LECTURE NOTES

ON

MACHINE TOOLS AND METROLOGY

B. Tech V Semester, Mechanical Engineering

(IARE – R16)

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UNIT – I

BASIC MECHANISM OF METAL CUTTING

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.

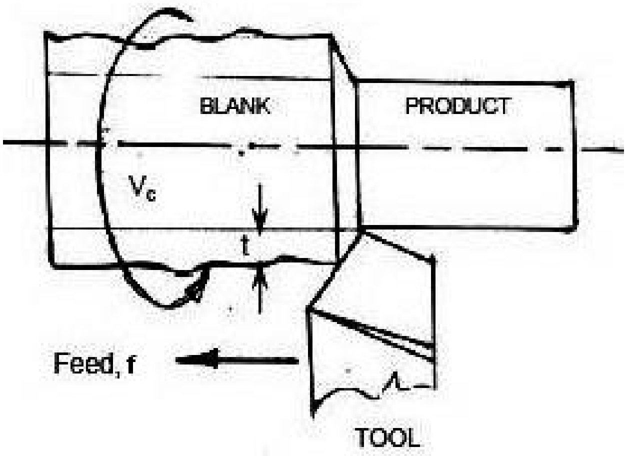
MATERIAL REMOVALPROCESSES

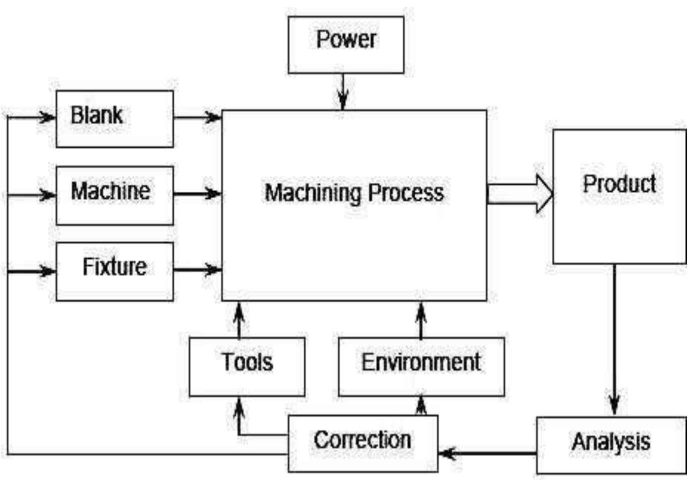
Definition of machining

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).

Principle of machining

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.





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. Performing 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.

Requirements of machining

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.

TYPES OF MACHINETOOLS

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).

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.

THEORY OF METALCUTTING

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.

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.

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.*

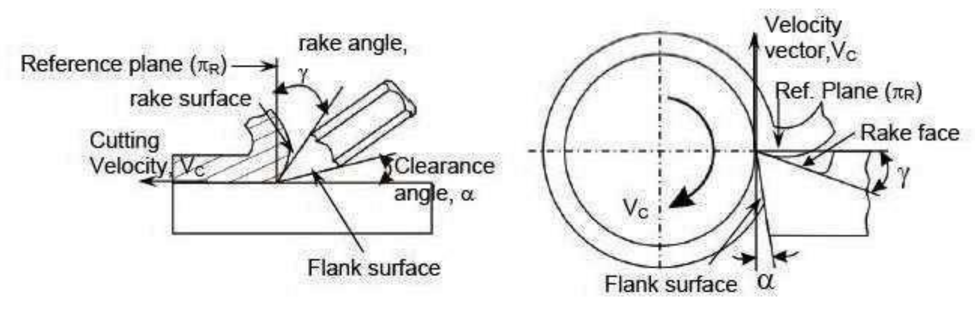
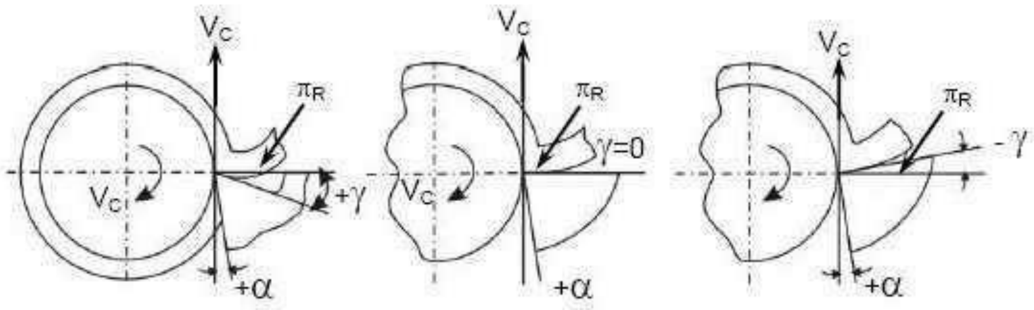


