But machining of steels by such tools at too high speeds reduces the tool life by rapid diffusion.

iii) SiC reinforced Nitride tools

The toughness, strength and thermal conductivity and hence the overall performance of nitride ceramics could be increased remarkably by adding SiC whiskers or fibers in 5 - 25 volume %. The SiC whiskers add fracture toughness mainly through crack bridging, crack deflection and fiber pull-out.

Such tools are very expensive but extremely suitable for high production machining of various soft and hard materials even under interrupted cutting.

iv) Zirconia (or partially stabilized Zirconia) toughened alumina (ZTA) ceramic

The enhanced strength, TRS and toughness have made these ZTAs more widely applicable and more productive than plain ceramics and cermets in machining steels and cast irons. Fine powder of partially stabilized zirconia (PSZ) is mixed in proportion of ten to twenty volume percentage with pure alumina, then either cold pressed and sintered at 1600^0 C - 1700^0 C or hot isostatically pressed (HIP) under suitable temperature and pressure. The phase transformation of metastable tetragonal zirconia (t-Z) to monoclinic zirconia (m-Z) during cooling of the composite (Al_2O_3 + ZrO_2) inserts after sintering or HIP and during polishing and machining imparts the desired strength and fracture toughness through volume expansion (3 - 5%) and induced shear strain (7%). The mechanisms of toughening effect of zirconia in the basic alumina matrix are stress induced transformation toughening *as indicated in Fig. 1.47* and micro crack nucleation toughening.

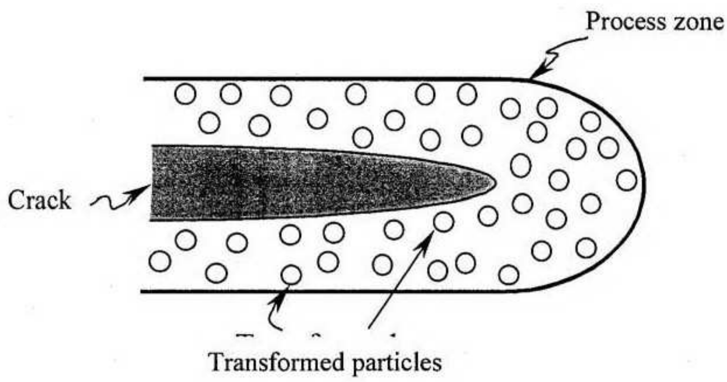


Fig. 1.47 The method of crack shielding by a transformation zone

Their hardness has been raised further by proper control of particle size and sintering process. Hot pressing and HIP raise the density, strength and hot hardness of ZTA tools but the process becomes expensive and the tool performance degrades at lower cutting speeds. However such ceramic tools can machine steel and cast iron at speed range of 150 - 500 m/min.

v) Alumina ceramic reinforced by SiC whiskers

The properties, performances and application range of alumina based ceramic tools have been improved spectacularly through drastic increase in fracture toughness (2.5 times), TRS and bulk thermal conductivity, without sacrificing hardness and wear resistance by mechanically reinforcing the brittle alumina matrix with extremely strong and stiff silicon carbide whiskers. The randomly oriented, strong and thermally conductive whiskers enhance the strength and toughness mainly by crack deflection and crack-bridging and also by reducing the temperature gradient within the tool.

After optimization of the composition, processing and the tool geometry, such tools have been found too effectively and efficiently machine wide range of materials, over wide speed range (250 - 600 m/min) even under large chip loads. But manufacturing of whiskers need very careful handling and precise control and these tools are costlier than zirconia toughened ceramic tools.

vi) Silver toughened alumina ceramic

Toughening of alumina with metal particle became an important topic since 1990 though its possibility was reported in 1950s. Alumina-metal composites have been studied primarily using addition of metals like aluminium, nickel, chromium, molybdenum, iron and silver. Compared to zirconia and carbides, metals were found to provide more toughness in alumina ceramics. Again compared to other metal-toughened ceramics, the silver-toughened ceramics can be manufactured by simpler and more economical process routes like pressureless sintering and without atmosphere control.

All such potential characteristics of silver-toughened alumina ceramic have already been exploited in making some salient parts of automobiles and similar items. Research is going on to develop and use silver-toughened alumina for making cutting tools like turning inserts.. *The toughening of the alumina matrix by the addition of metal occurs mainly by crack deflection and crack bridging by the metal grains as schematically shown in Fig. 1.48.*

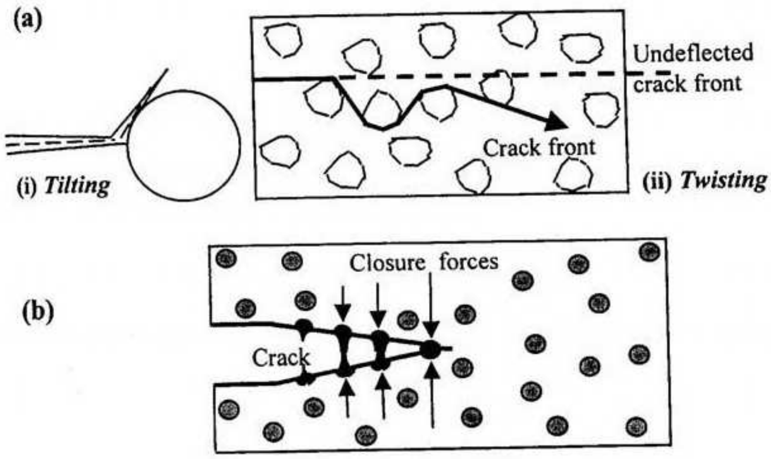


Fig. 1.48 Toughening mechanism of alumina by metal dispersion

Addition of silver further helps by increasing thermal conductivity of the tool and self lubrication by the traces of the silver that oozes out through the pores and reaches at the chip-tool interface. Such HPC tools can suitably machine with large MRR and V_C (250 - 400 m/min) and long tool life even under light interrupted cutting like milling. Such tools also can machine steels at speed from quite low to very high cutting velocities (200 to 500 m/min).

e) Cubic Boron Nitride

Next to diamond, cubic boron nitride is the hardest material presently available. Only in 1970 and onward CBN in the form of compacts has been introduced as cutting tools. It is made by bonding a 0.5 - 1 mm layer of polycrystalline cubic boron nitride to cobalt based carbide substrate at very high temperature and pressure. It remains inert and retains high hardness and fracture toughness at elevated machining speeds. It shows excellent performance in grinding any material of high hardness and strength. The extreme hardness, toughness, chemical and thermal stability and wear resistance led to the development of CBN cutting tool inserts for high material removal rate (MRR) as well as precision machining imparting excellent surface integrity of the products. Such unique tools effectively and beneficially used in machining wide range of work materials covering high carbon and alloy steels, non-ferrous metals and alloys, exotic metals like Ni-hard, Inconel, Nimonic etc and many non-metallic materials which are as such difficult to machine by conventional tools. It is firmly stable at temperatures up to 1400^0 C. The operative speed range for CBN when machining grey cast iron is 300 ~ 400 m/min. *Speed ranges for other materials are as follows:*

- Hard cast iron (> 400 BHN): 80 - 300 m/min.
- Superalloys (> 35 RC): 80 - 140 m/min.
- Hardened steels (> 45 RC): 100 - 300 m/min.

In addition to speed, the most important factor that affects performance of CBN inserts is the preparation of cutting edge. It is best to use CBN tools with a honed or chamfered edge preparation, especially for interrupted cuts. Like ceramics, CBN tools are also available only in the form of indexable inserts. The only limitation of it is its high cost.

(f) Diamond Tools

Single stone, natural or synthetic, diamond crystals are used as tips/edge of cutting tools. Owing to the extreme hardness and sharp edges, natural single crystal is used for many applications, particularly where high accuracy and precision are required. Their important uses are:

- Single point cutting tool tips and small drills for high speed machining of non-ferrous metals, ceramics, plastics, composites, etc. and effective machining of difficult-to-machine materials.
- Drill bits for mining, oil exploration, etc.
- Tool for cutting and drilling in glasses, stones, ceramics, FRPs etc.
- Wire drawing and extrusion dies.
- Superabrasive wheels for critical grinding.

Limited supply, increasing demand, high cost and easy cleavage of natural diamond demanded a more reliable source of diamond. It led to the invention and manufacture of artificial diamond grits by ultra-high temperature and pressure synthesis process, which enables large scale manufacture of diamond with some control over size, shape and friability of the diamond grits as desired for various applications.

i) Polycrystalline Diamond (PCD)

The polycrystalline diamond (PCD) tools consist of a layer (0.5 to 1.5 mm) of fine grain size, randomly oriented diamond particles sintered with a suitable binder (usually cobalt) and then metallurgically bonded to a suitable substrate like cemented carbide or Si_3N_4 inserts. PCD exhibits excellent wear resistance, hold sharp edge, generates little friction in the cut, provide high fracture strength, and had good thermal conductivity. These properties contribute to PCD tooling's long life in conventional and high speed machining of soft, non-ferrous materials (aluminium, magnesium, copper etc), advanced composites and metal-matrix composites, superalloys, and non-metallic materials.

PCD is particularly well suited for abrasive materials (i.e. drilling and reaming metal matrix composites) where it provides 100 times the life of carbides. PCD is not usually recommended for ferrous metals because of high solubility of diamond (carbon) in these materials at elevated temperature. However, they can be used to machine some of these materials under special conditions; for example, light cuts are being successfully made in grey cast iron. The main advantage of such PCD tool is the greater toughness due to finer microstructure with random orientation of the grains and reduced cleavage.

But such unique PCD also suffers from some limitations like:

- High tool cost.
- Presence of binder, cobalt, which reduces wear resistance and thermal stability.
- Complex tool shapes like in-built chip breaker cannot be made.
- Size restriction, particularly in making very small diameter tools.

The above mentioned limitations of polycrystalline diamond tools have been almost overcome by developing Diamond coated tools.

ii) Diamond coated carbide tools

Since the invention of low pressure synthesis of diamond from gaseous phase, continuous effort has been made to use thin film diamond in cutting tool field. These are normally used as thin (<50 μm) or thick (> 200 μm) films of diamond synthesized by CVD method for cutting tools, dies, wear surfaces and even abrasives for Abrasive Jet Machining (AJM) and grinding.

Thin film is directly deposited on the tool surface. Thick film (> 500 μm) is grown on an easy substrate and later brazed to the actual tool substrate and the primary substrate is removed by dissolving it or by other means. Thick film diamond finds application in making inserts, drills, reamers, end mills, routers.

CVD coating has been more popular than single diamond crystal and PCD mainly for:

- Free from binder, higher hardness, resistance to heat and wear more than PCD and properties close to natural diamond.
- Highly pure, dense and free from single crystal cleavage.
- Permits wider range of size and shape of tools and can be deposited on any shape of the tool including rotary tools.
- Relatively less expensive.

However, achieving improved and reliable performance of thin film CVD diamond coated tools; (carbide, nitride, ceramic, SiC etc) in terms of longer tool life, dimensional accuracy and surface finish of jobs essentially need:

- Good bonding of the diamond layer.
- Adequate properties of the film, e.g. wear resistance, micro-hardness, edge coverage, edge sharpness and thickness uniformity.
- Ability to provide work surface finish required for specific applications.

While CBN tools are feasible and viable for high speed machining of hard and strong steels and similar materials, Diamond tools are extremely useful for machining stones, slates, glass, ceramics, composites, FRPs and non ferrous metals specially which are sticky and BUE former such as pure aluminium and its alloys. *CBN and Diamond tools are also essentially used for ultra precision as well as micro and nano machining.*

1.8 TOOL WEAR

1.8.1 Failure of cutting tools

Smooth, safe and economic machining necessitates:

- Prevention of premature and terrible failure of the cutting tools.
- Reduction of rate of wear of tool to prolong its life.

To accomplish the aforesaid objectives one should first know why and how the cutting tools fail. *Cutting tools generally fail by:*

- Mechanical breakage due to excessive forces and shocks. Such kind of tool failure is random and catastrophic in nature and hence is extremely detrimental.
- Quick dulling by plastic deformation due to intensive stresses and temperature. This type of failure also occurs rapidly and is quite detrimental and unwanted.
- Gradual wear of the cutting tool at its flanks and rake surface.

The first two modes of tool failure are very harmful not only for the tool but also for the job and the machine tool. Hence these kinds of tool failure need to be prevented by using suitable tool materials and geometry depending upon the work material and cutting condition.

But failure by gradual wear, which is inevitable, cannot be prevented but can be slowed down only to enhance the service life of the tool. The cutting tool is withdrawn immediately after it fails or, if possible, just before it totally fails. For that one must understand that the tool has failed or is going to fail shortly.

It is understood or considered that the tool has failed or about to fail by one or more of the following conditions:

(a) In R&D laboratories

- Total breakage of the tool or tool tip(s).
- Massive fracture at the cutting edge(s).

- Excessive increase in cutting forces and/or vibration.
- Average wear (flank or crater) reaches its specified limit(s).

(b) In machining industries

- Excessive (beyond limit) current or power consumption.
- Excessive vibration and/or abnormal sound (chatter).
- Total breakage of the tool.
- Dimensional deviation beyond tolerance.
- Rapid worsening of surface finish.
- Adverse chip formation.

1.8.2 Mechanisms and pattern (geometry) of cutting tool wear

For the purpose of controlling tool wear one must understand the various mechanisms of wear that the cutting tool undergoes under different conditions.

The common mechanisms of cutting tool wear are:

(a) Mechanical wear

- Thermally insensitive type; like abrasion, chipping and de-lamination.
- Thermally sensitive type; like adhesion, fracturing, flaking etc.

Flank wear is a flat portion worn behind the cutting edge which eliminates some clearance or relief. It takes place when machining brittle materials. Wear at the tool-chip interface occurs in the form of a depression or crater. It is caused by the pressure of the chip as it slides up the face of the cutting tool. Both flank and crater wear take place when feed is greater than 0.15 mm/rev at low or moderate speeds.

(b) Thermo chemical wear

- Macro-diffusion by mass dissolution.
- Micro-diffusion by atomic migration.

In diffusion wear the material from the tool at its rubbing surfaces, particularly at the rake surface gradually diffuses into the flowing chips either in bulk or atom by atom when the tool material has chemical affinity or solid solubility towards the work material. The rate of such tool wears increases with the increase in temperature at the cutting zone. This wear becomes predominant when the cutting temperature becomes very high due to high cutting velocity and high strength of the work material.

(c) Chemical wear

Chemical wear, leading to damages like grooving wear may occur if the tool material is not enough chemically stable against the work material and/or the atmospheric gases.

(d) Galvanic wear

Galvanic wear, based on electrochemical dissolution, seldom occurs when the work and tool materials are electrically conductive, cutting zone temperature is high and the cutting fluid acts as an electrolyte.

The usual pattern or geometry of wear of face milling inserts, turning tools and turning inserts are typically shown in Fig. 1.49 (a, b, c and d).

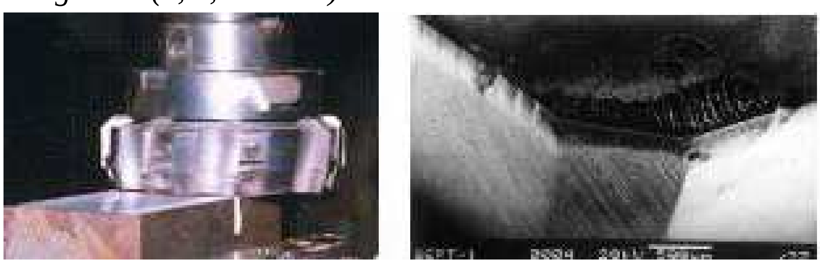


Fig. 1.49 (a) Schematic view of wear pattern of face milling insert

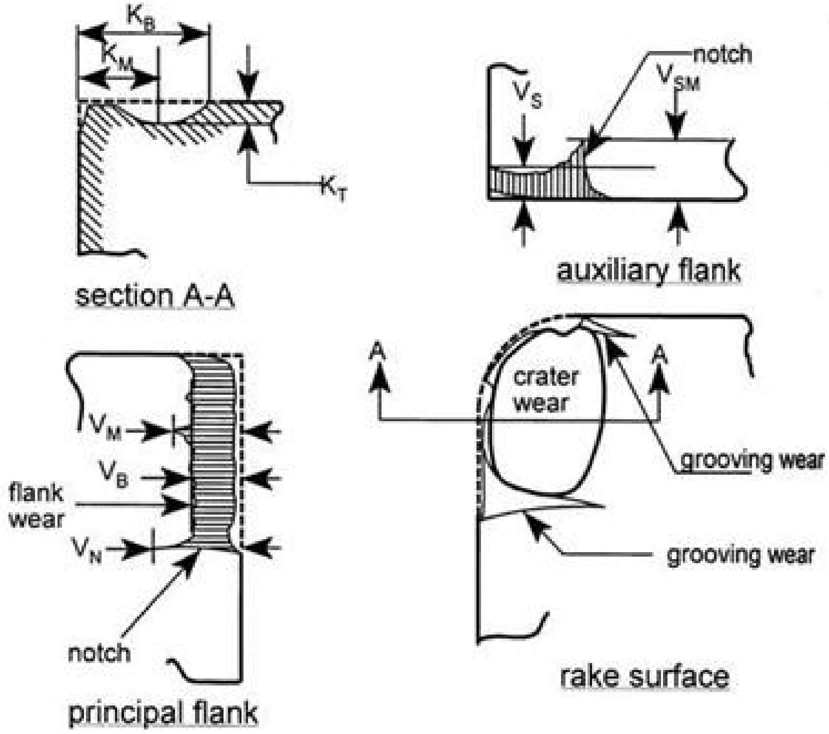


Fig. 1.49 (b) Geometry and major features of wear of turning tools

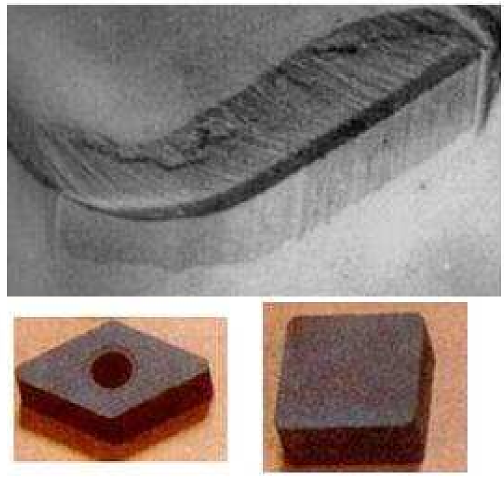


Fig. 1.49 (c) Photographic view of the wear pattern of a turning tool insert

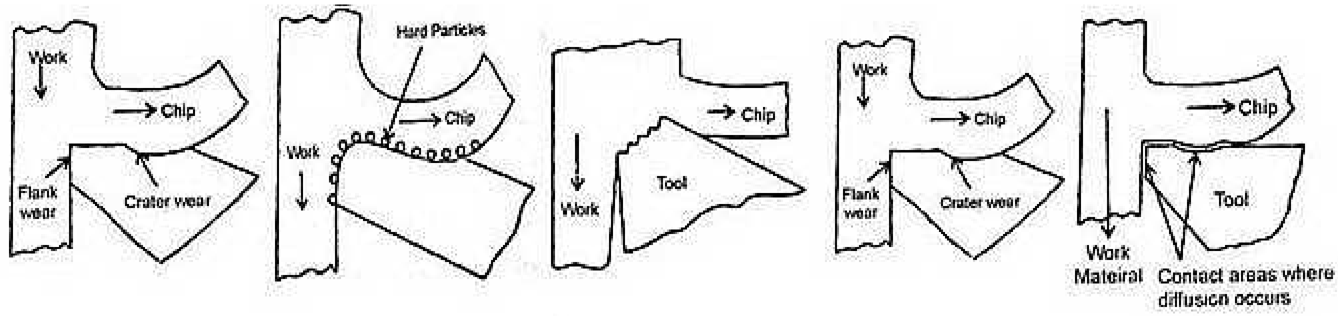


Fig. 1.49 (d) Different types of wears of turning tools

In addition to ultimate failure of the tool, the following effects are also caused by the growing tool-wear:

- Increase in cutting forces and power consumption mainly due to the principal flank wear.
- Increase in dimensional deviation and surface roughness mainly due to wear of the tool-tips and auxiliary flank wear (Vs).
- Odd sound and vibration.
- Worsening surface integrity.
- Mechanically weakening of the tool tip.

1.8.3 Measurement of tool wear

The various methods are:

- By loss of tool material in volume or weight, in one life time - this method is crude and is generally applicable for critical tools like grinding wheels.
- By grooving and indentation method - in this approximate method wear depth is measured indirectly by the difference in length of the groove or the indentation outside and inside the worn area.
- Using optical microscope fitted with micrometer - very common and effective method.
- Using scanning electron microscope (SEM) - used generally, for detailed study; both qualitative and quantitative.
- Talysurf, especially for shallow crater wear.

1.9 TOOL LIFE

Definition:

Tool life generally indicates the amount of satisfactory performance or service rendered by a fresh tool or a cutting point till it is declared failed. *Tool life is defined in two ways:*

(a) In R & D: Actual machining time (period) by which a fresh cutting tool (or point) satisfactorily works after which it needs replacement or reconditioning. The modern tools hardly fail prematurely or abruptly by mechanical breakage or rapid plastic deformation. Those fail mostly by wearing process which systematically grows slowly with machining time. In that case, tool life means the span of actual machining time by which a fresh tool can work before attaining the specified limit of tool wear. Mostly tool life is decided by the machining time till flank wear, V_B reaches 0.3 mm or crater wear, K_T reaches 0.15 mm.

(b) In industries or shop floor: The length of time of satisfactory service or amount of acceptable output provided by a fresh tool prior to it is required to replace or recondition.

Assessment of tool life

For R & D purposes, tool life is always assessed or expressed by span of machining time in minutes, whereas, in industries besides machining time in minutes some other means are also used to assess tool life, depending upon the situation, such as:

- Number of pieces of work machined.
- Total volume of material removed.
- Total length of cut.

1.9.1 Taylor's tool life equation

Wear and hence tool life of any tool for any work material is governed mainly by the level of the machining parameters i.e., cutting velocity (V_C), feed (f) and depth of cut (t). Cutting velocity affects maximum and depth of cut minimum.

The usual pattern of growth of cutting tool wear (mainly V_B), principle of assessing tool life and its dependence on cutting velocity are schematically shown in Fig. 1.50.

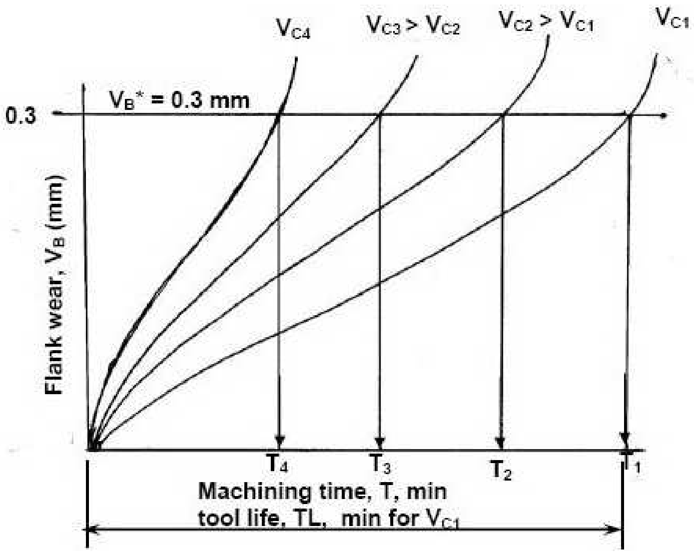


Fig. 1.50 Growth of flank wear and assessment of tool life

The tool life obviously decreases with the increase in cutting velocity keeping other conditions unaltered *as indicated in Fig. 1.51.* If the tool lives, T_1, T_2, T_3, T_4 etc are plotted against the corresponding cutting velocities, V_1, V_2, V_3, V_4 etc *as shown in Fig. 1.51,* a smooth curve like a rectangular hyperbola is found to appear. When F. W. Taylor plotted the same figure taking both V and T in log-scale, a more distinct linear relationship appeared *as schematically shown in Fig. 1.52.*

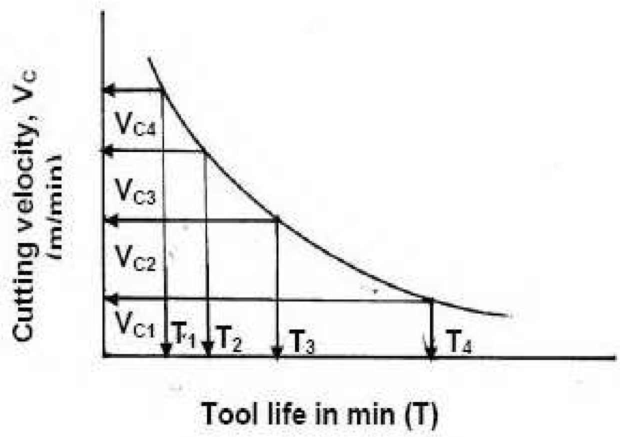


Fig. 1.51 Cutting velocity - tool life relationship

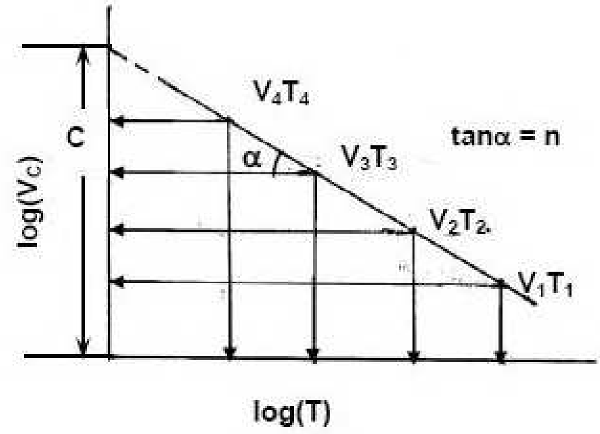


Fig. 1.52 Cutting velocity - tool life on a log-log scale

With the slope, n and intercept, c, Taylor derived the simple equation as,

$$\mathbf{V_C T^n = C} \qquad 1.53$$

where, n is called, Taylor's tool life exponent. The values of both 'n' and 'c' depend mainly upon the tool-work materials and the cutting environment (cutting fluid application). The value of C depends also on the limiting value of V_B undertaken (i.e., 0.3 mm, 0.4 mm, 0.6 mm etc.).

1.9.2 Modified Taylor's tool life equation

In Taylor's tool life equation, only the effect of variation of cutting velocity, V_C on tool life has been considered. But practically, the variation in feed (f) and depth of cut (t) also play role on tool life to some extent. Taking into account the effects of all those parameters, the Taylor's tool life equation has been modified as,

$$\mathbf{T = C_T / V_C^x . f^y . t^z} \qquad 1.54$$

where, T = tool life in minutes, C_T – a constant depending mainly upon the tool - work materials and the limiting value of V_B undertaken. x, y and z – exponents so called tool life exponents depending upon the tool - work materials and the machining environment. Generally, x > y > z as V_C affects tool life maximum and t minimum. The values of the constants, C_T, x, y and z are available in Machining Data Handbooks or can be evaluated by machining tests.

1.9.3 Effect of tool geometry on tool life

The tool life is also affected by tool geometry. The nose radius (R) tends to improve tool life and is evident from the relation: $\mathbf{V_C T^{0.0927} = 331\ R^{0.244}}$ 1.55

1.9.4 Effect of side cutting edge angle on tool life

The side cutting edge angle (φ_s) may improve tool life under non-chatter conditions:

$$\mathbf{V_C T^{0.11} = 78\ (\varphi_s + 15^0)^{0.264}} \qquad 1.56$$

1.9.5 Tool life in terms of metal removal

The volume of metal removal from the work piece between tool sharpening for definite depth of cut, feed and cutting speed can be determined as follows. For example in case of turning:

Cutting speed $V_C = \pi DN / 1000$ m/min 1.57

where D - Diameter of work piece (mm).

N - Rotation speed of work piece (rpm).

Let t - Depth of cut (mm).

f - Feed rate (mm/min).

t_{tf} - Time of tool failure (min).

T - Tool life in 1 mm^3 of metal removal.

Volume of metal removed per revolution = $\pi.D.t.f\ mm^3$ 1.58

Volume of metal removed per minute = $\pi.D.t.f.N\ mm^3$ 1.59

Volume of metal removed in 't_{tf}' minute = $\pi.D.t.f.N.t_{tf}\ mm^3$ 1.60

Therefore, Volume of metal removed between tool grinds = $\pi.D.t.f.N.t_{tf}\ mm^3$ 1.61

$T = \pi.D.t.f.N.t_{tf}\ mm^3 = 1000.V_C.t.f.t_{tf}\ mm^3$ 1.62

$\mathbf{T = V_C.t.f.t_{tf}\ cm^3}$ 1.63

1.9.6 Factors affecting tool life

The life of the cutting tool is affected by the following factors:

- Cutting speed.
- Feed and depth of cut.
- Tool geometry.
- Tool material.
- Cutting fluid.
- Work piece material.
- Rigidity of work, tool and machine.

1.9.7 Machinability

1.9.7.1 Concept, definition and criteria of judgement of machinability

The term; 'Machinability' has been introduced for gradation of work materials with respect to machining characteristics. But truly speaking, there is no unique or clear meaning of the term machinability. *People tried to describe "Machinability" in several ways such as:*

- It is generally applied to the machining properties of work material.
- It refers to material (work) response to machining.
- It is the ability of the work material to be machined.
- It indicates how easily and fast a material can be machined.

But it has been agreed, in general, that it is difficult to clearly define and quantify Machinability. *For instance, saying 'material A is more machinable than material B' may mean that compared to 'B':*

- 'A' causes lesser tool wear or longer tool life.
- 'A' requires lesser cutting forces and power.
- 'A' provides better surface finish.

Attempts were made to measure or quantify machinability and it was done mostly in terms of:

- Tool life which substantially influences productivity and economy in machining.
- Magnitude of cutting forces which affects power consumption and dimensional accuracy.
- Surface finish which plays role on performance and service life of the product.

Often cutting temperature and chip form are also considered for assessing machinability.

$$\textit{Machinability rating (MR)} = \frac{speed(fpm) of machining\ the\ work\ giving\ 60\ minute\ tool\ life}{speed(fpm) of machining\ the\ standard\ metal\ giving\ 60\ minute\ tool\ life}\ x\ 100 \qquad 1.64$$

The free cutting steel, AISI - 1112, when machined (turned) at 100 fpm, provided 60 min of tool life. If the work material to be tested provides 60 min of tool life at cutting velocity of 60 fpm (say), as indicated in Fig. 1.53, under the same set of machining condition, then machinability (rating) of that material would be,

MR = $\frac{60}{100}\ x\ 100 = 60\ \%$ or simply 60 (based on 100% for the standard material) or, simply the value of the cutting velocity expressed in fpm at which a work material provides 60 min tool life was directly considered as the MR of that work material. In this way the MR of some materials, for instance, were evaluated as,

Metal	MR
Ni	200
Br	300
Al	200
CI	70
Inconel	30

But usefulness and reliability of such practice faced several genuine doubts and questions:

- Tool life cannot or should not be considered as the only criteria for judging machinability.
- Under a given condition a material can yield different tool life even at a fixed speed (cutting velocity); exact composition, microstructure, treatments etc. of that material may cause significant difference in tool life.
- The tool life - speed relationship of any material may substantially change with the variation in:
    - Material and geometry of the cutting tool.
    - Level of process parameters (Vc, f, t).
    - Machining environment (cutting fluid application).
    - Machine tool condition.

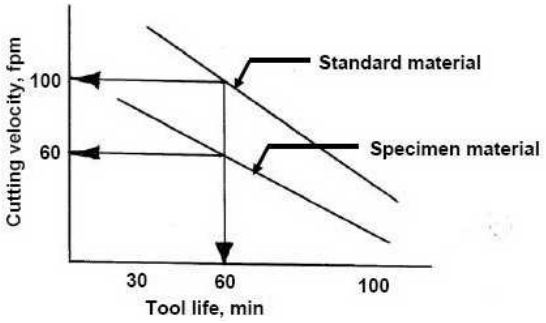


Fig. 1.53 Machinability rating in terms of cutting velocity giving 60 min tool life

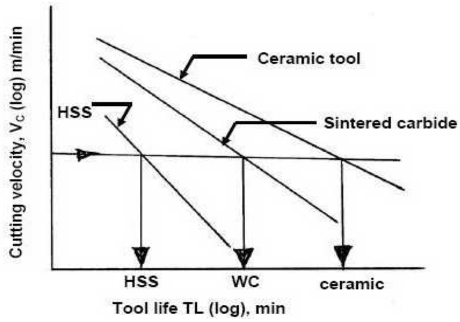


Fig. 1.54 Role of cutting tool material on machinability (tool life)

Keeping all such factors and limitations in view, ***Machinability can be tentatively defined as "ability of being machined" and more reasonably as "ease of machining".***

Such ease of machining or machinability characteristics of any tool-work pair is to be judged by:

- Magnitude of the cutting forces.
- Tool wear or tool life.
- Surface finish.
- Magnitude of cutting temperature.
- Chip forms.

Machinability will be considered desirably high when cutting forces, temperature, surface roughness and tool wear are less, tool life is long and chips are ideally uniform and short enabling short chip-tool contact length and less friction.

1.9.7.2 Role of the properties of the work material on machinability

The work material properties that generally govern machinability in varying extent are:

- The basic nature - brittleness or ductility etc.
- Microstructure.
- Mechanical strength - fracture or yield.
- Hardness and hot hardness, hot strength.
- Work hardenability.
- Thermal conductivity.
- Chemical reactivity.
- Stickiness / self lubricity.

1.10 SURFACE FINISH

Generally, surface finish of any product depends on the following factors:

- Cutting speed.
- Feed.
- Depth of cut.

Cutting speed

Better surface finish can be obtained at higher cutting speeds. Rough cutting takes place at lower cutting speeds.

Feed

Surface finish will not be good when coarse feed is applied. But better finish can be obtained in fine feeds.

Depth of cut

Lighter cuts provide good surface finish to the work piece. If depth of cut increases during machining, the quality of surface finish will reduce.

Therefore, higher cutting speeds, fine feeds and low depth of cuts or applied to ensure good surface finish. Usually, it is done in finishing cuts. But, lower cutting speeds, coarse feeds and heavier depth of cuts are applied in rough cutting operations.

1.11 CUTTING FLUIDS

1.11.1 Purposes and application of cutting fluid

The basic purposes of cutting fluid application are:

- Cooling of the job and the tool to reduce the detrimental effects of cutting temperature on the job and the tool.
- Lubrication at the chip - tool interface and the tool flanks to reduce cutting forces and friction and thus the amount of heat generation.
- Cleaning the machining zone by washing away the chip - particles and debris which, if present, spoils the finished surface and accelerates damage of the cutting edges.
- Protection of the nascent finished surface - a thin layer of the cutting fluid sticks to the machined surface and thus prevents its harmful contamination by the gases like SO_2, O_2, H_2S, and N_XO_Y present in the atmosphere.

However, the main aim of application of cutting fluid is to improve machinability through reduction of cutting forces and temperature, improvement by surface integrity and enhancement of tool life.

1.11.2 Essential properties of cutting fluids

To enable the cutting fluid fulfill its functional requirements without harming the Machine - Fixture - Tool - Work (M-F-T-W) system and the operators, the cutting fluid should possess the following properties:

- *For cooling:*
  - High specific heat, thermal conductivity and film coefficient for heat transfer.
  - Spreading and wetting ability.
- *For lubrication:*
  - High lubricity without gumming and foaming.
  - Wetting and spreading.
  - High film boiling point.
  - Friction reduction at extreme pressure (EP) and temperature.

- Chemical stability, non-corrosive to the materials of the M-F-T-W system.
- Less volatile and high flash point.
- High resistance to bacterial growth.
- Odourless and also preferably colourless.
- Non toxic in both liquid and gaseous stage.
- Easily available and low cost.

1.11.3 Principles of cutting fluid action

The chip-tool contact zone is usually comprised of two parts; *plastic or bulk contact zone and elastic contact zone as indicated in Fig. 1.55.*

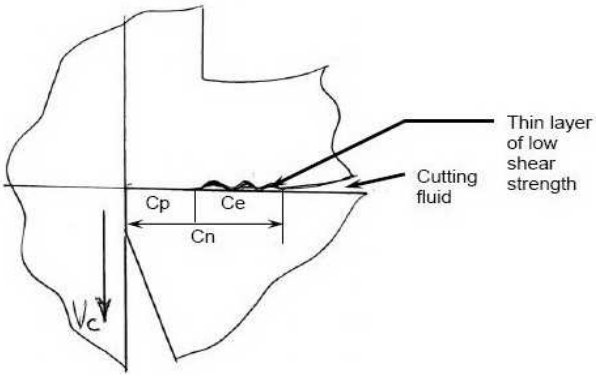


Fig. 1.55 Cutting fluid action in machining

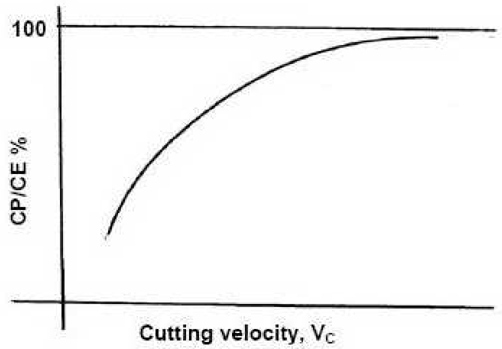


Fig. 1.56 Apportionment of plastic and elastic contact zone with increase in cutting velocity

The cutting fluid cannot penetrate or reach the plastic contact zone but enters in the elastic contact zone by capillary effect. With the increase in cutting velocity, the fraction of plastic contact zone gradually increases and covers almost the entire chip-tool contact zone *as indicated in Fig. 1.56.* Therefore, at high speed machining, the cutting fluid becomes unable to lubricate and cools the tool and the job only by bulk external cooling.

The chemicals like chloride, phosphate or sulphide present in the cutting fluid chemically reacts with the work material at the chip under surface under high pressure and temperature and forms a thin layer of the reaction product. The low shear strength of that reaction layer helps in reducing friction.

To form such solid lubricating layer under high pressure and temperature some extreme pressure additive (EPA) is deliberately added in reasonable amount in the mineral oil or soluble oil.

For extreme pressure, chloride, phosphate or sulphide type EPA is used depending upon the working temperature, i.e. moderate (200^0 C ~ 350^0 C), high (350^0 C ~ 500^0 C) and very high (500^0 C ~ 800^0 C) respectively.

1.11.4 Types of cutting fluids and their application

Generally, cutting fluids are employed in liquid form but occasionally also employed in gaseous form. Only for lubricating purpose, often solid lubricants are also employed in machining and grinding.

The cutting fluids, which are commonly used, are:

Air blast or compressed air only

Machining of some materials like grey cast iron become inconvenient or difficult if any cutting fluid is employed in liquid form. In such case only air blast is recommended for cooling and cleaning.

Solid or semi-solid lubricant

Paste, waxes, soaps, graphite, Moly-disulphide (MoS_2) may also often be used, either applied directly to the workpiece or as an impregnant in the tool to reduce friction and thus cutting forces, temperature and tool wear.

Water

For its good wetting and spreading properties and very high specific heat, water is considered as the best coolant and hence employed where cooling is most urgent.

Soluble oil

Water acts as the best coolant but does not lubricate. Besides, use of only water may impair the machine-fixture-tool-work system by rusting. So oil containing some emulsifying agent and additive like EPA, together called cutting compound, is mixed with water in a suitable ratio (1 ~ 2 in 20 ~ 50).

This milk like white emulsion, called soluble oil, is very common and widely used in machining and grinding.

Cutting oils

Cutting oils are generally compounds of mineral oil to which are added desired type and amount of vegetable, animal or marine oils for improving spreading, wetting and lubricating properties. As and when required some EP additive is also mixed to reduce friction, adhesion and BUE formation in heavy cuts.

Chemical fluids

These are occasionally used fluids which are water based where some organic and or inorganic materials are dissolved in water to enable desired cutting fluid action.

There are two types of such cutting fluid:

- *Chemically inactive type* - high cooling, anti-rusting and wetting but less lubricating.
- *Active (surface) type* - moderate cooling and lubricating.

Cryogenic cutting fluid

Extremely cold (cryogenic) fluids (often in the form of gases) like liquid CO_2 or N_2 are used in some special cases for effective cooling without creating much environmental pollution and health hazards.

1.11.5 Methods of application of cutting fluid

The effectiveness and expense of cutting fluid application significantly depend also on how it is applied in respect of flow rate and direction of application. *In machining, depending upon the requirement and facilities available, cutting fluids are generally employed in the following ways (flow):*

- Drop-by-drop under gravity.
- Flood under gravity.
- In the form of liquid jet(s).
- Mist (atomized oil) with compressed air.
- Z-Z method - centrifugal through the grinding wheels (pores) *as indicated in Fig. 1.57.*

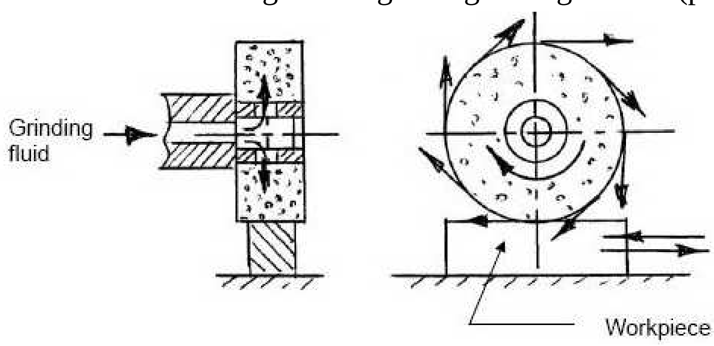


Fig 1.57 Z-Z method of cutting fluid application in grinding

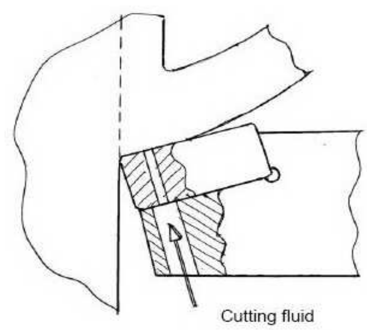


Fig. 1.58 Application of cutting fluid at high pressure through the hole in the tool

The direction of application also significantly governs the effectiveness of the cutting fluid in respect of reaching at or near the chip-tool and work-tool interfaces. Depending upon the requirement and accessibility the cutting fluid is applied from top or side(s). In operations like deep hole drilling the pressurized fluid is often sent through the axial or inner spiral hole(s) of the drill.

For effective cooling and lubrication in high speed machining of ductile metals having wide and plastic chip-tool contact, cutting fluid may be pushed at high pressure to the chip-tool interface through hole(s) in the cutting tool*, as schematically shown in Fig. 1.58.*

1.11.6 Selection of cutting fluid

The benefits of application of cutting fluid largely depend upon proper selection of the type of the cutting fluid depending upon the work material, tool material and the machining condition. As for example, for high speed machining of not-difficult-to-machine materials greater cooling type fluids are preferred and for low speed machining of both conventional and difficult-to-machine materials greater lubricating type fluid is preferred.

Selection of cutting fluids for machining some common engineering materials and operations are presented as follows:

Grey cast iron:

- Generally dry for its self lubricating property.
- Air blast for cooling and flushing chips.
- Soluble oil for cooling and flushing chips in high speed machining and grinding.

Steels:

- If machined by HSS tools, sol. Oil (1: 20 ~30) for low carbon and alloy steels and neat oil with EPA for heavy cuts.
- If machined by carbide tools thinner sol. Oil for low strength steel, thicker sol. Oil (1:10 ~ 20) for stronger steels and straight sulphurised oil for heavy and low speed cuts and EP cutting oil for high alloy steel.
- Often steels are machined dry by carbide tools for preventing thermal shocks.

Aluminium and its alloys:

- Preferably machined dry.
- Light but oily soluble oil.
- Straight neat oil or kerosene oil for stringent cuts.

Copper and its alloys:

- Water based fluids are generally used.
- Oil with or without inactive EPA for tougher grades of Cu-alloy.

Stainless steels and Heat resistant alloys:

- High performance soluble oil or neat oil with high concentration with chlorinated EP additive.

The brittle ceramics and cermets should be used either under dry condition or light neat oil in case of fine finishing.

Grinding at high speed needs cooling (1: 50 ~ 100) soluble oil. For finish grinding of metals and alloys low viscosity neat oil is also used.

UNIT - II

CENTRE LATHE AND SPECIAL PURPOSE LATHES

2.1 CENTRE LATHE

Lathe is the oldest machine tool invented, starting with the Egyptian tree lathes. It is the father of all machine tools. Its main function is to remove material from a work piece to produce the required shape and size. This is accomplished by holding the work piece securely and rigidly on the machine and then turning it against the cutting tool which will remove material from the work piece in the form of chips. It is used to machine cylindrical parts. Generally single point cutting tool is used. In the year 1797 Henry Maudslay, an Englishman, designed the first screw cutting lathe which is the forerunner of the present day high speed, heavy duty production lathe.

2.1.1 Classification of lathes

Lathes are very versatile of wide use and are classified according to several aspects:

According to configuration:

- Horizontal - Most common for ergonomic conveniences.
- Vertical - Occupies less floor space, only some large lathes are of this type.

According to purpose of use:

- General purpose - Very versatile where almost all possible types of operations are carried out on wide ranges of size, shape and materials of jobs; e.g.: centre lathes.
- Single purpose - Only one (occasionally two) type of operation is done on limited ranges of size and material of jobs; e.g.: facing lathe, roll turning lathe etc.
- Special purpose - Where a definite number and type of operations are done repeatedly over long time on a specific type of blank; e.g.: capstan lathe, turret lathe, gear blanking lathe etc.

According to size or capacity:

- Small (low duty) - In such light duty lathes (up to 1.1 kW), only small and medium size jobs of generally soft and easily machinable materials are machined.
- Medium (medium duty) - These lathes of power nearly up to 11 kW are most versatile and commonly used.
- Large (heavy duty)
- Mini or micro lathe - These are tiny table-top lathes used for extremely small size jobs and precision work; e.g.: Swiss type automatic lathe.

According to configuration of the jobs being handled:

- Bar type - Slender rod like jobs being held in collets.
- Chucking type - Disc type jobs being held in chucks.
- Housing type - Odd shape jobs, being held in face plate.

According to precision:

- Ordinary
- Precision (lathes) - These sophisticated lathes meant for high accuracy and finish and are relatively more expensive.

According to number of spindles:

- Single spindle - Common.
- Multi-spindle (2, 4, 6 or 8 spindles) - Such uncommon lathes are suitably used for fast and mass production of small size and simple shaped jobs.

According to type of automation:

- Fixed automation - Conventional; e.g.: single spindle automat & Swiss type automatic lathe
- Flexible automation - Modern; e.g.: CNC lathe, turning centre etc.

According to degree of automation:

- Non-automatic - Almost all the handling operations are done manually; e.g.: centre lathes.
- Semi-automatic - Nearly half of the handling operations, irrespective of the processing operations, are done automatically and rest manually; e.g.: copying lathe, relieving lathe etc.
- Automatic - Almost all the handling operations (and obviously all the processing operations) are done automatically; e.g.: single spindle automat, Swiss type automatic lathe, etc.

2.2 CONSTRUCTIONAL FEATURES

2.2.1 Major parts of a centre lathe

Amongst the various types of lathes, centre lathes are the most versatile and commonly used. *Fig. 2.1 shows the basic configuration of a center lathe.* The major parts are:

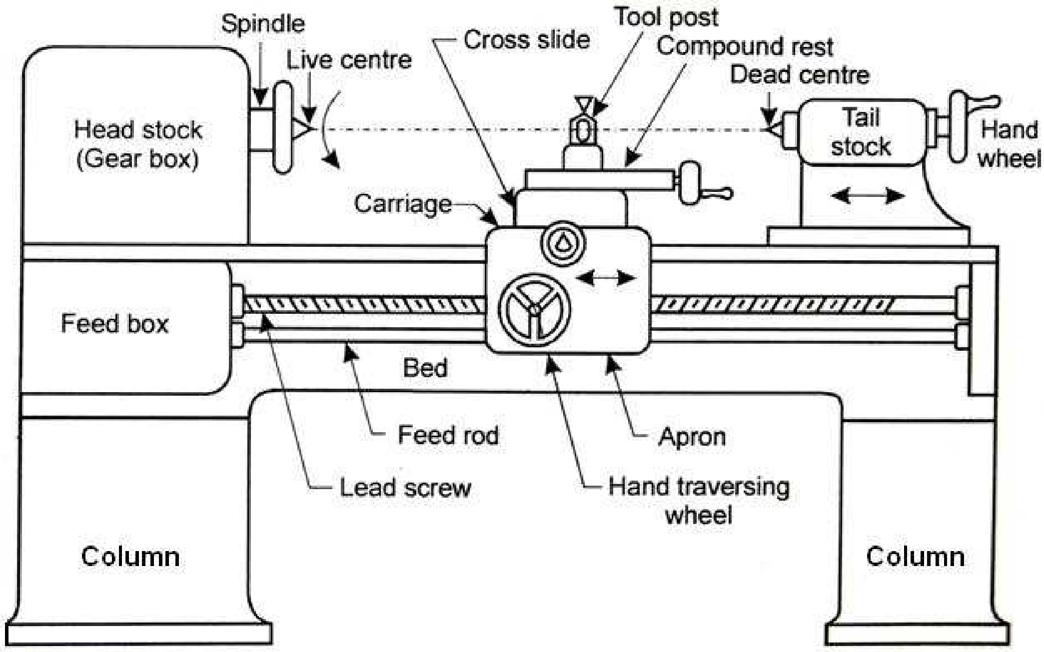


Fig. 2.1 Schematic view of a center lathe

Headstock It holds the spindle and through that power and rotation are transmitted to the job at different speeds. Various work holding attachments such as three jaw chucks, collets, and centres can be held in the spindle. The spindle is driven by an electric motor through a system of belt drives and gear trains. Spindle rotational speed is controlled by varying the geometry of the drive train.

Tailstock The tailstock can be used to support the end of the work piece with a center, to support longer blanks or to hold tools for drilling, reaming, threading, or cutting tapers. It can be adjusted in position along the ways to accommodate different length work pieces. The tailstock barrel can be fed along the axis of rotation with the tailstock hand wheel.

Bed Headstock is fixed and tailstock is clamped on it. Tailstock has a provision to slide and facilitate operations at different locations. The bed is fixed on columns and the carriage travels on it.

Carriage It is supported on the lathe bed-ways and can move in a direction parallel to the lathe axis. The carriage is used for giving various movements to the tool by hand and by power. It carries saddle, cross-slide, compound rest, tool post and apron.

Saddle It carries the cross slide, compound rest and tool post. It is an H-shaped casting fitted over the bed. It moves alone to guide ways.

Cross-slide It carries the compound rest and tool post. It is mounted on the top of the saddle. It can be moved by hand or may be given power feed through apron mechanism.

Compound rest It is mounted on the cross slide. It carries a circular base called swivel plate which is graduated in degrees. It is used during taper turning to set the tool for angular cuts. The upper part known as compound slide can be moved by means of a hand wheel.

Tool post It is fitted over the compound rest. The tool is clamped in it.

Apron Lower part of the carriage is termed as the apron. It is attached to the saddle and hangs in front of the bed. It contains gears, clutches and levers for moving the carriage by a hand wheel or power feed.

Feed mechanism The movement of the tool relative to the work piece is termed as "feed". The lathe tool can be given three types of feed, namely, longitudinal, cross and angular.

When the tool moves parallel to the axis of the lathe, the movement is called longitudinal feed. This is achieved by moving the carriage.

When the tool moves perpendicular to the axis of the lathe, the movement is called cross feed. This is achieved by moving the cross slide.

When the tool moves at an angle to the axis of the lathe, the movement is called angular feed. This is achieved by moving the compound slide, after swiveling it at an angle to the lathe axis.

Feed rod The feed rod is a long shaft, used to move the carriage or cross-slide for turning, facing, boring and all other operations except thread cutting. Power is transmitted from the lathe spindle to the apron gears through the feed rod via a large number of gears.

Lead screw The lead screw is long threaded shaft used as a master screw and brought into operation only when threads have to cut. In all other times the lead screw is disengaged from the gear box and remains stationary. The rotation of the lead screw is used to traverse the tool along the work to produce screw. The half nut makes the carriage to engage or disengage the lead screw.

2.2.2 Kinematic system and working principle of a centre lathe

Fig. 2.2 schematically shows the kinematic system of a 12 speed centre lathe.

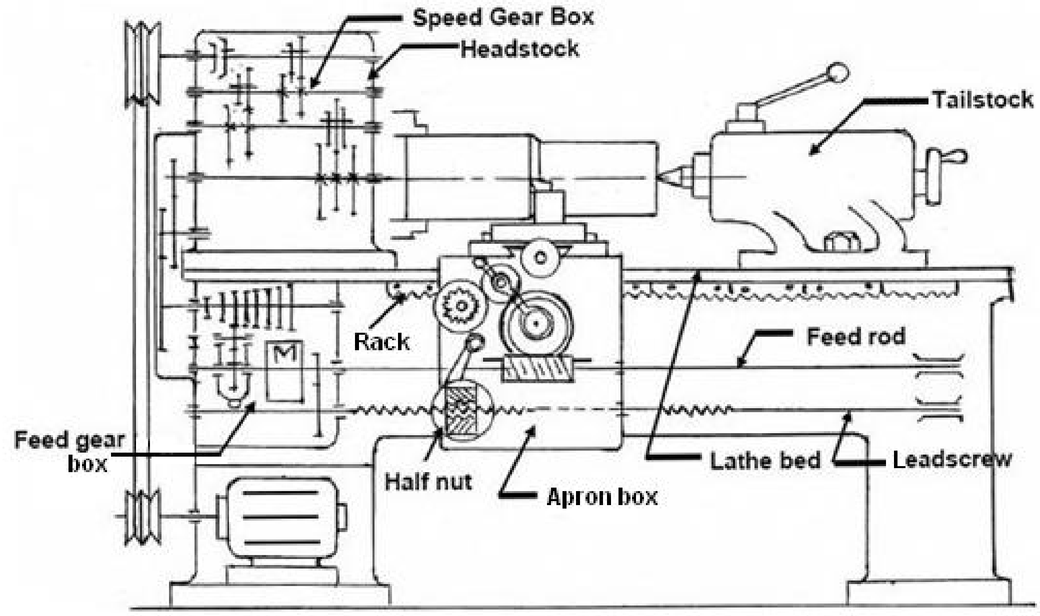


Fig. 2.2 Kinematic system of a 12 speed centre lathe

For machining in machine tools the job and the cutting tool need to be moved relative to each other. ***The tool-work motions are:***

- Formative motions: - cutting motion, feed motion.
- Auxiliary motions: - indexing motion, relieving motion.

In lathes: Cutting motion is attained by rotating the job and feed motion is attained by linear travel of the tool either axially for longitudinal feed or radially for cross feed.

It is noted, in general, from Fig. 2.2. The job gets rotation (and power) from the motor through the belt-pulley, clutch and then the speed gear box which splits the input speed into a number (here 12) of speeds by operating the cluster gears.

The cutting tool derives its automatic feed motion(s) from the rotation of the spindle via the gear quadrant, feed gear box and then the apron mechanism where the rotation of the feed rod is transmitted:

- Either to the pinion which being rolled along the rack provides the longitudinal feed.
- Or to the screw of the cross slide for cross or transverse feed.

While cutting screw threads the half nuts are engaged with the rotating lead screw to positively cause travel of the carriage and hence the tool parallel to the lathe bed i.e., job axis.

The feed-rate for both turning and threading is varied as needed by operating the Norton gear and the Meander drive systems existing in the feed gear box (FGB). The range of feeds can be augmented by changing the gear ratio in the gear quadrant connecting the FGB with the spindle.

As and when required, the tailstock is shifted along the lathe bed by operating the clamping bolt and the tailstock quill is moved forward or backward or is kept locked in the desired location. *The versatility or working range of the centre lathes is augmented by using several special attachments.*

2.2.3 Headstock driving mechanisms

There are two types of headstock driving mechanisms as follows:

1. Back geared headstock.
2. All geared headstock.

2.2.3.1 Back geared headstock

Back gear arrangement is used for reducing the spindle speed, which is necessary for thread cutting and knurling. *The back gear arrangement is shown in Fig.2.3.*

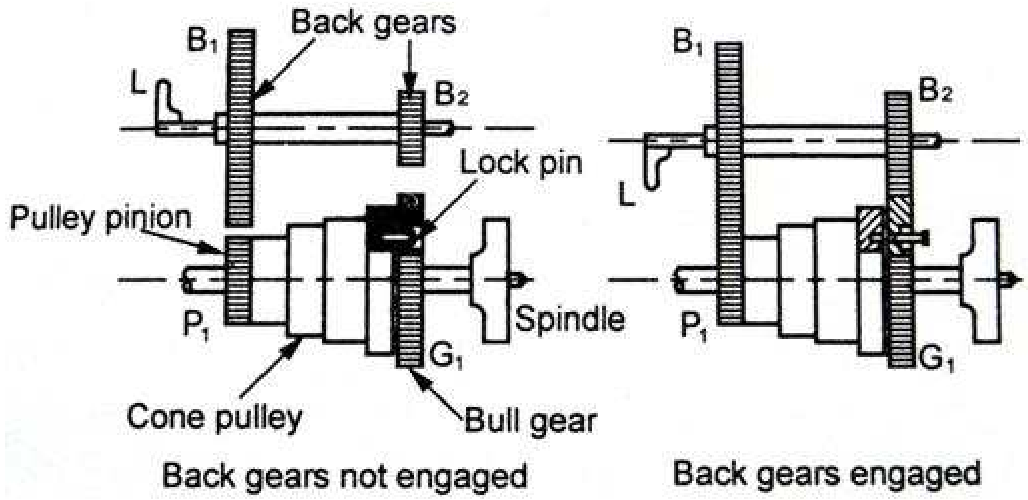


Fig. 2.3 Back gear arrangement

There is one stepped cone pulley in the lathe spindle. This pulley can freely rotate on the spindle. A pinion gear P_1 is connected to small end of the cone pulley. P_1 will rotate when cone pulley rotates. Bull gear G_1 is keyed to lathe spindle such that the spindle will rotate when Gear G_1 rotates. Speed changes can be obtained by changing the flat belt on the steps. A bull gear G_1 may be locked or unlocked with this cone pulley by a lock pin.

There are two back gears B_1 and B_2 on a back shaft. It is operated by means of hand lever L; back gears B_1 and B_2 can be engaged or disengaged with G_1 and P_1. For getting direct speed, back gear is not engaged. The step cone pulley is locked with the main spindle by using the lock pin. The flat belt is changed for different steps. Thus three or four ranges of speed can be obtained directly.

For getting slow or indirect speeds, back gear is engaged by lever L and lock pin is disengaged. Now, power will flow from P_1 to B_1. B_1 to B_2 (same shaft), B_2 to G_1 to spindle. As gear B_1 is larger than P_1, the speed will further be reduced at B_1. B_1 and B_2 will have the same speeds. The speed will further be reduced at G_1 because gear G_1 is larger than B_2. So, the speed of spindle is reduced by engaging the back gear.

2.2.3.2 All geared headstock

All geared headstock is commonly used in modern lathes because of the following advantages:

- It gives wider range of spindle speeds.
- It is more efficient and compact than cone pulley mechanism.
- Power available at the tool is almost constant for all spindle speeds.
- Belt shifting is eliminated.
- The vibration of the spindle is reduced.
- More power can be transmitted.

The all geared headstock is shown in Fig 2.4.

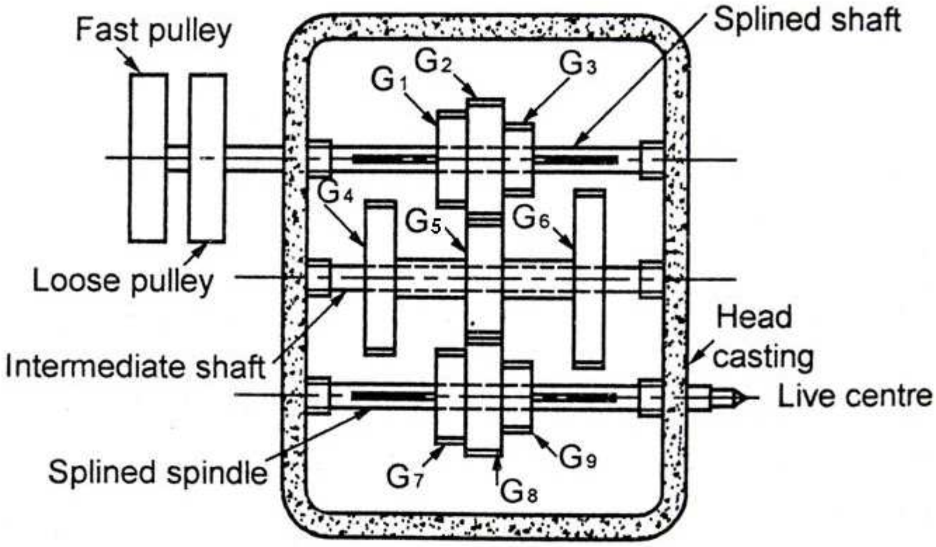


Fig. 2.4 All geared headstock

The power from the constant speed motor is delivered to the spindle through a belt drive. Speed changing is made by levers. The different spindle speeds are obtained by shifting the levers into different positions to obtain different gear combinations. This mechanism has a splined spindle, intermediate shaft and a splined shaft. The splined shaft receives power from motor through a belt drive.

This shaft has 3 gears namely G_1, G_2 and G_3. These gears can be shifted with the help of lever along the shaft. Gears G_4, G_5 and G_6 are mounted on intermediate shaft and cannot be moved axially. Gears G_7, G_8 and G_9 are mounted on splined headstock spindle and can be moved axially be levers. Gears G_1, G_2 and G_3 can be meshed with the gears G_4, G_5 and G_6 individually. Similarly, gears G_7, G_8, G_9 can be meshed with gear G_4, G_5 and G_6 individually. Thus, it provides nine different speeds.

2.2.4 Feed mechanisms

The feed mechanism is used to transmit power from the spindle to the carriage. Therefore, it converts rotary motion of the spindle into linear motion of the carriage. The feed can be given either by hand or automatically. For automatic feeding, the following feed mechanisms are used:

- Tumbler gear reversing mechanism.
- Quick-change gearbox.
- Tumbler gear quick-change gearbox.
- Apron mechanism.
- Bevel gear feed reversing mechanism.

2.2.4.1 Tumbler gear reversing mechanism

Tumbler gear mechanism is used to change the direction of lead screw and feed rod. By engaging tumbler gear, the carriage can be moved along the lathe axis in either direction during thread cutting or automatic machining. *Fig. 2.5 shows the schematic arrangement of tumbler gear reversing mechanism.*

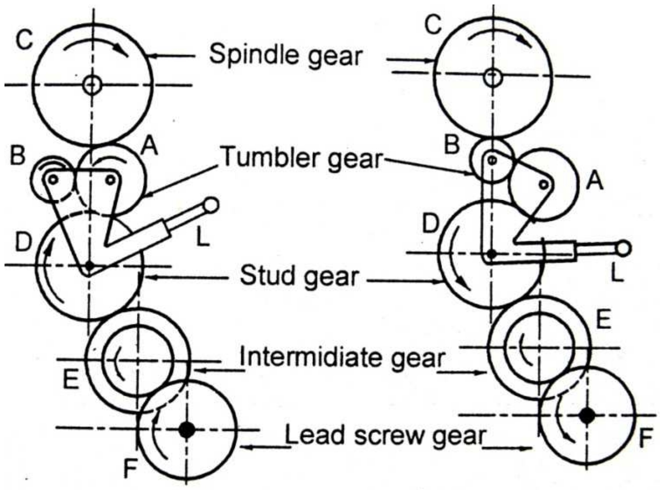


Fig. 2.5 Tumbler gear reversing mechanism

The tumbler gear unit has two pinions (A and B) of same size and is mounted on a bracket. The bracket is pivoted at a point and can be moved up and down by a lever L. The bracket may be placed in three positions i.e., upward, downward and neutral. Gear 'C' is a spindle gear attached to the lathe spindle. Gear 'D' is the stud gear. The stud gear is connected to the lead screw gear through a set of intermediate gears.

When the lever is shifted upward position, the gear 'A' is engaged with spindle gear 'C' and the power is transmitted through C-A-D-E-F. During this position, lead screw will rotate in the same direction as spindle rotates (i.e. both anticlockwise). Now, the carriage moves towards the headstock. When the lever is shifted downward, the gear 'B' is engaged with spindle gear 'C' and the power is transmitted through C-B-A-D-E-F. Hence, the lead screw will rotate in the opposite direction of the spindle. Now, the carriage moves towards tailstock.

When the bracket is in neutral position, the engagement of tumbler gears is disconnected with the spindle gear. Hence, there is no power transmission to lead screw.

2.2.4.2 Quick-change gear box

Quick-change gearbox is used to get various power feeds in the lathe. *Fig. 2.6 shows the schematic arrangement of quick-change gear box.*

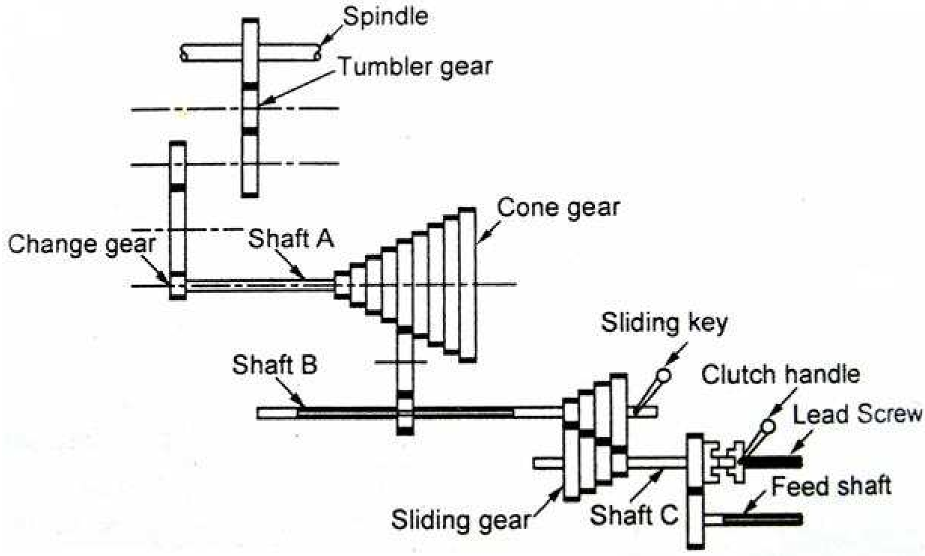


Fig. 2.6 quick-change gear box

Power from the lathe spindle is transmitted to feed shaft through tumbler gear, change gear train and quick-change gearbox. Shaft A (Cone gear shaft) contains 9 different sizes of gears keyed with it. Shaft B (Sliding gear shaft) has a gear and it receives 9 different speeds from shaft A by the use of sliding gear. Shaft B is connected to shaft C (Driven shaft) through 4 cone years. Therefore, Shaft C can get 9 X 4 = 36 different speeds. The shaft C is connected to lead screw by a clutch and feed rod by a gear train. Lead screw is used for thread cutting and feed rod is used for automatic feeds.

2.2.4.3 Tumbler gear quick-change gear box

The different speed of the driving shaft is obtained by a tumbler gear and cone gear arrangement. *Fig. 2.7 shows the schematic arrangement of tumbler gear quick-change gear box.*

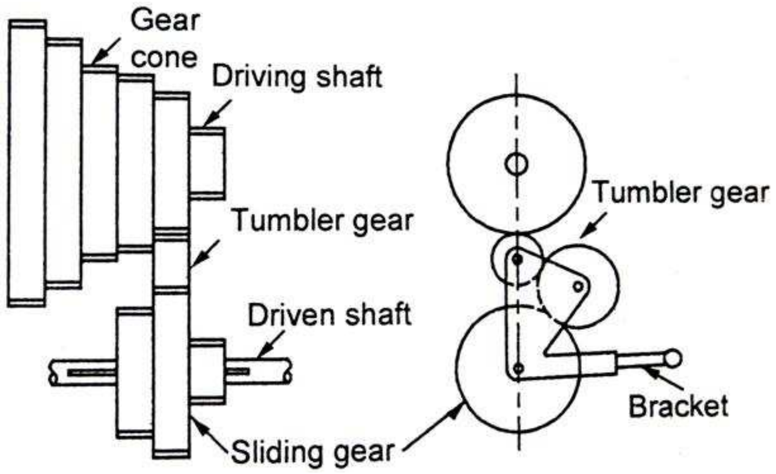


Fig. 2.7 Tumbler gear quick-change gearbox

It is simpler than quick-change gearbox. A tumbler gear and a sliding gear are attached to the bracket as shown in Fig. 2.7. Driving shaft has a cone gear made up of different sizes of gears. The sliding gear is keyed to the driven shaft which is connected by the lead screw or feed rod. The sliding gear can be made to slide and engaged at any desired position. By sliding the sliding gear to various positions and engaging the tumbler gear, various speeds can be obtained.

2.2.4.4 Apron mechanism

Fig. 2.8 shows the schematic arrangement of apron mechanism.

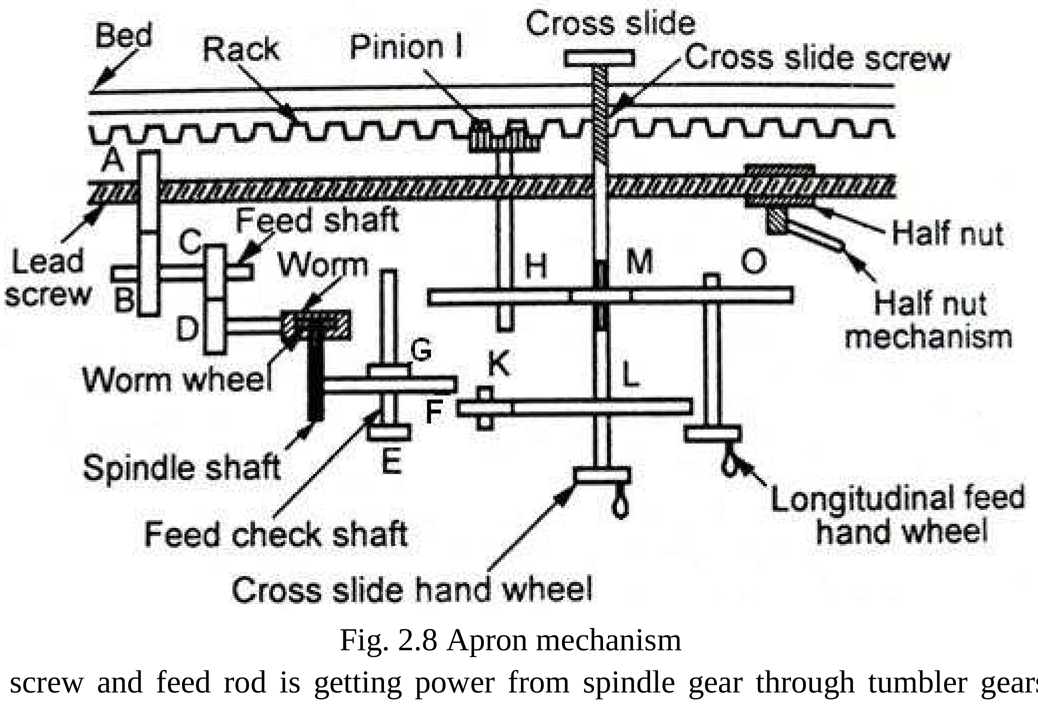


Fig. 2.8 Apron mechanism

Lead screw and feed rod is getting power from spindle gear through tumbler gears. Power is transmitted from feed rod to the worm wheel through gears A, B, C, D and worm.

A splined shaft is attached with worm wheel. The splined shaft is always engaged with the gears F and G which are keyed to the feed check shaft. A knob 'E' is fitted with feed check shaft. Feed check knob 'E' can be placed in three positions such as neutral, push-in and pull-out.

When the feed check knob 'E' is in neutral position, power is not transmitted either to cross feed screw or to the carriage since gears F and G have no connection with H and K. Therefore, hand feed is given as follows. When the longitudinal feed hand wheel rotates, pinion I will also be rotated through I and H. pinion I will move on rack for taking longitudinal feed. For getting cross feed, cross slide screw will be rotated by using cross slide hand wheel.

When the feed check knob 'E' is push-in, rotating gear G will be engaged to H. then the power will be transmitted to pinion I. pinion I will rotate on rack. So, automatic longitudinal feed takes place. When the feed check knob 'E' is pulled-out, the rotating gear F will be engaged to K. Hence, the power will be transmitted to cross feed screws through L. This leads to automatic cross feed.

For thread cutting, half nut is engaged by half nut lever after putting knob 'E' neutral position. Half nut is firmly attached with the carriage. As the lead screw rotates, the carriage will automatically move along the axis of the lathe. Both longitudinal and cross feed can be reversed by operating the tumbler gear mechanism.

2.2.4.5 Bevel gear feed reversing mechanism

The tumbler gear mechanism being a non-rigid construction cannot be used in a modern heavy duty lathe. The clutch operated bevel gear feed reversing mechanism incorporated below the head stock or in apron provides sufficient rigidity in construction. *Fig. 2.9 shows the schematic arrangement of bevel gear feed reversing mechanism.*

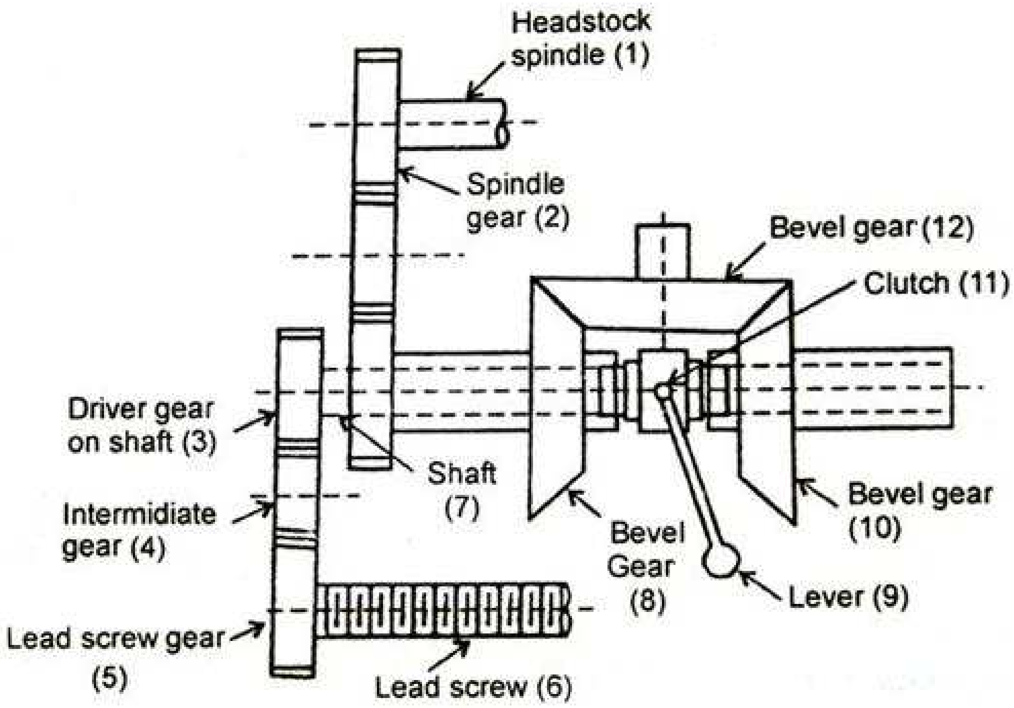


Fig. 2.9 Bevel gear feed reversing mechanism

The motion is communicated from the spindle gear 2 to the gear on the stud shaft through the intermediate gear. The bevel gear 8 is attached to the gear on the stud shaft and both of them can freely rotate on shaft 7. The bevel gear 8 meshes with bevel gear 12 and 12 mesh with 10. 12, 10 and 8 are having equal number of teeth. The bevel gear 10 can also rotate freely on shaft 7.

A clutch 11 is keyed to the shaft 7 by a feather key and may be shifted to left or right, by the lever 9 to be engaged with the gear 8 or 10 or it remains in the neutral position. When the clutch engages with bevel gear 8, gear 3 which is keyed to the shaft 7 and the lead screw, rotates in the same direction as the gear 2. The direction of rotation is reversed when the clutch 11 engages with gear 10.

2.2.5 Mounting of jobs in centre lathe

2.2.5.1 Without additional support from the tailstock

Chucks - 3 jaw self centering chuck or universal chuck and 4 jaw independent chuck

Fig. 2.10 (a and b) visualizes 3-jaw and 4-jaw chucks which are mounted at the spindle nose and firmly hold the job in centre lathes. Premachined round bars are quickly and coaxially mounted by simultaneously moving the three jaws radially by rotating the scroll (disc with radial threads) by a key *as can be seen in the diagram 2.10 (a)*

The four jaw chucks, available in varying sizes, are generally used for essentially more strongly holding non-circular bars like square, rectangular, hexagonal and even odder sectional jobs in addition to cylindrical bars, both with and without premachining at the gripping portion. The jaws are moved radially independently by rotating the corresponding screws which push the rack provided on the back side of each jaw *as can be seen in the diagram 2.10 (b).*

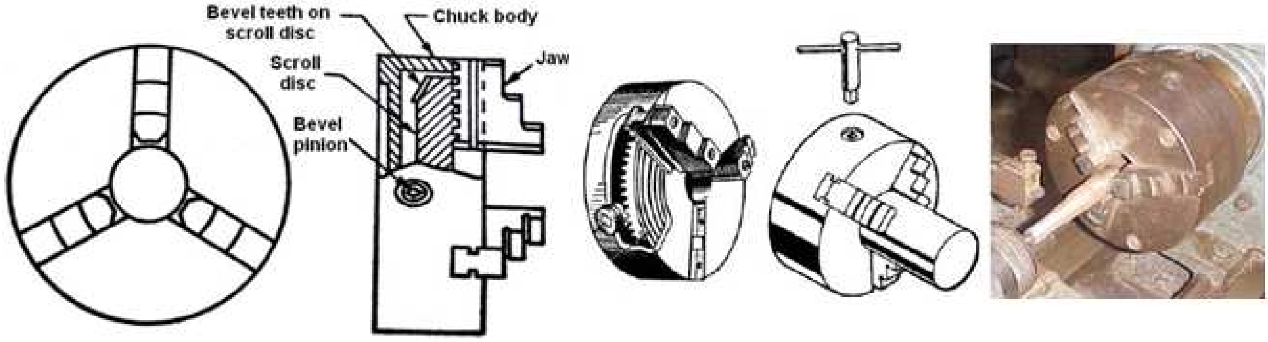


Fig. 2.10 (a) 3-jaw self centering chuck or universal chuck

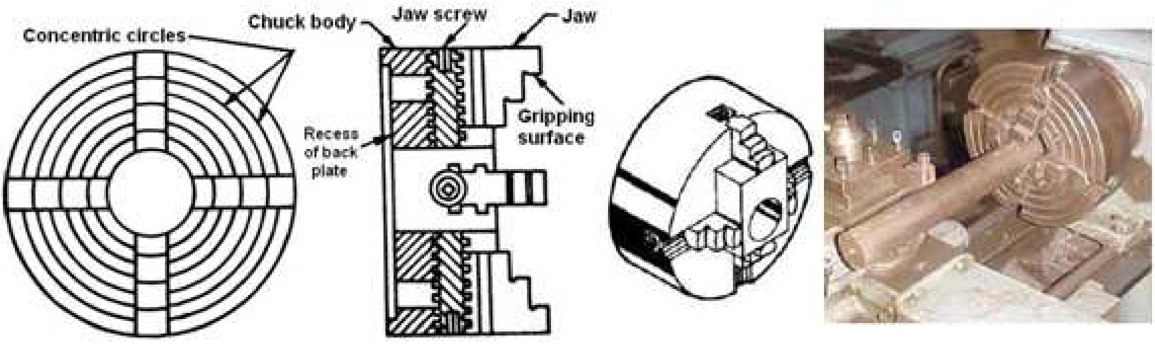
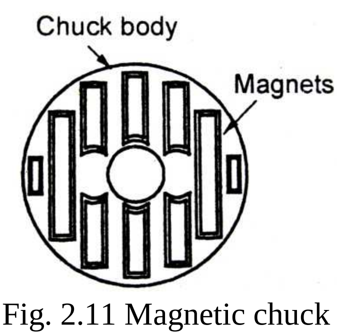


Fig. 2.10 (b) 4-jaw independent chuck

Magnetic chuck

This is used for holding thin jobs. When the pressure of jaws is to be prevented, this chuck is used. The chuck gets magnetic power from an electro-magnet. Only magnetic materials can be held on this chuck. *Fig. 2.11 shows the magnetic chuck.*



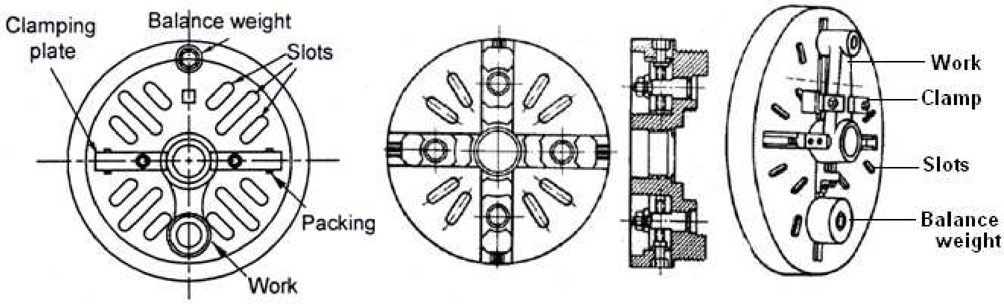


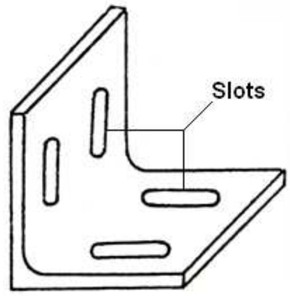
Fig. 2.11 Magnetic chuck Fig. 2.12 Face plate

Face plate

A face plate *as shown in Fig. 2.12* consists of a circular disc bored out and threaded to fit the nose of lathe spindle. This has radial, plain and T slots for holding work by bolts and clamps. Face plates are used for holding work pieces which cannot be conveniently held between centres or by chucks.

Angle plate

Angle plate is a cast iron plate that has two faces at right angles to each other. Holes and slots are provided on both faces *as shown in Fig. 2.13 (a).* An angle plate is used along with the face plate when holding eccentric or unsymmetrical jobs that are difficult to grip directly on the face plate *as shown in Fig. 2.13 (b).*



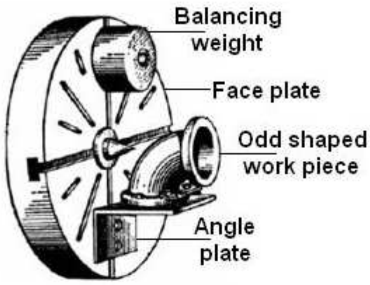


Fig. 2.13 (a) Angle plate Fig. 2.13 (b) Angle plate used along with face plate

2.2.5.2 With additional support from the tailstock

Catch plate or driving plate

It is circular plate of steel or cast iron having a projected boss at its rear. The boss has a threaded hole and it can be screwed to the nose of the headstock spindle. The driving is fitted to the plate. It is used to drive the work piece through a carrier or dog when the work piece is held between the centres. *Fig. 2.14 shows the catch plate.*

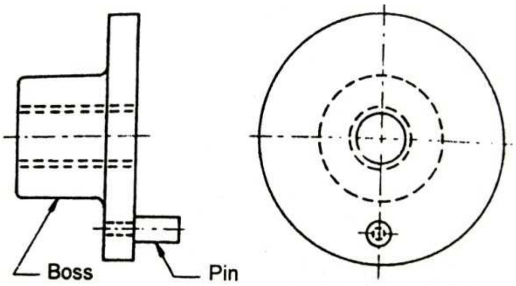


Fig. 2.14 Catch plate

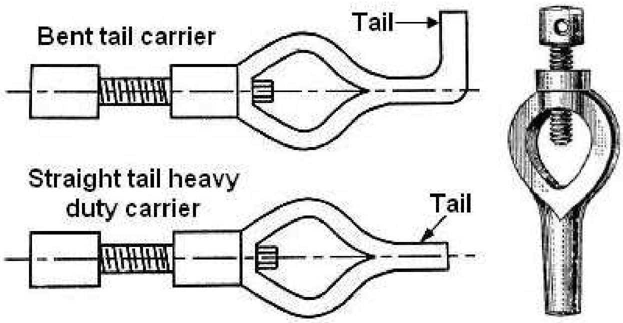


Fig. 2.15 Types of carriers

Carriers or Dogs

It is used to transfer motion from the driving plate to the work piece held between centres. The work piece is inserted into the hole of the dog and firmly secured in position by means of set screw. *The different types of carriers are shown in Fig 2. 15.*

Mandrels

A mandrel is a device used for holding and rotating a hollow work piece that has been previously drilled or bored. The work revolves with the mandrel which is mounted between two centres. The mandrel should be true with accurate centre holes for machining outer surface of the work piece concentric with its bore. To avoid distortion and wear it is made of high carbon steel.

The ends of a mandrel are slightly smaller in diameter and flattened to provide effective gripping surface of the lathe dog set screw. The mandrel is rotated by the lathe dog and the catch plate and it drives the work by friction. Different types of mandrels are employed according to specific requirements. *Fig. 2.16 shows the different types of mandrels in common use.*

In-between centres (by catch plate and carriers)

Fig. 2.17 schematically shows how long slender rods are held in between the live centre fitted into the headstock spindle and the dead centre fitted in the quill of the tailstock. The torque and rotation are transmitted from the spindle to the job with the help of a lathe dog or catcher which is again driven by a driving plate fitted at the spindle nose.

Depending upon the situation or requirement, different types of centres are used at the tailstock end *as indicated in Fig. 2.18.* A revolving centre is preferably used when desired to avoid sliding friction between the job and the centre which also rotates along with the job.

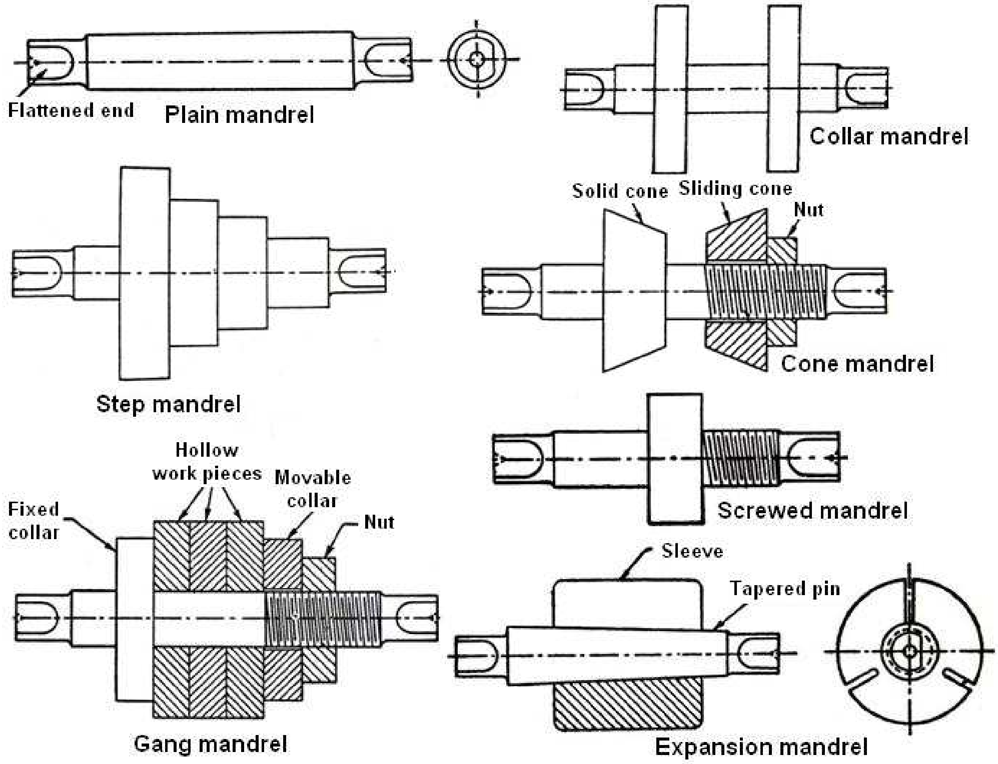


Fig. 2.16 Types of mandrels

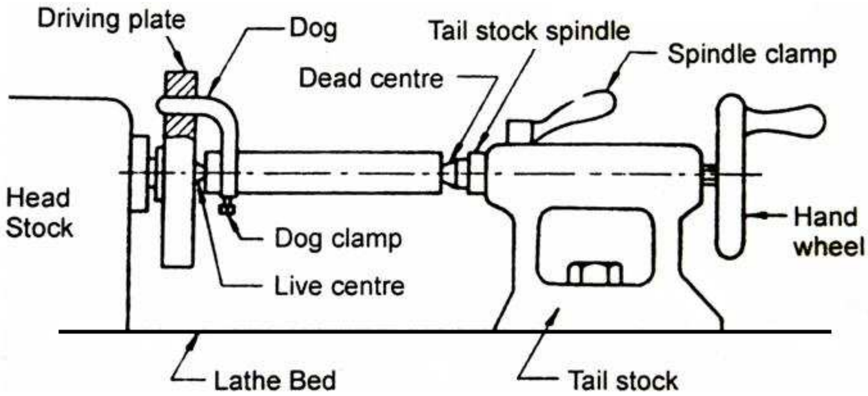


Fig. 2.17 Work held between centres

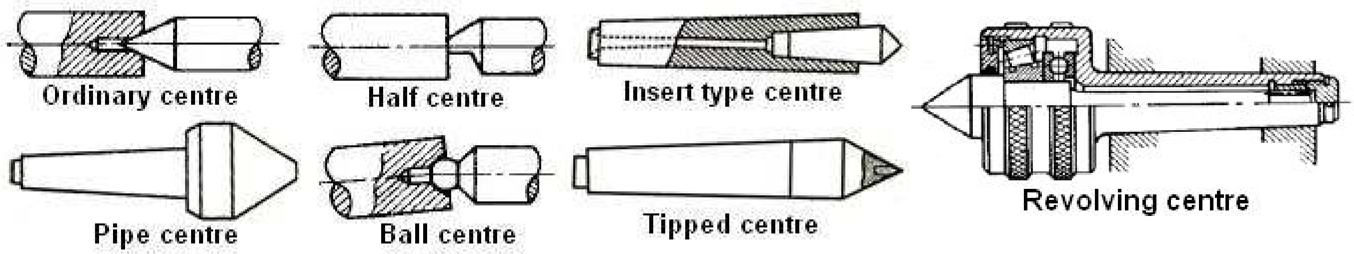


Fig. 2.18 Types of centres

Ordinary centre: It is used for general works.

Insert type centre: In this the steel "insert" can be replaced instead of replacing the whole centre.

Half centre: It is similar to ordinary centre and used for facing bar ends without removal of the centre.

Pipe centre: It is used for supporting pipes and hollow end jobs.

Ball centre: It has ball shaped end to minimize the wear and strain. It is suitable for taper turning.

Tipped centre: Hard alloy tip is brazed into steel shank. The hard tip has high wear resistant.

Revolving centre: The ball and roller bearings are fitted into the housing to reduce friction and to take up end thrust. This is used in tail stock for supporting heavy work revolving at a high speed.

In-between chuck and centre

Heavy and reasonably long jobs of large diameter and requiring heavy cuts (cutting forces) are essentially held strongly and rigidly in the chuck at headstock with support from the tailstock through a revolving centre *as can be seen in Fig. 2.19.*

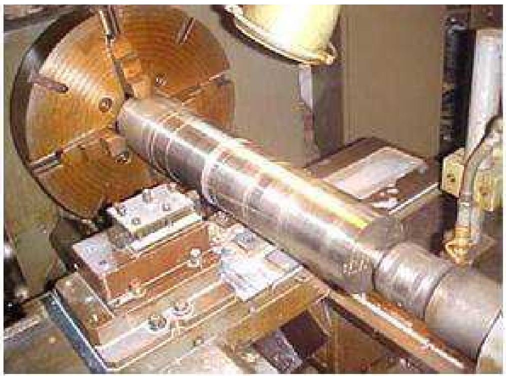


Fig. 2.19 Work held between chuck and revolving centre

In-between headstock and tailstock with additional support of rest

To prevent deflection of the long slender jobs like feed rod, lead screw etc. due to sagging and cutting forces during machining, some additional supports are provided *as shown in Fig. 2.20.* Such additional support may be a steady rest which remains fixed at a suitable location or a follower rest which moves along with the cutting tool during long straight turning without any steps in the job's diameter. *Fig. 2.21 (a and b) shows the steady rest and follower rest.*

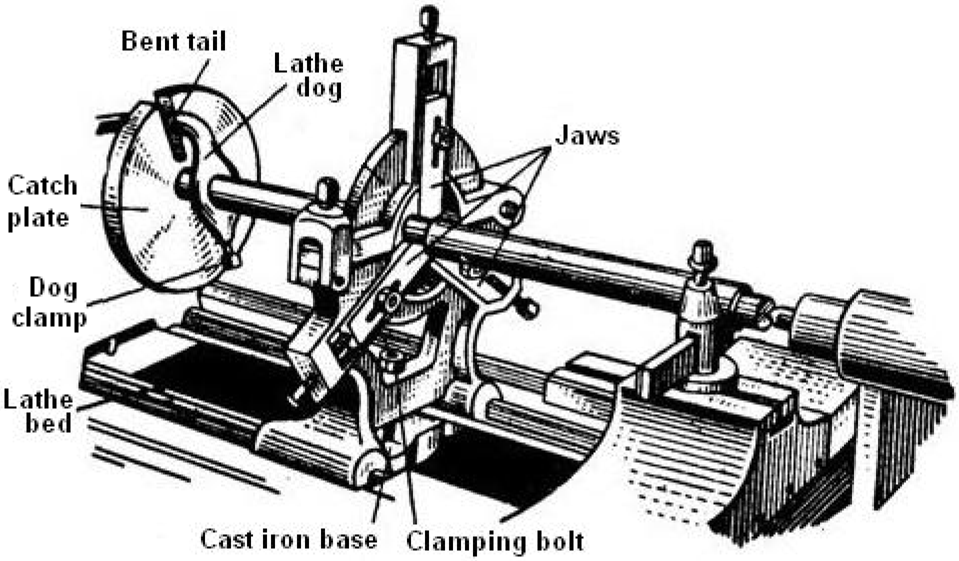


Fig. 2.20 Slender job held with extra support by steady rest

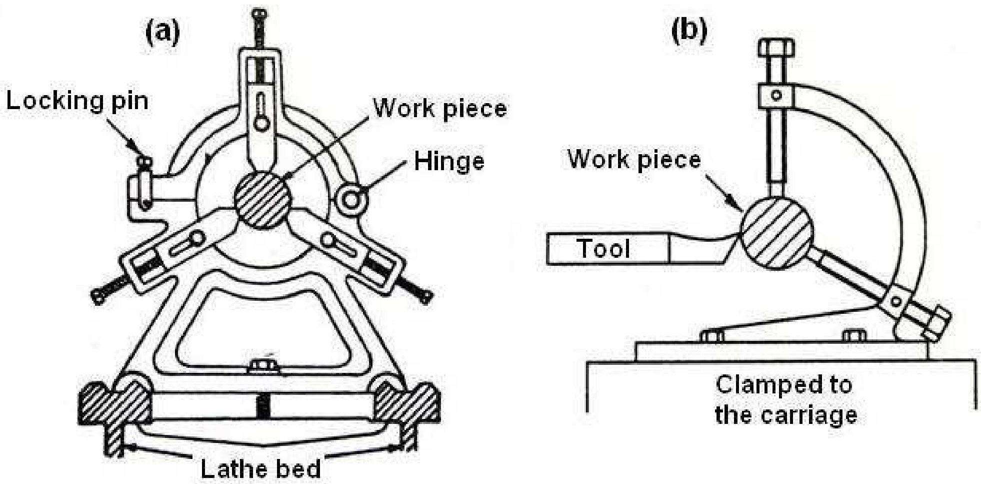


Fig. 2.21 (a) Steady rest and (b) Follower rest

2.2.6 Mounting of tools in centre lathe

Different types of tools, used in centre lathes, are usually mounted in the following ways:

- HSS tools (shank type) in tool post.
- HSS form tools and threading tools in tool post.
- Carbide and ceramic inserts in tool holders.
- Drills and reamers, if required, in tailstock.
- Boring tools in tool post.

Fig. 2.22 (a and b) is typically showing mounting of shank type HSS single point tools in rotatable (only one tool) and indexable (up to four tools) tool posts. *Fig. 2.22 (c) typically shows* how a circular form or thread chasing HSS tool is fitted in the tool holder which is mounted in the tool post.

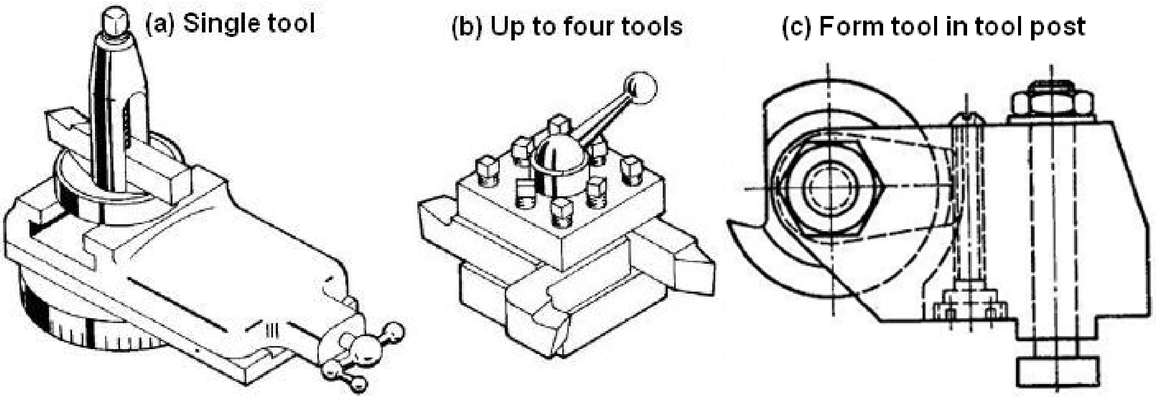


Fig. 2.22 Mounting of (a and b) shank type tools in tool post and (c) form tool in tool post

Carbide, ceramic and cermet inserts of various size and shape are mechanically clamped in the seat of rectangular sectioned steel bars which are mounted in the tool post. *Fig. 2.23 (a, b, c and d) shows the common methods of clamping such inserts.* After wearing out of the cutting point, the insert is indexed and after using all the corner tips the insert is thrown away.

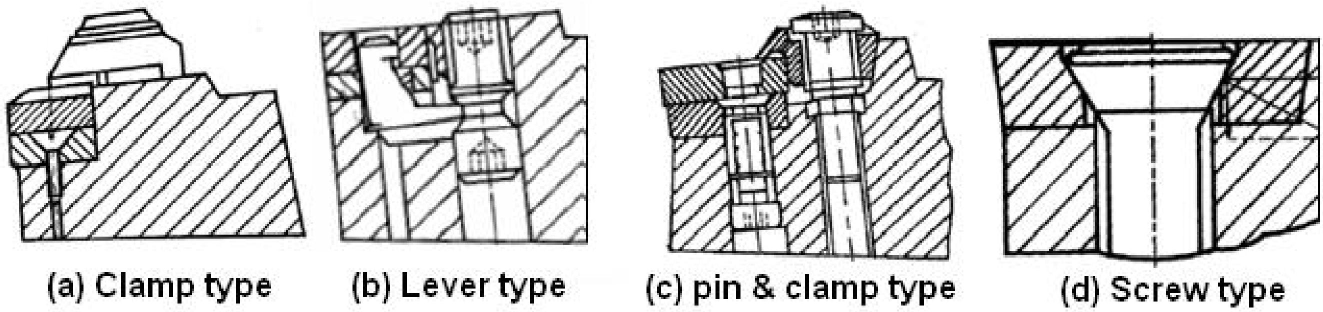


Fig. 2.23 Mounting of tool inserts in tool holders by mechanical clamping

For originating axial hole in centre lathe, the drill bit is fitted into the tailstock which is slowly moved forward against the rotating job *as indicated in Fig. 2.24.* Small straight shank drills are fitted in a drill chuck whereas taper shank drill is fitted directly into the tailstock quill without or with a socket.

Fig. 2.24 Holding drill chuck and drill in tailstock

Often boring operation is done in centre lathe for enlarging and finishing holes by simple shank type HSS boring tool. The tool is mounted on the tool post and moved axially forward, along with the saddle, through the hole in the rotating job *as shown in Fig. 2.25 (a).* For precision boring in centre lathe, the tool may be fitted in the tailstock quill supported by bush in the spindle *as shown in Fig. 2.25 (b).*

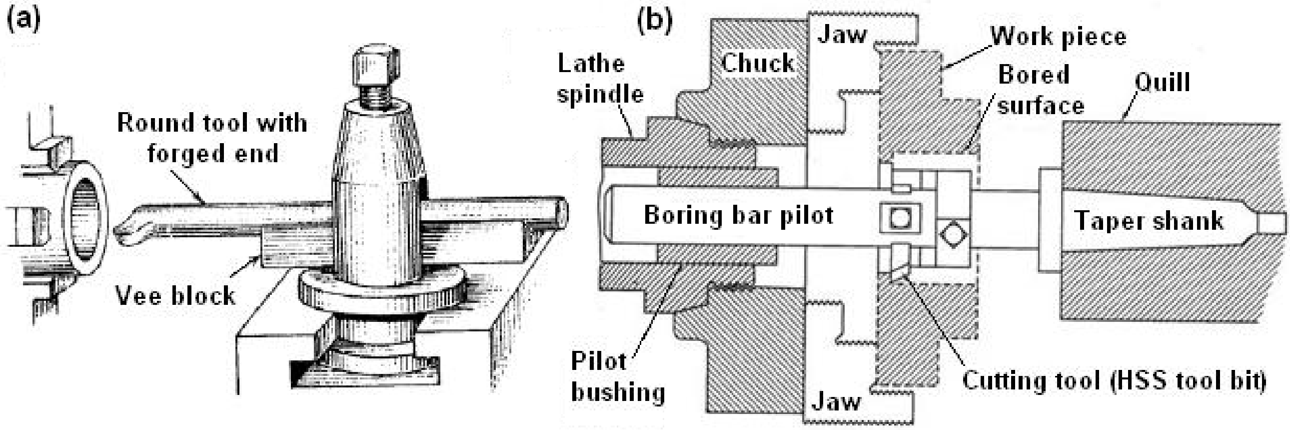


Fig. 2.25 (a) Boring tool mounted in the tool post Fig. 2.25 (b) Precision boring in centre lathe

2.3 CUTTING TOOLS

For general purpose work, a single point cutting tool is used in centre lathes. But for special operations multi point tools may be used. *Single point lathe tools are classified as follows:*

According to the method of manufacturing the tool

- Forged tool.
- Tipped tool brazed to the carbon steel shank.
- Tipped tool fastened mechanically to the carbon steel shank.

According to the method of holding the tool

- Solid tool.
- Tool bit inserted in the tool holder.

According to the method of using the tool

- Turning tool, facing tool, forming tool, chamfering tool, finishing turning tool, round nose tool, external threading tool, internal threading tool, boring tool, parting tool, knurling tool, etc.

According to the method of applying feed

- Right hand tool.
- Left hand tool.
- Round nose tool.

2.3.1 According to the method of manufacturing the tool

Forged tool

These tools are manufactured from high carbon steel or high speed steel. The required shape of the tool is given by forging the end of a solid tool steel shank. The cutting edges are then ground to the shape to provide necessary tool angles. *Fig. 2.26 (a) shows a forged tool.*

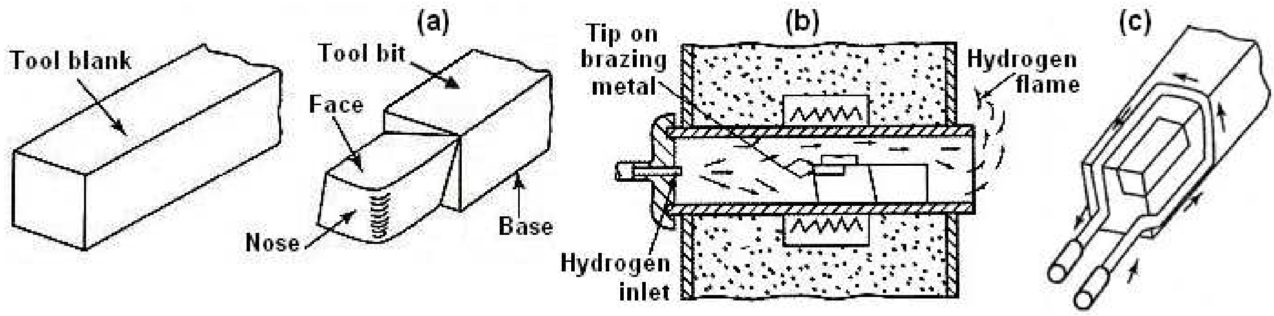


Fig. 2.26 (a) Forged tool (b) Furnace bracing of a tool tip (c) Induction brazing of a tool tip

Tipped tool brazed to the carbon steel shank

Stellite and cemented carbide tool materials, in view of the very high cost, brittleness, and low tensile strength, are used in the form of small tips. They are made to the various shapes to form different types of tools and are attached permanently to the end of a carbon steel shank by a brazing operation. High speed steel due to its high cost is also sometimes used in the form of tips brazed on carbon steel shank. *Fig. 2.26 (b and c) shows the furnace and induction brazing of a tool tip on carbon steel shank.*

Tipped tool fastened mechanically to the carbon steel shank

To ensure rigidity that a brazed tool does not offer, tips are sometimes clamped at the end of a tool shank by means of a clamp and bolt. Ceramic tips which are difficult to braze are clamped at the end of a shank. *Fig. 2.27 shows a mechanically fastened tipped tool.*

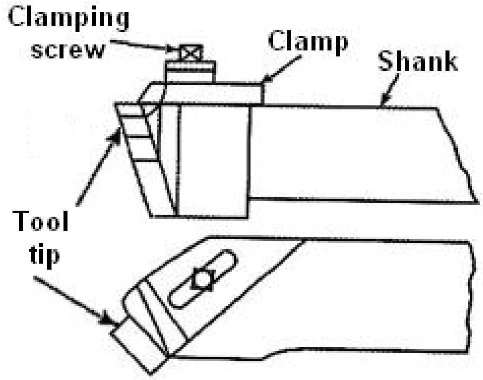


Fig. 2.27 Mechanically fastened tool tip

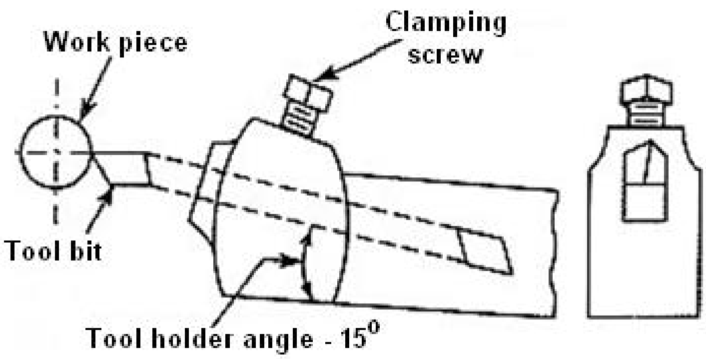


Fig. 2.28 Tool holder and tool bit

2.3.2 According to the method of holding the tool

Solid tool

Solid tools are made of high carbon steel forged and ground to the required shape. They are mounted directly on the tool post of a lathe. *Fig. 2.26 (a) shows a solid tool.*

Tool bit inserted in the tool holder

A tool bit is a small piece of cutting material having a very short shank which is inserted in a forged carbon steel tool holder and clamped in position by bolt or screw. A tool bit may be of solid type or tipped one according to the type of the cutting tool material. Tool holders are made of different designs according to the shape and purpose of the cutting tool. *Fig. 2.28 illustrates a common type of tool holder using high speed steel tool bit.*

2.3.3 According to the method of using the tool

Fig. 2.29 shows the various tools used in centre lathe according to the method of using the tool.

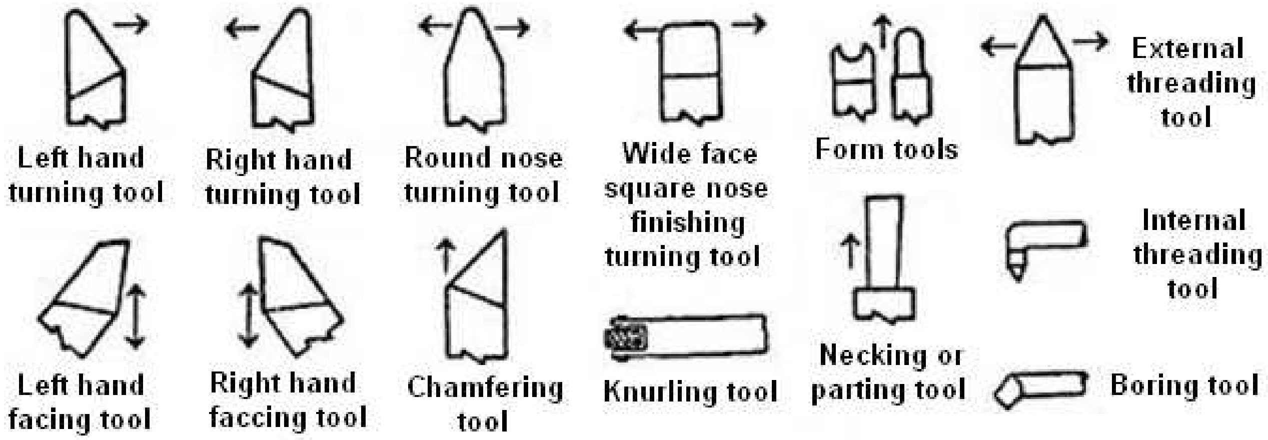


Fig. 2.29 Various tools used in centre lathe according to the method of using the tool

2.4 VARIOUS OPERATIONS

The machining operations generally carried out in centre lathe are:

- Rough and finish turning - The operation of producing cylindrical surface.
- Facing - Machining the end of the work piece to produce flat surface.
- Centering - The operation of producing conical holes on both ends of the work piece.
- Chamfering - The operation of beveling or turning a slope at the end of the work piece.
- Shouldering - The operation of turning the shoulders of the stepped diameter work piece.
- Grooving - The operation of reducing the diameter of the work piece over a narrow surface. It is also called as recessing, undercutting or necking.
- Axial drilling and reaming by holding the cutting tool in the tailstock barrel.
- Taper turning by
  - Offsetting the tailstock.
  - Swiveling the compound slide.
  - Using form tool with taper over short length.
  - Using taper turning attachment if available.
  - Combining longitudinal feed and cross feed, if feasible.
- Boring (internal turning); straight and taper – The operation of enlarging the diameter of a hole.
- Forming; external and internal.
- Cutting helical threads; external and internal.
- Parting off - The operation of cutting the work piece into two halves.
- Knurling - The operation of producing a diamond shaped pattern or impression on the surface.

In addition to the aforesaid regular machining operations, some more operations are also occasionally done, if desired, in centre lathes by mounting suitable attachments available in the market. *Some of those common operations carried out in centre lathe are shown in Fig. 2.30.*

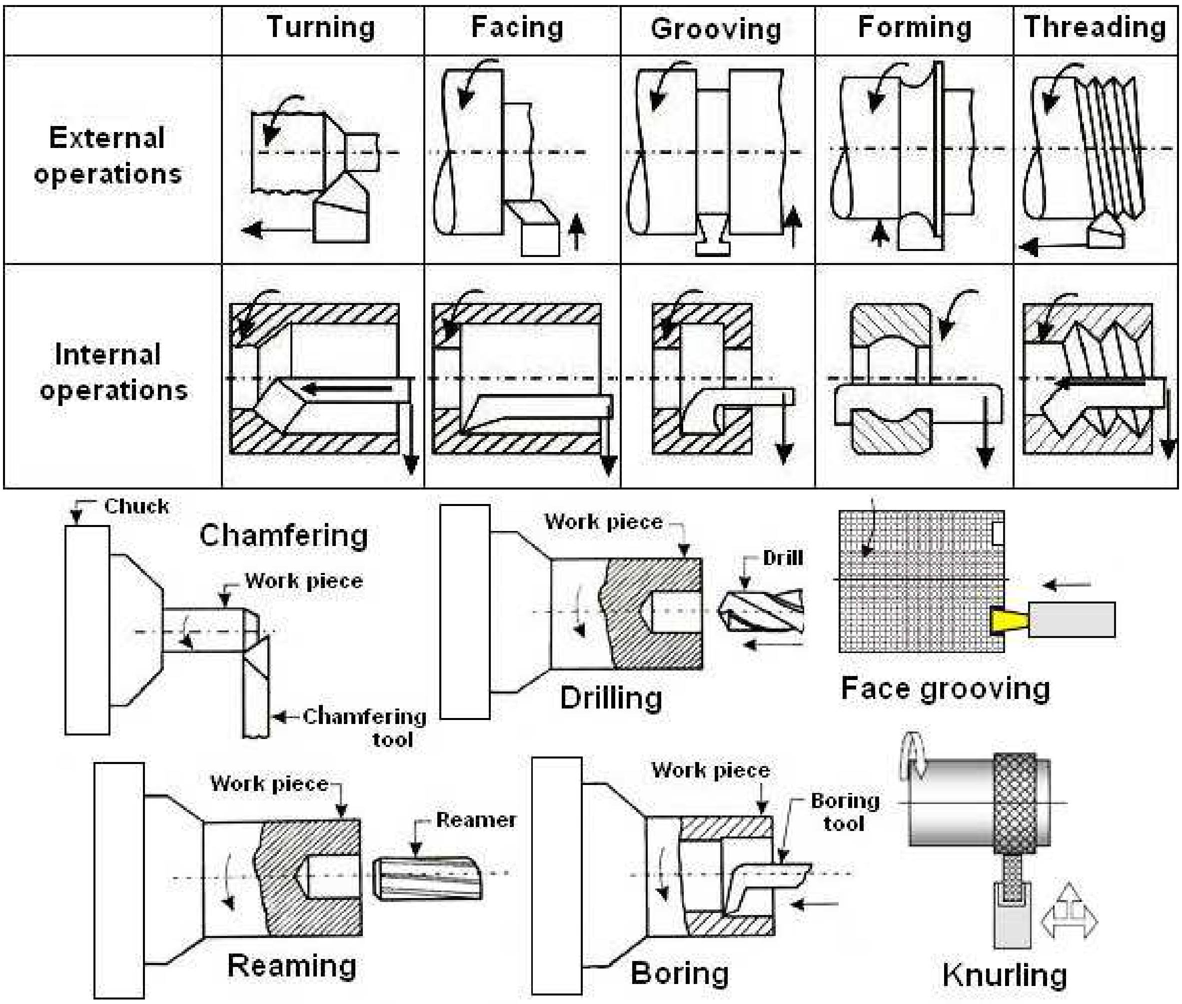


Fig. 2.30 Some common machining operations carried out in a centre lathe

2.5 TAPER TURING METHODS

A taper may be defined as a uniform change in the diameter of a work piece measured along its length. *Taper may be expressed in two ways:*

- Ratio of difference in diameter to the length.
- In degrees of half the included angle.

Fig. 2.31 shows the details of a taper.

D - Large diameter of the taper.

d - Small diameter of the taper.

l - Length of tapered part.

α - Half angle of taper.

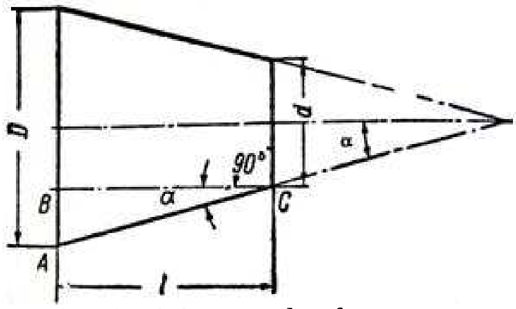


Fig. 2.31 Details of a taper

Generally, taper is specified by the term conicity. *Conicity is defined as the ratio of the difference in diameters of the taper to its length.* Conicity, $\mathbf{K = \frac{D - d}{l}}$ 2.1

Taper turning is the operation of producing conical surface on the cylindrical work piece on lathe.

2.5.1 Taper turning by a form tool

Fig. 2.32 illustrates the method of turning taper by a form tool. A broad nose tool having straight cutting edge is set on to the work at half taper angle, and is fed straight into the work to generate a tapered surface. In this method the tool angle should be properly checked before use. This method is limited to turn short length of taper only. This is due to the reason that the metal is removed by the entire cutting edge will require excessive cutting pressure, which may distort the work due to vibration and spoil the work surface.

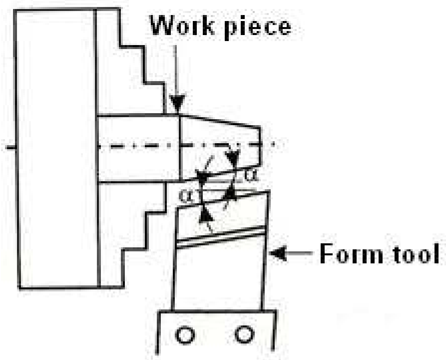


Fig. 2.32 Taper turning by a form tool

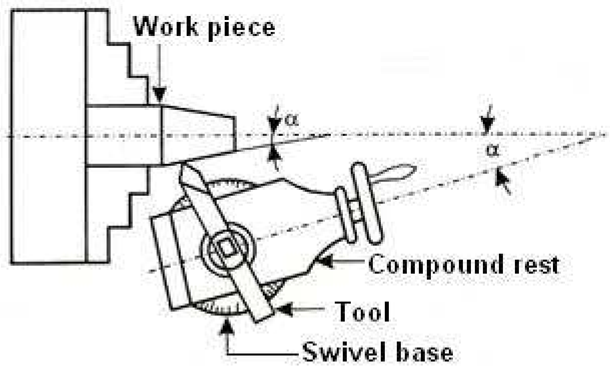


Fig. 2.33 Taper turning by swiveling the compound rest

2.5.2 Taper turning by swiveling the compound rest

Fig. 2.33 illustrates the method of turning taper by swiveling the compound rest. This method is used to produce short and steep taper. In this method, work is held in a chuck and is rotated about the lathe axis. The compound rest is swiveled to the required angle and clamped in position.

The angle is determined by using the formula, $\mathbf{\tan\alpha = \frac{D - d}{2l}}$ 2.2

Then the tool is fed by the compound rest hand wheel. This method is used for producing both internal and external taper. This method is limited to turn a short taper owing to the limited movement of the compound rest. The compound rest may be swiveled at 45^0 on either side of the lathe axis enabling it to turn a steep taper. The movement of the tool in this method being purely controlled by hand, this gives a low production capacity and poorer surface finish.

2.5.3 Taper turning by offsetting the tailstock

Fig. 2.34 illustrates the method of turning taper by offsetting the tailstock. The principle of turning taper by this method is to shift the axis of rotation of the work piece, at an angle to the lathe axis, which is equal to half angle of the taper, and feeding the tool parallel to the lathe axis.

This is done when the body of the tailstock is made to slide on its base towards or away from the operator by a set over screw. The amount of set over being limited, this method is suitable for turning small taper on long jobs. The main disadvantage of this method is that live and dead centres are not equally stressed and the wear is not uniform. Moreover, the lathe carrier being set at an angle, the angular velocity of the work is not constant.

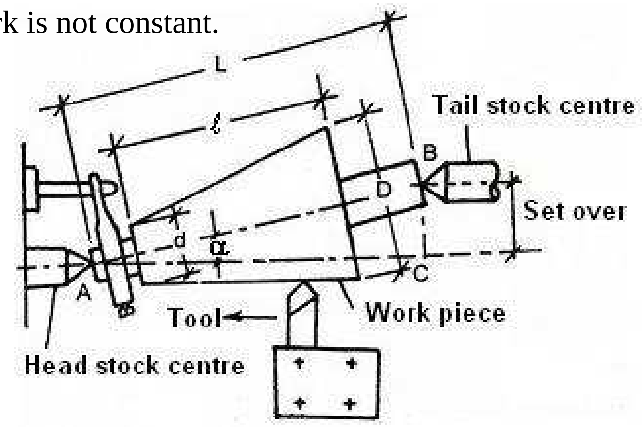


Fig. 2.34 Taper turning by offsetting the tailstock

The amount of set over required to machine a particular taper may be calculated as:

From the right angle triangle ABC in Fig.2.34; BC =AB sinα, where BC = set over

Set over = L sinα 2.3

If the half angle of taper (α), is very small, for all practical purposes, sinα = tanα

Set over = L tanα = L x $\frac{D - d}{2l}$ in mm. 2.4

If the taper is turned on the entire length of the work piece, then l= L, and the equation (2.4) becomes:

Set over = L x $\frac{D - d}{2L} = \frac{D - d}{2}$ 2.5

$\frac{D - d}{l}$ being termed as the conicity or amount of taper, the formula (2.4) may be written in the following form: **Set over =** $\frac{\text{entire length of the work x conicity}}{2}$ 2.6

2.5.4 Taper turning by using taper turning attachment

Fig. 2.35 schematically shows a taper turning attachment. It consists of a bracket or frame which is attached to the rear end of the lathe bed and supports a guide bar pivoted at the centre. The guide bar having graduations in degrees may be swiveled on either side of the zero graduation and is set at the desired angle with the lathe axis. When this attachment is used the cross slide is delinked from the saddle by removing the binder screw. The rear end of the cross slide is then tightened with the guide block by means of a bolt. When the longitudinal feed is engaged, the tool mounted on the cross slide will follow the angular path, as the guide block will slide on the guide bar set at an angle to the lathe axis.

The required depth of cut is given by the compound slide which is placed at right angles to the lathe axis. The guide bar must be set at half taper angle and the taper on the work must be converted in degrees. The maximum angle through which the guide bar may be swiveled is 10^0 to 12^0 on either side of the centre line. *The angle of swiveling the guide bar can be determined from the equation 2.2.*

The advantages of using a taper turning attachment are:

- The alignment of live and dead centres being not disturbed; both straight and taper turning may be performed on a work piece in one setting without much loss of time.
- Once the taper is set, any length of work piece may be turned taper within its limit.
- Very steep taper on a long work piece may be turned, which cannot be done by any other method.
- Accurate taper on a large number of work pieces may be turned.
- Internal tapers can be turned with ease.

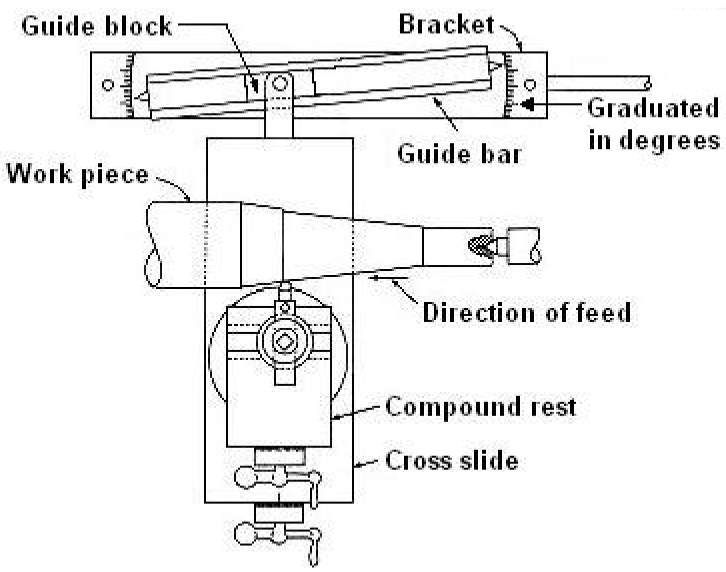


Fig. 2.35 Taper turning attachment

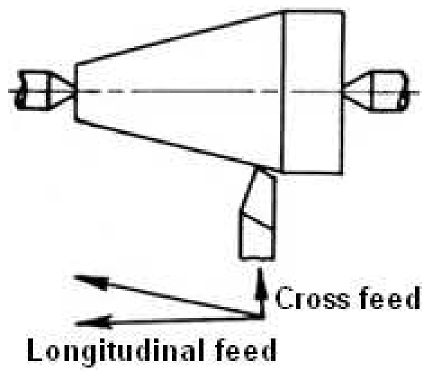


Fig. 2.36 Taper turning by combining feed

2.5.5 Taper turning by combining longitudinal feed and cross feed

Fig. 2.36 illustrates the method of turning taper by combining longitudinal feed and cross feed. This is a more specialized method of turning taper. In certain lathes both longitudinal and cross feeds may be engaged simultaneously causing the tool to follow a diagonal path which is the resultant of the magnitude of the two feeds. The direction of the resultant may be changed by varying the rate of feeds by changing gears provided inside the apron.

2.6 THREAD CUTTING METHODS

Thread cutting is one of the most important operations performed in a centre lathe. It is possible to cut both external and internal threads with the help of threading tools. There are a large number of thread forms that can be machined in a centre lathe such as Whitworth, ACME, ISO metric, etc. The principle of thread cutting is to produce a helical groove on a cylindrical or conical surface by feeding the tool longitudinally when the job is revolved between centres or by a chuck (for external threads) and by a chuck (for internal threads). The longitudinal feed should be equal to the pitch of the thread to be cut per revolution of the workpiece.

The lead screw of the lathe has a definite pitch. The saddle receives its traversing motion through the lead screw. Therefore a definite ratio between the longitudinal feed and rotation of the headstock spindle should be found out so that the relative speeds of rotation of the work and the lead screw will result in the cutting of a thread of the desired pitch. This is effect by change gears arranged between the spindle and the lead screw or by the change gear mechanism or feed gear box used in a modern lathe. Thread cutting on a centre lathe is a slow process, but it is the only process of producing square threads, as other methods develop interference on the helix. *Fig.2.37 illustrates the principle of thread cutting.*

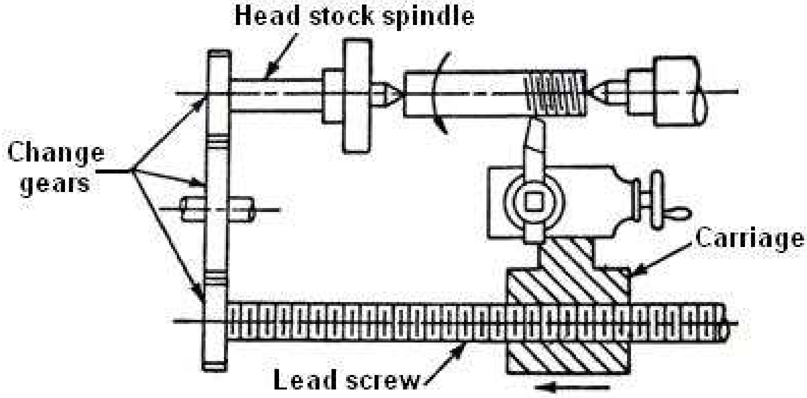


Fig. 2.37 Principles of thread cutting

2.6.1 Change gear ratio

Centre lathes are equipped with a set of change gears. A typical set contains the following change gears with number of teeth: 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 110, 120, 125 and 127. The change gear ratio (i_{cg}) must be transformed by multiplying numerator and denominator by a suitable number, to obtain gears available in the change gear set.

The change gear ratio may result either in a 'Simple gear train' or 'Compound gear train'. In modern lathes using quick change gears, the correct gear ratio for cutting a particular thread is quickly obtained by simply shifting the levers in different positions which are given in the charts or instruction plates supplied with the machine.

2.6.1.1 Calculation for change gear ratio

Metric thread on Metric lead screw

Calculation for change gear ratio for cutting metric thread on a centre lathe with a metric lead screw is as follows;

$$\frac{\textbf{Driver teeth}}{\textbf{Driven teeth}} = \frac{\textbf{Lead screw turn}}{\textbf{Spindle turn}} = \frac{\textbf{Pitch of the thread to be cut}}{\textbf{Pitch of the lead screw}} \qquad 2.7$$

Example 2.1: The pitch of the lead screw is 12 mm, and the pitch of the thread to be cut is 3 mm. For this condition the change gear ratio is as follows;

$$\frac{\textbf{Driver teeth}}{\textbf{Driven teeth}} = \frac{\textbf{Pitch of the thread to be cut}}{\textbf{Pitch of the lead screw}} = \frac{3}{12} = \frac{1}{4} = \frac{1 \times 20}{4 \times 20} = \frac{20}{80}$$

Therefore the driver gear will have 20 teeth and the driven gear will have 80 teeth. This is effect by simple gear train.

Example 2.2: The pitch of the lead screw is 6 mm, and the pitch of the thread to be cut is 1.25 mm. For this condition the change gear ratio is as follows;

$$\frac{\textbf{Driver teeth}}{\textbf{Driven teeth}} = \frac{\textbf{Pitch of the thread to be cut}}{\textbf{Pitch of the lead screw}} = \frac{1.25}{6} = \frac{1.25 \times 4}{6 \times 4} = \frac{5}{4} \times \frac{1}{6} = \frac{5 \times 10}{4 \times 10} \times \frac{1 \times 20}{6 \times 20} = \frac{50 \times 20}{40 \times 120}$$

Therefore the driver gears will have 50 teeth & 20 teeth and the driven gears will have 40 teeth & 120 teeth. This is effect by compound gear train.

Metric thread on British or English standard lead screw

Calculation for change gear ratio for cutting metric thread on a centre lathe with a British or English standard lead screw may be carried out by introducing a translating gear of 127 teeth. If the lead screw has *n* threads per inch and the thread to be cut has *p* mm pitch then;

$$\frac{\textbf{Driver teeth}}{\textbf{Driven teeth}} = \frac{\textbf{Pitch of the thread to be cut}}{\textbf{Pitch of the lead screw}} = \frac{p}{1/n} = \frac{p\,n}{25.4} = \frac{p\,n}{25.4 \times 5/5} = \frac{5\,p\,n}{127} \qquad 2.8$$

Since pitch = $\frac{1}{\textbf{number of threads per inch}}$ and 1 inch = 25.4 mm

Example 2.3: The lead screw has 4 threads per inch, and the pitch of the thread to be cut is 7 mm. For this condition the change gear ratio is as follows;

$$\frac{\textbf{Driver teeth}}{\textbf{Driven teeth}} = \frac{5\,p\,n}{127} = \frac{5 \times 7 \times 4}{127} = \frac{140}{127} = \frac{70 \times 2}{127} = \frac{70 \times 2 \times 20}{127 \times 20} = \frac{70 \times 40}{127 \times 20}$$

Therefore the driver gears will have 70 teeth & 40 teeth and the driven gears will have 127 teeth & 20 teeth. This is effect by compound gear train.

British or English standard thread on English lead screw

Calculation for change gear ratio for cutting British or English standard thread on a centre lathe with an English lead screw is as follows;

$$\frac{\textbf{Driver teeth}}{\textbf{Driven teeth}} = \frac{1/\textbf{number of threads per inch to be cut}}{1/\textbf{number of threads per inch on the lead screw}} = \frac{\textbf{Pitch of the thread to be cut}}{\textbf{Pitch of the lead screw}} \qquad 2.9$$

Example 2.4: The lead screw has 4 threads per inch, and the screw thread to be cut has 26 threads per inch. For this condition the change gear ratio is as follows;

$$\frac{\text{Driver teeth}}{\text{Driven teeth}} = \frac{1/\text{number of threads per inch to be cut}}{1/\text{number of threads per inch on the lead screw}} = \frac{1/26}{1/4} = \frac{4}{26} = \frac{4 \times 5}{26 \times 5} = \frac{4 \times 5}{13 \times 10}$$

$$= \frac{4 \times 5}{13 \times 5} \times \frac{5 \times 10}{10 \times 10} = \frac{20 \times 50}{65 \times 100}$$

Therefore the driver gears will have 20 teeth & 50 teeth and the driven gears will have 65 teeth & 100 teeth. This is effect by compound gear train.

2.6.2 Thread cutting procedure

1. The work piece should be rotated in anticlockwise direction when viewed from the tail stock end.
2. The excess material is removed from the workpiece to make its diameter equal to the major diameter of the screw thread to be generated.
3. Change gears of correct size are fitted to the end of the bed between the spindle and the lead screw.
4. The thread cutting tool is selected such that the shape or form of the cutting edge is of the same form as the thread to be generated. In a metric thread, the included angle of the cutting edge should be ground exactly 60^0.
5. A thread tool gauge or a centre gauge is used against the turned surface of the workpiece to check the form of the cutting edge so that each face may be equally inclined to the centre line of the workpiece. *This is illustrated in Fig. 2.38.*

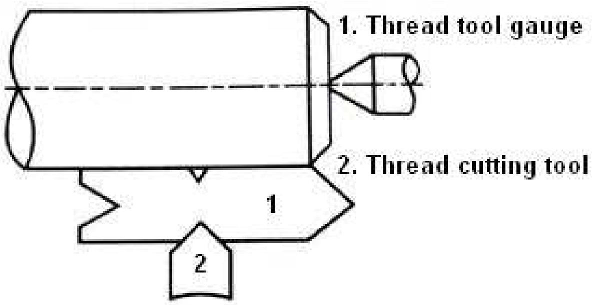


Fig. 2.38 Checking of the cutting edge

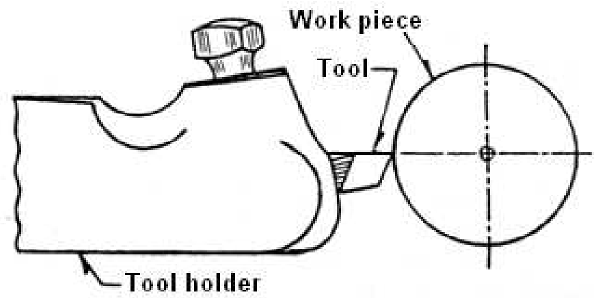


Fig. 2.39 Mounting of the cutting tool

6. Then the tool is mounted in the tool post such that the top of the tool nose is horizontal and is in line with the axis of rotation of the workpiece. *This is illustrated in Fig. 2.39.*
7. The speed of the spindle is reduced by ½ to ¼ of the speed required for turning according to the type of material being machined.
8. The tool is fed inward until it first scratches the surface of the workpiece. The graduated dial on the cross slide is noted or set to zero. Then the split nut or half nut is engaged and the tool moves along helical path over the desired length.
9. At the end of tool travel, it is quickly withdrawn by means of cross slide. The split nut is disengaged and the carriage is returned to the starting position, for the next cut. These successive cuts are continued until the thread reaches its desired depth (checked on the dial of cross slide).
10. For cutting left hand threads the carriage is moved from left to right (i.e. towards tail stock) and for cutting right hand threads it is moved from right to left (i.e. towards headstock).

2.6.2.1 Depth of cut in thread cutting

The depth of first cut is usually 0.2 to 0.4 mm. This is gradually decreased for the successive cuts until for the final finishing cut; it is usually 0.025 to 0.075 mm. The depth of cut is applied by advancing the tool either radially (called as plunge cutting) or at an angle equal to half angle of the thread (called as compound cutting) (30^0 incase of metric threads) by swiveling the compound rest. *Fig. 2.40 schematically shows the method of applying plunge cut and compound cut.*

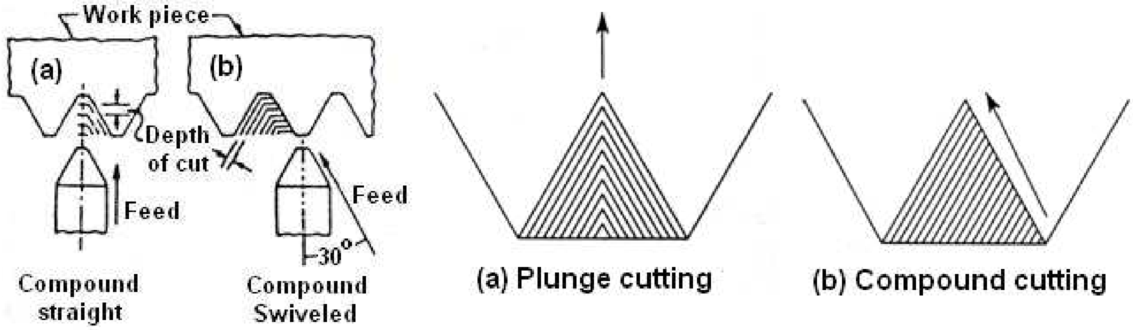


Fig. 2.40 *schematic view of the method of applying plunge cut and compound cut*

Plunge cutting In this the absence of side and back rake will not produce proper cutting except on brass and cast iron. Cutting takes place along a longer length of the tool. This gives rise to difficulties in machining in terms of higher cutting forces and consequently chattering. This result in poor surface finish and lower tool life, thus this method is not generally preferred. This method is used for taking very light finishing cuts and for cutting square, acme and worm threads.

Compound cutting *Compound cutting is superior to the plunge cutting as it:*

- Permits the tool to have a top rake.
- Permits cutting to take place on one edge of the tool only.
- Allows the chips to slide easily across the face of the tool without crowding.
- Reduces cutting strain that acts on the tool.
- Reduces the tendency to cause the tool to 'dig-in'.

So compound cutting is more preferred compared with plunge cutting.

2.6.2.2 Picking up the thread

Several cuts are necessary before the full depth of thread is reached. It is essential that the tool tip should always follow the same thread profile generated in the first cut; otherwise the workpiece will be spoiled. This is termed as picking up the thread. The different methods of picking up the thread are:

Reversing the machine After the end of one cut the machine is reversed while keeping the half nut permanently engaged and retaining the engagement between the tool and the workpiece. The spindle reversal would bring the cutting tool to the starting point of the thread following the same path in reverse. After giving a further depth of cut the spindle is again reversed and the thread cutting is continued in the normal way. This is easy to work and is some what more time consuming due to the idle time involved in stopping and reversing of the spindle at the end of each stroke.

Marking the lathe parts The procedure is to mark the lead screw and its bracket, the large gear and the head stock casting, and the starting position of the carriage on the lathe bed. The aim is to bring each of the markings on the lead screw and gear opposite the markings on the stationary portions of the lathe, and have the carriage at the starting position before attempting to engage the split nut.

Using a chasing dial *Fig. 2.41 shows the basic configuration of a chasing dial.* This is also called as thread indicator. This is a special attachment used in modern lathes for accurate "picking up" of the thread. This dial indicates when to close the split or half nuts. This is mounted on the right end of the apron. It consists of a vertical shaft with a worm gear engaged with the lead screw. The top of the vertical shaft has a revolving dial marked with lines and numbers to indicate equal divisions of the circumference. The dial turns with the lead screw so long the half nut is not engaged. If the half nut is closed and the carriage moves along, the dial stands still.

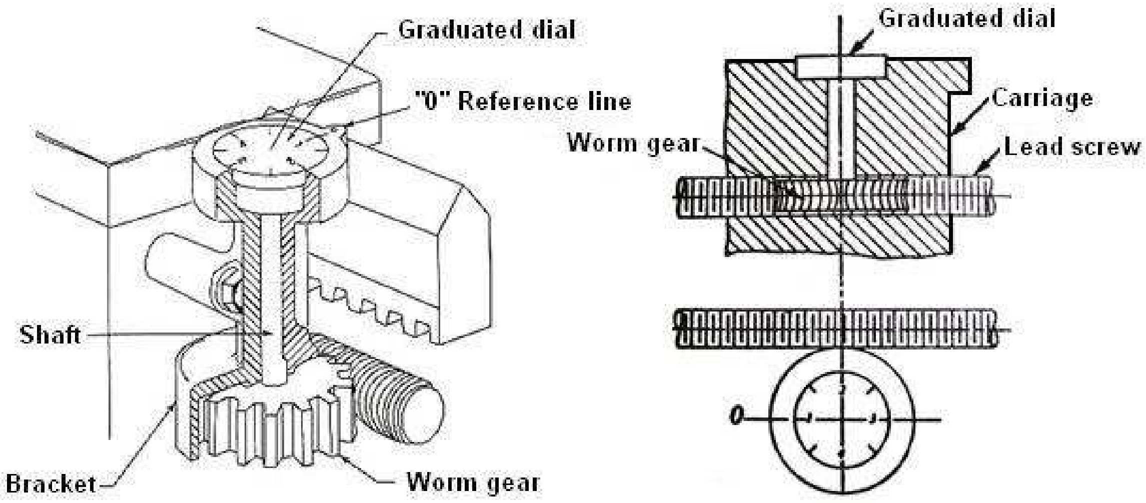


Fig. 2.41 Thread chasing dial

As the dial turns, the graduations pass a fixed reference line. The half-nut is closed for all even threads when any line on the dial coincides with the reference line. For all odd threads, the half-nut is closed at any numbered line on the dial coincides with the reference line. The corresponding number is determined from the charts. If the pitch of the thread to be cut is an exact multiple of the pitch of the lead screw, the thread is called even thread; otherwise the thread is called odd thread.

Thread chaser A chaser is a multipoint threading tool having the same form and pitch of the thread to be chased. *An external thread chaser is shown in Fig. 2.42 (a).* A chaser is used to finish a partly cut thread to the size and shape required. *Fig. 2.42 (b) shows finishing of a partly cut thread by a thread chaser.* Thread chasing is done at about ½ of the speed of turning.

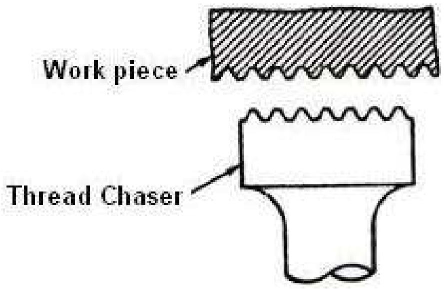


Fig. 2.42 (a) External thread chaser

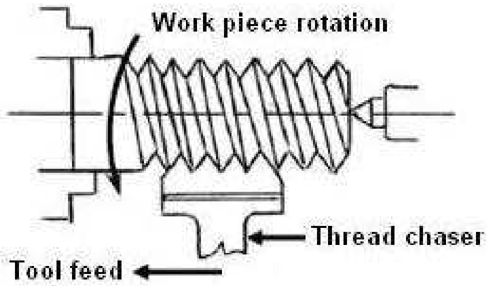


Fig. 2.42 (b) Finishing of a partly cut thread

2.6.3 Other methods for cutting external threads

2.6.3.1 External thread cutting by dies

Machine screws, bolts or studs are quickly made by different types of dies which look and apparently behave like nuts but made of hardened tool steel or HSS and having sharp internal cutting edges. The dies are coaxially rotated around the premachined rod like blank with the help of handle, die stock or die holder. First the proper die is selected according to the thread to be cut. A die holder is selected and the die is inserted in the holder. Then the die holder with die is placed in the tail stock spindle. The work piece is held in a chuck or a collet and rotated at a very slow speed. The tail stock is turned in to cut the threads. The machine is stopped as soon as the correct length of the thread is machined. The threads can also be cut by screwing the die (held in a die holder) on the work piece held and rotated between centres.

Different types of dies used for cutting external threads are:

- ***(a) Solid die:*** It is used for making threads of usually small pitch and diameter in one pass.
- ***(b) Spring die:*** The die ring is provided with a slit, the width of the slit is adjustable by a screw to enable elastically slight reduction in the bore and thus cut the thread in number of passes with lesser force on hands.

- ***(c) Split die:*** The die is made in two pieces, one fixed and one movable (adjustable) within the cavity of the handle or wrench to enable cut relatively larger threads or fine threads on harder blanks easily in number of passes, the die pieces can be replaced by another pair for cutting different threads within small range of variation in size and pitch.
- ***(d) Pipe die:*** Pipe threads of large diameter but smaller pitch are cut by manually rotating the large wrench (stock) in which the die is fitted through a guide bush.

However the quality of the threads will depend upon the perfection of the dies and skill of the operator. *Fig. 2.43 shows the hand operated dies of common use.*

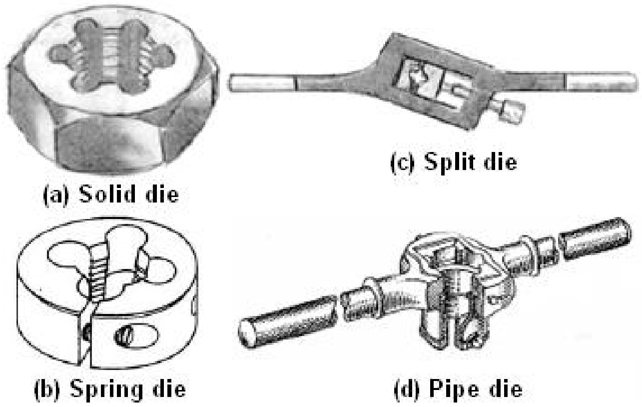


Fig. 2.43 Hand operated dies

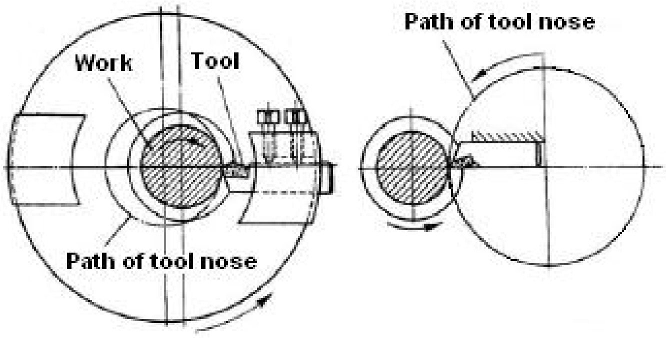


Fig. 2.44 Thread cutting by rotating tool

2.6.3.2 External thread cutting by rotating tools

Often it becomes necessary to machine large threads on one or very few pieces of heavy blanks of irregular size and shape like heavy castings or forgings. In such cases, the blank is mounted on face plate in a centre lathe with proper alignment. The deep and wide threads are produced by intermittent cutting action by a rotating tool. A separate attachment carrying the rotating tool is mounted on the saddle and fed as usual by the lead screw of the centre lathe. *Fig. 2.44 schematically shows the principles of thread cutting by rotating tool.* The tool is rotated fast but the blank much slowly. This intermittent cut enables more effective lubrication and cooling of the tool.

2.6.3.3 External thread cutting by milling cutters

This process gives quite fast production by using suitable thread milling cutters in centre lathes. The milling attachment is mounted on the saddle of the lathe. *Thread milling is of two types:*

Long thread milling Long and large diameter screws like machine lead screws are reasonably accurately made by using a large disc type form milling cutter *as illustrated in Fig. 2.45 (a).*

Short thread milling Threads of shorter length and fine pitch are machined at high production rate by using a HSS milling cutter having a number of annular threads with axial grooves cut on it for generating cutting edges. Each job requires only around 1.25 revolution of the blank and very short axial (1.25 pitch) and radial (1.5 pitch) travel of the rotating tool. *This is illustrated in Fig. 2.45 (b).*

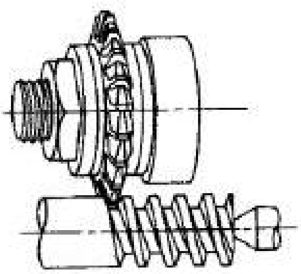


Fig. 2.45 (a) Long thread milling

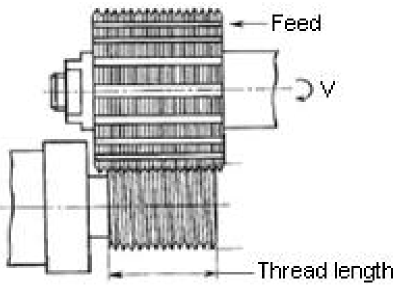


Fig. 2.45 (b) Short thread milling

2.6.3.4 External thread cutting on tapered surface

First the surface is turned taper to the required angle by any one of the taper turning methods. The thread cutting tool is then set perpendicular to the lathe axis and not to the tapered surface. To produce an accurate thread a taper turning attachment is used. This is swiveled to be the half taper angle. The thread is finished in the usual manner. *Fig. 2.46 shows the setup for thread cutting on a taper.*

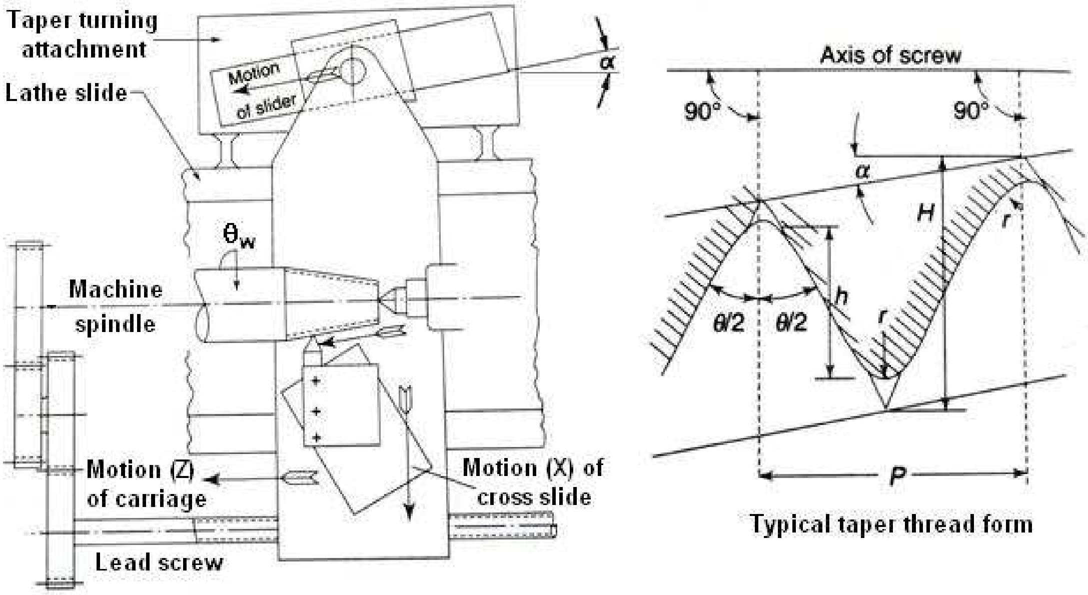


Fig. 2.46 Setup for thread cutting on a taper

2.6.4 Internal thread cutting

The principle of cutting internal threads is shown in Fig. 2.47 (a). It is similar to that of an external thread, the only difference being in the tool used. The tool is similar to a boring tool with cutting edges ground to the shape conforming to the type of the thread to be cut. The hole is first bored to the root diameter of the thread. For cutting metric thread, the compound slide is swiveled 30^0 towards the headstock. The tool is fixed on the tool post or on the boring bar after setting it at right angles to the lathe axis, using a thread gauge. *The use of thread gauge is illustrated in Fig. 2.47 (b).* The depth of cut is given by the compound slide and the thread is finished in the usual manner.

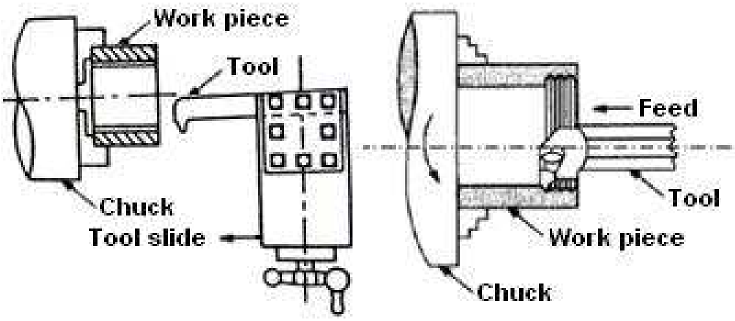


Fig. 2.47 (a) Internal thread cutting operation

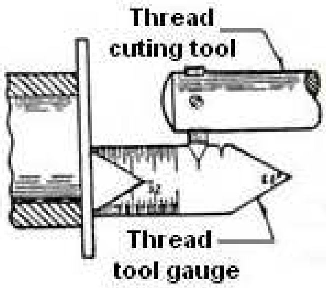


Fig. 2.47 (b) Setting of cutting edge

2.6.5 Other methods for cutting internal threads

2.6.5.1 Internal thread cutting by taps

Internal screw threads of usually small size are cut manually, if needed, in plates, blocks, machine parts etc. by using taps which look and behave like a screw but made of tool steel or HSS and have sharp cutting edges produced by axial grooving over the threads *as shown in Fig. 2.48 (a).* Three taps namely, taper tap, second tap and bottoming tap are used consecutively after drilling a tap size hole through which the taps are axially pushed helically with the help of a handle or wrench. Threads are often tapped by manually rotating and feeding the taps through the drilled hole in the blank held in centre lathe spindle *as shown in Fig. 2.48 (b).*

Different types of taps used for cutting internal threads are:

- ***Straight solid taps:*** Used for small jobs.
- ***Taps with adjustable blades:*** Usually for large diameter jobs.
- ***Taper or nut taps*:** Used for cutting threads in nuts.

However the quality of the threads will depend upon the perfection of the taps and skill of the operator.

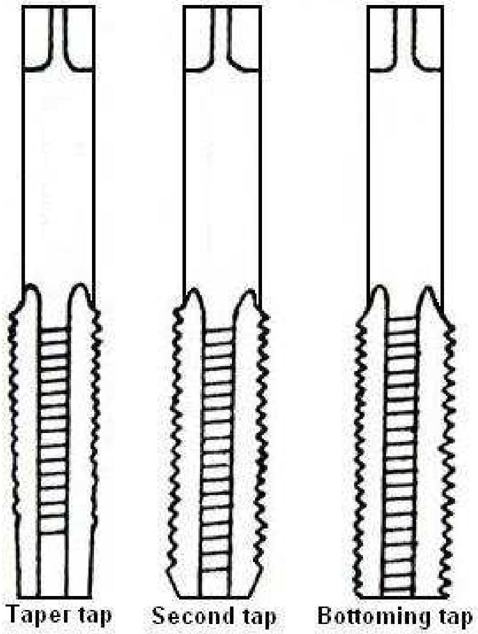


Fig. 2.48 (a) Hand operated taps

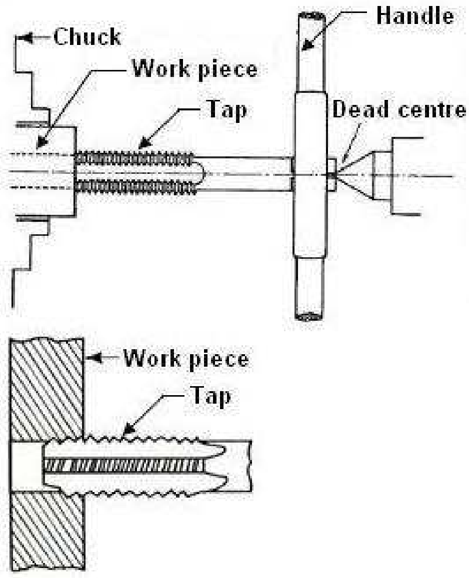


Fig. 2.48 (b) Hand operated tapping in centre lathe

2.6.5.2 Internal thread cutting by milling cutters

The typical internal thread milling cutters are shown in Fig. 2.49. This cutter produces internal threads very rapidly. The principle of operation is similar to that of an external short thread milling.

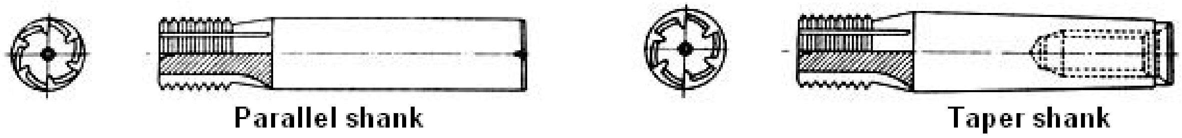


Fig. 2.49 Internal thread milling cutters

2.7 SPECIAL ATTACHMENTS

Each general purpose conventional machine tool is designed and used for a set of specific machining work on jobs of limited range of shape and size. But often some unusual work also need to be done in a specific machine tools, e.g. milling in a lathe, tapping in a drilling machine, gear teeth cutting in shaping machine and so on. Under such conditions, some special devices or systems are additionally used being mounted in the ordinary machine tools. Such additional special devices, which augment the processing capability of any ordinary machine tool, are known as attachments. Unlike accessories, attachments are not that inevitable and procured separately as and when required and obviously on extra payment.

Conditions and places suitable for application of attachments in machine tools

With the rapid and vast advancement of science and technology, the manufacturing systems including machine tools are becoming more and more versatile and productive on one hand for large lot or mass production and also having flexible automation and high precision on the other hand required for production of more critical components in pieces or small batches. With the increase of versatility and precision (e.g., CNC machines) and the advent of dedicated high productive special purpose machines, the need of use of special attachments is gradually decreasing rapidly.

However, some attachments are occasionally still being used on non automatic general purpose machine tools in some small and medium scale machining industries:

- When and where machining facilities are very limited.
- When production requirement is very small, may be few pieces.
- Product changes frequently as per job order.
- Repair work under maintenance, especially when spare parts are not available.
- When CNC machine tools and even reasonable number of conventional machine tools cannot be afforded.

Therefore, use of aforesaid attachments is restricted to manufacture of unusual jobs in small quantities under limited facilities and at low cost.

2.7.1 Taper turning attachment

The construction and working principle of the taper turning attachment has been described in Article 2.5.4, Page 66 and illustrated in Fig. 2.35.

2.7.2 Copy turning attachments

The two common types of copy turning attachments are:

2.7.2.1 Mechanical copy turning attachment

A simple mechanical type copy turning attachment is schematically shown in Fig. 2.50. The entire attachment is mounted on the saddle after removing the cross slide from that. The template replicating the job-profile desired is clamped at a suitable position on the bed. The stylus is fitted in the spring loaded tool slide and while travelling longitudinally along with saddle moves in transverse direction according to the template profile enabling the cutting tool produce the same profile on the job as indicated in the Fig. 2.50.

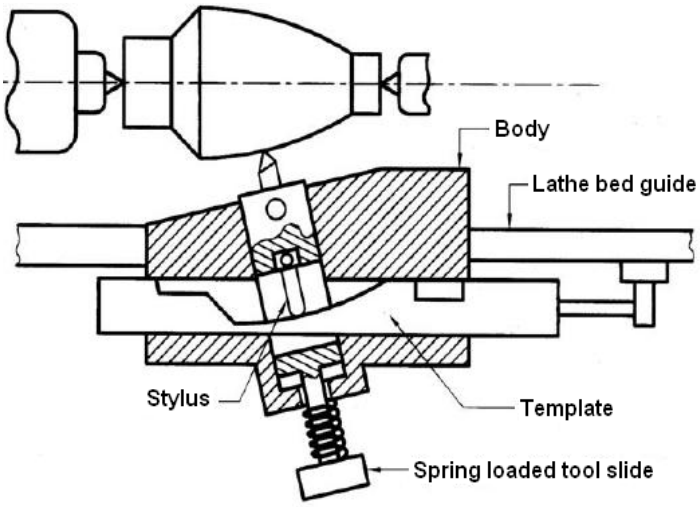


Fig. 2.50 Mechanical type copying attachment

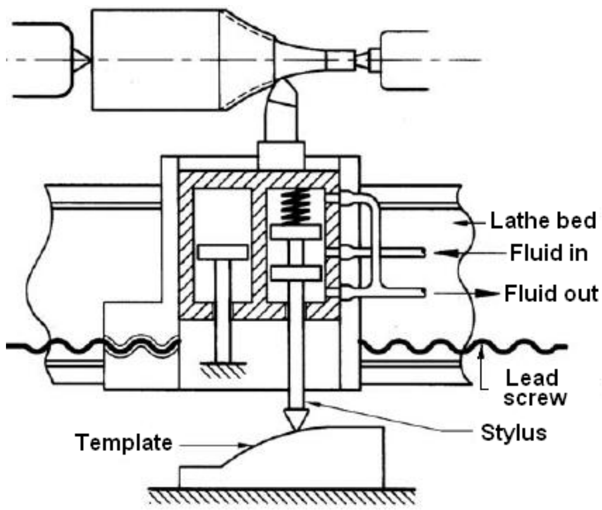


Fig. 2.51 Hydraulic copying attachment

2.7.2.2 Hydraulic copy turning attachment

The mounting and working principle of hydraulic copying attachment for profile turning in centre lathe are schematically shown in Fig. 2.51. Here also, the stylus moves along the template profile to replicate it on the job. In mechanical system *(Fig. 2.50)* the heavy cutting force is transmitted at the tip of the stylus, which causes vibration, large friction and faster wear and tear. Such problems are almost absent in hydraulic copying, where the stylus works simply as a valve spool against a light spring and is not affected by the cutting force. Hydraulic copying attachment is costlier than the mechanical type but works much smoothly and accurately. The cutting tool is rigidly fixed on the cross slide which also acts as a valve cum cylinder *as shown in Fig 2.51.*

So long the stylus remains on a straight edge parallel to the lathe bed, the cylinder does not move transversely and the tool causes straight turning. As soon as the stylus starts moving along a slope or profile, i.e., in cross feed direction the ports open and the cylinder starts moving accordingly against the piston fixed on the saddle. Again the movement of the cylinder i.e., the slide holding the tool, by same amount travelled by the stylus, and closes the ports. Repeating of such quick incremental movements of the tool, Δx and Δy result in the profile with little surface roughness.

2.7.3 Radius turning attachment

In this attachment, the cross slide is attached to the bed by means of a radius arm whose length is equal to the radius of the spherical component to be produced. The radius arm couples any movement of the cross slide or the carriage and hence the tool tip traces the radius R. *This is illustrated in Fig. 2.52.*

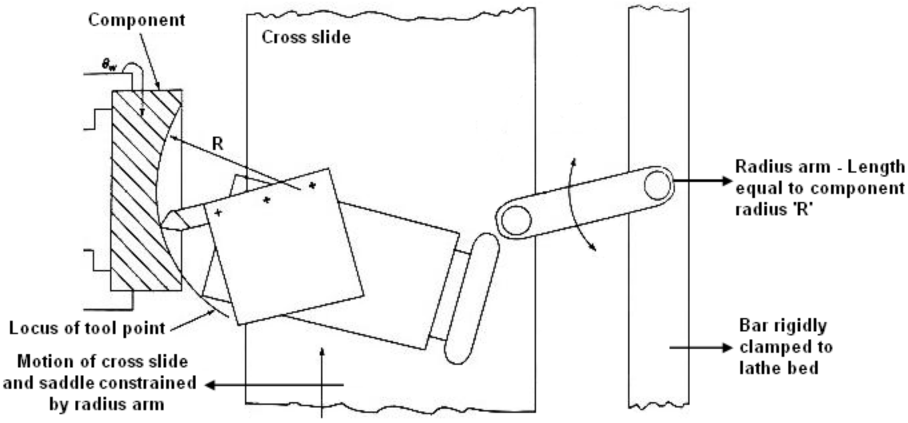


Fig. 2.52 Radius turning attachment

2.7.4 Spherical turning attachment

These simple attachments are used in centre lathes for machining spherical; both convex and concave surfaces and similar surfaces. *Fig. 2.53 schematically visualizes the usual setting and working principle of such attachments. In Fig. 2.53 (a),* the distance R_i can be set according to the radius of curvature desired. *In the type shown in Fig. 2.53 (b),* the desired path of the tool tip is controlled by the profile of the template which is pre-made as per the radius of curvature required. The saddle is disconnected from the feed rod and the lead-screw. So when the cross slide is moved manually in transverse direction, the tool moves axially freely being guided by the template only.

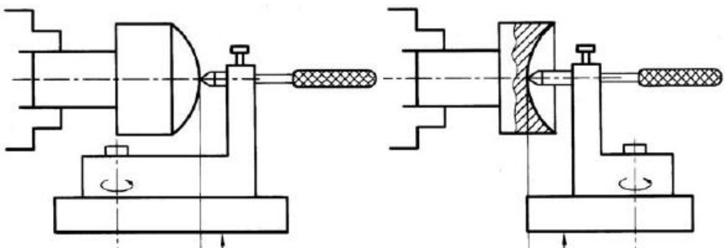


Fig. 2.53 (a) Spherical turning without template

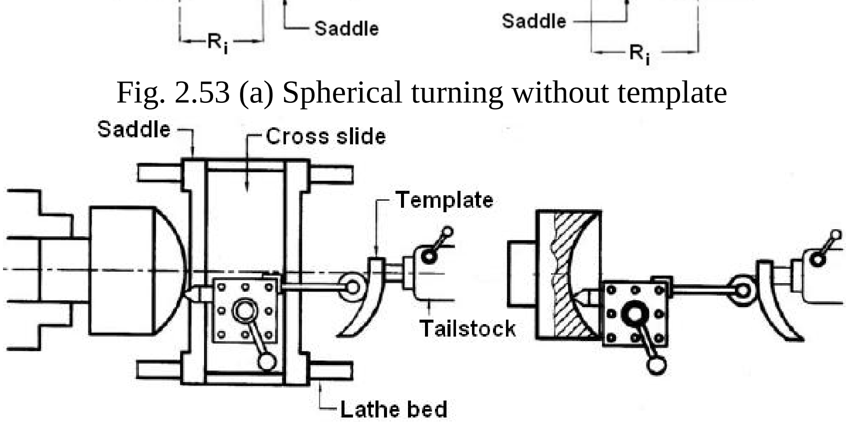


Fig. 2.53 (b) Spherical turning using template

2.7.5 Milling attachment

For cutting grooves or keyways Here, the work piece is held on the cross slide by using a special attachment and the end milling cutter is held in the chuck. Then the feed is given by a vertical slide provided on the special attachment. *Fig. 2.54 (a) shows a typical end milling attachment.*

For cutting multiple grooves and gear The attachment has a milling head, comprising a motor, a small gear box and a spindle to hold the milling cutter, mounted on the saddle after removing the cross slide etc., *as shown in Fig. 2.54 (b).* The work piece is held stationary between centres. The feeding is given by the carriage and vertical movement is given by the provision made on the attachment. Grooves are made on the periphery of the work piece by rotating the work piece. For cutting gears, a universal dividing head is fitted on the rear end of the headstock spindle to divide the work equally.

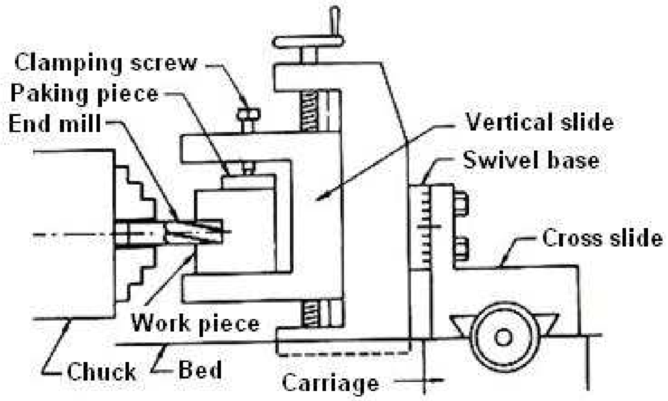


Fig. 2.54 (a) End milling attachment

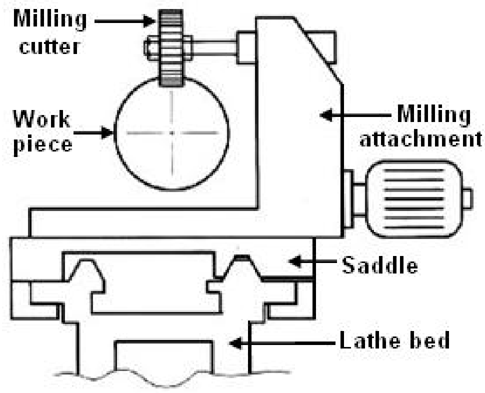


Fig. 2.54 (b) Milling attachment

2.7.6 Cylindrical grinding attachment

Grinding attachment is very similar to milling attachment. It has a bracket. It is mounted on the cross slide. A grinding wheel attached to the bracket is driven by a separate motor. The work piece may be held between centres or in a chuck. The grinding wheel is fed against the work piece. In this operation both work piece and grinding wheel rotate. By using this attachment both the external and internal grinding operation can be done. *Fig. 2.55 Shows a typical grinding attachment used in centre lathe.*

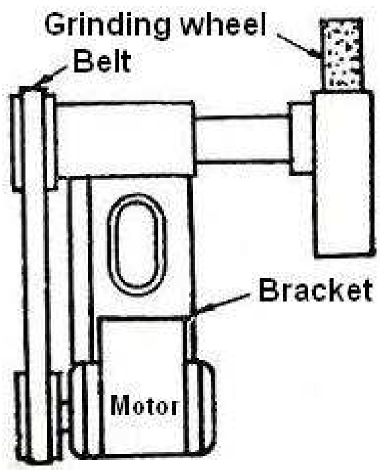


Fig. 2.55 Cylindrical grinding attachment

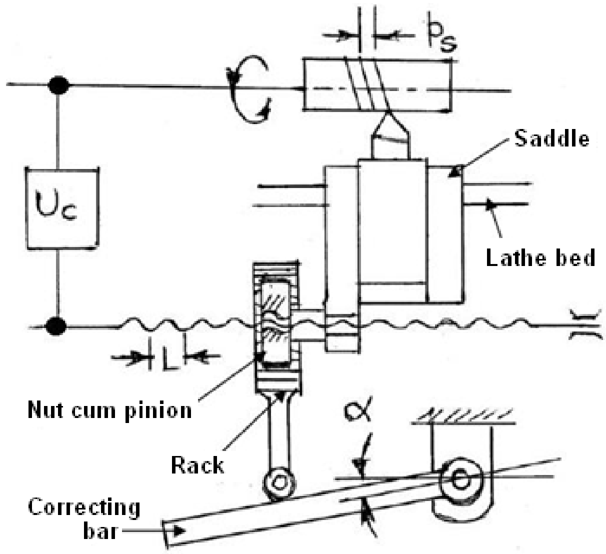


Fig. 2.56 Thread pitch correcting attachment

2.7.7 Thread pitch correcting attachment

While cutting screw thread in centre lathes by single point chasing tool, often the actual pitch, p_a deviates from the desired (or stipulated) pitch, p_s by an error (say $\pm \Delta p$) due to some kinematic error in the lathe. *Mathematically:* $\mathbf{p_s - p_a = \pm \Delta p}$ 2.10

Therefore for correct pitch, the error ± Δp need to be compensated and this may be done by a simple differential mechanism, namely correcting bar attachment *as schematically indicated in Fig. 2.56. In equation 4.6.1:*

$$p_a = U_C.L \quad (2.11)$$

$$\pm \Delta p = p_s.L \tan(\pm\alpha) / (\pi m Z) \quad (2.12)$$

where, UC - Transmission ratio.
L - Lead of the lead screw.
M - Module of teeth.
Z - No. of teeth of the gear fixed with the nut and is additionally rotated slightly by the movement of the rack along the bar.

Such differential mechanism of this attachment can also be used for intentionally cutting thread whose pitch will be essentially slightly more or less than the standard pitch, as it may be required for making differential screws having threads of slightly different pitch at two different locations of the screw.

2.7.8 Relieving attachment

The teeth of form relieved milling cutters like gear milling cutters, taps, hobs etc. are provided with flank having Archimedean spiral curvature. Machining and grinding of such curved flanks of the teeth need relieving motion to the tool (or wheel) *as indicated in Fig. 2.57 (a). The attachment schematically shown in Fig. 2.57 (b)* is comprised of a spring loaded bracket which holds the cutting tool and is radially reciprocated on the saddle by a plate cam driven by the feed rod as indicated.

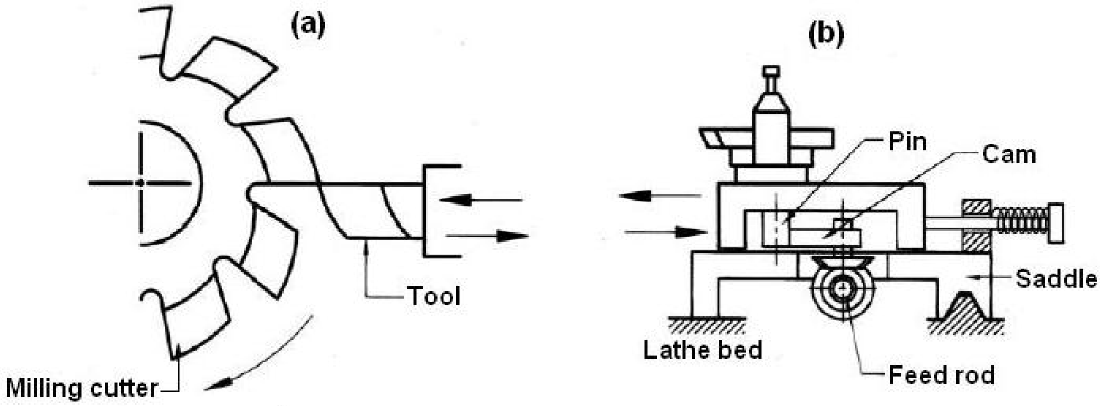


Fig. 2.57 Relieving attachment used in lathe

2.7.9 Super finishing attachment

Super finishing attachment used on a centre lathe is shown in Fig. 2.58 (a and b). Major parts and operating elements of super finishing attachment are discussed below:

Support bar: It is clamped into the tool holder of the lathe, and the super finishing attachment is fastened to the round shaft. It can be turned into right position to the work piece and then fixed.

Stone guide: The stone guide consists of an air cylinder with piston, to which the stone holder is fastened. It is operated by the control valve. By actuating this valve, the stone moves against the work piece. The stone guide is connected with the attachment by means of a dovetail guide, allowing longitudinal adjustment and fastening in every position desired. The attachment can be provided with a second stone guide to attain a double efficiency when machining larger work piece, or for finishing two bearing sections at the same time.

Stone holder: The stone holders are fastened in the position rod of the stone guide by means of their spherical head part. The universal movability allows the stone to be set precisely in the work piece.

Stroke regulation valve: This Valve is used for regulating the oscillation stroke. The stroke is lengthened by turning the valve to the left and reduced by turning to the right up to its complete stop.

Stroke value indicator: The stone guide is provided with a scale showing two crossing straight lines. The stroke value can be read off from the apparent intersection of this straight line.

Pressure gauge: The gauge indicates the pressure applied to the piston of the stone guide. Stone pressure = Gauge indication x Piston surface of stone guide.

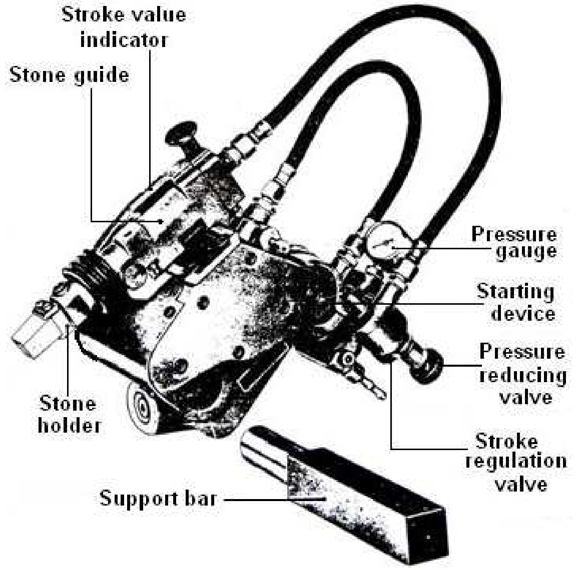


Fig. 2.58 (a) Super finishing attachment

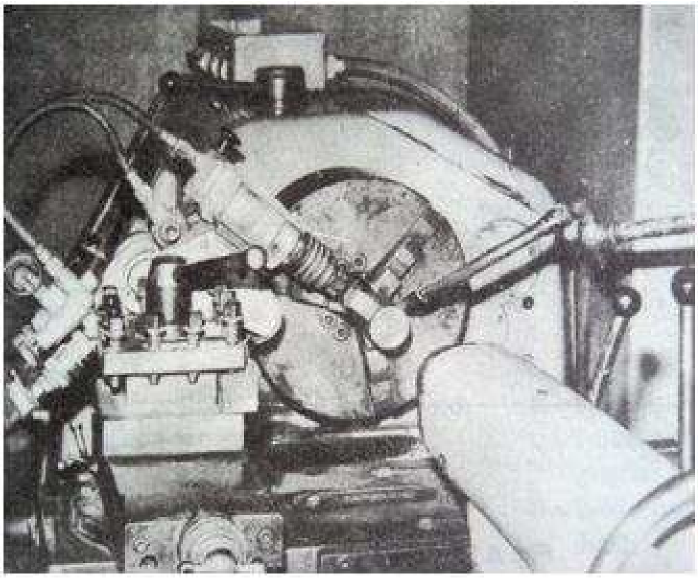


Fig. 2.58 (b) Super finishing attachment on a centre lathe

2.8 MACHINING TIME AND POWER ESTIMATION

2.8.1 Machining time

Cutting speed **(V)** = $\frac{\pi DN}{1000}$ m / min 2.13

where, D – Mean diameter of the work piece (mm).
N – Rotational speed of the work piece (rpm).

The time (t) for a single pass is given by

$$t = \frac{L + L_o}{fN} \text{ min} \quad 2.14$$

where, L – Length of the work piece (mm).
L_o – Over travel of the tool (mm).
f – Feed rate (mm / rev).

The number of roughing passes (P_r) is given by

$$P_r = \frac{A - A_f}{d_r} \quad 2.15$$

where, A – Total machining allowance (mm).
A_f – Finish machining allowance (mm).
D_r – Depth of cut in roughing (mm).

The number of finishing passes (P_f) is given by

$$P_f = \frac{A_f}{d_f} \quad 2.16$$

where, d_f – depth of cut in finishing (mm).

2.8.2 Power estimation

Power is the product of cutting force and velocity. In machining process, force component is nothing but the force in the direction of cutting speed. This only considered. Forces in the direction of feed and depth are too small when compared to the force in the direction of cutting speed. So, these two are insignificant. Force involved in orthogonal cutting is the force component in the direction of cutting speed. E.g. turning, facing, parting-off operations, etc. so;

Power required **(W_C) = F_C x V** 2.17

where, V – Cutting speed (m/min) and F_C – Force in the direction of cutting speed (N).

Due to shear and friction, the total power is divided into two components. They are;

1. Power due to shear.
2. Power due to friction.

So, Total power = Power due to shear + Power due to friction

$$\mathbf{W_C = W_s + W_f = [F_s \times V_s] + [F_f \times V_f]} \quad 2.18$$

where, F_s – Force due to shear.
V_s – Velocity of shear.
F_f – Force due to friction.
V_f – Velocity of friction.

2.8.3 Tool force dynamometers

To estimate power required for machining operations, the force has to be measured by a suitable measuring instruments. Generally, cutting forces in cutting tool are measured in different ways such as: *Dynamometer, Ammeter, Wattmeter, Calorimeter, Thermocouple, etc.* Among these, dynamometers are generally used for measuring cutting forces. Especially, strain gauge dynamometers are used. In this case, spring deflection is measured which is proportional to the cutting forces.

2.8.3.1 Design requirements for Tool force Dynamometers

For consistently accurate and reliable measurement, the following requirements are considered during design and construction of any tool force dynamometers:

- *Sensitivity:* The dynamometer should be reasonably sensitive for precision measurement.
- *Rigidity:* The dynamometer need to be quite rigid to withstand the forces without causing much deflection which may affect the machining condition.
- *Cross Sensitivity:* The dynamometer should be free from cross sensitivity such that one force (say P_Z) does not affect measurement of the other forces (say P_X and P_Y).
- Stability against humidity and temperature.
- Quick time response.
- High frequency response such that the readings are not affected by vibration within a reasonably high range of frequency.
- *Consistency:* The dynamometer should work desirably over a long period.

2.8.3.2 Construction and working principle of turning dynamometers

The dynamometers being commonly used nowadays for measuring machining forces accurately and precisely (both static and dynamic characteristics) are either strain gauge type or piezoelectric type. Strain gauge type dynamometers are inexpensive but less accurate and consistent, whereas, the piezoelectric type are highly accurate, reliable and consistent but very expensive for high material cost and rigid construction.

Turning dynamometers may be strain gauge or piezoelectric type and may be of one, two or three dimensions capable to monitor all of P_X, P_Y and P_Z. For ease of manufacture and low cost, strain gauge type turning dynamometers are widely used and preferably of 2D for simpler construction, lower cost and ability to provide almost all the desired force values.

Design and construction of a strain gauge type 2D turning dynamometer is shown schematically in Fig. 2.59 (a and b) and Fig. 2.59 (c) shows the photographic view. Two full bridges comprising four live strain gauges are provided for P_Z and P_X channels which are connected with the strain measuring bridge for detection and measurement of strain in terms of voltage which provides the magnitude of the cutting forces through calibration. *Fig. 2.59 (d) shows the photographic view of a piezoelectric type 3D turning dynamometer.*

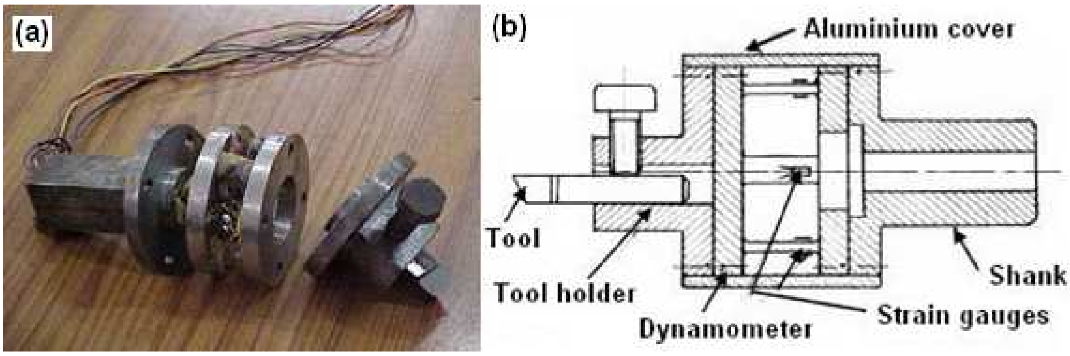


Fig. 2.59 (a and b) Construction of a strain gauge type 2D turning dynamometer

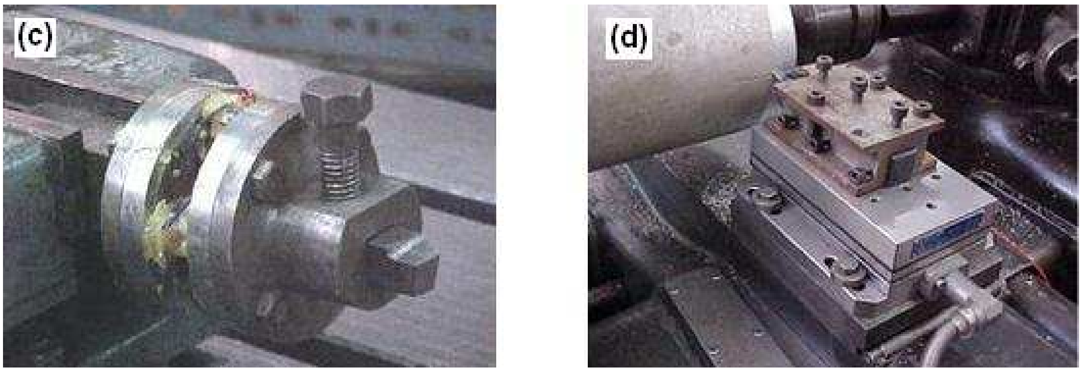


Fig. 2.59 (c) Photographic view of a strain gauge type 2D turning dynamometer
Fig. 2.59 (d) Photographic view of a piezoelectric type 3D turning dynamometer

2.9 SPECIAL PURPOSE LATHES

The centre lathe is a general purpose machine tool; it has a number of limitations that preclude it to become a production machine tool. The main limitations of centre lathes are:

- The setting time for the job in terms of holding the job is large.
- Only one tool can be used in the normal course. Sometimes the conventional tool post can be replaced by a square tool post with four tools.
- The idle times involved in the setting and movement of tools between the cuts is large.
- Precise movement of the tools to destined places is difficult to achieve if proper care is not taken by the operator.

All these difficulties mean that the centre lathe cannot be used for production work in view of the low production rate. The centre lathe is thus modified to improve the production rate. The various modified lathes are capstan and turret lathes, semi automatics and automatics. Improvements are achieved basically in the following areas:

- Work holding methods.
- Multiple tool availability.
- Automatic feeding of the tools.
- Automatic stopping of tools at precise locations.
- Automatic control of the proper sequence of operations.

2.10 CAPSTAN AND TURRET LATHES

Capstan and turret lathes are production lathes used to manufacture any number of identical pieces in the minimum time. These lathes are development of centre lathes. The capstan lathe was first developed in the year 1860 by Pratt and Whitney of USA.

In contrast to centre lathes, capstan and turret lathes:

- Are relatively costlier.
- Are requires less skilled operator.
- Possess an axially movable indexable turret (mostly hexagonal) in place of tailstock.

- Holds large number of cutting tools; up to four in indexable tool post on the front slide, one in the rear slide and up to six in the turret (if hexagonal) as indicated in the schematic diagrams.
- Are more productive for quick engagement and overlapped functioning of the tools in addition to faster mounting and feeding of the job and rapid speed change.
- Enable repetitive production of same job requiring less involvement, effort and attention of the operator for pre-setting of work-speed and feed rate and length of travel of the cutting tools.
- Are suitable and economically viable for batch production or small lot production.
- Capable of taking multiple cuts and combined cuts at the same time.

2.10.1 Major parts of capstan and turret lathes

Capstan and turret lathes are very similar in construction, working, application and specification. *Fig. 2.60 schematically shows the basic configuration of a capstan lathe and Fig. 2.61 shows that of a turret lathe.* The major parts are:

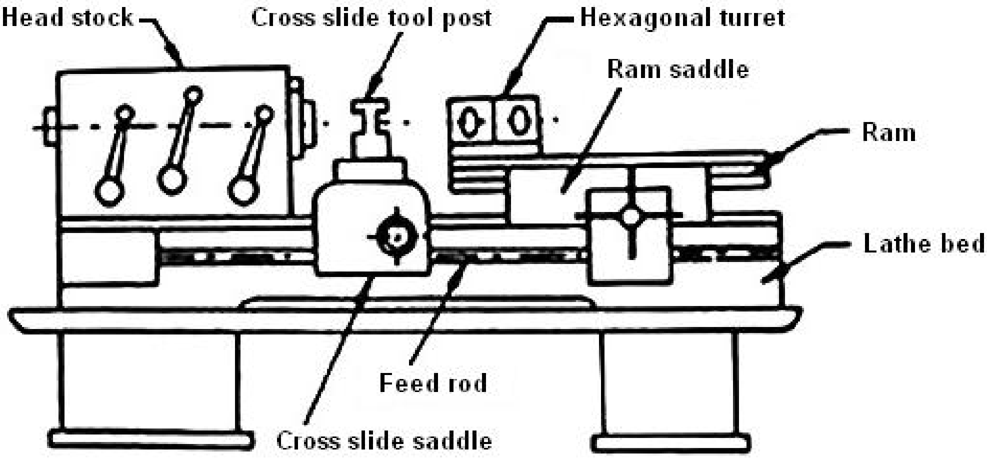


Fig. 2.60 Basic configuration of a Capstan lathe

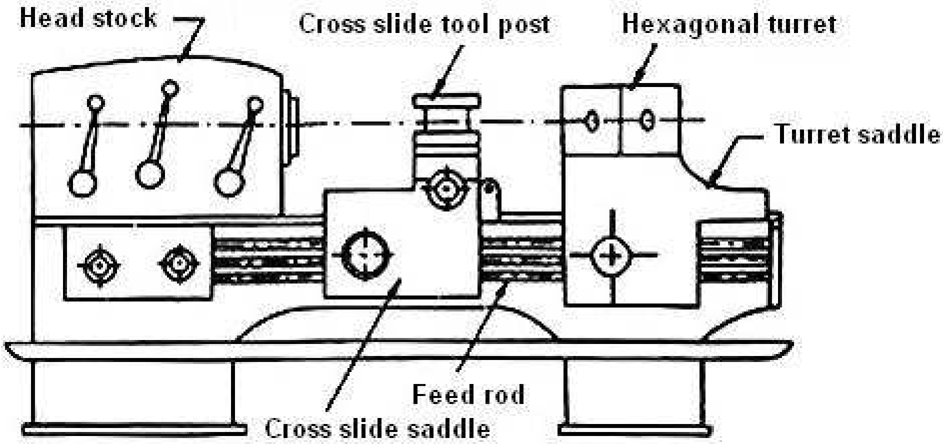


Fig. 2.61 Basic configuration of a Turret lathe

Bed The bed is a long box like casting provided with accurate guide ways upon which the carriage and turret saddle are mounted. The bed is designed to ensure strength, rigidity and permanency of alignment under heavy duty services.

Headstock The head stock is a large casting located at the left hand end of the bed. *The headstock of capstan and turret lathes may be of the following types:*

- Step cone pulley driven headstock.
- Direct electric motor driven headstock.
- All geared headstock.
- Pre-optive or pre-selective headstock.

Step cone pulley driven headstock: This is the simplest type of headstock and is fitted with small capstan lathes where the lathe is engaged in machining small and almost constant diameter of workpieces. Only three or four steps of pulley can cater to the needs of the machine. The machine requires special countershaft unlike that of an engine lathe, where starting, stopping and reversing of the machine spindle can be effected by simply pressing a foot pedal.

Electric motor driven headstock: In this type of headstock the spindle of the machine and the armature shaft of the motor are one and the same. Any speed variation or reversal is effected by simply controlling the motor. Three of four speeds are available and the machine is suitable for smaller diameter of workpieces rotated at high speeds.

All geared headstock: On the larger lathes, the headstocks are geared and different mechanisms are employed for speed changing by actuating levers. The speed changing may be performed without stopping the machine.

Pre-optive or pre-selective headstock: It is an all geared headstock with provisions for rapid stopping, starting and speed changing for different operations by simply pushing a button or pulling a lever. The required speed for next operation is selected beforehand and the speed changing lever is placed at the selected position. After the first operation is complete, a button or a lever is simply actuated and the spindle starts rotating at the selected speed required for the second operation without stopping the machine. This novel mechanism is effect by the friction clutches.

Cross slide and saddle In small capstan lathes, hand operated cross slide and saddle are used. They are clamped on the lathe bed at the required position. The larger capstan lathes and heavy duty turret lathes are equipped with usually two designs of carriage.