Fig. 1.3 Rake and clearance angles of cutting tools

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. Rakeangle is provided forease of chip flowand overall lmachining. Rake angle maybepositive, 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 ($3^0 \sim 15^0$) depending upon tool-work materials and type of the machining operations like turning, drilling, boring etc.

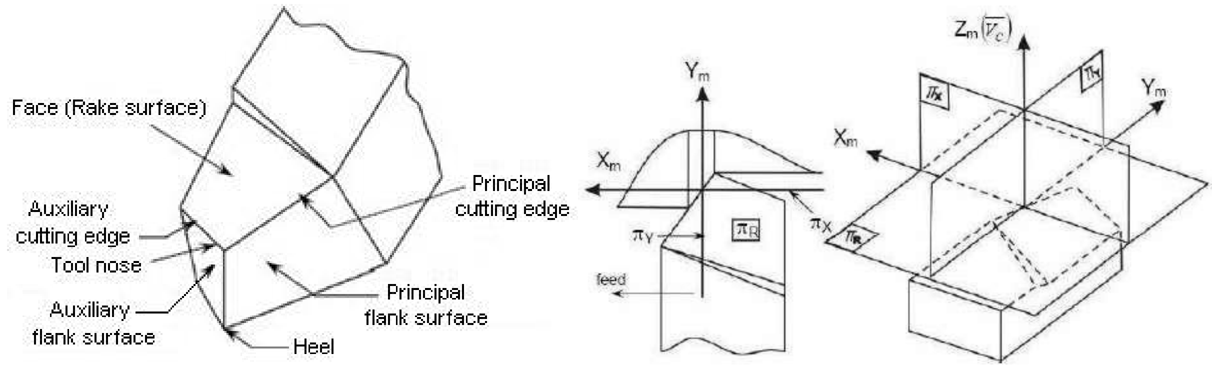
Systems of description of tool geometry

- 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
- Tool Reference System
  - ASA system.
  - Orthogonal RakeS ystem
  - Normal Rake System- NRS.
- Work Reference System - WRS.

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).* or negative or even zero *as shown in Fig. 1.4 (a, b and c).* cutting (turning)tool in ASA system



(a) Basic features of single point Fig. 1.5 (b) Planes and axes of reference

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

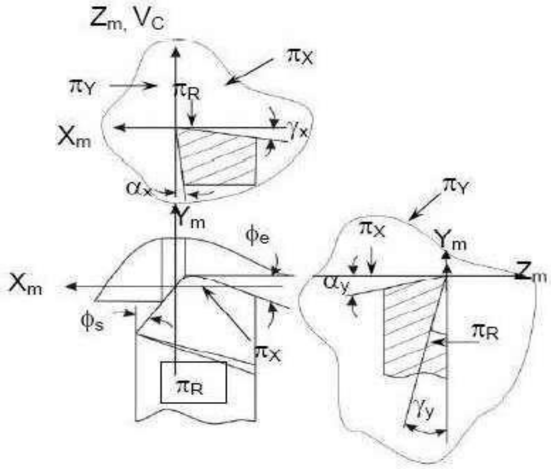
Π_R - Π_X - Π_Y and X_m - Y_m - Z_m; where,

***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.*



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.

Face: The surface against which the chip slides upward.

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. [

Heel: The lowest portion of the side cutting edges.

Nose radius: The conjunction of the side cutting edge and end cutting edge. It provides strengthening of the tool nose and better surface finish.

Base: The underside of the shank.

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:

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:

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.

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

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.