- Conventional type carriage.
- Side hung type carriage.

Conventional type carriage This type of carriage bridges the gap between the front and rear bed ways and is equipped with four station type tool post at the front, and one rear tool post at the back of the cross slide. This is simple in construction.

Side hung type carriage The side-hung type carriage is generally fitted with heavy duty turret lathes where the saddle rides on the top and bottom guide ways on the front of the lathe bed. The design facilitates swinging of larger diameter of workpieces without being interfered by the cross-slide. The saddle and the cross-slide may be fed longitudinally or crosswise by hand or power. The longitudinal movement of each tool may be regulated by using stop bars or shafts set against the stop fitted on the bed and carriage. The tools are mounted on the tool post and correct heights are adjusted by using rocking or packing pieces.

Ram saddle In a capstan lathe, the ram saddle bridges the gap between two bed ways, and the top face is accurately machined to provide bearing surface for the ram or auxiliary slide. The saddle may be adjusted on lathe bed ways and clamped at the desired position. The hexagonal turret is mounted on the ram or auxiliary slide.

Turret saddle In a turret lathe, the hexagonal turret is directly mounted on the top of the turret saddle and any movement of the turret is effected by the movement of the saddle. The movement of the turret may be effected by hand or power.

Turret The turret is a hexagonal-shaped tool holder intended for holding six or more tools. Each face of the turret is accurately machined. Through the centre of each face accurately bored holes are provided for accommodating shanks of different tool holders. The centre line of each hole coincides with the axis of the lathe when aligned with the headstock spindle. In addition to these holes, there are four tapped holes on each face of the turret for securing different tool holding attachments. *The photographic view of a hexagonal turret is shown in Fig. 2.62.*

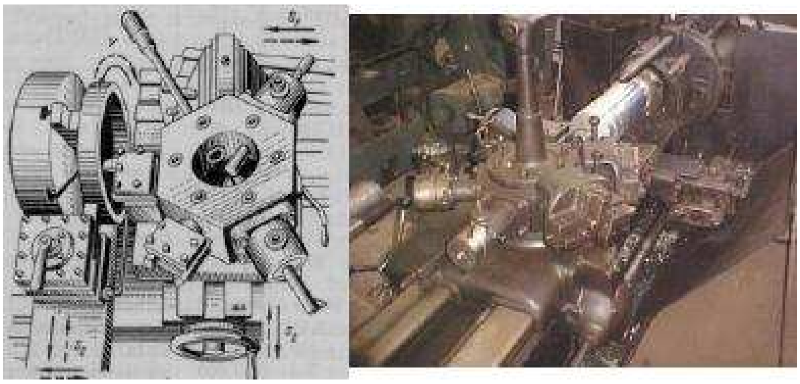


Fig. 2.62 Photographic view of a hexagonal turret

2.10.2 Working principle of capstan and turret lathes

The work pieces are held in collets or chucks. In turret lathes, large work pieces are held by means of jaw chucks. These chucks may be hydraulically or pneumatically operated. In a capstan lathe, bar stock is held in collet chucks. A bar feeding mechanism is used for automatic feeding of bar stock. At least eleven tools can be set at a time in turret and capstan lathes. Six tools are held on the turret faces, four tools in front square tool post and one parting off tool at the rear tool post. While machining, the turret head moves forward towards the job. After each operation, the turret head goes back. The turret head is indexed automatically and the next tool comes into machining position. The indexing is done by an indexing mechanism. The longitudinal movement of the turret corresponding to each of the turret position can be controlled independently.

By holding different tools in the turret faces, the operations like drilling, boring, reaming, counter boring, turning and threading can be done on the component. Four tools held on the front tool post are used for different operations like necking, chamfering, form turning and knurling. The parting off tool in the rear tool post is used for cutting off the workpiece. The cross wise movements of the rear and front tool posts are controlled by pre-stops.

2.10.3 Bar feeding mechanisms

The capstan and turret lathes while working on bar work require some mechanism for bar feeding. The long bars which protrude out of the headstock spindle require to be fed through the spindle up to the bar stop after the first piece is completed and the collet chuck is opened. In simple cases, the bar may be pushed by hand. But this process unnecessarily increases the total production time by stopping, setting, and starting the machine. Therefore, various types of bar feeding mechanisms have been designed which push the bar forward immediately after the collet releases the work without stopping the machine, enabling the setting time to be reduced to the minimum.

Type 1: *This mechanism is shown in Fig. 2.63.* After the work piece is complete and part off, the collet is opened by moving the lever manually in the rightward direction. Further movement of the lever in the same direction causes forward push of the bar with the help of ratchet - pawl system. After the projection of the bar from the collet face to the desired length controlled by a preset bar stop generally held in one face of the turret, the lever is moved in the leftward direction to close the collet. Just before closing the collet, the leftward movement of the lever pushes the ratchet bar to its initial position.

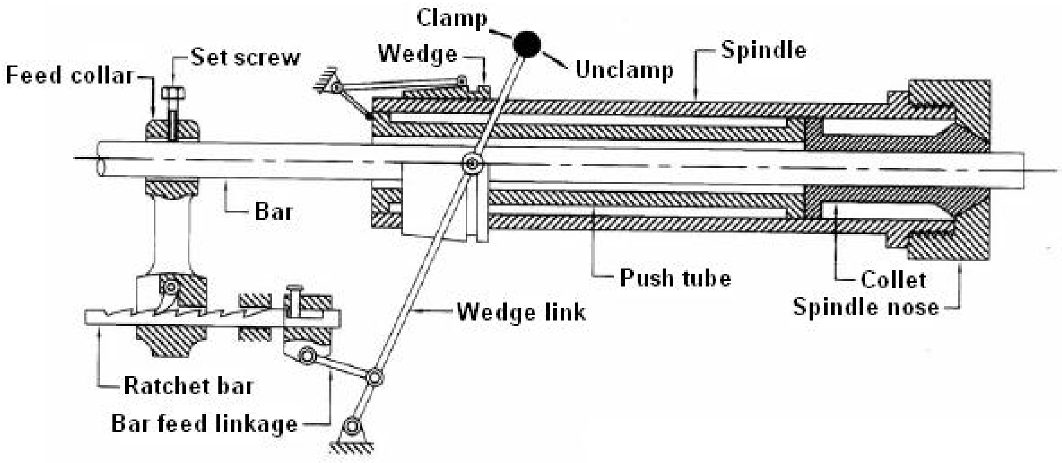


Fig. 2.63 Bar feeding mechanism

Type 2: *This mechanism is shown in Fig. 2.64.* The bar is passed through the bar chuck, spindle of the machine and then through the collet chuck. The bar chuck rotates in the sliding bracket body which is mounted on a long sliding bar. The bar chuck grips the bar centrally by two set screws and rotates with the bar in the sliding bracket body. One end of the chain is connected to the pin fitted on the sliding bracket and the other end supports a weight. The chain running over two fixed pulleys mounted on the sliding bar. The weight constantly exerts end thrust on the bar chuck while it revolves on the sliding bracket and forces the bar through the spindle at the moment the collet chuck is released. Thus bar feeding may be accomplished without stopping the machine.

In this way the bar is fed without stopping the machine. After a number of such feedings, the bar chuck will approach the rear end of the head stock. Now the bar chuck is released from the bar and brought to the left extreme position. Then it is screwed on to the bar.

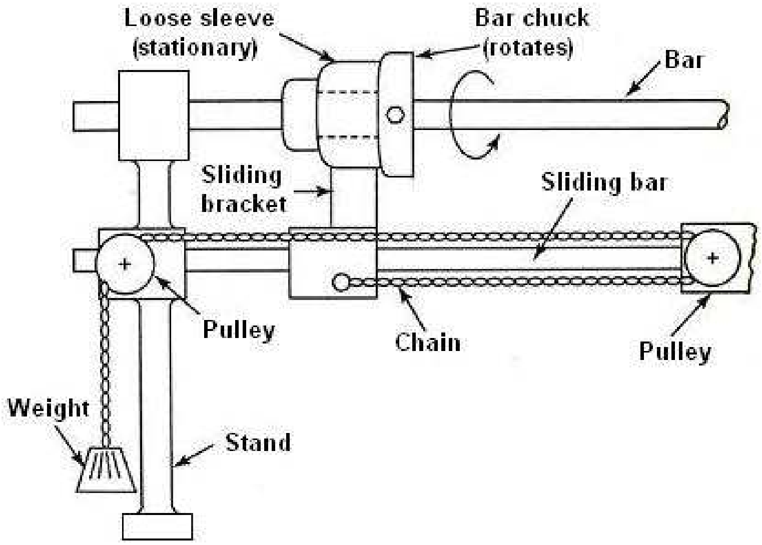


Fig. 2.64 Bar feeding mechanism

2.10.4 Turret indexing mechanism

Construction: *Fig. 2.65 shows the schematic view of the turret indexing mechanism.* It illustrates an inverted plan of the turret assembly. This mechanism is also called as Geneva mechanism. There is a small vertical spindle fixed on the turret saddle. At the top of the spindle, the turret head is mounted. Just below the turret head on the same spindle, a circular index plate having six slots, a bevel gear and a ratchet are mounted. There is a spring actuated plunger mounted on the saddle which locks the index plate this prevents the rotation of turret during the machining operation. A pin fitted on the plunger projects out of the housing. An actuating cam and an indexing pawl are fitted to the lathe bed at the required position. Both cam and pawl are spring loaded.

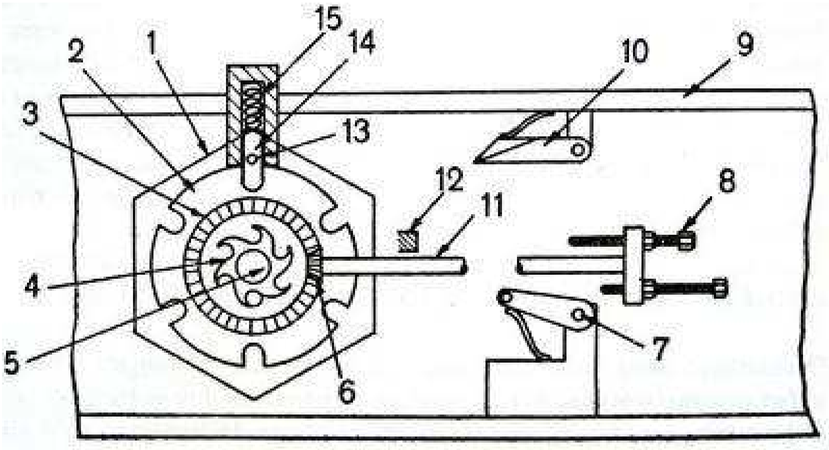


Fig. 2.65 Turret indexing mechanism

Working principle: When the turret reaches the backward position (after machining) the projecting pin of the plunger rides over the sloping surface of the cam. So the plunger is released from the groove of the index plate. Now the spring loaded pawl engages the ratchet groove and rotates it. The index plate and the turret spindle rotate through 1/6 of a revolution. The pin and the plunger drop out of the cam and hence the plunger locks the index plate at the next groove. The turret is thus indexed and again locked into the new position automatically. The turret holding the next tool is now fed forward and the pawl is released from the ratchet plate by the spring pressure.

The corresponding movement of the stop rods with the indexing of the turret can also be understood from the Fig. 2.65. The pinion shaft has a bevel pinion at one end. The bevel pinion meshes with the bevel gear mounted on the turret spindle. At its other end, a circular plate is connected. Six adjustable stop rods are fitted to this circular plate. When the turret rotates, the bevel pinion will also rotate. And hence the circular stop plate is also indexed by 1/6 of a revolution. The ratio of the teeth between the pinion and the gear is chosen according to this rotation.

2.10.5 Work holding devices used in capstan and turret lathes

The standard practice of holding the work piece between two centres in a centre lathe finds no place in a capstan lathe or turret lathe as there is no dead centre to support the work piece at the other end. Therefore, the work piece is held at the spindle end by the help of chucks and fixtures. The usual methods of holding the work piece in a capstan and turret lathes are:

1. Jaw chucks

The jaw chucks are used in capstan lathes having two, three or four jaws depending upon the shape of the work piece. The jaw chucks are used to support odd sized jobs or jobs having larger diameter which cannot be introduced through the headstock spindle and gripped by collet chucks.

2-jaw chuck self centering chuck

It is used for bar work. The two jaws hold the irregular work more readily since the clamping is at two points which are diametrically opposite. It is available in size from about 125 mm to 250 mm outside diameter to hold bar stock of diameter from about 20 mm to 45 mm.

3-jaw chuck self centering chuck

It is used for holding round or hexagonal bar stock or other symmetrical work. It is suitable for gripping larger diameter bars, circular castings, forgings etc. It is available in size from about 100 mm to 750 mm outside diameter and they can hold work up to about 650 mm diameter. The 3-jaw chuck has been described in Article 2.2.5.1, Page 57 and illustrated in Fig. 2.10 (a).

4-jaw independent chuck

It is used occasionally for gripping irregular shaped workpieces, where the number of articles required does not justify the manufacture of special fixtures. It is used for holding rough castings and square or octagonal work. Each jaw can be operated independently and is reversible. It is available in sizes up to about 1000 mm diameter. The 4-jaw chuck has been described in Article 2.2.5.1, Page 57 and illustrated in Fig. 2.10 (b).

Combination chuck

The combination chuck is shown in Fig. 2.66. As the name implies, a combination chuck may be used both as a self centering and an independent chuck to take advantage of both the types. The jaws may be operated individually by separate screws or simultaneously by the scroll disc. The screws mounted on the frame have teeth cut on its underside which meshes with the scroll and all the jaws together with the screws move radially when the scroll is made to rotate by a pinion.

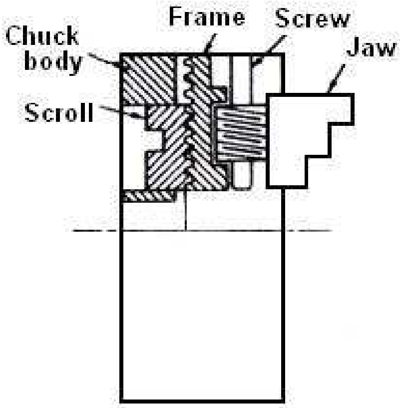


Fig. 2.66 Combination chuck

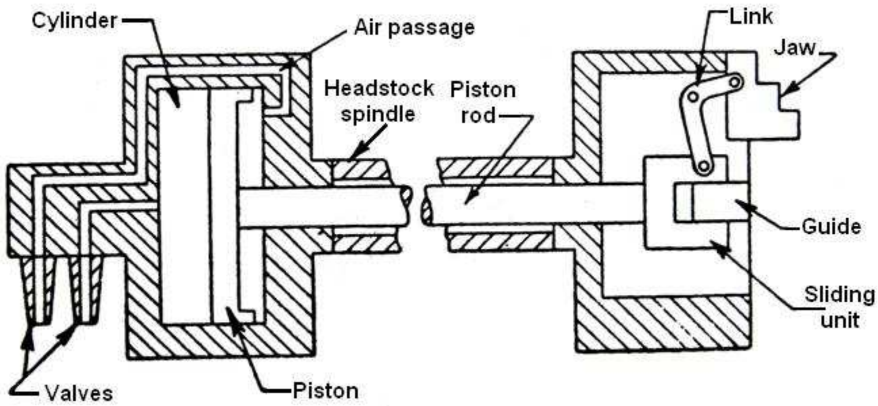


Fig. 2.67 Air operated chuck

Air operated chuck

The air operated chuck is shown in Fig. 2.67. Heavy duty turret lathes and capstan lathes engaged in mass production work are equipped with air operated chucks for certain distinct advantages. The chuck grips the work piece quickly and is capable of taking powerful grip with least manual exertion. The chucks are operated by air at a pressure of 5.5 kg/cm^2 to 7 kg/cm^2.

The mechanism incorporates an air cylinder mounted at the back end of the headstock spindle and rotates with it. Fluid pressure may be communicated to the cylinder by operating a valve with a lever and the piston will slide within the cylinder. The movement of the piston is transmitted to the jaws by means of connecting rod and links. A guide is provided for the movement of the connecting rod.

To clamp the work piece, compressed air is admitted to the cylinder at the right side of the piston. The piston slides to the left side and the jaws grip the work piece securely. To release the work piece, the air is admitted to the left side of the piston. Then the piston slides to the right side and the jaws unclamp the work piece.

2. Collet chucks

Collet chucks or collets are used mainly to hold bar stock, especially in the smaller sizes. A collet is a circular steel shell having three or four equally spaced slits extending the greater part of its length. These slits impart springing action to the collet. That is why, collets are also known as “spring collets”. The collet nose is made thicker to form the jaws. The outside surface of the nose fits in the taper hole of the hood. The inside of the collet is made according to the shape of the work to be held.

Collets are much more suitable than a self centering chuck in mass production work due to its quickness in action and accurate setting. The collets may be operated by hand or by power. The collets are classified by the methods used to close the jaws on the work.

Push out type Collet chuck

The push out type collet chuck is shown in Fig. 2.68 (a). In this type the taper of the collet nose and hood converge towards the right. To grip the work, the tapered portion of the spring collet is pushed into the mating taper of the hood. There is a tendency of the bar to be pushed slightly outward when the collet is pushed for gripping. If the bar is fed against a stop bar fitted on the turret head, this slight outward movement of the bar ensures accurate setting of the length for machining.

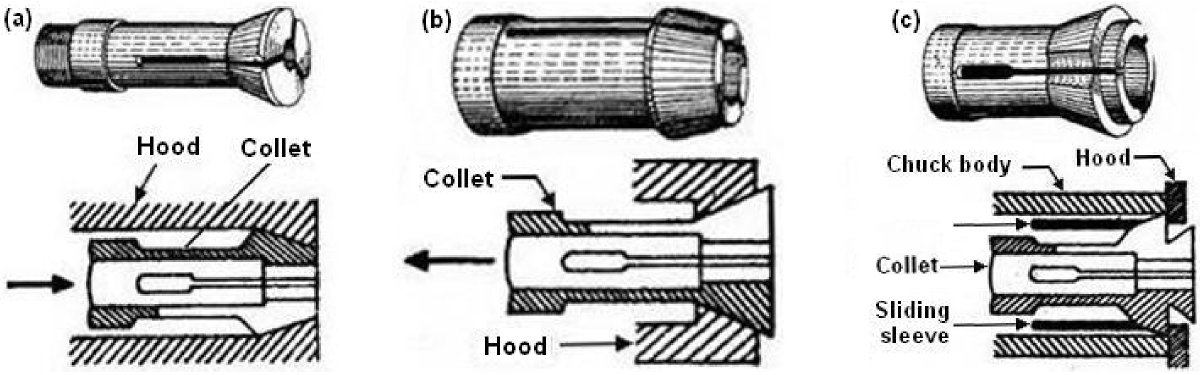


Fig. 2.68 Collet chucks (a) Push out type (b) draw back type (c) Dead length type

Draw back or Draw in type Collet chuck

The draw back type collet chuck is shown in Fig. 2.68 (b). In this type the taper of the collet nose and hood converge towards the left. To grip the work, the tapered portion of the spring collet is pulled back into the mating taper of the hood which causes the split end of the collet to close in and grip the bar. The machining length of the bar in this type of chuck cannot be accurately set as the collet while closing will draw the bar slightly inward towards the spindle.

Dead length type Collet chuck

The dead length type collet chuck is shown in Fig. 2.68 (c). For accurate positioning of the bar, both the push out and draw in type collet present some error due to the movement of the bar along with the collet while gripping. This difficulty is removed by using a stationary collet on the bar. In this type the taper of the collet nose converge towards the left. A sliding sleeve is placed between the collet and the hood. This sliding sleeve has a tapered edge which fits on the taper of the collet nose. To grip the work, the sliding sleeve is pushed towards the right. This makes the collet to close in and grip the bar. The end movement of the collet is prevented by the shoulder stop.

3. Fixtures

A fixture may be described as a special chuck built for the purpose of holding, locating and machining a large number of identical pieces which cannot be easily held by conventional gripping devices. Fixtures also serve the purpose of accurately locating the machining surface.

The main functions of a fixture are as follows:

- It accurately locates the work.
- It grips the work properly, preventing it from bending or slipping during machining operations.
- It permits rapid loading and unloading of workpieces.

2.10.6 Tool holding devices used in capstan and turret lathes

The wide variety of work performed in a capstan or turret lathe in mass production necessitated designing of many different types of tool holders for holding tools for typical operations. The tool holders may be mounted on turret faces or on cross-slide tool post and may be used for holding tools for bar and chuck work. Certain tool holders are used for holding tools for both bar and chuck work while box tools are particularly adapted in bar work.

Straight cutter holder

This is a simple tool holder constructed to take standard section tool bits. The shank of the holder can be mounted directly into the hole of the turret face or into a hole of a multiple turning head. In this type of holder, the tool is held perpendicular to the shank axis. The tool is gripped in the holder by three set screws. Different operations like turning, facing, boring, counter boring, chamfering, etc. can be performed by holding suitable tools in the holder. *Fig.2.69 illustrates a straight cutter holder*.

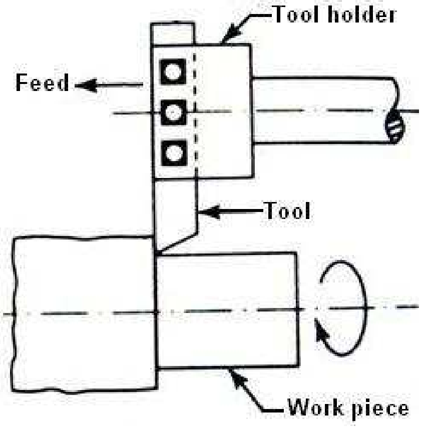


Fig. 2.69 straight cutter holder

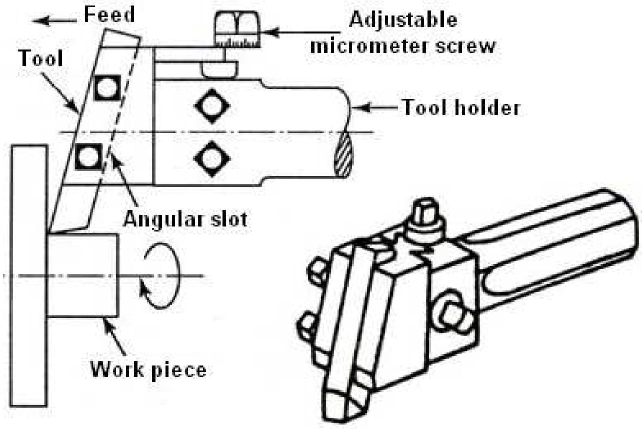


Fig. 2.70 Adjustable angle cutter holder

Plain or adjustable angle cutter holder

It is similar as that of a straight cutter holder but having an angular slot. The tool is fitted in this slot by means of setscrews. The inclination of the tool helps in turning or boring operations close to the chuck jaws or up to the shoulder of the work piece without any interference. In plain type of holder, the setting of the cutting edge relative to the work is effect by opening the set screws and then adjusting the tool by hand. In adjustable type of holder, the accurate setting of the tool can be effect by rotating a micrometer screw. *Fig.2.70 illustrates an adjustable angle cutter holder.*

Multiple cutter holder

This holder can accommodate two or more tools in its body. This feature enables turning of two different diameters simultaneously. This will reduce the time of machining. Turning and boring tools can also be set in the holder to perform two operations at a time. *Fig.2.71 illustrates a multiple cutter holder.*

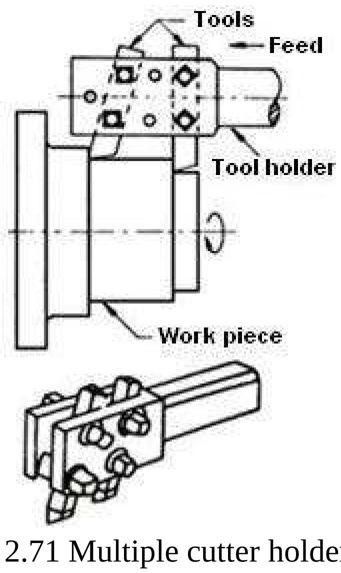


Fig. 2.71 Multiple cutter holder

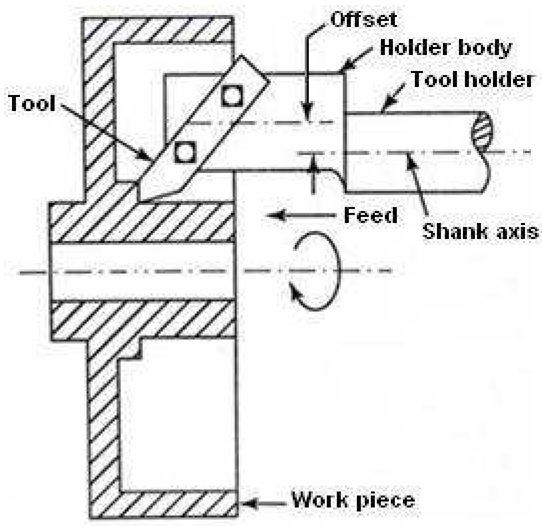


Fig. 2.72 Offset cutter holder

Offset cutter holder

In this type, the holder body is made offset with the shank axis. Larger diameter work can be turned or bored by this type of holder. *Fig.2.72 illustrates an offset cutter holder*.

Combination tool holder or multiple turning head

It is used for holding straight, angular, multiple or offset cutter holders, boring bars, etc. for various turning and boring operations, so that it may be possible to undertake a number of operations simultaneously. The tools are set at different positions on the work surface by inserting the shank of tool holders in different holes of the multiple head body, and they are secured to it by tightening separate set screws. A boring bar is held at the central hole of the head which is aligned with the axis of the supporting flange. The head is supported on the turret face by tightening four bolts passing through the holes of the flange. The tool holder has a guide bush. The pilot bar projecting from the head stock of the machine; slides inside the guide bush. This gives additional support to the tool while cutting and prevents any vibration or deflection. *Fig.2.73 illustrates a combination tool holder.*

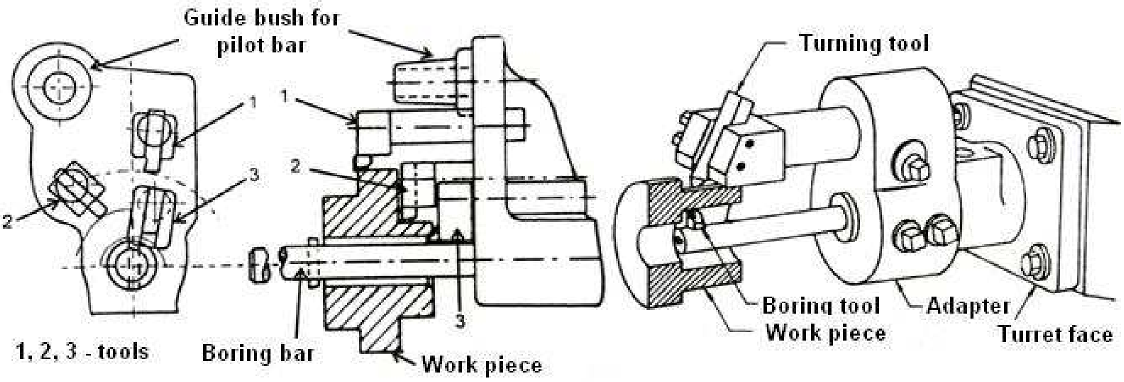


Fig. 2.73 Combination tool holder

Sliding tool holder

It is useful for rough and finish boring, recessing, grooving, facing, etc. The holder consists of a vertical base on which a slide is fitted. The slide may be adjusted up or down accurately by rotating a hand wheel provided with a micrometer dial. Two holes are provided on the sliding unit for holding tools. The lower hole which is aligned with the lathe axis is used for holding boring bars, drills, reamers, etc. The upper hole accommodates a turning tool holder. After necessary adjustments the slide is clamped to the base by a clamping lever for turning or boring operations. For facing or recessing operations, the crosswise movement of the tool is obtained in the vertical plane. The slide is equipped with two adjustable stops for facing or similar operations in order to be able to duplicate the workpiece. The holder base is clamped directly on the turret face by studs. *Fig.2.74 illustrates a sliding tool holder.*

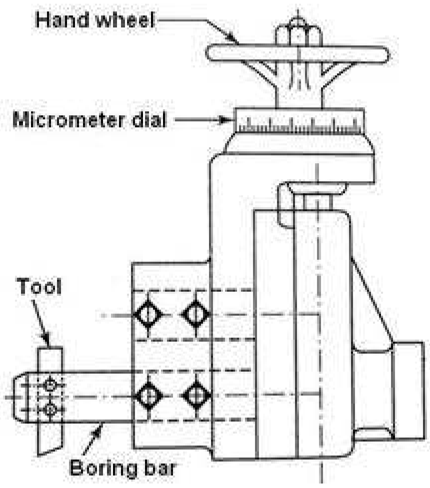


Fig. 2.74 Sliding tool holder

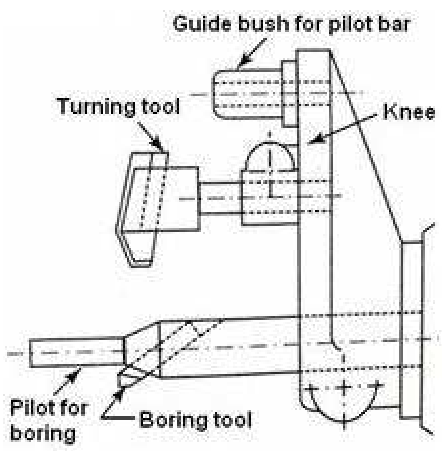


Fig. 2.75 Knee tool holder

Knee tool holder

It is useful for simultaneous turning and boring or turning and drilling operations. The knee holder is bolted directly on the turret face. The axis of the lower hole coincides with the lathe axis and is used for holding boring bars, drills, etc. The turning tool holder is fitted in to the centre hole. A guide bush is provided at the top of the holder for running of pilot bar. *Fig.2.75 illustrates a knee tool holder.*

Flange tool holder

This holder is also called as extension holder, drill holder or boring bar holder. These holders are intended for holding drills, reamers, boring bars, etc. The twist drills having Morse taper shanks are usually held in a socket which is parallel outside and tapered inside. The socket is introduced in the hole of the flange tool holder and clamped to it by set screws. The flanged end of the holder is bolted directly to the face of the turret and is accurately centered. *Fig.2.76 illustrates a flange tool holder.*

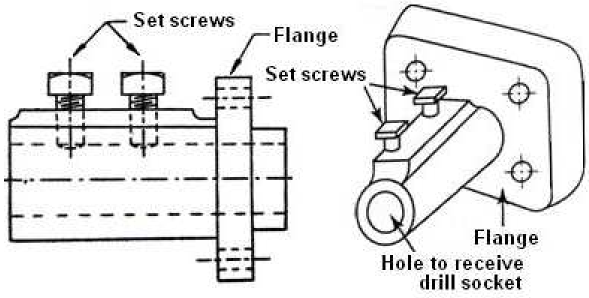


Fig. 2.76 Flange tool holder

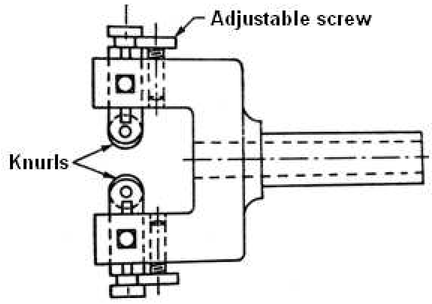


Fig. 2.77 Knurling tool holder

Knurling tool holder

It may be mounted on the turret face or on the tool posts of the cross-slide. The holders with knurls mounted on the cross-slide can perform knurling operation on any diameter work. *Fig 2.77 illustrates a knurling tool holder which is fitted on the turret face.* The position of knurls can be adjusted in a vertical plane to accommodate different diameters of work, while the relative angle between them can also be varied to produce different patterns of knurled surface.

Form tool holder

Two sets of form tool holders have been designed for holding straight and circular form cutters. The usual procedure of holding a form tool holder is on the cross-slide. In the straight form tool holder, the tool is mounted on a dovetail slide and the height of the cutting edge may be adjusted by moving the tool within the slide. The height of the circular form tool may be adjusted by rotating the circular cutter. *Fig.2.78 illustrates a form tool holder.*

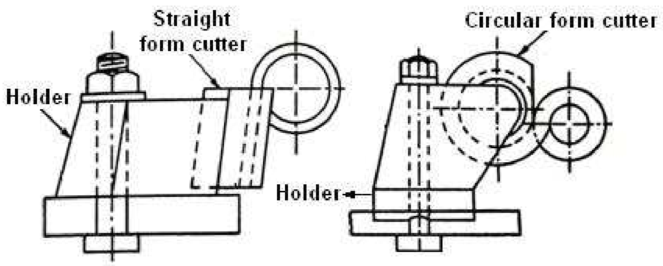


Fig. 2.78 Form tool holder

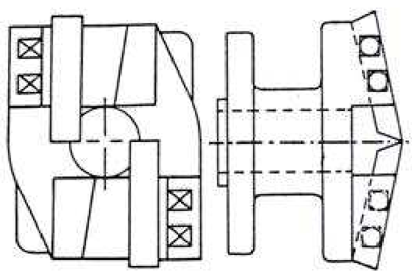


Fig. 2.79 Balanced tool holder

Balanced tool holder

Its name is derived from the fact that the tools mounted on the holder are so arranged that the cutting thrust exerted by one of the tools on the work is balanced by the cutting thrust developed by the other tool fitted on the holder. This prevents any bending of the work and obviates the use of any other work support. *Fig.2.79 illustrates a balanced tool holder.*

V-Steady tool holder

The V-steady box tool holders are used for lending support to the workpiece while cutting action progresses from the end of a bar stock. Both the tool and V-steady are mounted on the adjustable slide in order to set the required diameter of the machined part and to position the tool relative to the V-steady. The V-steady tool holder is mainly used in brass work. *Fig.2.80 illustrates a V-Steady tool holder.*

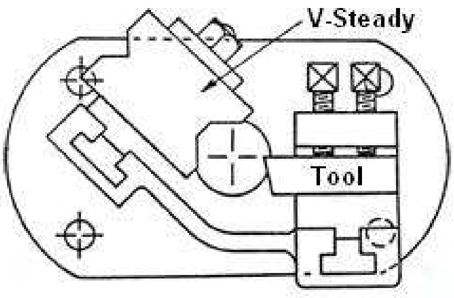


Fig. 2.80 V-Steady tool holder

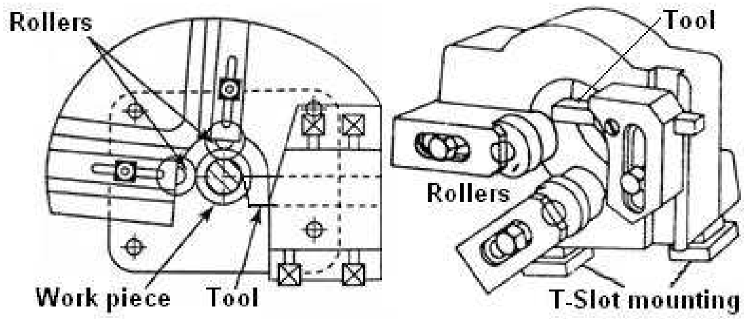


Fig. 2.81 Roller steady box tool holder

Roller steady box tool holder

It is commonly used in bar work for turning steel rods. In construction, it replaces V-steady and in its place two rollers are used to provide support to the work. The tool and the rollers can be adjusted in the holder for proper setting. A high class finish is obtained on the work surface due to burnishing action of the rollers on the work. The rollers acting against the cutting pressure remove the feed marks on the workpiece. *Fig.2.81 illustrates a roller steady box tool holder.*

2.10.7 Comparison of capstan and turret lathes

Sl . No.	Capstan lathe	Turret lathe
1	Turret head is mounted on a ram which slides over the saddle.	Turret head is directly mounted on saddle. But it slides on the bed.
2	The turret movement is limited.	The turret moves on the entire length of the bed without any restriction.
3	Hence shorter work piece can be machined.	Longer work piece can be machined.
4	Its construction does not provide rigidity due to overhanging of ram beyond the bed.	It provides rigidity and strong.
5	It is suitable for light duty applications.	It is suitable for heavy duty applications.
6	Turret head can be moved manually.	Turret head cannot be moved manually.
7	The maximum size of 60 mm diameter work can be accommodated.	It can accommodate only from 125 to 200mm.
8	No cross-wise movement to turret.	Facing and turning are usually done by cross-wise movement of turret.
9	Overhung type of cross-slide is not used.	Overhung type of cross-slide is provided for some specific operations.

2.10.8 Specifications of capstan and turret lathes

The main sizes to be specified in any capstan and turret lathes are:

- Maximum diameter of the workpiece that can be machined.
- Swing over cross slide.
- Swing over bed.

E.g. 100-200-250 refers to the maximum diameter that can be machined by using this size of lathe is 100 mm, the size of swing over cross slide is 200 mm and the size of swing over bed is 250 mm.

In addition to the above sizes, the following details are also needed to specify the full description about the machine:

- Power of the main drive motor.
- Range of spindle speeds.
- Range of feeds for the carriage.
- Range of feeds for the turret or saddle.
- Total weight of the machine.
- Floor space required.

2.11 AUTOMATIC LATHES

Highly automated machine tools especially of the lathe family are ordinarily classified as semi automatics and automatics. Automatics as their name implies are machine tools with a fully automatic work cycle. Semi automatics are machine tools in which the actual machining operations are performed automatically in the same manner as on automatics. In this case however, the operator loads the blank into the machine, starts the machine, checks the work size and removes the completed piece by hand.

2.11.1 Work holding devices used in automatic lathes

Automation is incorporated in machine tool systems to enable faster and consistently accurate processing operations for increasing productivity and reducing manufacturing cost in batch and mass production. Therefore, in semiautomatic and automatic machine tools mounting and feeding of the work piece or blank is done much faster but properly.

Mostly collet chucks are used for holding the work pieces. Collet chucks inherently work at high speed with accurate location and strong grip. The chucks are actuated manually or semi automatically in semi automatic lathes and automatically in automatic lathes. The collet chucks has been described in Article 2.10.5, Page 87 and illustrated in Fig. 2.68 (a, b and c).

2.12 SEMI AUTOMATICS

Semi automatics are employed for machining work from separate blanks. The operator loads and clamps the blanks, starts the machine and unloads the finished work. *The characteristic features of semi automatic lathes are:*

- Some major auxiliary motions and handling operations like bar feeding, speed change, tool change etc. are done quickly and consistently with lesser human involvement.
- The operators need lesser skill and putting lesser effort and attention.
- Suitable for batch or small lot production.
- Costlier than centre lathes of same capacity.

2.12.1 Classification of semi automatics

Depending upon the number of work spindle, these machines are classified as:

Single spindle semi automatics

- ***Centre type:*** In this type, the workpiece is held between centres, for which a head stock and a tail stock are mounted on the bed of the machine. Usually, external stepped or formed surfaces are machined on this machine. The work is machined by two groups of cutting tools. The front tool slide holds the cutting tools which require a longitudinal feed motion to turn the steps of a shaft, while the rear tool slide carries the tools that require a transverse feed motion to perform operations such as facing, shouldering, necking, chamfering etc.
- ***Chucking type:*** In this type, the workpiece is held in a chuck. Such a machine may be equipped with various tool slide arrangements. In addition to longitudinal and transverse feed tool slides, these machines may also be equipped with a central end working tool slide or a turret if internal surfaces are also to be machined in addition to the external surfaces.

Multi spindle semi automatics

The machine may also be built in two designs:

- Centre type.
- Chucking type.

These multi spindle semi automatics are classified as:

- Parallel action or single station type.
- Progressive action or multi station type.

2.13 AUTOMATS

These are machine tools in which the components are machined automatically. The working cycle is fully automatic that is repeated to produce identical parts without participation of the operator. All the working and idle operations are performed in a definite sequence by the control system adopted in the automats which is set up to suit a given work.

2.13.1 Classification of Automats

The automats can be classified as follows:

According to the type of work materials used:

- Bar stock machine.
- Chucking machine.

According to the number of spindles:

- Single spindle machine.
- Multi spindle machine.

According to the position of spindles:

- Horizontal spindle type.
- Vertical spindle type.

According to the use:

- General purpose machine.
- Single purpose machine.

According to the feed control:

- Single cam shaft rotating at constant speed.
- Single cam shaft with two speeds.
- Two cam shafts.

2.13.2 Advantages of automats over conventional lathes

- Mass production of identical parts.
- High accuracy is maintained.
- Time of production is minimized.
- Less floor space is required.
- Unskilled labor is enough. It minimizes the labor cost.
- Constant flow of production.
- One operator can be utilized to operate more than one machine.
- The bar stock is fed automatically.
- Scrap loss is reduced by eliminating operator error.

2.13.3 Comparison of automats and semiautomatics

Sl . No.	Automats	Semi automatics
1	Loading and unloading of work piece are done automatically by the machine.	Loading and unloading are done manually.
2	Feeding of bar stock and bringing the tools to correct machining positions are done automatically.	These are done manually.
3	A single operator can attend a number of machines when they are arranged together as a group.	An operator can attend to only one or two machines at a line.
4	Production time and cost less.	Not so less.
5	Best suitable for production of small size components.	Suitable for large size components.
6	Initial cost of machine is high.	Initial cost is lower than that of automatic lathe.

2.14 SINGLE SPINDLE AUTOMATS

These machines have only one spindle. So, one component can be machined at a time. These are modified form of turret lathe. These machines have maximum of 4 cross slides in addition to a 6 station or 8 station turret. These cross slides are operated by disc cams which draws the power from the main spindle through cycle time change gears. The single spindle automats are of the following types:

2.15 SINGLE SPINDLE AUTOMATIC CUTTING OFF MACHINE

This machine produces large quantities of workpieces of smaller diameter and shorter lengths. Components with simple form are produced in this machine by means of cross sliding tools.

Construction This machine is simple in design. The head stock with the spindle is mounted on the bed. Two cross slides are located on the bed at the front end of the spindle. The front cross slides are used for turning and forming operations. The rear tool slide is used for facing, chamfering, recessing, under cutting and cutting off operations. Cams on a camshaft actuate the movements of the cross slides through a system of levers.

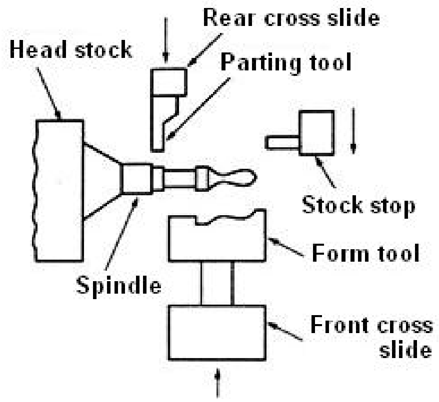


Fig. 2.82 Arrangement of tool slide

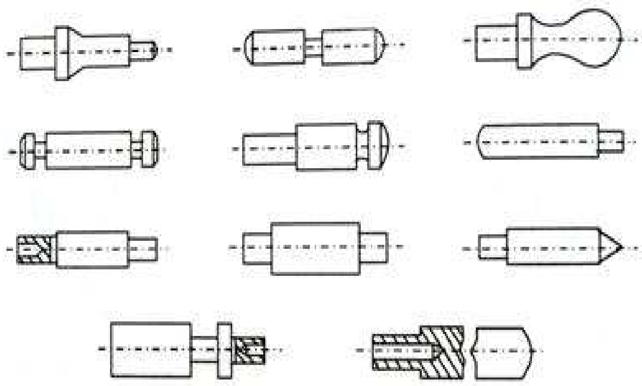


Fig. 2.83 Simple parts produced on cutting off machine

Working principle *Typical arrangement of tool slide in an automatic cutting off machine is illustrated in Fig. 2.82.* The required length of work piece (stock) is fed out with a cam mechanism, up to the stock stop which is automatically advanced in line with the spindle axis, at the end of each cycle. The stock is held in the collect chuck of the rotating spindle. The machining is done by tools held in cross slides operating only in the crosswise direction. The form tool held in the front tool slide produces the required shape of the component. The parting off tool in the rear tool slide is used to cut off the component after machining. Special attachments can be employed if holes or threads are required on the simple parts.

This machine has a single cam shaft which controls the working and idle motions of the tools. The cam shaft runs at constant speed. Therefore working motions and idle motions takes place at the same speed. Hence the cycle time is more. *Typical simple parts (from 3 mm to 20 mm in diameter) produced on this machine are shown in Fig. 2.83.*

2.16 SWISS TYPE AUTOMATIC SCREW MACHINE

This machine was designed and developed in Switzerland. So it is often called as Swiss auto lathe. This machine is also known as 'Sliding head screw machine', or 'Movable headstock machine', because the head stock is movable and the tools are fixed. This machine is used for machining long accurate parts of small diameter (2 mm to 25 mm).

Construction *Fig. 2.84 schematically shows the basic configuration of a Swiss type automatic screw machine.* This machine has the following parts:

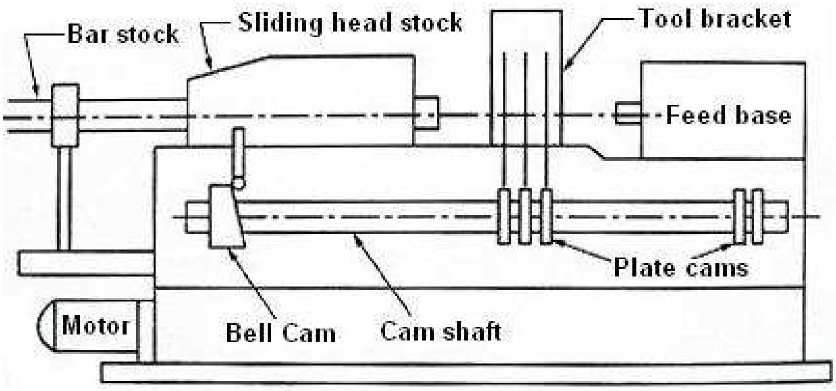


Fig. 2.84 Swiss type automatic screw machine

Sliding Head Stock: This head stock has a collet. The bar stock is held in this collet. The headstock slides along the guide ways of the bed. A bell cam connected to the cam shaft controls this sliding motion.

Tool Bracket: The tool bracket is mounted on the bed way near the head stock. The tool bracket supports 4 or 5 toll slides. It also has a bush for supporting and guiding the bar stock. Two slides are positioned horizontally (front and rear) on which the turning tools are normally clamped. The other slides are arranged above these slides. These slides can move radially. All the slides can move back and forth. These slides are actuated independently by sets or rocker arms and plate cams. Plate cams are fitted to the cam shaft. *The tool bracket is shown schematically in Fig. 2.85 (a) and photographically in Fig. 2.85 (b).*

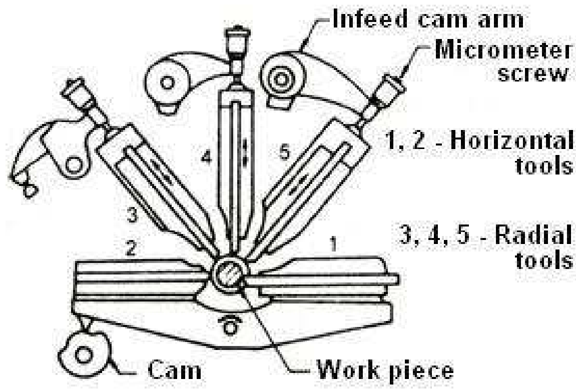


Fig. 2.85 (a) Schematic view of a tool bracket

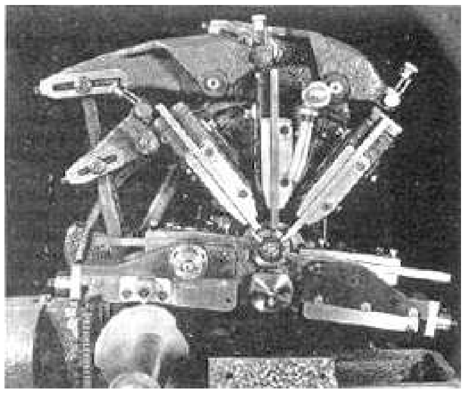


Fig. 2.85 (a) Photographic view of a tool bracket

Feed Base: The feed base is a special attachment mounted at the right hand side of the bed. This can move along the bed. Using this attachment, operations like drilling, boring, thread cutting with taps or dies etc., are done. The movement of the feed base is controlled by the plate cam fitted to the cam shaft.

Cam Shaft: The cam shaft is mounted at the front of the machine. It has a bell cam at the left end. This controls the sliding movement of the head stock. Plate cams fitted at the centre of the shaft controls the movement of the tool slides. Plate cam at the right end of the cam shaft controls the movement of the feed base.

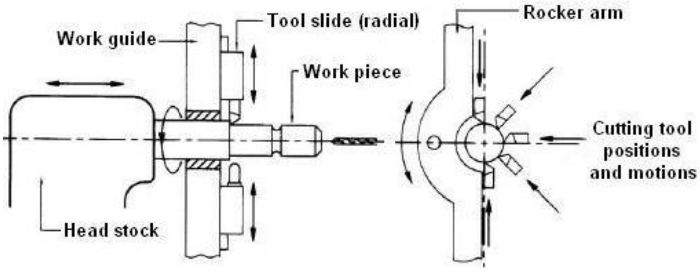


Fig. 2.86 Working principle of the Swiss type automatic screw machine

Working principle *Fig. 2.86 shows the working principle of the Swiss type automatic screw machine.* The stock is held by a rotating collet in the head stock and all longitudinal feeds are obtained by a cam which moves the head stock as a unit. Most diameters turning are done by two horizontal tool slides while the other three slides are used principally for such operations as knurling, chamfering, recessing and cutting off. The tools are controlled and positioned by cams that bring the tools in as needed to turn, face, form, and cut off the workpiece from the bar as it emerges from the bushing.

The cutting action is confined close to the support bushing reducing the overhang to a minimum. As a result, the work can be machined to very close limits. All tools can work at a time. After the work piece is machined, the head stock slides back to the original position. One revolution of the cam shaft produces one component.

A wide variety of formed surfaces may be obtained on the workpiece by synchronized alternating or simultaneous travel of the headstock (longitudinal feed) and the cross slide (approach to the depth of cut). The bar stock used in these machines has to be highly accurate and is first ground on centreless grinding machines to ensure high accuracy. *Parts produced on this machine are shown in Fig. 2.87.*

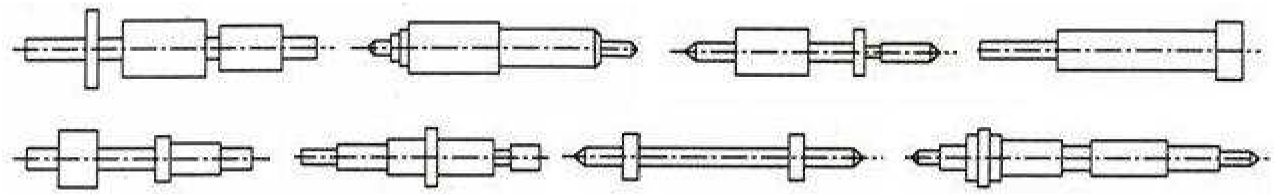


Fig. 2.87 Simple parts produced on Swiss auto lathe

Advantages

- It is used to precision turning of small parts.
- Wide range of speeds is available.
- It is rigid in construction.
- Micrometer tool setting is possible.
- Interchangeability of cams is possible.
- Tolerance of 0.005 mm to 0.0125 mm is obtained.

2.17 SINGLE SPINDLE AUTOMATIC SCREW TYPE MACHINE

This is essentially wholly automatic bar type turret lathe. This is very similar to capstan and turret lathes with reference to tool layout, but all the tool movements are cam controlled, such that full automation in manufacturing is achieved. This is designed for machining complex external and internal surfaces on parts made of bar stock or of separate blanks. These machines are made in several sizes for bar work from 12.7 mm to 60 mm diameter.

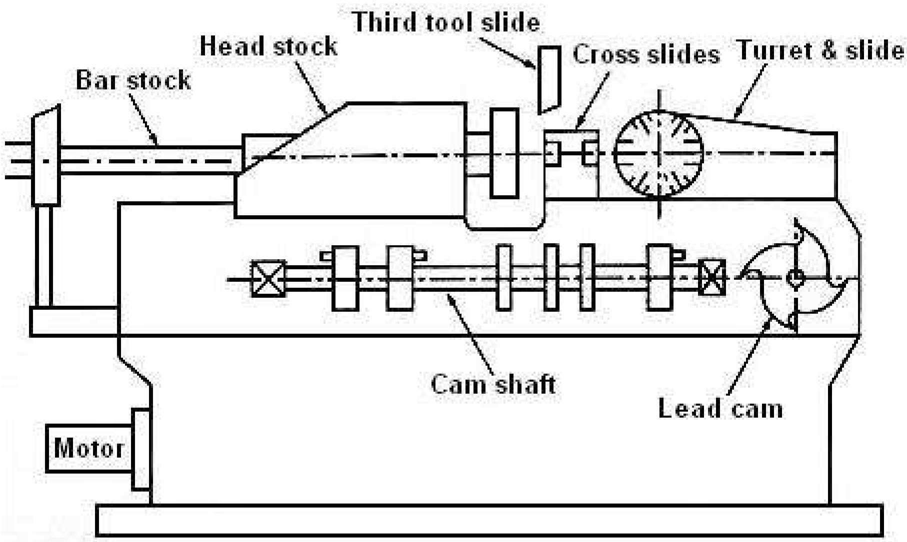


Fig. 2.88 Single spindle automatic screw cutting machine

Construction *Fig. 2.88 schematically shows the basic configuration of a single spindle automatic screw cutting machine.* Up to ten different cutting tools may be employed at a time in this machine. The tools are fixed in indexing turret and in cross-slides. The turret carries six tools. Two cross-slides (front and rear) are employed for cross-feeding tools. A vertical slide for parting off operation may also be provided. It is installed above the work spindle. The stationary headstock, mounted on the left end of the bed, houses the spindle which rotates in either direction.

Working principle The bar stock is held in a collet chuck and advanced by a feed finger after each piece is finished and cut off. All movements of the machine units are actuated by cams mounted on the camshaft. The bar stock is pushed through stock tube in a bracket and its leading end is clamped in rotating spindle by means of a collet chuck. The bar is then fed out for the next part by stock feeding mechanism. Longitudinal turning and machining of the central hole are performed by tools mounted on turret slide. The cut off and form tools are mounted on the cross-slides. At the end of each cut, turret slide is withdrawn automatically and indexed to bring the next tool into position. One revolution of camshaft produces one component. It is used for producing small jobs, screws, stepped pins, taper pins, bolts, etc. *Typical parts produced on this machine are shown in Fig. 2.89.*

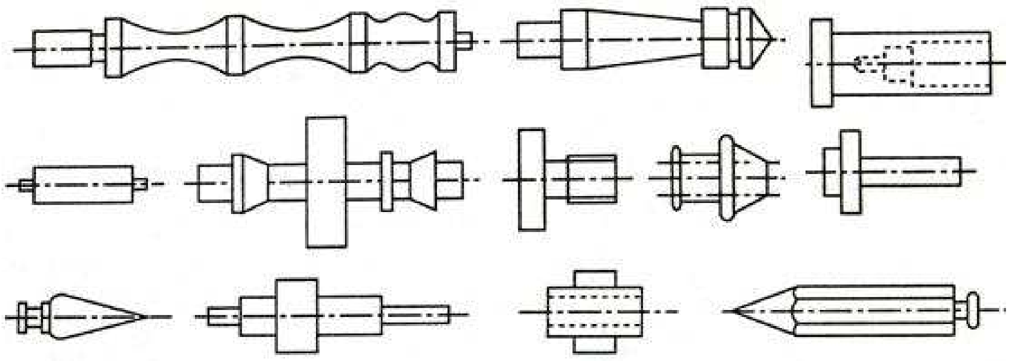


Fig. 2.89 Parts produced on single spindle automatic screw cutting machine

2.18 MULTI SPINDLE AUTOMATS

The multi spindle automats are the fastest type of production machines and are made in a variety of models with 2, 4, 5, 6 or 8 spindles. Each of the spindles is provided with its own set of tools for operation. As a result, more than one work piece can be machined simultaneously in these machines. In contrast to the single spindle automat, where one turret face at a time is working on one spindle, the multi spindle automat has all turret faces working on all spindles at the same time. The production rate of a multi spindle automat, however, is less than that of the corresponding number of single spindle automats. E.g. the production rate of a 4 spindle automat is not four times but only 2½ to 3 times more than that of a single spindle automat.

2.18.1 Classification of multi spindle automats

The multi spindle automats can be classified as follows:

According to the type of stock used:

- Bar stock machine.
- Chucking type machine.

According to the position of spindles:

- Horizontal spindle type.
- Vertical spindle type.

According to the principle of operation:

- Parallel action type.
- Progressive action type.

2.18.2 Comparison of single spindle automat and multi spindle automat

Sl . No.	Single spindle automat	Multi spindle automat
1	There is only one spindle.	There are 2,4,5,6 or 8 spindles.
2	Only one work piece can be machined at a time.	More number of work pieces can be machined at a time.
3	The rate of production is low.	The rate of production is high.
4	Machining accuracy is higher.	Machining accuracy is lower.
5	Tool setting time is less.	Tool setting time is more.
6	Tooling cost is less.	Tooling cost is more.
7	Economical for shorter as well as longer runs.	Economical for longer runs only.
8	The time required to produce one job is the sum of all turret operation times.	The time required to produce one job is the time of the longest cut in any one spindle.
9	Tools in turret are indexed.	Work pieces held in spindles are indexed (Progressive action machine)

2.19 PARALLEL ACTION MULTI SPINDLE AUTOMAT

These machines are usually automatic cutting off bar type machines. This is also called as 'multiple-flow' machine. In this machine, the same operation is performed on each spindle and a workpiece is finished in each spindle in one working cycle. The rate of production is very high, but the machine can be employed to machine simple parts only since all the machining processes are done at one position. *Fig. 2.90 shows the basic configuration of a parallel action multi spindle automat.*

They are used to perform the same work as single spindle automatic cutting off machines. Centering or a single drilling operation can also be performed on certain models. The machine consists of a frame with a head stock. The horizontal work spindles which are arranged in a line, one above the other, are housed in this headstock. Cross slides are located at the right and left hand sides of the spindles and carry the cross feeding tools. All the working and the auxiliary motions of the machine units are obtained from the cam mounted on the cam shaft.

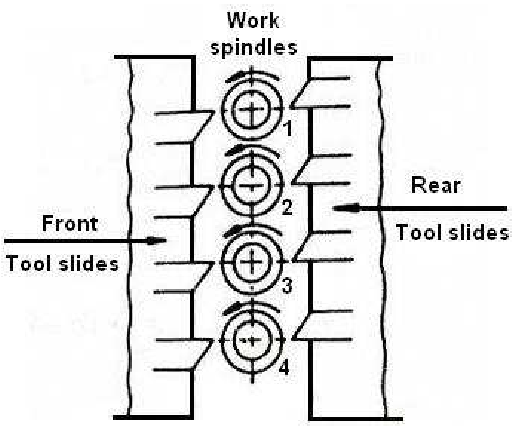


Fig. 2.90 Parallel action multi spindle automat

2.20 PROGRESSIVE ACTION MULTI SPINDLE AUTOMAT

In this machine the blanks clamped in each spindle are machined progressively in station after station.

Construction *Fig. 2.91 shows the basic configuration of a six-spindle progressive action automat.* The headstock is mounted at the left end of the base of the machine. It contains a spindle carrier which periodically indexes through a definite angle (360^0 divided by the number of spindles) about a horizontal axis through the centre of the machine at each tool retraction. The main tool slide (end tool slide), which accommodates tooling for all of the spindles, travels on the spindle carrier stem. The number of tool slides or faces is equal to the number of spindles.

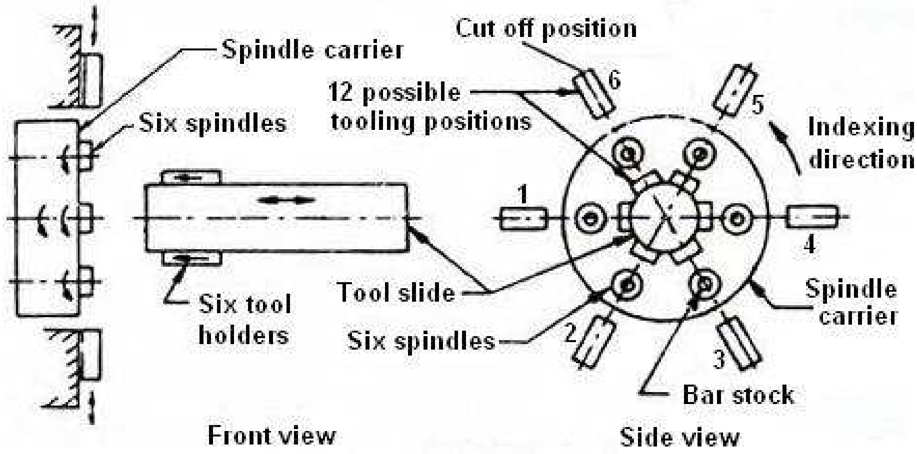


Fig. 2.91 Six-spindle progressive action automat

The working spindles are mounted in this spindle carrier. The working spindles carry the collets on which the workpieces are held. The bar stock is fed to the working spindle from the rear.

Cross slides which carry tools for operations such as cut off, turning, facing, forming, chamfering etc. are mounted in a frame above the face of the spindle carrier. These cross slides travel radially inward for cutting operation. The number of cross slides is equal to the number of spindles. The feed of each tool, both cross slide tools and end slide tools, is controlled by its own individual cam.

Working principle The spindle carrier indexes on its own axis by 60^0 ($360^0/6$) at each tool retraction. As the spindle carrier indexes, it carries the work from station to station, where various tools operate on it. The stock moves around the circle in counter clockwise direction and comes to the station number 6 for cutting off. A finished component is obtained for one full revolution of the spindle carrier. *Typical parts produced on this machine are shown in Fig. 2.92.*

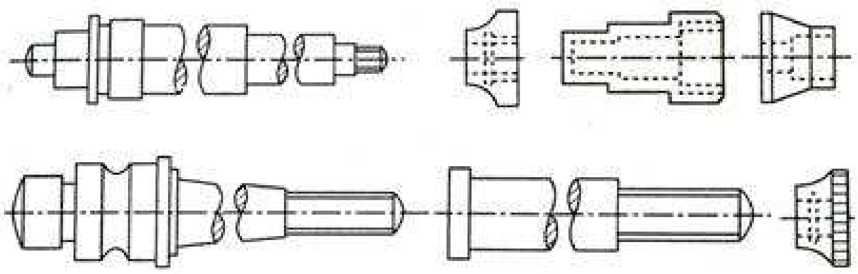


Fig. 2.92 Parts produced on multi spindle automatic lathe

2.20.1 Comparison of parallel action and progressive action multi spindle automat

Sl . No.	Parallel action multi spindle automat	Progressive action multi spindle automat
1	Same operation is done on all jobs in all the spindles.	Different operations are done on jobs at each station one after another.
2	In one cycle the number of components produced simultaneously is equal to the number of spindles.	It is not so. (i.e.) The number of components produced in one cycle is not equal to the number of spindles. For every indexing of component (spindle) one component is produced.
3	Rate of production is very high.	Rate of production is moderate.
4	If anything goes wrong in one station, the production in that particular station only is affected.	If anything goes wrong in one station, the production is completely affected in all the stations.
5	Small parts of simple shapes are produced.	Parts of complicate shapes can be produced.

UNIT - III

RECIPROCATING AND MILLING MACHINES

3.1 RECIPROCATING MACHINE TOOLS

In lathes the work piece is rotated while the cutting tool is moved axially to produce cylindrical surfaces. But in reciprocating machine tools the single point cutting tool is reciprocates and produces flat surfaces. The flat surfaces produced may be horizontal, vertical or inclined at an angle. These machine tools can also be arranged for machining contoured surfaces, slots, grooves and other recesses. The major machine tools that fall in this type are: Shaper, Planer and Slotter. The main characteristic of this type of machine tools is that they are simple in construction and are thus economical in operation.

3.2 SHAPER

The main function of the shaper is to produce flat surfaces in different planes. In general the shaper can produce any surface composed of straight line elements. Modern shapers can generate contoured surface. The shaper was first developed in the year 1836 by James Nasmyth, an Englishman. Because of the poor productivity and process capability the shapers are not widely used nowadays for production. The shaper is a low cost machine tool and is used for initial rough machining of the blanks.

3.2.1 Classification of shapers

Shapers are broadly classified as follows:

According to the type of mechanism used:

- Crank shaper.
- Geared shaper.
- Hydraulic shaper.

According to the position and travel of ram:

- Horizontal shaper.
- Vertical shaper.
- Traveling head shaper.

According to the type of design of the table:

- Standard or plain shaper.
- Universal shaper.

According to the type of cutting stroke:

- Push type shaper.
- Draw type shaper.

3.2.1.1 According to the type of mechanism used

Crank shaper

This is the most common type of shaper in which a single point cutting tool is given a reciprocating motion equal to the length of the stroke desired while the work is clamped in position on an adjustable table. In construction, the crank shaper employs a crank mechanism to change circular motion of “bull gear” to reciprocating motion of the ram.

Geared type shaper

The reciprocating motion of the ram is some type of shaper is effect by means of a rack and pinion. The rack teeth which are cut directly below the ram mesh with a spur gear. The pinion meshing with the rack is driven by a gear train. The speed and the direction in which the ram will traverse depend on the number of gears in the gear train. This type of shaper is not very widely used.

Hydraulic shaper

In a hydraulic shaper, reciprocating movement of the ram is obtained by hydraulic power. Oil under high pressure is pumped into the operating cylinder fitted with a piston. The end of the piston rod is connected to the ram. The high pressure oil first acts on one side of the piston and then on the other causing the piston to reciprocate and the motion is transmitted to the ram. The speed of the ram is changed by varying the amount of liquid delivered to the piston by the pump.

3.2.1.2 According to the position and travel of ram

Horizontal shaper

In a horizontal shaper, the ram holding the tool reciprocates in a horizontal axis. Horizontal shapers are mainly used to produce flat surfaces.

Vertical shaper

In a vertical shaper, the ram holding the tool reciprocates in a vertical axis. The work table of a vertical shaper can be given cross, longitudinal, and rotary movement. Vertical shapers are very convenient for machining internal surfaces, keyways, slots or grooves. Large internal and external gears may also be machined by indexing arrangement of the rotary table. The vertical shaper which is specially designed for machining internal keyway is called as Keyseater.

Travelling head shaper

The ram carrying the tool while it reciprocates moves crosswise to give the required feed. Heavy jobs which are very difficult to hold on the table of a standard shaper and fed past the tool are held static on the basement of the machine while the ram reciprocates and supplies the feeding movements.

3.2.1.3 According to the type of design of the table

Standard or plain shaper

A shaper is termed as standard or plain when the table has only two movements, vertical and horizontal, to give the feed. The table may or may not be supported at the outer end.

Universal shaper

In this type, in addition to the two movements provided on the table of a standard shaper, the table can be swiveled about an axis parallel to the ram ways, and the upper portion of the table can be tilted about a second horizontal axis perpendicular to the first axis. As the work mounted on the table can be adjusted in different planes, the machine is most suitable for different types of work and is given the name “Universal”. A universal shaper is mostly used in tool room work.

3.2.1.4 According to the type of cutting stroke

Push type shaper

This is the most general type of shaper used in common practice. The metal is removed when the ram moves away from the column, i.e. pushes the work.

Draw type shaper

In this type, the metal is removed when the ram moves towards the column of the machine, i.e. draws the work towards the machine. The tool is set in a reversed direction to that of a standard shaper. In this shaper the cutting pressure acts towards the column which relieves the cross rail and other bearings from excessive loading and allows to take deep cuts. Vibration in these machines is practically eliminated. The ram is generally supported by an overhead arm which ensures rigidity and eliminates deflection of the tool.

3.2.2 Major parts of a standard shaper

Fig. 3.1 shows the basic configuration of a standard shaper. The major parts are:

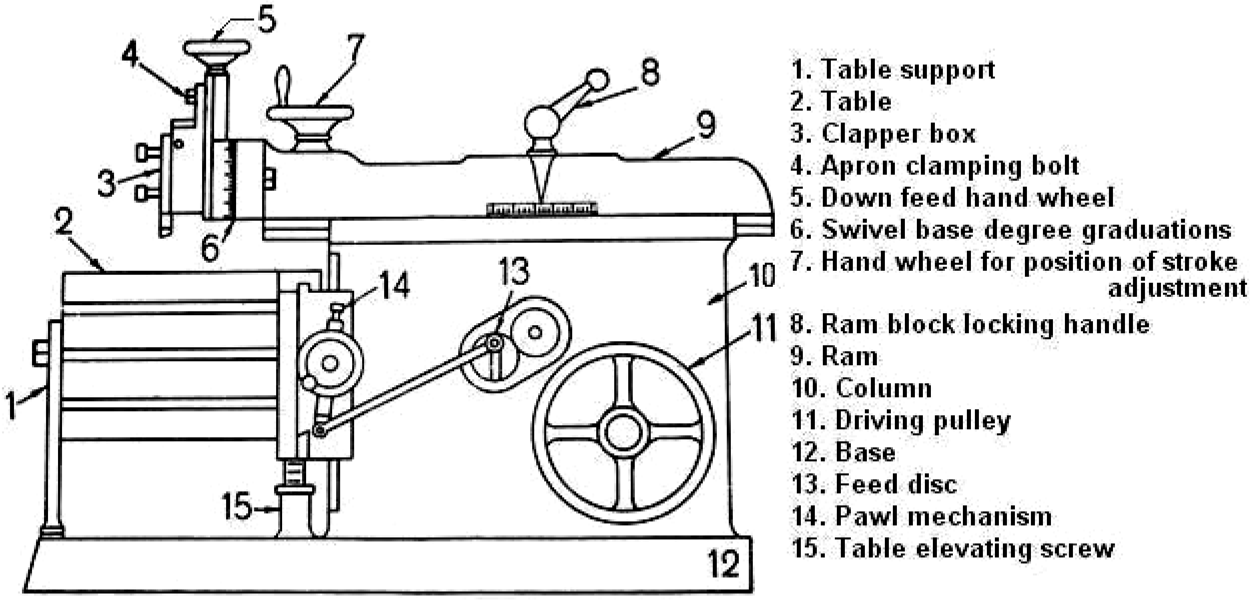


Fig. 3.1 Schematic view of a standard shaper

Base It provides the necessary support to the machine tool. It is rigidly bolted to the shop floor. All parts are mounted on the base. It is made up of cast iron to resist vibration and take up high compressive load. It takes the entire load of the machine and the forces set up by the cutting tool during machining.

Column It is a box like casting mounted upon the base. It encloses the drive mechanisms for the ram and the table. Two accurately machined guide ways are provided on the top of the column on which the ram reciprocates. The front vertical face of the column which serves as the guide ways for the cross rail is also accurately machined.

Cross rail It is mounted on the front vertical guide ways of the column. It has two parallel guide ways on its top in the vertical plane that is perpendicular to the ram axis. The table may be raised or lowered to accommodate different sizes of jobs by rotating an elevating screw which causes the cross rail to slide up and down on the vertical face of the column. A horizontal cross feed screw which is fitted within the cross rail and parallel to the top guide ways of the cross rail actuates the table to move in a crosswise direction.

Saddle It is mounted on the cross rail which holds the table firmly on its top. Crosswise movement of the saddle by rotating the cross feed screw by hand or power causes the table to move sideways.

Table It is bolted to the saddle receives crosswise and vertical movements from the saddle and cross rail. It is a box like casting having T-slots both on the top and sides for clamping the work. In a universal shaper the table may be swiveled on a horizontal axis and the upper part of the table may be tilted up or down. In a heavier type shaper, the front face of the table is clamped with a table support to make it more rigid.

Ram It holds and imparts cutting motion to the tool through reciprocation. It is connected to the reciprocating mechanism contained within the column. It is semi cylindrical in form and heavily ribbed inside to make it more rigid. It houses a screwed shaft for altering the position of the ram with respect to the work and holds the tool head at the extreme forward end.

Tool head It holds the tool rigidly, provides the feed movement of the tool and allows the tool to have an automatic relief during its return stroke. The vertical slide of the tool head has a swivel base which is held on a circular seat on the ram. So the vertical slide may be set at any desired angle. By rotating the down feed screw handle, the vertical slide carrying the tool executes the feed or depth of cut. The amount of feed or depth of cut may be adjusted by a micrometer dial on the top of the down feed screw. Apron consisting of clapper box, clapper block and tool post is clamped upon the vertical slide by a screw. By releasing the clamping screw, the apron may be swiveled upon the apron swivel pin with respect to the vertical slide. This arrangement is necessary to provide relief to the tool while making vertical or angular cuts. The two vertical walls on the apron called clapper box houses the clapper block which is connected to it by means of a hinge pin. The tool post is mounted upon the clapper block. On the forward cutting stroke the clapper block fits securely to the clapper box to make a rigid tool support. On the return stroke a slight frictional drag of the tool on the work lifts the block out of the clapper box a sufficient amount preventing the tool cutting edge from dragging and consequent wear. The work surface is also prevented from any damage due to dragging. *Fig.3.2 illustrates the tool head of a shaper.*

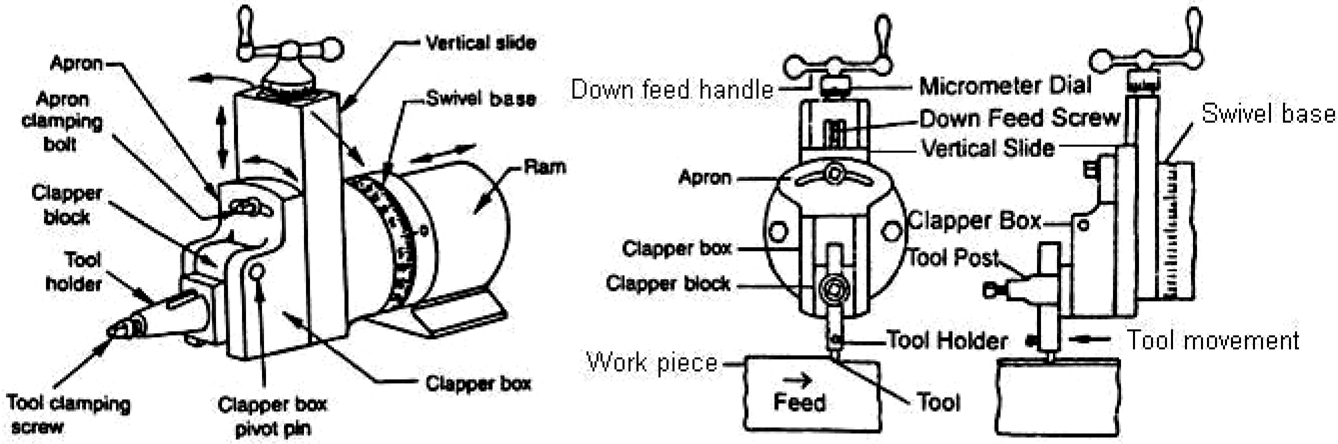


Fig. 3.2 Tool head of a shaper

3.2.3 Working principle of a standard shaper

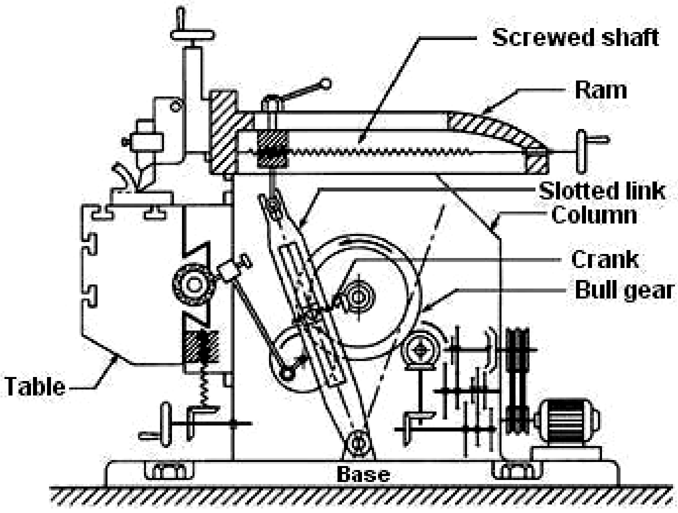


Fig. 3.3 (a) Kinematic system of a shaper

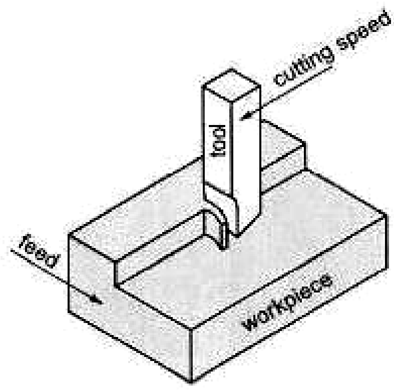


Fig. 3.3 (b) Principle of producing flat surface

Fig. 3.3 (a) schematically shows the kinematic system of a standard shaper. Fig. 3.3 (b) shows the basic principle of producing flat surface in a standard shaper. The bull gear receives its rotation from the motor through 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. The cutting motion provided by the reciprocating tool and the intermittent feed motion provided by the slow transverse motion of the work at different rate by using the ratchet - pawl system along with the saddle 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 cross rail or both. Straight grooves of various curved sections are also made in shaper by using specific form tools. The single point straight or form tool is clamped in the vertical slide of the tool head, which is mounted at the front face of the reciprocating ram. The work piece is clamped directly on the table or clamped in a vice which is mounted on the table. *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 ram block nut by rotating the lead screw.

3.2.4 Ram drive mechanism of a shaper

In a shaper, rotary movement of the drive is converted into reciprocating movement of the ram by the mechanism contained within the column of the machine. In a standard shaper metal is removed in the forward cutting stroke and during the return stroke no metal is removed. To reduce the total machining time it is necessary to reduce the time taken by the return stroke. Thus the shaper mechanism should be so designed that it can allow the ram to move at a comparatively slower speed during the forward cutting stroke and during the return stoke it can allow the ram to move at a faster rate to reduce the idle return time. This mechanism is known as quick return mechanism. The reciprocating movement and the quick return of the ram are usually obtained by using any one of the following mechanisms.

3.2.4.1 Crank and slotted link quick return mechanism

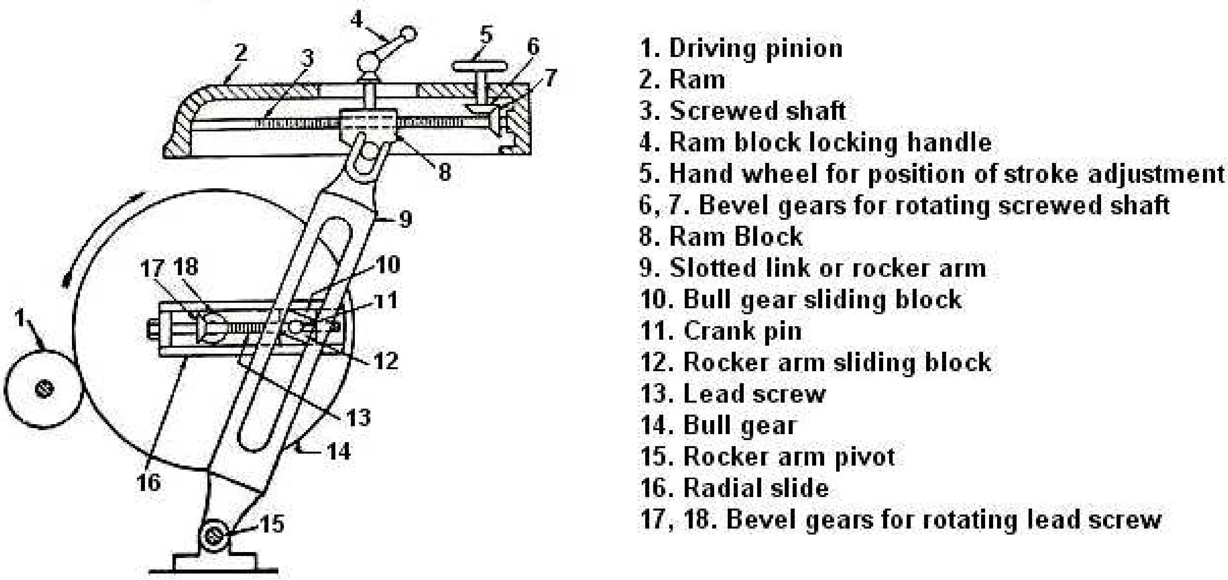


Fig. 3.4 Crank and slotted link quick return mechanism

The crank and slotted link quick return mechanism is shown in Fig. 3.4. This mechanism has a bull gear mounted within the column. The motion or power is transmitted to the bull gear through a pinion which receives its motion from an individual motor. A radial slide is bolted to the centre of the bull gear. This radial slide carries a bull gear sliding block into which the crank pin is fitted. Rotation of the bull gear will cause the crank pin to revolve at a constant speed about the centre of the bull gear. Rocker arm sliding block is mounted upon the crank pin and is free to rotate about the pin. The rocker arm sliding block is fitted within the slotted link and can slide along the slot in the slotted link (rocker arm). The bottom end of the rocker arm is pivoted to the frame of the column. The upper end is forked and connected to the ram block by a pin which can slide in the forked end.

As the bull gear rotates causing the crank pin to rotate, the rocker arm sliding block fastened to the crank pin will rotate on the crank pin circle, and at the same time will move up and down in the slot provided in the slotted link. This up and down movement will give rocking motion (oscillatory motion) to the slotted link (rocker arm), which communicated to the ram. Thus the rotary motion of the bull gear is converted into reciprocating movement of the ram.

Quick return principle

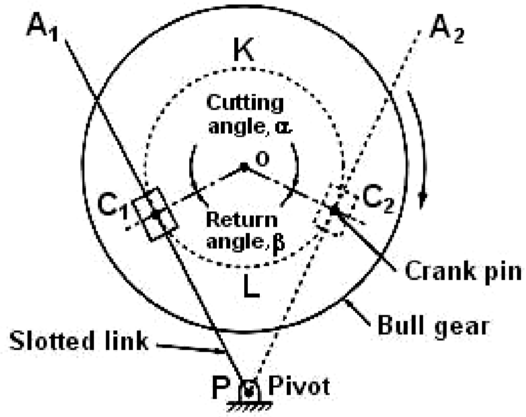


Fig. 3.5 Principle of quick return motion

The principle of quick return motion is illustrated in Fig. 3.5. When the slotted link is in the position PA_1, the ram will be at the extreme backward position of its stroke. When the slotted link is in the position PA_2, the ram will be at the extreme forward position of its stroke.

PA_1 and PA_2 are shown tangent to the crank pin circle. Therefore the forward cutting stroke takes place when the crank pin rotates through the angle C_1KC_2 (α) and the return stroke takes place when the crank pin rotates through the angle C_2LC_1 (β). It is clear that the angle α made by the forward or cutting stroke is greater than that the angle β described by the return stroke. The angular velocity of the crank pin being constant, therefore the return stroke is completed within a shorter time for which it is known as quick return motion.

m = ———— = ———— = – Standard value of m is 2:1. But the practical value is 3:2.

The only disadvantage of this mechanism is that the linear velocity of the ram is not constant throughout the stroke. The velocity is minimum when the rocker arm is at the two extremities and the velocity is maximum when the rocker arm is vertical.

Adjusting the length of stroke

Fig. 3.4 illustrates how the length of stroke in a crank shaper can be adjusted. The crank pin is fastened to the bull gear sliding block which can be adjusted and the radius of its travel may be varied. The bevel gear 18 placed at the centre of the bull gear may be rotated by a handle causing the bevel gear 17 to rotate. The bevel gear 17 is mounted upon the small lead screw which passes through the bull gear sliding block. Thus rotation of the bevel gear will cause the bull gear sliding block carrying the crank pin to be brought inwards or outwards with respect to the centre of the bull gear.

Fig. 3.6 (a) shows the detail arrangement for altering the position of the bull gear sliding block on the bull gear. The sketch has been drawn without the rocker arm in position. *Fig. 3.6 (b) shows the short and long stroke of the ram, effect by altering the position of the crank pin.*

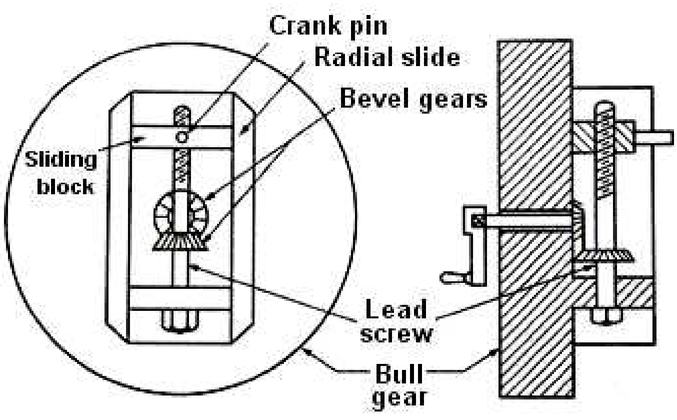


Fig. 3.6 (a) Arrangement of bull gear sliding block

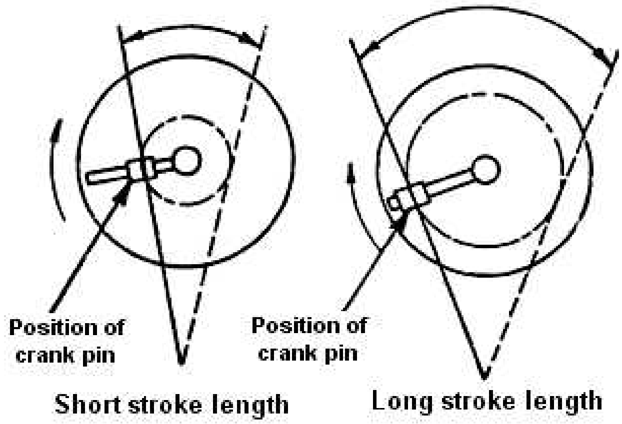


Fig. 3.6 (b) Short and long stroke length

Adjusting the position of stroke

The position of the ram relative to the work can also be adjusted. *Referring to the Fig. 3.4,* by rotating the hand wheel 5 the screwed shaft fitted in the ram may be made to rotate through two bevel gears 6 and 7. The ram block which is mounted upon the screwed shaft acts as a nut. The nut remaining fixed in position, rotation of the screwed shaft will cause the ram to move forward or backward with respect to the ram block according to the direction of rotation of the hand wheel. Thus the position of ram may be adjusted with respect to the work piece. The ram block locking handle 4 must be tightened after the adjustment has been made.

3.2.4.2 Whitworth quick return mechanism

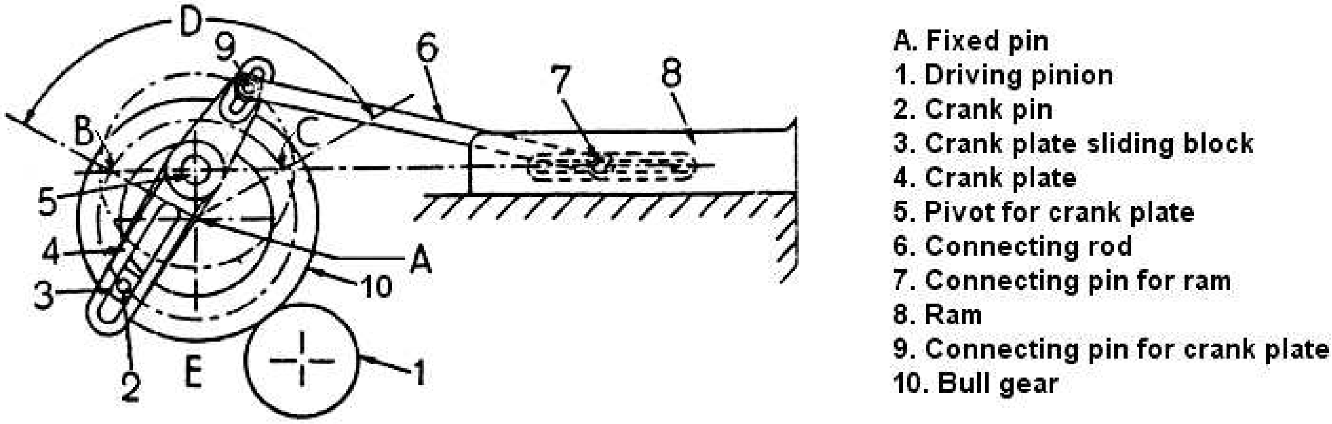


Fig. 3.7 Whitworth quick return mechanism

The Whitworth quick return mechanism is shown in Fig. 3.7. The bull gear is mounted on a large fixed pin A upon which it is free to rotate. The motion or power is transmitted to the bull gear through a pinion which receives its motion from an individual motor. The crank plate is pivoted eccentrically upon the fixed pin at 5. The crank pin is fitted on the face of the bull gear. The crank plate sliding block is mounted upon the crank pin and it fits into the slot provided on the crank plate. The crank plate sliding block can slide inside the slot. At the other end of the crank plate, a connecting rod connects the crank plate and the ram by two pin 9 and 7. When bull gear will rotate at a constant speed the crank pin with the sliding block will rotate on a crank circle of radius A2 and the sliding block will cause the crank plate to rotate about the point 5 with a variable angular velocity. Pin 9 fitted on the other end of the crank plate will rotate in a circle and the rotary motion of the pin 9 will be converted into reciprocating movement of the ram similar to the crank and connecting rod mechanism. The axis of reciprocating of the ram passes through the pin 5 and is normal to the line A5.

When the crank pin 2 is at the point C the ram will be at the extreme backward position of its stroke. When the crank pin 2 is at the point B the ram will be at the extreme forward position of its stroke. Therefore the forward cutting stroke takes place when the crank pin rotates through the angle CEB (α) and the return stroke takes place when the crank pin rotates through the angle BDC (β). It is clear that the angle α made by the forward or cutting stroke is greater than the angle β described by the return stroke. The angular velocity of the crank pin being constant, therefore the return stroke is completed within a shorter time for which it is known as quick return motion. The length of stroke of the ram may be changed by shifting the position of pin 9 closer or away from the pivot 5. The position of stroke may be altered by shifting the position of pin 7 on the ram.

3.2.4.3 Hydraulic drive quick return mechanism

A typical hydraulic drive for horizontal shaper is shown in Fig. 3.8. A constant speed motor drives a hydraulic pump which delivers oil at a constant pressure to the line. A regulating valve admits oil under pressure to each end on the piston alternately, at the same time allowing oil from the opposite end of the piston to return to the reservoir.

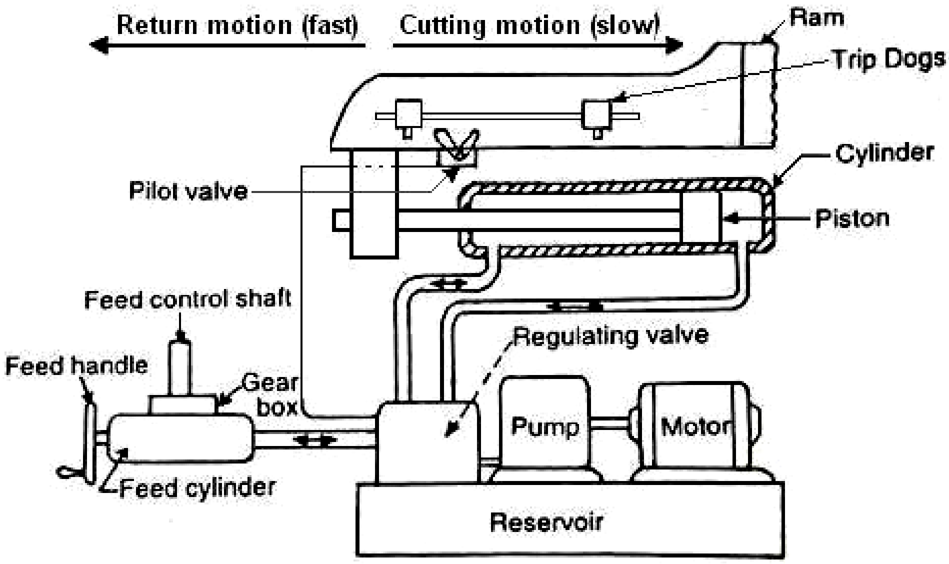


Fig. 3.8 Hydraulic drive for horizontal shaper

The piston is pushed by the oil and, being connected to the ram by the piston rod, pushes the ram carrying the tool. The admission of oil to each end of the piston, alternately, is accomplished with the help of trip dogs and pilot valve. As the ram moves and completes its stroke (forward or return) a trip dog will trip the pilot valve which operates the regulating valve. The regulating valve will admit the oil to the other side of the piston and the motion of the ram will get reversed. It is clear that the length of the ram stroke will depend upon the position of the trip dogs. The length of the ram stroke can be changed by unclamping and moving the trip dogs to the desired positions.

The above system is a constant pressure system. The velocity of the ram travel will be directly proportional to the oil pressure and the piston area to which it is applied. The return stroke is quicker, since the piston area on which the oil pressure acts is greater as compared to the other end for which it gets reduced because of the piston rod. Another oil line is connected to a smaller feed cylinder to change the hydraulic power to mechanical power for feeding the work past the tool.

Advantages of Hydraulic drive

- Does not make any noise and operates very quietly.
- Ability to stall against an obstruction without damage to the tool or the machine.
- Ability to change length and position of stroke or speed while the machine is running.
- The cutting and return speeds are practically constant throughout the stroke. This permits the cutting tool to work uniformly during cutting stroke.
- The reversal of the ram is obtained quickly without any shock as the oil on the other end of the cylinder provides cushioning effect.
- Offers great flexibility of speed and feed and the control is easier.
- The hydraulic drive shows a very nearly constant velocity as compared with a mechanical drive, which has a constantly changing velocity because the horizontal component of the crankpin moving about its circle is constantly changing. *The velocity diagram is shown in Fig. 3.9.*

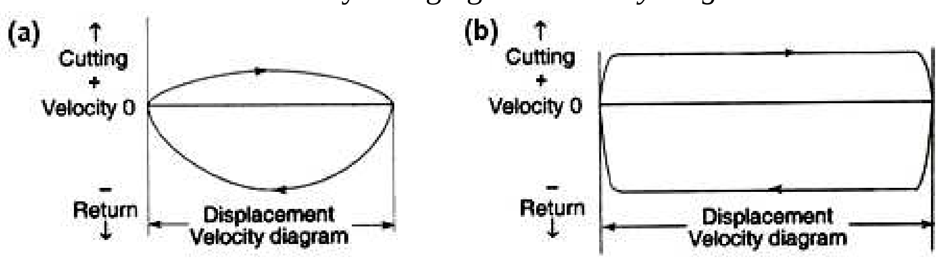


Fig. 3.9 Velocity diagram of (a) Crank shaper and (b) Hydraulic shaper

On the other hand, a mechanical shaper has the following plus points: Lower first cost and simpler in operation. The cutting stroke has a definite stopping point.

3.2.5 Feed mechanism of a shaper

The mechanism used for providing feed is known as feed mechanism. In a shaper both down feed and cross feed movements may be obtained. Unlike a lathe, these feed movements are provided intermittently and during the end of return stroke only. Vertical or bevel surfaces are produced by rotating the down feed screw of the tool head by hand. This movement of the tool is called down feed.

The horizontal movement of table is called cross feed. Cross feed movement is used to machine a flat horizontal surface. The cross feed of the table is effect by rotating the cross feed screw. This screw is engaged with a nut fitted in the table. Rotation of the cross feed screw causes the table mounted upon the saddle to move sideways on the cross rail. Cross feed is given either by hand or power. If this screw is rotated manually by handle, then it is called hand feed. If this screw is rotated by power, then it is called automatic feed. The power is given through an automatic feed mechanism. *The down feed and cross feed mechanism of a shaper is schematically shown in Fig. 3.10.*

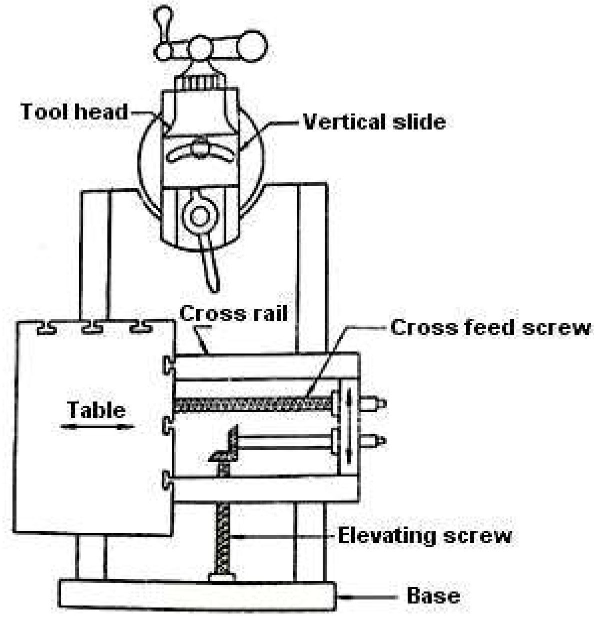


Fig. 3.10 Down feed and cross feed mechanism

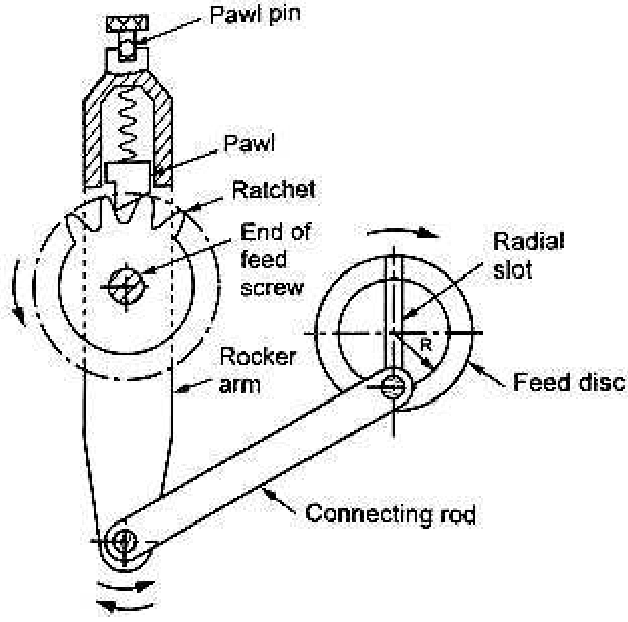


Fig. 3.11 Automatic feed mechanism

3.2.5.1 Automatic feed mechanism of a shaper

Fig. 3.11 illustrates the automatic feed mechanism of a shaper. In this mechanism, a ratchet wheel is keyed to the end of the cross feed screw. A rocker arm is pivoted at the centre of the ratchet wheel. The rocker arm houses a spring loaded pawl at its top. The spring pushes against the pawl to keep it in contact with the ratchet wheel. The pawl is straight on one side and bevel on the other side. So the pawl moves the ratchet wheel in one direction only. The rocker arm is connected to the driving disc or feed disc by a connecting rod. The driving disc has a T-slot on its face along its diameter. The driving pin or crank pin fits into this slot. One end of the connecting rod is attached to this crank pin.

We know that the table feed is intermittent and is accomplished on the return stroke when the tool has cleared the work piece. The driving disc is driven from the bull gear through a spur gear drive and rotates at the same speed as the bull gear. As the driving disc rotates, the connecting rod oscillates the rocker arm about the cross feed screw. During the forward stroke of the ram, the rocker arm moves in the clockwise direction. As bevel side of the pawl fits on the right side, the pawl slips over the teeth of the ratchet wheel. It gives no movement to the table. During the return stroke of the ram, the rocker arm moves in the counter clockwise direction. The left side of the pawl being straight; so that it moves the ratchet wheel by engaging with it and hence rotates the cross feed screw which moves the table.

A knob at the top of the pawl enables the operator to rotate it 180^0 to reverse the direction of feed or 90^0 to stop it altogether. The rate of feed is controlled by adjusting the eccentricity or offset of the crank pin in the driving disc.

3.2.6 Work holding devices used in a shaper

The top and side of the table of a shaper have T-slots for clamping the work piece. The work piece may be supported on the shaper table by using any one of the following work holding devices depending upon the geometry of the work piece and nature of the operation to be performed.

- Machine vise.
- Clamping work on the table.
- Angle plate.
- V-blocks.
- Shaper centre.

3.2.6.1 Machine vise

A vise is a quick method of holding and locating small and regular shaped work pieces. It consists of a base, screw, fixed jaw and movable jaw. The work piece is clamped between fixed and movable jaws by rotating the screw. Types of machine vise are plain vise, swivel vise and universal vise.

A plain vise is the most simple of all the types. The vise may have a single screw or double screws for actuating the movable jaw. The double screws add gripping strength while taking deeper cuts or handling heavier jobs. *Fig. 3.12 (a) illustrates a plain vise.*

In a swivel vise the base is graduated in degrees, and the body of the vise may be swiveled at any desired angle on a horizontal plane. The swiveling arrangement is useful in beveling the end of work piece. *Fig. 3.12 (b) illustrates a swivel vise.*

A universal vise may be swiveled like a swivel vise. In addition to that, the body may be tilted in a vertical plane up to 90 degrees from the horizontal. An inclined surface may be machined by a universal vise. *Fig. 3.12 (c) illustrates a universal vise.*

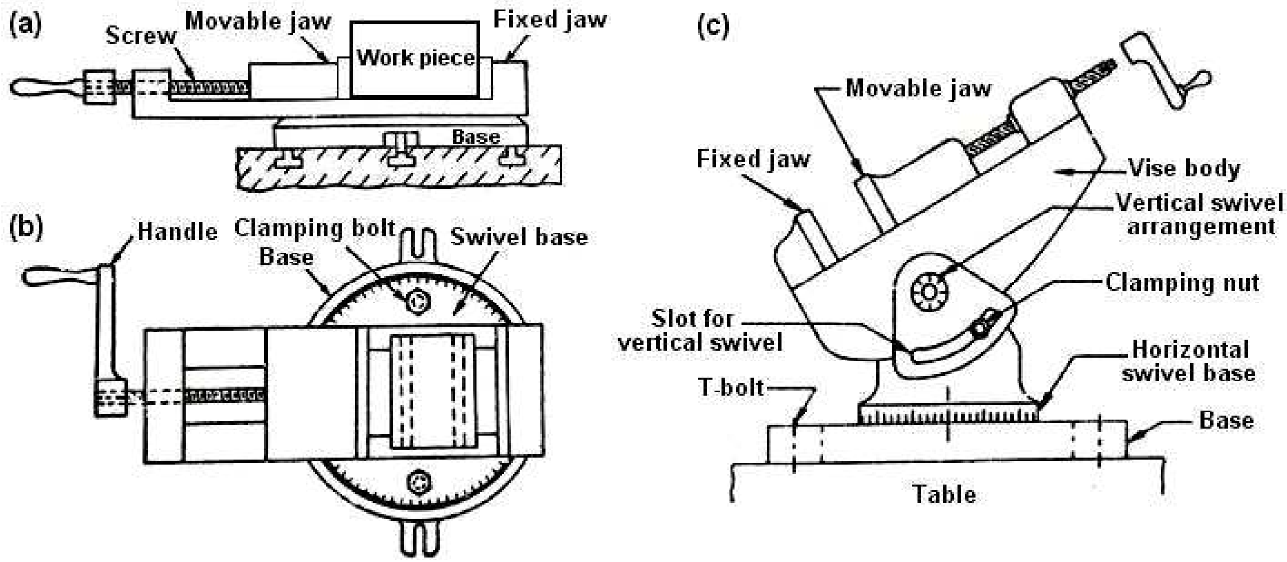


Fig. 3.12 Machine vise (a) Plain vise (b) Swivel vise and (c) Universal vise

Parallels When the height of the job is less than the height of the jaws of the vise, parallels are used to raise and seat the work piece above the vise jaws and parallel with the vise bottom. Parallels are square or rectangular hardened bars of steel or cast iron. *Fig 3.13 illustrates the use of parallels.*

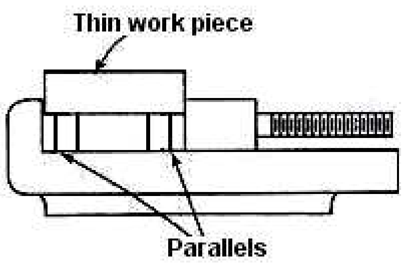


Fig. 3.13 Use of parallels

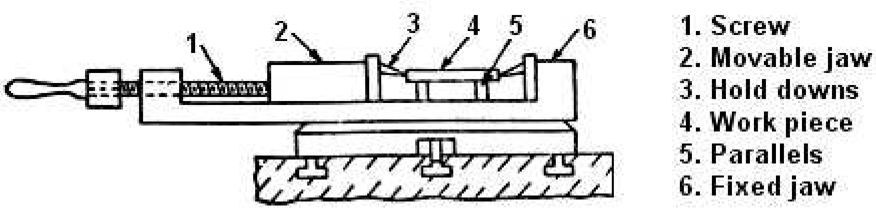


Fig. 3.14 Use of hold downs

Hold downs *Fig 3.14 illustrates the use of hold downs.* Hold downs or grippers are used for holding thin pieces of work in a shaper vise. These are also used for holding work of smaller height than the vise jaws. These are hardened wedge shaped piece with a taper angle of 5^0. These are placed between two jaws of the vise and the work piece. When the screw is tightened the typical shape of the hold down exerts downward pressure on the work to hold it tight on the parallels or on the vise table.

3.2.6.2 Clamping work on the table

When the work piece is too large to be held in a vise it must be fastened directly on the shaper table. The different methods employed to clamp different types of work on a shaper table are:

- T-bolts, step blocks and clamps.
- Stop pins.
- Stop pins and toe dogs.
- Strip and stop pins.

T-bolts, step blocks and clamps *Fig. 3.15 illustrates the use of T-bolt and clamp for holding the work.* T-bolt having T-head is fitted in the T-slot of the table. The length of the threaded portion is sufficiently long in order to accommodate different heights of work. One end of the clamp rests on the side of the work while the other end rests on a fulcrum block or step block. The fulcrum block should be of the same height as the part being clamped. To hold a large work on the table a series of clamps and T-bolts are used all round the work.

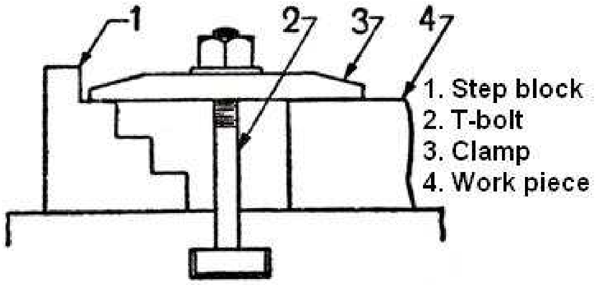


Fig. 3.15 Use of T-bolt, step block and clamp

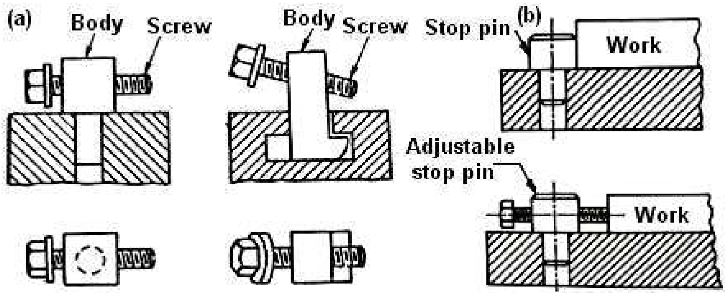


Fig. 3.16 (a) Stop pins and (b) Use of stop pins

Stop pins *Fig.3.16 (a) illustrates the stop pins and Fig. 3.16 (b) illustrates the use of stop pins.* A stop pin is a one-leg screw clamp. Stop pins are used to prevent the work piece from coming out of position during the cutting stroke. The body of the stop pin is fitted in the slot on the table and the screw is tightened till it forces against the work.

Stop pins and toe dogs *Fig.3.17 (a) illustrates the use of stop pins and toe dogs.* While holding thin work on the table stop pins in conjunction with toe dogs are used. A toe dog is similar in shape to that of a centre punch or a cold chisel. *Fig.3.17 (b) shows the two types of toe dogs.* When screw of the stop pin is tightened, the work is gripped down on the table.

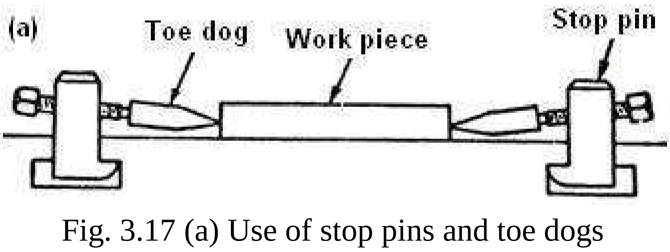


Fig. 3.17 (a) Use of stop pins and toe dogs

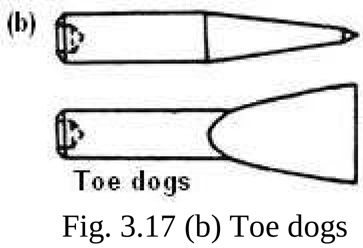


Fig. 3.17 (b) Toe dogs

Strip and stop pin Work having sufficient thickness is held on the table by strip and stop pin. A strip is a long bar having a tongue with holes for fitting the T-bolts. The strip with bolts is fitted in the T-slot of the table. *Fig.3.18 illustrates the use of strip and stop pin for holding the work.*

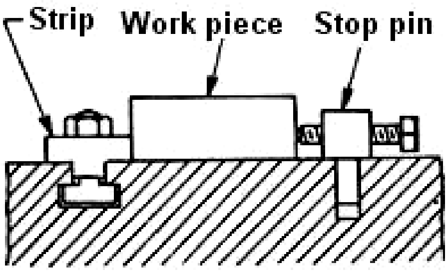


Fig. 3.18 Use of strip and stop pin

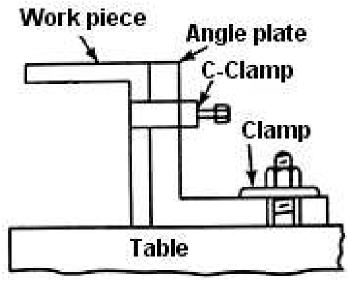


Fig. 3.19 Use of angle plate

3.2.6.3 Angle plate *Fig. 3.19 illustrates the use of angle plate.* For holding "L" shaped work piece, angle plate is used. Angle plate is made of cast iron and is accurately planed on two sides at right angles. One of the sides is clamped to the table by T-bolts while the other side holds the work by clamps.

3.2.6.4 V-blocks *Fig. 3.20 illustrates the use of V-blocks.* V-blocks are used for holding round rods. Work piece may be supported on two V-blocks at its two ends and is clamped to the table by T-bolts and clamps. V-blocks are made of cast iron or steel and are accurately machined.

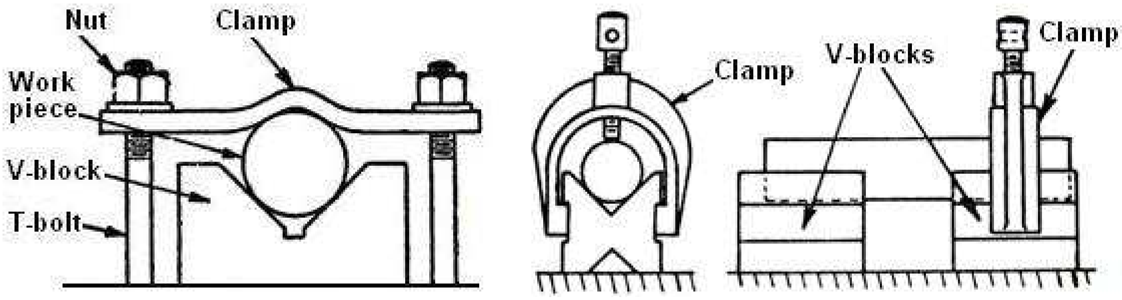


Fig. 3.20 Use of V-blocks

3.2.6.5 Shaper centre

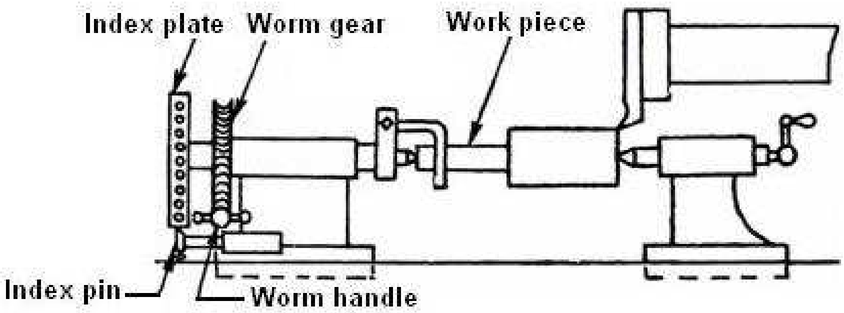


Fig. 3.21 Use of shaper centre

Fig.3.21 illustrates the shaper center. This is a special attachment used for cutting equally spaced grooves or splines and gears. A shaper centre consists of a headstock and a tailstock, and the work is mounted between two centres. The worm gear is mounted upon the head stock spindle and it meshes with the worm. The handle is connected with the worm shaft. Rotation of the handle causes the worm gear to rotate and the motion is transmitted to the work through a catch plate and carrier. After cutting a slot or groove on the top of the work, it may be turned to a predetermined amount by an index plate. The index plate is mounted on the worm gear shaft. The index plate has a series of holes around its circumference and is locked in any desired position by engaging the index pin in the corresponding hole.

3.2.7 Shaper tools

The cutting tool used in a shaper is a single point cutting tool having rake, clearance and other tool angles similar to a lathe tool. It differs from a lathe tool in tool angles. Shaper tools are much more rigid and heavier to withstand shock experienced by the cutting tool at the commencement of each cutting stroke. In a shaper tool the amount of side clearance angle is only 2^0 to 3^0 and the front clearance angle is 4^0 for cast iron and steel. Small clearance angle adds strength to the cutting edge.

As the tool removes metal mostly from its side cutting edge, side rake of 10^0 is usually provided with little or no rake. A shaper can also use a right hand or left hand tool. High speed steel is the most common material for a shaper tool but shock resistant cemented carbide tipped tool is also used where harder material is to be machined. As in a lathe, tool holders are also used to hold the tool bits.

3.2.7.1 Classification of shaper tools

The shaper tools are classified as follows:

According to the shape:

- Straight tool.
- Cranked tool.
- Goose necked tool.

According to the direction of cutting:

- Left hand tool.
- Right hand tool.

According to the finish required:

- Roughing tool.
- Finishing tool.

According to the type of operation:

- Down cutting tool.
- Parting off tool.
- Squaring tool.
- Side recessing tool.

According to the shape of the cutting edge:

- Round nose tool.
- Square nose tool.

Commonly used shaper tools are shown in Fig. 3.22.

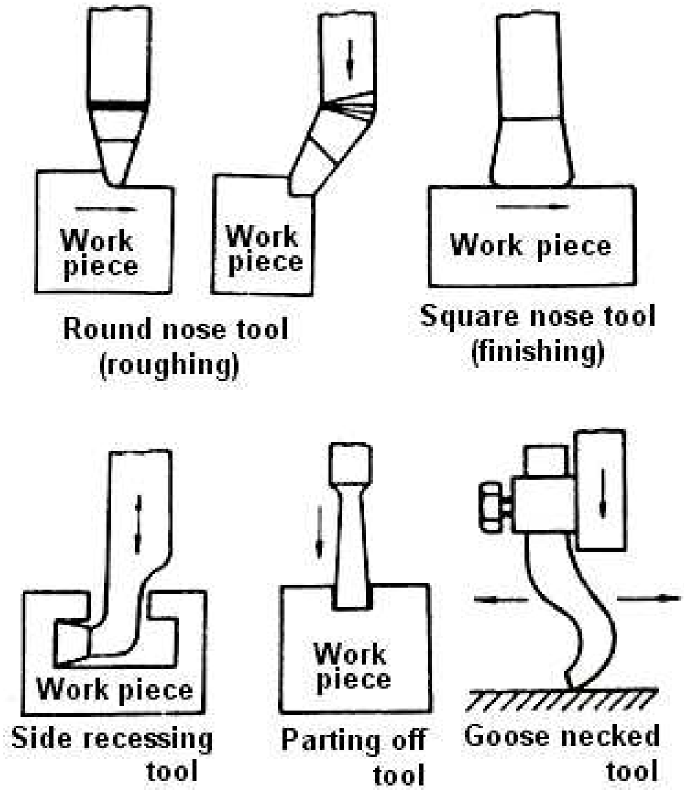


Fig. 3.22 Commonly used shaper tools

Round nose tool: This is used for roughing operations. The tool has no top rake. It has side rake angle, in between 10 to 20^0. Round tool is of two types - plain and bent types. The plain straight type is used for rough machining of horizontal surface. Round nose tool can be left handed or right handed. Another type of round nose tool which is cranked or bent is used for machining vertical surfaces. It is known as round nose cutting down tool.

Square nose tool: This tool is used for finishing operations. The cutting edge may have different widths. It is also used to machine the bottom surfaces of key ways and grooves.

Side recessing tool: This is a special tool used for machining T-slots and narrow vertical surfaces. This tool can be both left handed and right handed.

Parting off tool: This is used for parting off operation. It is also used for cutting narrow slots. It has no side rake angle. It has front and side clearance angle of 3^0.

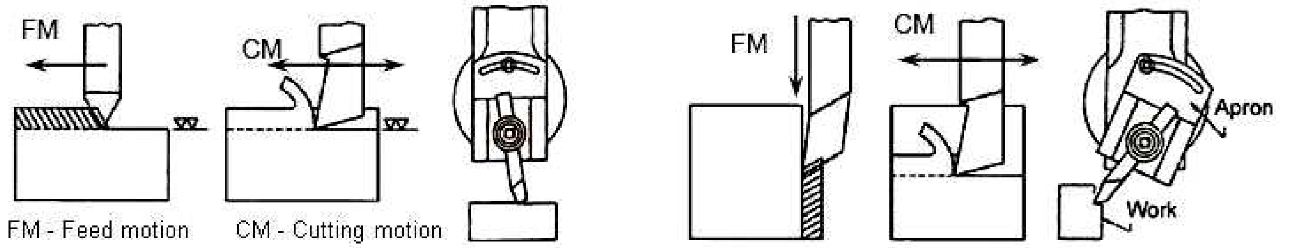
Goose necked tool: This is also known as spring tool. The special shape of tool reduces chatter and prevents digging of tool into the work piece. This tool is generally used for finishing cast iron.

3.2.8 Shaper operations

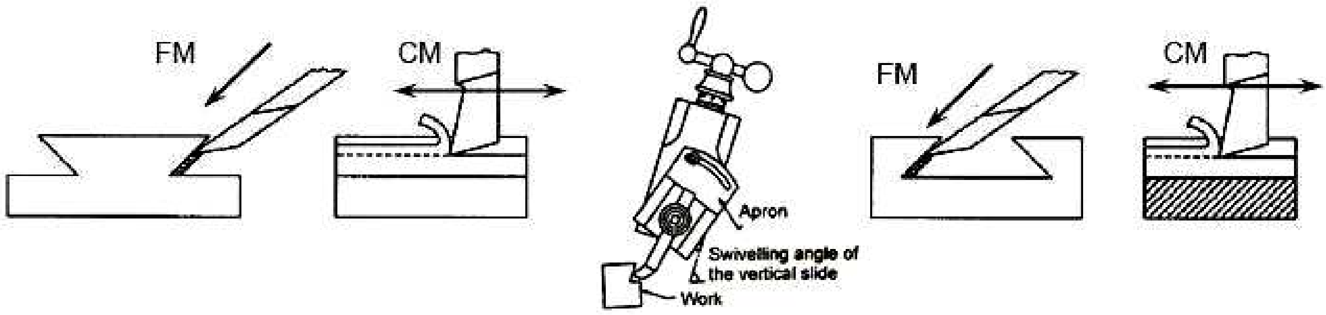
A shaper is a versatile machine tool primarily designed to generate a flat surface by a single point cutting tool. But it may also be used to perform many other operations. The different operations which a shaper can perform are as follows:

Machining flat surfaces in different planes

Fig. 3.23 shows how flat surfaces are produced in a shaper by single point cutting tools in (a) Horizontal (b) Vertical and (c) Inclined planes.



(a) Horizontal surface (b) Vertical surface



(c) Inclined surfaces (dovetail slides and guides)

Fig. 3.23 Machining of flat surfaces in a shaper

Making features like slots, steps etc. which are also bounded by flat surfaces

Fig. 3.24 visualizes the methods of machining (a) Slot (b) Pocket (c) T-slot and (d) V-block in a shaper by single point cutting tools.

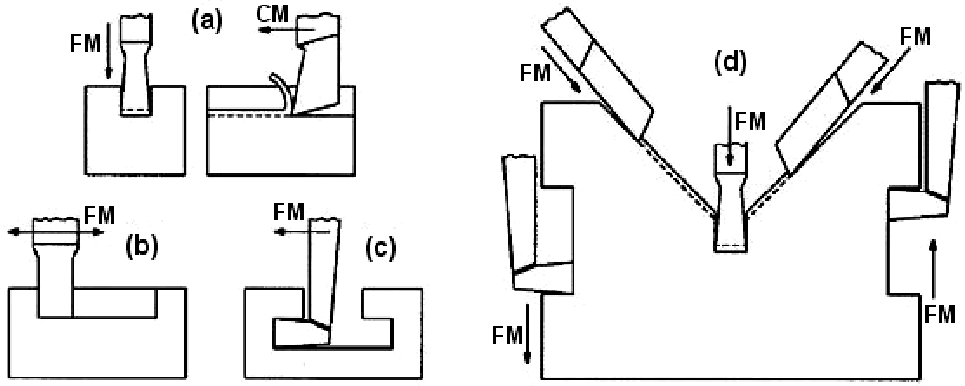


Fig. 3.24 Machining (a) Slot (b) Pocket (c) T-slot and (d) V-block in a shaper

Forming grooves bounded by short width curved surfaces

Fig. 3.25 typically shows how oil groove and contour form are made in a shaper by using single point form tools.

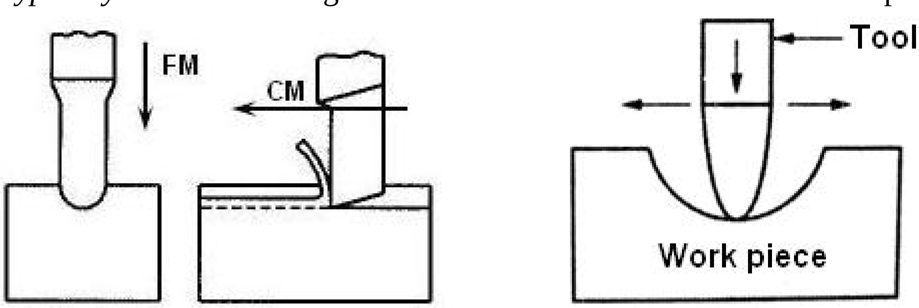


Fig. 3.25 Making grooves in a shaper by form tools

Cutting external and internal keyways

Fig. 3.26 visualizes the methods of machining (a) External keyway and (b) Internal keyway in a shaper by using single point tools.

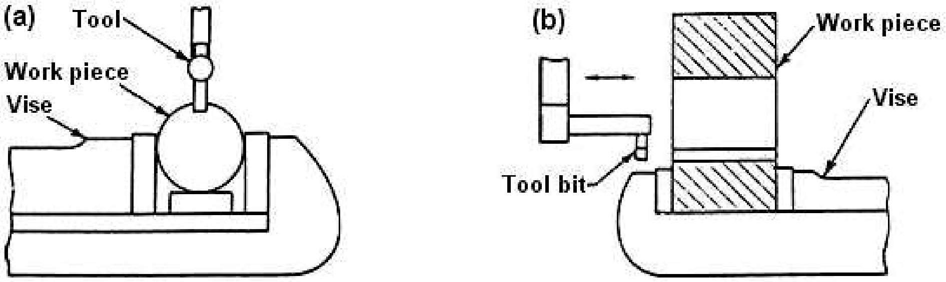


Fig. 3.26 Machining of (a) External keyway and (b) Internal keyway in a shaper

Machining of external gears, external and internal splines

Fig. 3.27 visualizes the methods of machining (a) External gear (b) External splines and (c) Internal splines by using a shaper centre with single point tools.

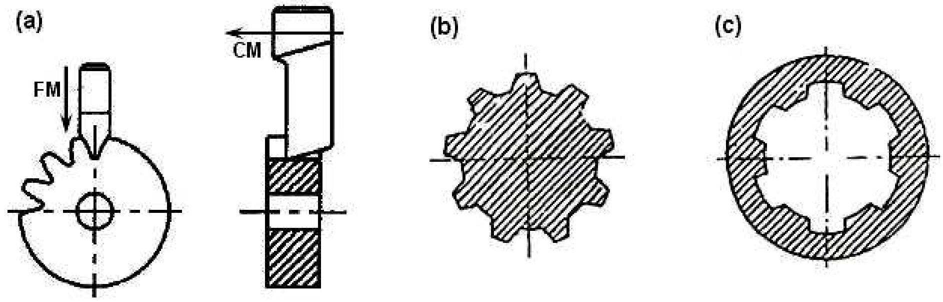


Fig. 3.27 Machining of (a) External gear (b) External splines and (c) Internal splines in a shaper

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

3.2.9 Special attachments used in a shaper

Some special attachments are often used for extending the processing capabilities of a shaper and also for getting some unusual work in an ordinary shaper.

3.2.9.1 Double cut attachment

Fig. 3.28 schematically shows the double cut attachment. This simple attachment is rigidly mounted on the vertical face of the ram replacing the clapper box. It is comprised of a fixed body with two working flat surfaces and a swing type tool holder having two tools on either faces. The tool holder is tilted by a spring loaded lever which is moved by a trip dog at the end of its strokes. Such attachment simply enhances the productivity by utilizing both the strokes in shaping machines.

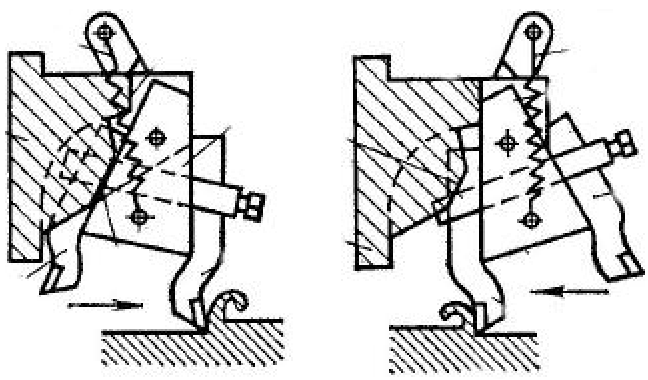


Fig. 3.28 Double cut attachment used in a shaper

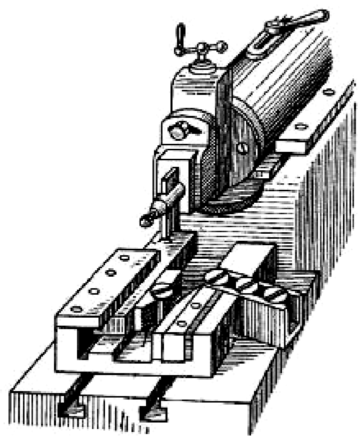


Fig. 3.29 Thread rolling attachment used in a shaper

3.2.9.2 Thread rolling attachment

The thread of fasteners is done by mass production methods. Thread rolling is hardly done nowadays in shaping machines. However the configuration, mounting and the working principle of the thread rolling attachment are *visualized in Fig. 3.29.* In between the flat dies, one fixed and one reciprocating, the blanks are pushed and thread - rolled one by one.

3.3 PLANER

Like shapers, planers are also basically used for producing flat surfaces. But planers are very large and massive compared to the shapers. Planers are generally used for machining large work pieces which cannot be held in a shaper. The planers are capable of taking heavier cuts. The planer was first developed in the year 1817 by Richard Roberts, an Englishman.

3.3.1 Types of planer

The different types of planer which are most commonly used are:

- Standard or double housing planer.
- Open side planer.
- Pit planer.
- Edge or plate planer.
- Divided or latching table planer.

3.3.1.1 Standard or double housing planer

It is most widely used in work shops. It has a long heavy base on which a table reciprocates on accurate guide ways. It has one draw back. Because of the two housings, one on each side of the bed, it limits the width of the work that can be machined. *Fig. 3.30 shows a double housing planer.*

3.3.1.2 Open side planer

It has a housing only on one side of the base and the cross rail is suspended from the housing as a cantilever. This feature of the machine allows large and wide jobs to be clamped on the table. As the single housing has to take up the entire load, it is made extra-massive to resist the forces. Only three tool heads are mounted on this machine. The constructional and driving features of the machine are same as that of a double housing planer. *Fig. 3.31 shows an open side planer.*

3.3.1.3 Pit planer

It is massive in construction. It differs from an ordinary planer in that the table is stationary and the column carrying the cross rail reciprocates on massive horizontal rails mounted on both sides of the table. This type of planer is suitable for machining a very large work which cannot be accommodated on a standard planer and the design saves much of floor space. The length of the bed required in a pit type planer is little over the length of the table. *Fig. 3.32 shows a pit planer*.

3.3.1.4 Edge or plate planer

The design of a plate or edge planer is totally unlike that of an ordinary planer. It is specially intended for squaring and beveling the edges of steel plates used for different pressure vessels and ship-building works. *Fig. 3.33 shows an edge planer.*

3.3.1.5 Divided table planer

This type of planer has two tables on the bed which may be reciprocated separately or together. This type of design saves much of idle time while setting the work. To have a continuous production one of the tables is used for setting up the work and the other is used for machining. This planer is mainly used for machining identical work pieces. The two sections of the table may be coupled together for machining long work. *Fig. 3.34 shows a divided table planer*.

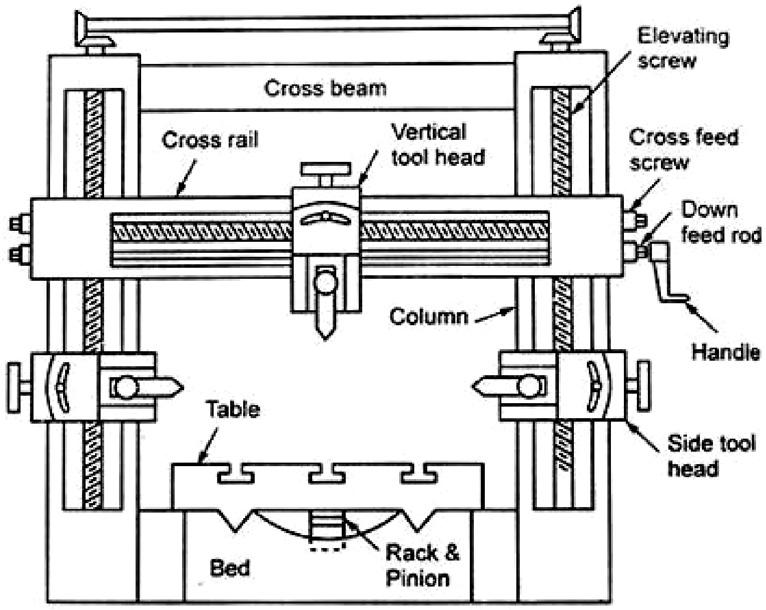


Fig. 3.30 Schematic view of a double housing planer

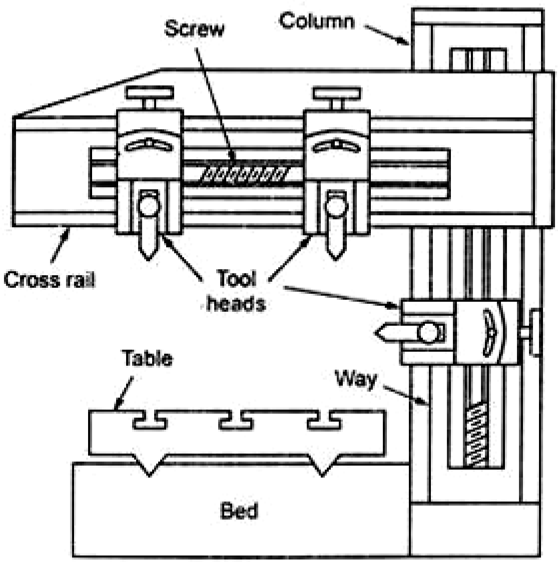


Fig. 3.31 Schematic view of an open side planer

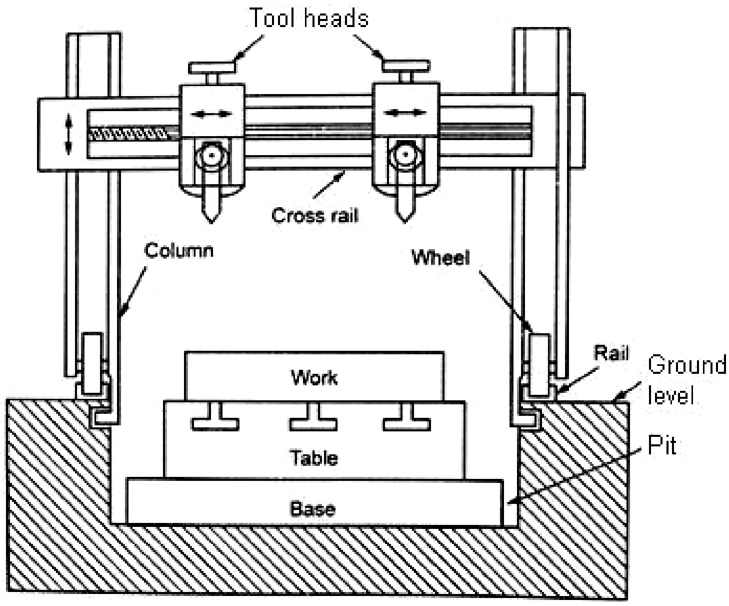


Fig. 3.32 Schematic view of a pit planer

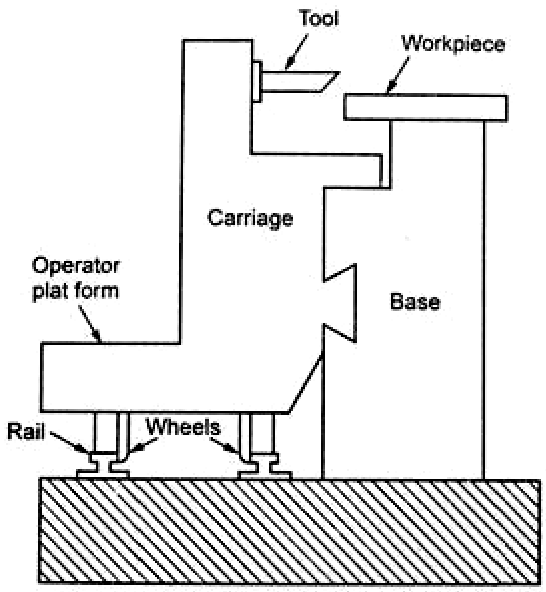


Fig. 3.33 Schematic view of an edge planer

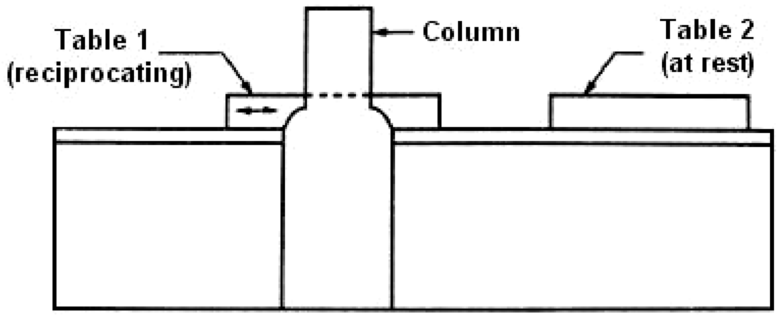


Fig. 3.34 Schematic view of a divided table planer

3.3.2 Major parts of a double housing planer

Fig. 3.30 shows the basic configuration of a double housing planer. The major parts are:

Bed It is box like casting having cross ribs. It is a very large in size and heavy in weight and it supports the column and all other moving parts of the machine. The bed is made slightly longer than twice the length of the table so that the full length of the table may be moved on it. It is provided with precision ways over the entire length on its top surface and the table slides on it. The hollow space within the box like structure of the bed houses the driving mechanism for the table.

Table It supports the work and reciprocates along the ways of the bed. The top face of the planer table is accurately finished in order to locate the work correctly. T-slots are provided on the entire length of the table so that the work and work holding devices may be bolted upon it. Accurate holes are drilled on the top surface of the planer table at regular intervals for supporting the poppet and stop pins. At each end of the table a hollow space is left which acts as a trough for collecting chips. Long works can also rest upon the troughs. A groove is cut on the side of the table for clamping planer reversing dogs at different positions.

Housing It is also called columns or uprights are rigid box like vertical structures placed on each side of the bed and are fastened to the sides of the bed. They are heavily ribbed to trace up severe forces due to cutting. The front face of each housing is accurately machined to provide precision ways on which the cross rail may be made to slide up and down for accommodating different heights of work. Two side-tool heads also slide upon it. The housing encloses the cross rail elevating screw, vertical and cross feed screws for tool heads, counterbalancing weight for the cross rail, etc. these screws may be operated either by hand or power.

Cross rail It is a rigid box like casting connecting the two housings. This construction ensures rigidity of the machine. The cross rail may be raised or lowered on the face of the housing and can be clamped at any desired position by manual, hydraulic or electrical clamping devices. The two elevating screws in two housing are rotated by an equal amount to keep the cross rail horizontal in any position.

The front face of the cross rail is accurately machined to provide a guide surface for the tool head saddle. Usually two tool heads are mounted upon the cross rail which are called railheads. The cross rail has screws for vertical and cross feed of the tool heads and a screw for elevating the rail. These screws may be rotated either by hand or by power.

Tool head It is similar to that of a shaper both in construction and operation.

3.3.3 Working principle of a double housing planer

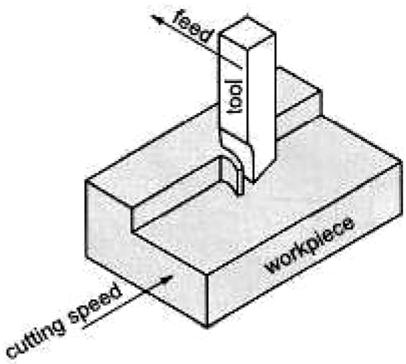


Fig. 3.35 Principle of producing flat surface

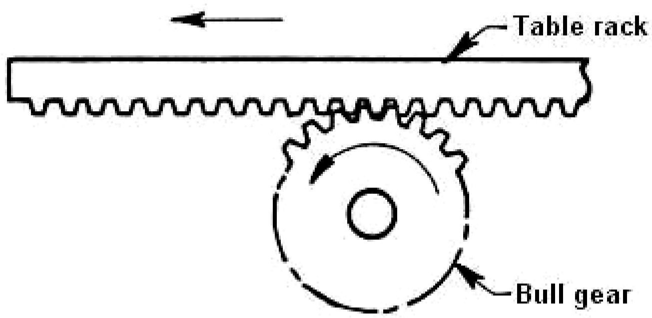


Fig. 3.36 Meshing of bull gear with table rack

Fig. 3.35 shows the basic principle of producing flat surface in a planer. The work piece is mounted on the reciprocating table and the tools are mounted on the tool heads. The tool heads holding the cutting tools are moved horizontally along the cross rail by screw-nut system and the cross rail is again moved up and down along the vertical rails by another screw-nut pair. The simple kinematical system of the planer 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 tool heads. The reciprocation of the table, which imparts cutting motion to the work piece, is attained by rack and pinion (bull gear) mechanism. *Fig. 3.36 illustrates meshing of the bull gear with the table rack.* 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. The feed to the tool is given at the end of the return stroke.

3.3.4 Table drive mechanism of a planer

3.3.4.1 Open and cross belt drive quick return mechanism

In this mechanism the movement of the table is effect by an open belt and a cross belt drive. It is an old method of quick return drive used in planers of smaller size where the table width is less than 900 mm. *Fig. 3.37 schematically shows the open and cross belt drive quick return mechanism of a planer.*

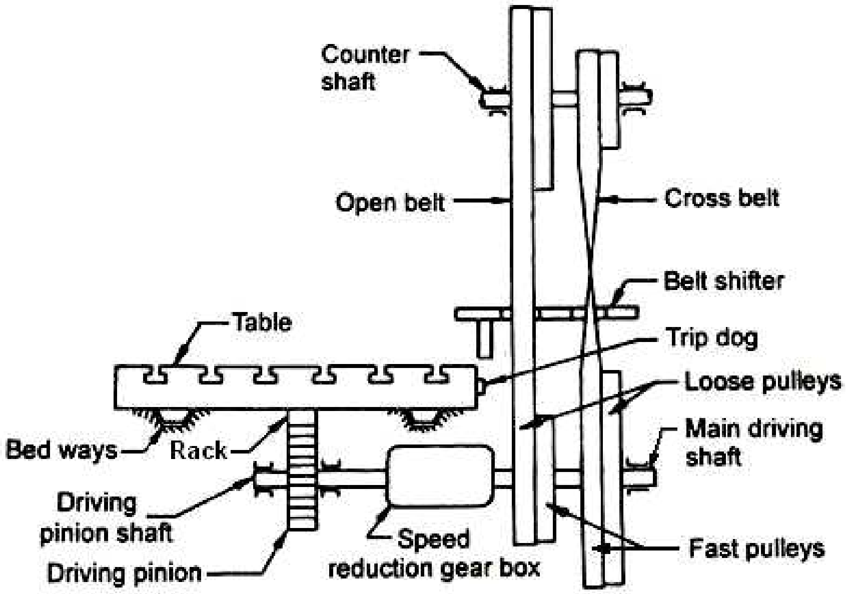


Fig. 3.37 Open and cross belt drive quick return mechanism

It has a counter shaft mounted upon the housings receives its motion from an overhead line shaft. Two wide faced pulleys of different diameters are keyed to the counter shaft. The main shaft is placed under the bed. One end of the shaft carries a set of two larger diameter pulleys and two smaller diameter pulleys. The outer pulleys are rotate freely on the main shaft and they are called loose pulleys. The inner pulleys are keyed tightly to the main shaft and they are called fast pulleys. The open belt connects the larger diameter pulley on the countershaft with the smaller diameter pulley on the main shaft. The cross belt connects the smaller diameter pulley on the counter shaft with the larger diameter pulley on the main shaft. The speed of the main shaft is reduced through a speed reduction gear box. From this gear box, the motion is transmitted to the bull gear shaft. The bull gear meshes with a rack cut at the underside of the table and the table will receive a linear movement.

Referring to the Fig. 3.37, the open belt connects the smaller loose pulley, so no motion is transmitted by the open belt to the main shaft. But the cross belt connects the larger fast pulley, so the motion is transmitted by the cross belt to the main shaft. The forward stroke of the table takes place. During the cutting stroke, greater power and less speed is required. The cross belt giving a greater arc of contact on the pulleys is used to drive the table during the cutting stroke. The greater arc of contact of the belt gives greater power and the speed is reduced as the belt connects smaller diameter pulley on the counter shaft and larger diameter pulley on the main shaft. At the end of the forward stroke a trip dog pushes the belt shifter through a lever arrangement. The belt shifter shifts both the belts to the right side.

The open belt is shifted to the smaller fast pulley and the cross belt is shifted to the larger loose pulley. Now the motion is transmitted to the main shaft through the open belt and no motion is transmitted to the main shaft by the cross belt. The direction of rotation of the main shaft is reversed. The return stroke of the table takes place. The speed during return stroke is increased as the open belt connects the larger diameter pulley on the counter shaft with the smaller diameter pulley on the main shaft. Thus a quick return motion is obtained by the mechanism. At the end of the return stroke, the belts are shifted to the left side by another trip dog. So the cycle is repeated. The length and position of the stroke may be adjusted by shifting the position of trip dogs.

3.3.4.2 Reversible motor drive quick return mechanism

All modern planers are equipped with variable speed electric motor which drives the bull gear through a gear train. The most efficient method of an electrical drive is based on Ward Leonard system. *Fig. 3.38 schematically shows the reversible motor drive quick return mechanism of a planer.*

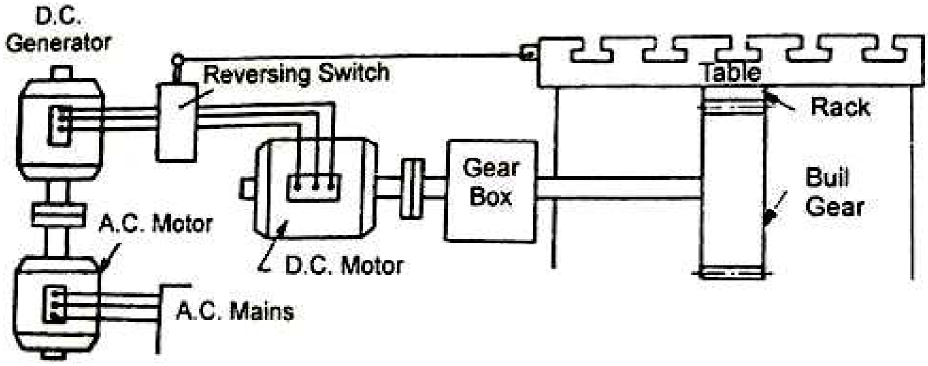


Fig. 3.38 Reversible motor drive quick return mechanism

This system was introduced by Harry Ward Leonard in 1891. This system consists of an AC motor which is coupled with a DC generator, a DC motor and a reversing switch. When the AC motor runs, the DC motor will receive power from the DC generator. At that time, the table moves in forward direction. At the end of this stroke, a trip dog actuates an electrical reversing switch. Due to this action, it reverses the direction of current in DC generator with increased current strength. Now, the motor rotates in reverse direction with higher speed. So, the table moves in the reverse direction to take the return stroke with comparatively high speed. Thus the quick return motion is obtained by the mechanism.

The distinct advantages of electrical drive over a belt drive are:

- Cutting speed, stroke length and stroke position can be adjusted without stopping the machine.
- Large number of cutting speeds and return speeds are available.
- Quick and accurate control. Push button controls the start, stop and fine movement of the table.
- Return speed can be greatly increased reducing idle time.

3.3.4.3 Hydraulic drive quick return mechanism

The hydraulic drive is quite similar to that used for a horizontal shaper. More than one hydraulic cylinder may be used to give a wide range of speeds. The main drawback of the hydraulic drive on long planers is irregular movement of the table due to the compressibility of the hydraulic fluid. The hydraulic drive has been described in Article 3.2.4.3, Page 107 and illustrated in Fig. 3.8.

3.3.5 Feed mechanism of a planer

In a planer the feed is provided intermittently and at the end of the return stroke similar to a shaper. The feed of a planer, both down feed and cross feed, is given by the tool head. The down feed is applied while machining a vertical or angular surface by rotating the down feed screw of the tool head.

The cross feed is given while machining horizontal surface by rotating the cross feed screw passes through a nut in the tool head. Both the down feed and cross feed may be provided either by hand or power by rotating two feed screws, contained within the cross rail.

If the two feed screws are rotated manually by a handle, then it called hand feed. If the two feed screws are rotated by power, then it is called automatic feed.

3.3.5.1 Automatic feed mechanism of a planer

Fig. 3.39 illustrates the front and top view of the automatic feed mechanism of a planer. A trip dog is fitted to the planer table. At the end of the return stroke, the trip dog strikes a lever. A pawl attached to this lever rotates a ratchet. So a splined shaft attached to the ratchet rotates. A bevel gear cast integral with a spur gear is fitted freely on the down feed screw. This bevel gear meshes with other bevel gear slides on the splined shaft.

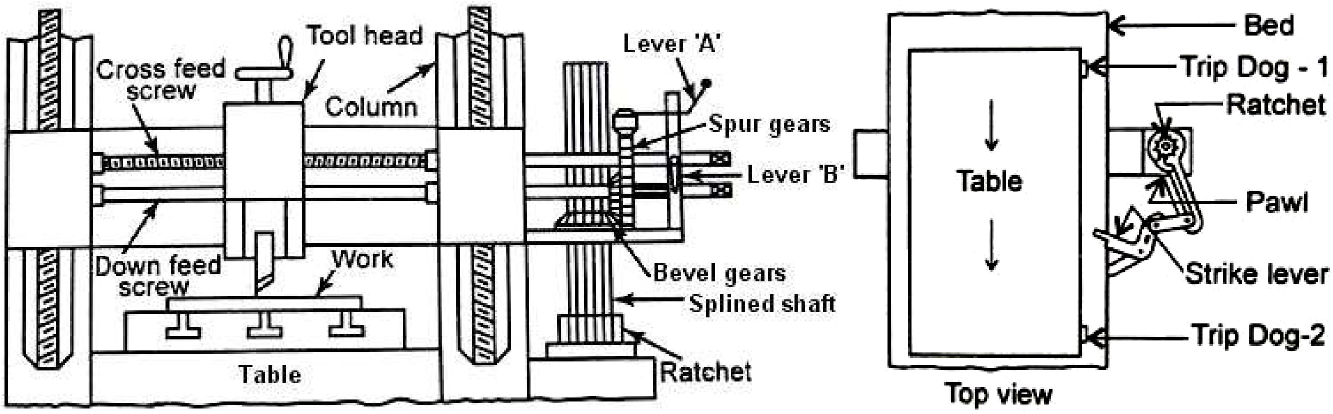


Fig. 3.39 Front and top view of the automatic feed mechanism of a planer

The spur gear meshes with another spur gear which is keyed to the cross feed screw. So the power from the splined shaft is transmitted to the cross feed screw. Then the rotation is transmitted to the tool head through a nut. The tool head moves horizontally. It is known a cross feed. At the end of the forward stroke, another trip dog strikes the lever. The lever comes to its original position. During this time, the pawl slips over the ratchet. The ratchet wheel does not rotate.

For giving automatic down feed, the spur gear keyed to the cross feed screw is disengaged. The bevel gear freely fitted to the down feed rod is keyed to the down feed rod. At the end of return stroke, the power is transmitted to the down feed rod through the lever, ratchet and bevel gears. Then the rotation is transmitted to the tool head though the bevel gears. The tool moves downward.

3.3.6 Work holding devices used in a planer

A planer table is used to hold very large, heavy and intricate work pieces, and in many cases, large number of identical work pieces together. Setting up of the work pieces on a planer table requires sufficient amount of skill. *The work piece may be held on a planer table by the following methods:*

- By standard clamping.
- By special fixtures.

3.3.6.1 Standard clamping devices

The standard clamping devices are used for holding most of the work pieces on a planer table. *The standard clamping devices are as follows:*

- Heavy duty vises.
- T-bolts, step blocks and clamps.
- Stop pins and toe dogs.
- Angle plates.
- Planer jacks.
- Planer centres (similar to shaper centre).
- V-blocks.

Most of them have been described in Article 3.2.6 and Page 110.

A planer vise is much more robust in construction than a shaper vise as it is used for holding comparatively larger size of work. The vise may be plain or swiveled base type.

Large work pieces are clamped directly on the table by T- bolts and clamps. Different types of clamps are used for different types of work. *Fig. 3.40 illustrates the method of clamping a large work piece on a planer table.* Step blocks are used to lend support to the other end of the clamp.

Planer jacks are used for supporting the overhanging part of a work to prevent it from bending. *Fig. 3.41 illustrates the use of a planer jack.*

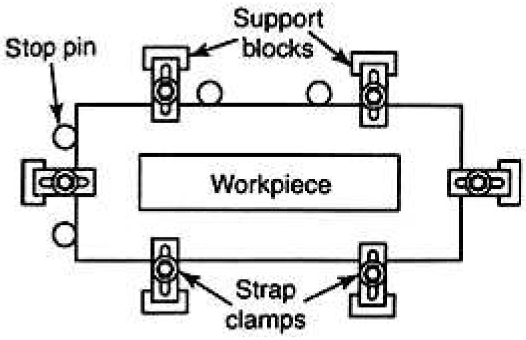


Fig. 3.40 Clamping a large work piece on a planer table

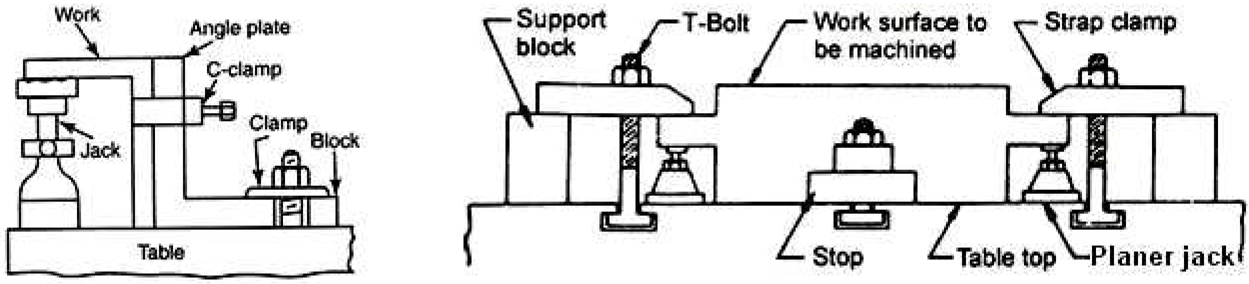


Fig. 3.41 Use of planer jack

3.3.6.2 Special fixtures

These are used for holding a large number of identical pieces of work on a planer table. Fixtures are specially designed for holding a particular type of work. By using a fixture the setting time may be reduced considerably compared to the individual setting of work by conventional clamping devices. *Fig. 3.42 illustrates the use of a fixture.*

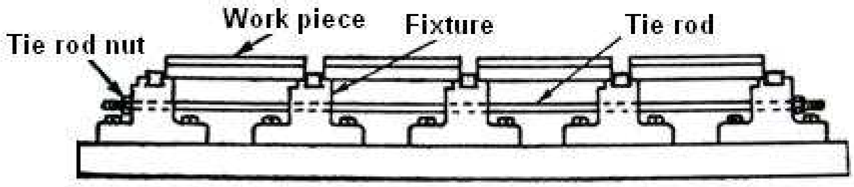


Fig. 3.42 Use of a fixture

3.3.7 Planer tools

The cutting tools used on planers are all single point cutting tools. They are in general similar in shapes and tool angles to those used on a lathe and shaper. As a planer tool has to take up heavy cut and coarse feed during a long cutting stroke, the tools are made heavier and larger in cross-section. Planer tools may be solid, forged type or bit type. Bits are made of HSS, stellite or cemented carbide and they may be brazed, welded or clamped on a mild steel shank. Cemented carbide tipped tool is used for production work. *Fig. 3.43 shows the typical tools used in a planer.*

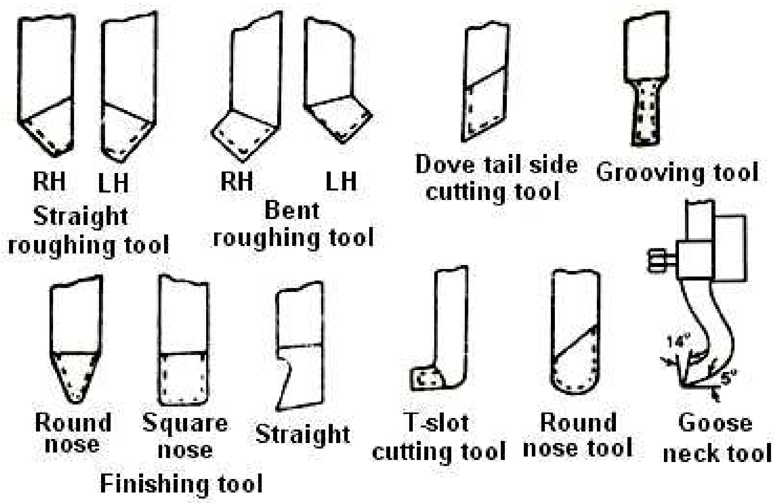


Fig. 3.43 Typical tools used in a planer

3.3.8 Planer operations

All the operations done in a shaper can be done in a planer. But large size, stroke length and higher rigidity enable the planers do more heavy duty work on large jobs and their long surfaces. Simultaneous use of number of tools further enhances the production capacity of planers. The common types of work machined in a planer are: Beds and tables of various machine tools, large structures, long parallel T-slots, V and inverted V type guide ways, frames of different engines and identical pieces of work which may be small in size but large in number.

Machining the major surfaces and guide ways of beds and tables of various machines like lathes, drilling machines, milling machines, grinding machines, broaching machines and planers itself are the common applications of a planer *as illustrated in Fig. 3.44.* Where the several parallel surfaces of typical machine bed and guide way are machined by a number of single point HSS or carbide tools.

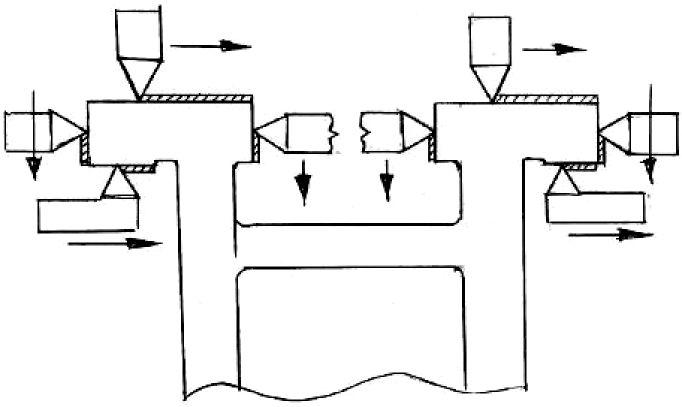


Fig. 3.44 Machining of a machine bed in a planer

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.

3.3.9 Special attachments used in a planer

3.3.9.1 Contour forming attachment

Fig. 3.45 illustrates the contour forming attachment used in a planer. The machining operation is performed by using the attachment which consists of a radius arm and a bracket. The bracket is connected to the cross member attached to the two housings. One end of the radius arm is pivoted on the bracket and the other end to the vertical slide of the tool head. The down feed crew of the tool head is removed. The horizontal rail is kept delinked from the vertical lead screws. The tool which is guided by the radius arm planes a convex or a concave surface. The radius of convex or concave surface produced is dependent upon the length of the radius arm.

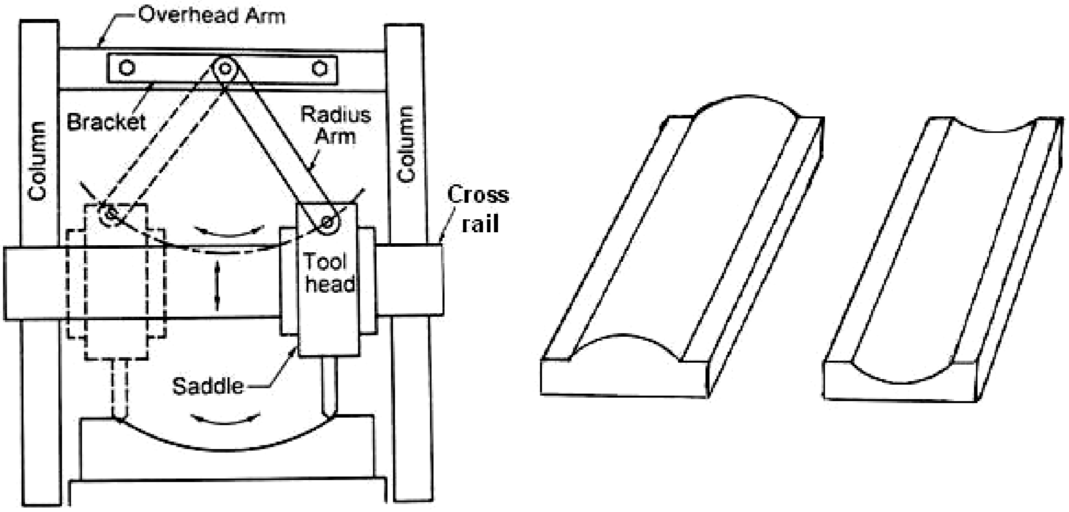


Fig. 3.45 Contour forming attachment used in a planer

3.3.10 Specifications of a planer

The planer is specified by the following parameters:

- Radial distance between the top of the table and the bottom most position of the cross rail.
- Maximum length of the table and maximum stroke length of table.
- Power of the motor.
- Range of speeds and feeds available.
- Type of feed and type of drives required.
- Horizontal distance between two vertical housings.
- Net weight of machine and Floor area required.

3.3.11 Difference between shaper and planer

Sl. No.	Shaper	Planer
1	The tool reciprocates and the work is stationary.	The work reciprocates and the tool is stationary.
2	Feed is given to the work during the idle stroke of the ram.	Feed is given to the tool during the idle stroke of the work table.
3	It gives more accuracy as the tool is rigidly supported during cutting.	Less accuracy due to the over hanging of the ram.
4	Suitable for machining small work pieces.	Suitable for machining large work pieces.
5	Only light cuts can be applied.	Heavy cuts can be applied.
6	Only one tool can be used at a time. So machining takes longer time.	Vertical and side tool heads can be used at a time. So machining is quicker.
7	Setting the work piece is easy.	Setting the work piece is difficult.
8	Only one work piece can be machined at a time.	Several work pieces can be machined at a time.
9	Tools are smaller in size.	They are larger in size.
10	Shapers are lighter and smaller.	Planers are heavier and larger.

3.4 SLOTTER

Slotter can simply be considered as vertical shaper where the single point (straight or formed) cutting tool reciprocates vertically and the work piece, being mounted on the table, is given slow longitudinal and / or rotary feed. The slotter is used for cutting grooves, keyways, internal and external gears and slots of various shapes. The slotter was first developed in the year 1800 by Brunel.

3.4.1 Types of slotter

The different types of slotter which are most commonly used are:

- Puncher slotter.
- Precision slotter.

3.4.1.1 Puncher slotter

It is a heavy, rigid machine designed for removal of a large amount of metal from large forging or castings. The length of a puncher slotter is sufficiently large. It may be as long as 1800 to 2000 mm. The ram is usually driven by a spiral pinion meshing with the rack teeth cut on the underside of the ram. The pinion is driven by a variable speed reversible electric motor similar to that of a planer. The feed is also controlled by electrical gears.

3.4.1.2 Precision slotter

It is a lighter machine and is operated at high speeds. The machine is designed to take light cuts giving accurate finish. Using special jigs, the machine can handle a number of identical works on a production basis. The precision machines are also used for general purpose work and are usually fitted with Whitworth quick return mechanism.

3.4.2 Major parts of a slotter

Fig. 3.46 shows the basic configuration of a slotter. The major parts are:

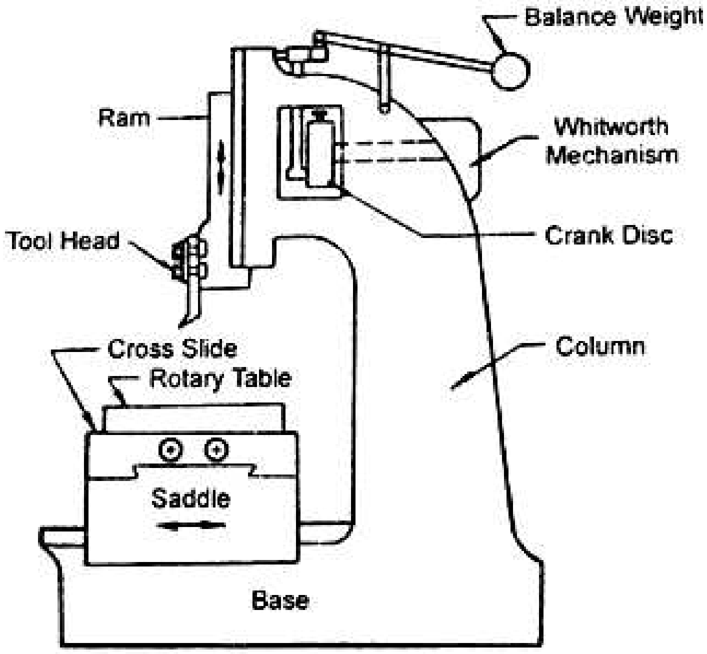


Fig. 3.46 Schematic view of a slotter

Base It is rigidly built to take up all the cutting forces and entire load of the machine. The top of the bed is accurately finished to provide guide ways on which the saddle is mounted. The guide ways are perpendicular to the column face.

Column It is the vertical member which is cast integral with the base and houses driving mechanism of the ram and feeding mechanism. The front vertical face of the column is accurately finished for providing ways on which the ram reciprocates.

Saddle It is mounted upon the guide ways and may be moved toward or away from the column either by power or manual control to supply longitudinal feed to the work. The top face of the saddle is accurately finished to provide guide ways for the cross-slide. These guide ways are perpendicular to the guide ways on the base.

Cross slide It is mounted upon the guide ways of the saddle and may be moved parallel to the face of the column. The movement of the slide may be controlled either by hand or power to supply cross feed.

Rotary table It is a circular table which is mounted on the top of the cross-slide. The table may be rotated by rotating a worm which meshes with a worm gear connected to the underside of the table. The rotation of the table may be effected either by hand or power. In some machines the table is graduated in degrees that enable the table to be rotated for indexing or dividing the periphery of a job in equal number of parts. T-slots are cut on the top face of the table for holding the work by different clamping devices. The rotary table enables a circular or contoured surface to be generated on the work piece.

Ram It is the reciprocating member of the machine mounted on the guide ways of the column. It is connected to the reciprocating mechanism contained within the column. A slot is cut on the body of the ram for changing the position of the stroke. It carries the tool head at its bottom end.

Tool head It holds the tool rigidly. In some machines, special types of tool holders are provided to relieve the tool during its return stroke.

3.4.3 Working principle of a slotter

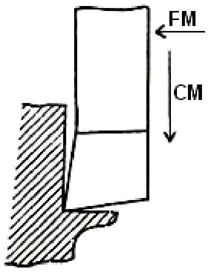


Fig. 3.47 Principle of producing vertical flat surface

Fig. 3.47 shows the basic principle of producing vertical flat surface in a slotter. The vertical ram holding the cutting tool is reciprocated by a ram drive mechanism. The work piece, to be machined, is mounted directly or in a vice on the work table. Like shaper, in slotter also the fast cutting motion is imparted to the tool and the feed motions to the work piece. In slotter, 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 an automatic feed mechanism. The intermittent rotation of the feed rod is transmitted to the lead screws 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 may be changed by changing the belt-pulley ratio or using an additional “speed gear box”. Only light cuts are taken due to lack of rigidity of the tool holding ram. Unlike shapers and planers, slotters are generally used to machine internal surfaces (flat, formed grooves and cylindrical).

3.4.4 Ram drive mechanism of a slotter

A slotter removes metal during downward cutting stroke only whereas during upward return stroke no metal is removed. To reduce the idle return time, quick return mechanism is incorporated in the machine. The reciprocating movement and the quick return of the ram are usually obtained by using any one of the following mechanisms.

3.4.4.1 Whitworth quick return mechanism

The Whitworth quick return mechanism is most widely used in a medium sized slotter for driving the ram. This mechanism has been described in Article 3.2.4.2, Page 107 and illustrated in Fig. 3.7.

3.4.4.2 Hydraulic drive quick return mechanism

The hydraulic drive is adapted in slotters which are used in precision or tool-room work. In a hydraulic drive, the vibration is minimized resulting improved surface finish. The hydraulic drive has been described in Article 3.2.4.3, Page 107 and illustrated in Fig. 3.8.

3.4.4.3 Electrical drive quick return mechanism

Large slotters are driven by variable voltage reversible motor. The drive is similar to that described in Article 3.3.4.2, Page 119 and illustrated in Fig. 3.38.

3.4.5 Feed mechanism of a slotter

In a slotter, the feed is given by the table. A slotting machine table may have three types of feed movements: Longitudinal, cross and circular.

If the table is fed perpendicular to the column toward or away from its face, the feed movement is termed as longitudinal. If the table is fed parallel to the face of the column the feed movement is termed as cross. If the table is rotated on a vertical axis, the feed movement is termed as circular.

Like a shaper or a planer, the feed movement of a slotter is intermittent and supplied at the beginning of the cutting stroke. The feed movement may be provided either by hand or power. If the feed screws are rotated manually by a handle, then it called hand feed. If the feed screws are rotated by power, then it is called automatic feed.

3.4.5.1 Automatic feed mechanism of a slotter

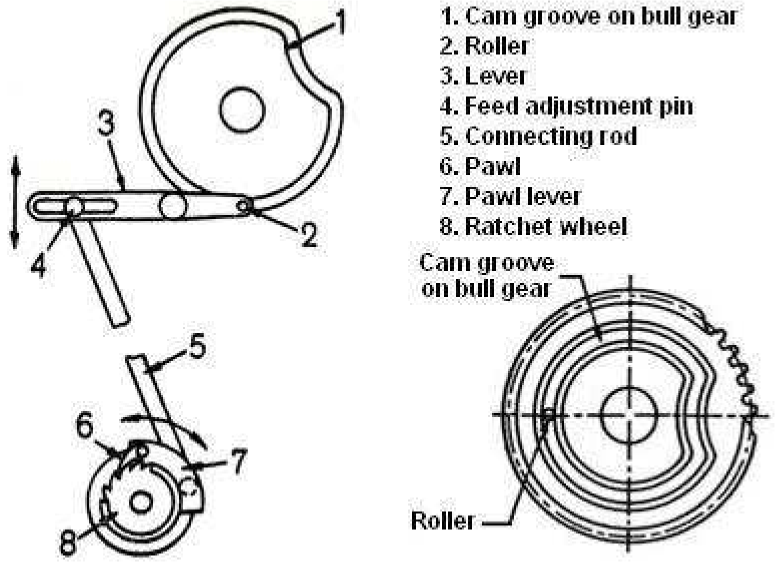


Fig. 3.48 Automatic feed mechanism of a slotter

Fig. 3.48 illustrates the automatic feed mechanism of a slotter. A cam groove is cut on the face of the bull gear in which a roller slides. As the bull gear rotates, the roller attached to a lever follows the contour of the cam groove and moves up and down only during a very small part of revolution of the bull gear. The cam groove may be so cut that the movement of the lever will take place only at the beginning of the cutting stroke. Fig3. Shows the cam groove cut on a bull gear. The rocking movement of the lever is transmitted to the ratchet and pawl mechanism, so that the ratchet will move in one direction only during this short period of time. The ratchet wheel is mounted on a feed shaft which may be engaged with cross, longitudinal or rotary feed screws individually or together to impart power feed movement to the table.

3.4.6 Work holding devices used in a slotter

The work is held on a slotter table by a vise, T-bolts and clamps or by special fixtures. T-bolts and clamps are used for holding most of the work on the table. Before clamping, parallels are placed below the work piece so as to allow the tool to complete the cut without touching the table. Holding work by T-bolts and clamps have been described in Article 3.2.6.2, Page 111 and illustrated in Fig. 3.15. Special fixtures are used for holding repetitive work. *Fig. 3.49 shows a typical slotting fixture.*

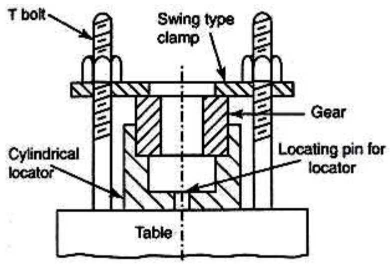


Fig. 3.49 Slotting fixture

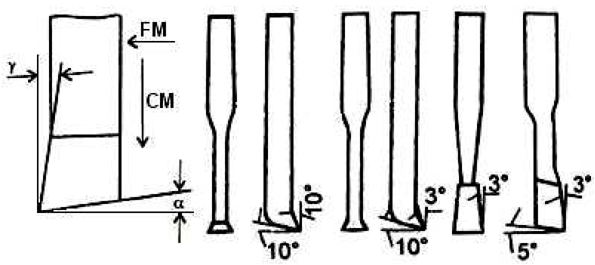


Fig. 3.50 Different tools used in a slotter

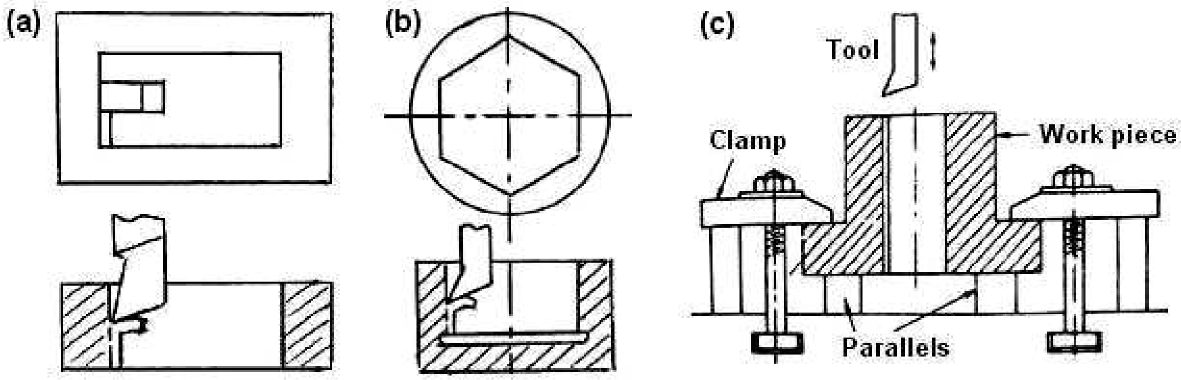
3.4.7 Slotter tools

Fig. 3.50 illustrates different slotter tools used in different operations. A slotter tool differs widely from a shaper tool as the tool in a slotter removes metal during its vertical cutting stroke. This changed cutting condition presents a lot of difference in the tool shape. In a shaper tool the cutting pressure acts perpendicular to the tool length, whereas in a slotter tool the pressure acts along the length of the tool. The rake angle (α) and clearance angle (γ) of a slotter tool look different from a shaper tool. The slotter tools are robust in cross section and are usually of forged type: of course, bit type tools fitted in heavy tool holders are also used. Keyway cutting tools are thinner at the cutting edges. Round nose tools are used for machining contoured surfaces. Square nose tools are used for machining flat surfaces.

3.4.8 Slotter operations

Slotter is mostly used for machining internal surfaces. The usual and possible machining operations of a slotter are:

- Internal flat surfaces.
- Enlargement and / or finishing non-circular holes bounded by a number of flat surfaces *as shown in Fig. 3.51 (a).*
- Blind geometrical holes like hexagonal socket *as shown in Fig. 3.51 (b).*
- Internal grooves and slots of rectangular and curved sections.
- Internal keyways and splines, straight tooth of internal spur gears, internal curved surfaces, and internal oil grooves etc *as shown in Fig. 3.51 (c),* which are not possible in shaper.



(a) Through rectangular hole (b) Hexagonal socket and (c) Internal keyway

Fig. 3.51 Typical machining operations performed in a slotter

However, the productivity and process capability of slotters are very poor and hence used mostly for piece production required for maintenance and repair in small industries. Scope of use of slotter for production has been further reduced by more and regular use of broaching machines.

Shapers, planers and slotters are becoming obsolete and getting replaced by Plano-millers where instead of single point cutting tools more number of large size and high speed milling cutters are used.

3.4.9 Specifications of a slotter

The slotter is specified by the following parameters:

- The maximum stroke length.
- Diameter of rotary table.
- Maximum travel of saddle and cross slide.
- Type of drive used.
- Power of the motor.
- Net weight of machine.
- Number and amount of feeds.
- Floor area required.

3.5 MILLING MACHINE

This is a machine tool that removes material as the work is fed against a rotating cutter. The cutter rotates at a high speed and because of the multiple cutting edges it removes material at a very fast rate. The machine can also hold two or more number of cutters at a time. That is why a milling machine finds wide application in machine shop. The first milling machine came into existence in about 1770 and was of French origin. The milling cutter was developed by Jacques de Vaucanson in the year 1782. The first successful plain milling machine was designed by Eli Whitney in the year 1818. The universal milling machine was invented in the year 1861 by Joseph R Brown.

3.6 TYPES OF MILLING MACHINE

Milling machines are broadly classified as follows:

Column and knee type

- Hand milling machine.
- Plain or horizontal milling machine.
- Universal milling machine.
- Omniversal milling machine.
- Vertical milling machine.

Manufacturing or bed type

- Simplex milling machine.
- Duplex milling machine.
- Triplex milling machine.

Planer type

Special type

- Drum milling machine.
- Rotary table milling machine.
- Profile milling machine.
- Pantograph milling machine.
- Planetary milling machine.

3.6.1 Column and knee type milling machines

This is the most commonly used machine in view of its flexibility and easier setup. In such small and medium duty machines the table with work travels above the saddle in horizontal direction (X axis) (left and right). The saddle with table moves on the slideways provided on the knee in transverse direction (Y axis) (front and back). The knee with saddle and table moves on a dovetail guide ways provided on the column in vertical direction (Z axis) (up and down).

3.6.1.1 Hand milling machine

This is the simplest form of milling machine where even the table feed is also given manually. The cutter is mounted on a horizontal arbor. This is suitable for light and simple milling operations such as machining slots, grooves and keyways. *Fig. 3.52 (a) shows the photographic view of a horizontal hand milling machine and Fig. 3.52 (b) shows that of a vertical hand milling machine.*

Fig. 3.52 (a) Horizontal hand milling machine

Fig. 3.52 (b) Vertical hand milling machine

3.6.1.2 Plain or horizontal milling machine

This non automatic general purpose milling machine of small to medium size possesses a single horizontal axis milling arbor. The work table can be linearly fed along three axes (X, Y, and Z) only. The table may be fed by hand or power. These machines are most widely used for piece or batch production of jobs of relatively simple design and geometry. *Fig. 3.53 schematically shows the basic configuration of a horizontal milling machine.*

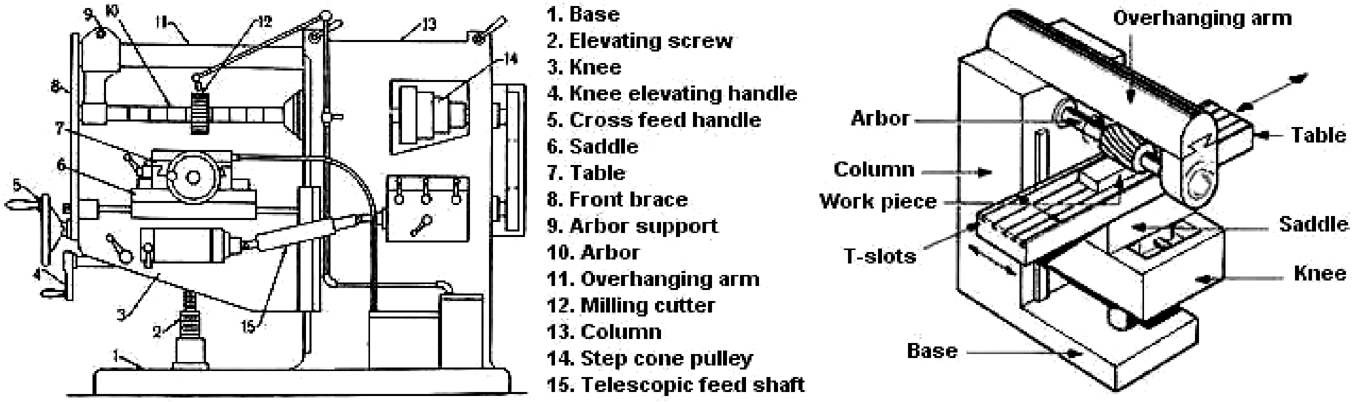


Fig. 3.53 Plain or horizontal milling machine

3.6.1.3 Universal milling machine

It is so named because it may be adapted to a very wide range of milling operations. It can be distinguished from a plain milling machine in that the table of a universal milling machine is mounted on a circular swiveling base which has degree graduations, and the table can be swiveled to any angle up to 45^0 on either side of the normal position.

Thus in a universal milling machine, in addition to the three movements as incorporated in a plain milling machine, the table have a fourth movement when it is fed at an angle to the milling cutter. This additional feature enables it to perform helical milling operation which cannot be done on a plain milling machine unless a spiral milling attachment is used. The capacity of a universal milling machine is considerably increased by the use of special attachments such as dividing head or index head, vertical milling attachment, rotary attachment, slotting attachment, etc. The machine can produce spur, spiral, bevel gears, twist drills, reamers, milling cutters, etc. besides doing all conventional milling operations. *Fig. 3.54 schematically shows the basic configuration of a universal milling machine.*

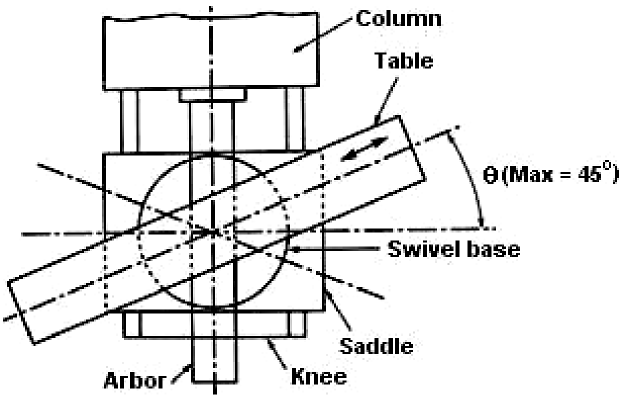


Fig. 3.54 Universal milling machine

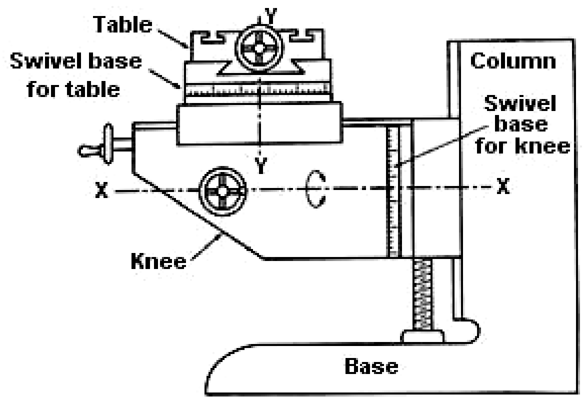


Fig. 3.55 Omniversal milling machine

3.6.1.4 Omniversal milling machine

Fig. 3.55 schematically shows the basic configuration of an omniversal milling machine. In this machine, the table besides having all the movements of a universal milling machine can be tilted in a vertical plane by providing a swivel arrangement at the knee. Also the entire knee assembly is mounted in such a way that it may be fed in a longitudinal direction horizontally. The additional swiveling arrangement of the table enables it to machine taper spiral grooves in reamers, bevel gears, etc. It is essentially a tool room and experimental shop machine.

3.6.1.5 Vertical milling machine

This machine is very similar to a horizontal milling machine. The only difference is the spindle is vertical. The work table may or may not have swiveling features. The spindle head may be swiveled at an angle, permitting the milling cutter to work on angular surfaces. In some machines, the spindle can also be adjusted up or down relative to the work piece. This machine works using end milling and face milling cutters. This machine is adapted for machining grooves, slots and flat surfaces. *Fig. 3.56 schematically shows the basic configuration of a vertical milling machine.*

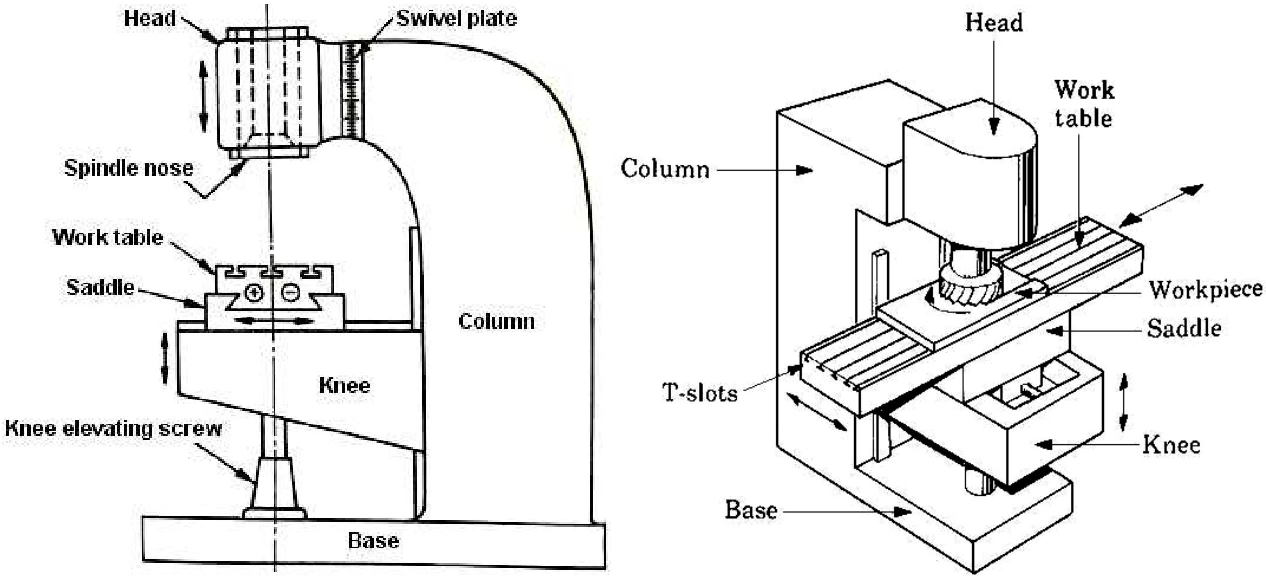


Fig. 3.56 Vertical milling machine

3.6.2 Manufacturing or bed type milling machines

The fixed bed type milling machines are comparatively large, heavy, and rigid and differ radically from column and knee type milling machines by the construction of its table mounting. The table is mounted directly on the guide ways of the fixed bed. The table movement is restricted to reciprocation at right angles to the spindle axis with no provision for cross or vertical adjustment. The cutter mounted on the spindle head may be moved vertically on the column, and the spindle may be adjusted horizontally to provide cross adjustment. The name simplex, duplex and triplex indicates that the machine is provided with single, double and triple spindle heads respectively. In a duplex machine, the spindle heads are arranged one on each side of the table. In triplex type the third spindle (vertical) is mounted on a cross rail. The usual feature of these machines is the automatic cycle of operation for feeding the table, which is repeated in a regular sequence. The feed cycle of the table includes the following: Start, rapid approach, slow feed for cutting, rapid traverse to the next work piece, quick return and stop. This automatic control of the machine enables it to be used with advantage in repetitive types of work. *Fig. 3.57 (a) and (b) shows the simplex milling machine and duplex milling machine.*

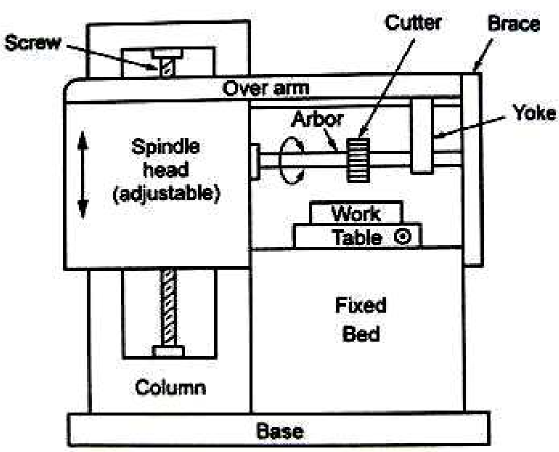


Fig. 3.57 (a) Simplex milling machine

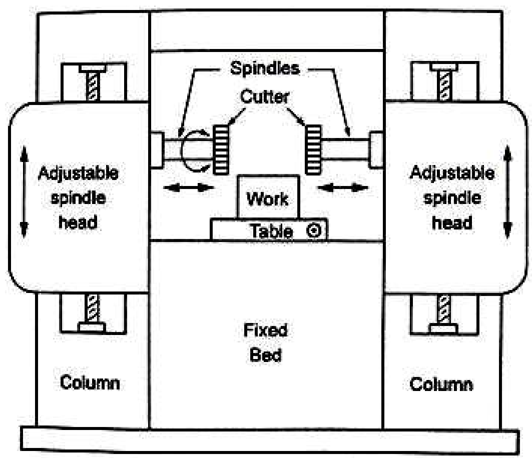


Fig. 3.57 (b) Duplex milling machine

3.6.3 Planer type milling machine

This heavy duty large machine, called Plano-miller, look like planer where the single point tools are replaced by one or a number of milling heads. This is generally used for machining a number of longitudinal flat surfaces simultaneously, such as lathe beds, table and bed of planer etc. Modern Plano-millers are provided with high power driven spindles powered to the extent of 100 hp. and the rate of metal removal is tremendous. The use of this machine is limited to production work only and is considered ultimate in metal removing capacity. *Fig. 3.58 shows a planer type milling machine.*

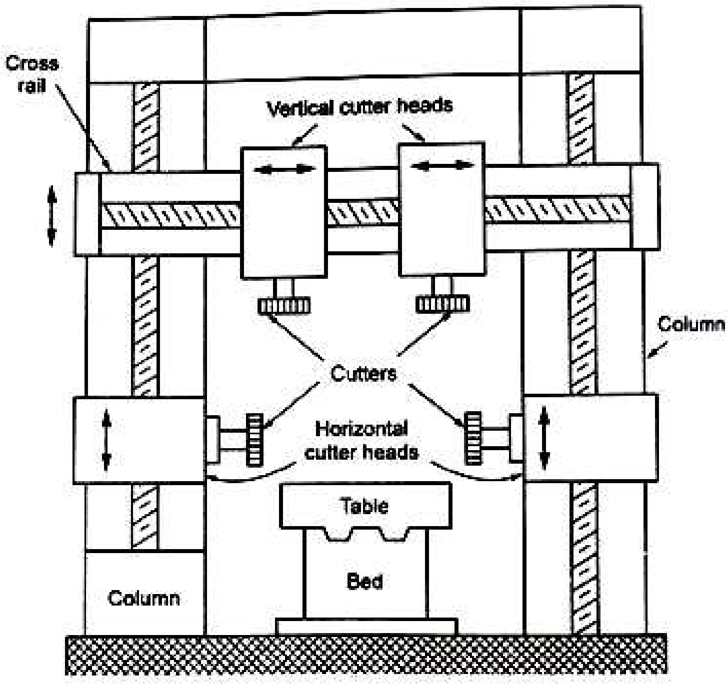


Fig. 3.58 Planer type milling machine

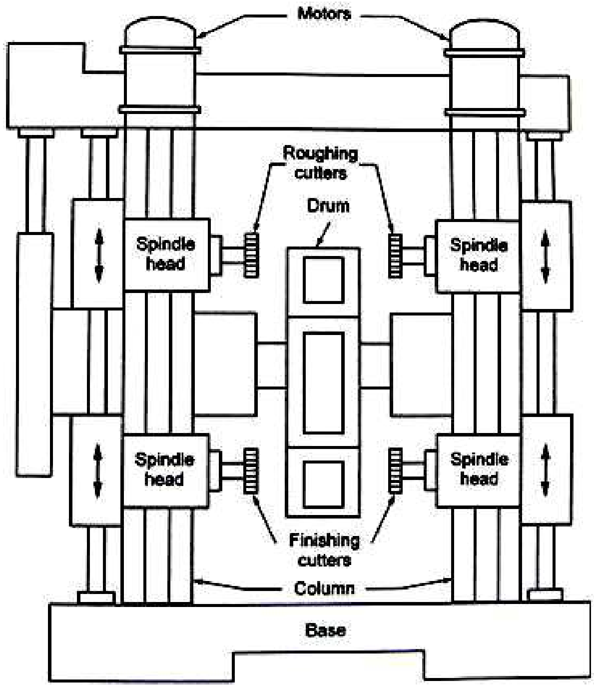


Fig. 3.59 Drum type milling machine

3.6.4 Special type milling machines

3.6.4.1 Drum milling machine

Fig. 3.59 schematically shows a drum milling machine. These machines are of the continuous-operation type. They are mostly found in large-lot and mass production shops for production of large parts such as motor blocks, gear cases, and clutch housings. Two flat surfaces of the workpiece can be milled simultaneously.