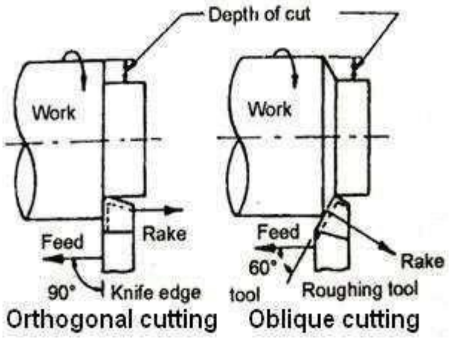
Orthogonal and oblique cutting

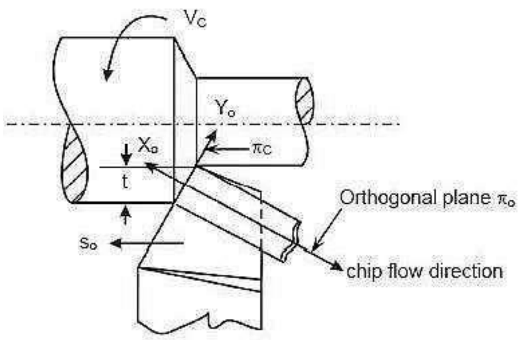
It is appears from the diagram *shown in Fig. 1.7 (a and b)* that while turning ductile material by a sharp tool, the continuous chip would flow over the tool‘s rake surface and in the direction apparently perpendicular to the principal cutting edge, i.e., along orthogonal plane which is normal to the 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, $\rho_c = 0^0$.

- Flow is deviated from π_o and $\rho_c = \lambda$ where ρ_c is chip flow deviation (from π_o)

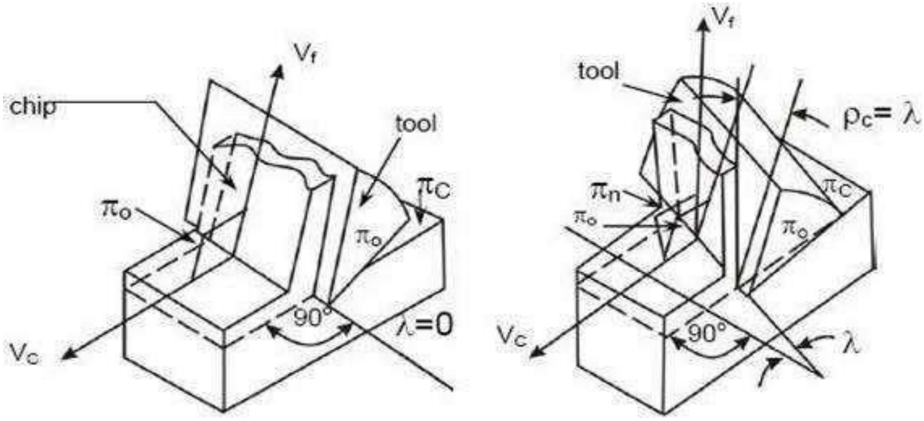




angle.

(a) Setup of orthogonal and oblique cutting

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



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.

CHIPFORMATION

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:

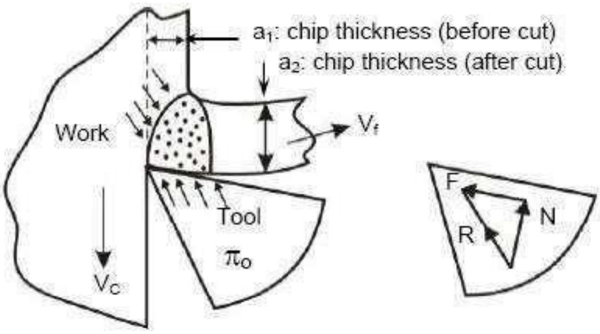
- Work material.
- Material and geometry of the cutting tool.
- Levels of cutting velocity and feed and also to some extent on depth of cut.

- Machining environment or cutting fluid that affects temperature and friction at the chip-tool and work-tool

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

Mechanism of chip formation in machining ductile materials

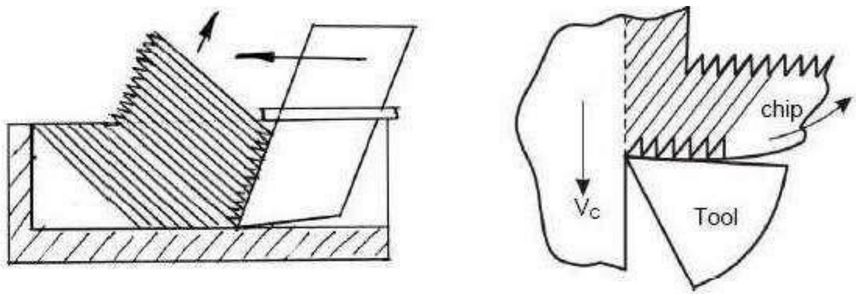
During continuous machining the uncut layer of the work material just ahead of the cutting tool (edge) is subjected to almost all sided compression



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 the chip-tool engagement.