A square drum (sometimes it may be a regular pentagon or hexagon), is mounted on a shaft passing through the frame. Parts are carried in fixtures mounted on the drum faces. The drum rotates continuously in a horizontal axis, carrying the parts between face milling cutters. The milling cutters are mounted on three or four spindle heads and rotates in a horizontal axis. The milling heads can be adjusted along the housing and clamped as required for the set up. In addition to rotation, the milling spindles also have axial adjustment to set the cutters to the depth of cut. The output of such machines depends upon the number of simultaneously machined parts and the speed of rotation of the drum (rate of feed). The machined parts are removed after one complete turn of the drum, and then the new ones are clamped to it.

3.6.4.2 Rotary table milling machine

The construction of this machine is the modification of a vertical milling machine and is adapted for machining flat surfaces. Such open or closed ended high production milling machines possess one large rotary work table rotates about a vertical axis and one or two vertical spindles. The positions of the work piece(s) and the milling head are adjusted according to the size and shape of the work piece. A continuous loading and unloading of work pieces may be carried out by the operator while the milling is in progress. *Fig. 3.60 schematically shows a rotary table milling machine.*

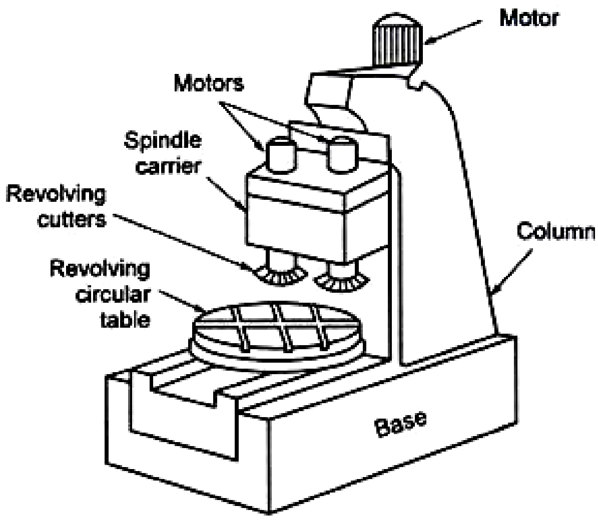


Fig. 3.60 Rotary table milling machine

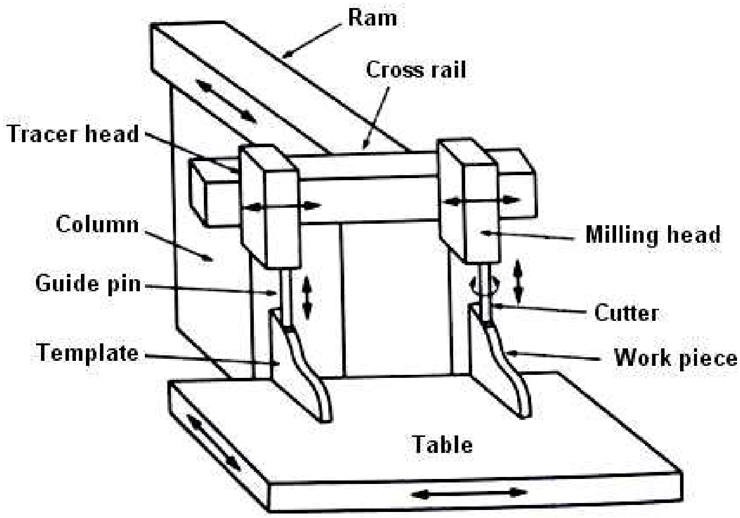


Fig. 3.61 Profile milling machine

3.6.4.3 Profile milling machine

Fig. 3.61 schematically shows a profile milling machine. This machine duplicates the full size of the template attached to the machine. This is practically a vertical milling machine of bed type in which the spindle can be adjusted vertically and the cutter head horizontally across the table. The movement of the cutter is regulated by a hardened guide pin. The pin is held against and follows outline or profile of a template mounted on the table at the side of the work piece. The longitudinal movement of the table and crosswise movement of the cutter head follow the movements of the guide pin on the template.

3.6.4.4 Pantograph milling machine

This machine can duplicate a work by using a pantograph mechanism which permits the size of the work piece reproduced to be smaller than, equal to or greater than the size of a template or model used for the purpose. Pantograph machines are available in two dimensional or three dimensional models. Two dimensional models are used for engraving letters or other designs, whereas three dimensional models are employed for copying any shape and contour of the work piece. The tracing stylus is moved manually on the contour of the model to be duplicated and the milling cutter mounted on the spindle moves in a similar path on the work piece.

3.6.4.5 Planetary milling machine

In this machine, the work is held stationary while the revolving cutter(s) move in a planetary path to finish a cylindrical surface on the work either internally or externally or simultaneously. This machine is particularly adapted, for milling internal or external threads of different pitches.

3.6.5 Major parts of a column and knee type milling machine

The general configuration of a column and knee type conventional milling machine with horizontal arbor is shown in Fig. 3.53. The major parts are:

Base It is accurately machined on its top and bottom surface and serves as a foundation member for all other parts. It carries the column at its one end. In some machines, the base is hollow and serves as a reservoir for cutting fluid.

Column It is the main supporting frame mounted vertically on the base. The column is box shaped, heavily ribbed inside and houses all the driving mechanisms for the spindle and table feed. The front vertical face of the column is accurately machined and is provided with dovetail guide ways for supporting the knee. The top of the column is finished to hold an over arm that extends outward at the front of the machine.

Knee It slides up and down on the vertical guide ways of the column face. The adjustment of height is effected by an elevating screw mounted on the base that also supports the knee. The knee houses the feed mechanism of the table, and different controls to operate it. The top face of the knee forms a slideway for the saddle to provide cross travel of the table.

Table The table rests on ways on the saddle and travels longitudinally. The top of the table is accurately finished and T-slots are provided for clamping the work and other fixtures on it. A lead screw under the table engages a nut on the saddle to move the table horizontally by hand or power. The longitudinal travel of the table may be limited by fixing trip dogs on the side of the table. in universal machines, the table may also be swiveled horizontally.

Overhanging arm The overhanging arm that is mounted on the top of the column extends beyond the column face and serves as a bearing support for the other end of the arbor. The arm is adjustable so that the bearing support may be provided nearest to the cutter.

Front brace The front brace is and extra support that is fitted between the knee and the over arm to ensure further rigidity to the arbor and the knee. The front brace is slotted to allow for the adjustment of the height of the knee relative to the over arm.

Spindle The spindle of the machine is located in the upper part of the column and receives power from the motor through belts, gears, clutches and transmits it to the arbor. The front end of the spindle just projects from the column face and is provided with a tapered hole into which various cutting tools and arbors may be inserted. The accuracy in metal machining by the cutter depends primarily on the accuracy, strength, and rigidity of the spindle.

Arbor It may be considered as an extension of the machine spindle on which milling cutters are securely mounted and rotated. The arbors are made with taper shanks for proper alignment with the machine spindles having taper holes at their nose. The arbor may be supported at the farthest end from the overhanging arm or may be of cantilever type which is called stub arbor. The arbor shanks are properly gripped against the spindle taper by a draw bolt which extends throughout the length of the hollow spindle. The threaded end of the draw bolt is fastened to the tapped hole of the arbor shank and then the lock nut is tightened against the spindle. The spindle has also two keys for imparting positive drive to the arbor in addition to the friction developed in the taper surfaces. The cutter is set at the required position on the arbor by spacing collars or spacers of various lengths but of equal diameter. The entire assembly of the milling cutter and the spacers are fastened to the arbor by a long key. The end spacer on the arbor is slightly larger in diameter and acts as a bearing bush for bearing support which extends from the over arm. *Fig. 3.62 illustrates an arbor assembly used in a milling machine.*

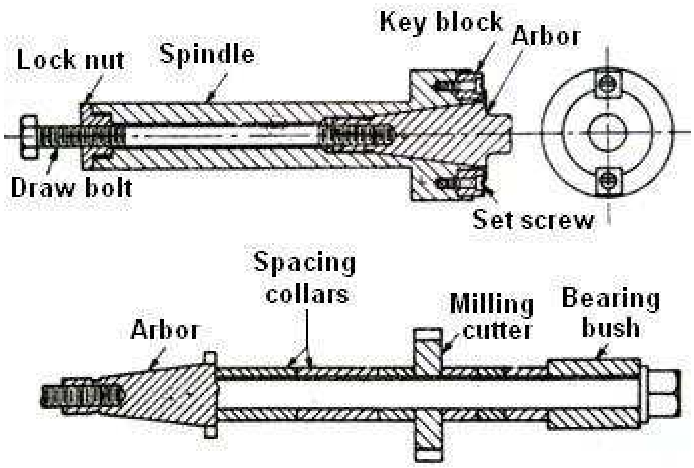


Fig. 3.62 Arbor assembly

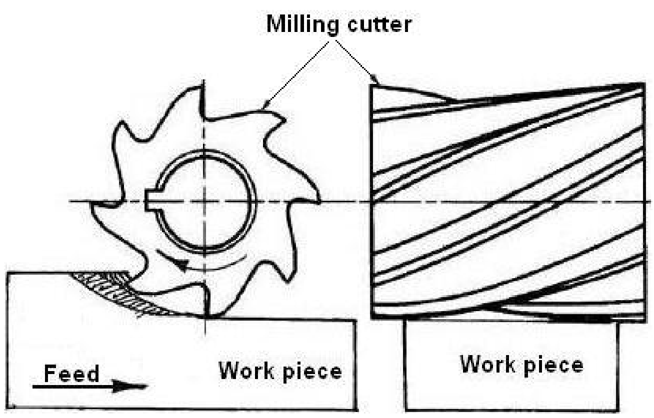


Fig. 3.63 Principle of producing flat surface

3.6.6 Working principle of a column and knee type milling machine

Fig. 3.63 shows the basic principle of producing flat surface in a milling machine by a plain milling cutter. The kinematic system comprising of several mechanisms enables transmission of motion and power from the motor to the cutting tool for its rotation at varying speeds and to the work table for its slow feed motions along X, Y and Z directions. The milling cutter mounted on the horizontal milling arbor, receives its rotary motion at different speeds from the main motor through the speed gear box. The feeds of the work piece can be given by manually or automatically by rotating the respective wheels by hand or by power. The work piece is clamped on the work table by a work holding device. Then the work piece is fed against the rotating multipoint cutter to remove the excess material at a very fast rate.

3.6.7 Mechanism of a column and knee type milling machine

This mechanism is composed of spindle drive mechanism and table feed mechanism. The spindle drive mechanism is incorporated in the column. All modern machines are driven by individual motors housed within the column, and the spindle receives power from a combination of gears and clutch assembly. Multiple speed of the spindle may be obtained by altering the gear ratio. *Fig. 3.64 illustrates the power feed mechanism contained within the knee of the machine to enable the table to have three different feed movements, i.e. longitudinal, cross and vertical.*

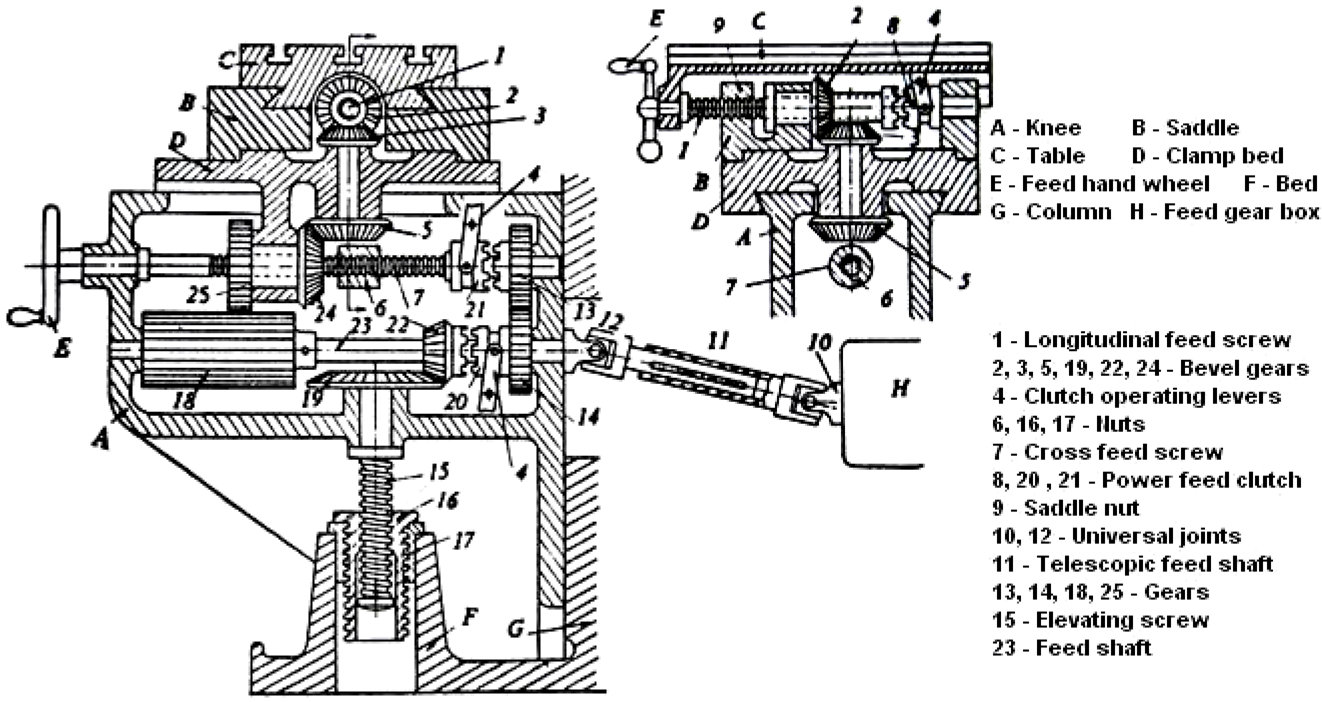


Fig. 3.64 Power feed mechanism of a column and knee type milling machine

The power is transmitted from the speed gear box consisting of change gears to the feed shaft in the knee of the machine by a telescopic feed shaft. Both ends of the telescopic feed shaft are provided with universal joints. Telescopic feed shaft and universal joints are necessary to allow vertical movement of the knee, gear 14, attached to the jaw clutch 20. The jaw clutch 20 is keyed to the feed shaft and drives gear 13, which is free to rotate on the extreme end of the cross feed screw. Bevel gear 22 is free to rotate on feed shaft and is in mesh with gear 19 fastened to the evaluating screw. 16 serve as a nut for 15, and it is screwed in nut 17. Therefore, 15 and 16 serve as a telescopic screw combination and a vertical movement of the knee is thus possible. As soon as the clutch 20 is engaged with the clutch attached to the bevel gear 22 by means of a clutch operating lever, the bevel gear 22 rotates and this being in mesh with gear 19 causes the elevating screw to rotate in nut 16 giving a vertical movement of the knee.

Like-wise, when the clutch 21 attached to the cross feed screw, is engaged with the clutch attached to gear 13, power comes to the screw through gears 14 and 13. This causes the cross feed screw to rotate in nut 6 of the clamp bed giving a cross feed movement of the clamp bed and saddle.

Gear 18 is fastened to feed shaft, and meshes with gear 25 which is fastened to the bevel gear 24. The bevel gear 24 meshes with bevel gear 5 attached to a vertical shaft which carries one more bevel gear 3 at its upper end. The bevel gear 3 meshes with bevel gear 2 which is fastened to the table feed screw. Therefore, longitudinal feed movement of the table is possible through gears 18, 25, 24, 5, 3, & 2.

3.6.8 Work holding devices used in a milling machine

It is necessary that the work piece should be properly and securely held on the milling machine table for effective machining operations. The work piece may be supported on the milling machine table by using any one of the following work holding devices depending upon the geometry of the work piece and nature of the operation to be performed.

- T-bolts and clamps.
- Angle plate.
- V-blocks.
- Vises.
- Special fixtures.
- Dividing heads.

T-bolts and clamps Bulky work pieces of irregular shapes are clamped directly on the milling machine table by using T-bolts and clamps. *Fig. 3.15 illustrates the use of T-bolts and clamps.* Different designs of clamps are used for different patterns of work. *Fig. 3.65 shows the different types of clamps.*

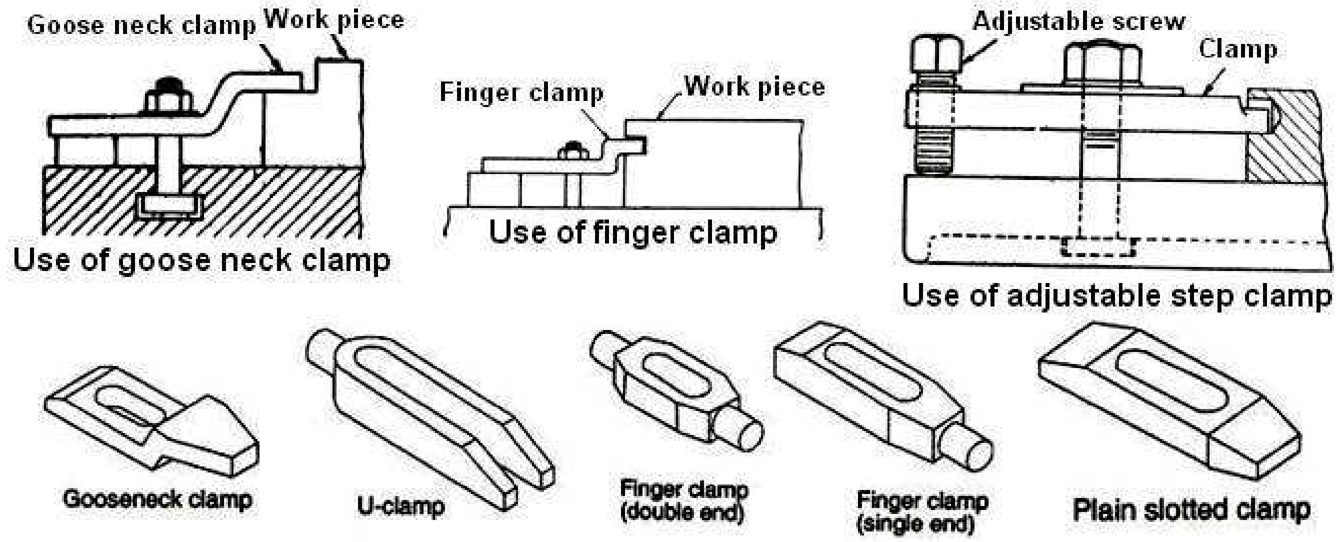


Fig. 3.65 Different types of clamps

Angle plate The angle plate has been described in Article 3.2.6.3, Page 112 and illustrated in Fig. 3.19. Sometimes a titling type angle plate in which one face can be adjusted relative to another face for milling at a required angle is also used. *Fig. 3.66 shows a tilting type angle plate.*

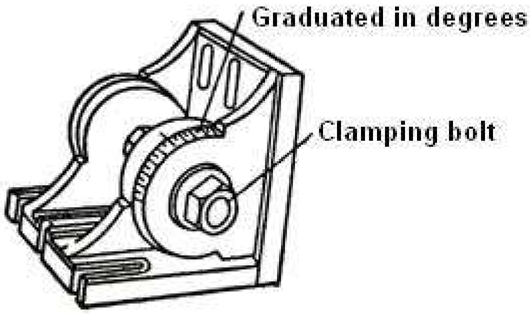


Fig. 3.66 Tilting type angle plate

V-blocks The V-block has been described in Article 3.2.6.4, Page 112 and illustrated in Fig. 3.20. This is used for holding shafts on the table in which keyways, slots and flats are to be milled.

Vises The different types of vise has been described in Article 3.2.6.1, Page 110 and illustrated in Fig. 3.12 (a), (b) and (c). Vises are the most common appliances for holding work on milling machine table due to its quick loading and unloading arrangement.

Special fixtures The fixtures are special devices designed to hold work for specific operations more efficiently than standard work holding devices. Fixtures are especially useful when large numbers of identical parts are being produced. By using fixtures loading, locating, clamping and unloading time is greatly minimized.

3.6.8.1 Indexing head or dividing head

It is a special work holding device used in a milling machine. Dividing head can also be considered as a milling machine attachment. *Fig. 3.67 shows a dividing head used in a milling machine.*

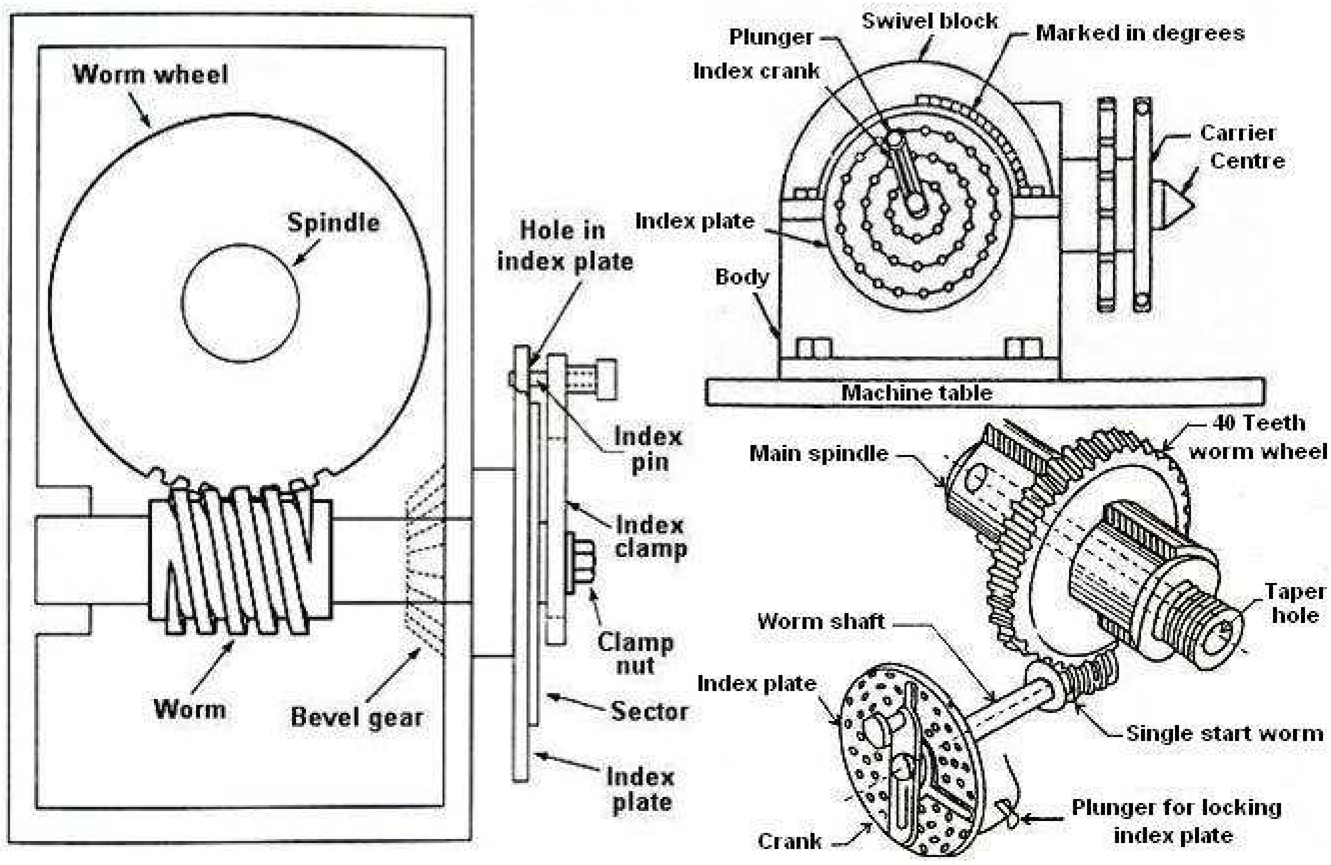


Fig. 3.67 Dividing head

An important function and use of milling machines is for cutting slots, grooves etc. which are to be equally spaced around the circumference of a blank, for example, gear cutting, ratchet wheels, milling cutter blanks, reamers etc. This necessitates holding of the blank (work piece) and rotating it the exact amount for each groove or slot to be cut. This process is known as “indexing”. The dividing head is the device used for this purpose. It is lined and bolted to the machine table so that the axis passing through the head stock centre and tail stock centre is at right angle to the spindle axis of the machine. The head stock of the dividing head consists of a spindle to which a 40 tooth worm wheel is keyed. A single threaded worm meshes with this wheel. The worm spindle projects from the front of the head and has a crank and handle attached. The head spindle is bored with a tapered hole and is also screwed on its end.

The work piece is mounted between centres, one inserted into the dividing head spindle and the other into the tail stock. The work piece may also be mounted on a mandrel between these centres. A chuck may be mounted on the spindle nose for holding short work pieces having no centre holes. The work piece is rotated by turning the index crank by means of handle. Since the gear ratio of worm and worm wheel is 40:1, it takes 40 turns of the crank to rotate the spindle and hence the work piece through one complete revolution. Thus one turn of the crank rotates the work piece through 1/40th of a turn.

If divisions other than factors of 40 are required “index plates”. An index plate has several circles of holes (each circle containing a different number of holes) and is mounted on the worm shaft. A pin on the crank can be adjusted to a radius such that it will fit in any desired circle of holes. By using different circles of holes and index plates, any fractional part of a turn of the index crank can be obtained. The two sector arms shown on front of the index plate are used for avoiding counting of holes during indexing.

Index plate It helps to accomplish indexing (dividing) of the work into equal divisions. It is a circular plate approximately 6 mm thick, with holes (equally spaced) arranged in concentric circles. The space between two subsequent holes is same for each circle; however it is different for different circles. A plate can have through holes or blind holes on its faces.

For a plain dividing head, the index plate is fixed to the body of the dividing head while in the case of universal dividing head it is mounted on the sleeve of the worm shaft. Various manufactures in U.S.A. and other countries have produced index plates with different number of hole circles.

For example *The index plates available with the Brown and Sharpe milling machines are:*

- 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

The index plate used on the Cincinnati and Parkinson milling machine is:

- Obverse (A) - 24, 25, 28, 30, 34, 37, 38, 39, 41, 42, 43
- Reverse (B) - 46, 47, 49, 51, 53, 54, 57, 58, 59, 62, and 66

Index plates made in Germany are:

	Plate No. 1	-	23, 25, 28, 31, 39, 43, 51, 59
	Plate No. 2	-	16, 27, 30, 33, 41, 47, 53, 61
	Plate No. 3	-	22, 24, 29, 36, 37, 49, 57, 63

The high number index plates are used to increase the indexing capacity. These index plates are similar to those discussed earlier except that these contain very large number of holes. Cincinnati Milling Machine Co. U.S.A. produces a set of three plates with holes on both sides of the plate as given below:

Plate No. 1	Obverse (A)	-	30, 48, 69, 91, 99, 117, 129, 147, 171, 177, 189
	Reverse (B)	-	36, 67, 81, 97, 111, 127, 141, 157, 169, 183, and 194
Plate No 2	Obverse (A)	-	34, 46, 79, 93, 109, 123, 139, 153, 167, 181, 197
	Reverse (B)	-	32, 44, 77, 89, 107, 121, 137, 151, 163, 179, and 193
Plate No. 3	Obverse (A)	-	26, 42, 73, 87, 103, 119, 133, 149, 161, 175, 191
	Reverse (B)	-	28, 38, 71, 83, 101, 113, 131, 143, 159, 173, and 187

It is importance to note that there is no standard followed internationally in this regard. The number of plates supplied varies with different manufacturers. However this does not change the principle of indexing. It should be put up with in mind that larger the number of plates, and more the hole circles and holes wider is the range of indexing and accuracy.

Types of dividing heads The various dividing heads used with milling machines are:

Plain indexing head A plain dividing head has a fixed spindle axis and the spindle rotates only about a horizontal axis.

Universal indexing head In this, the spindle can be rotated at different angles in the vertical plane from horizontal to vertical. This head performs the following functions: indexes the work piece, imparts a continuous rotary motion to the work piece for milling helical grooves (flutes of drills, reamers, milling cutters etc.) and setting the work piece in a given inclined position with reference to the table.

Optical indexing head These models are used for high precision angular setting of the work piece with respect to the cutter. For reading the angles, an optical system is built into the dividing head.

Methods of indexing The various methods of indexing are discussed below:

Direct indexing In this, the index plate is directly mounted on the dividing head spindle. The intermediate use of worm and worm wheel is avoided. For indexing, the index pin is pulled out on a hole, the work and the index plate are rotated the desired number of holes and the pin is engaged. Both plain and universal heads can be used in this manner. Direct indexing is the most rapid method of indexing, but fractions of a complete turn of the spindle are limited to those available with the index plate. With a standard indexing plate having 24 holes, all factors of 24 can be indexed, that is, the work can be divided into 2,3,4,6,8,12 and 24 parts.

Simple or plain indexing In this, the index plate selected for the particular application, is fitted on the worm shaft and locked through a locking pin. To index the work through any required angle, the index crank pin is withdrawn from a hole in the index plate. The work piece is indexed through the required angle by turning the index crank through a calculated number of whole revolutions and holes on one of the hole circles, after which the index pin is relocated in the required hole. If the number of divisions on the job circumference (that is number of indexing) needed is z, then the number of turns (n) that the crank must be rotated for each indexing can be found from the formula: $\mathbf{n = \frac{40}{Z}}$ turns.

Example 3.1: Indexing 28 divisions.

The rotation of the index crank = $\frac{40}{Z} = \frac{40}{28} = \frac{10}{7} = 1\frac{3}{7}$ turns.

This can be done as follows using any one of the Brown and Sharpe plates.

One full rotation + 9 holes in 21 hole circle in plate No. 2.

One full rotation + 21 holes in 49 hole circle in plate No. 3.

Example 3.2: Indexing 62 divisions.

The rotation of the crank = $\frac{40}{Z} = \frac{40}{62} = \frac{20}{31}$ turns.

This can be done as follows using the Brown and Sharpe plates.

20 holes in 31 hole circle in plate No. 2.

Compound indexing

When the available capacity of the index plates is not sufficient to do a given indexing, the compound indexing method can be used. First, the crank is moved in the usual fashion in the forward direction. Then a further motion is added or subtracted by rotating the index plate after locking the plate with the plunger. This is termed as compound indexing. For example, if the indexing is done by moving the crank by 5 holes in the 20 hole circle and then the index plate together with the crank is indexed back by a hole with the locking plunger registering in a 15 hole circle *as shown in Fig. 3.68.*

Then the total indexing done is $\frac{5}{20} - \frac{1}{15} = \frac{11}{60}$ i.e., 11 holes in a 60 hole circle. Unfortunately the 60 hole circle is not available in the range of index plates. Similarly it is possible to have the two motions in the same direction as well. In this, the total indexing will be $\frac{5}{20} + \frac{1}{15} = \frac{19}{60}$ i.e., 19 holes in a 60 hole circle.

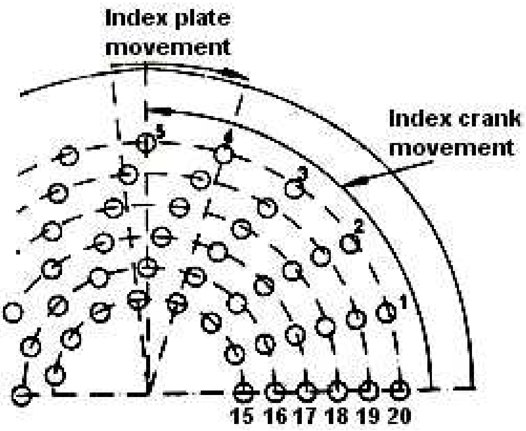


Fig. 3.68 An example of compound indexing

Differential indexing

This is an automatic way to carry out the compound indexing method. In this the required division is obtained by a combination of two movements:

- The movement of the index crank similar to the simple indexing.
- The simultaneous movement of the index plate, when the crank is turned.

Fig. 3.69 schematically shows the arrangement for differential indexing.

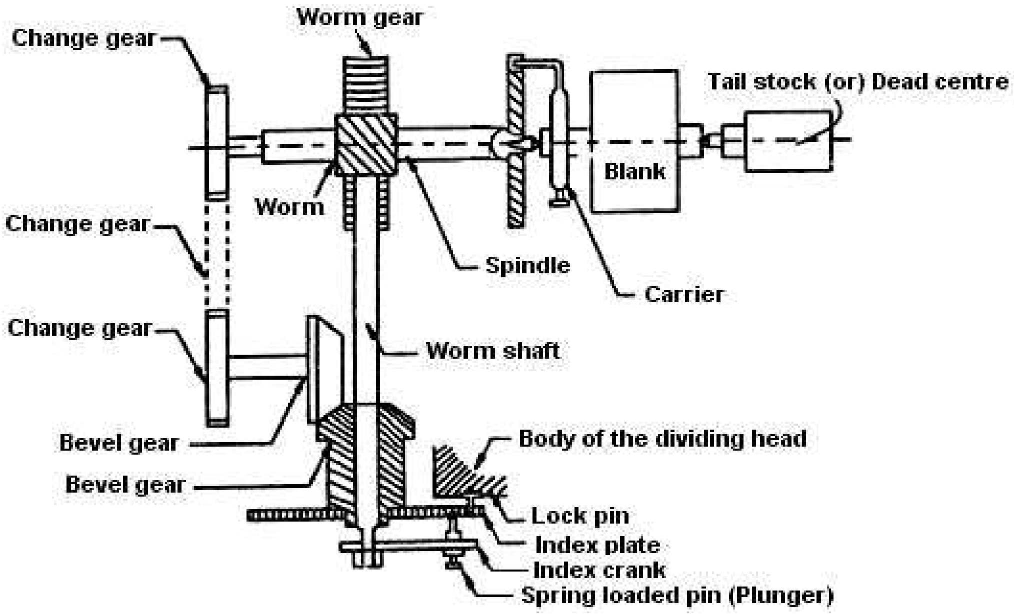


Fig. 3.69 Arrangement for differential indexing

In differential indexing, the index plate is made free to rotate. A gear is connected to the back end of the dividing head spindle while another gear is mounted on a shaft and is connected to the shaft of the index plate through bevel gears *as shown in Fig.3.69.* When the index crank is rotated, the motion is communicated to the work piece spindle. Since the work piece spindle is connected to the index plate through the intermediate gearing as explained above, the index plate will also start rotating. If the chosen indexing is less than the required one, then the index plate will have to be moved in the same direction as the movement of the crank to add the additional motion. If the chosen indexing is more, then the plate should move in the opposite direction to subtract the additional motion.

The direction of the movement of the index plate depends upon the gear train employed. If an idle gear is added between the spindle gear and the shaft gear in case of a simple gear train, then the index plate will move in the same direction to that of the indexing crank movement. In the case of a compound gear train an idler is used when the index plate is move in the opposite direction. The procedure of calculation is explained with the following example.

The change gear set available is 24 (2), 28, 32, 40, 44, 48, 56, 64, 72, 86 and 100.

Example 3.3: Obtain the indexing for 97 divisions.

The required indexing is 40/97 which cannot be obtained with any of the index plates available. Choose the nearest possible division. For example, the indexing decided is 40/100 = 2/5 = 8/20.

The actual indexing decided is 8 holes in a 20 hole circle. This indexing will be less than required. Ideally the workpiece should complete one revolution when the crank is moved through 97 turns at the above identified indexing. The actual motion generated when the crank is moved 97 times is

$$40 - \frac{97 \text{ x } 40}{100} = \frac{3 \text{ x } 40}{100}$$

Hence the index plate has to move forward by this amount during the 97 turns to compensate for the smaller indexing being done by the index crank. Hence the gear ratio between the spindle and the index crank is $\frac{3 \text{ x } 40}{100} = \frac{6}{5}$

The change gear set used is $\frac{\text{Gear on spindle}}{\text{Gear on index crank}} = \frac{6}{5} = \frac{48}{40}$

An idler gear is to be used since the index plate has to move in the same direction.

Example 3.4: Obtain the indexing for 209 divisions.

The required indexing is 40/209 which cannot be obtained with any of the index plates available. Choose the nearest possible division. For example, the indexing decided is 40/200= 4/20

The actual indexing decided is 4 holes in a 20 hole circle. This indexing will be more than required. Ideally the workpiece should complete one revolution when the crank is moved through 209 turns at the above identified indexing. The actual motion generated when the crank is moved 209 times is $40 - \frac{209 \text{ x } 40}{200} = -\frac{9 \text{ x } 40}{200}$

Hence the index plate has to move in the reverse by this amount during the 209 turns to compensate for the larger indexing being done by the index crank. Hence the gear ratio between the spindle and the index crank is $\frac{9 \text{ x } 40}{200} = \frac{36}{20}$

The change gear set used is $\frac{\text{Gear on spindle}}{\text{Gear on index crank}} = \frac{36}{20}$

Angular indexing

Sometimes it is desirable to carry out indexing using the actual angles rather than equal numbers along the periphery. Here, angular indexing would be useful. The procedure remains the same as in the previous cases, except that the angle will have to be first converted to equivalent divisions. Since 40 revolutions of the crank equals to a full rotation of the work piece, which means 360^0, one revolution of the crank is equivalent to 9^0. The formula to find the index crank movement is given below.

Index crank movement	=	Angular displacement of work (in degrees) / 9
	=	Angular displacement of work (in minutes) / 540
	=	Angular displacement of work (in seconds) / 32400

Example 3.5: Calculate the indexing for 41^0.

Indexing required = $\frac{41}{9} = 4\frac{5}{9}$

This can be done as follows using the Brown and Sharpe plates.

Four full rotations + 10 holes in 18 hole circle in plate No. 1.

Example 3.6: Calculate the indexing for 19^0 40'.

19^0 40' = (19 x 60) + 40 = 1140 + 40 = 1180

Indexing required = $\frac{1180}{540} = \frac{59}{27} = 2\frac{5}{27}$

This can be done as follows using the Brown and Sharpe plates.

Two full rotations + 5 holes in 27 hole circle in plate No. 2.

3.6.9 Cutter holding devices used in a milling machine

There are several methods of holding and rotating milling cutters by the machine spindle depending on the different designs of the cutters. They are:

3.6.9.1 Arbors

The cutters have a bore at the centre are mounted and keyed on a short shaft called arbor. The arbor has been described in Article 3.6.5, Page 133 and illustrated in Fig. 3.62.

3.6.9.2 Collets

A milling machine collet is a form of sleeve bushing for reducing the size of the taper hole at the nose of the spindle so that an arbor or a milling cutter having a smaller shank than the spindle taper can be fitted into it. *Fig. 3.70 (a) illustrates a milling machine collet.*

3.6.9.3 Adapter

An adapter is a form of collet used on milling machine having standardized spindle end. Cutters having straight shanks are usually mounted on adapters. An adapter can be connected with the spindle by a draw bolt or it may be directly bolted to it. *Fig. 3.70 (b) illustrates a milling machine adapter.*

3.6.9.4 Spring collets

Straight shank cutters are usually held on a special adapter called "spring collet" or "spring chuck". The cutter shank is introduced in the cylindrical hole provided at the end of the adapter and then the nut is lightened. This causes the split jaws of the adapter to spring inside, and grip the shank firmly. *Fig. 3.70 (c) illustrates a spring collet.*

3.6.9.5 Bolted cutters

The face milling cutters of larger diameter having no shank are bolted directly on the nose of the spindle. For this purpose four bolt holes are provided on the body of the spindle. This arrangement of holding cutter ensures utmost rigidity. *Fig. 3.70 (d) illustrates a face milling cutter bolted on the spindle.*

3.6.9.6 Screwed on cutters

The small cutters having threaded holes at the centre are screwed on the threaded nose of an arbor which is mounted on the spindle in the usual manner. *Fig. 3.70 (e) shows a screwed on cutter.*

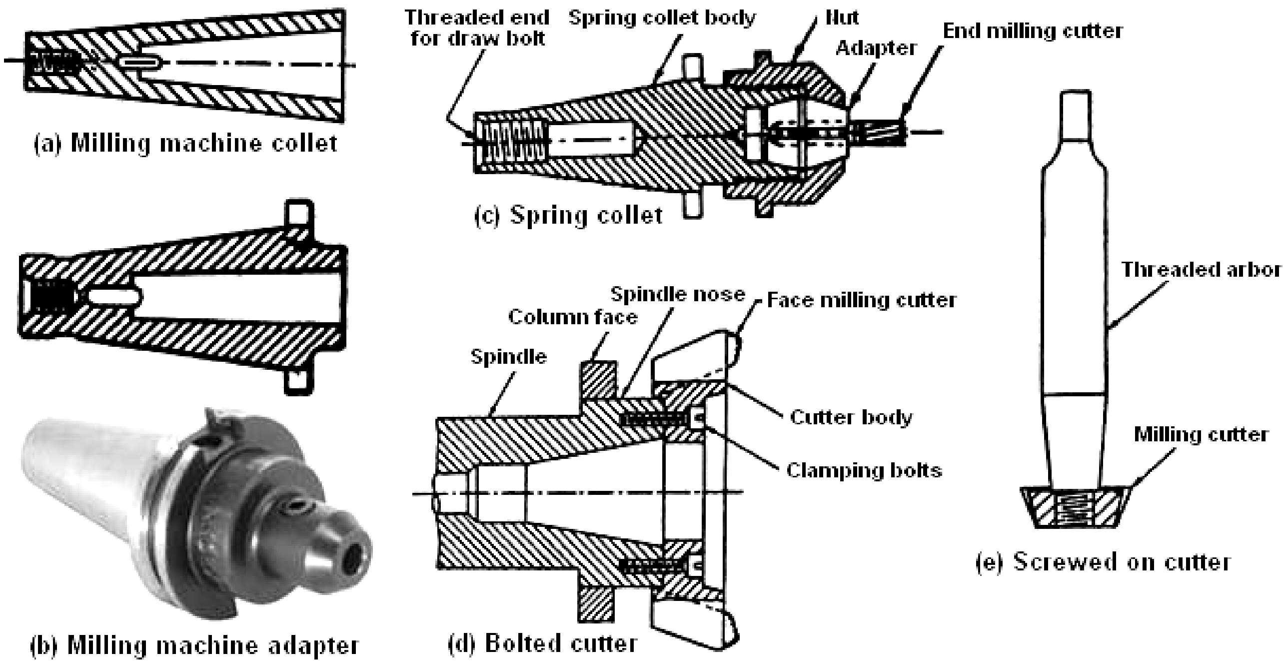


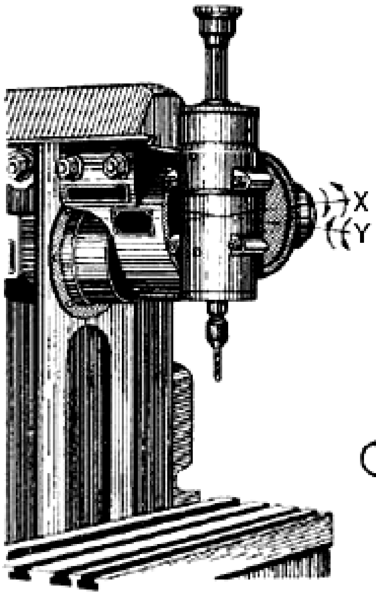
Fig. 3.70 Different types of cutter holding devices used in milling machines

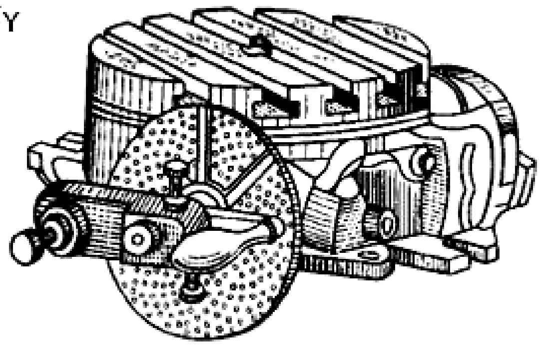
3.6.10 Special attachments used in milling machines

The attachments are intended to be fastened to or joined with one or more components of the milling machine for the purpose of enhancing the range, versatility, productivity and accuracy of operation. Some classes of milling machine attachments are used for positioning and driving the cutter by altering the cutter axis and speed, whereas other classes are used for positioning, holding and feeding the work along a specified geometric path. The following are the different attachments used on standard column and knee type horizontal milling machine.

3.6.10.1 Universal milling attachment

Amongst the column and knee type conventional milling machines, horizontal arbor type is very widely used, where various types and sizes of milling cutters having axial bore are mounted on the horizontal arbor. For milling by solid end mill type and face milling cutters, separate vertical axis type milling machines are available. But horizontal arbor type milling machines can also be used for those operations to be done by end milling and smaller size face milling cutters by using the universal milling attachment. The rotation of the horizontal spindle is transmitted into rotation about vertical axis and also in any inclined direction by this attachment which thus extends the processing capabilities and application range of the milling machine. *The universal milling attachment is shown in Fig. 3.71.*





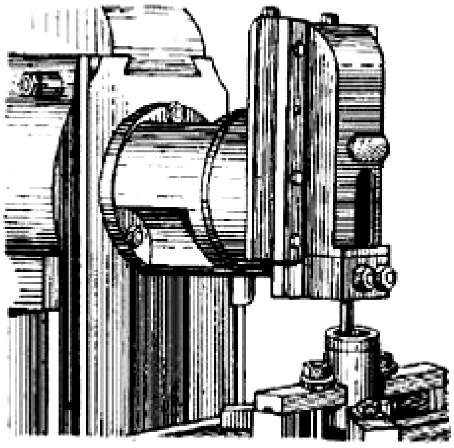


Fig. 3.71 Universal milling attachment   Fig. 3.72 Rotary table   Fig. 3.73 Slotting attachment

3.6.10.2 Indexing head or dividing head

This attachment is also considered as an accessory. The indexing head has been described in Article 3.6.8.1, Page 137 and illustrated in Fig. 3.67.

3.6.10.3 Rotary table

This device may also be considered both accessory or attachment and is generally used in milling machines for both offline and online indexing / rotation of the work piece, clamped on it, about vertical axis. *Fig. 3.72 visualizes such a rotary table which is clamped or mounted on the machine bed / table.*

3.6.10.4 Slotting attachment

Such simple and low cost attachment is mounted on the horizontal spindle for producing keyways and contoured surface requiring linear travel of single point tool in milling machine where slotting machine and broaching machine are not available. *The configuration of such a slotting attachment and its mounting and operation can be seen in Fig. 3.73.* The mechanism inside the attachment converts rotation of the spindle into reciprocation of the single point tool in vertical direction. The direction of the tool path can also be tilted by swiveling the circular base of the attachment body.

3.7 MILLING CUTTERS

Milling machines are mostly general purpose and have wide range of applications requiring various types and sizes of milling cutters.

A milling cutter is a multi edged rotary cutting tool having the shape of a solid of revolution with cutting teeth arranged either on the periphery or on the end face or on both. Usually, the cutter is held in a fixed (but rotating) position and the work piece moves past the cutter during the machining operation.

3.7.1 Cutter materials

Intermittent cutting nature and usually complex geometry necessitate making the milling cutters mostly by HSS which is unique for high tensile and transverse rupture strength, fracture toughness and formability almost in all respects i.e. forging, rolling, powdering, welding, heat treatment, machining (in annealed condition) and grinding. Tougher grade cemented carbides are also used without or with coating, where feasible, for high productivity and product quality. In some cutters tungsten carbide teeth are brazed on the tips of the teeth or individually inserted and held in the body of the cutter by some mechanical means. Carbide tipped cutter is especially adapted to heavy cuts and increased cutting speeds. *The advantages of carbide tipped cutters (either solid or inserted blade type) are:*

- Their high production capacity.
- The high quality of the surfaces they produce.
- Elimination of grinding operation in some cases, the possibility of machining hardened steels and the reduction in machining costs that their use leads to.

Due to these advantages, they have been successfully applied in metal cutting industry where they have replaced many solid cutters of tool steels. Along with the especially popular carbide tipped face milling cutters, carbide tipped side and form milling cutters and various end mills are used in industry.

3.7.2 Types of milling cutters

Many different kinds of milling cutters are used in milling machines. They are:

3.7.2.1 Slab or plain milling cutters: Straight or helical fluted

Plain milling cutters are hollow straight HSS cylinder of 40 to 80 mm outer diameter having 4 to 16 straight or helical equi-spaced flutes or cutting edges on the circumference. These are used in horizontal arbor to machine flat surfaces parallel to the axis of rotation of the spindle. Very wide plain milling cutters are termed as slab milling cutters. *Fig. 3.74 illustrates a plain milling cutter*.

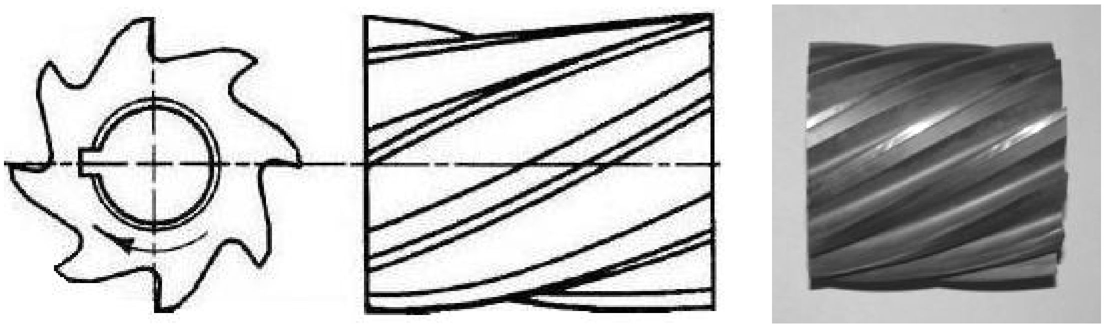


Fig. 3.74 Slab or plain milling cuttre

3.7.2.2 Side milling cutters: Single side or double sided type

These arbor mounted disc type cutters have a large number of cutting teeth at equal spacing on the periphery. Each tooth has a peripheral cutting edge and another cutting edge on one face in case of single side cutter and two more cutting edges on both the faces leading to double sided cutter. One sided cutters are used to produce one flat surface or steps comprising two flat surfaces at right angle. Both sided cutters are used for making rectangular slots bounded by three flat surfaces. *Fig. 3.75 illustrates a side milling cutter*.

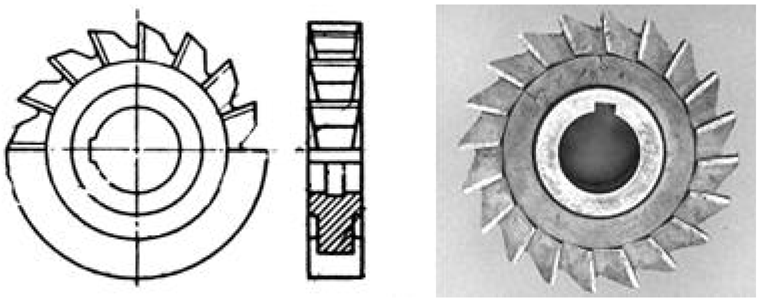


Fig. 3.75 Side milling cutter

3.7.2.3 Slitting saws or parting tools

These milling cutters are very similar to the slotting cutters having only one peripheral cutting edge on each tooth. *Fig. 3.76 illustrates a slitting saw.* However, the slitting saws:

- Are larger in diameter and much thin.
- Possess large number of cutting teeth but of small size.
- Used only for slitting or parting.

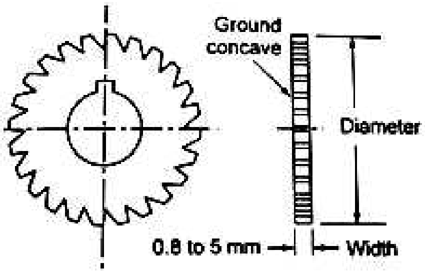


Fig. 3.76 Slitting saw

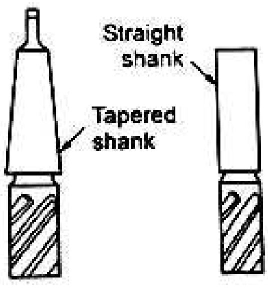


Fig. 3.77 End milling cutters

Fig. 3.78 Face milling cutter

3.7.2.4 End milling cutters: With straight or taper shank

Fig. 3.77 illustrates end milling cutters. The common characteristics of end milling cutters are:

- Mostly made of High Speed Steel.
- 4 to 12 straight or helical teeth on the periphery and face.
- Diameter ranges from about 1 mm to 40 mm.
- Very versatile and widely used in vertical spindle type milling machines.
- End milling cutters requiring larger diameter are made as a separate cutter body which is fitted in the spindle through a taper shank arbor (Shell end mills).

3.7.2.5 Face milling cutters

Fig. 3.78 illustrates a face milling cutter. The main characteristics of face milling cutters are:

- Usually large in diameter (80 to 800 mm) and heavy.
- Used only for machining flat surfaces in different orientations.
- Mounted directly in the vertical and / or horizontal spindles.
- Coated or uncoated carbide inserts are clamped at the outer edge of the carbon steel body.
- Generally used for high production machining of large jobs.

3.7.2.6 Form cutters

These cutters have irregular profiles on the cutting edges in order to generate an irregular outline of the work. These disc type HSS cutters are generally used for making grooves or slots of various profiles.

Slotting cutters

Slotting cutters are of end mill type like T-slot cutter or dove tail cutter. *Fig. 3.79 illustrates a T-slot milling cutter.*

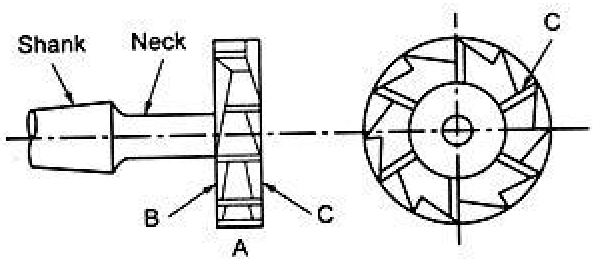


Fig. 3.79 T-slot milling cutter

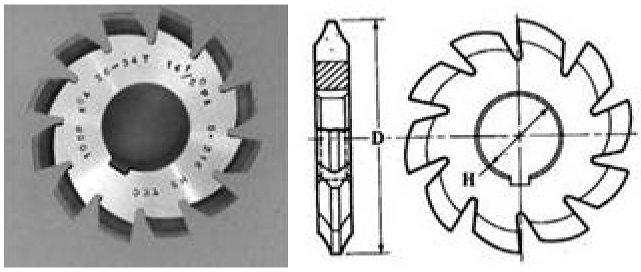


Fig. 3.80 Involute gear milling cutter

Gear (teeth) milling cutters

Fig. 3.80 illustrates an involute gear milling cutter. Gear milling cutters are made of HSS and available mostly in disc form like slot milling cutters and also in the form of end mill for producing teeth of large module gears. The form of these tools conforms to the shape of the gear tooth-gaps bounded by two involutes. Such form relieved cutters can be used for producing teeth of straight and helical toothed external spur gears and worm wheels as well as straight toothed bevel gears.

Spline shaft cutters

These disc type HSS form relieved cutters are used for cutting the slots of external spline shafts having 4 to 8 straight axial teeth. *Fig. 3.81 illustrates the tooth section of a spline shaft cutter.*

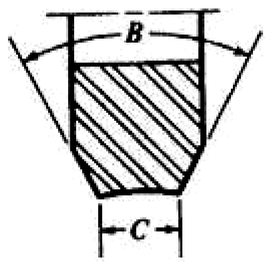


Fig. 3.81 Tooth section of a spline shaft cutter

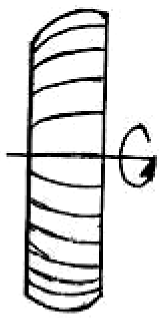


Fig. 3.82 Tool form cutter

Tool form cutters

Fig. 3.82 illustrates a tool form cutter. Form milling type cutters are also used widely for cutting slots are flutes of different cross section e.g. the flutes of twist drills, milling cutters, reamers etc., and gushing of hobs, taps, short thread milling cutters etc.

Thread milling cutters

These shank type solid HSS or carbide cutters having threaded like annular grooves with equi-spaced gushing are used in automatic single purpose milling machines for cutting the threads in large lot production of screws, bolts etc. Both internal and external threads are cut by the tool. These milling cutters are used for long thread milling also (e.g. lead screws, power screws, worms etc).

Fig. 3.83 (a) shows internal thread milling cutters, Fig. 3.83 (b) shows a short thread milling cutter and Fig. 3.83 (c) shows a long thread milling cutter.

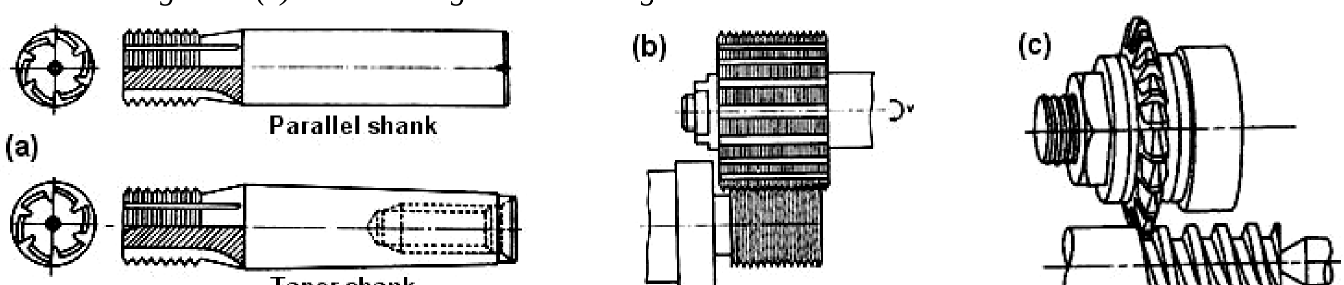


Fig. 3.83 (a) Internal thread milling cutters (b) Short thread milling cutter (c) Long thread milling cutter

Convex and concave milling cutters

These cutters have teeth curved outwards or inwards on the circumferential surface to form the contour of a semicircle. These cutters produces concave or convex semicircular surface on the work pieces. The diameter of the cutters ranges from 50 mm to 125 mm and the radius of the semicircle varies from 1.5 mm to 20 mm. *Fig. 3.84 (a and b) illustrates the convex and concave milling cutters.*

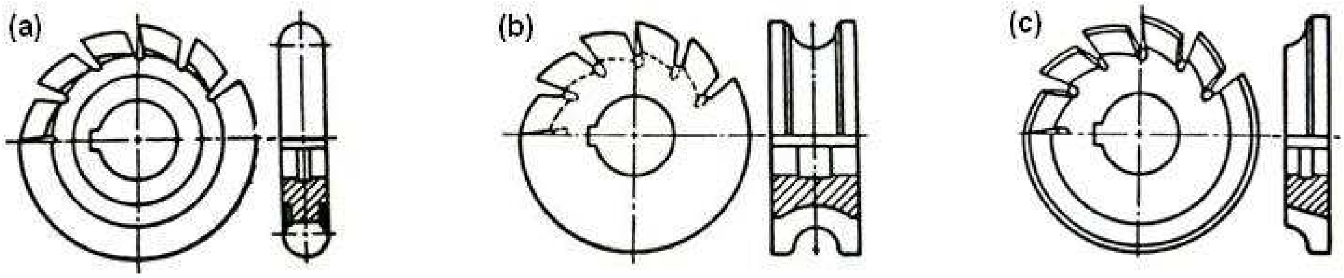


Fig. 3.84 (a) Convex milling cutter (b) Concave milling cutter and (c) Corner rounding milling cutter

Corner rounding milling cutters

Fig 3.84 (c) illustrates a corner rounding milling cutter. These cutters have teeth curved inwards on the circumferential surface to form the contour of a quarter circle. The cutter produces a convex quarter circular surface on the work piece. These are used for cutting a radius on the corners or edge of the work piece. The diameter of the cutter ranges from 1.5 mm to 20 mm.

Angle milling cutters

These cutters are made as single or double angle cutters and are used to machine angles other than 90^0. The cutting edges are formed at the conical surface around the periphery of the cutter. The double angle milling cutters are mainly used for cutting spiral grooves on a piece of blank. *Fig 3.85 (a) shows a single angle milling cutters and Fig. 3.85 (b) shows a double angle milling cutter.*

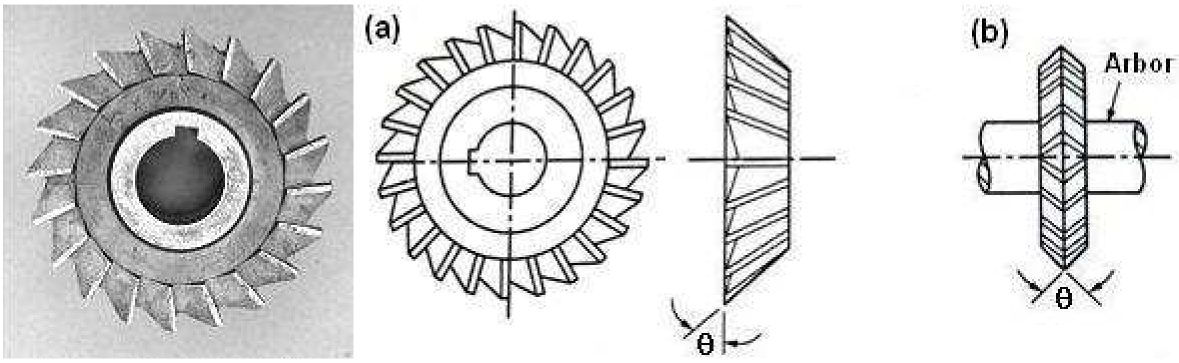


Fig. 3.85 (a) Single angle milling cutter and (b) Double angle milling cutter

3.7.2.7 Woodruff key slot milling cutters

These cutters are small standard cutters similar in construction to a thin small diameter plain milling cutter, intended for the production of woodruff key slots. The cutter is provided with a shank and may have straight or staggered teeth. *Fig. 3.86 illustrates a woodruff key slot milling cutter.*

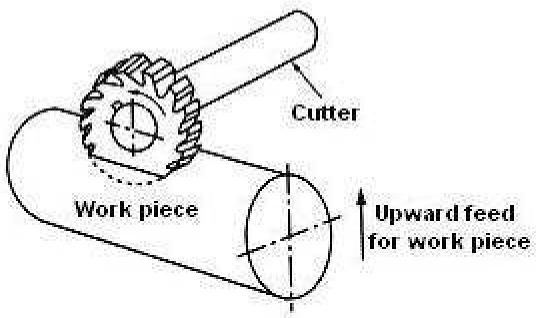


Fig. 3.86 Woodruff key slot milling cutter

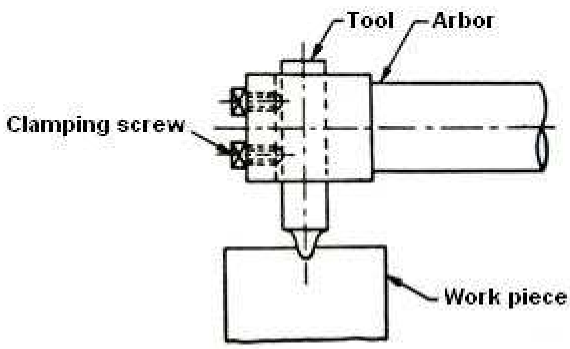


Fig. 3.87 Schematic view of a fly cutter

3.7.2.8 Fly cutter

These are simplest form of cutters and are mainly used in experimental shops or in tool room works. The cutter consists of a single point cutting tool attached to the end of an arbor. This cutter may be considered as an emergency tool when the standard cutters are not available. The shape of the tool tip is the replica of the contour to be machined. *Fig. 3.87 schematically shows a fly cutter.*

3.7.2.9 Ball nose end mill

Small end mill with ball like hemispherical end is often used in CNC milling machines for machining free form 3-D or 2-D contoured surfaces. These cutters may be made of HSS, solid carbide or steel body with coated or uncoated carbide inserts clamped at its end *as can be seen in the Fig. 3.88.*

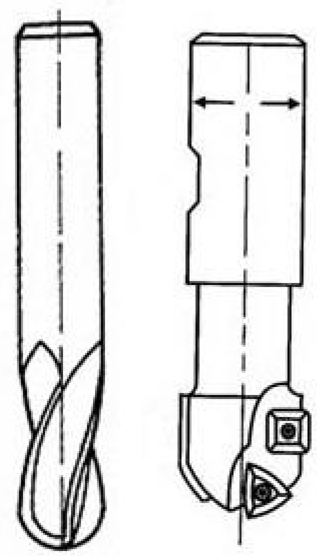


Fig. 3.88 Ball nose end mills

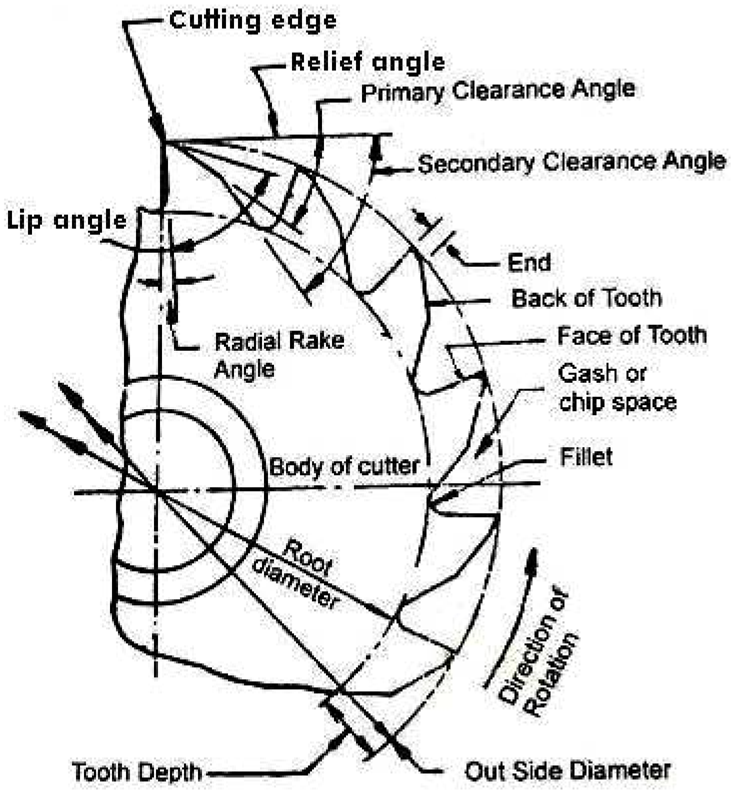


Fig. 3.89 Elements of a plain milling cutter

3.7.3 Elements of a plain milling cutter

The major parts and angles of a plain milling cutter are illustrated in Fig. 3.89.

Body of cutter	The part of the cutter left after exclusion of the teeth and the portion to which the teeth are attached.
Cutting edge	The edge formed by the intersection of the face and the circular land or the surface left by the provision of primary clearance.
Face	The portion of the gash adjacent to the cutting edge on which the chip impinges as it is cut from the work.
Fillet	The curved surface at the bottom of gash that joins the face of one tooth to the back of the tooth immediately ahead.
Gash	The chip space between the back of one tooth and the face of the next tooth.
Land	The part of the back of tooth adjacent to the cutting edge which is relieved to avoid interference between the surface being machined and the cutter.

Outside diameter The diameter of the circle passing through the peripheral cutting edge.

Root diameter The diameter of the circle passing through the bottom of the fillet.

Cutter angles Similar to a single point cutting tool, the milling cutter teeth are also provided with rake, clearance and other cutting angles in order to remove metal efficiently.

Relief angle The angle in a plane perpendicular to the axis. The angle between land of a tooth and tangent to the outside diameter of cutter at the cutting edge of that tooth.

Lip angle The included angle between the land and the face of the tooth, or alternatively the angle between the tangent to the back at the cutting edge and the face of the tooth.

Primary clearance angle The angle formed by the back of the tooth with a line drawn tangent to the periphery of the cutter at the cutting edge.

Secondary clearance angle The angle formed by the secondary clearance surface of the tooth with a line drawn tangent to the periphery of the cutter at the cutting edge.

Rake angle (Radial) The angle measured in the diametral plane between the face of the tooth and a radial line passing through the tooth cutting edge. *The rake angle which may be positive, negative or zero is illustrated in Fig. 3.90.*

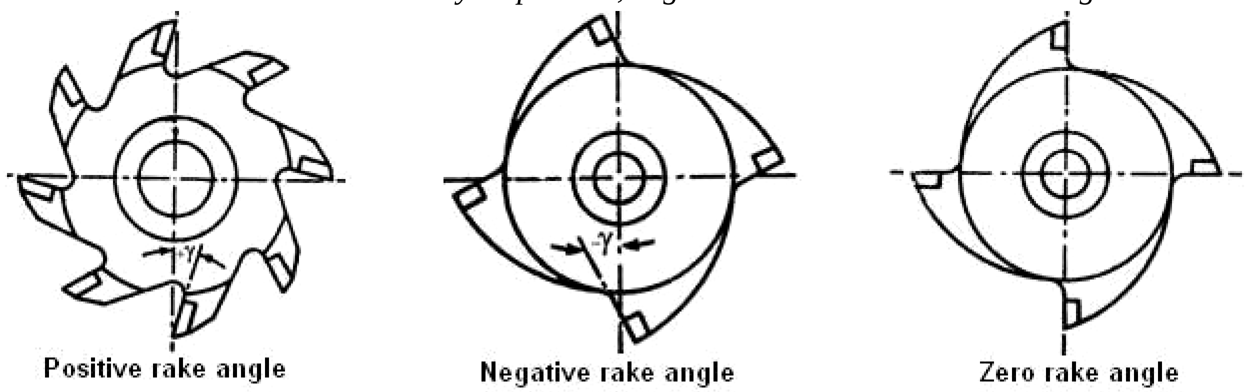


Fig. 3.90 Three types of rake angle of a plain milling cutter

3.8 MILLING OPERATIONS

Milling machines are mostly general purpose machine tools and used for piece or small lot production. In general, all milling operations can be grouped into two types.
They are: peripheral milling and face milling.

Peripheral milling Here, the finished surface is parallel to the axis of rotation of the cutter and is machined by cutter teeth on the periphery of the cutter. *Fig. 3.91 schematically shows the peripheral milling operation.*

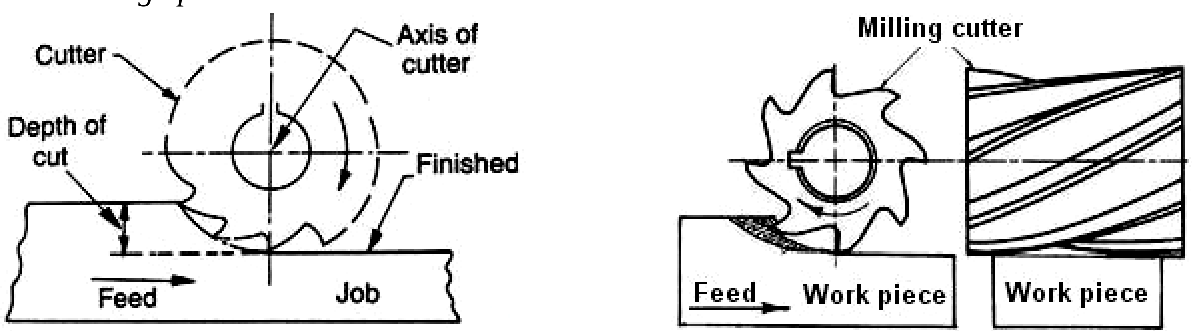


Fig. 3.91 Schematic view of the peripheral milling operation

Face milling Here, the finished surface is perpendicular to the axis of rotation of the cutter and is machined by cutter teeth on the periphery and the flat end of the cutter. The peripheral cutting edges do the actual cutting, whereas the face cutting edges finish up the work surface by removing a very small amount of material. *Fig. 3.92 schematically shows the face milling operation.*

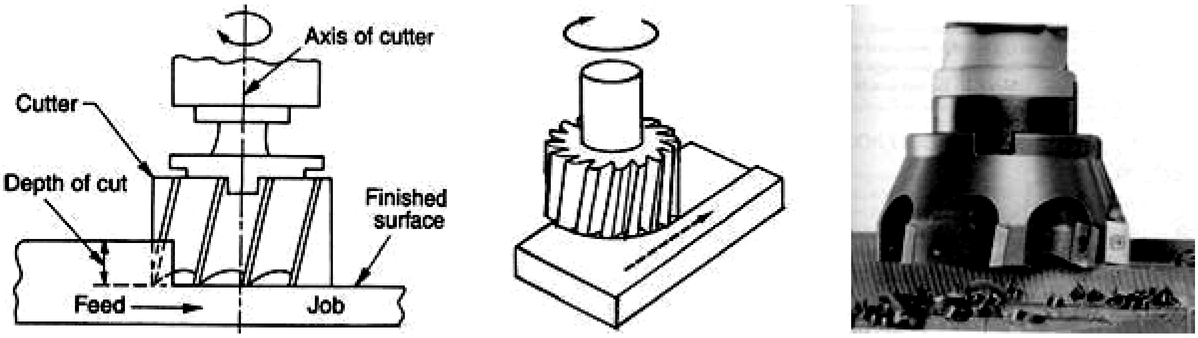


Fig. 3.92 Schematic view of the face milling operation

Special type - End milling It may be considered as the combination of peripheral and face milling operation. The cutter has teeth both on the end face and on the periphery. The cutting characteristics may be of peripheral or face milling type according to the cutter surface used. *Fig. 3.93 schematically shows the different end milling operation.*

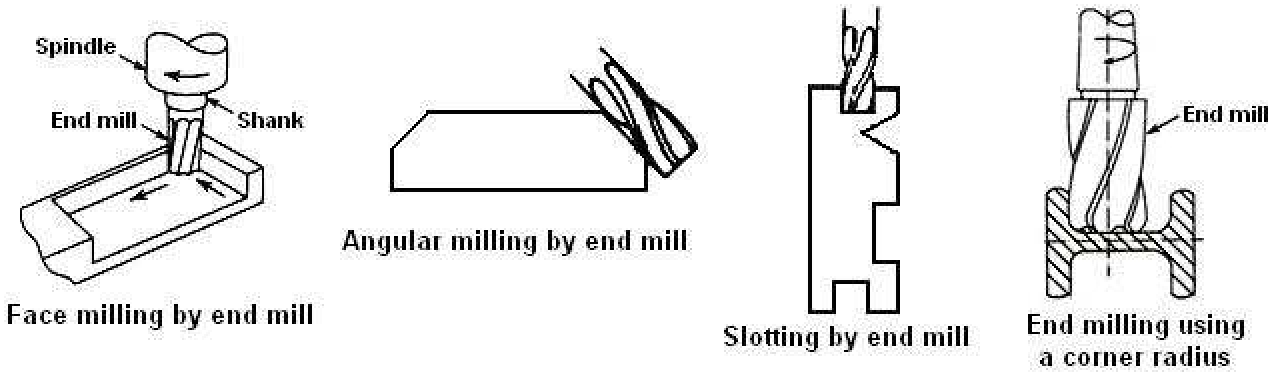


Fig. 3.93 Schematic views of the different end milling operations

According to the relative movement between the tool and the work, the peripheral milling operation is classified into two types. They are: up milling and down milling.

Up milling or conventional milling Here, the cutter rotates in the opposite direction to the work table movement. In this, the chip starts as zero thickness and gradually increases to the maximum. The cutting force is directed upwards and this tends to lift the work piece from the work holding device. Each tooth slides across a minute distance on the work surface before it begins to cut, producing a wavy surface. This tends to dull the cutting edge and consequently have a lower tool life. As the cutter progresses, the chip accumulate at the cutting zone and carried over with the teeth which spoils the work surface. *Fig. 3.94 (a) schematically shows the up milling or conventional milling process.*

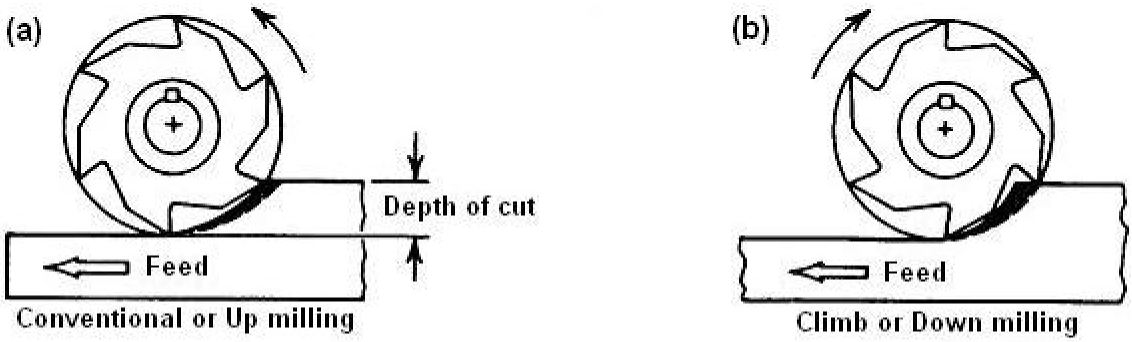


Fig. 3.94 Schematic views of (a) Up milling process and (b) Down milling process

Down milling or climb milling Here, the cutter rotates in the same direction as that of the work table movement. In this, the chip starts as maximum thickness and gradually decreases to zero thickness. This is suitable for obtaining fine finish on the work surface. The cutting force acts downwards and this tends to seat the work piece firmly in the work holding device. The chips are deposited behind the cutter and do not interfere with the cutting. Climb milling allows greater feeds per tooth and longer tool life between regrinds than up milling. *Fig. 3.94 (b) schematically shows the down or climb milling process.*

3.8.1 Basic functions of milling machine

Milling machines of various types are widely used for the following purposes:

Producing flat surface in horizontal, vertical and inclined planes *as shown in Fig. 3.95.*

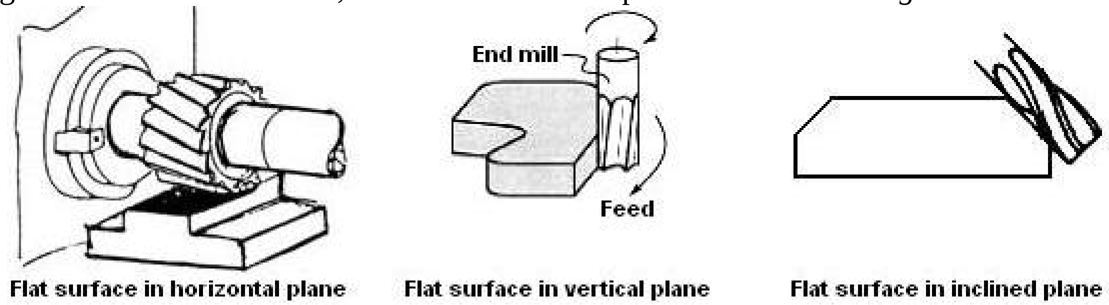


Fig. 3.95 Producing flat surface in horizontal, vertical and inclined planes

Machining slots of various cross sections *as shown in Fig. 3.96.*

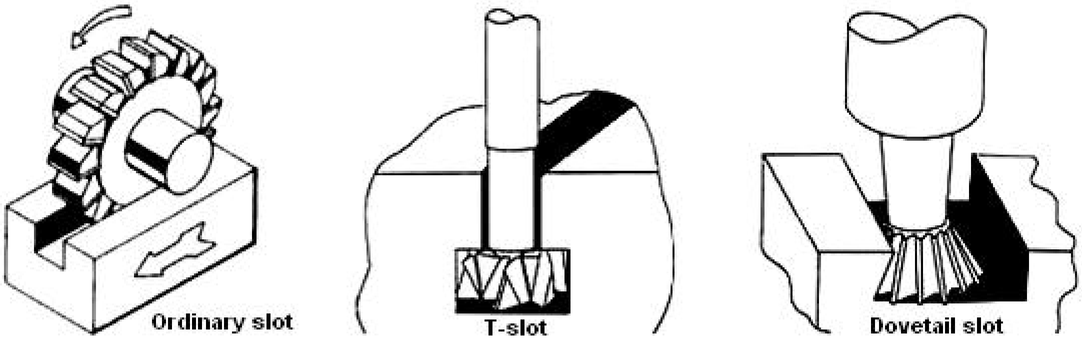


Fig. 3.96 Machining slots of various cross sections

Slitting or parting operation *as shown in Fig. 3.97.*

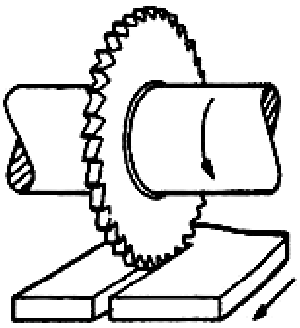


Fig. 3.97 Parting by slitting saw

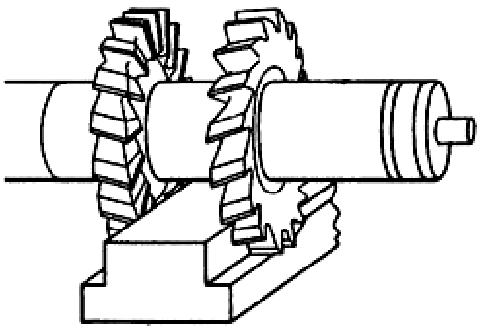


Fig. 3.98 Straddle milling

Straddle milling or parallel facing operation by two single side milling cutters *as shown in Fig. 3.98.*

Form milling operation by form cutters *as shown in Fig. 3.99.*

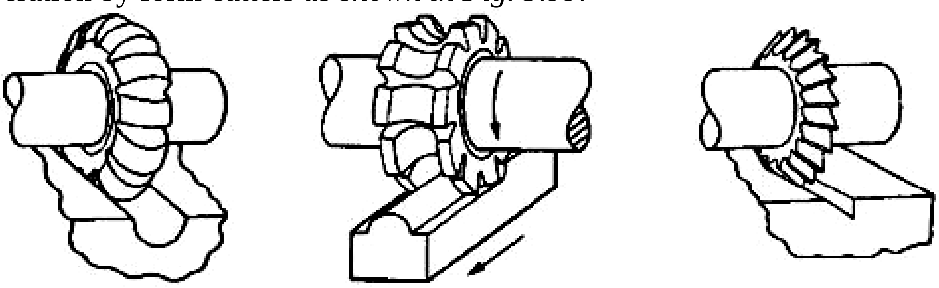


Fig. 3.99 Form milling operations

Cutting helical grooves like flutes of the drills *as shown in Fig. 3.100.*

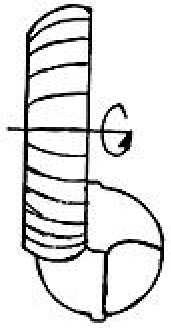


Fig. 3.100 Cutting of drill flutes

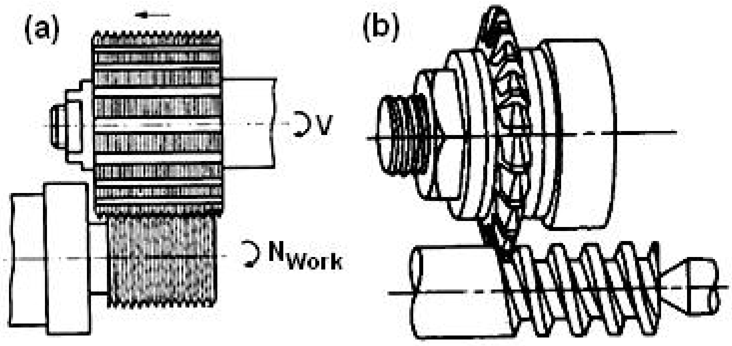


Fig. 3.101 (a) Short thread milling (b) Long thread milling

Short thread milling for small size fastening screws, bolts etc. and long thread milling on large lead screws, power screws, worms etc. *These are illustrated in Fig. 3.101 (a and b).*

Cutting teeth of spur gears, straight toothed bevel gears, worm wheels, sprockets in piece or batch production. *These are illustrated in Fig. 3.102 (a, b and c).*

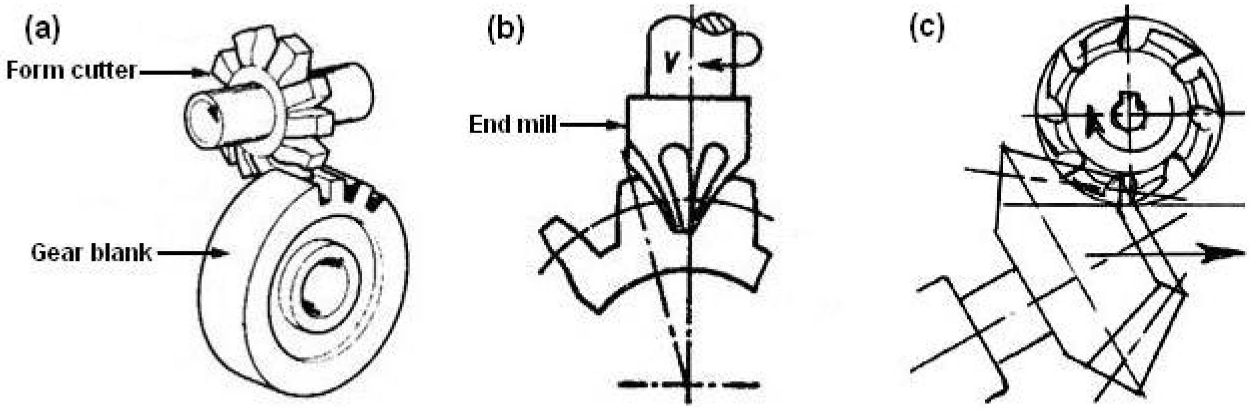
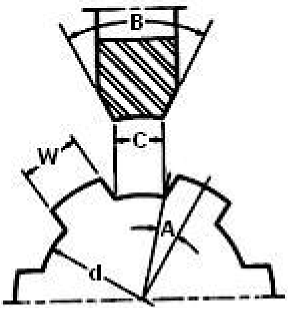


Fig. 3.102 (a) Cutting teeth of spur gear by disc type cutter (b) Cutting teeth of spur gear by end mill (c) Cutting teeth of straight toothed bevel gear by disc type cutter

Cutting the slots of external spline shafts *as shown in Fig. 3.103.*



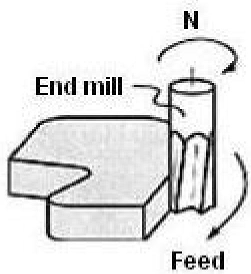


Fig. 3.103 Cutting slots of external spline shaft

Fig. 3.104 Profile milling of a cam

Profile milling like cam profiles *as shown in Fig. 3.104.*

Surface contouring or 3-D contouring like die or mould cavities *as shown in Fig. 3.105 (a and b).*

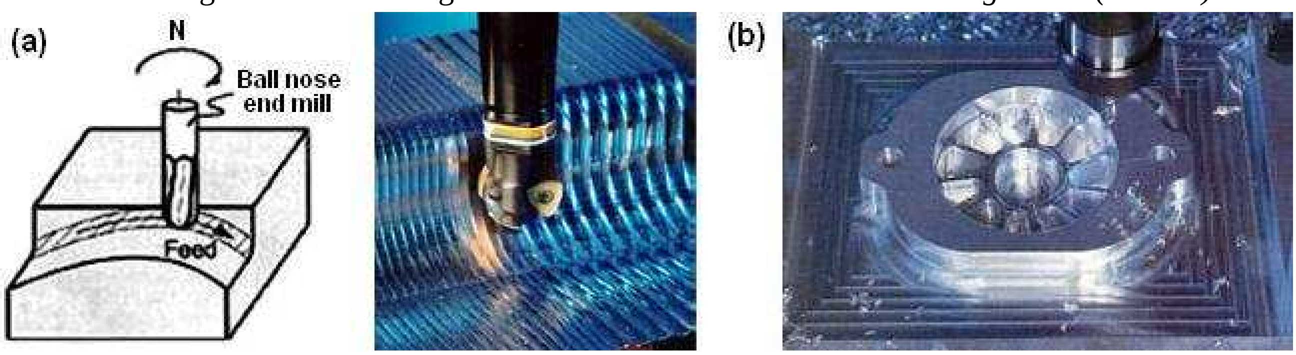


Fig. 3.105 (a) Surface contouring of 3-D surface (b) Surface contouring of die cavity

Gang milling Gang milling operation is employed for quick production of complex contours comprising a number of parallel flat or curved surfaces. *Proper combinations of several cutters are mounted tightly on the horizontal arbor are indicated in Fig. 3.106.*

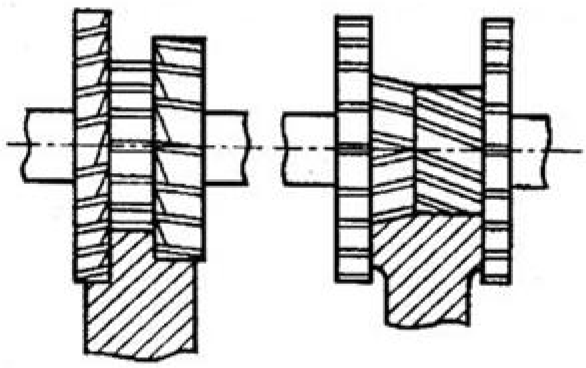


Fig. 3.106 Gang milling

Turning by rotary tools During turning like operations in large heavy and odd shaped jobs its speed (rpm) is essentially kept low. For enhancing productivity and better cutting fluid action rotary tools like milling cutters are used *as shown in Fig. 3.107 (a, b and c).*

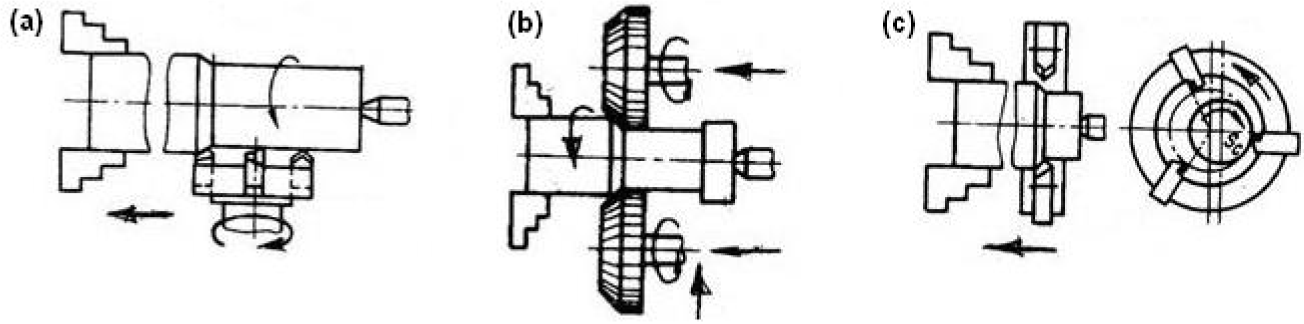


Fig. 3.107 (a, b and c) Turning by rotary milling cutters

3.9 HOLE MAKING

Machining round holes in metal stock is one of the most common operations in the manufacturing industry. It is estimated that of all the machining operations carried out, there are about 20 % hole making operations. Literally no work piece leaves the machine shop without having a hole made in it. *The various types of holes are shown in Fig. 3.108.*

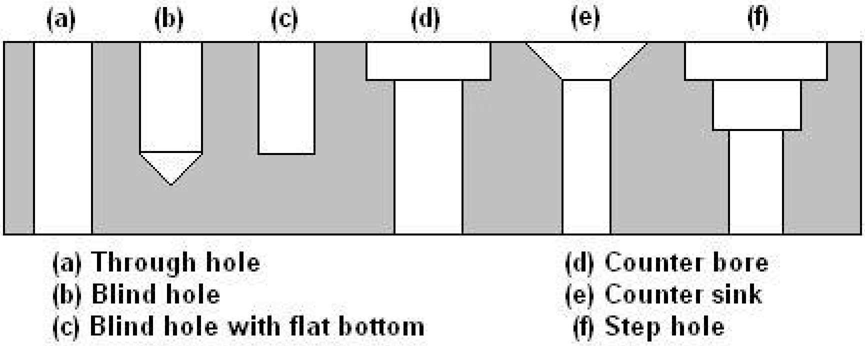


Fig. 3.108 Various types of holes

3.10 DRILLING

Drilling is the process of originating holes in the work piece by using a rotating cutter called drill. The machine used for this purpose is called drilling machine. Although it was primarily designed to originate a hole, it can perform a number of similar operations. In a drilling machine holes may be drilled quickly and at a low cost. As the machine tool exerts vertical pressure to originate a hole it is also called drill press. Holes were drilled by the Egyptians in 1200 B.C. by bow drills. The bow drill is the mother of present day metal cutting drilling machine.

3.10.1 Types of drilling machine

The different types of drilling machine which are most commonly used are:

- Portable drilling machine.
- Sensitive drilling machine (Bench mounting or table top and Floor mounting).
- Upright drilling machine (Pillar or Round column section and Box column section).
- Radial drilling machine (Plain, Semi-universal and Universal).
- Gang drilling machine.
- Multiple spindle drilling machine.
- Deep hole drilling machine.
- Turret type drilling machine

But in working principle all are more or less the same.