As a result the slip or shear stops propagating long before the 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 information and removal of chips in thin layers by layer. *This phenomenon has been explained in a simple way by Piispannen*[*1] *using a card analogy*



Shifting of the postcards by partial sliding against each other (b) Chip formation by shear in lamella 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 *(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, depend upon:

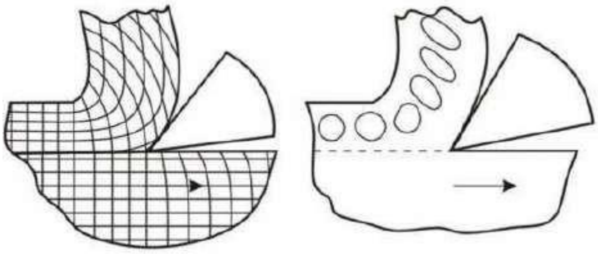
- Work material.
- Tool; material and geometry.
- The machining speed (VC) and feed (so).
- Cutting fluid application.

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
- 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

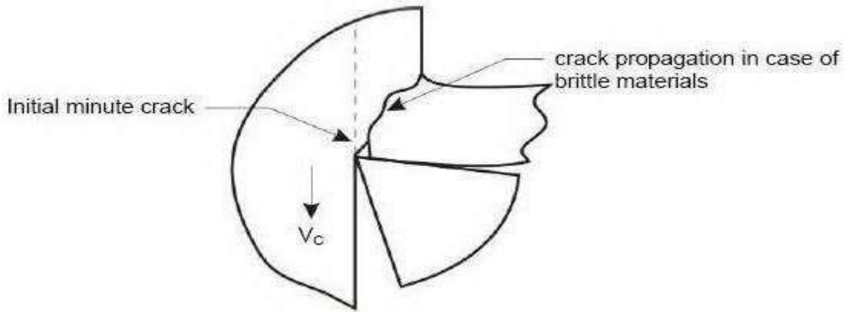
Pattern of grid deformation during chip formation

Mechanism of chip formation in machining brittle materials

The basic two mechanisms involved in chip formation are:

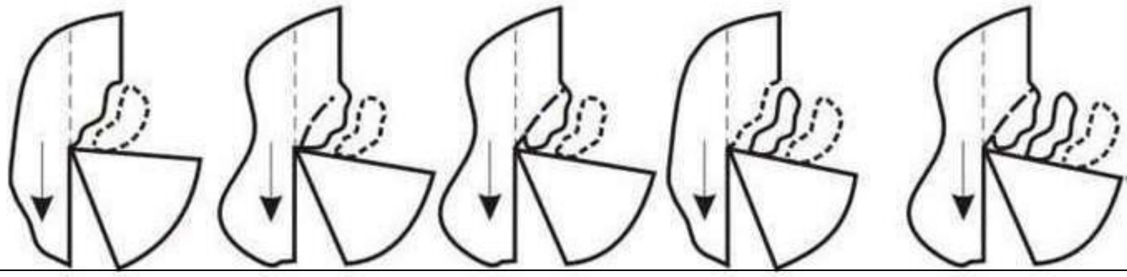
- Yielding - generally for ductile materials.
- Brittle fracture - generally for brittle materials.

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



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



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.

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

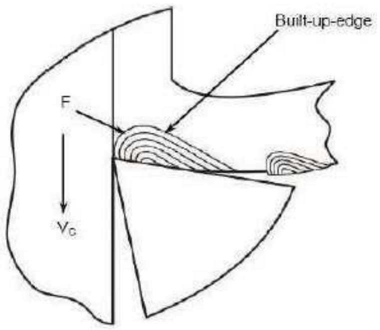


Fig Scheme of built-up-edge formation

With the growth of the BUE, the force, F (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.

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.