3.10.1.1 Portable drilling machine or hand drilling machine

Unlike the mounted stationary drilling machines, the hand drill is a portable drilling device which is mostly held in hand and used at the locations where holes have to be drilled. The small and reasonably light hand drilling machines are run by a high speed electric motor. In fire hazardous areas the hand drilling machine is often rotated by compressed air. The maximum size of the drill that it can accommodate is not more than 12 to 18 mm. *Fig. 3.109 illustrates a hand drilling machine.*

Fig. 3.109 Hand drilling machine

Fig. 3.110 Table top sensitive drilling machine

3.10.1.2 Bench mounting or table top sensitive drilling machine

This small capacity (≤ 0.5 kW) upright (vertical) single spindle drilling machine is mounted on rigid table and manually operated using usually small size (φ ≤ 10 mm) drills. *Fig. 3.110 illustrates a table top sensitive drilling machine.*

3.10.1.3 Floor mounting sensitive drilling machine

The floor mounting sensitive drilling machine is a small machine designed for drilling small holes at high speed in light jobs. The base of the machine is mounted on the floor. It consists of a vertical column, a horizontal table, a head supporting the motor and driving mechanism, and a vertical spindle for driving and rotating the drill. There is no arrangement for any automatic feed of the drill spindle. The drill is fed into the work by purely hand control. High speed is necessary for drilling small holes. High speeds are necessary to attain required cutting speed by small diameter drill. Hand feed permits the operator to feel or sense the progress of the drill into the work, so that if the drill becomes worn out or jams on any account, the pressure on the drill may be released immediately to prevent it from breaking. As the operator senses the cutting action, at any instant, it is called sensitive drilling machine. Sensitive drilling machines are capable of rotating drills of diameter from 1.5 to 15.5 mm. Super sensitive drilling machines are designed to drill holes as small as 0.35 mm in diameter and the machine is rotated at a high speed of 20,000 r.p.m. or above. *Fig. 3.111 illustrates a floor mounting sensitive drilling machine.*

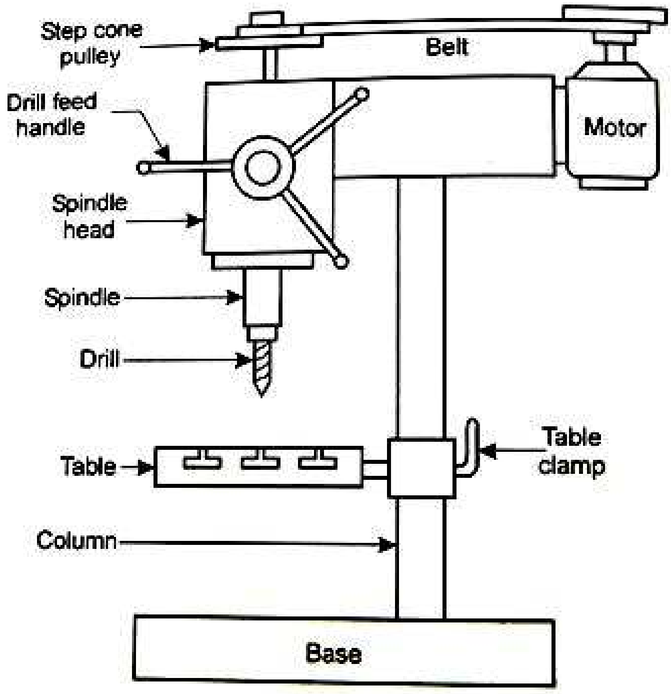


Fig. 3.111 Floor mounting sensitive drilling machine

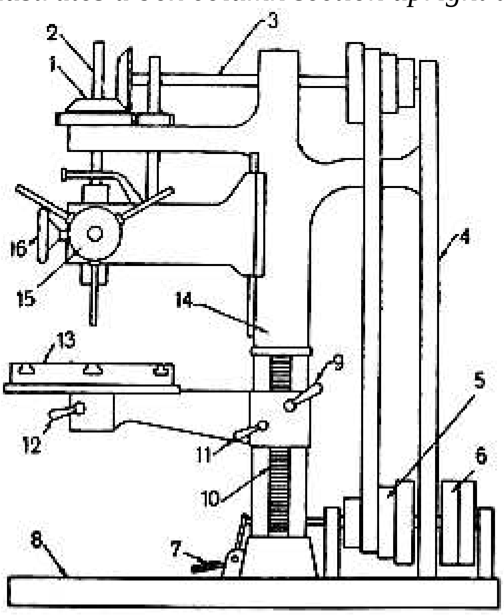
Fig. 3.112 Pillar drilling machine

3.10.1.4 Pillar or Round column section upright drilling machine

Fig. 3.112 illustrates a pillar or round column section upright drilling machine. This machine is usually called pillar drilling machine. It is quite similar to the table top drilling machine but of little larger size and higher capacity (0.55 ~ 1.1 kW) and are mounted on the floor. In this machine the drill feed and the work table movements are done manually. This low cost drilling machine has a base, a tall tubular column, an arm supporting the table and a drill head assembly. The arm may be moved up and down on the column and also be moved in an arc up to 180^0 around the column. The table may be rotated 360^0 about its own centre independent of the position of the arm. It is generally used for small jobs and light drilling. The maximum size of holes that can be drilled is not more than 50 mm.

3.10.1.5 Box column section upright drilling machine

Fig. 3.113 illustrates a box column section upright drilling machine. The major parts are:



1. Bevel gear drive to spindle
2. Spindle
3. Overhead shaft
4. Back stay
5. Counter shaft cone pulley
6. Fast and loose pulley
7. Foot pedal
8. Base
9. Table elevating handle
10. Rack on column
11. Table elevating clamp handle
12. Table clamp
13. Table
14. Column
15. Handwheel for quick hand feed
16. Handwheel for sensitive hand feed

Fig. 3.113 Box column section upright drilling machine

Base It is a part of the machine on which vertical column is mounted. The top of the base is accurately machined and has T-slots on it so that large work pieces and work holding devices may be set up and bolted to it.

Column It is the vertical member of the machine which supports the table and the head containing all the driving mechanism. The column should be sufficiently rigid so that it can take up the entire cutting pressure of the drill. The column may be made of box section or of round section. Box column is a more rigid unit. In box column type, the front face of the column is accurately machined to form guide ways on which the table can slide up and down for vertical adjustment.

Table It is mounted on the column and is provided with T-slots for clamping the work directly on its face. The table may be round or rectangular in shape. The table may have three types of adjustments: vertical adjustment, radial adjustment about the column, and circular adjustment about its own axis. After the required adjustments have been made the table and the arm are clamped in position.

Drill head It is mounted on the top of the column and houses the driving and feeding mechanism for the spindle. In some of the machines the drill head may be adjusted up or down for accommodating different heights of work in addition to the table adjustment.

Spindle Holds the drill and transmits rotation and axial translation to the tool for providing cutting motion and feed motion - both to the drill.

3.10.1.6 Radial drilling machine

Fig. 3.114 illustrates a radial drilling machine. The major parts are:

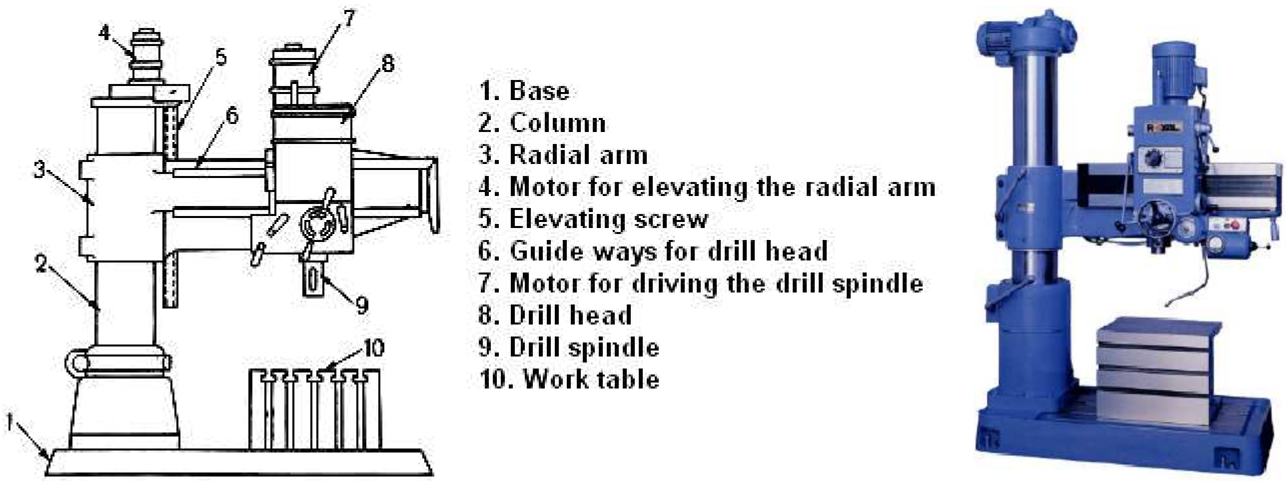


Fig. 3.114 Radial drilling machine

Base It is a large rectangular casting that is finished on its top to support a column on its one end and to hold the work table at the other end. In some machines T-slots are provided on the base for clamping work when it serves as a table.

Column The column is a cylindrical casting that is mounted vertically at one end of the base. It supports the radial arm which may slide up or down on its face. An electric motor is mounted on the top of the column which imparts vertical adjustment of the arm by rotating a screw passing through a nut attached to the arm.

Radial arm The radial arm that is mounted on the column extends horizontally over the base. It is a massive casting with its front vertical face accurately machined to provide guide ways on which the drill head may be made to slide. The arm may be swung round the column. In some machines this movement is controlled by a separate motor.

Drill head The drill head is mounted on the radial arm and drives the drill spindle. It encloses all the mechanism for driving the drill at multiple speeds and at different feed. All the mechanisms and controls are housed within a small drill head which may be made to slide on the guide ways of the arm for adjusting the position of drill spindle with respect to the work.

Spindle drive and feed mechanism

There are two common methods of driving the spindle. A constant speed motor is mounted at the extreme end of the radial arm. The motor drives a horizontal spindle which runs along the length of the arm and the motion is transmitted to the drill head through bevel gears. By the gear train within the drill head, the speed of the spindle may be varied. Through another gear train within the drill head, different feeds of the spindle are obtained. In some machines, a vertical motor is fitted directly on the drill head and through gear box multiple speed and the feed of the spindle can be obtained.

Working principle The work is mounted on the table or when the work is very large it may be placed on the floor or in a pit. Then the position of the arm and the drill head is altered so that the drill may be pointed exactly on the location where the hole is to be drilled. When several holes are drilled on a large work piece, the drill head is moved from one position to the other after drilling the hole without altering the setting of the work. This versatility of the machine allows it to work on large work pieces. There are some more machines where the drill spindle can be additionally swiveled and / or tilted.

3.10.1.7 Gang drilling machine

In this almost single purpose and more productive drilling machine a number of spindles (2 to 6) with drills (of same or different size) in a row are made to produce number of holes progressively or simultaneously through the jig. *Fig. 3.115 illustrates a typical gang drilling machine.*

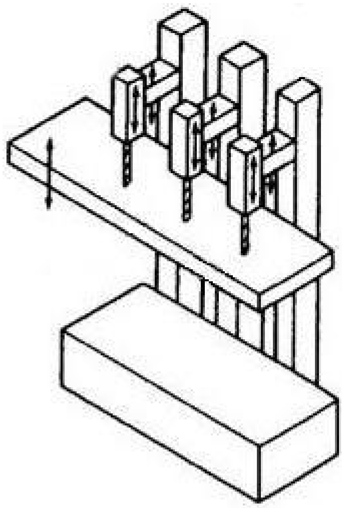


Fig. 3.115 Gang drilling machine

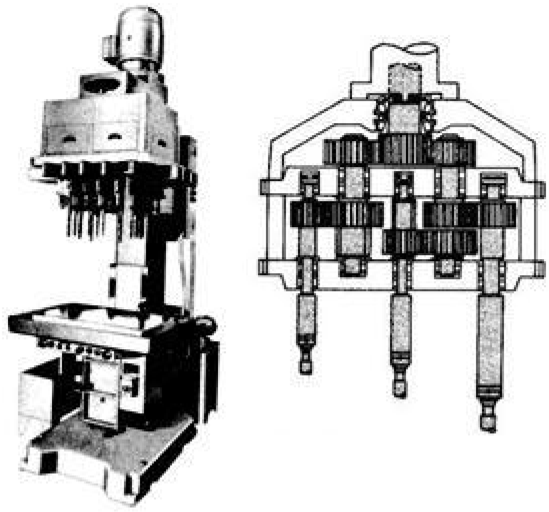


Fig. 3.116 Multiple spindle drilling machine

3.10.1.8 Multiple spindle drilling machine

Fig. 3.116 schematically shows a typical multiple spindle drilling machine. In this high production machine a large number of drills work concurrently on a blank through a jig specially made for the particular work. The entire drilling head works repeatedly using the same jig for batch or lot production. The rotations of the drills are derived from the main spindle and the central gear through a number of planetary gears in mesh with the central gear and the corresponding flexible shafts. The positions of those parallel shafts holding the drills are adjusted depending upon the locations of the holes to be made on the job. Each shaft possesses a telescopic part and two universal joints at its ends to allow its change in length and orientation respectively for adjustment of location of the drills of varying size and length. In some heavy duty multi spindle drilling machines, the work-table is raised to give feed motion instead of moving the heavy drilling head.

3.10.1.9 Deep hole drilling machine

Very deep holes of L/D ratio 6 to even 30, required for rifle barrels, long spindles, oil holes in shafts, bearings, connecting rods etc, are very difficult to make for slenderness of the drills and difficulties in cutting fluid application and chip removal. Such drilling cannot be done in ordinary drilling machines and by using ordinary drills. It needs machines like deep hole drilling machine such as gun drilling machines with horizontal axis or vertical axis.

These machines are provided with:

- High spindle speed.
- High rigidity.
- Tool guide.
- Pressurized cutting oil for effective cooling, chip removal and lubrication at the drill tip.

Fig. 3.117 schematically shows a deep hole drill tool used in the deep hole drilling operation.

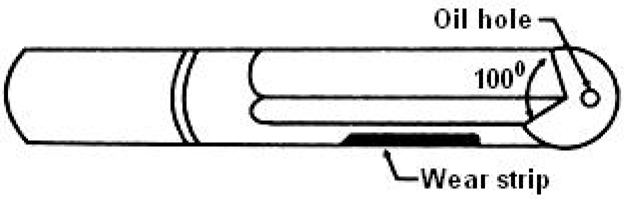


Fig. 3.117 Deep hole drill

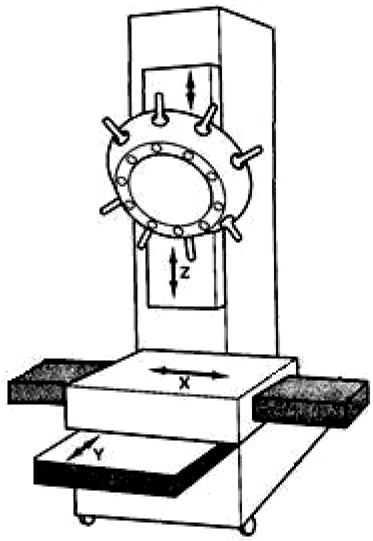


Fig. 3.118 Turret type drilling machine

3.10.1.10 Turret type drilling machine

Fig. 3.118 schematically shows a typical turret type drilling machine. Turret drilling machine is structurally rigid column type drilling machine but is more productive like gang drill machine by having a pentagon or hexagon turret. The turret holds a number of drills and similar tools, is indexed and moved up and down to perform quickly the desired series of operations progressively. These drilling machines are available with varying degree of automation both fixed and flexible type.

3.10.2 Spindle and drill head assembly

The spindle is a vertical shaft which holds the drill. It receives its motion from the top shaft though bevel gears. A long key-way is cut on the spindle and the bevel gear is connected to it by a sliding key. This construction is made to allow the spindle to be connected with the top shaft irrespective of its position when the spindle is raised or lowered for feeding the drill into the work piece. The spindle rotates within a non-rotating sleeve which is known as the quill. Rack teeth are cut on the outer surface of the sleeve. The sleeve may be moved up or down by rotating a pinion which meshes with the rack and this movement is imparted to the spindle to give the required feed.

The downward movement of the spindle is effected by rotating the pinion which causes the quill to move downward exerting pressure on the spindle through a thrust bearing and washer. The spindle is moved upward by the upward pressure exerted by the quill acting against a nut attached to the spindle through the thrust bearing. The lower end of the spindle is provided with Morse taper hole for accommodating taper shank drill. A slot is provided at the end of the taper hole for holding the tang of the drill to impart it a positive drive. *The drill spindle assembly is illustrated in Fig. 3.119.*

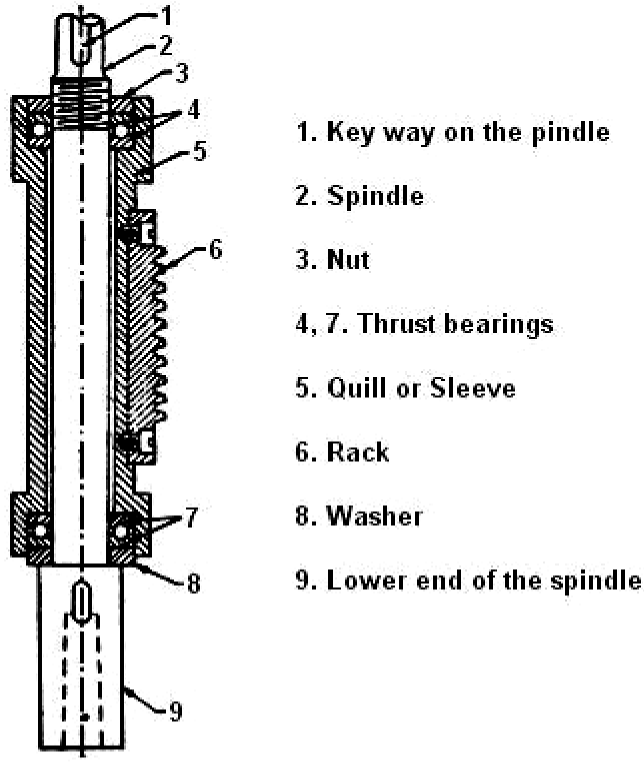


Fig. 3.119 Drill spindle assembly

3.10.2.1 Spindle drive mechanism

The spindle drive mechanism of a drilling machine incorporates an arrangement for obtaining multiple speed of the spindle similar to a lathe to suit to various machining conditions.

Multiple speed of the spindle may be obtained as follows:

- By step cone pulley drive.
- By step cone pulley drive with one or more back gears.
- By gearing.

Step cone pulley drive *Fig. 3.113 shows the schematic view of a spindle driving mechanism incorporating a step cone pulley.* The motion is transmitted from an overhead line shaft to the countershaft mounted on the base of the machine. The countershaft may be started or stopped by shifting the belt from loose pulley to fast pulley or vice versa by operating the foot-pedal 7. The step cone pulley mounted on the head of the machine receives power from the countershaft step cone pulley 5 through the belt. The drill spindle 2 receives power from the overhead shaft 3 through bevel gears 1 and the speed of the spindle may be varied by shifting the belt on different steps of the cone pulley 5. The number of spindle speeds available is dependent upon the number of steps on the cone pulley.

Step cone pulley drive with back gear In order to obtain larger number of spindle speeds back gears are incorporated in the machine in addition to the step cone pulley.

Spindle drive by gearing Modern heavy duty drilling machines are driven by individual motor mounted on the frame of the machine. The multiple speeds may be obtained by sliding gear or sliding clutch mechanism or by the combination of the above two methods.

3.10.2.2 Feed mechanism

In a drilling machine, the feed is effect by the vertical movement of the drill into the work. The feed movement of the drill may be controlled by hand or power.

The hand feed may be applied by two methods:

- Quick traverse hand feed.
- Sensitive hand feed.

The quick traverse feed is used to bring the cutting tool rapidly to the hole location or for withdrawing the drill when the operation is completed. Quick hand feed is obtained by rotating the hand wheel pivoted to the pinion. One turn of the hand wheel will cause the pinion to rotate through one complete revolution giving quick hand feed movement of the spindle.

The sensitive hand feed is applied for trial cut and for drilling small holes. The sensitive feed hand wheel is attached to the rear end of the worm shaft. Rotation of the hand wheel will cause the worm and worm gear to rotate and a slow but sensitive feed is obtained.

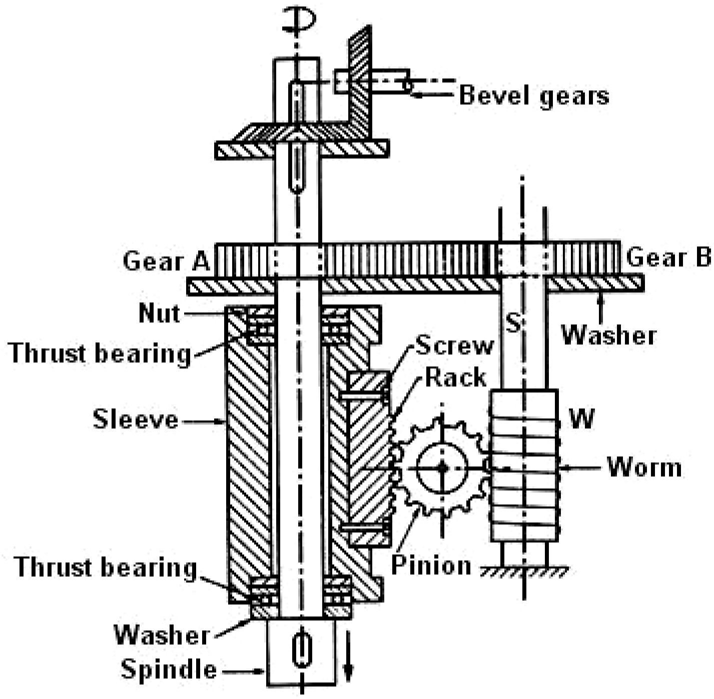


Fig. 3.120 Automatic feed mechanism

The automatic feed is applied while drilling larger diameter holes as the cutting pressure required is sufficiently great. *Fig.3.120 illustrates the automatic feed mechanism.* The gear A rotates with the spindle as the spindle passes through it. Gear B is connected with gear A, so it also rotates. The shaft S rotates with the gear B as it connected to it. At a suitable distance under the shaft, there is a worm which drives a pinion. The pinion is connected with the rack on the non rotating sleeve (quill) fitted over the spindle. The rotation of the worm rotates the pinion. The rotation of the pinion moves the quill up and down through the rack cut on it. The quill moves the drill spindle up and down. Thus the automatic feed of the drill spindle is achieved. Different ranges of feed can be obtained by means of feed gearbox.

3.10.3 Work holding devices used in drilling machines

Before performing any operation in a drilling machine it is absolutely necessary to secure the work firmly on the drilling machine table. The work should never be held by hand, because the drill while revolving exerts so much of torque on the work piece that it starts revolving along with the tool and may cause injuries to the operator. The work holding devices commonly used for holding the work piece in a drilling machine table are: T-bolts and clamps, machine vises, step blocks, V-blocks, angle plate and drill jigs. *All of them except drill jig have been described in Article 3.2.6 and Page 110.* When the work is heavy and / or of odd shape and size, it is directly clamped on the drilling machine table.

3.10.3.1 Drill jigs

These are used for holding the work in a mass production process. A drill jig can hold the work securely, locate the work and guide the tool at any desired position. The work may be clamped and unclamped quickly. Jigs are specially designed for each type of work where quantity production is desired. The work is clamped below the jig and the holes are located. The drill is guided by the drill bush. *Fig. 3.121 schematically shows some types of drill jigs used in mass production.*

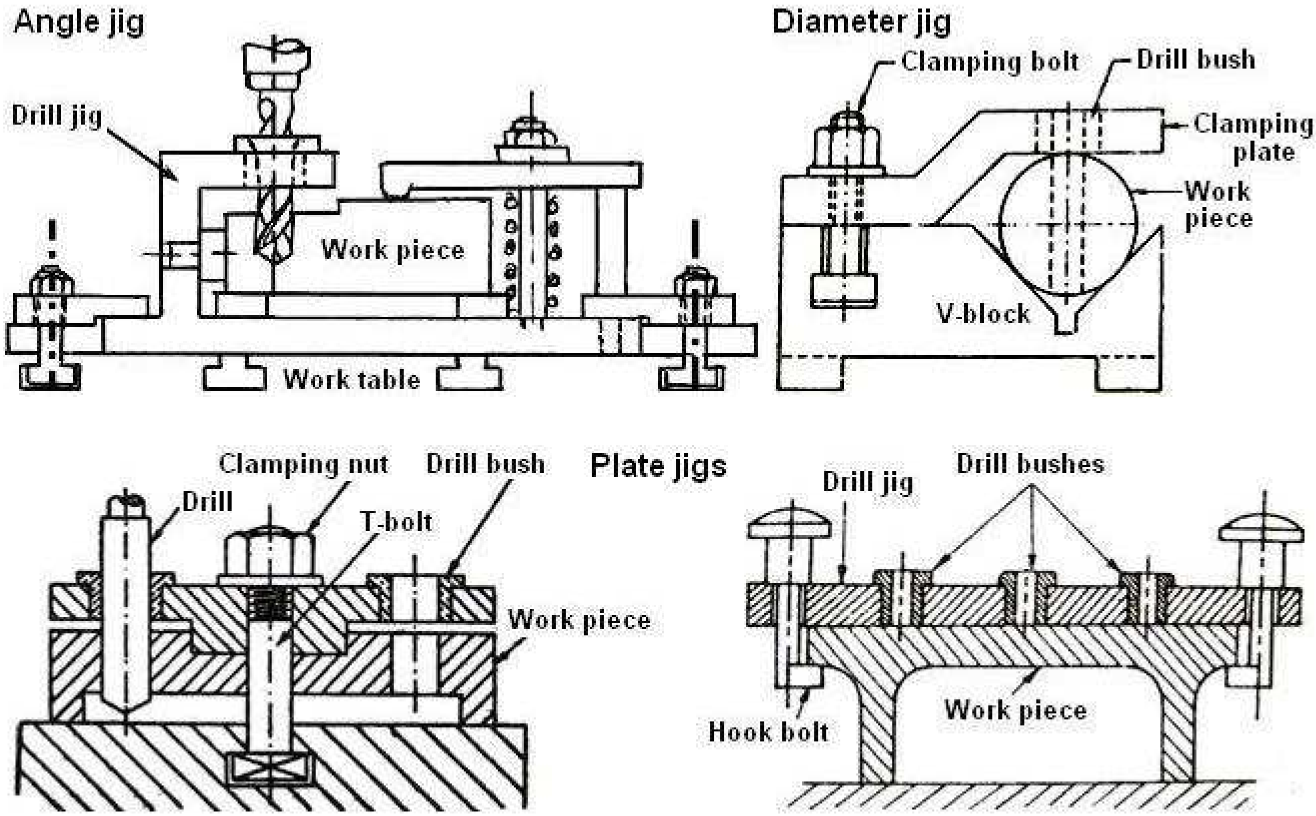


Fig. 3.121 Some types of drill jigs

3.10.4 Tool holding devices used in drilling machines

In drilling machines mostly drills of various type and size are used for drilling holes. Often some other tools are also used for enlarging and finishing drilled holes, counter boring, countersinking, tapping etc. The different methods used for holding tools in a drill spindle are:

- By directly fitting in the spindle.
- By a sleeve.
- By a socket.
- By chucks.

3.10.4.1 Drill directly fitted in the spindle

All drilling machines have the spindle bored out to a standard Morse taper (1:20) to receive the taper shank of the tool. While fitting the tool the shank is forced in the tapered hole and the tool is gripped by friction. The tool may be rotated with the spindle by friction between the tapered surface and the spindle; but to ensure a positive drive the tang or tongue of the tool fits into a slot at the end of the taper hole. The tool is removed by pressing a tapered wedge known as the drift or key into the slotted hole of the spindle. *Fig. 3.122 (a) shows a drill directly fitted in the spindle. Fig. 3.122 (b) shows a drift.*

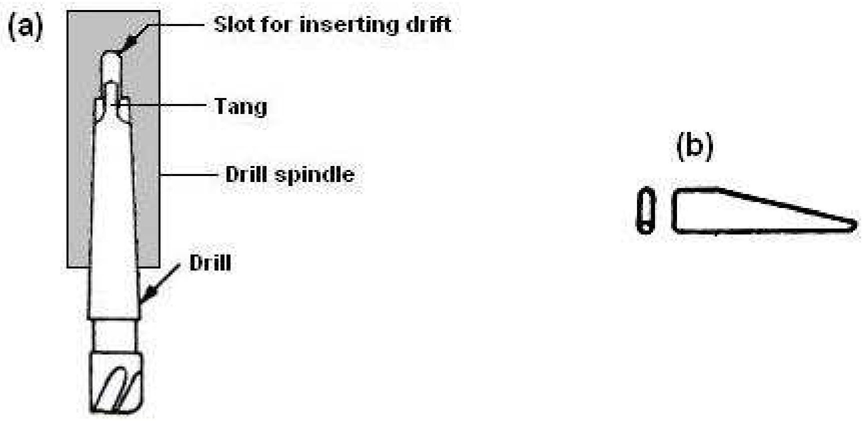


Fig. 3.122 (a) Drill directly fitted in the spindle and (b) Drift or key

3.10.4.2 Drill sleeve

The drill spindle is suitable for holding only one size of shank. If the taper shank of the tool is smaller than the taper in the spindle hole, a taper sleeve is used. The outside taper of the sleeve conforms to the drill spindle taper and the inside the taper holds the shanks of smaller size tools or smaller sleeves. The sleeve fits into the taper hole of the spindle. The sleeve has a tang which fits into the slot of the spindle. The tang of the tool fits into a slot provided at the end of the taper hole of the sleeve. The sleeve with the tool may be removed by forcing a drift within the slot of the spindle and the tool may be separated from the sleeve by the similar process. Different size of the tool shanks may be held in the spindle by using different sizes of sleeves. *Fig. 3.123 (a) shows a drill sleeve. Fig. 3.123 (b) shows a drill sleeve holding a drill fitted in the drill spindle. Fig. 3.123 (c) shows different sizes of drill sleeves.*

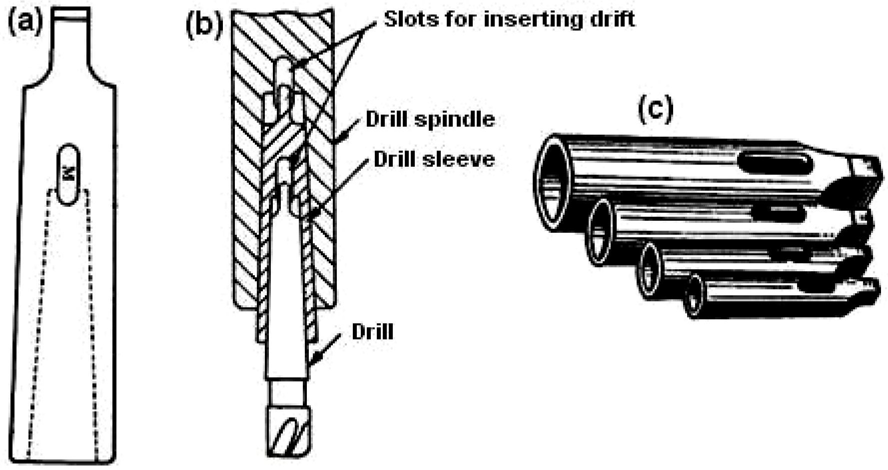


Fig. 3.123 (a) Drill sleeve (b) Drill sleeve holding a drill fitted in the drill spindle and (c) Different sizes of drill sleeves.

3.10.4.3 Drill socket

When the tapered tool shank is larger than the spindle taper, drill sockets are used to hold the tool. Drill sockets are much longer in size than the drill sleeves. A socket consists of a solid shank attached to the end of a cylindrical body. The taper shank of the socket conforms to the taper of the drill spindle and fits into it. The body of the socket has a tapered hole larger than the drill spindle taper into which the taper shank of any tool may be fitted. The tang of the socket fits into the slot of the spindle and the tang of the tool fits into the slot of the socket. *Fig. 3.124 shows a drill socket.*

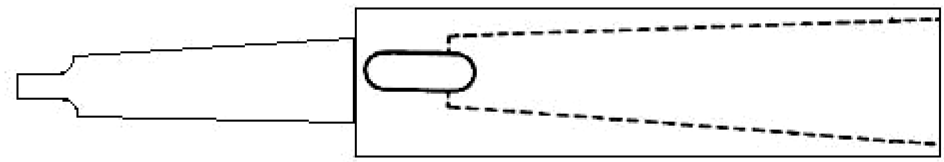


Fig. 3.124 Drill socket

3.10.4.4 Drill chucks

The chucks are especially intended for holding smaller size drills are any other tools. A sleeve or socket can hold one size of tool shank only; but a drill chuck may be used to hold different sizes of tool shanks within a certain limit. Drill chucks have tapered shanks which are fitted into the drilling machine spindle. Different types of drill chucks are manufactured for different purposes. The most common type of drill chuck used is three jaw self centering drill chuck.

This type of chuck is particularly adapted for holding tools having straight shanks. Three slots are cut 120^0 apart in the chuck body which houses three jaws having threads cut at the back that meshes with a ring nut. The ring nut is attached to the sleeve. Bevel teeth are cut all round the sleeve body. The sleeve may be rotated by rotating a key having bevel teeth cut on its face which meshes with the bevel teeth on the sleeve. The rotation of the sleeve causes the ring nut to rotate in a fixed position and all the three jaws close or open by the same amount from the centre holding or releasing the shank of a tool. *Fig. 3.125 shows a three jaw self centering drill chuck.*

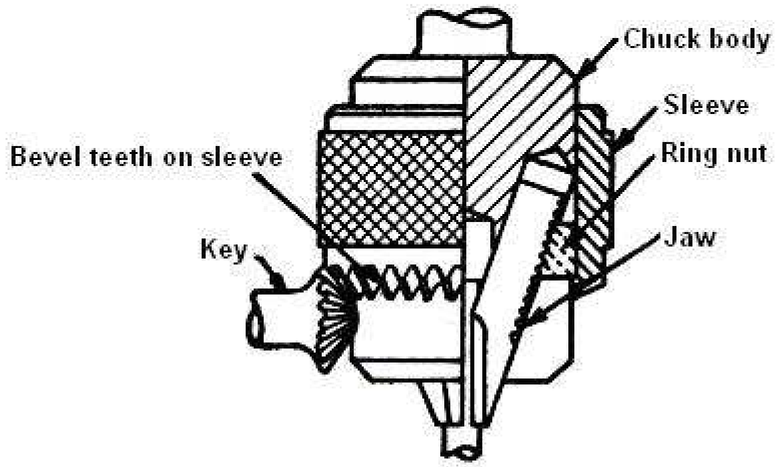


Fig. 3.125 Three jaw self centering drill chuck

3.10.5 Drilling tools

Different types of drills are properly used for various applications depending upon work material, tool material, depth and diameter of the holes. General purpose drills may be classified as:

According to material:

- High speed steel - most common.
- Cemented carbides.
  - Without or with coating.
  - In the form of brazed, clamped or solid.

According to size:

- Large twist drills of diameter around 40 mm.
- Micro drills of diameter 25 μm to 500 μm.
- Medium range diameter ranges between 3 mm to 25 mm (most widely used).

According to number of flutes:

- Two fluted - most common.
- Single flute - e.g., gun drill (robust).
- Three or four flutes - called slot drill.

According to helix angle of the flutes:

- Usual: 20^0 to 35^0 - most common.
- Large helix: 45^0 to 60^0 - suitable for deep holes and softer work materials.
- Small helix: for harder / stronger materials.
- Zero helix: spade drills for high production drilling micro-drilling and hard work materials.

According to length to diameter ratio:

- Deep hole drill; e.g. crank shaft drill, gun drill etc.
- General type: $L/\varphi \cong 6$ to 10.
- Small length: e.g. centre drill.

According to shank:

- Straight shank - small size drill being held in drill chuck.
- Taper shank - medium to large size drills being fitted into the spindle nose directly or through taper sockets and sleeves.

According to specific applications:

- Centre drill *[Fig. 3.126 (a)]* for small axial holes with 60^0 taper ends to hold the lathe centre.
- Step drill and sub land drill *[Fig. 3.126 (b and c)]* for small holes with 2 or 3 steps.
- Half round drill, gun drill and crank shaft drill *[Fig. 3.126 (d, e and f)]* for making oil holes.
- Ejector drill for high speed drilling of large diameter holes.
- Taper drill for batch production.
- Trepanning tool *[Fig. 3.126 (g)]* for large holes in soft materials.

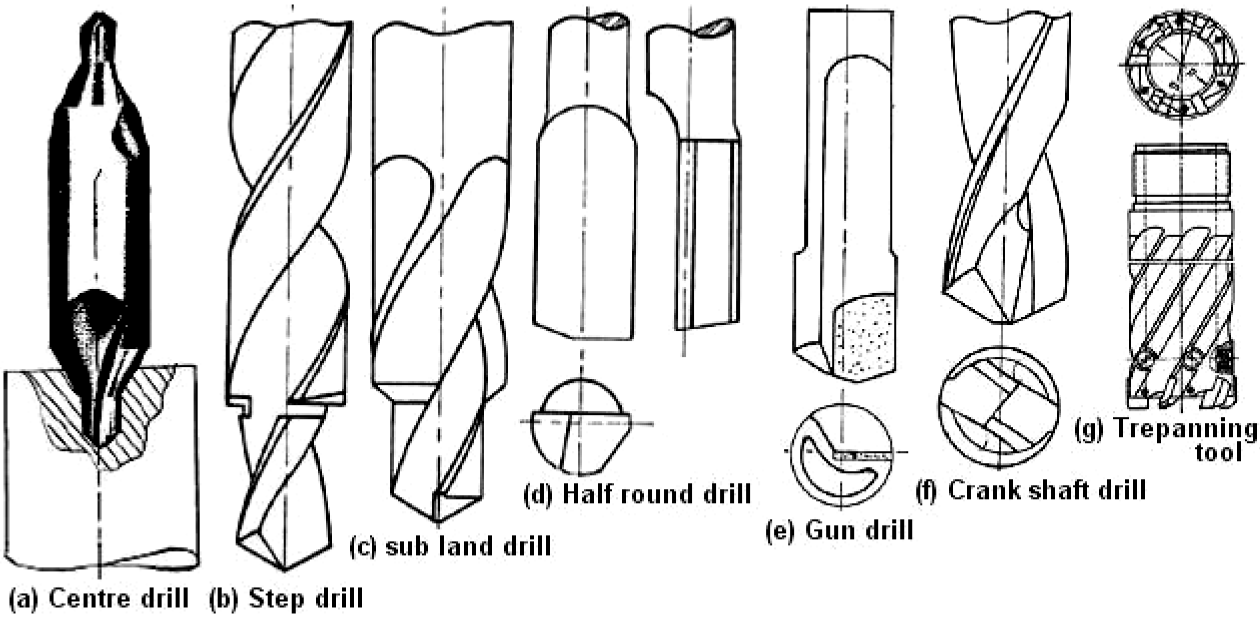


Fig. 3.126 Different types of drills used in various applications

3.10.5.1 Twist drill nomenclature

The following are the nomenclature, definitions and functions of the different parts of a drill illustrated in Fig. 3.127.

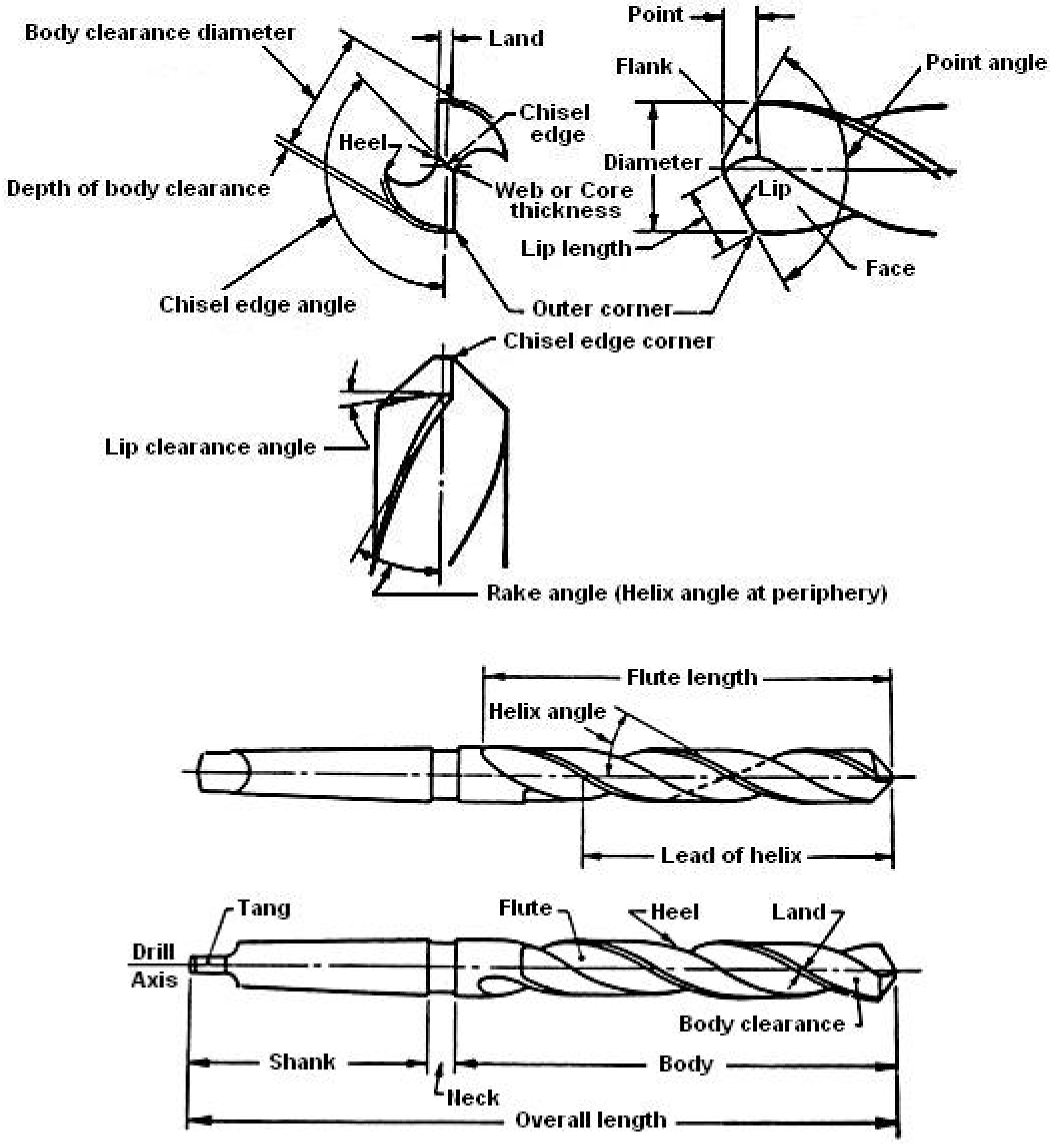


Fig. 3.127 Twist drill nomenclature

Twist drill elements

Axis	The longitudinal centre line of the drill.
Body	That portion of the drill extending from its extreme point to the commencement of the neck, if present, otherwise extending to the commencement of the shank.
Body clearance	That portion of the body surface which is reduced in diameter to provide diametral clearance.
Chisel edge	The edge formed by the intersection of the flanks. The chisel edge is also sometimes called dead centre.
Chisel edge corner	The corner formed by the intersection of a lip and the chisel edge.
Face	The portion of the flute surface adjacent to the lip on which the chip impinges as it is cut from the work.
Flank	That surface on a drill point which extends behind the lip to the following flute.
Flutes	The groove in the body of the drill which provides lip. *The functions of the flutes are:* ▪ To form the cutting edges. ▪ To allow the chips to escape. ▪ To cause the chips to curl. ▪ To permit the cutting fluid to reach the cutting edges.
Heel	The edge formed by the intersection of the flute surface and the body clearance.
Lands	The cylindrically ground surface on the leading edges of the drill flutes. The width of the land is measured at right angles to the flute helix.
Lip (cutting edge)	The edge formed by the intersections of the flank and face. *The requirements of the drill lip are:* ▪ Both lips should be at the same angle of inclination (59^0) with the drill axis. ▪ Both lips should be of equal length. ▪ Both lips should be provided with the correct clearance.
Neck	The diametrically undercut portion between the body and the shank of the drill. Diameter and other particulars of the drill are engraved at the neck.
Outer corner	The corner formed by the intersection of the flank and face.
Point	The sharpened end of the drill, which is shaped to produce lips, faces, flanks and chisel edge.
Shank	That part of the drill by which it is held and driven. The most common types of shank are the taper shank and the straight shank.
Tang	The flattened end of the taper shank intended to fit into a drift slot in the spindle, socket or drill holder. The tang ensures positive drive of the drill from the spindle.
Web	The central portion of the drill situated between the roots of the flutes and extending from the point toward the shank; the point end of the web or core forms the chisel edge.

Linear dimensions

Back taper (longitudinal clearance) It is the reduction in diameter of the drill from the point towards the shank. This permits all parts of the drill behind the point to clear and not rub against the sides of the hole being drilled. The taper varies from 1:4000 for small diameter drills to 1:700 for larger diameters.

Body clearance diameter The diameter over the surface of the drill body which is situated behind the lands.

Depth of body clearance The amount of radial reduction on each side to provide body clearance.

Diameter The measurement across the cylindrical lands at the outer corners of the drill.

Flute length The axial length from the extreme end of the point to the termination of the flute at the shank end of the body.

Lead of helix The distance measured parallel to the drill axis between the corresponding points on the leading edge of the flute in one complete turn of the flute.

Lip length The minimum distance between the outer corner and the chisel edge corner of the lip.

Overall length The length over the extreme ends of the point and the shank of the drill.

Web (core) taper The increase in the web or core thickness from the point of the drill to the shank end of the flute. This increasing thickness gives additional rigidity to the drill and reduces the cutting pressure at the point end.

Web thickness The minimum dimension of the web or core measured at the point end of the drill.

Drill angles

Chisel edge angle The obtuse angle included between the chisel edge and the lip as viewed from the end of the drill.

Helix angle or rake angle This is the angle formed by the leading edge of the land with a plane having the axis of the drill.

Point angle This is the angle included between the two lips.

Lip clearance angle The angle formed by the flank and a plane at right angles to the drill axis.

3.10.6 Drilling operations

The wide range of applications of drilling machines includes:

- Drilling machines are generally or mainly used to originate through or blind straight cylindrical holes in solid rigid bodies and/or enlarge (coaxially) existing holes:
  - Of different diameters up to 40 mm.
  - Of varying length depending upon the requirement and the diameter of the drill.
  - In different materials excepting very hard or very soft materials like rubber, polythene etc.
- Originating stepped cylindrical holes of different diameter and depth.
- Making rectangular section slots by using slot drills having 3 or 4 flutes and 180^0 cone angle.
- Boring, after drilling, for accuracy and finish or prior to reaming
- Counter boring, countersinking, chamfering or combination using suitable tools.
- Spot facing by flat end tools.
- Trepanning for making large through holes and or getting cylindrical solid core.

- If necessary Reaming is done on drilled or bored holes for accuracy and good surface finish. Different types of reamers of standard sizes are available for different applications.
- Also used for cutting internal threads in parts like nuts using suitable attachment.

The different operations that can be performed in a drilling machine are shown in Fig. 3.128.

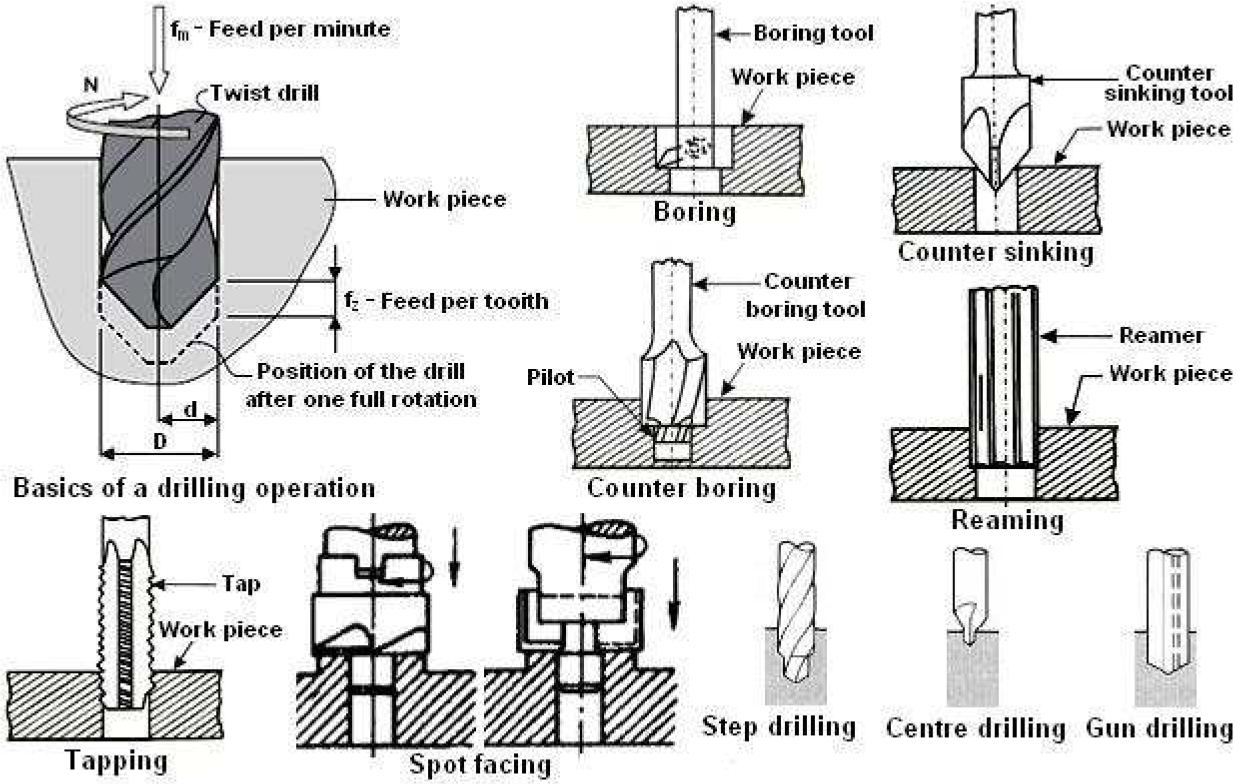


Fig. 3.128 Different operations performed in a drilling machine

3.11 REAMING

Reaming is an operation of finishing a hole previously drilled to give a good surface finish and an accurate dimension. A reamer is a multi tooth cutter which rotates and moves axially into the hole. The reamer removes relatively small amount of material. Generally the reamer follows the already existing hole and therefore will not be able to correct the hole misalignment. *Fig. 3.129 illustrates the elements of a reamer. Fig. 3.130 shows the different types of reamers of standard sizes.*

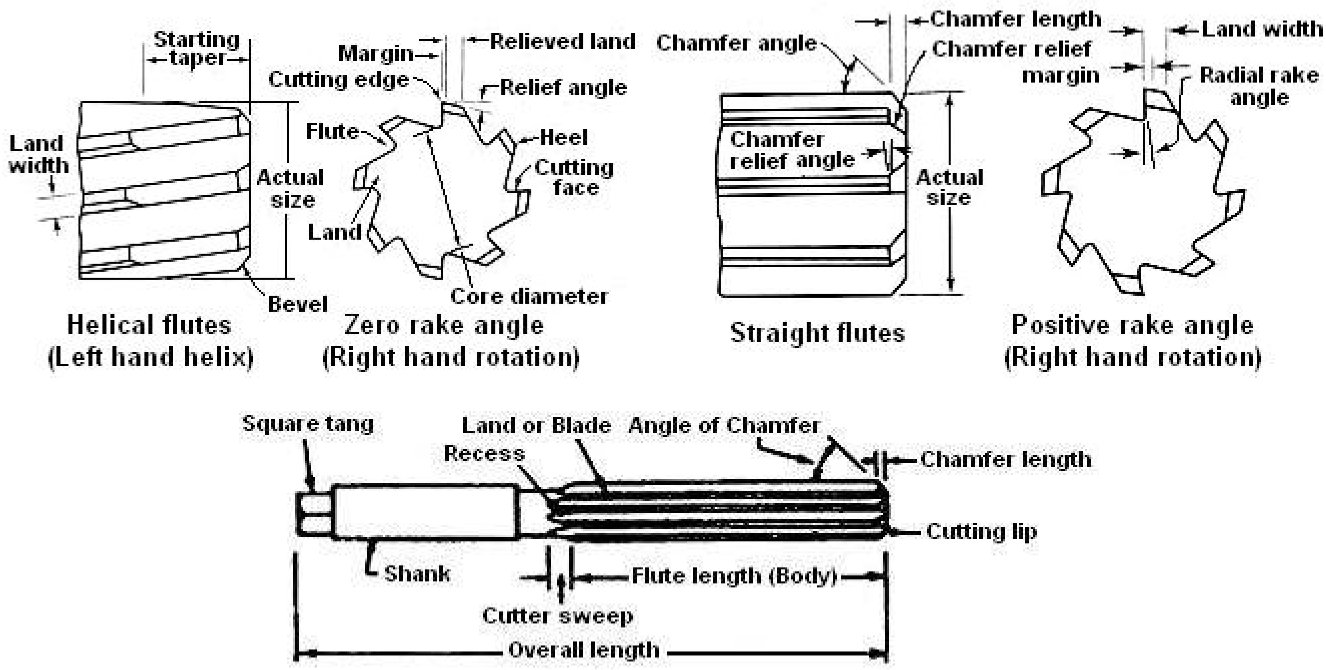


Fig. 3.129 Elements of a reamer

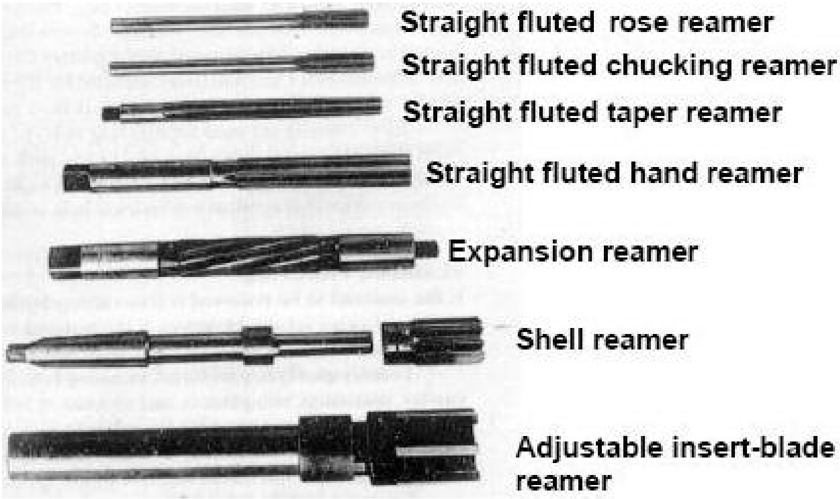


Fig. 3.130 Different types of reamers

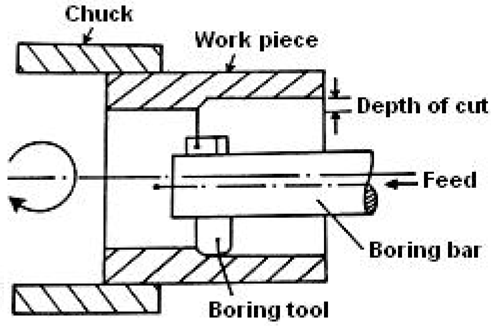


Fig. 3.131 Principle of boring operation

3.12 BORING

Boring is an operation of enlarging and locating previously drilled holes with a single point cutting tool. The machine used for this purpose is called boring machine. The boring machine is one of the most versatile machine tools used to bore holes in large and heavy parts such as engine frames, steam engine cylinders, machine housings etc. Drilling, milling and facing operations also can be performed in this machine. Screw cutting. Turning, planetary grinding and gear cutting operations also can be done by fitting simple attachments. *The principle of boring operation is illustrated in Fig. 3.131.*

3.12.1 Horizontal boring machines

In horizontal boring machine, the tool revolves and the work is stationary. A horizontal boring machine can perform boring, reaming, turning, threading, facing, milling, grooving, recessing and many other operations with suitable tools. Work pieces which are heavy, irregular, unsymmetrical or bulky can be conveniently held and machined. This machine has two vertical columns. A headstock slides up and down in one column. It may be adjusted to any desired height and clamped. The headstock holds the cutting tool. The cutting tool revolves in the headstock in horizontal axis. A sliding type bearing block is provided in the other vertical column. It is used to support the boring bar. The work piece is mounted on the table and is clamped with ordinary strap clamps, T-slot bolts and nuts, or it is held in a special fixture if so required. Various types of rotary and universal swiveling attachments can be installed on the horizontal boring machines table to bore holes at various angles in horizontal and vertical planes. *Fig. 3.132 schematically shows the basic configuration of a horizontal boring machine.*

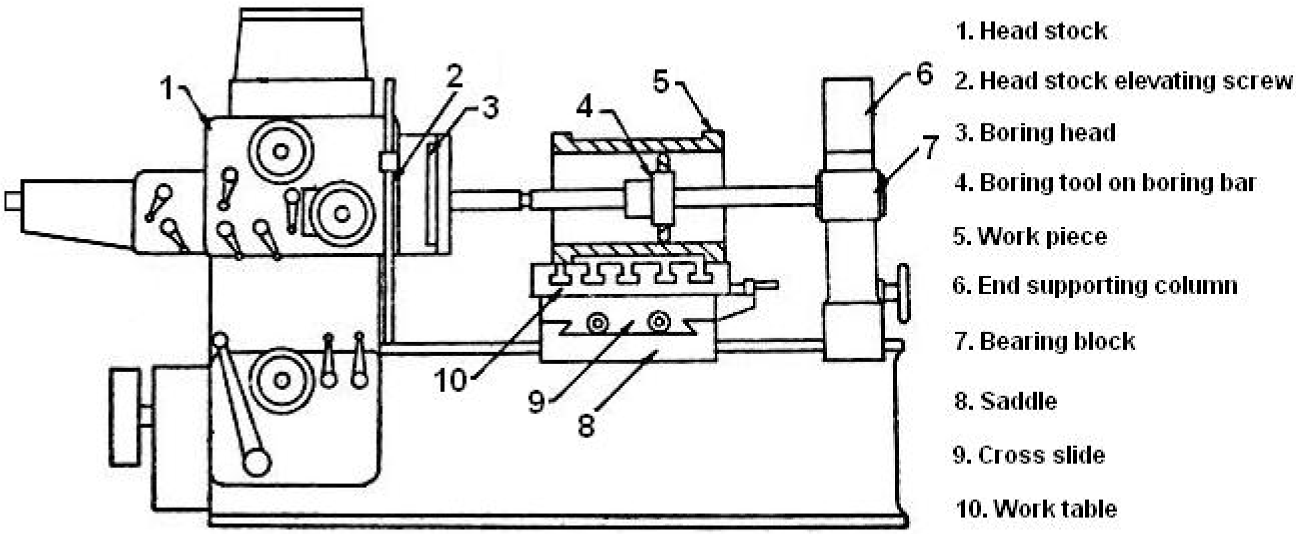


Fig. 3.132 Basic configuration of a horizontal boring machine

3.12.2 Types of horizontal boring machine

Different types of horizontal boring machines have been designed to suit different purposes. They are:

3.12.2.1 Table type horizontal boring machine

The work is held stationary on a coordinate work table having in and out as well as back and forth movements that is perpendicular and parallel to the spindle axis. The spindle carrying the tool can be fed axially. Alternatively, the table travels parallel to the spindle axis (longitudinal feed). This method of boring with longitudinal feed of the table is employed when holes are of considerable length and being bending of the boring bar is possible. *Fig. 3.133 shows the table type horizontal boring machine.*

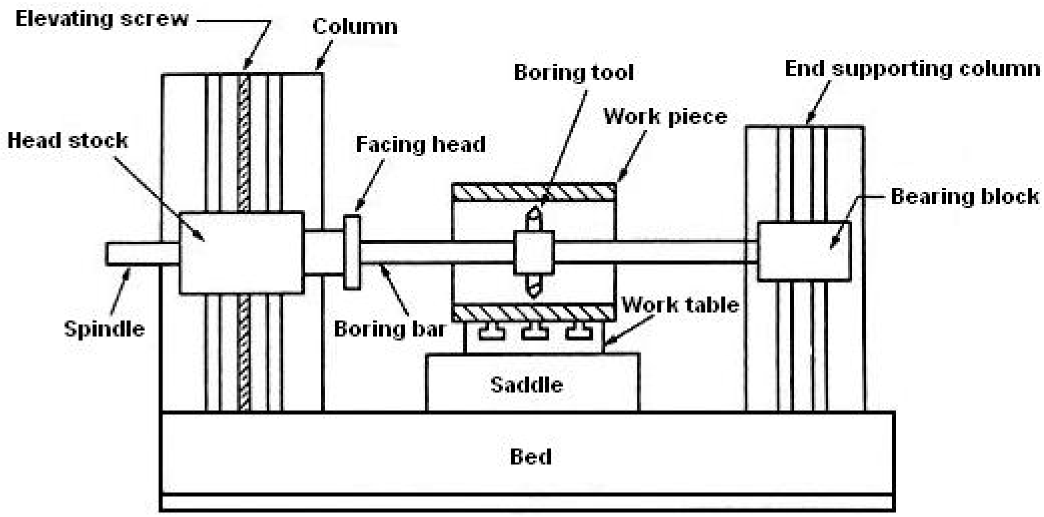


Fig. 3.133 Table type horizontal boring machine

3.12.2.2 Planer type horizontal boring machine

This machine is similar to the table type horizontal boring machine except that the work table has only in and out movements that is perpendicular to the spindle axis. Other features and applications of this machine are similar to the table type horizontal boring machine. This type of machine is suitable for supporting a long work. *Fig. 3.134 shows the planer type horizontal boring machine.*

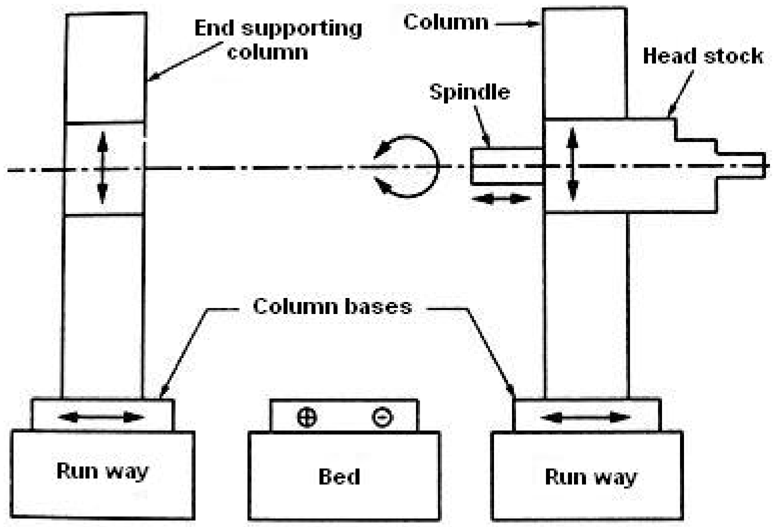


Fig. 3.134 Planer type horizontal boring machine

3.12.2.3 Floor type horizontal boring machine

Here, there is no work table and the job is mounted on a stationary T-slotted floor plate. This design is used when large and heavy jobs can not be mounted and adjusted on the work table. Horizontal movement perpendicular to the spindle axis is obtained by traversing the column carrying the head stock, on guide ways. *Fig. 3.135 shows the floor type horizontal boring machine.*

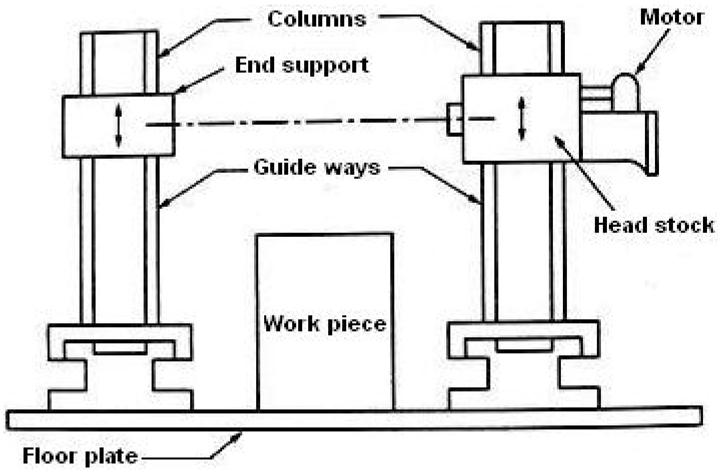


Fig. 3.135 Floor type horizontal boring machine

3.12.2.4 Multiple head type horizontal boring machine

The machine resembles a double housing planer or a Plano-miller and is used for boring holes of large diameter is mass production. The machine may have two, three or four headstocks. This type of machine may be used both as a horizontal and vertical machine. *Fig. 3.136 shows the multiple head type horizontal boring machine.*

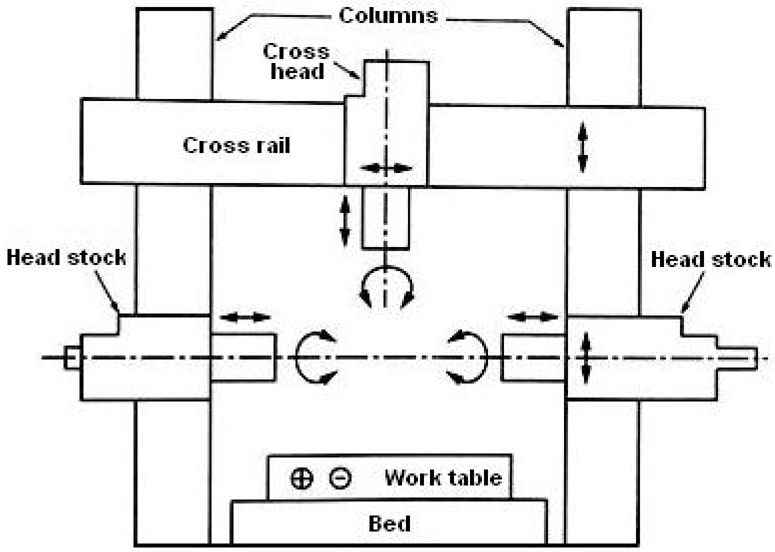


Fig. 3.136 Multiple head type horizontal boring machine

3.12.3 Vertical boring machines

For convenience, parts whose length or height is less than the diameter are machined on vertical boring machines. The typical works are: Large gear blanks, locomotive and rolling stock tires, fly wheels, large flanges, steam and water turbine castings etc. On a vertical boring machine, the work is fastened on a horizontal revolving table, and the cutting tool(s) which are stationary, advance vertically into it are as the table revolves.

There are two types of vertical boring machine: Single column vertical boring machine and double column vertical boring machine. The single column vertical boring machine looks like a drilling machine or a knee type vertical milling machine. Guide ways are employed on the column to support the spindle head in the vertical direction. *A double column vertical boring machine is shown in Fig. 3.137.* The work is accommodated on the horizontal revolving table at the front of the machine. The circular work can be clamped on to the table with the help of jaw chucks whereas the T-slots can be used with bolts and clamps for setting up and holding irregular work. A horizontal cross rail is carried on vertical slideways and carries the tool holder slide(s). On machines designed for working on large batches of identical parts, a single slide with turret may be employed. *Fig. 3.138 shows the turret boring machine.*

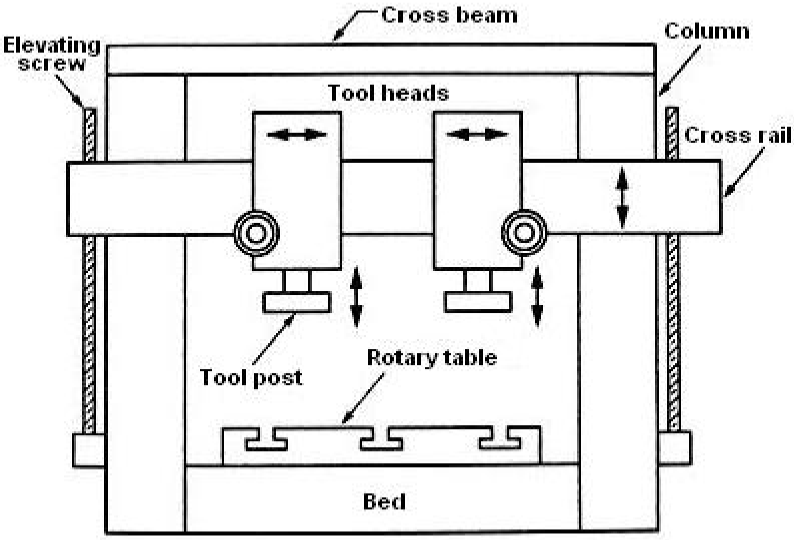


Fig. 3.137 Double column vertical boring machine

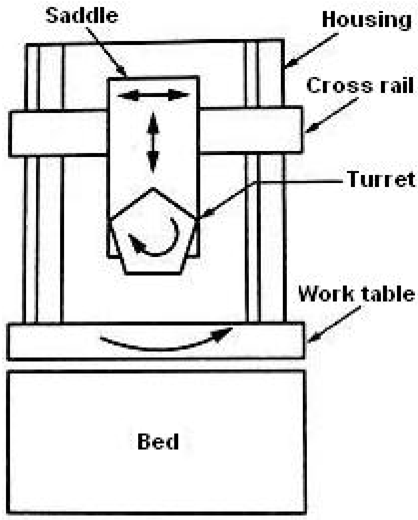


Fig. 3.138 Turret boring machine

3.12.4 Jig borers or jig boring machines

It is very precise vertical type boring machine. The spindle and spindle bearings are constructed with very high precision. The table can be moved precisely in two mutually perpendicular directions in a plane normal to the spindle axis. The coordinate method for locating holes is employed. Holes can be located to within tolerances of 0.0025 mm. Jig boring machines are relatively costlier. Hence, they are found only in the large machine shops, where a sufficient amount of accurate hole locating is done. Jig boring machines are basically designed for use in the making jigs, fixtures and other special tooling. *Fig. 3.139 shows the block diagram of a jig boring machine.*

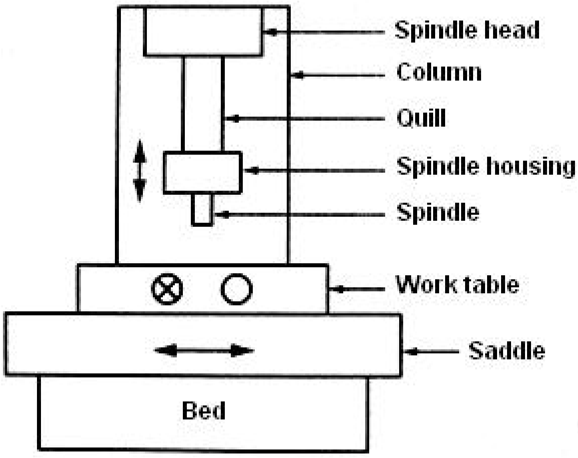


Fig. 3.139 Block diagram of a jig boring machine

3.12.5 Boring tools

A boring tool consists of a single point cutting tool (boring bit) held in a tool holder known as boring bar. The boring bit is held in a cross hole at the end of the boring bar. The boring bit is adjusted and held in position with the help of set screws. The material of the boring bit can be: Solid HSS, solid carbide, brazed carbide, disposable carbide tips or diamond tips. Boring tools are of two types: fixed type and rotating type. Fixed type boring tools are used on working rotating machines such as lathes, whereas rotating type boring tools are used on tool rotating machines such as drilling machines, milling machines and boring machines. *Fig. 3.140 shows the different types of boring tools (bars).*

3.13 TAPPING

Tapping is the faster way of producing internal threads. A tap is a multi fluted cutting tool with cutting edges on each blade resembling the shape of threads to be cut. A tap is used after carrying out the pre drilling operation corresponding to the required size. *Fig. 3.141 shows the hand (solid) taps. Fig. 3.142 shows the elements of a solid tap.*

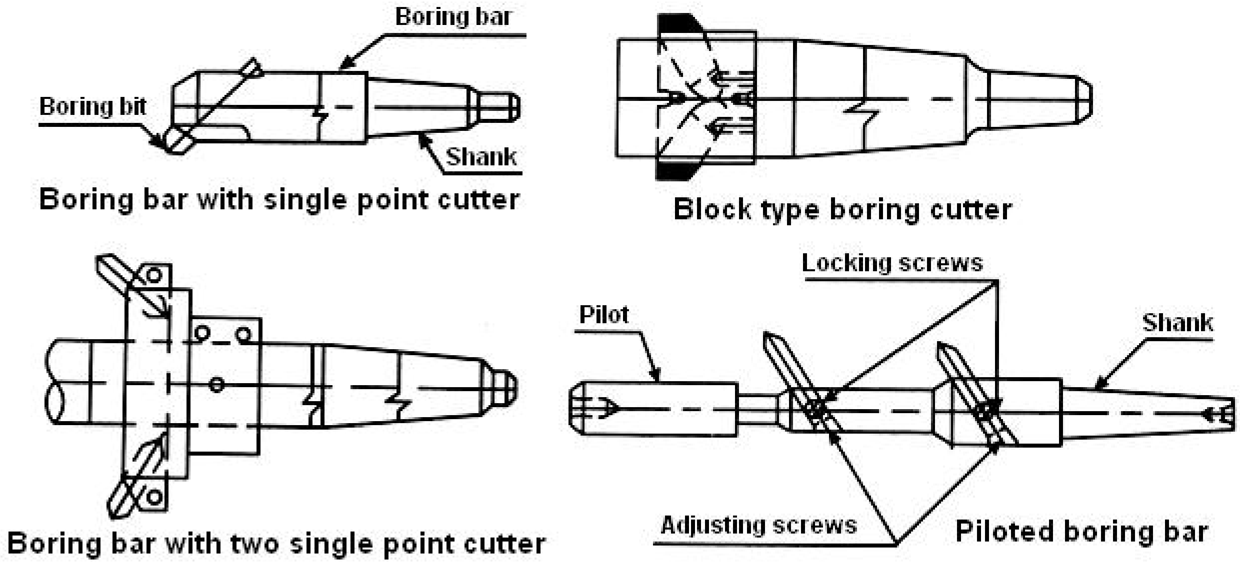


Fig. 3.140 Different types of boring tools (bars)

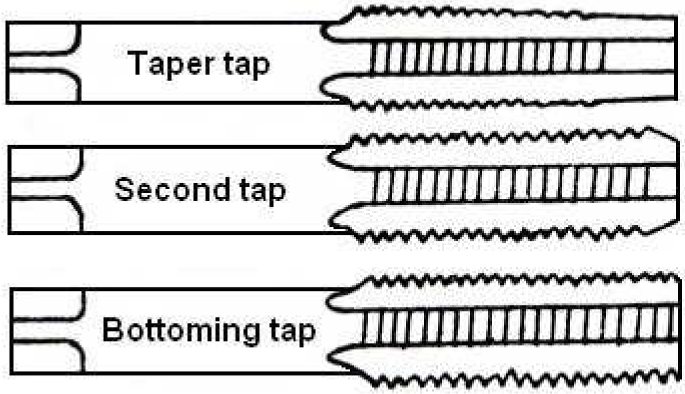


Fig. 3.141 Hand (solid) taps

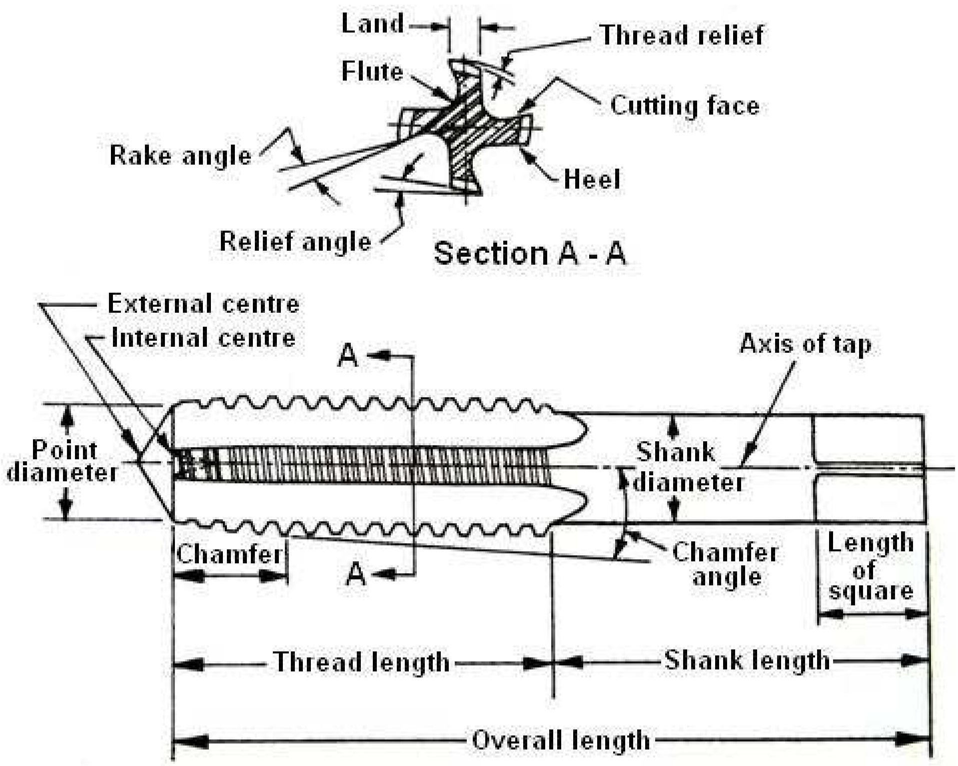


Fig. 3.142 Elements of a solid tap

UNIT - IV

ABRASIVE PROCESS, SAWING, BROACHING & GEAR CUTTING

4.1 ABRASIVE PROCESSES: GRINDING

Grinding is the most common form of abrasive machining. The art of grinding goes back many centuries. Over 5000 years ago the Egyptians abraded and polished building stones to hairline fits for the pyramids. Grinding is a metal cutting process which engages an abrasive tool whose cutting elements are grains of abrasive material known as grit. These grits are characterized by sharp cutting points, high hot hardness, wear resistance and chemical stability. The grits are held together by a suitable bonding material to give shape of an abrasive tool. Simply it is a metal removal process in which the metal is removed with the help of rotating grinding wheel. *Fig. 4.1 illustrates the cutting action of abrasive grits of disc type grinding wheel similar to cutting action of teeth of the cutter in slab milling.*

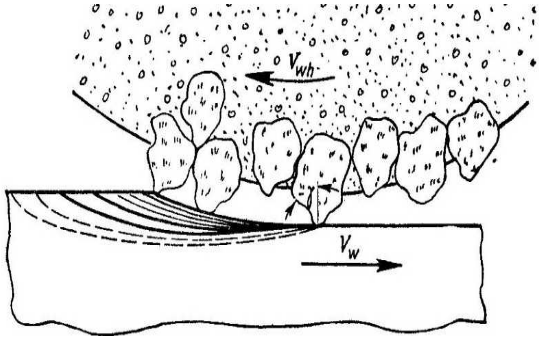


Fig. 4.1 Cutting action of abrasive grains

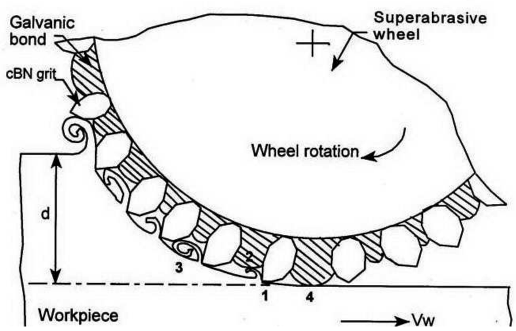


Fig. 4.2 Grinding wheel and work piece interaction

4.1.1 Applications of grinding

- To remove small amount of metal from work pieces and finish then to close tolerances.
- To obtain a better surface finish.
- To machine hard surfaces that cannot be machined by high-speed steels.
- Grinding of tools and cutters and resharpening of the same.
- Grinding of threads.
- Stock removal (abrasive milling) finishing of flat as well as cylindrical surface.
- Slitting and parting.
- Descaling and deburring.

4.1.2 Advantages of grinding

- Dimensional accuracy and good surface finish.
- Good form and locational accuracy.
- Applicable to both hardened and unhardened material.

4.2 GRINDING WHEELS

Grinding wheel consists of hard abrasive grains called grits, which perform the cutting or material removal, held in the weak bonding matrix. A grinding wheel commonly identified by the type of the abrasive material used. The conventional wheels include Aluminium Oxide (Al_2O_3) and Silicon Carbide (SiC) wheels while diamond and CBN (Cubic Boron Nitride) wheels fall in the category of super abrasive wheel. Thus, it forms a multi-edge cutter.

4.2.1 Grinding wheel and work piece interaction

The bulk grinding wheel-work piece interaction as illustrated in Fig. 4.2 can be divided into the following:

1. Grit-work piece (forming chip).
2. Chip-bond.
3. Chip-work piece.
4. Bond-work piece.

Except the grit-work piece interaction which is expected to produce chip, the remaining three undesirably increases the total grinding force and power requirement. Therefore, efforts should always be made to maximize grit-work piece interaction leading to chip formation and to minimize the rest for best utilization of the available power.

4.2.2 Interaction of grit with the work piece

The importance of the grit shape can be easily realized because it determines the grit geometry e.g. rake and clearance angle as illustrated in Fig. 4.3. It appears that the grits do not have definite geometry unlike a cutting tool and the grit rake angle may vary from $+45^0$ to -60^0 or more.

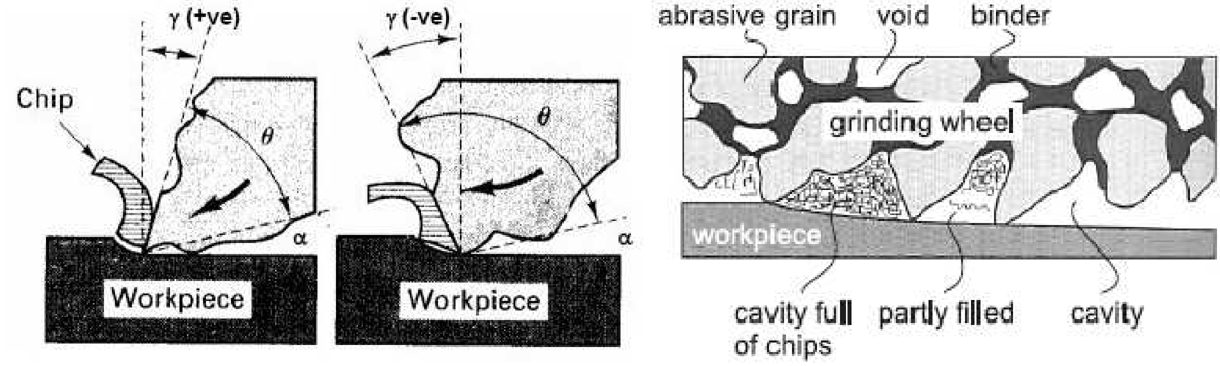


Fig. 4.3 Variation in rake angle with grits of different shape

Grit with favorable geometry can produce chip in shear mode. However, grits having large negative rake angle or rounded cutting edge do not form chips but may rub or make a groove by ploughing leading to lateral flow of the work piece material as illustrated in Fig. 4.4

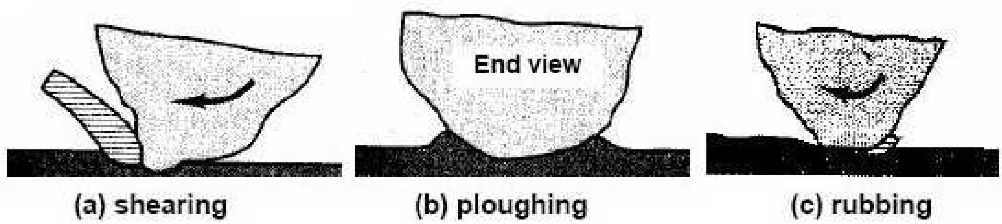


Fig. 4.4 Grits engage shearing, ploughing and rubbing

4.2.3 Reconditioning of grinding wheel

4.2.3.1 Truing of grinding wheel

Truing is the act of regenerating the required geometry on the grinding wheel, whether the geometry is a special form or flat profile. Therefore, truing produces the macro-geometry of the grinding wheel.

Truing is also required on a new conventional wheel to ensure concentricity with specific mounting system. In practice the effective macro-geometry of a grinding wheel is of vital importance and accuracy of the finished work piece is directly related to effective wheel geometry.

Truing tools

There are four major types of truing tools:

- Steel cutter: These are used to roughly true coarse grit conventional abrasive wheel to ensure freeness of cut.
- Steel or carbide crash roll: It is used to crush-true the profile on vitrified bond grinding wheel.

- Vitrified abrasive stick and wheel: It is used for off hand truing of conventional abrasive wheel. These are used for truing resin bonded super abrasive wheel.
- Diamond truing tool:
    - Single point diamond truing tools. [shown in Fig. 4.5]
    - Multi stone diamond truing tools. [shown in Fig. 4.6]
    - Impregnated diamond truing tools. [shown in Fig. 4.7]
    - Rotary powered diamond truing wheels. [shown in Fig. 4.8]
    - Surface set truing wheels.
    - Impregnated truing wheels.
    - Electroplated truing tools.
    - Diamond form truing blocks. [shown in Fig. 4.9]

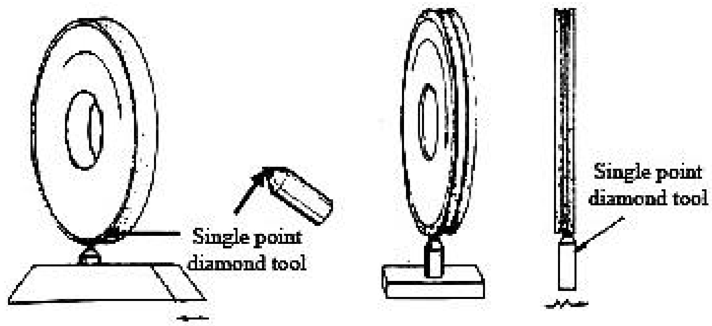
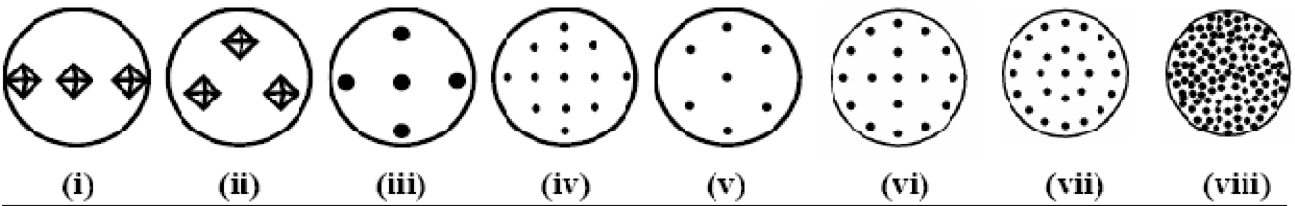


Fig. 4.5 Application of single point diamond truing tool



Distribution of diamond	Diamond weight (carat)	Distribution of diamond	Diamond weight (carat)
(i) 1 layer – 3 stone	10	(v) 5 layer – 7 stone	50
(ii) 2 layer – 3 stone	10	(vi) 5 layer – 17 stone	10
(iii) 3 layer – 5 stone	10	(vii) 5 layer – 25 stone	250
(iv) 5 layer – 13 stone	25	(viii) throughout	50

Fig. 4.6 Distribution pattern of diamond particles in multi-stone diamond truing tools

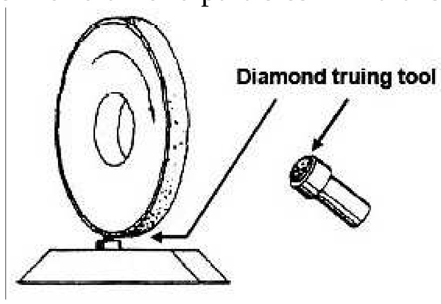


Fig. 4.7 Impregnated diamond truing tools

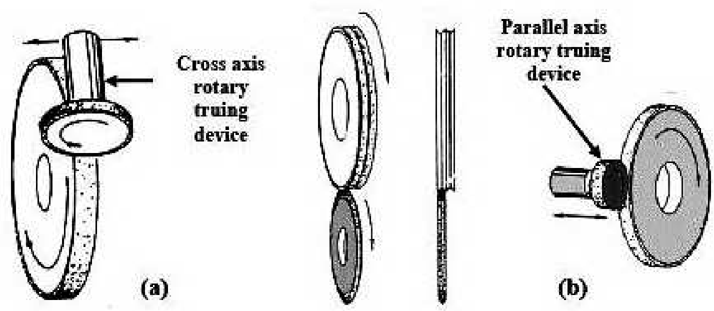


Fig. 4.8 Rotary power truing wheel being used in (a) cross-axis (b) parallel-axis

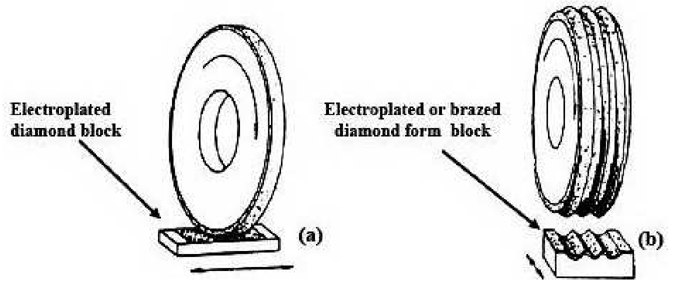


Fig. 4.9 Diamond form truing block to true (a) a straight faced wheel (b) a form wheel

4.2.3.2 Dressing of grinding wheel

Dressing is the conditioning of the wheel surface which ensures that grit cutting edges are exposed from the bond and thus able to penetrate into the work piece material. Also, in dressing attempts are made to splinter the abrasive grains to make them sharp and free cutting and also to remove any residue left by material being ground. Dressing therefore produces micro-geometry. The structure of micro-geometry of grinding wheel determines its cutting ability with a wheel of given composition. Dressing can substantially influence the condition of the grinding tool.

Truing and dressing are commonly combined into one operation for conventional abrasive grinding wheels, but are usually two distinctly separate operation for super abrasive wheel.

Dressing of super abrasive wheel

Dressing of the super abrasive wheel is commonly done with soft conventional abrasive vitrified stick, which relieves the bond without affecting the super abrasive grits. However, modern technique like electrochemical dressing has been successfully used in metal bonded super abrasive wheel. The wheel acts like an anode while a cathode plate is placed in front of the wheel working surface to allow electrochemical dissolution.

Electro discharge dressing is another alternative route for dressing metal bonded super abrasive wheel. In this case a dielectric medium is used in place of an electrolyte. Touch-dressing, a new concept differs from conventional dressing in that bond material is not relieved. In contrast the dressing depth is precisely controlled in micron level to obtain better uniformity of grit height resulting in improvement of work piece surface finish.

4.3 SPECIFICATION OF GRINDING WHEEL

A grinding wheel requires two types of specification:

1. Geometrical specification. 2. Compositional specification.

4.3.1 Geometrical specification

This is decided by the type of grinding machine and the grinding operation to be performed in the work piece. This specification mainly includes wheel diameter, width and depth of rim and the bore diameter. The wheel diameter, for example can be as high as 400mm in high efficiency grinding or as small as less than 1mm in internal grinding. Similarly, width of the wheel may be less than an mm in dicing and slicing applications. Standard wheel configurations for conventional and super abrasive grinding wheels are shown in Fig. 4.10 and Fig. 4.11.

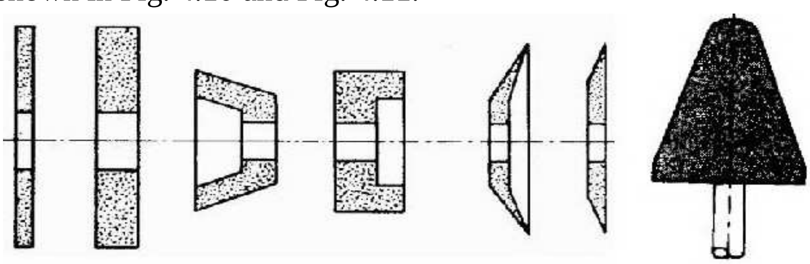


Fig. 4.10 Standard wheel configuration for conventional grinding wheels

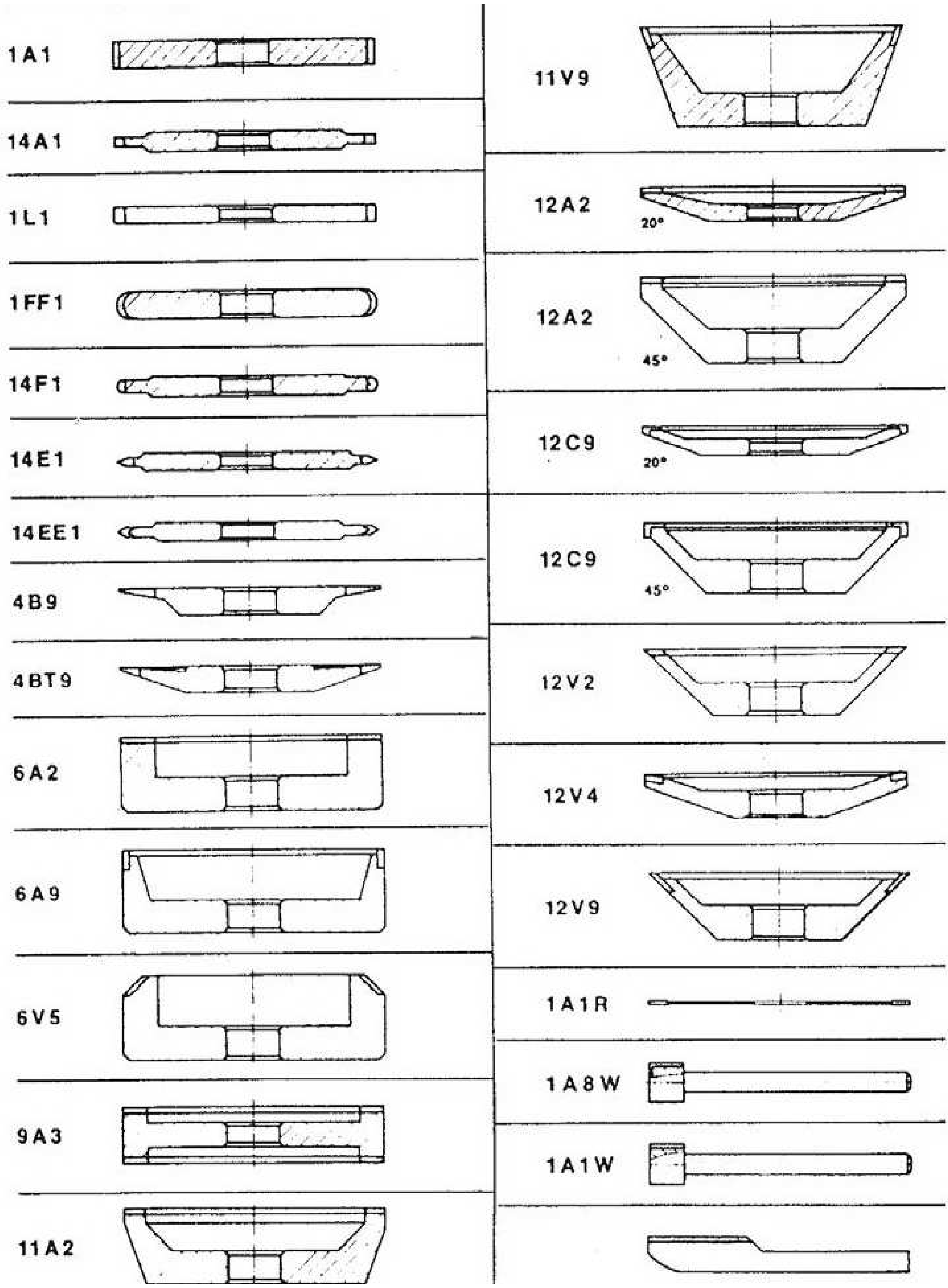


Fig. 4.11 Standard wheel configuration for super abrasive wheel

4.3.2 Compositional specifications

Specification of a grinding wheel ordinarily means compositional specification. Conventional abrasive grinding wheels are specified encompassing the following parameters.

- The type of grit material.
- The grit size.
- The bond strength of the wheel, commonly known as wheel hardness.
- The structures of the wheel denoting the porosity i.e. the amount of inter grit spacing.
- The type of bond material.
- Other than these parameters, the wheel manufacturer may add their own identification code prefixing or suffixing (or both) the standard code.

4.3.2.1 Marking system for conventional grinding wheel

The standard marking system for conventional abrasive wheel can be as follows:

51 A 60 K 5 V 05

where

- The number '51' is manufacturer's identification number indicating exact kind of abrasive used.
- The letter 'A' denotes that the type of abrasive is Aluminium Oxide (Al_2O_3). In case of Silicon Carbide (SiC) the letter 'C' is used.
- The number '60' specifies the average grit size in inch mesh. For a very large size grit this number may be as small as 6 where as for a very fine grit the number may be as high as 600.
- The letter 'K' denotes the hardness of the wheel. The letter symbol can range between 'A' and 'Z', 'A' denoting the softest grade and 'Z' denoting the hardest one.
- The number '5' denotes the structure or porosity of the wheel. This number can assume any value between 1 to 20, '1' indicating high porosity and '20' indicating low porosity.
- The letter code 'V' means that the bond material used is vitrified.
- The number '05' is a wheel manufacturer's identifier.

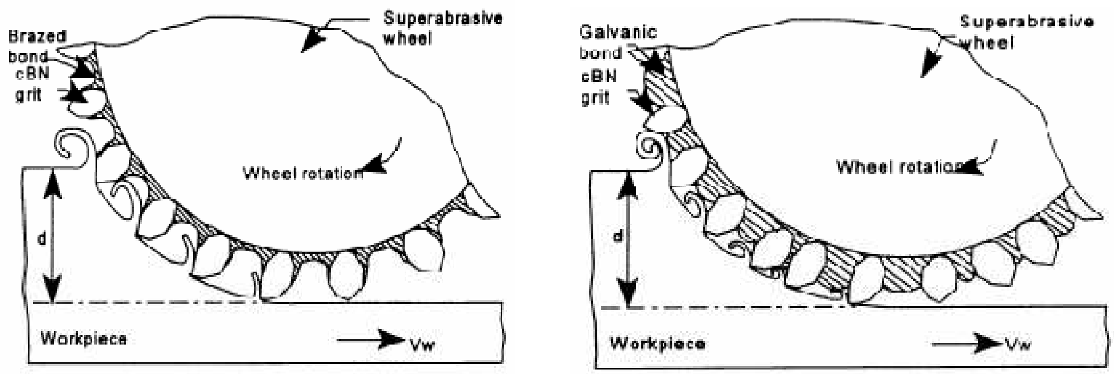
4.3.2.2 Marking system for super abrasive grinding wheel

Marking system for super abrasive grinding wheel is somewhat different as illustrated below:

R D 120 N 100 M 4

where

- The letter 'R' is manufacture's code indicating the exact type of super abrasive used.
- The letter 'D' denotes that the type of abrasive is Diamond. In case of Cubic Boron Nitride (CBN) the letter 'B' is used.
- The number '120' specifies the average grain size in inch mesh. However, a two number designation (e.g. 120/140) is utilized for controlling the size of super abrasive grit.
- Like conventional abrasive wheel, the letter 'N' denotes the hardness of the wheel. However, resin and metal bonded wheels are produced with almost no porosity and effective grade of the wheel is obtained by modifying the bond formulation.
- The number '100' is known as concentration number indicating the amount of abrasive contained in the wheel. The number '100' corresponds to an abrasive content of 4.4 carats/cm3. For diamond grit, '100' concentration is 25% by volume. For CBN the corresponding volumetric concentration is 24%.
- The letter 'M' denotes that the type of bond is metallic. The other types of bonds used in super abrasive wheels are resin, vitrified or metal bond, which make a composite structure with the grit material. However, another type of super abrasive wheel with both diamond and CBN is also manufactured where a single layer of super abrasive grits are bonded on a metal perform by a galvanic metal layer or a brazed metal layer as illustrated in Fig. 4.12.



Brazed type wheel Galvanic type wheel

Fig. 4.12 Comparison of brazed type and galvanic type bonded single layer CBN grinding wheel

4.3.2.3 Indian standard marking system

W A 36 K 5 R 17

Where

W	-	Manufacture's symbol indicating exact kind of abrasive, (optional use).
A	-	Abrasive type: A for Al_2O_3, C for SiC, D for Diamond.
36	-	Grain size.
K	-	Grade.
5	-	Structure.
R	-	Bond type.
17	-	Private marking to identify the wheel, (optional use).

4.4 SELECTION OF GRINDING WHEEL

Selection of a proper grinding wheel is very important for getting the best results in grinding work. *The selection will depend upon the following factors:*

1. Constant factors

a. Physical and chemical properties of material to be ground. b. Area of contact.
c. Amount and rate of stock to be removed. d. Types of grinding machine.

2. Variable factors

a. Work speed. b. Wheel speed. c. Condition of the grinding machine.
d. Personal factor. e. Type of grinding (stock removal grinding or form finish grinding).

4.4.1 Types of abrasives

Abrasives may be classified into two types:

1. ***Natural abrasives*** - Emery (50 - 60 % crystalline Al_2O_3 + Iron Oxide), Sandstone or Solid Quartz, Corundum (75 - 90 % crystalline Al_2O_3 + Iron Oxide) and Diamond.

2. ***Artificial abrasives*** - Aluminium Oxide (Al_2O_3), Silicon Carbide (SiC), Artificial diamond, Boron Carbide and Cubic Boron Nitride (CBN).

The abrasives that are generally used are

1. Aluminium Oxide. (Al_2O_3)
2. Silicon Carbide. (SiC)
3. Diamond.
4. Cubic Boron Nitride. (CBN)

1. Aluminium oxide (Al_2O_3)

Aluminium oxide may have variation in properties arising out of differences in chemical composition and structure associated with the manufacturing process. Pure Al_2O_3 grit with defect structure like voids leads to unusually sharp free cutting action with low strength and is advantageous in fine tool grinding operation, and heat sensitive operations on hard, ferrous materials. Regular or brown aluminium oxide (doped with TiO_2) possesses lower hardness and higher toughness than the white Al_2O_3 and is recommended heavy duty grinding to semi finishing. Al_2O_3 alloyed with chromium oxide (<3%) is pink in colour. Monocrystalline Al_2O_3 grits make a balance between hardness and toughness and are efficient in medium pressure heat sensitive operation on ferrous materials.

Microcrystalline Al_2O_3 grits of enhanced toughness are practically suitable for stock removal grinding. Al_2O_3 alloyed with zirconia also makes extremely tough grit mostly suitably for high pressure, high material removal grinding on ferrous material and are not recommended for precision grinding. Microcrystalline sintered Al_2O_3 grit is the latest development particularly known for its toughness and self sharpening characteristics. *Trade names: Alundum, Aloxide, corundum, emery, etc.*

2. Silicon carbide (SiC)

Silicon carbide is harder than alumina but less tough. Silicon carbide is also inferior to Al2O3 because of its chemical reactivity with iron and steel. Black carbide containing at least 95% SiC is less hard but tougher than green SiC and is efficient for grinding soft nonferrous materials. Green silicon carbide contains at least 97% SiC. It is harder than black variety and is used for grinding cemented carbide. *Trade names: Carborundum, Crystolon, Electrolon, etc.*

3. Diamond

Diamond grit is best suited for grinding cemented carbides, glass, sapphire, stone, granite, marble, concrete, oxide, non-oxide ceramic, fiber reinforced plastics, ferrite, graphite. Natural diamond grit is characterized by its random shape, very sharp cutting edge and free cutting action and is exclusively used in metallic, electroplated and brazed bond.

Monocrystalline diamond grits are known for their strength and designed for particularly demanding application. These are also used in metallic, galvanic and brazed bond. Polycrystalline diamond grits are more friable than monocrystalline one and found to be most suitable for grinding of cemented carbide with low pressure. These grits are used in resin bond.

4. Cubic Boron Nitride (CBN)

Diamond though hardest is not suitable for grinding ferrous materials because of its reactivity. In contrast, CBN the second hardest material, because of its chemical stability is the abrasive material of choice for efficient grinding of HSS, alloy steels, HSTR alloys.

Presently CBN grits are available as monocrystalline type with medium strength and blocky monocrystals with much higher strength. Medium strength crystals are more friable and used in resin bond for those applications where grinding force is not so high. High strength crystals are used with vitrified, electroplated or brazed bond where large grinding force is expected.

Microcrystalline CBN is known for its highest toughness and auto sharpening character and found to be best candidate for HEDG and abrasive milling. It can be used in all types of bond.

4.4.2 Grit size or grain size

It refers to the actual size of the abrasive particles. The grain size is denoted by the number. *Table 4.1 shows the different types of grit or grain sizes and their corresponding numbers.*

Table 4.1

Grinding operation	Grit or Grain size						
Coarse	10	12	14	16	20	24	
Medium	30	36	46	54	60		
Fine	80	100	120	150	180		
Very fine	220	240	280	320	400	500	600

The grain size affects material removal rate and the surface quality of work piece in grinding.

- Large grit : Big grinding capacity, rough work piece surface.
- Fine grit : Small grinding capacity, smooth work piece surface.

4.4.3 Grade

Grade or hardness indicates the strength with which the bonding material holds the abrasive grains in the grinding wheel. This means the amount of force required to pull out a single bonded abrasive grit by bond fracture. *It does not refer to the hardness of the abrasive grain.* The worn out grit must pull out from the bond and make room for fresh sharp grit in order to avoid excessive rise of grinding force and temperature.

Therefore, a soft grade should be chosen for grinding hard material. On the other hand, during grinding of low strength soft material grit does not wear out so quickly. Therefore, the grit can be held with strong bond so that premature grit dislodgement can be avoided.

Table 4.2 shows the different grades of grinding wheels and their corresponding letter symbols.

Table 4.2 Different grades of grinding wheels

Soft	A	B	C	D	E	F	G	H		
Medium	I	J	K	L	M	N	O	P		
Hard	Q	R	S	T	U	V	W	X	Y	Z

4.4.4 Structure / Concentration of wheels

This term denotes the spacing between the abrasive grains or in other words the density of the wheel. Structure of the grinding wheel is designated by a number.

Table 4.3 shows the two types of structure with their numbers.

Table 4.3 Two types of structure with their numbers

Structure	**Symbol**							
Dense	1	2	3	4	5	6	7	8
Open	9	10	11	12	13	14	15	or more

The structure should be open for grinding wheels engaged in high material removal to provide chip accommodation space. The space between the grits also serves as pocket for holding grinding fluid. On the other hand dense structured wheels are used for longer wheel life, for holding precision forms and profiles.

4.4.5 Bond

It is an adhesive substance which holds the abrasive grains together to form the grinding wheel.

Types of bonds *- Bonds are classified into two types:*

1. Organic - Resinoid, Rubber, Shellac & Oxychloride
2. Non - Organic - Metallic, Vitrified & Silicate

Vitrified bond (V)

Vitrified bond is suitable for high stock removal even at dry condition. It can also be safely used in wet grinding. It can not be used where mechanical impact or thermal variations are like to occur. This bond is also not recommended for very high speed grinding because of possible breakage of the bond under centrifugal force.

Rubber bond (R)

Its principal use is in thin wheels for wet cut-off operation. Rubber bond was once popular for finish grinding on bearings and cutting tools.

Silicate bond (S)

Silicate wheels are made by mixing abrasive grains with silicate of soda. The mixture is moulded in a mould and dried for several hours. After drying, the moulded material is kept in a furnace at about 260^0 C for 20 to 80 hours. Silicate bonded wheels are light grey in colour. These wheels are having a fairly high tensile strength.

Metal bond (M)

Metal bond is extensively used with super abrasive wheels. Extremely high toughness of metal bonded wheels makes these very effective in those applications where form accuracy as well as large stock removal is desired.

Shellac bond (E)

Shellac bonded grinding wheels are relatively strong but not rigid. At one time this bond was used for flexible cut off wheels. At present use of shellac bond is limited to grinding wheels engaged in fine finish of rolls.

Oxychloride bond (O)

It is less common type bond, but still can be used in disc grinding operation. It is used under dry condition. It is produced by mixing abrasive grains with oxide and chloride of magnesium.

Resinoid bond (B)

Conventional abrasive resin bonded wheels are widely used for heavy duty grinding because of their ability to withstand shock load. This bond is also known for its vibration absorbing characteristics and finds its use with diamond and CBN in grinding of cemented carbide and steel respectively.

Resin bond is not recommended with alkaline grinding fluid for a possible chemical attack leading to bond weakening. Fiberglass reinforced resin bond is used with cut off wheels which requires added strength under high speed operation.

Electroplated bond

This bond allows large (30-40%) crystal exposure above the bond without need of any truing or dressing. This bond is specially used for making small diameter wheel, form wheel and thin super abrasive wheels. Presently it is the only bond for making wheels for abrasive milling and ultra high speed grinding.

Brazed bond

This is relatively a recent development, allows crystal exposure as high 60-80%. In addition grit spacing can be precisely controlled. This bond is particularly suitable for very high material removal either with diamond or CBN wheel. The bond strength is much greater than provided by electroplated bond. This bond is expected to replace electroplated bond in many applications.

4.5 TYPES OF GRINDING PROCESS

Grinding processes are generally classified based on the type of surface produced. *They are:*

1. Cylindrical grinding process. [shown in Fig. 4. 13 (a)]
2. Surface grinding process. [shown in Fig. 4. 13 (b)]
3. Centreless grinding process. [shown in Fig 4.13 (c)]

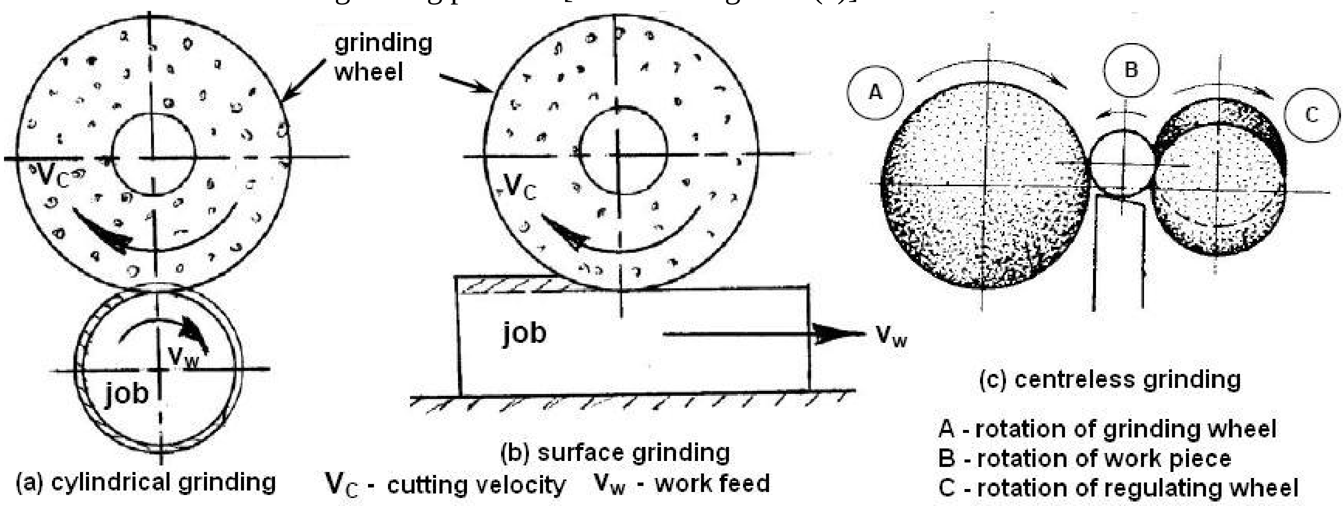


Fig. 4.13 Schematic illustration of (a) Cylindrical grinding process
(b) Surface grinding process and (c) Centreless grinding process

4.6 CYLINDRICAL GRINDING PROCESS

It is used generally for producing external cylindrical surfaces. The machine is very similar to a centre lathe. The grinding wheel is located similar to the tool post with an independent power and is driven at a high speed suitable for the grinding operation. *There are four movements in a cylindrical grinding process.*

i. Rotation of cylindrical work piece about its axis.
ii. Rotation of grinding wheel about its axis.
iii. Longitudinal feed movement of the work past the wheel face.
iv. Movement of wheel into the work perpendicular to the axis of the work to give depth of cut.

The work which is normally held between the centres is rotated at a much lower speed in a direction opposite to that of the grinding wheel. The table assembly which houses the centres can be reciprocated to provide the necessary traverse feed of the work piece past the grinding wheel. The infeed is provided by the movement of the grinding wheel head into the work piece. Typical grinding allowances left are about 0.1 to 0.3mm. Beyond this the grinding operation becomes too expensive.

Types of operations in cylindrical grinding are:

(i) Traverse grinding or infeed grinding - In this grinding wheel is moved into the work. The desired surface is then produced by traversing the work piece across the wheel as shown in Fig. 4.14 (a).

(ii) Plunge grinding - The basic movement is of the grinding wheel being fed radially into the work while the later revolves on centres as shown in Fig. 4.14 (b). It is similar to form cutting on lathe. The method is used for short work pieces where the width of the wheel overlaps the length to be ground. Short rigid work pieces can be ground by this method.

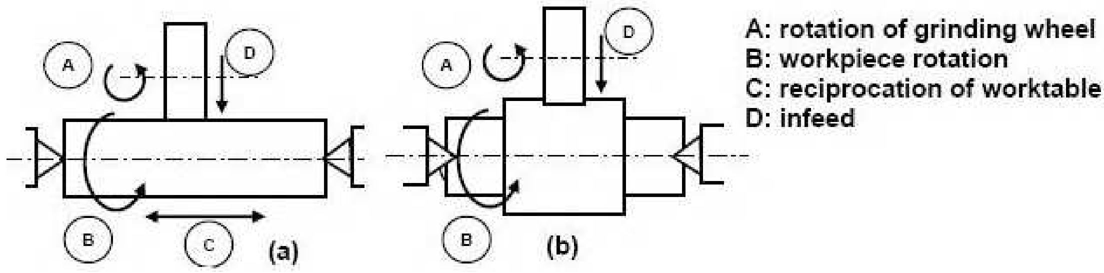


Fig. 4.14 Cylindrical grinding process (a) traverse grinding and (b) plunge grinding

(iii) Full-depth grinding - The wheel is trued to obtain an entering taper or step, and the whole allowance is ground off in one or two lengthwise passes. The method is usually applied to relatively short surfaces of rigid shaft-type work pieces.

4.6.1 Plain centre type cylindrical grinding machine

Fig. 4.15 illustrates schematically this machine and various motions required for grinding action.

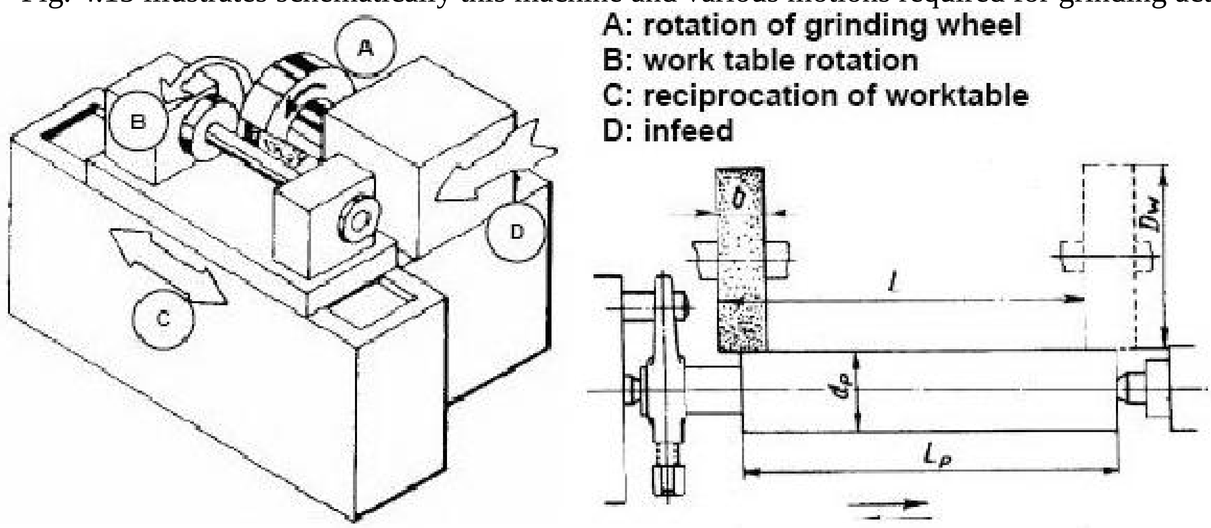


Fig. 4.15 Plain centre type cylindrical grinding machine

Base: The base or bed is the main casting that rest on the floor and supports the parts mounted on it. On the top of the base are precision horizontal ways set at right angles for the table to slide on the base. The base also houses the table drive mechanism.

Tables: There are two tables, lower table and upper table. The lower table slides on ways on the bed and provides traverse of the work past the grinding wheel. It can be moved by hand or power within desired limits. The upper table that is pivoted at its centre is mounted on the top of the sliding table. It has T-slots for securing the head stock and tail stock or foot stock and can be positioned along the table to suit the length of the work. The upper table can be swiveled and clamped in position to provide adjustment for grinding straight or tapered work as desired. Setting for tapers up to $\pm 10^0$ can be made in this way. Steep tapers are ground be swiveling the wheel head. Adjustable dogs are clamped in longitudinal slots and they are provided at the side of the lower or sliding table and are set up to reverse the table at the ends of the stroke.

Head stock: The headstock supports the work piece by means of a dead centre and drives it be means of a dog, or it may hold and drive the work piece in a chuck.

Tail stock: The tail stock can be adjusted and dampen in various positions to accommodate different lengths of work piece.

Wheel head: The wheel head carries a grinding wheel and its driving motor is mounted on a slide at the top and rear of the base. The wheel head may be moved perpendicularly to the table ways, by hand or power, to feed the wheel to the work. The grinding wheel is fed to the work by hand or power as determined by the engagement of the cross-feed control lever.

Working principle: The machine is similar to a centre lathe in many respects. The work piece is held between head stock and tailstock centres. A disc type grinding wheel performs the grinding action with its peripheral surface. Both traverse and plunge grinding can be carried out in this machine as shown in Fig. 4.14 (a and b).

4.6.2 Universal cylindrical grinding machine

These grinders, in addition to the features offered by plain grinders, are provided with a swiveling headstock and a swiveling wheel head. This permits the grinding of taper of any angle, much greater than is possible in plain grinder. Universal machines are available to handle parts requiring swings up to 450 mm and centre distance of 1800mm. This allows grinding of any taper on the work piece. Universal grinder is also equipped with an additional head for internal grinding. Schematic illustration of important features of this machine is shown in Fig. 4.16.

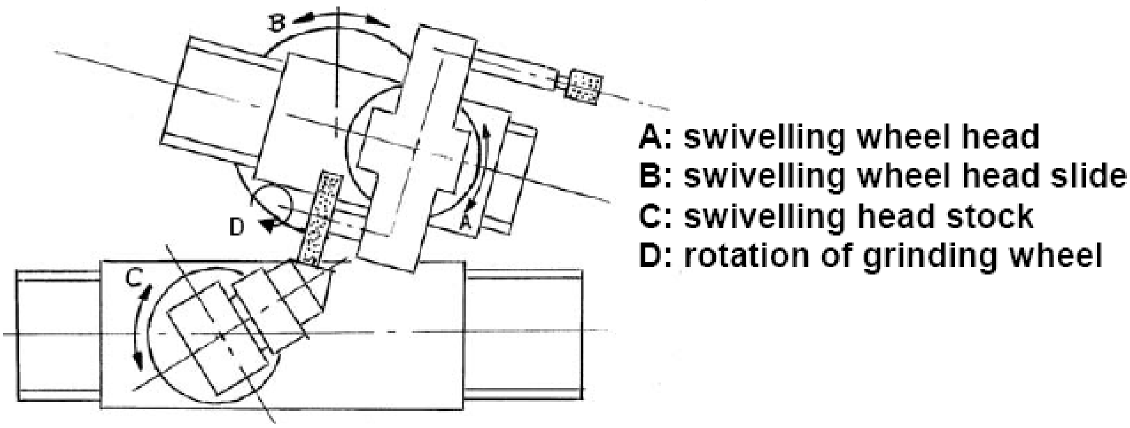


Fig. 4.16 Important features of universal cylindrical grinding machine

Universal grinder has the following additional features:

- The centre of the head stock spindle can be used alive or dead. The work can be held and revolved by a chuck. It can also be held between centres and revolved.
- The wheel head can be swiveled in a horizontal plane in any angle. The wheel head can be fed in the inclined direction also.
- The headstock can be swiveled to any angle in the horizontal plane.

4.6.3 Internal cylindrical grinding machine

Internal grinding is employed chiefly for finishing accurate holes in hardened parts, and also when it is impossible to apply other more productive methods of finishing accurate hold, for example, precision boring, honing etc.

There are two general methods of internal grinding:

- With a rotating work piece.
- With the work piece held stationary.

The first method is used in grinding holes in relatively small work pieces, mostly bodies of revolution, for example, the bores of gears and the inner surfaces of ball bearing rings. The work piece is held in a chuck or special fixture and rotated in the same manner as in a lathe. A straight type grinding wheel is rotated and has two feed-longitudinal feed along the wheel axis and is thus reciprocated back and forth through the length of the hole, and intermittent cross feed(radial feed) at the end of each pass, which determines the depth of cut.

The second method of internal grinding is used for grinding holes in large bulky work pieces (housing-type parts) that are inconvenient or even impossible to clamp in a chuck of the grinder. They are mounted on the table of a planetary grinding machine. In addition to rotation about its axis, the wheel spindle of this type of machine also rotates with a planetary motion about the axis of the hole being ground. Axial motion of the wheel provides the longitudinal feed.

4.6.3.1 Chucking type internal grinding machine

Fig. 4.17 illustrates schematically this machine and various motions required for grinding action. The work piece is usually mounted in a chuck. A magnetic face plate can also be used. A small grinding wheel performs the necessary grinding with its peripheral surface. Both transverse and plunge grinding can be carried out in this machine as shown in Fig. 4.18.

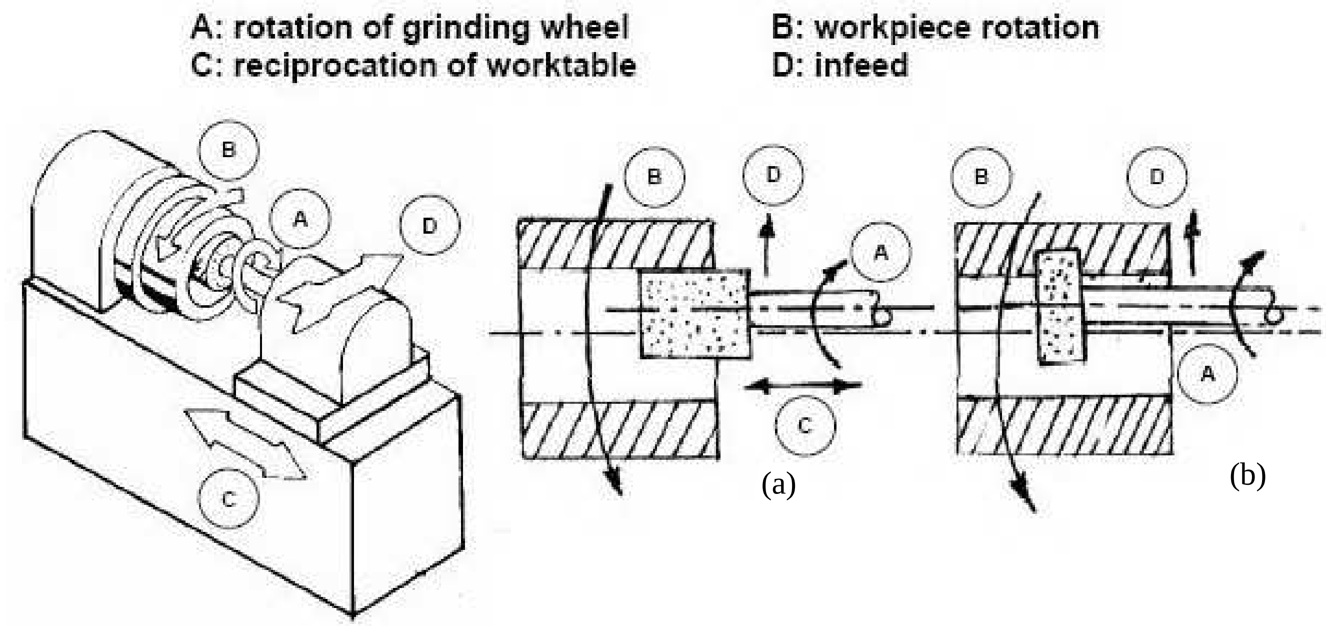


Fig. 4.17 Internal cylindrical grinding machine

Fig. 4.18 Internal (a) transverse grinding and (b) plunge grinding

4.6.3.2 Planetary internal grinding machine

Planetary internal grinding machine is used where the work piece is of irregular shape and can not be rotated conveniently as shown in Fig. 4.19. In this machine the work piece does not rotate. Instead, the grinding wheel orbits the axis of the hole in the work piece.

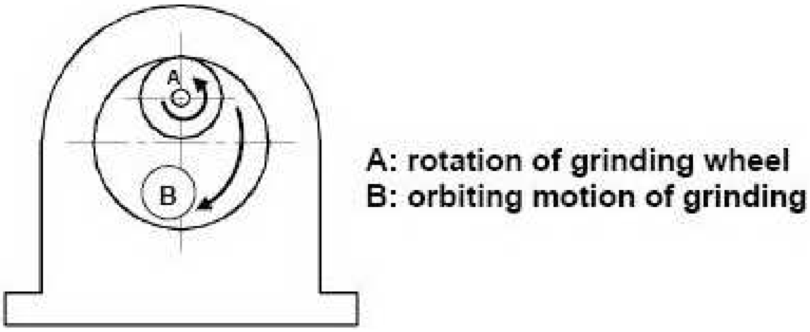


Fig. 4.19 Planetary internal grinding machine

4.6.4 Special application of cylindrical grinding machine

Principle of cylindrical grinding is being used for thread grinding with specially formed wheel that matches the thread profile. A single ribbed wheel or a multi ribbed wheel can be used as shown in Fig. 4.20.

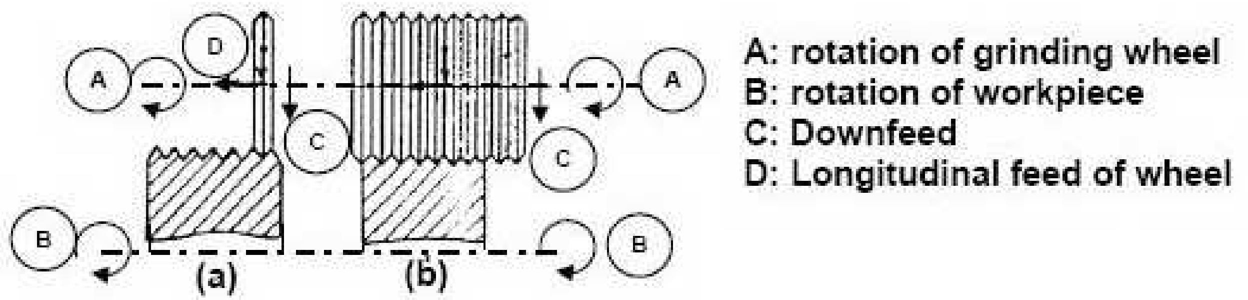


Fig. 4.20 Thread grinding with (a) single rib (b) multi-ribbed wheel

Roll grinding is a specific case of cylindrical grinding wherein large work pieces such as shafts, spindles and rolls are ground. Crankshaft or crank pin grinders also resemble cylindrical grinder but are engaged to grind crank pins which are eccentric from the centre line of the shaft as shown in Fig. 4.21. The eccentricity is obtained by the use of special chuck.

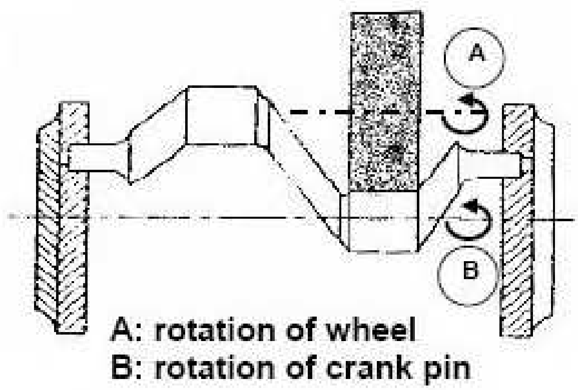


Fig. 4.21 Grinding of crank pin

Cam and camshaft grinders are essentially subsets of cylindrical grinding machine dedicated to finish various profiles on disc cams and cam shafts. The desired contour on the work piece is generated by varying the distance between wheel and work piece axes. The cradle carrying the head stock and tail stock is provided with rocking motion derived from the rotation of a master cam that rotates in synchronization with the work piece. Newer machines however, use CNC in place of master cam to generate cam on the work piece.

4.7 SURFACE GRINDING

Surface grinding machines are generally used for generating flat surfaces. These machines are similar to milling machines in construction as well as motion. There are basically four types of machines depending upon the spindle direction and the table motion. *They are,*

1. Horizontal spindle and rotating table grinding machine.
2. Vertical spindle and rotating table grinding machine.
3. Horizontal spindle and reciprocating table grinding machine, and
4. Vertical spindle and reciprocating table grinding machine.

The table in the case of reciprocating machines is generally moved by the hydraulic power. The wheel head is given a cross feed motion at the end of each table motion. In this machine the wheel should over travel the work piece at both the ends to prevent the grinding wheel removing the metal at the same work spot during the table reversal.

Vertical spindle machines are generally of a bigger capacity. The diameter of the wheel is wider than the work piece and as a result no traverse feed is required. The complete machining surface is covered by the grinding wheel face. They are suitable for production grinding of very flat surfaces.

4.7.1 Horizontal spindle and rotating table grinding machine

Surface grinding in this machine is shown in Fig. 4.22. In principle the operation is same as that for facing on the lathe. This machine has a limitation in accommodation of work piece and therefore does not have wide spread use. However, by swiveling the worktable, concave or convex or tapered surface can be produced on individual part as illustrated in Fig. 4.23.

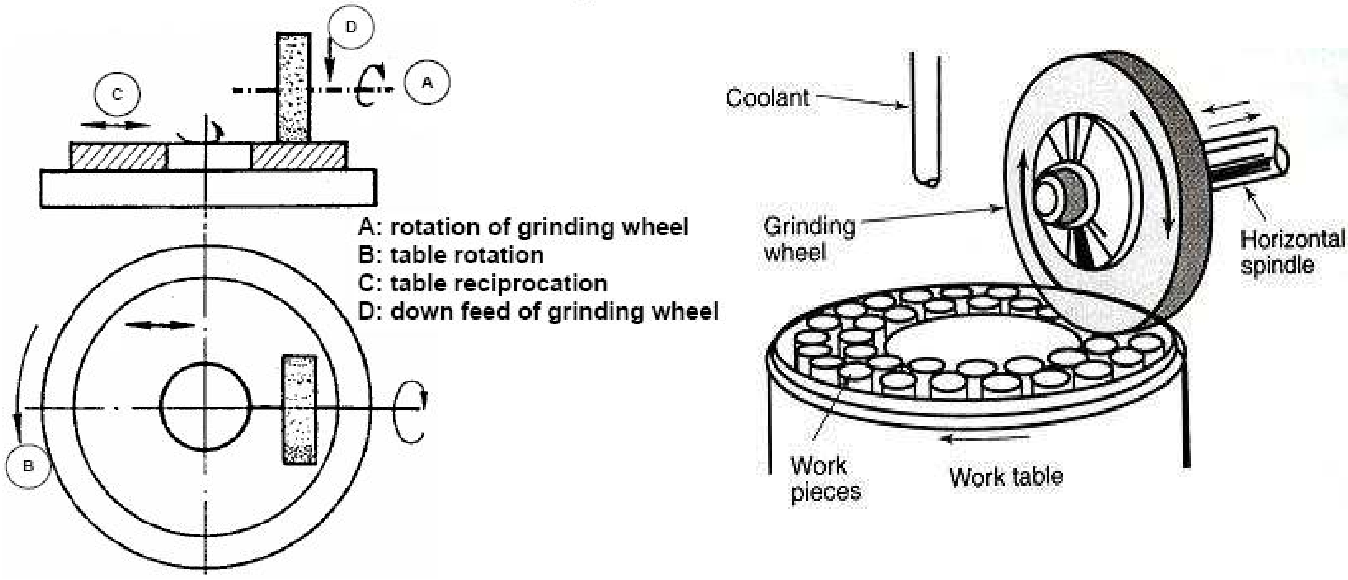


Fig. 4.22 Surface grinding in horizontal spindle and rotating table grinding machine

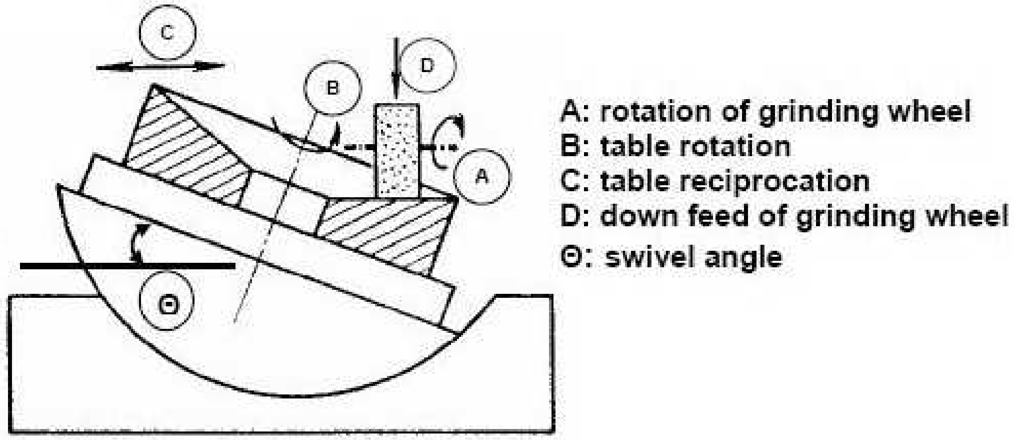


Fig. 4.23 Grinding of a tapered surface in horizontal spindle and rotating table grinding machine

4.7.2 Vertical spindle and rotating table grinding machine

The principle of grinding in this machine is shown in Fig. 4.24. The machine is mostly suitable for small work pieces in large quantities. This primarily production type machine often uses two or more grinding heads thus enabling both roughing and finishing in one rotation of the work table.

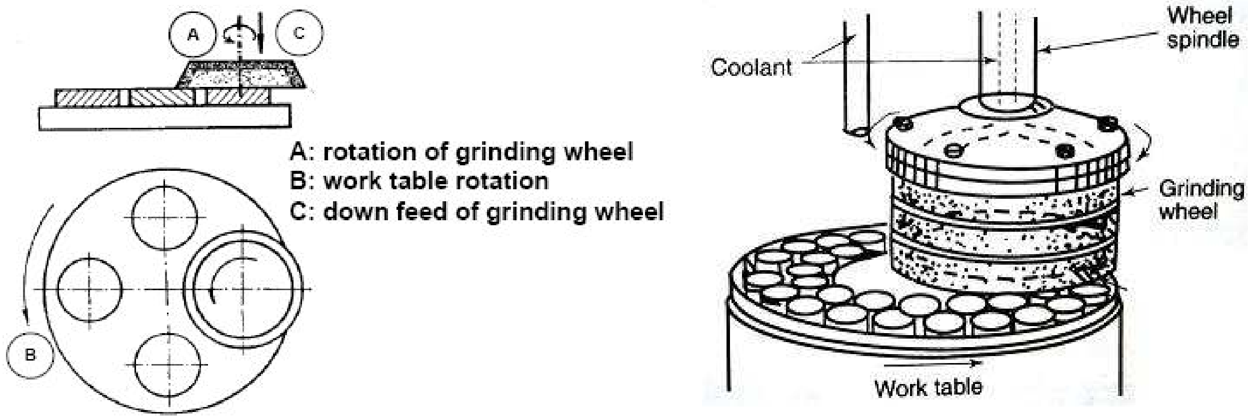


Fig. 4.24 Surface grinding in vertical spindle and rotating table grinding machine

4.7.3 Horizontal spindle and reciprocating table grinding machine

Fig. 4.25 illustrates this machine with various motions required for grinding action. A disc type grinding wheel performs the grinding action with its peripheral surface as shown in Fig. 4.26. Both traverse and plunge grinding can be carried out in this machine as shown in Fig. 4.27.

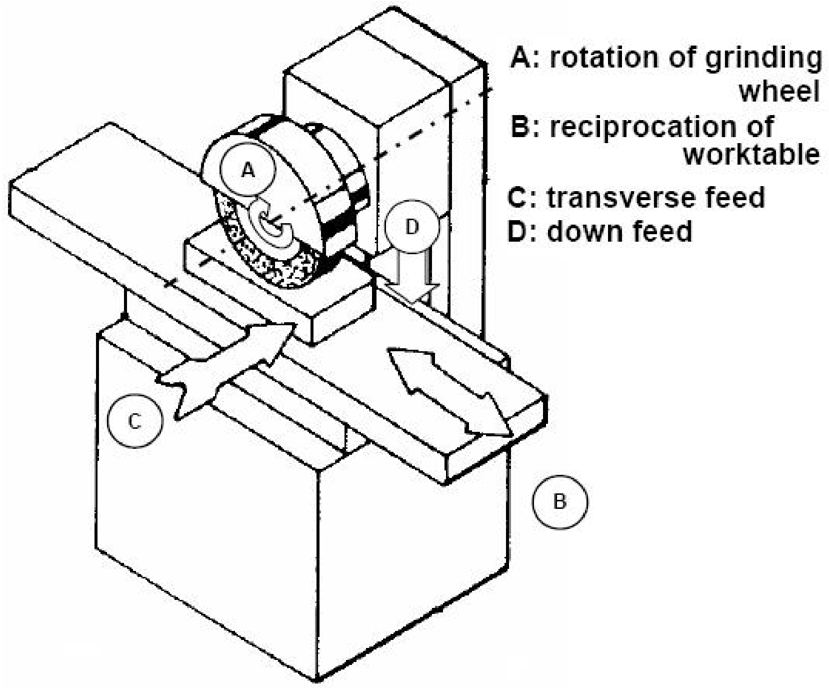


Fig. 4.25 Horizontal spindle and reciprocating table grinding machine

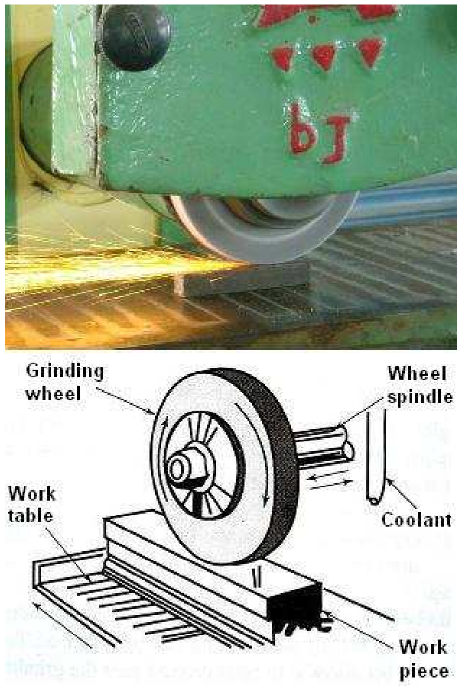


Fig. 4.26 Horizontal spindle and reciprocating table surface grinding process

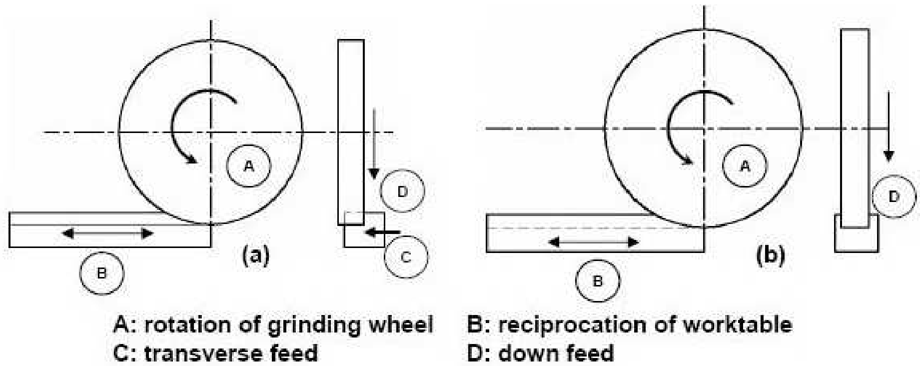


Fig. 4.27 Surface grinding (a) traverse grinding (b) plunge grinding

4.7.4 Vertical spindle and reciprocating table grinding machine

This grinding machine with all working motions is shown in Fig. 4.28. The grinding operation is similar to that of face milling on a vertical milling machine. In this machine a cup shaped wheel grinds the work piece over its full width using end face of the wheel as shown in Fig. 4.29. This brings more grits in action at the same time and consequently a higher material removal rate may be attained than for grinding with a peripheral wheel.

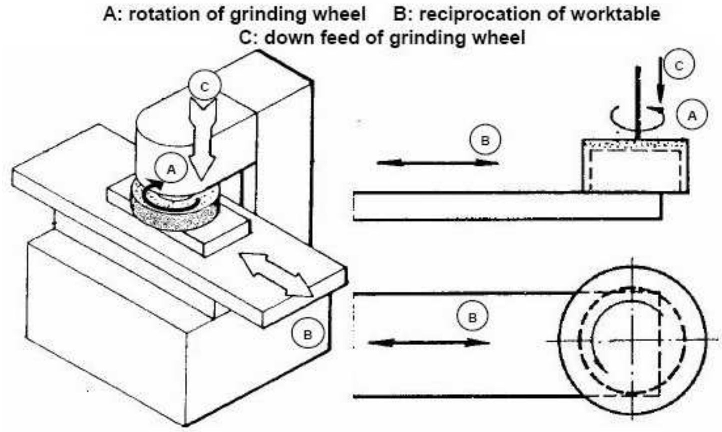


Fig. 4.28 Vertical spindle and reciprocating table grinding machine

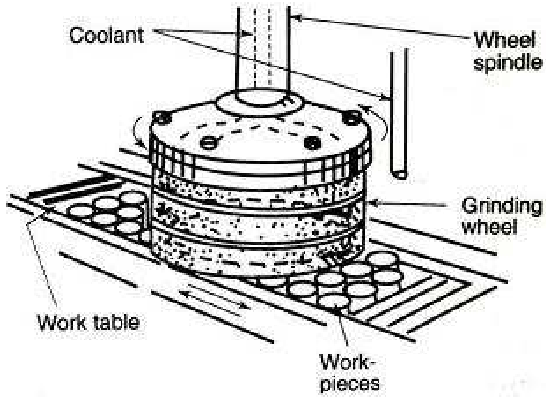


Fig. 4.29 Vertical spindle and reciprocating table surface grinding process

4.8 CENTRELESS GRINDING

Centreless grinding makes it possible to grind cylindrical work pieces without actually fixing the work piece using centres of a chuck. As a result no work rotation is separately provided. The process consists of two wheels, one large grinding wheel and another smaller regulating wheel. The work is held on a work rest blade. The regulating wheel is mounted at an angle to the plane of the grinding wheel.

The centre of the work piece is slightly above the centre of the grinding wheel. The work piece is supported by the rest blade and held against the regulating wheel by the grinding force. As a result the work rotates at the same surface speed as that of regulating wheel. The axial feed of the work piece is controlled by the angle of tilt of the regulating wheel. Typical work speeds are about 10 to 50m/min.

4.8.1 Centreless external grinding machine

This grinding machine [shown in Fig. 4.30] is a production machine in which out side diameter of the work piece is ground. The work piece is not held between centres but by a work support blade. It is rotated by means of a regulating wheel and ground by the grinding wheel. In through-feed centreless grinding, the regulating wheel revolving at a much lower surface speed than grinding wheel controls the rotation and longitudinal motion of the work piece. The regulating wheel is kept slightly inclined to the axis of the grinding wheel and the work piece is fed longitudinally as shown in Fig. 4.31.

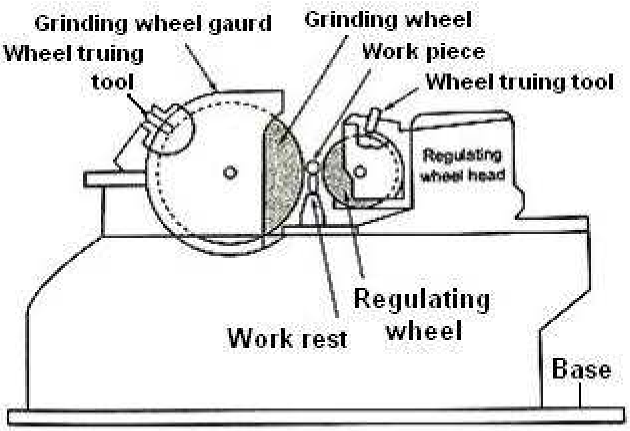


Fig.4.30 Centreless external grinding machine

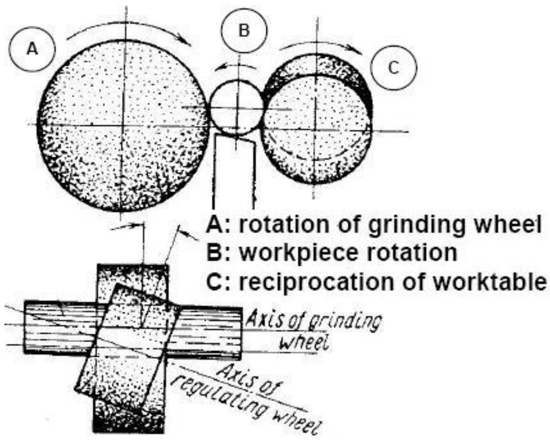


Fig. 4.31 Centreless through feed grinding

Parts with variable diameter can be ground by Centreless infeed grinding as shown in Fig. 4.32 (a). The operation is similar to plunge grinding with cylindrical grinder. End feed grinding shown in Fig. 4.32 (b) is used for work piece with tapered surface. The grinding wheel or the regulating wheel or both require to be correctly profiled to get the required taper on the work piece.

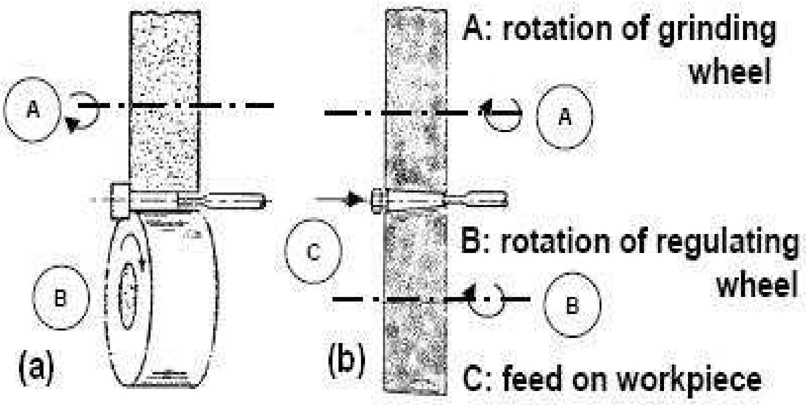


Fig. 4.32 Centreless (a) infeed and (b) end feed grinding

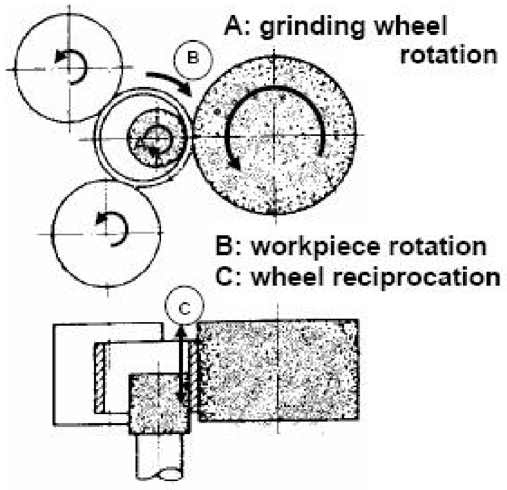


Fig. 4.33 Internal centreless grinding

4.8.2 Centreless internal grinding machine

This machine is used for grinding cylindrical and tapered holes in cylindrical parts (e.g. cylindrical liners, various bushings etc). The work piece is rotated between supporting roll, pressure roll and regulating wheel and is ground by the grinding wheel as illustrated in Fig. 4.33.

4.9 SURFACE FINISHING PROCESSES OR MICRO FINISHING PROCESSES

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 severe requirement. Table 4.4 illustrates gradual improvement of surface roughness produced by various processes ranging from precision turning to super finishing including lapping and honing. The typical surface finishes for these operations are presented in the table 4.5.

Table 4.4

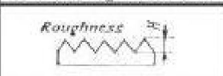
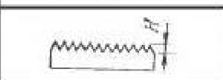
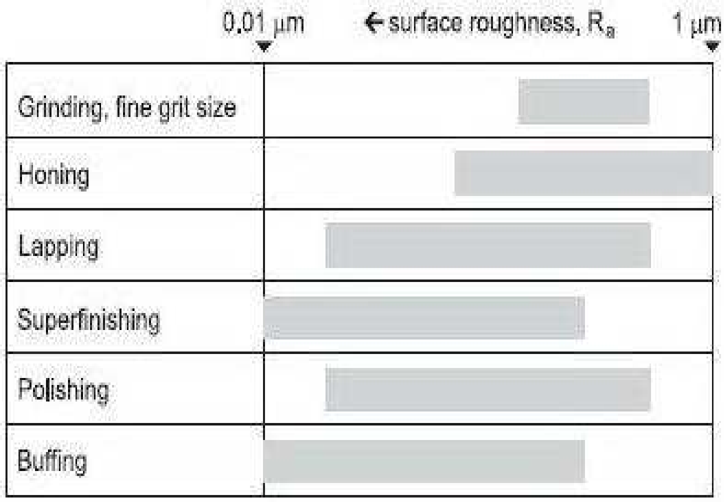
Process	Diagram of resulting surface	Height of micro irregularity (μm)
Precision Turning		1.25-12.50
Grinding		0.90-5.00
Honing		0.13-1.25
Lapping		0.08-0.25
Super Finishing		0.01-0.25

Table 4.5



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

4.10 HONING

Honing is a low abrading process which uses bonded abrasive sticks for removing stock from metallic and non-metallic surfaces. This process is used primarily to remove the grinding or the tool marks left on the surface by previous operations. However, it can be used for external cylindrical surfaces as well as flat surfaces. It is most commonly used for internal surfaces.

The advantages of honing are:

- Correction of geometrical accuracy.
- Dimensional accuracy.

Honing is a finishing process performed by a honing tool called as hone [shown in Fig. 4.34], which contains a set of three to a dozen and more bonded abrasive sticks. The sticks are equally spaced about the periphery of the honing tool. The sticks are held against the work surface with controlled light pressure, usually exercised by small springs.

The honing tool is given a complex rotational and oscillatory axial motion, which combine to produce a crosshatched lay pattern [shown in Fig. 4.35] of very low surface roughness. In addition to the surface finish of about 0.1 μm, honing produces a characteristic crosshatched surface that tends to retain lubrication during operation of the component, thus contributing to its function and service life.

A cutting fluid must be used in honing to cool and lubricate the tool and to help remove the chips. A common application of honing is to finish the holes. Typical examples include bores of internal combustion engines, bearings, hydraulic cylinders, and gun barrels.

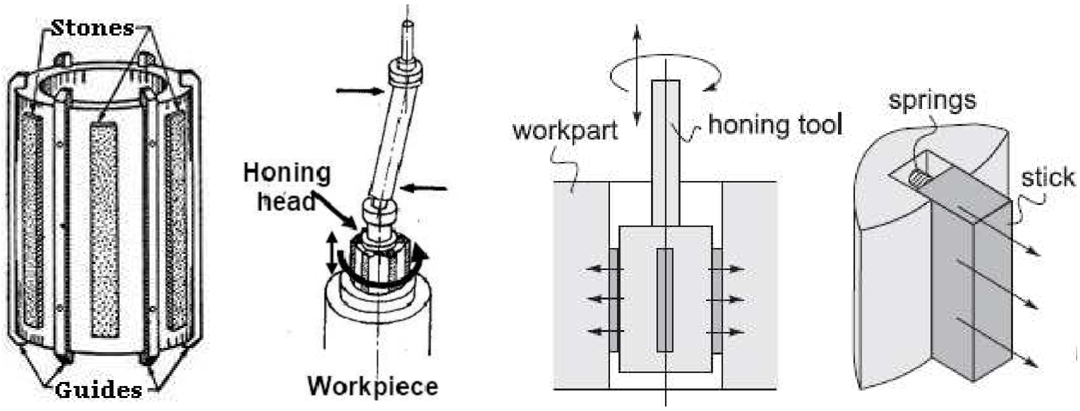


Fig. 4.34 Honing tool

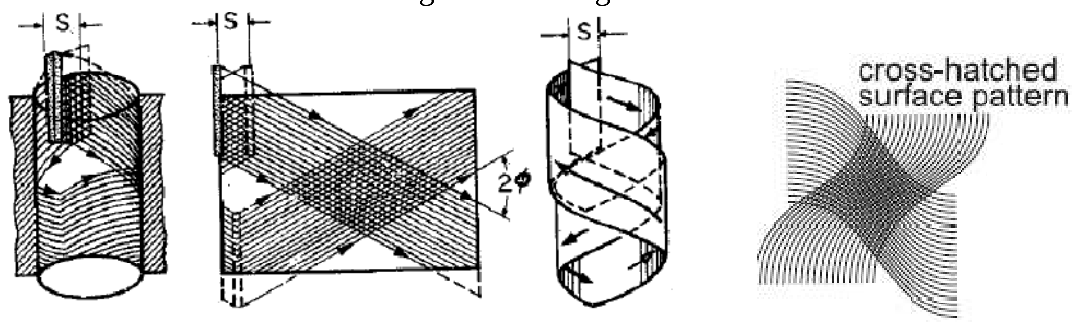


Fig. 4.35 Lay pattern produced by combination of rotary and oscillatory motion

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:*

- Rotation speed.
- Oscillation speed.
- Length and position of the stroke.
- 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. Super abrasive honing stick with monolayer configuration, where a layer of CBN grits are attached to stick by a galvanically deposited metal layer [shown in Fig. 4.36], is typically found in single stroke honing application.

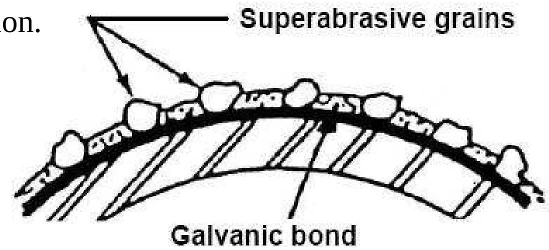


Fig. 4.36 Super abrasive honing stick with single layer configuration

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.

4.11 LAPPING

Lapping is a surface finishing process used on flat or cylindrical surfaces. Lapping is the abrading of a surface by means of a lap (which is made of a material softer than the material to be lapped), which has been charged with the fine abrasive particles. *The process is employed to get:*

- Geometrically true surface.
- Extreme accuracy of dimension.
- Correction of minor imperfections in shape.
- Refinement of the surface finish, and
- Close fit between mating surfaces.

Lapping methods:

- Hand lapping for flat work.
- Hand lapping for external cylindrical work, (Ring lapping).
- Machine lapping.

In *lapping*, instead of a bonded abrasive tool, oil-based fluid suspension of very small free abrasive grains (aluminum oxide and silicon carbide, with typical grit sizes between 300 and 600) called a *lapping compound* is applied between the work piece and the lapping tool.

The lapping tool is called a *lap*, which is made of soft materials like copper, lead or wood. The lap has the reverse of the desired shape of the work part. To accomplish the process, the lap is pressed against the work and moved back and forth over the surface in a figure-eight or other motion pattern, subjecting all portions of the surface to the same action. Lapping is sometimes performed by hand, but *lapping machines* accomplish the process with greater consistency and efficiency.

The cutting mechanism in lapping is that the abrasives become embedded in the lap surface, and the cutting action is very similar to grinding, but a concurrent cutting action of the free abrasive particles in the fluid cannot be excluded. Lapping is used to produce optical lenses, metallic bearing surfaces, gauges, and other parts requiring very good finishes and extreme accuracy. Fig. 4.37 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 work piece.
- Usually lap and work piece 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 work piece.

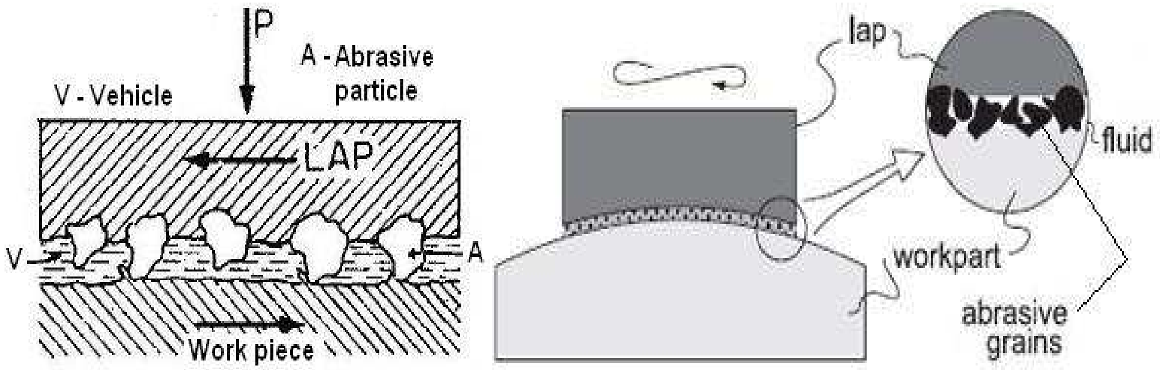


Fig. 4.37 Schematics of lapping process showing the lap and the cutting action of suspended abrasive particles.

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.

4.12 SUPER FINISHING

Super finishing is a micro finishing process that produces a controlled surface condition on parts which is not obtainable by any other method. It is abrasive process which utilizes either a bonded abrasive like honing for cylindrical surfaces or a cup wheel for flat surfaces. Fig. 4.38 schematically shows the super finishing process.

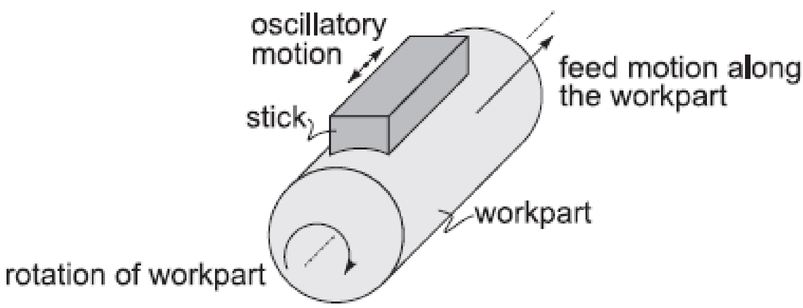


Fig. 4.38 Schematics of the super finishing process.

Super finishing is a finishing operation similar to honing, but it involves the use of a single abrasive stick. The reciprocating motion of the stick is performed at higher frequency and smaller amplitudes. Also, the grit size and pressures applied on the abrasive stick are smaller. A cutting fluid is used to cool the work surface and wash away chips.

In super finishing, the cutting action terminates by itself when a lubricant film is built up between the tool and work surface. Thus, super finishing is capable only of improving the surface finish but not dimensional accuracy. The result of these operating conditions is mirror like finishes with surface roughness values around 0.01 μm. Super finishing can be used to finish flat and external cylindrical surfaces. The operation also called ‘micro stoning’ consists of scrubbing a stone against a surface to produce a fine quality metal finish. *Super finishing is generally used for:*

- Removing surface fragmentation.
- Reducing surface stresses and burns and thus restoring surface integrity.
- Correcting inequalities in geometry.
- Super finishing produces a high wear resistant surface on any objet which is symmetrical.

Fig. 4.39 illustrates super finishing end-face of a cylindrical work piece. In this both feeding and oscillation of the super finishing stone is given in the radial direction. Fig. 4.40 shows the super finishing operation in plunge mode. In this case the abrasive stone covers the section of the work piece requiring super finish. The abrasive stone is slowly fed in radial direction while its oscillation is imparted in the axial direction.

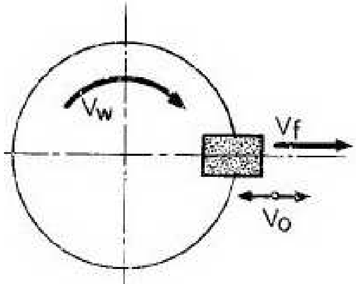


Fig. 4.39 Super finishing of end face of a cylindrical work piece in radial mode

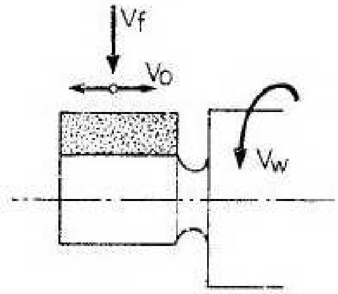


Fig. 4.40 Super finishing operation in plunge mode

Super finishing can be effectively done on a stationary work piece as shown in Fig. 4.41. In this the abrasive stones are held in a disc which oscillates and rotates about the axis of the work piece. Fig. 4.42 shows that internal cylindrical surfaces can also be super finished by axially oscillating and reciprocating the stones on a rotating work piece.

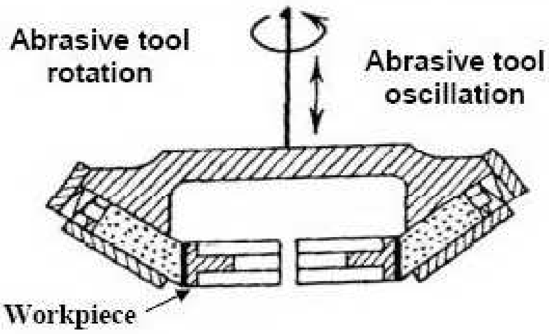


Fig. 4.41 Abrasive tool rotating and oscillating about a stationary work piece

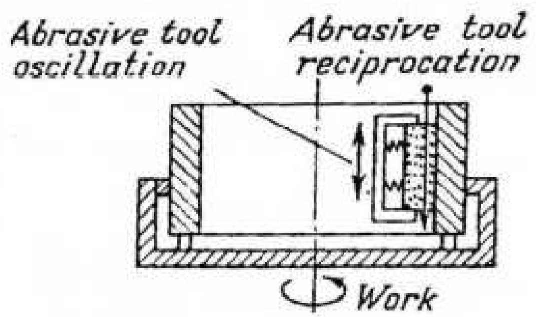


Fig. 4.42 Super finishing of internal surface

4.12.1 Burnishing

The burnishing process consists of pressing hardened steel rolls or balls into the surface of the work piece and imparting a feed motion to the same. Ball burnishing of a cylindrical surface is illustrated in Fig. 4.43. During burnishing considerable residual compressive stress is induced in the surface of the work piece and thereby fatigue strength and wear resistance of the surface layer increase.

4.12.2 Magnetic float polishing

Magnetic float polishing (shown in Fig. 4.44) 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.

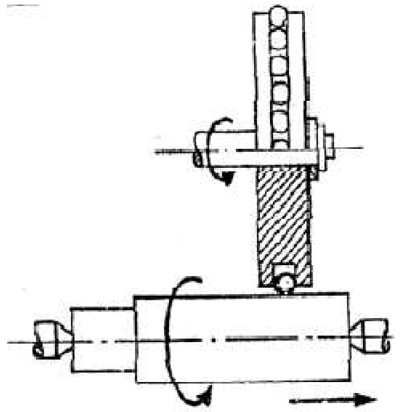


Fig. 4.43 Scheme of ball burnishing

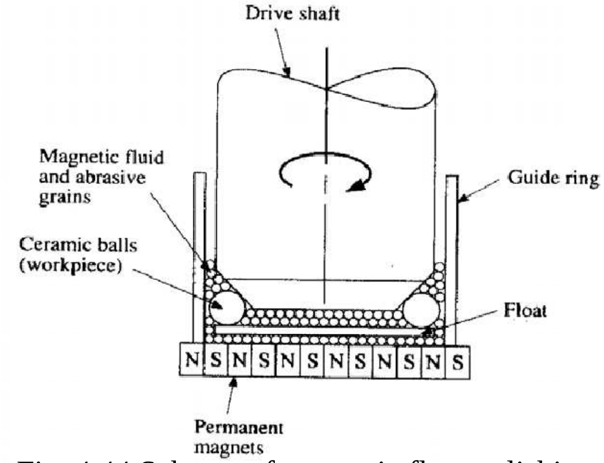


Fig. 4.44 Scheme of magnetic float polishing

4.12.3 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. 4.45. 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 these 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.

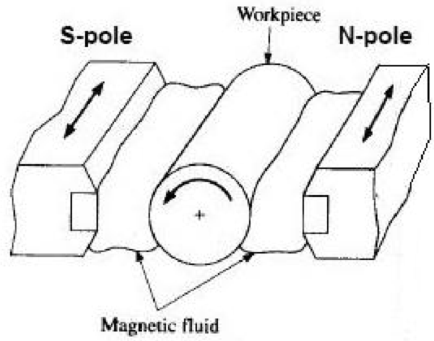


Fig. 4.45 scheme of magnetic field assisted polishing

4.12.4 Electro polishing

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

4.13 POLISHING

Polishing is a surface finishing process to a smooth and lustrous surface. Polishing is done with very fine abrasive particles of Al_2O_3 or diamond in loose form smeared on the polishing wheel with the work rubbing against the flexible wheel. The fine lustrous surface is obtained due to the cutting action of fine abrasive particles and the softening and smearing of surface layers by frictional heating during the process. Polishing operations are often accomplished manually.

A very small amount of material is removed in polishing. ***The grit size of the abrasive is:*** 20 - 80 for roughing, 90 - 120 for dry fining and 130 - 150 for fine finishing.

***Limitations* -** The parts with irregular shapes, sharp corners, deep recesses and sharp projections are difficult to polish.

4.14 BUFFING

Buffing is a finishing operation similar to polishing, in which the abrasive grains in a suitable carrying medium such as grease are applied at suitable intervals to the buffing wheel. Negligible amount of material is removed in buffing while a very high luster is generated on the buffed surface. Fig. 4.46 schematically shows the buffing process.

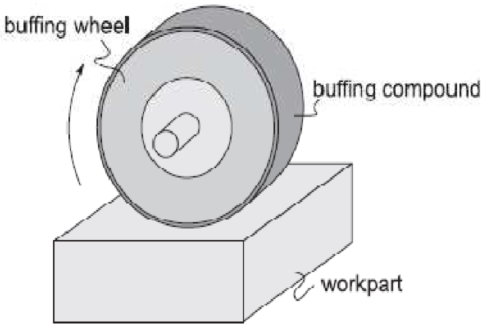


Fig. 4.46 Schematics of the buffing operation

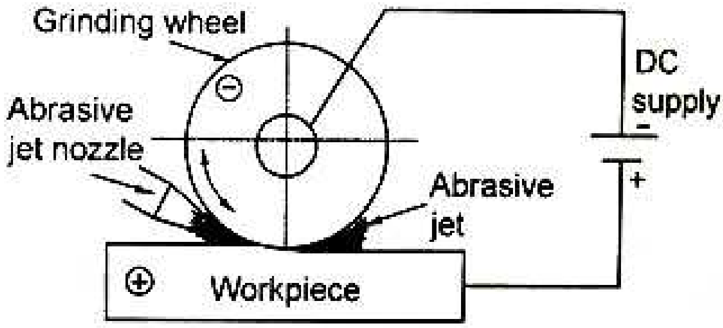


Fig. 4.47 Setup of abrasive jet grinding

As in polishing, the abrasive particles must be periodically replenished. As in polishing, buffing is usually done manually, although machines have been designed to perform the process automatically.

Polishing is used to remove scratches and burrs and to smooth rough surfaces while buffing is used to provide attractive surfaces with high luster. The dimensional accuracy of the parts is not affected by polishing and buffing operations.

4.15 ABRASIVE JET GRINDING

In this process, abrasive particles are used for grinding. The abrasive particles carried by high pressure gas of air, are forced on the work piece through a nozzle. These particles act as cutting tools and the cutting force is provided by the high kinetic energy of the carrier gas. Fig. 4.47 shows the schematic arrangement of the abrasive grinding process. *The process parameters are given below:*

- Velocity of the abrasive 200 - 400 m/sec.
- Inside diameter of the nozzle 0.075 - 0.4 mm.
- Stand off distance 0.7 - 1 mm.
- Size of abrasive particles 10 - 50 microns.
- Abrasives used Al_2O_3, SiC.
- Carrier gas CO_2, Air, N_2.

***Merits* -** no heat is generated, pressure exerted on the work is less, it has no wheel wear and high MRR.
***Demerits* -** cost is high, power consumption is high and skilled labor is required.
Applications - mainly used in grinding hardened steel and cemented carbides, used in resharpening and reconditioning of carbide tools and used in grinding thin-wall tube without leaving burr or distortion which are difficult to grind in any other processes.

4.16 SAWING MACHINES

Sawing is one of the basic machining operations carried out in a narrow cutting zone though the successive removal of chips by the teeth on a saw blade. *The types of sawing machines used are:*

1. ***Hack saw*** (i) Manual hack saw (ii) Power hack saw
2. ***Band saw*** (i) Vertical band saw (ii) Horizontal band saw (iii) Contour band saw
3. ***Circular saw***

4.17 HACK SAW

A power hack saw [shown in Fig. 4.48] uses the hack saw blade. The blade is mounted in the hacksaw frame and reciprocated for the sawing operation. It is a very simple machine with a tool frame for holding the saw and some work holding device similar to a vice. The reciprocating motion is inherently inefficient because no cutting takes place during the return stroke.

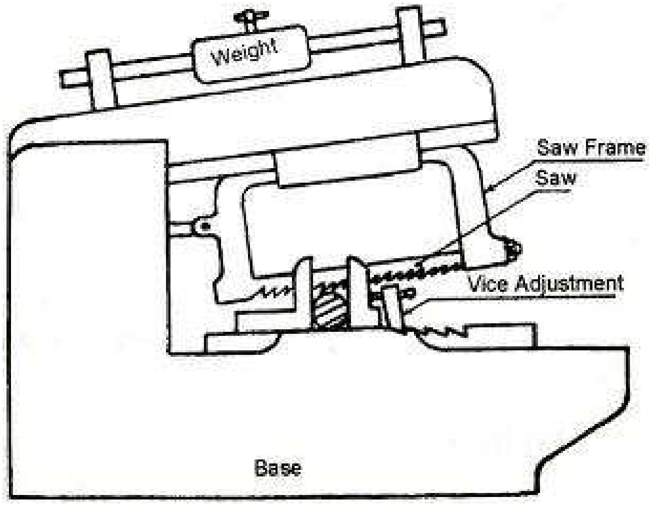


Fig. 4.48 Power hack saw machine

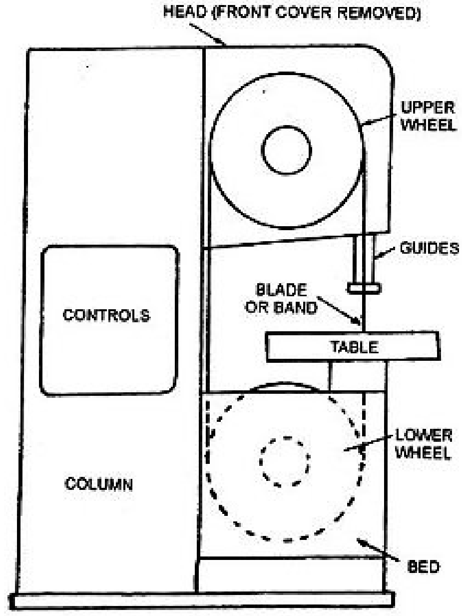


Fig. 4.49 (a) Vertical band saw machine

4.18 BAND SAW

A band saw basically has a continuous band of saw blade rotated between two disks such that the cutting action is continuous unlike the power hacksaw. Band saws are generally used for cutting off single stationary work pieces that can be held on to the table of the band saw. The saw blade can be tilted up to 45^0 to permit cutting at any angle. The band saw operates continuously such that the cutting force is always directed against the table.

It is relatively safer to use compared to the hack saw and it can cut work pieces without even clamping them to the table. Contour band saw machines are similar to band sawing machines and are used for sawing of any predefined contours in the work piece. Fig. 4.49 (a and b) schematically shows the vertical and horizontal band saw machine.

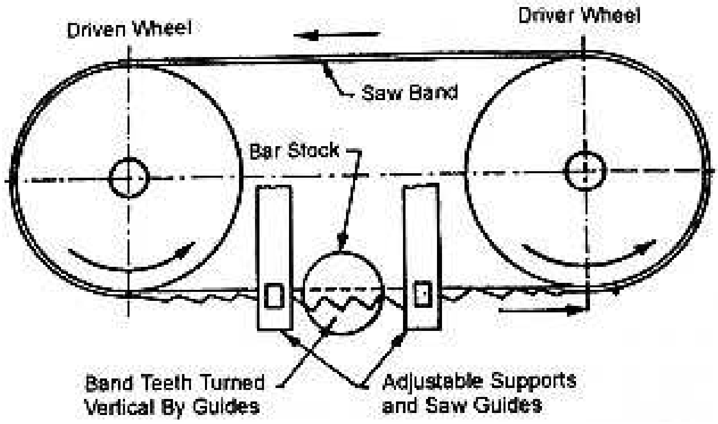


Fig. 4.49 (b) Horizantal band saw machine

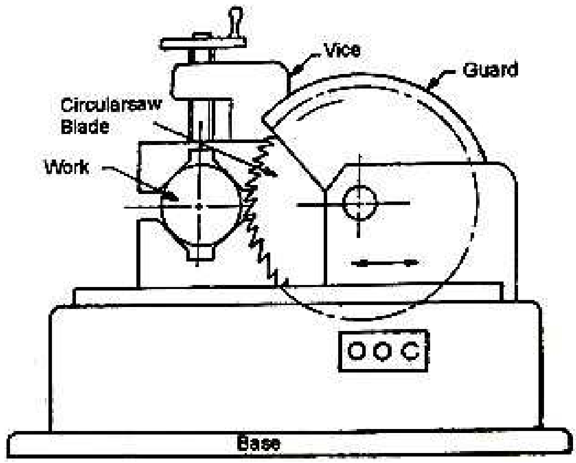


Fig. 4.50 Circular saw machine

4.19 CIRCULAR SAW

Circular saw [shown in Fig. 4.50] has the ability to run the saw at very high cutting speeds up to about 130 m/s and large feed rates. The stock can be cut very quickly and therefore care has to be takes in the selection of the parameters to maximize the productivity.

4.20 BROACHING

4.20.1 Basic principles of broaching

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. 4.51 (b). 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 as illustrated in Fig. 4.51 (a). 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.

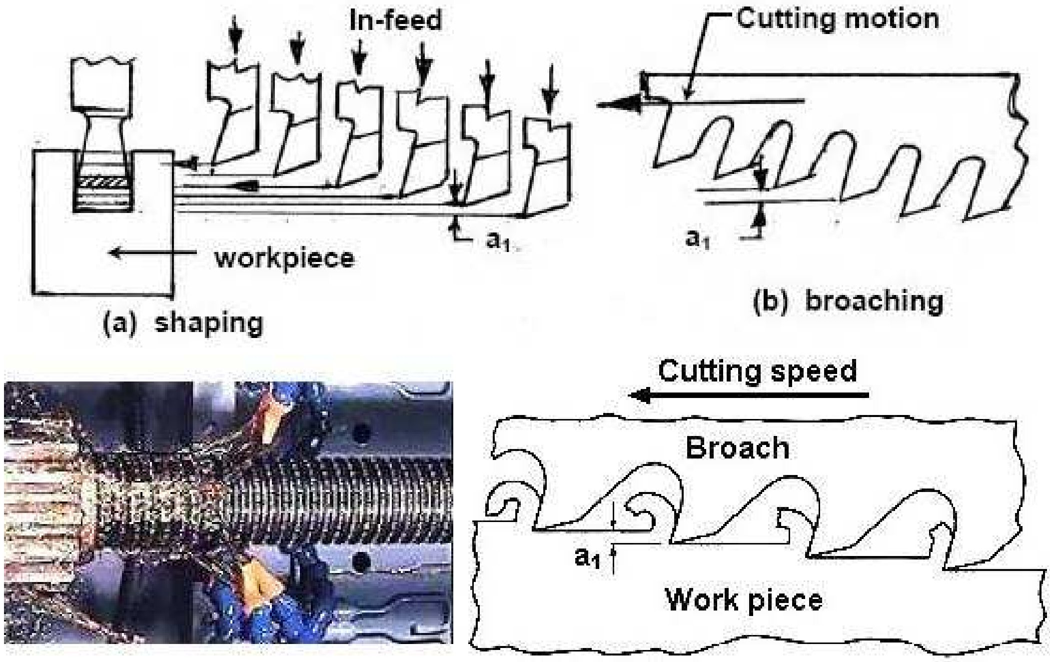


Fig. 4.51 Basic principle of broaching

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. 4.52 schematically shows how a through hole is enlarged and finished by broaching.

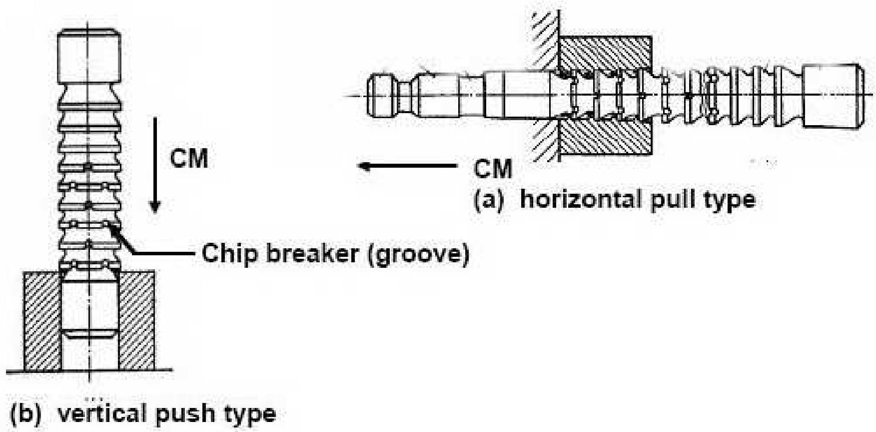


Fig. 4.52 Schematic views of finishing hole by broaching

The cutting tool is called a broach, and the machine tool is called a broaching machine. The shape of the machined surface is determined by the contour of the cutting edges on the broach, particularly the shape of final cutting teeth. Broaching is a highly productive method of machining. Advantages include good surface finish, close tolerances, and the variety of possible machined surface shapes, some of them can be produced only by broaching. Owing to the complicated geometry of the broach, tooling is expensive. Broaching is a typical mass production operation.

Productivity improvement to ten times or even more be not uncommon, as the metal removal rate by broaching is vastly greater. Roughing, semi finishing and finishing of the component is done just in one pass by broaching, and this pass is generally accomplished in seconds.

Broaching can be used for machining of various integrate shapes which can not be otherwise machined with other operations. *Some of the typical examples of shapes produced by internal broaching are shown in Fig. 4.53.*

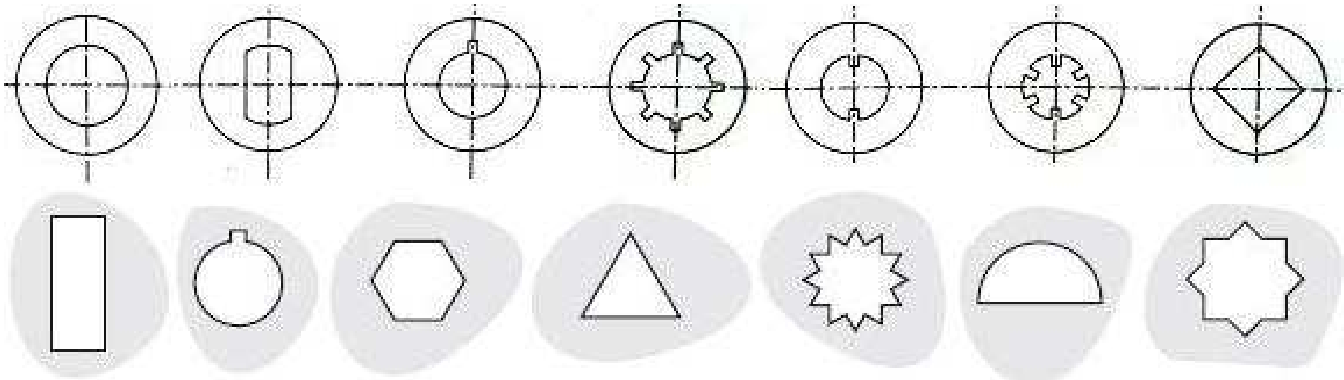


Fig. 4.53 Typical examples of shapes produced by internal broaching

4.20.2 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 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. [Fig. 4.54]
- Non-circular holes and internal slots. [Fig. 4.54]
- Internal keyway and splines. [Fig. 4.54]
- Teeth of straight and helical fluted internal spur gears. [Fig. 4.54]

External broaching and broaches

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. 4.55 (a)]
- Grooves, slots, keyways etc. on through outer surfaces of objects. [Fig. 4.55 (a)]
- External splines of different forms.
- Teeth of external spur gears or gear sectors as shown in Fig. 4.55 (b).

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

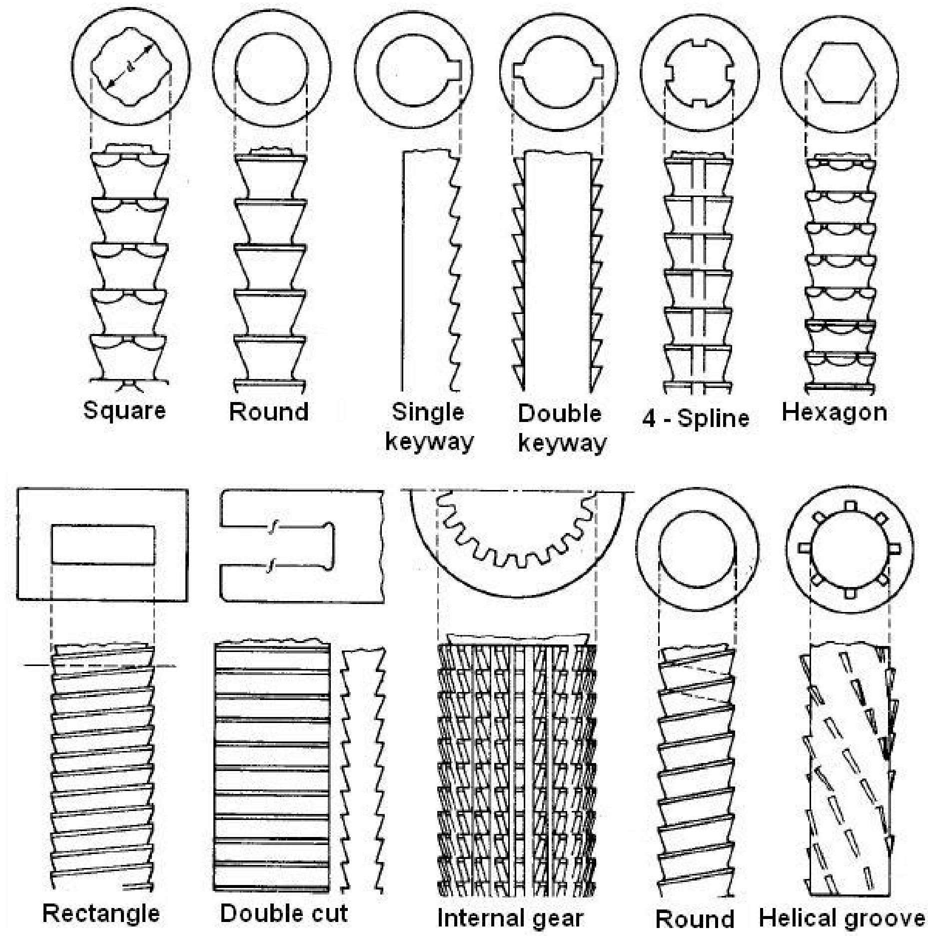


Fig. 4.54 Internal broaching – tools and applications

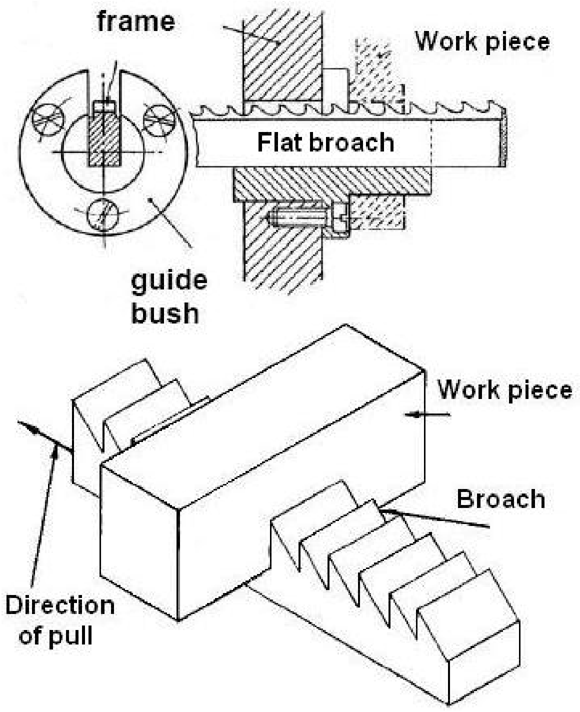


Fig. 4.55 (a) External broaching – making slot

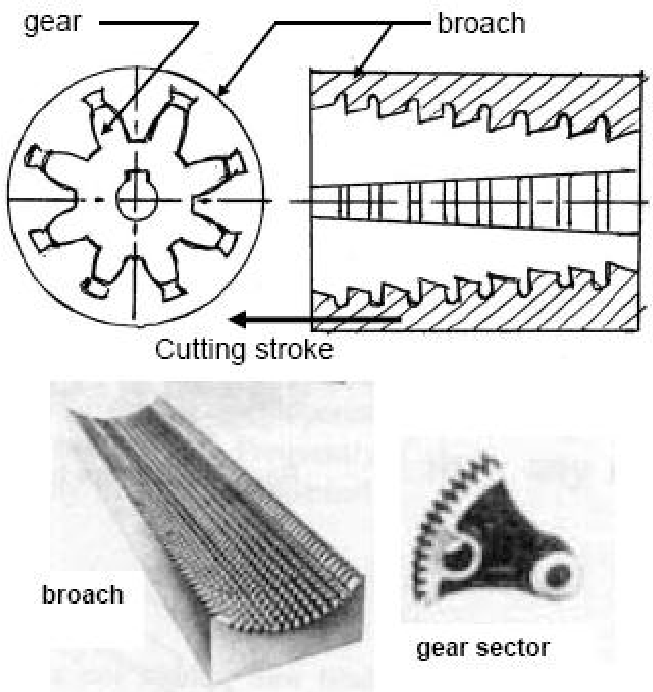


Fig 4.55 (b) Broaching of gears and gear sectors

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 or 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. 4.56 shows the working principle and configuration of such broach.*

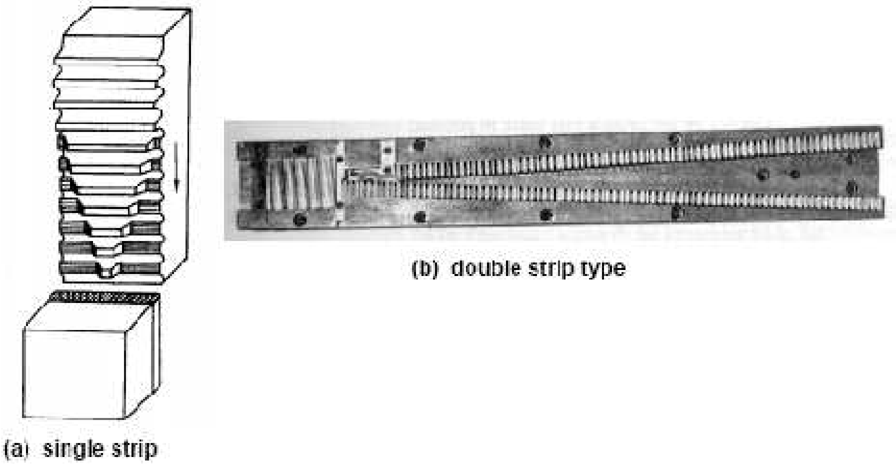


Fig. 4.56 Progressive cut type broaches; (a) single bar and (b) double bar type

Solid, Sectional and module type broaches

Broaches are mostly made in single pieces especially those used for pull type internal broaching. But some broaches called sectional broaches, are made by assembling 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. 4.57 typically shows solid, sectional and segmented (module) type broaches.*

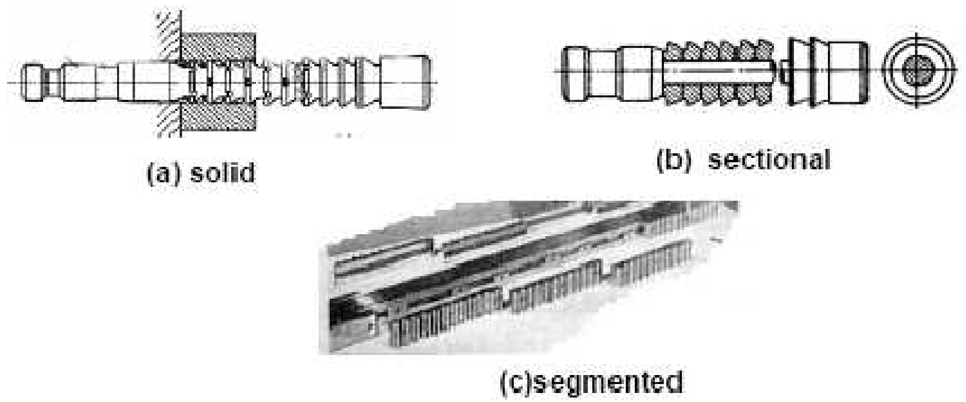


Fig. 4.57 (a) Solid, (b) Sectional and (c) Segmented broaches

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.

4.20.3 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.
- Since all the machining parameters are built into the broach, very little skill is required from the operator.
- Any type of surface, internal or external can be generated with broaching.

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 used when the size, shape and geometry of the job changes.
- Economic only when the production volume is large.

4.21 BROACH CONSTRUCTION

The broach is composed of a series of teeth, each tooth standing slightly higher than the previous one. This rise per tooth is the feed per tooth and determines the material removed by the tooth. There are basically three sets of teeth present in a broach. The roughing teeth that have the highest rise per tooth removes bulk of the material.