Types of chips

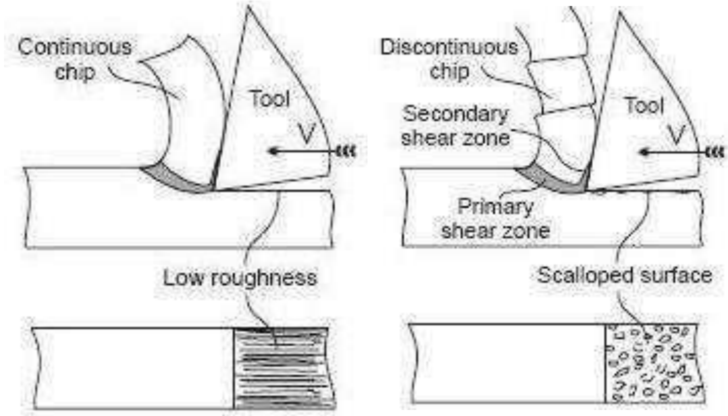
Different types of chips of various shape, size, colour etc. are produced by machining dependingupon:

- 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*



Formation ofcontinuous chips 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 following condition favors the formation of discontinuous chips:

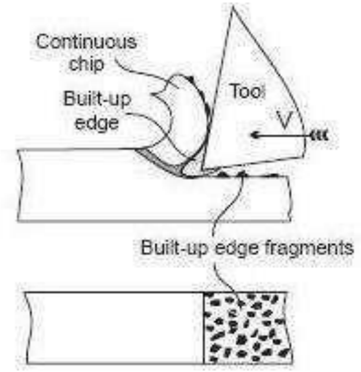
- Of irregular size and shape: - work material - brittle like gray cast iron.
- Of regular size and shape: - work material ductile but hard and work hardenable.
- Feed rate -large.
- Tool rake -negative.
- Cutting fluid - absent or inadequate.

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..



Formation of continuous chips with BUE

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

- Work material -ductile.
- Cutting velocity - low (~0.5m/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.

Chip breakers

1.2.2.1 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.

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 the machining of ductile metals and alloys at high speed.

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

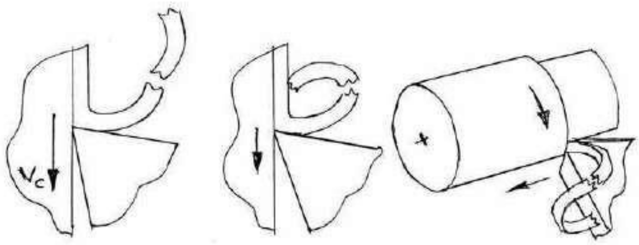
- ***Self chip breaking* -** This is accomplished without using a separate chip-breaker either as an attachment or an additional geometrical modification of the tool.
- ***Forced chip breaking* -** This is accomplished by additional tool geometrical features or devices.

Self breaking of chips

Ductile chips usually become curled or tend to curl (like clock spring) even in the machining of tools with flat rake surface due to the 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 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, mostly under pure orthogonal cutting.
- By striking against the tool flank after each half to full turn



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

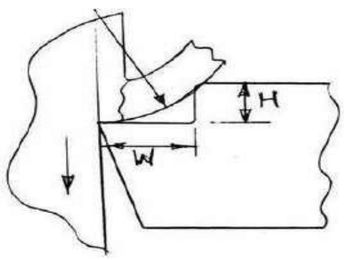
- In-built type.
- Clamped or attachment type.

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.

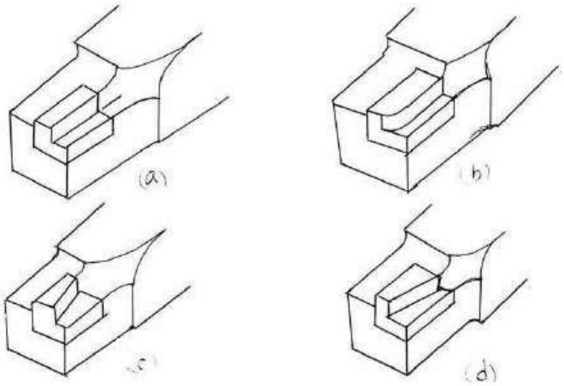
When the strain hardened and brittle running chip strikes the heel, the cantilever chip gets forcibly bent and then breaks.

- Parallel step.
- Angular step; positive and negative type.



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

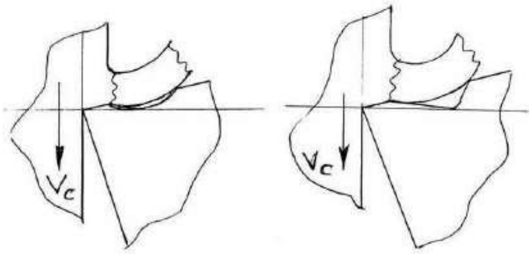
Principle of forced chip breaking



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

(a and b) schematically shows some commonly used groove type in-built chip

- Circular groove.
- Tilted Vee groove.



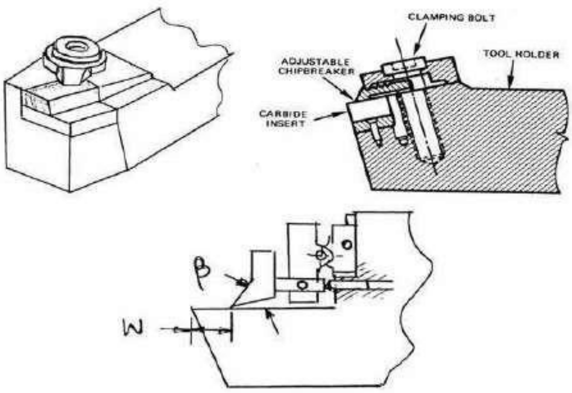
(a) Circular groove (b) Tilted V groove *the unique characteristics of in-built chip breakers are:*

- 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.

(b) 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.

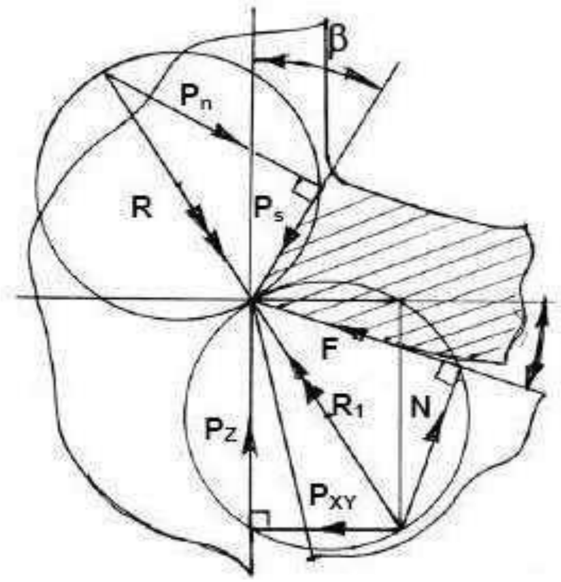
- With fixed distance and angle of the additional strip - effective only for a limited domain of parametric combination.
- With variable width (W) only – little versatile.
- With variable width (W), height (H) and angle (β) - quite versatile but less rugged and more expensive.



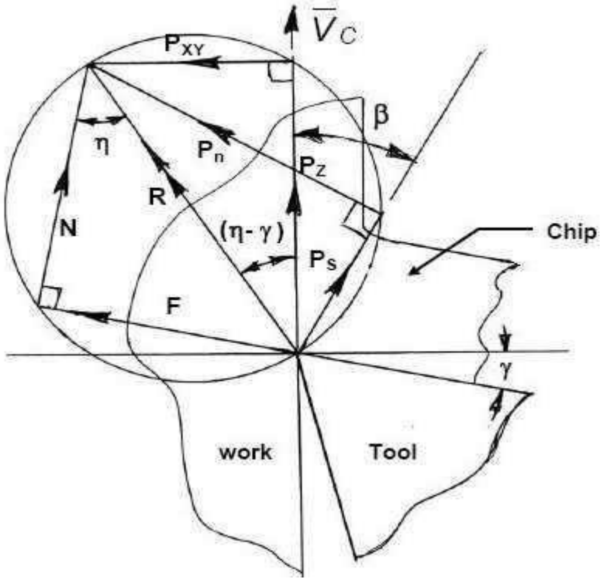
(a) Fixed geometry (b) Variable width (c) Variable width and angle Fig Clamped type chip breakers

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.



Development of Merchant's diagram with cutting forces



Merchant's Circle Diagramcircle

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 stateo f 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.

CUTTING TOOLMATERIALS

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:*

- 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.