The semi-finishing tooth whose rise per tooth is smaller follows this. Hence they remove relatively smaller amounts of material compared to the roughing teeth. The last set of teeth is called the finishing or sizing teeth. Very little material is removed by these teeth. The necessary size is achieved by these teeth and hence all the teeth are of the same size as that required finally.

The pull end of the broach is attached to the pulling mechanism of the broaching machine with the front pilot aligning the broach properly with respect to the work piece axis before the actual cutting starts. The rear pilot helps to keep the broach to remain square with the work piece as it leaves the work piece after broaching. Broaching speeds are relatively low. However the production rate is high. Broaches are generally made to high speed steel in view of its high impact strength.

4.21.1 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. 4.58.

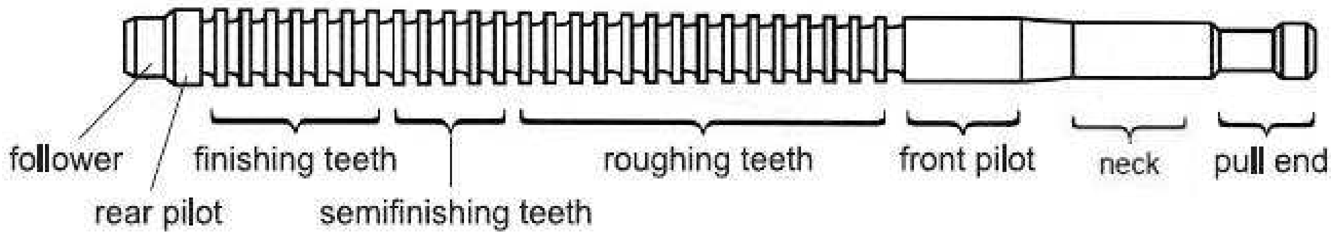


Fig. 4.58 Configuration of a pull type broach used for internal broaching

The essential elements of the broach (Fig. 4.58) 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,

$\boldsymbol{p = 1.25\sqrt{L}}$ **to** $\boldsymbol{1.5\sqrt{L}}$ 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 to be removed / 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.

4.21.2 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. 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.

4.21.3 Geometry of broaching teeth and their cutting edges

Fig. 4.59 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 (5^0 to 15^0) and sufficient primary and secondary clearance angles (2^0 to 5^0 and 5^0 to 20^0 respectively) as indicated in Fig. 4.59. Small in-built chip breakers are alternately provided on the roughing teeth of the broach as can be seen in Fig. 4.52 to break up the wide curling chips and thus preventing them from clogging the chip spaces and increasing forces and tool wear. More ductile materials need wider and frequent chip breakers.

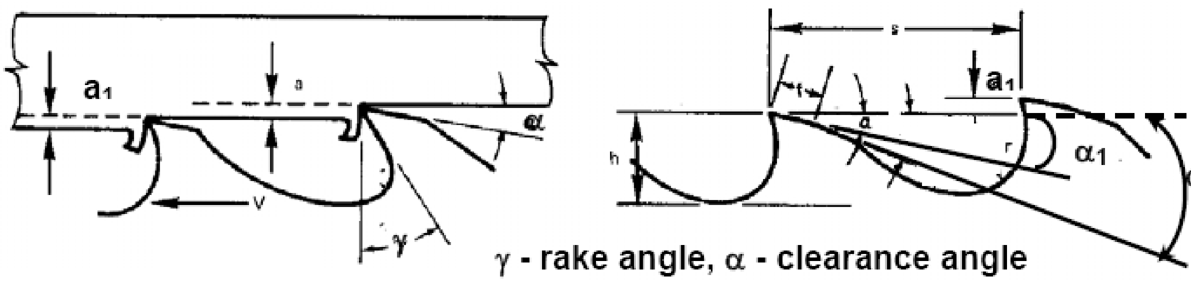


Fig. 4.59 Geometry of teeth of broaching tools

4.22 BROACHING MACHINES

4.22.1 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 work piece in the machine.
- Planning tool - work motions.
- Selection of the levels of the process parameters and their setting.
- Conducting machining by the broach.

4.22.2 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 work piece.
- Strength, power and rigidity required for the broaching machine to provide the desired productivity and process capability.

4.22.3 Function of broaching machines

The basic function of a broaching machine is to provide a precise linear motion of the tool past a stationary work position. There are two principal modifications of the broaching machines, horizontal, and vertical. The former are suitable for broaching of relatively long and small diameter holes, while the later are used for short lengths and large diameters.

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.

4.22.4 Specification of broaching machines

Broaching machines are generally specified by:

- Type; horizontal, vertical etc.
- Maximum stroke length.
- Maximum working forces (pull or push).
- Maximum cutting velocity possible.
- Type of drive - Electro-Mechanical, Hydraulic etc.
- Power rating of electrical motor.
- Floor space required.

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.

4.22.5 Classification of broaching machines

There are different types of broaching machines which are broadly classified as:

According to purpose of use

- General purpose.
- Single purpose.
- Special purpose.

According to nature of work

- Internal broaching.
- External (surface) broaching.

According to configuration

- Horizontal.
- Vertical.

According to number of slides or stations

- Single station type.
- Multiple station type.
- Indexing type.

According to tool / work motion

- Intermittent (one job at a time) type.
- Continuous type.

According to the type of drive

- Mechanical drive.
- Hydraulic drive.

4.23 PUSH BROACHING MACHINES

In these machines the broach movement is guided by a ram. These machines are simple, since the broach only needs to be pushed through the component for cutting and then retracted. The work piece is fixed into a boring fixture on the table. Even simple arbor presses can be used for push broaching.

4.23.1 Push down type vertical surface broaching machine

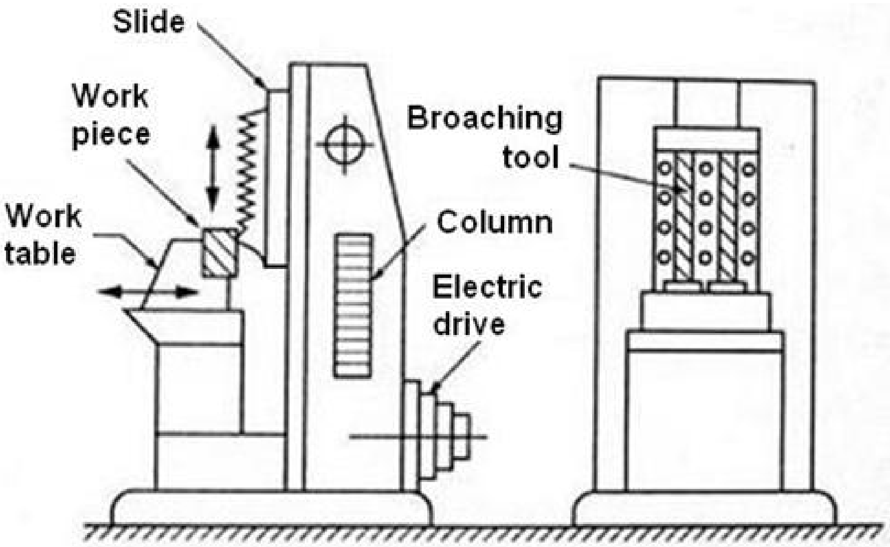


Fig. 4.60 Push down type vertical surface broaching machine

Fig. 4.60 shows the push down type vertical surface broaching machine. It consists of a box shape column, slide and drive mechanism. Broach is mounted on the slide which is hydraulically operated and accurately guided on the column ways. Slide with the broach travels at various speeds. The slide is provided with quick return mechanism. The worktable is mounted on the base in front of the column. The fixture is clamped to the table. The work piece is held in the fixture.

After advancing the table to the broaching position, it is clamped and the slide with the broach travel downwards for machining the workpiece. Then the table recedes to load a new work piece and the slide returns to its upper position. The same cycle is then repeated.

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

4.24 PULL BROACHING MACHINES

These machines consist of a work holding mechanism, and a broach pulling mechanism along with a broach elevator to help in the removal and threading of the broach through the work piece. The work piece is mounted in the broaching fixture and the broach is inserted through the hole present in the work piece.

Then the broach is pulled through the work piece completely and the work piece is then removed from the table. Afterwards the broach is brought back to the starting point before a new work piece is located on the table. The same cycle is then repeated.

4.24.1 Pull type horizontal internal broaching machine

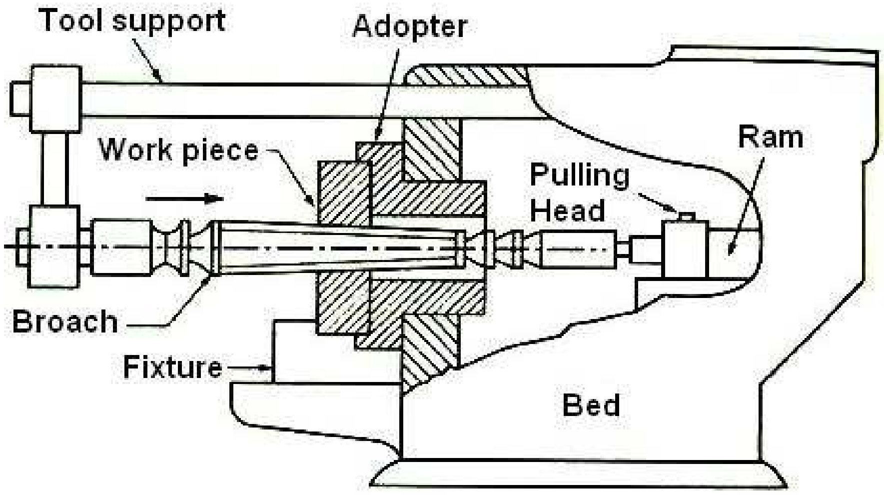


Fig. 4.61 Pull type horizontal internal broaching machine

Fig. 4.61 shows the pull type horizontal internal broaching machine. This machine has a box type bed. The length of bed is twice the length of stroke. Most of the modern horizontal broaching machines are provided with hydraulic or electric drive. It is housed in the bed. The job is located in the adopter. The adopter is fitted in the front vertical face of the machine. The small end of the broach is inserted through the hole of the job and connected to the pulling head.

The pulling head is mounted in the front end of the ram. The ram is connected to the hydraulic drive mechanism. The rear end of the broach is supported by a guide. The broach is moved along the guide ways. It is used for small and medium sized works. It is used for machining keyways, splines, serrations, internal gears, etc.

Horizontal broaching machines 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 is also possible. The horizontal broaching machines are usually hydraulically driven and occupy large floor space.

4.24.2 Pull down type vertical internal broaching machine

This machine has an elevator at the top. The pulling mechanism is enclosed in the base of the machine. The workpiece is mounted on the table by means of fixture. The tail end of the broach is gripped in the elevator. The broach is lowered through the work piece.

The broach is automatically engaged by the pulling mechanism and is pulled down through the job. After the operation is completed, the broach is raised and gripped by the elevator. The elevator returns to its initial position. *This is illustrated in Fig. 4.62 (a).*

4.24.2 Pull up type vertical internal broaching machine

In this type, the ram slides on the vertical column of the machine. The ram carries the pulling head at its bottom. The pulling mechanism is above the worktable and the broach is in the base of the machine. The broach enters the job held against the underside of the table and is pulled upward. At the end of the operation, the work is free and falls down into a container. *This is illustrated in Fig. 4.62 (b).*

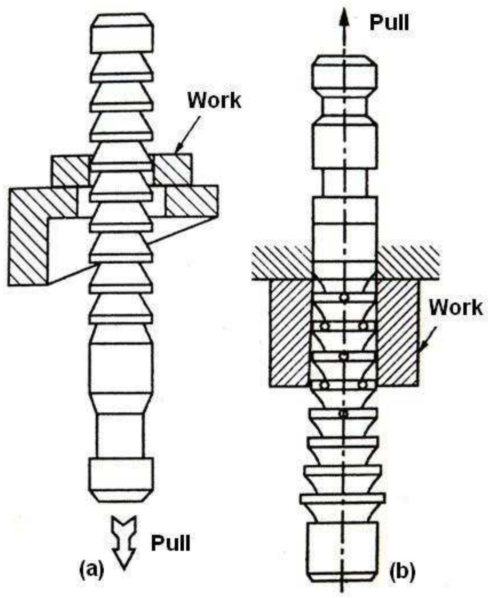


Fig. 4.62 Vertical internal broaching operation (a) pull down type (b) pull up type

4.25 SURFACE BROACHING MACHINES

In horizontal surface broaching machines, the broach is pulled over the top surface of the work piece held in the fixture on the worktable as shown in Fig. 4.63. The cutting speed ranges from 3 to 12 *mpm* with a return speed up to 30 *mpm*. The construction and working principle of horizontal surface broaching machine is similar to that of pull type horizontal internal broaching machine.

In vertical surface broaching machines, the work piece is held in the fixture while the surface broach is reciprocated with the ram on the vertical guide ways on the column as shown in Fig. 4.64. Surface broaching is relatively simple since the broach can be continuously held and then it will carry out only a reciprocating action. The construction and working principle of vertical surface broaching machine is already discussed in the article no. 4.23.1 at page no.

Instead of using simple broach some times the progressive cut type broach with the teeth segments distributed into the three areas as shown in Fig. 4.56 (b) is used in surface broaching. The progressive action reduces the maximum broaching force, but results in a longer broach.

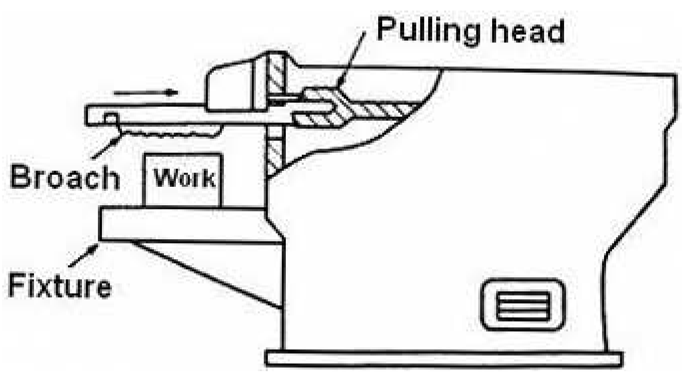


Fig. 4.63 Horizontal surface broaching machine

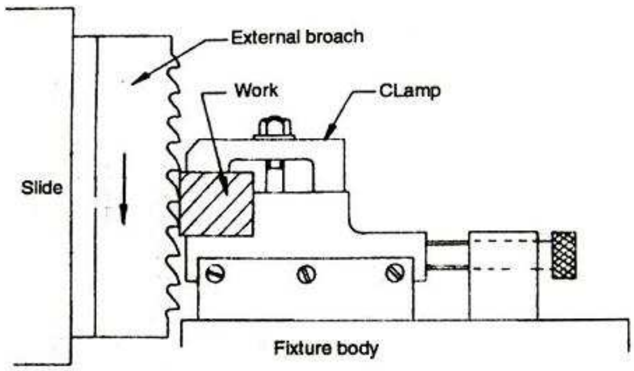


Fig. 4.64 Vertical surface broaching machine

4.26 CONTINUOUS BROACHING MACHINES

These broaching machines are also known as high production broaching machines. The reciprocation of the broach always involves an unproductive return stroke, which is eliminated in a continuous surface broaching machine. These machines are used for fast production of large number of pieces by surface broaching.

4.26.1 Horizontal continuous broaching machine

In this the small work pieces are mounted on the broaching fixtures which are in turn fixed to an endless chain continuously moving in between two sprockets. Broaches which are normally stationary are kept above the work pieces. The work pieces are pushed past the stationary broaches by means of the conveyor for cutting. The work pieces are loaded and unloaded onto the conveyor manually or automatically. *This is illustrated in Fig. 4.65 (a).*

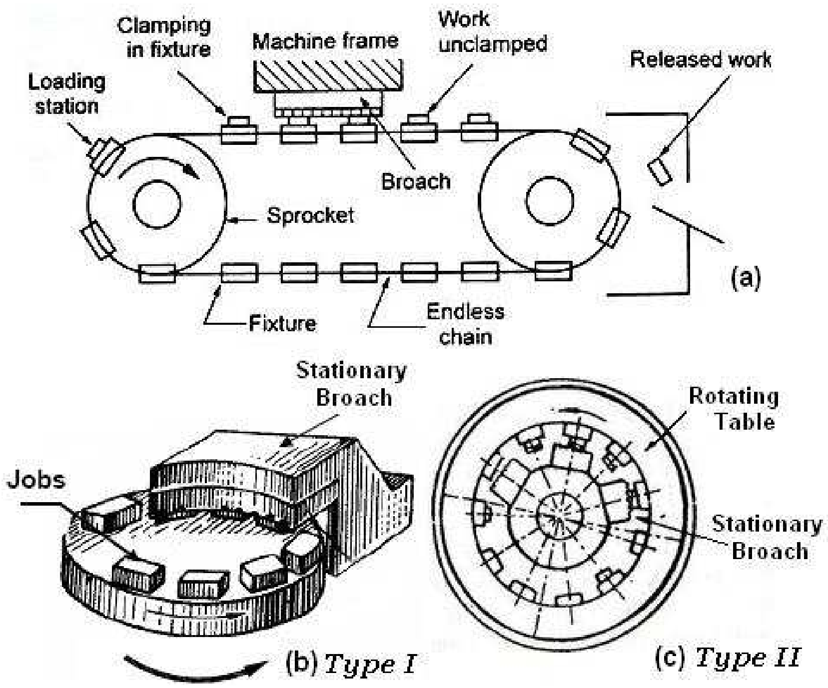


Fig. 4.65 Continuous broaching machine (a) Horizontal type (b) and (c) Rotary type

4.26.2 Rotary continuous broaching machine

Type I: This machine has a rotary table and a vertical column. The vertical column has a guide way. An arm is fixed in the vertical column and it moves up and down in the guide way. Work pieces are clamped in the fixtures horizontally above the work table. The broach is fixed underside of the arm. Now the work table is rotated and the broaching operation is carried out. Depth of cut is given by moving the work table in upward direction. *This is illustrated in Fig. 4.65 (b).*

Type II: This machine has a ring shaped rotating work table. Work pieces are clamped in the fixtures in the inner periphery of the work table. The stationary broaches are fixed in the outer periphery of the vertical column located inside the work table. Now the table is rotated and the broaching operation is carried out. *This is illustrated in Fig. 4.65 (c).*

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

- Incorporating automation in tool – job mounting and releasing.
- Increasing number of workstations or slides for simultaneous multiple production.
- Quick changing the broach by turret indexing.
- Continuity of working.

4.27 GEAR CUTTING

Gears are important machine elements and widely used in various mechanisms and devices to transmit power and motion positively (without slip) between parallel, intersecting (axis) and non-intersecting non parallel shafts:

- Without change in the direction of rotation
- With change in the direction of rotation
- Without change of speed (of rotation)
- With change in speed at any desired ratio

Often some gearing system (rack – and – pinion) is also used to transform rotary motion into linear motion and vice-versa. There are large varieties of gears used in industrial equipments as well as a variety of other applications.

Special attention is paid to gear manufacturing because of the specific requirements to the gears. The gear tooth flanks have a complex and precise shape with high requirements to the surface finish. Gears can be manufactured by most of manufacturing processes. (casting, forging, extrusion, powder metallurgy, blanking, etc.)

But machining is applied to achieve the final dimensions, shape and surface finish in the gear. The initial operations that produce a semi finishing part ready for gear machining as referred to as blanking operations; the starting product in gear machining is called a gear blank.

Two principal methods of gear manufacturing include:

- **Gear forming** - where the profile of the teeth are obtained as the replica of the form of the cutting tool (edge); e.g., milling, broaching etc.
- **Gear generation** - where the complicated tooth profile are provided by much simpler form cutting tool (edges) through rolling type, tool – work motions, e.g., hobbing, gear shaping etc.

Each method includes a number of machining processes, the major of them discussed in this section.

Manufacture of gears needs several processing operations in sequential stages depending upon the material and type of the gears and quality desired. *Those stages generally are:*

- Preforming the blank without or with teeth.
- Annealing of the blank, if required, as in case of forged or cast steels.
- Preparation of the gear blank to the required dimensions by machining.
- Producing teeth or finishing the preformed teeth by machining.
- Full or surface hardening of the machined gear (teeth), if required.
- Finishing teeth, if required, by shaving, grinding etc.
- Inspection of the finished gears.

4.28 GEAR FORMING

Production of gears by gear forming method uses a single point cutting tool or a milling cutter having the same form of cutting edge as the space between the gear teeth being cut. This method uses simple and cheap tools in conventional machines and the setup required is also simple. *The principle of gear forming is shown in Fig. 4.66.*

4.28.1 Shaping, planing and slotting

Fig. 4.67 schematically shows how teeth of straight toothed spur gear can be produced in shaping machine. Both productivity and product quality are very low in this process. So this process is used only for making one or few teeth on one or two pieces of gears as and when required for repair and maintenance purpose. The planning and slotting machines work on the same principle. Planing machine is used for making teeth of large gears whereas slotting, generally, for internal gears.

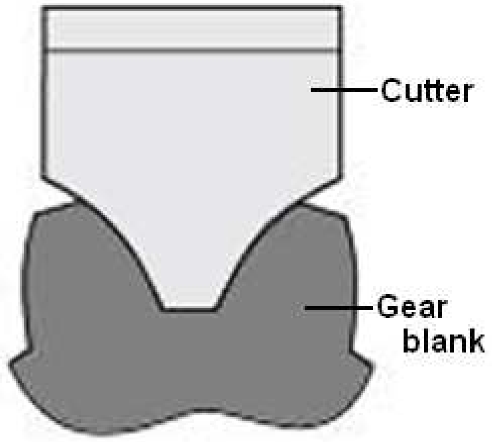


Fig. 4.66 Principle of gear forming

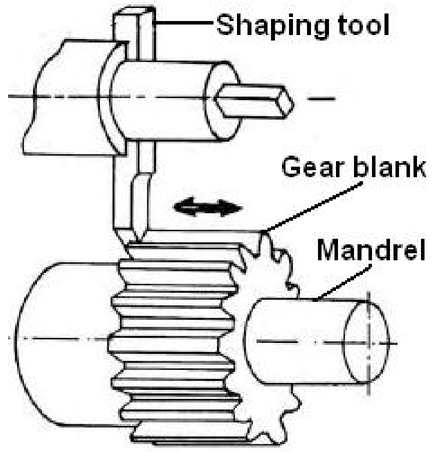


Fig. 4.67 Gear teeth cutting in ordinary shaping machine

4.28.2 Milling

Gear teeth can be produced by both disc type and end mill type form milling cutters in a milling machine. Fig. 4.68 illustrates the production of external spur gear teeth by using disc type and end mill type cutters. Fig. 4.69 shows the form cutters used for finishing cuts and for rough cuts. Fig. 4.70 illustrates the production of external helical gear teeth by using form milling cutter. Fig. 4.71 shows the dividing head and foot stock used to index the gear blank in form milling.

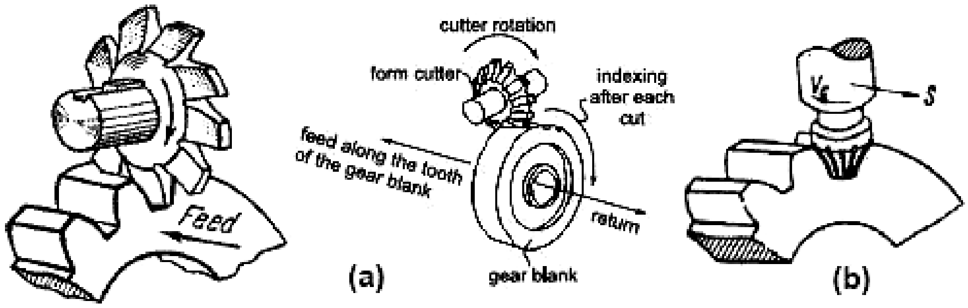


Fig. 4.68 Producing external teeth by form milling cutters
(a) disc type and (b) end mill type

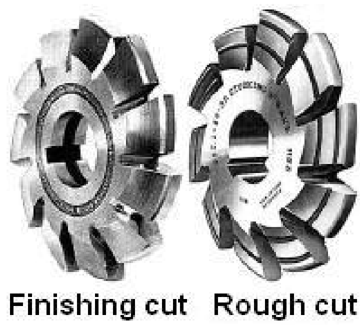


Fig. 4.69 Form milling cutters

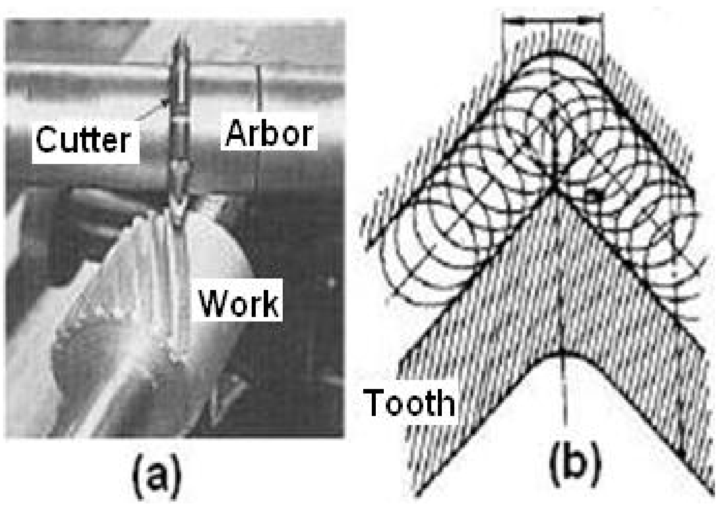


Fig. 4.70 Producing external teeth by form milling cutters (a) single helical and (b) double helical teeth

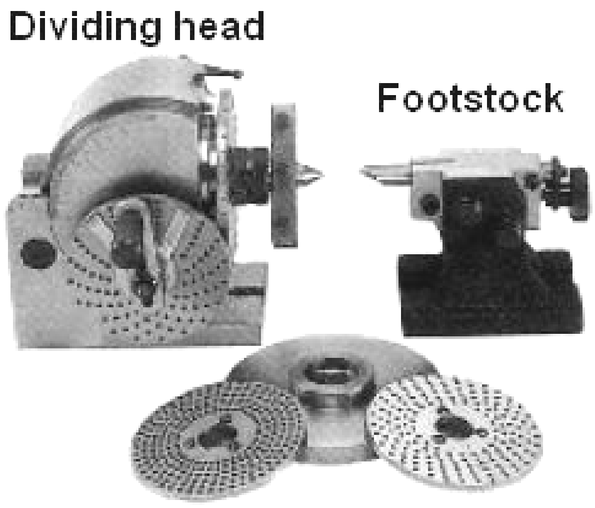


Fig. 4.71 Dividing head and footstock used to index the gear blank in form milling

The form milling cutter called DP (Diametral Pitch, used in inch systems which is equivalent to the inverse of a module) cutter have the shape of the teeth similar to the tooth space with the involute form of the corresponding size gear. These can be used on either horizontal axis or vertical axis milling machines, through horizontal axis is more common.

The cutting tool is fed radially into the work piece till the full depth is reached. Then the work piece is fed past the cutter to complete the machining of one tooth space. Milling of gears is relatively common process in machine shops; it is suitable for small volume production.

The work piece is actually mounted in the dividing head. In form milling, indexing of the gear blank is required to cut all the teeth. Indexing is the process of evenly dividing the circumference of a gear blank into equally spaced divisions. The index head of the indexing fixture is used for this purpose.

The index fixture consists of an index head (also dividing head, gear cutting attachment) and footstock, which is similar to the tailstock of a lathe. The index head and footstock attach to the worktable of the milling machine. An index plate containing graduations is used to control the rotation of the index head spindle. Gear blanks are held between centers by the index head spindle and footstock. Workpieces may also be held in a chuck mounted to the index head spindle or may be fitted directly into the taper spindle recess of some indexing fixtures.

Production of gear teeth by form milling are characterized by:

- Use of HSS form milling cutters.
- Use of ordinary milling cutters.
- Low production rate:
  - Need of indexing after machining each tooth gap.
  - Slow speed and feed.
- Low accuracy and surface finish.
- Inventory problem – due to need of a set of eight cutters for each module – pressure angle combination.
- End mill type cutters are used for teeth of large gears and / or module.

4.28.3 Fast production of teeth of spur gears by parallel multiple teeth shaping

In principle, it is similar to ordinary shaping but all the tooth gaps are made simultaneously, without requiring indexing, by a set of radially infeeding single point form tools as indicated in Fig. 4.72. This old process was highly productive but became almost obsolete for very high initial and running costs.

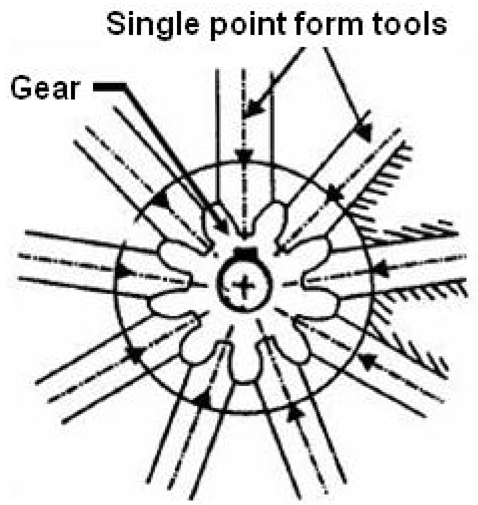


Fig. 4.72 High production of straight teeth of external spur gears by parallel shaping

4.28.4 Fast production of teeth of spur gears by Broaching

Teeth of small internal and external spur gears; straight or single helical, of relatively softer materials are produced in large quantity by this process. Fig. 4.73 (a and b) schematically shows how external teeth are produced by a broaching in one pass. The process is rapid and produces fine surface finish with high dimensional accuracy. However, because broaches are expensive and a separate broach is required for each size of gear, this method is suitable mainly for high-quantity production.

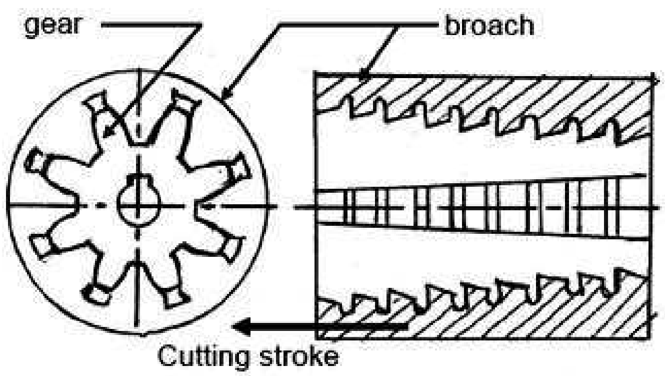


Fig. 4.73 (a) High production of straight teeth of external spur gears by broaching

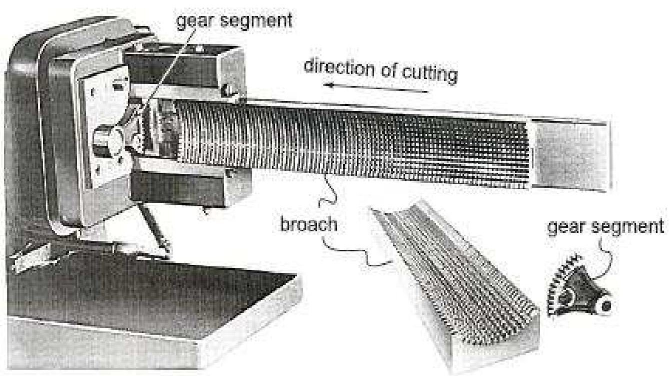


Fig. 4.73 (b) Broaching the teeth of a gear segment by horizontal external broaching in one pass

4.29 GEAR GENERATION

To obtain more accurate gears, the gear is generally generated using a cutter, which is similar to the gear with which it meshes by following the general gear theory. The gears produced by generation are more accurate and the manufacturing process is also fast.

Generation method is characterized by automatic indexing and ability of a single cutter to cover the entire range of number of teeth for a given combination of module and pressure angle and hence provides high productivity and economy. These are used for large volume production.

In gear generating, the tooth flanks are obtained (generated) as an outline of the subsequent positions of the cutter, which resembles in shape the mating gear in the gear pair. In gear generating, two machining processes are employed, shaping and milling. There are several modifications of these processes for different cutting tool used:

- Milling with a hob (gear hobbing).
- Gear shaping with a pinion-shaped cutter.
- Gear shaping with a rack-shaped cutter.

Cutters and blanks rotate in a timed relationship: a proportional feed rate between them is maintained. Gear generating is used for high production runs and for finishing cuts.

4.29.1 Sunderland method using rack type cutter

Fig. 4.74 schematically shows the principle of this generation process where the rack type HSS cutter (having rake and clearance angles) reciprocates to accomplish the machining (cutting) action while rolling type interaction with the gear blank like a pair of rack and pinion.

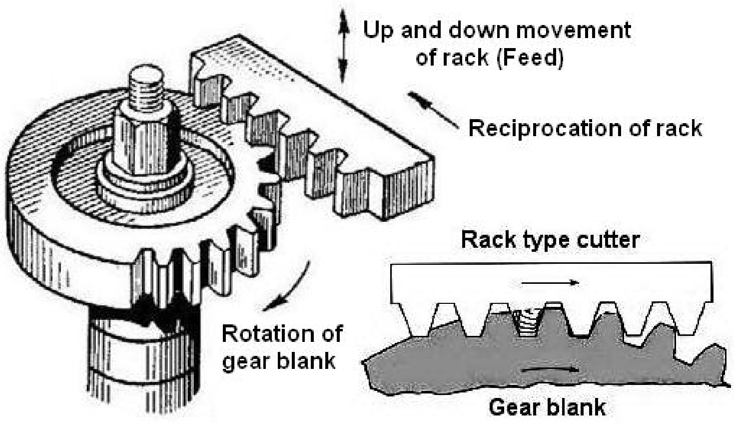


Fig. 4.74 External gear teeth generation by rack type cutter

The favourable and essential applications of this method (and machine) include:

- Moderate size straight and helical toothed external spur gears with high accuracy and finish.
- Cutting the teeth of double helical or herringbone gears with a central recess (groove).
- Cutting teeth of straight or helical fluted cluster gears.

However this method needs, though automatic, few indexing operations. Advantages of this method involve a very high dimensional accuracy and cheap cutting tool (the rack type cutter's teeth blanks are straight, which makes sharpening of the tool easy). The process can be used for low-quantity as well as high-quantity production of spur and helical external gears.

4.29.2 Gear shaping

In principle, gear shaping is similar to the rack type cutting process, except that, the linear type rack cutter is replaced by a circular cutter as indicated in Fig. 4.75, where both the cutter and the blank rotate as a pair of spur gears in addition to the reciprocation of the cutter. Fig. 4.76 schematically shows the generating action of a gear-shaper cutter.

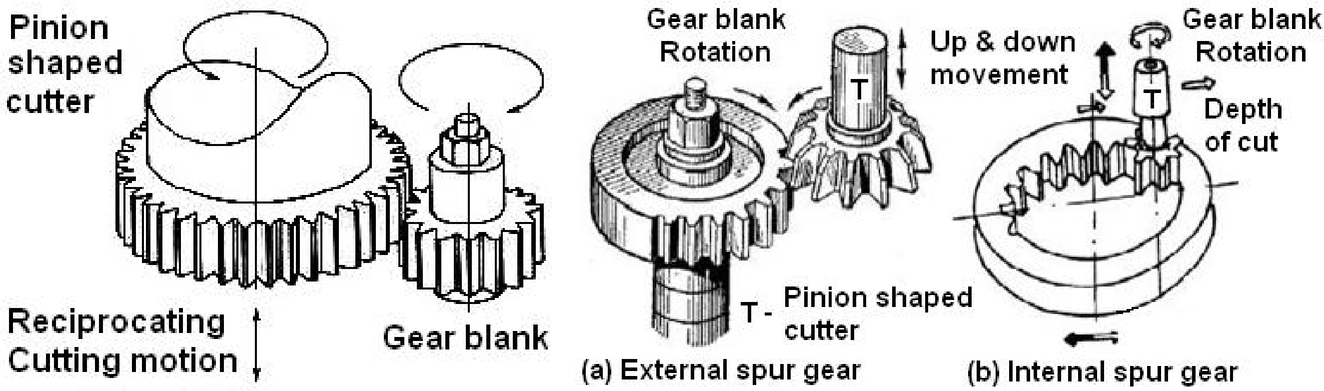


Fig. 4.75 Setup of gear teeth generation by gear shaping operation with a pinion-shaped cutter

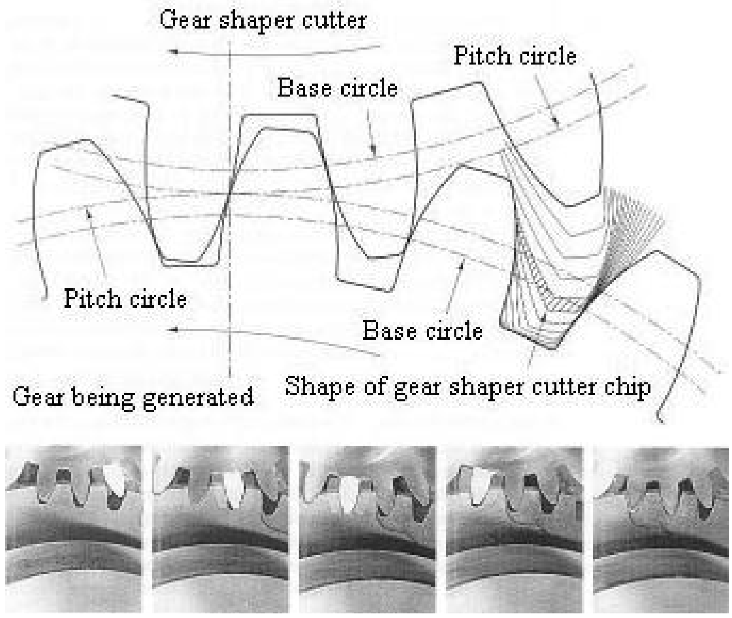


Fig. 4.76 Generating action of a gear-shaper cutter; (Bottom) series of photographs showing various stages in generating one tooth in a gear by means of a gear-shaper cutter, action taking place from right to left. One tooth of the cutter was painted white.

The gear shaper cutter is mounted on a vertical ram and is rotated about its axis as it performs the reciprocating action. The work piece is also mounted on a vertical spindle and rotates in mesh with the shaping cutter during the cutting operation. The relative rotary motions of the shaping cutter and the gear blank are calculated as per the requirement and incorporated with the change gears.

The cutter slowly moves into the gear blank surface with incremental depths of cut, till it reaches the full depth. The cutter and gear blank are separated during the return (up) stroke and come to the correct position during the cutting (down) stroke. Gear shaping can cut internal gears, splines and continuous herringbone gears that cannot be cut by other processes. The gear type cutter is made of HSS and possesses proper rake and clearance angles.

The additional advantages of gear shaping over rack type cutting are:

- Separate indexing is not required at all.
- Straight or helical teeth of both external and internal spur gears can be produced with high accuracy and finish.
- Productivity is also higher.

4.29.3 Gear hobbing

Gear hobbing is a machining process in which gear teeth are progressively generated by a series of cuts with a helical cutting tool (hob). The gear hob is a formed tooth milling cutter with helical teeth arranged like the thread on a screw. These teeth are fluted to produce the required cutting edges. All motions in hobbing are rotary, and the hob and gear blank rotate continuously as in two gears meshing until all teeth are cut. This process eliminates the unproductive return motion of the gear shaping operation. The work piece is mounted on a vertical axis and rotates about its axis.

The hob is mounted on an inclined axis whose inclination is equal to the helix angle of the hob. The hob is rotated in synchronization with the rotation of the blank and is slowly moved into the gear blank till the required tooth depth is reached in a plane above the gear blank.

The tool-work configuration and motions in hobbing are shown in Fig. 4.77, where the HSS or carbide cutter having teeth like gear milling cutter and the gear blank apparently interact like a pair of worm and worm wheel. The hob (cutter) looks and behaves like a single or multiple start worms. Having lesser number (only three) of tool – work motions, hobbing machines are much more rigid, strong and productive than gear shaping machine. But hobbing provides lesser accuracy and finish and is used only for cutting straight or helical teeth (single) of external spur gears and worm wheels.

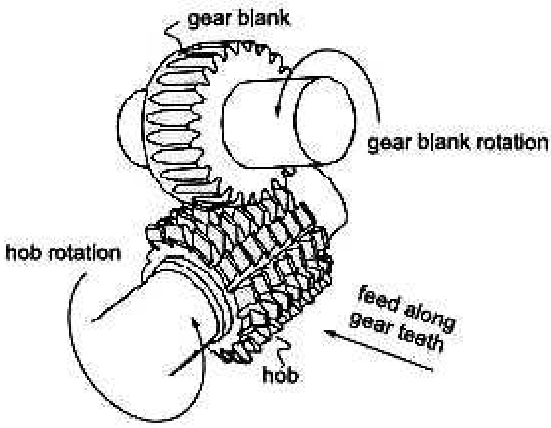


Fig. 4.77 Setup of gear hobbing operation

Fig. 4.78 shows the generation of different types of gears by gear hobbing. When bobbing a spur gear, the angle between the hob and gear blank axes is 90° minus the lead angle at the hob threads. For helical gears, the hob is set so that the helix angle of the hob is parallel with the tooth direction of the gear being cut. Additional movement along the tooth length is necessary in order to cut the whole tooth length. Machines for cutting precise gears are generally CNC type and often are housed in temperature controlled rooms to avoid dimensional deformations.

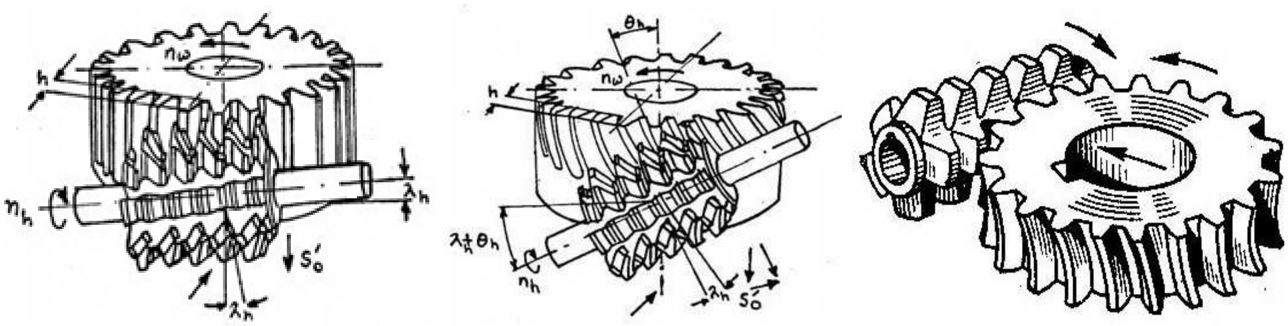


Fig. 4.78 Generation of external gear teeth by hobbing (a) spur gear (b) helical gear and (c) worm wheel

UNIT - V

CNC MACHINE TOOLS AND PART PROGRAMMING

5.1 NUMERICAL CONTROL MACHINE TOOLS

Numerical control of machine tools may be defined as a method of automation in which various functions of machine tools are controlled by letters, numbers, symbols and alphanumeric instructions. Basically a NC machine runs on a program fed to it, by means of punched card, punched tape or magnetic tap. The program consists of precise instructions about the manufacturing methodology as well as the movements.

For example, what tool is to be used, at what speed, at what feed and to move from which point to which point in which path, all these instructions are given. Numerical control is a form of programmable automation. All the functions of an NC machine tool are controlled electronically, hydraulically or pneumatically.

NC Machine Tool = MCU + Machine Tool
MCU = Machine Control Unit = DPU + CLU
DPU = Data Processing Unit, CLU = Control Loop Unit

Block diagram of a NC machine tool is schematically shown in Fig. 5.1

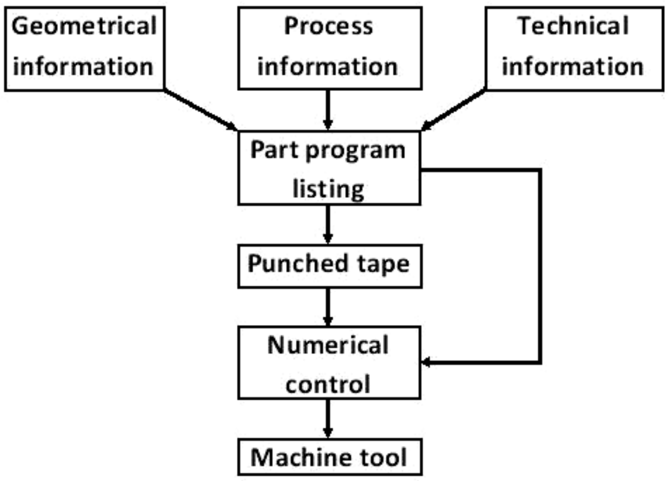


Fig. 5.1 Block diagram of a NC machine tool

5.1.1 Classification of NC machine tools

5.1.2 Components of a NC machine tool

The components of a traditional NC machine tool are:

Program of instructions The program of instruction, often called part program is the detailed set of directions for producing a component by the NC machine. Each line of instruction is a mixture of alphabetic codes and numeric data and is punched in a input media (usually paper tape) in a specified format. This program is translated into electrical signals to drive various motors to operate the machine to carry out the required operations.

Tape punch Usually it is a paper tape of 1 inch width. Paper-Mylar, Aluminium Mylar or plastics are also used as tape materials. Paper tapes are cheap and popular but cannot last long. It is treated to resist oil and water. Mylar tapes are expensive but durable. These are still used by machine manufacturers to store information as executive tapes. Punching machine (Flexo writers) of various types is used to key in program instructions to tapes. Presently tapes are prepared by micro computers by keying in the information from the manuscript. The end of NC tapes was the result of two competing developments, CNC and DNC.

Tape readers

A tape reader reads the hole pattern on the tape and converts the patterns to a corresponding electrical signal.

Machine controller

It receives the electrical signals from tape reader or an operating panel and causes NC machine to respond. It contains a decoder/encoder, an interpolator and facilities to execute auxiliary functions which are machine dependent. The decoder/encoder receives the data and stores them in two separate memory locations. One for the part geometry data and the other for the process data.

For cutting complex surfaces, the interpolator breaks down these curves into small individual increments for each controlled motion of machine tools. Controller also interfaces various machine units like drive motors, transducers and other control functions of the machine tools.

NC machine

It responds to the electrical signals from the controller. Accordingly the machine executes various slide motions and spindle rotations to manufacture a part.

The major advantages of NC over conventional methods of machine control are as follows:

- Higher precision: NC machine tools are capable of machining at very close tolerances, in some operations as small as 0.005 mm.
- Machining of complex three-dimensional shapes: this is discussed in Section 6.2 in connection with the problem of milling of complex shapes.
- Better quality: NC systems are capable of maintaining constant working conditions for all parts in a batch thus ensuring less spread of quality characteristics.
- Higher productivity: NC machine tools reduce drastically the non machining time. Adjusting the machine tool for a different product is as easy as changing the computer program and tool turret with the new set of cutting tools required for the particular part.
- Multi-operational machining: some NC machine tools, for example machine centers, are capable of accomplishing a very high number of machining operations thus reducing significantly the number of machine tools in the workshops.
- Low operator qualification: the role of the operation of a NC machine is simply to upload the work piece and to download the finished part. In some cases, industrial robots are employed for material handling, thus eliminating the human operator.

Types of NC systems

Machine controls are divided into three groups:

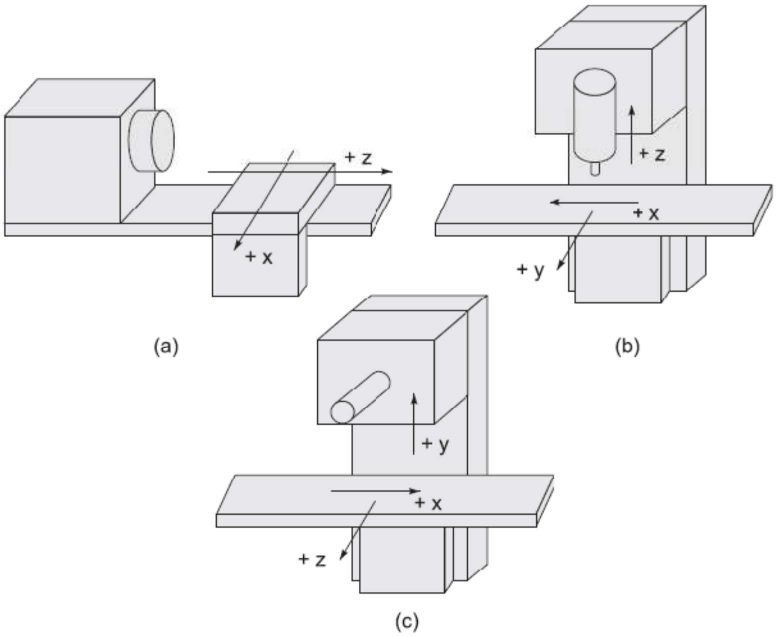
- Traditional numerical control (NC).
- Computer numerical control (CNC).
- Distributed numerical control (DNC).

CNC refers to a system that has a local computer to store all required numerical data. While CNC was used to enhance tapes for a while, they eventually allowed the use of other storage media, magnetic tapes and hard disks. The advantages of CNC systems include but are not limited to the possibility to store and execute a number of large programs (especially if a three or more dimensional machining of complex shapes is considered), to allow editing of programs, to execute cycles of machining commands, etc.

The development of CNC over many years, along with the development of local area networking, has evolved in the modern concept of DNC. Distributed numerical control is similar to CNC, except a remote computer is used to control a number of machines. An off-site mainframe host computer holds programs for all parts to be produced in the DNC facility. Programs are downloaded from the mainframe computer, and then the local controller feeds instructions to the hardwired NC machine. The recent developments use a central computer which communicates with local CNC computers (also called Direct Numerical Control).

Controlled axes

NC system can be classified on the number of directions of motion they are capable to control simultaneously on a machine tool. Each free body has six degree of freedom, three positive or negative translations along x, y, and z-axis, and three rotations clockwise or counter clockwise about these axes. Commercial NC system are capable of controlling simultaneously two, two and half, three, four and five degrees of freedom, or axes. The NC systems which control three linear translations (3-axis systems), or three linear translations and one rotation of the worktable (4-axis systems) are the most common.



Identification of controlled axes for (a) lathe, (b) vertical spindle milling machine and (c) horizontal spindle milling machine

Although the directions of axes for a particular machine tool are generally agreed as shown in the figure, the coordinate system origin is individual for each part to be machined and has to be decided in the very beginning of the process of CNC part programming.

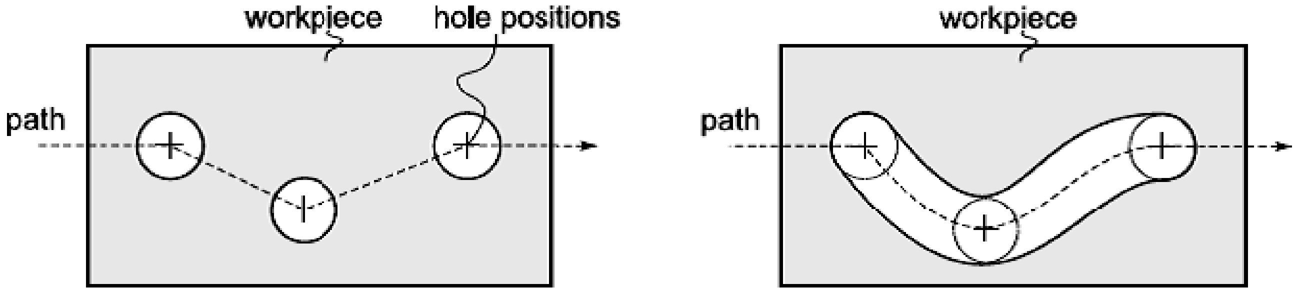
Point-to-point vs. continuous systems

The two major types of NC systems are (see the figure):

- Point-to-point (PTP) system.
- Contouring system.

PTP is a NC system, which controls only the position of the components. In this system, the path of the component motion relative to the work piece is not controlled. The travelling between different positions is performed at the traverse speed allowable for the machine tool and following the shortest way.

Contouring NC systems are capable of controlling not only the positions but also the component motion, i.e., the travelling velocity and the programmed path between the desired positions:



Schematics of point-to-point (Left) and contouring (Right) NC systems.

CNC

The abbreviation CNC stands for computer numerical control, and refers specifically to a computer "controller" that reads G-code instructions and drives a machine tool, a powered mechanical device typically used to fabricate components by the selective removal of material. CNC does numerically directed interpolation of a cutting tool in the work envelope of a machine. The operating parameters of the CNC can be altered via a software load program

CNC was preceded by NC (Numerically Controlled) machines, which were hard wired and their operating parameters could not be changed. NC was developed in the late 1940s and early 1950s by John T. Parsons in collaboration with the MIT Servomechanisms Laboratory. The first CNC systems used NC style hardware, and the computer was used for the tool compensation calculations and sometimes for editing.

Punched tape continued to be used as a medium for transferring G-codes into the controller for many decades after 1950, until it was eventually superseded by RS232 cables, floppy disks, and now is commonly tied directly into plant networks. The files containing the G-codes to be interpreted by the controller are usually saved under the .NC extension. Most shops have their own saving format that matches their ISO certification requirements.

The introduction of CNC machines radically changed the manufacturing industry. Curves are as easy to cut as straight lines, complex 3-D structures are relatively easy to produce, and the number of machining steps that required human action has been dramatically reduced.

With the increased automation of manufacturing processes with CNC machining, considerable improvements in consistency and quality have been achieved with no strain on the operator. CNC automation reduced the frequency of errors and provided CNC operators with time to perform additional tasks. CNC automation also allows for more flexibility in the way parts are held in the manufacturing process and the time required changing the machine to produce different components.

History of CNC

1949 - US Air Force asks MIT to develop a "numerically controlled" machine.
1952 - Prototype NC machine demonstrated (punched tape input).
1980 - CNC machines (computer used to link directly to controller).
1990 - DNC: external computer “drip feeds” control programmer to machine tool controller.

Motivation and uses

- To manufacture complex curved geometries in 2D or 3D was extremely expensive by mechanical means (which usually would require complex jigs to control the cutter motions).
- Machining components with repeatable accuracy.
- Unmanned machining operations.

Advantages of CNC

- Easier to program.
- Easy storage of existing programs.
- Easy to change a program.
- Avoids human errors.
- NC machines are safer to operate.
- Complex geometry is produced as cheaply as simple ones.
- Usually generates closer tolerances than manual machines.

CNC terminology

BLU: basic length unit - smallest programmable move of each axis.

Controller: (Machine Control Unit, MCU) - Electronic and computerized interface between operator and m/c.

Controller components:

- Data Processing Unit (DPU).
- Control-Loops Unit (CLU).

Data Processing Unit:

- Input device [RS-232 port/ Tape Reader/ Punched Tape Reader].
- Data Reading Circuits and Parity Checking Circuits.
- Decoders to distribute data to the axes controllers.

Control Loops Unit:

- Interpolator to supply machine-motion commands between data points.
- Position control loop hardware for each axis of motion.

Types of CNC machines

Based on Motion Type : Point-to-Point or Continuous path.
Based on Control Loops : Open loop or Closed loop.
Based on Power Supply : Electric or Hydraulic or Pneumatic.
Based on Positioning System : Incremental or Absolute.

CONSTRUCTIONAL FEATURES

Spindle drives of CNC machine tools

DC drive units

Direct current motors allow precise control of the speed over a wide operating range by manipulation of the voltage applied to the motor. They are ideally suited for driving the axes of small to medium sized NC machines and robots.

Merits

- It is relatively easy to control the speed of rotation.
- High over load capacity.
- Excellent dynamic response.

Demerits

- High cost.
- Large dimension and weight.
- Regular maintenance is required.

AC drive units

Now a days AC spindle motors are preferred for the main drive by CNC machine tool designers due to a variety of reasons. *They are:*

- AC motors are more reliable than Dc motors under severe operating conditions including floating dust and coolant splash.
- AC motors being free of brushes and other wearing parts do not require frequent maintenance.
- The unique stator cooling system in AC motors results in high speed high output characteristics with compact size.
- AC drive units provide stable and smooth operation with reduced vibrations and noise from low speed to high speed.

Demerits

- Inverters used for converting DC into AC are very costly.
- Size of the inverters is big which occupies more space.

Digital Ac servo drives are preferred today because of:

- Good response for stable, high cutting performance.
- Improved acceleration and deceleration in low speed range.
- Improving rigidity at spindle orientation.
- Improve in linearity of loadmeter.
- Easy setting of maximum rpm through parameter values.

AC spindle drives for machine tools comprise a squirrel cage induction motor and a transistor inverter type controller. *These motors:*

- Are maintenance free.
- Enable fast installation.
- Have high degree of safety.
- Save mechanical gear reductions.
- Have low inertia.
- Have short speed and torque response time.

In order to reduce inertia rotors are made hollow. The magnetic material used is samarium cobalt. Two thermistors are used to protect motor from excessive temperature rise.

Transmission belting

Different types of transmission belting are used with CNC machine drives. For low speed operation (say up to 3000 rpm) it is common to use toothed belt, in conjunction with a toothed pullers. For higher speeds a poly V belt is recommended. This belt has a higher strength but lower mass. The matching profile on the pulley reduces slip. Some CNC machines are found to be fitted with standard V- belts.

Axes feed drives

CNC machines are provided with independent axis drives to provide the feed movements for the slides. The arrangements for the slides are similar with variation only in the ratings of motors or sizes of ball screws. In order to obtain fast response, a special type of motor called servomotor is used to power the slides. The servomotors can be directly coupled or drive is transmitted through a toothed belt drive. The encoders or resolver mounted on the servomotor is used to generate the signals required for position/velocity feedback. *The servomotors are of two types:*

1. DC servomotors
2. AC servomotors

DC servomotors

These are characterized by high overload capacity and excellent dynamic response. They have low moment of inertia. The speeds usually vary upto 3000 rpm. These motors provide smooth rotation even at low speeds.

AC servomotors

3 phase servomotors are now becoming popular with CNC machine tool designers. *These have the followings merits:*

- Low moment of inertia.
- High power/weight ratio.
- Constant acceleration torque up to maximum speed.
- Practically no maintenance required.
- Light weight motor.
- Low speed and torque response times.
- High frequency response.
- High reliability.
- These are self cooled motors.

These motors are provided with integrated holding brake and pulse generator or resolver.

Slideways for CNC machines

Precise positioning and repeatability of machine tool slides are the major functional requirements of CNC machines. The inaccuracies that are caused are mainly due to the stick slip motion when plain slideways (metal to metal contact) are used. To eliminate the stick slip motion rolling friction slideways and slideways with low friction PTFE (Poly Tetra Fluoro Ethylene) are used. These have low wear, negligible stick-slip, good vibration damping, easy machinability, low price and low coefficient of friction properties. *Combinations of machine tool slideway systems:*

Plain

- Metal to metal.
  - Cast iron to cast iron.
  - Cast iron to steel.
  - Steel to steel.
- Plastic to metal.
  - Plastic to cast iron.
  - Plastic to steel.

Rolling friction

Linear motion system with

- Recirculating balls.
- Recirculating rollers.

The requirements of a good slideway system:

A good slideway system must possess;

- Low coefficient of friction at varying slide velocities.
- Minimum difference between static and dynamic friction co efficient - positive slope for friction - velocity characteristics.
- Low rate of wear.
- High stiffness at the sliding joints.
- Sufficient damping.

Plastic coated slideways

In this slideways a plastic or non-metallic inserts are used. These inserts are bonded to the underside of the sliding members. They can be of thermoplastics (Trucite-B) or thermosetting (SKC-3, moglice) types. These inserts/ composites are made of two or more materials in which one reduces co efficient of friction. The other increases strength, war resistance and load bearing capacity. They also have self lubricating property; have a soft matrix for taking up dust or particles and to eliminate scoring. Another advantage is the ease with which a worn out strip can be replaced without the need for any scraping or machining of bed ways.

Linear motion bearings

Rolling element when applied to reciprocating motion has following advantages.

- With rolling element linear motion bearings there is little difference between dynamic friction and static friction. This means that is possible to reduce the drive power to be used and also makes the drive equipment more compact. Further machine weight, overall costs and maintenance cost can be reduced.
- Even though internal clearance is reduced to zero to absorb machine vibration and shock, smooth motion is obtained.
- Stick slip problem is completely eliminated.
- Lubrication of metal to metal contact slideways is difficult at low speed. So a high degree of wear results in conventional slides. But a rolling element slide requires only small quantities of lubricant, shows little wear and lasts long.

Construction

Linear motion guide system consists of a bearing block and rail. Two race ways are provided on one side of the bearing block where two rows of rolls are retained and caused to recirculate by means of retainer and two end plates. The unit is constructed in such a manner that each of the rows of balls rolling over the rail comes into contact with the race way at an angle of 45^o.

The race is in line contact rather than the conventional point contact. Thus the ball has 13 more times allowable load carrying capacity than conventional point contact system. This system is capable of withstanding equal load in any direction.

Ball screws

Ball screws are primarily employed in feed mechanism of CNC machine tools. *When compared with conventional acme and trapezoidal screws, the ball screws provide many advantages, they are:*

- In a ball screws, the load between the threads of the screw and nut is not transmitted by direct contact, but through intermediate rolling members (spherical balls).
- Low coefficient of friction.
- High transmission efficiency. This allows larger thrust loads to be carried with less torque.
- Friction force is virtually independent of the travel velocity and the friction at rest is very small.
- Consequently the stick slip phenomenon is absent, ensuring uniformity of motion.

General arrangement of ball screws

The basic idea of ball screw is to interpose a series of bearing balls between the screw and the nut. These balls rolls in the groove as the nut or screw moves and the rolling friction thus replaces the sliding friction of the conventional acme or trapezoidal screws.

The balls rolling in the grooves exit from the trailing end of the nut, and are picked up by the return tube inserted from outside and are recirculated into the loading end of the nut. The ball screws can have circular or Gothic arch grooves. Gothic arch grooves have a small axial clearance.

Nut configurations

Ball screw nuts are available in different types:

- Round flanged nut with embedded tube for return of the balls.
- Round cylindrical nut with embedded tube.
- Small outside diameter flanged nut with outside tube.
- Rectangular nuts.

Accessories of CNC machines

Automatic Tool Changer (ATC)

An ATC is an important part of a CNC machining centre. An ATC picks up a tool from the magazine and keeps it ready for swapping with the tool in the spindle which is presently cutting. The time for tool change varies between 3 to 7 seconds. The ATC plays a significant role in reducing idle time during tool change operations.

Types of ATC and magazine

Drum type - For holding small number of tools not more than 30, stored on the periphery of the drum. Tool search speed is faster.

Chain type - For more number of tools (more than 30 - 40). Tool search speed is less.

Work tables

Work tables can be indexed or tilted to present a fresh surface for machining. Table tilting is usually done by hinges in the case of horizontal machining centre. Hinges are provided at the side of the table closest to the spindle column and the table is tilted from the other side via a ball screw. A variety of drive systems, including Geneva mechanism for simple indexing have been used. The typical rotary table features DC servomotors connected to a worm drive that rotates the table on preloaded roller bearings.

Spindles

Requirements of spindles for CNC machines are:

- High stiffness both static and dynamic.
- Running accuracy.
- Axial load carrying capacity.
- Thermal stability.
- Axial freedom for thermal expansion.
- High speeds of operation.

The bearings are used are generally ball bearings, roller bearings or hydrostatic bearings. A combination of cylindrical roller bearings for radial loads and double direction angular contact ball bearings for axial thrusts is employed by many designers. High speed spindles are supported by ceramic bearings. The bearing diameter is directly dependent on the spindle taper.

Spindle heads

These are of three types:

- Robot like head.

- Horizontal/vertical head (universal head).
- Inclinable head.

In robot like heads nine axes are usually available in the machine, of which six axes are controlled simultaneously.

Beds and columns

Cast or a welded box type structures are generally used for beds and columns. Large base structures can be economically fabricated with concrete plus resin mixture which gives high rigidity and reduced vibration. In CNC lathes epoxy concrete and concrete mixed with other synthetic material are also used in lathes. These have high damping capacity.

Post process metrology

Work piece probes can be mounted on the tool post which can measure the dimensional accuracy of the work pieces.

Special features

Feedback devices

Feed back devices measure the position of the slide and close the control loop. The accuracy of the positioning of the slide is largely dependent on the resolution of the feedback device. *Feedback devices can be broadly classified into:*

- Digital incremental measuring devices.
- Digital absolute measuring devices
- Analog measuring devices.

Digital incremental displacement measuring systems

Digital measuring methods offer three fundamental advantages when applied to numerical control systems:

- The measured value can be transmitted directly to a numerical data processing unit.
- The data can be processed numerically right from the moment when it is originally produced to the end of the process.
- It is possible to provide a numerical value for the actual position of the slide using very simple means.

Incremental rotary encoders

The visible exterior of the unit includes the shaft, the flange, the rotor housing, and output cable. The shaft carries a graduated glass disc with radial crating. Incremental linear measuring systems use a glass scale with line grating which consists of opaque lines and transparent spaces of equal width.

The digital absolute measuring system

A NC system in which all positional dimensions are measured with respect to a common datum point called a digital absolute system. In such a system, the transducers therefore give a direct reading of position with reference to the common datum (zero point). The zero point may be either a floating or a fixed point. An absolute rotary encoder is used in this system.

Electro magnetic analog position transducers

Synchros and synchro-resolvers

A synchro is an electromagnetic position transducer comprising a rotor and a stator with a number of windings. The level of output voltage depends upon the angular position of the rotor. The voltage reduces to zero when the axis of the rotor coil coincided with the field vector of the stator. A synchro resolver has the windings at exactly 90^o to each other and resolves the voltage into two components at a phase difference of 90^o.

Inductosyn

The Inductosyn is a precision feedback device for the accurate measurement and control of angles or linear distances with inductive coupling between conductors separated by a small air space. Accuracy of better than one second or arc and linear accuracy of better than 0.5 microns is achieved. There are two forms in inductosyns. Rotary form is used in precision servo systems on machine tools and other equipments as a primary generator for shaft digitizers. The linear form provides means for accurate control of elements moving in translation and widely used in automatic machine tool controls.

Laser interferometer

Interferometric techniques have been developed due to the demand for greater accuracy and due to inherent manufacturing errors which lead to decreased accuracy in conventional position and velocity transducers. LASER having high coherence and frequency stability. This can be used in wide environmental conditions and does not require highly skilled operator. Laser interferometers are mainly used for the calibration of CNC machine tools.

Part programming fundamentals

The term CNC programming refers to the methods for generating the instructions used to drive CNC machine tools. For two dimensional components with little geometric complexity, the instructions can be written manually. However as geometrical complexity increases more sophisticated techniques are required, particularly for driving 3 axis, 4 axis CNC machines.

Four distinct techniques are used for generating CNC instructions:

- Manual CNC programming.
- Computer assisted part programming.
- Graphic numerical control programming(CAD/cam based programming system).
- CNC programming based on solid modeling.

Manual part programming

Manual programming is one of the conventional methods of CNC programming. This technique is widely used for work pieces of relatively simple geometry. Manual programming begins with careful study of component drawing. The tool path of the CNC machine is then described in machine codes, which usually take the following general form some of the terms being optional.

N - G - X - Y - Z - A - B - C - F - S - T - M

NC program

A program of NC consists of a sequence of directions that causes an NC machine to accomplish a certain operation. The NC program describes the sequence of actions of the controlled NC machine.

These actions include but are not limited to:

- Component movements, incl. direction, velocity and positioning.
- Tool selection, tool change, tool offsets, and tool corner wear compensation.
- Spindle rotation and spindle rotation speed, incl. possibility to change it to keep constant.
- Cutting speed for different diameters in turning.
- Application of cutting fluids.

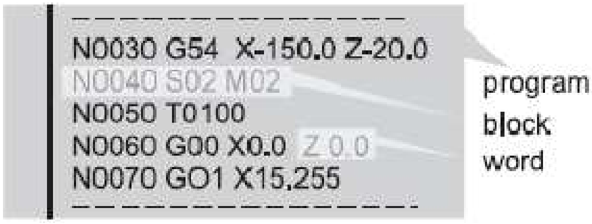
A part program is simply an NC program used to manufacture a part. Part programming for NC may be performed manually (manual part programming) or by the aid of a computer (Computer-aided part programming).

Many programming languages have been developed for part programming. The first that used English like statements and one of the most popular languages is called APT (for Automatically Programmed Tools). Many variations of APT have been developed, including ADAPT (ADaptation of APT), EXAPT (a European flavor of APT), UNIAPT (APT controller for smaller computer systems), etc.

NC programming for complex parts are generated using advanced computer programs (CAD/CAM programs), which create automatically the machine code (so called G-code) in a graphic environment. Machine code is also largely used for manual part programming of simple shapes and is covered in the present section.

Machine code

The structure of a NC program written in machine code is standardized and for a two-axis NC system has the following format:



Structure of a NC program

NC program block consists of a number of program words. The NC program is executed block by block: each next block is entered in the system and executed only after entirely completing the current block.

Each program word is an ordered set of characteristics, letters and numbers, to specify a single action of the machine tool. *Program words fall into two categories:*

- Modal, which are active in the block in which they are specified and remain active in the subsequent blocks until another program word overrides them.
- Non-modal, which are only active in the block in which they are specified.

Some of the most important program words are as follows:

- ***Sequence numbers (N****)***

Sequence numbers are a means of identifying program blocks. In some systems they are not required although sequence numbers are needed in most canned cycles (covered later in this section).

- ***Preparatory functions (also G-codes) (G**)***

Preparatory functions are used to set up the mode in which the rest of the operation is to be executed. Some of examples of G-codes are given in the table.

- ***Dimension words (D****.***), where D stands for X, Z, U, or W***

Dimension words specify the coordinate positions of the programmed path. X and Z specify the absolute coordinates, and U and W specify the incremental coordinates (absolute and incremental programming are explained later in this section);

- ***Arc center coordinates (D****.***), where D stands for I, or K***

Arc center coordinates specify the incremental coordinate position of the arc center (I in the direction of X-axis, and K in the direction of Z-axis), measured from the arc starting point;

- ***Feed function (F**.**)***

  Specifies the velocity of feed motion;
- ***Spindle control function (S****)***

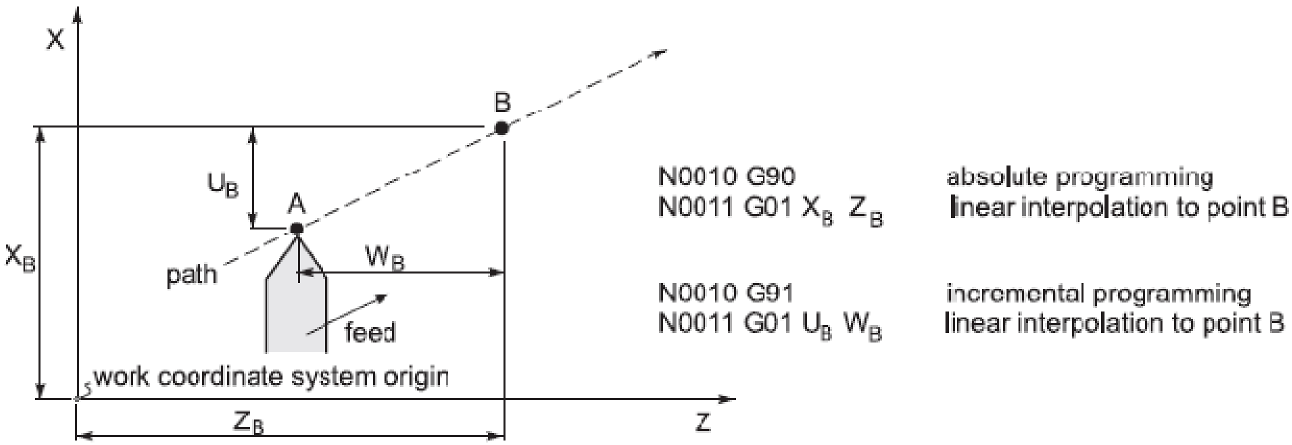
  Specifies spindle rotational speed in revolutions per minute, or cutting velocity in meter per minute depending on the type of NC system and machine tool;
- ***Tool calls (T**.**)***

  The tool call word is used to access the required tool. It also gives the information for the radial compensation of tool corner wear for each new run of the program (and each new part);
- ***Miscellaneous functions (M**)***

  The M-function performs miscellaneous machine actions such as these listed in the table:

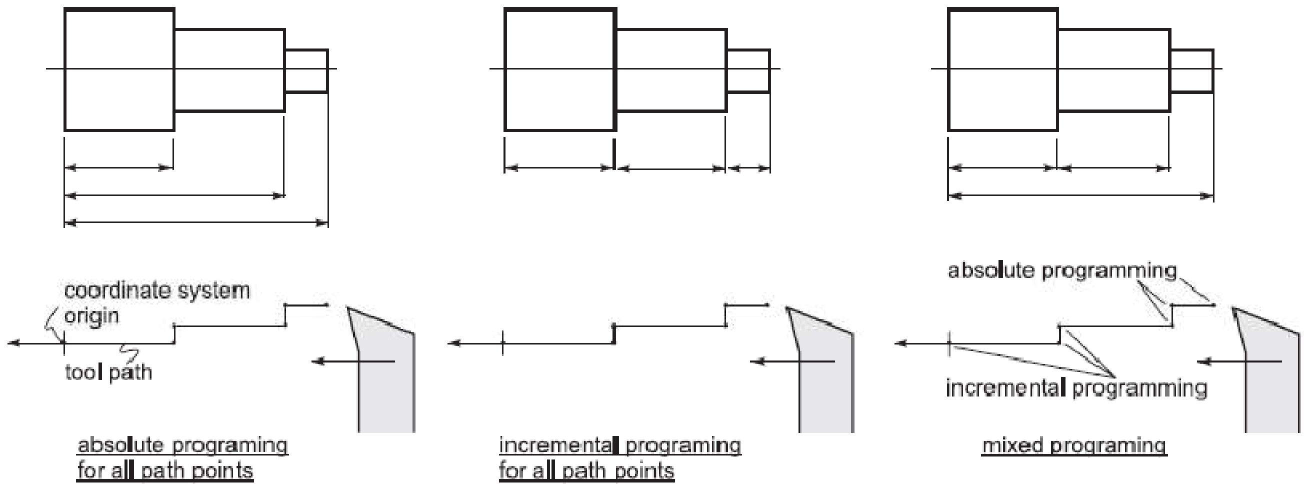
Absolute vs. incremental programming

Absolute and incremental programming specifies the coordinates of points with respect to the work coordinate system (absolute coordinates), or from the point where the component is located (incremental coordinates):



Absolute (X and Z) and incremental (U and W) coordinates of point B,
and sections of NC programs showing both types of programming.

Incremental positioning is also called a point-to-point positioning (do not mix with point-to-point NC systems). Both types of programming can be used for the whole program or just for certain sections of the program. Which kind of programming to apply generally depends on the type of dimensioning used in the part drawing? The next figure illustrates some examples of different dimensioning styles applied to one and the same part configuration, which suggest either absolute, or incremental, or mixed programming:



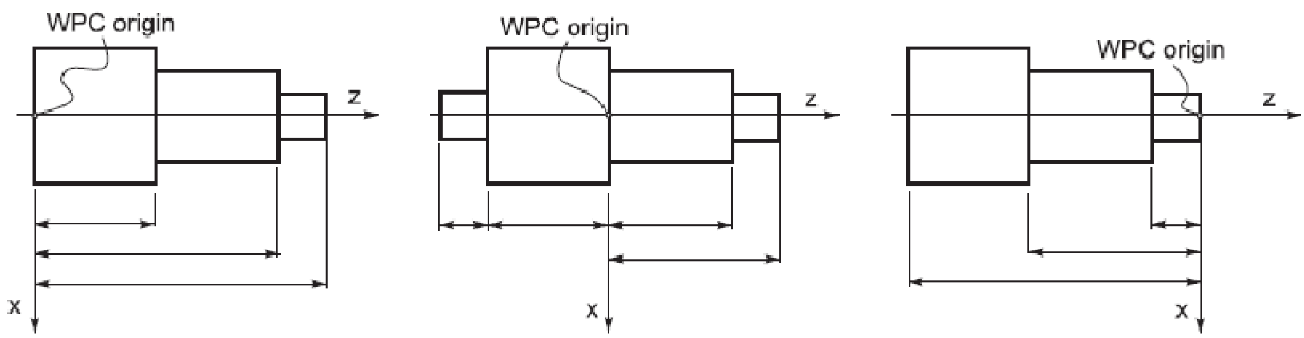
The type of part dimensioning defines the type of programming used.

Program points

The NC system must know where the part is positioned in the work space. The procedure for defining the work coordinate system (WPC) is called work piece coordinate setting. *Two important factors deal with work piece coordinate setting:*

- Where the part datum (the origin of the WPC) is situated with respect to the work piece.
- Where the part datum is situated with respect to the machine tool.

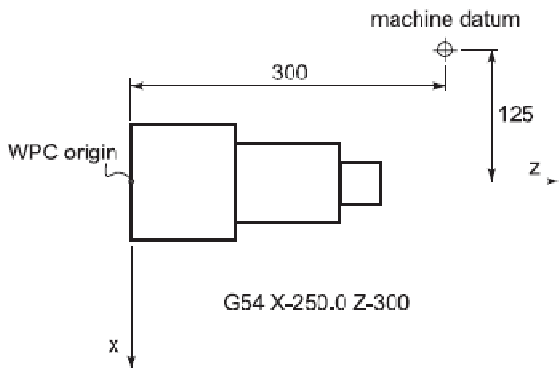
The WPC origin may be located at any part of the work piece, but to avoid dimensional recalculations and respectively errors, the good programmers will chose the WPC origin at the point, from where the part features are dimensioned.



Selection of WPC origin

The method for locating the positions of the WPC origin with respect to the machine tool varies for each machine tool. Some systems use a zero-set button to set the WPC origin. On other types of NC systems, the WPC is set with a G54 or a G92 code followed by X, and Z dimensions.

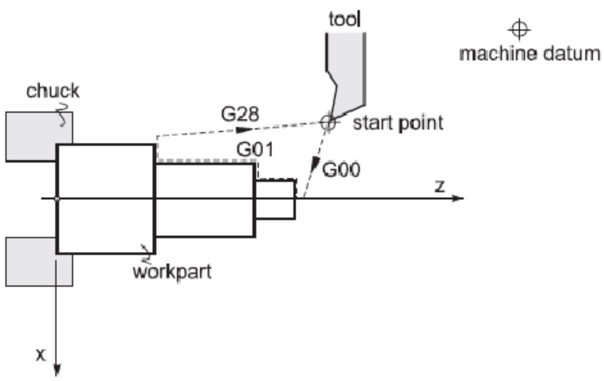
The G54 code tells the machine where the position of the WPC measured from the machine zero point is. Machine zero point (machine datum) is a fixed point on the machine tool and cannot be programmed or altered.



Example of how G54 is used to set the WPC. Note that in turning X is given as a diameter, not radius

Another important point is the program start point (also tool home position). This point is selected by the programmer at some distance from the work piece, not too far to save some time when the tool returns home, and not too close to allow for safe indexing of the tool turret when the cutting tool is changed. The program, therefore the new part machining, starts and ends with the tool at home position, but the tool needs also to be returned to home whenever a tool change take place during the program execution.

Some NC system uses a G28 command to return to home position; other systems return to home automatically when a tool change (M06) is commanded.

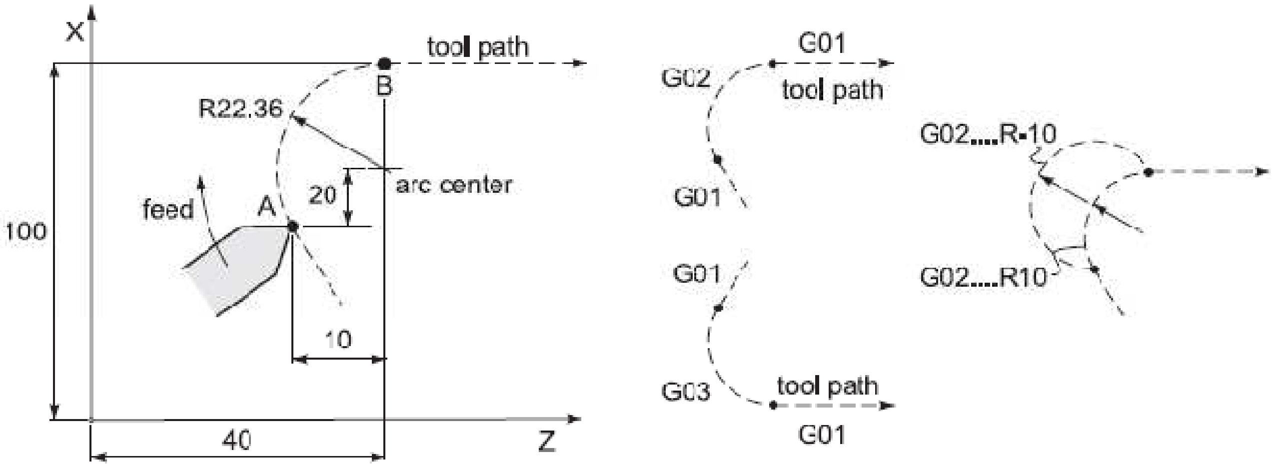


The use of G-codes for rapid positioning of the tool (G00),
linear feed motion (G01) and rapid home return (G28)

Linear and circular interpolation

A G01 linear interpolation code moves the tool to a position with coordinates defined with program words in a straight, including angular line at the specified with F-code feed rate. The command is modal and is active until either a G00, or G02, or G03 overrides it.

NC systems are capable of commanding a circular motion. Arc movement is known as circular interpolation and is carried out with a G02 (clockwise circular interpolation) or G03 (counter clockwise circular interpolation) codes. The arc radius is specified either by the incremental dimensional words I and K, which defines the position of arc center point with respect to the arc start point, or directly by the radius R-code. In both methods, the program block, which starts with a G02 or G03 codes must also include the coordinates of the arc end point. If R-code is used, arcs less than 180o are given a positive radius and arcs more than 180o are given a negative radius value.



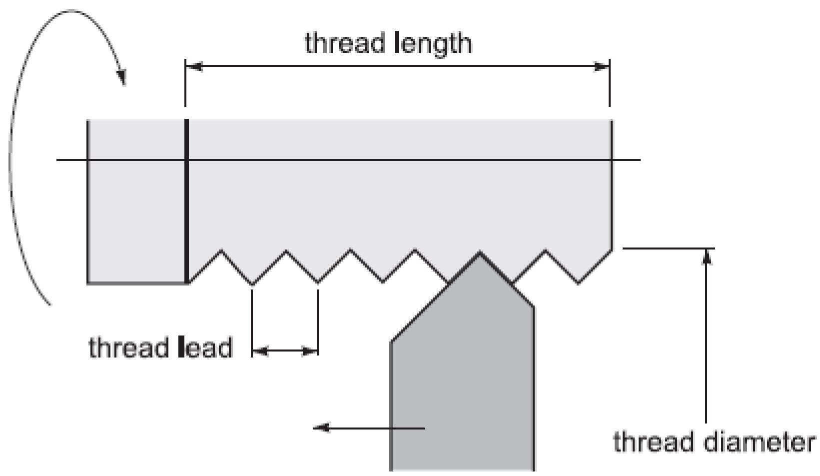
Linear and circular interpolation.

Cycles

The repetitive program (and machining) sequence is called a cycle. Cycles are classified into two principle groups:

- Canned cycles (also fixed cycles).
- User-defined cycles (sub-routines).

Canned cycles are an inbuilt feature of the NC system. The usage of canned cycles makes easier programming for threading, drilling holes and other repetitive machining tasks. The next figure illustrates a thread cutting canned cycle.



Example of threaded canned cycle.

User sub-routines are useful, when the necessary canned cycle is not available. The user sub-routine is a NC program, which describes a sequence of operations, which is often repeated when machining particular part. The sub-routine is called from the main NC program with a M98 command.

A special type of user-defined cycles is so-called macros, which are generic cycles with parametric variables. The macro is called from the main program with a set of numerical values for these variables. This allow to use one and the same macro to machine different in size, but similar in shape components. Programming with macros is often referred to as a parametric programming.

Nomenclature of the CNC machines

According to international standard ISO/R841, the US standard EIA (Electronics Industries Association) document RS267 formed the basis of the ISO standard.

Co-ordinate system

Discussed earlier in NC machines.

Machine types

CNC machines are classified into four groups:

- Group1 – machines with rotating tools.
- Group2 – machines with rotating work pieces.
- Group3 – machines with non rotating work pieces and non rotating tools.
- Group4 – machines other than belongs to above 3 groups – CNC drafting machine.

Motion designation

Discussed earlier in NC machines.

Reference points for manual programming

The machine datum point –M

The machine datum is the origin of the co-ordinate system. With lathes it is on the mounting flange of the main spindle and the turning axis.

It is fixed by the manufacturer and programmed into the computer memory. It cannot be changed by the user of the machine.

The machine reference point – R

The position of the reference point R is determined by the manufacturer. The value of machine reference co-ordinates X_{MR} and Z_{MR} are fixed and cannot be changed by the user.

The machine reference point serves for the calibration of the measuring system.

The workpiece zero point –W

It is also called the program zero point.

This point determines the workpiece co-ordinate system in relation to the machine zero point. This point is chosen by the programmer and inputted to the CNC system when setting up the machine.

Tool post reference point – T

It is the point of rotation of the tool post. It is useful for cutter tool compensation, tool changing etc.

Zero points or zero datum

It is the origin point of the co-ordinate system of the NC machine.

With respect to this origin point programmer decides the tool positions and movements.

There are two methods of specifying this zero point.

Fixed zero

It is fixed by the manufacturer and cannot be changed by the user.

e.g. machine datum point(M) , machine reference point (R)

Floating zero

It is set by the operator at any position on the machine.

e.g. work piece zero point (W), tool post reference point (T)

Part program formats

1. Fixed block format
    a. Fixed sequential format
    b. Tab sequential format
2. Word address format (variable block)

Address Characters as per DIN 66025

Characters	Meaning
A	Rotation about **X** - Axis
B	Rotation about **Y** - Axis
C	Rotation about **Z** - Axis
D & E	Rotations about Additional Axes
F	Feed Rate
G	Preparatory Function
H	Unassigned
I	Interpolation Parameter / Thread Pitch Parallel to **X** - Axis
J	Thread Pitch Parallel to **Y** - Axis
K	Thread Pitch Parallel to **Z** - Axis
L	Unassigned
M	Auxiliary Function
N	Block Number
O	Not Used
P	Thread Movement Parallel to **X** - Axis, Also used as a Parameter in Cycles
Q	Thread Movement Parallel to **Y** - Axis, Also used as a Parameter in Cycles
R	Thread Movement Parallel to **Z** - Axis, Also used as a Parameter in Cycles
S	Spindle Speed
T	Tool Number
U	Secondary Movement Parallel to **X** - Axis
V	Secondary Movement Parallel to **Y** - Axis
W	Secondary Movement Parallel to **Z** - Axis
X	Movement in **X** - Axis
Y	Movement in **Y** - Axis
Z	Movement in **Z** - Axis

Preparatory functions or G functions or G codes in CNC programming

These are the commands which prepare the machine tool for different modes of movement like positioning, turning, facing, thread cutting etc. The preparatory functions always precede the dimension words.

As per DENFORD - FANUC OT (Offline turning) & FANUC OM (offline milling) programming the preparatory functions are given below.

G - CODES - Preparatory Functions

Codes	Function in turning centre	Function in machining centre
G00	Rapid movement or positioning	Rapid movement or positioning
G01	Linear movement with feed rate	Linear movement with feed rate
G02	Circular movement with feed rate (CW)	Circular movement with feed rate (CW)
G03	Circular movement with feed rate (CCW)	Circular movement with feed rate (CCW)
G04	Dwell	Dwell
G05 - G19	Not assigned	Not assigned
G20	Inch data input	Inch data input
G21	Metric data input	Metric data input
G22 - G27	Not assigned	Not assigned
G28	Return to home position	Return to home position

G29 - G39	Not assigned	Not assigned
G40	Tool nose radius compensation cancel	Cutter compensation cancel
G41	Tool nose radius compensation left	Cutter compensation left
G42	Tool nose radius compensation right	Cutter compensation right
G43	Not assigned	Z length offset
G44 - G49	Not assigned	Not assigned
G50	Work coordinate system shift / Clamping maximum spindle speed	Cancel scaling
G51	Not assigned	Scaling
G52, G53	Not assigned	Not assigned
G54	Not assigned	Datum shift
G55 - G67	Not assigned	Not assigned
G68	Not assigned	Coordinate rotation
G69	Not assigned	Cancel rotation
G70	Finishing cycle	Not assigned
G71	Multiple turning cycle	Not assigned
G72	Multiple facing cycle	Not assigned
G73	Pattern repeating cycle	High speed peck drilling
G74	End face peck drilling cycle	Counter tapping
G75	Grooving cycle	Not assigned
G76	Multiple threading cycle	Fine boring
G80	Not assigned	Canned cycle cancel
G81	Deep hole drilling cycle	Drilling - Spot boring
G82	Not assigned	Drilling - Counter boring
G83	Not assigned	Deep hole peck drilling
G84	Not assigned	Tapping
G85, G86	Not assigned	Boring
G87	Not assigned	Back boring
G89	Not assigned	Boring
G90	Turning cycle	Absolute zero command
G91	Not assigned	Incremental command
G92	Threading cycle	Not assigned
G93	Not assigned	Not assigned
G94	Facing cycle	Feed rate in mm / min
G95	Not assigned	Feed rate in mm / rev
G96	Constant surface speed control	Not assigned
G97	Constant surface speed control cancel	
G98	Feed rate in mm / min	Return to initial level
G99	Feed rate in mm / rev	Return to R point level
G170, G171	Not assigned	Circular pocket milling
G172, G173	Not assigned	Rectangular pocket milling

The G codes are divided into two types:

- Model G codes.
- One shot or non-model G codes.

Model G codes - This G code is effective until another G code in the same group is commanded.

Non-model G codes - This G code is effective only at the block in which it was specified.

Motion group – GO0, G01, GO2, GO3
Dwell group – GO4

Active plane selection group – G17, G18, G19
Cutter compensation group – G40, G41, G42
Units Group – G20, G21
Hole making canned cycle group – G80, G81-G89
Co – ordinate system group – G90, G91

Canned cycles or fixed cycles

The routine that automatically generates multiple tool movements from a single block is known as canned or fixed cycle. e.g. G71,G70,G81-G89, G92

G80 – canned cycle cancel.

Merits

- Program becomes simple and needs less memory.
- Program writing is easier.

Miscellaneous or Auxiliary functions or M codes

The function related to the auxiliary or switching information like spindle start-stop, coolant on-off, etc., and not related to any dimensional movement of the machine is known as miscellaneous functions.

As per Denford - FANUC OT (offline turning) and FANUC OM (offline milling) programming the miscellaneous functions are given below.

M - CODES - Miscellaneous Functions

Codes	Function in turning centre	Function in machining centre
M00	Program stop	Program stop
M01	Optional stop	Optional stop
M02	End of program	Program reset
M03	Spindle forward	Spindle forward
M04	Spindle reverse	Spindle reverse
M05	Spindle stop	Spindle stop
M06	Automatic tool change	Automatic tool change
M07	High pressure coolant ON	Not assigned
M08	Low pressure coolant ON	Coolant ON
M09	Coolant OFF	Coolant OFF
M10	Chuck open	Vice open
M11	Chuck close	Vice close
M13	Spindle forward and coolant ON	Spindle forward and coolant ON
M14	Spindle reverse and coolant ON	Spindle reverse and coolant ON
M19	Not assigned	Spindle orientation
M20	Not assigned	ATC arm in
M21	Not assigned	ATC arm out
M22	Not assigned	ATC arm down
M23	Not assigned	ATC arm up
M24	Not assigned	ATC draw bar unclamp
M25	Tail stock quill extend	ATC draw bar clamp
M26	Tail stock quill retract	Not assigned
M27	Not assigned	Reset carousel to pocket one
M30	Program stop and reset	Program reset and rewind
M32	Not assigned	Carousel CW
M33	Not assigned	Carousel CCW
M38	Door open	Door open
M39	Door close	Door close

M40	Parts catcher extend	Not assigned
M41	Parts catcher retract	Not assigned
M62 - M67	Auxiliary output functions	Not assigned
M70	Not assigned	Mirror in ‘X’ ON
M71	Not assigned	Mirror in ‘Y’ ON
M76, M77	Auxiliary output functions	Not assigned
M80	Not assigned	Mirror in ‘X’ OFF
M81	Not assigned	Mirror in ‘Y’ OFF
M98	Sub program call	Sub program call
M99	Sub program end and return	Sub program end and return

Computer assisted part programming

In computer aided part programming, much of the tedious computational work needed in manual programming is performed by the computer processor. In this programming the programmer prepare the set of instructions in high level computer language. The high level computer languages use simple English words which can be converted to machine tool level program with the help of processors.

***Merit* –** programming becomes less time consuming and accurate.

e.g. APT, UNIAPT, ADAPT, COMPACT-II

APT language

The APT (automatically Programmed Tools) language system was designed at the servomechanism laboratory of Massachusetts institute of technology. The APT NC reference language consists of a specially structured set of vocabulary, symbols, rules and conventions which are easily understood by the part programmer and would help him in faster preparation of control tapes.

Today it is used for continuous path programming up to five axes. It includes:

- APTURN for Lathes
- APTMIC for mill and drill
- APTPOINT for point-point operation

APT program is used to command the cutting tool through its sequence of machining process. APT is also used to calculate the cutter positions. APT is a three dimensional system controlling up to five axes including rotational co-ordinates.

The complete APT part program consists of the following four types of statements:

- Geometric statements.
- Motion statements.
- Post processor statements.
- Special or compilation control or Auxiliary statements.

Geometric statements

These are used to define the part configuration, which includes points, lines, circles, planes, cylinders, ellipses, cones, general conics and quadrics with a total of fifteen different surfaces.

Format:

Symbol = Geometry type/ descriptive data

Motion statements

These statements are used to control the cutter path to generate the part and include start-up procedures, point-to-point programming, cutter description and direction modifiers.

Format:

Motion command/ descriptive data

Post processor statements

These are used to specify the machine tool functions and are supposed to be acted upon by the post processor identified earlier in the part program.

e.g. COOLNT/ON, SPINDL/ON, FEDRAT/20

Auxiliary statements

These are used for cutter size definition, part identification and so on. These statements control the output listing, translation, rotation and repetitive programming techniques.

e.g. CLPRNT, OUTTOL, INTOL, FINI.

Normally, a part program is executed sequentially starting from a PARTNO statement to the FINI statement. After entering the program, a printout of the APT processor can be obtained showing the canonical information of all the geometry defined and the cutter location data. A plot of the CLDATA is also obtained to prove the validity of the program.

A CNC Turning Center

A CNC Milling Machine

CNC panel Siemens Sinumerik

Siemens CNC panel

The abbreviation **CNC** stands for **computer numerical control**, and refers specifically to a computer "controller" that reads G-code instructions and drives a machine tool, a powered mechanical device typically used to fabricate components by the selective removal of material. CNC does numerically directed interpolation of a cutting tool in the work envelope of a machine. The operating parameters of the CNC can be altered via a software load program.