Needs and chronological development of cutting tool materials

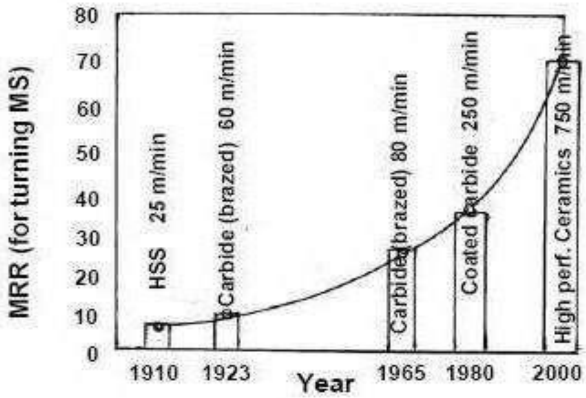
With the progress of the industrial world it has been needed to continuously develop and improve the cutting tool materials and geometry:

- 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.



The chronological development of cutting tool materials is.

Productivity raised by cutting tool materials Chronological development of cutting tool materials

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 re sharpening.

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 of HSS are given in 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.

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 250m/min.
- Alumina; with or without additives - hot pressed, black colour, hard and strong - used for machining steels and cast iron at VC = 150 to 250m/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 200m/min.

Development and applications of advanced tool materials

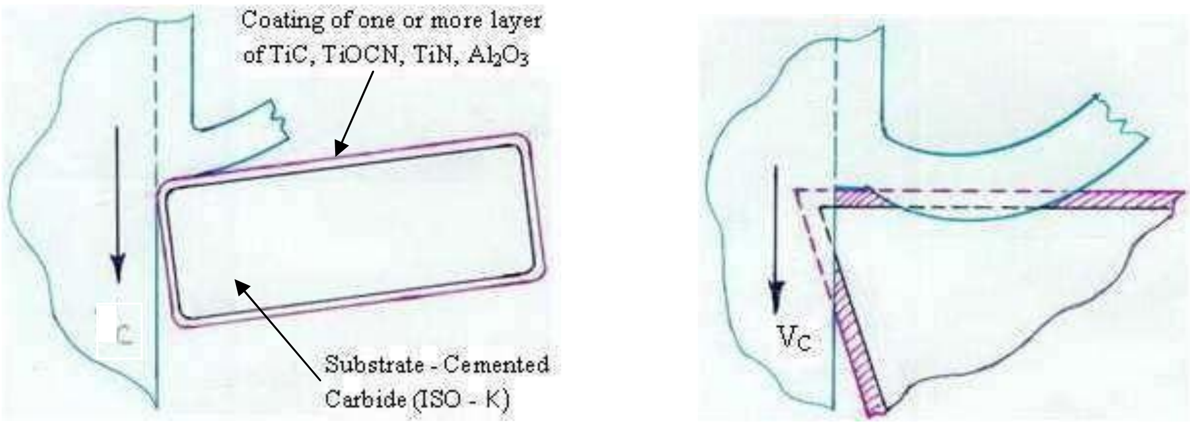
a) Coated carbides

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.



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.
- Multi layering (already up to 13 layers within 12 ~ 16μm).
- 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 to20%.
- 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.

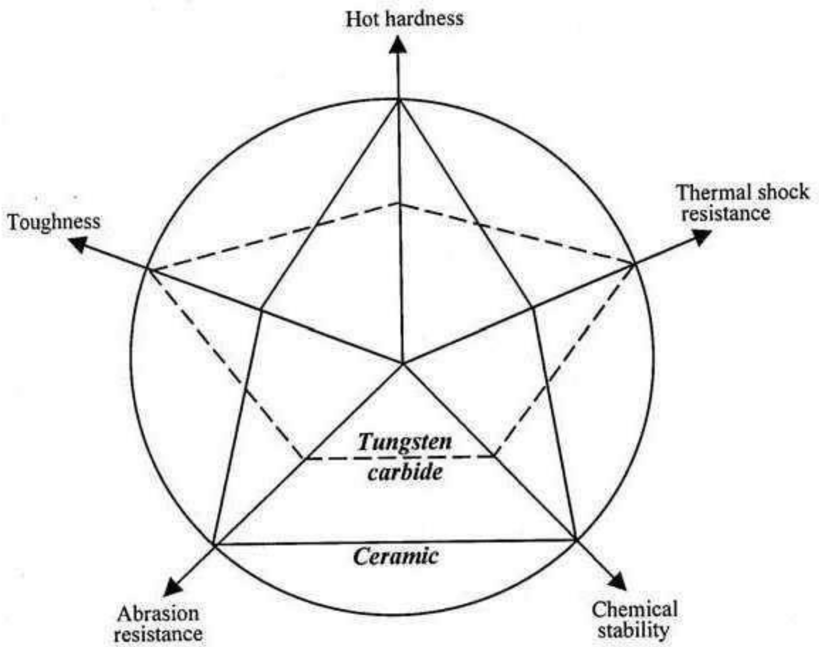
Unlike solid carbide, the coronite based tool is made of three layers:

- 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



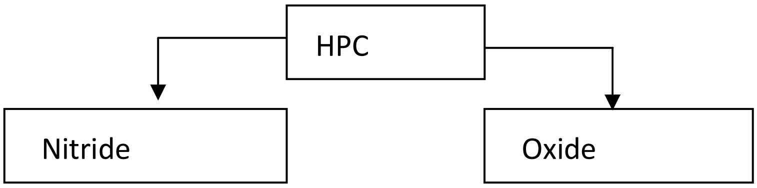
Through last few years" remarkable improvements in strength and toughness and hence overall performance of ceramic tools could have been possible by several means which include:

- Sinterability, microstructure, strength and toughness of Al_2O_3 ceramics were improved to some extent by adding TiO_2 andMgO.
- 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 andSi_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:



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.

i) 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.

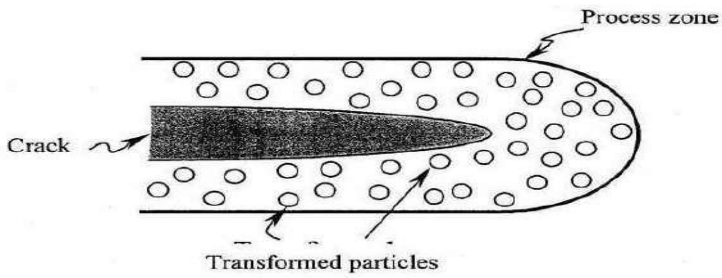
ii) SiC reinforced Nitride tools

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.

iii) 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 and micro crack nucleation toughening.

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 - 500m/min.

iv) Alumina ceramic reinforced by SiC whiskers

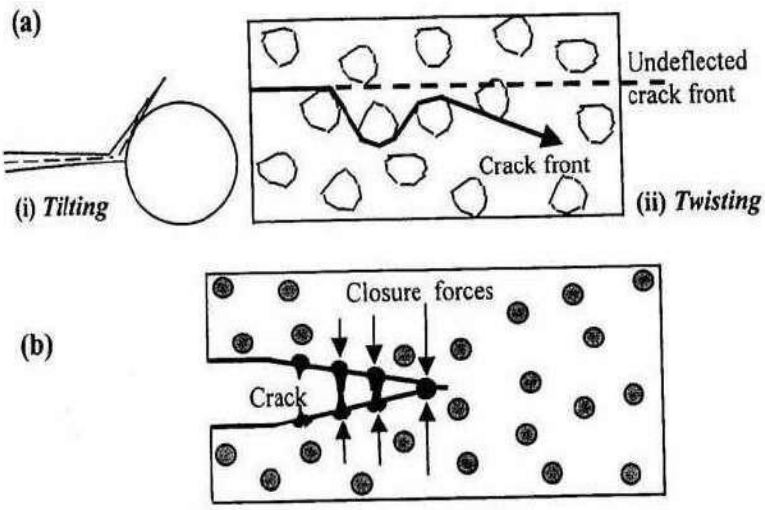
The properties, performances and application range of alumina based ceramic tools have been improved spectacularly through drastic increase in fracture toughness (2.5 times), TRS and bulk thermal conductivity, without sacrificing hardness and wear resistance by mechanically reinforcing the brittle alumina 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.

v) 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 pressure less 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*



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 - 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 - 300m/min.
- Super alloys (> 35 RC): 80 - 140m/min.
- Hardened steels (> 45 RC): 100 - 300m/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.
- Super abrasive 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, super alloys, 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, and 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.*

TOOLWEAR

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 tooltip(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.

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

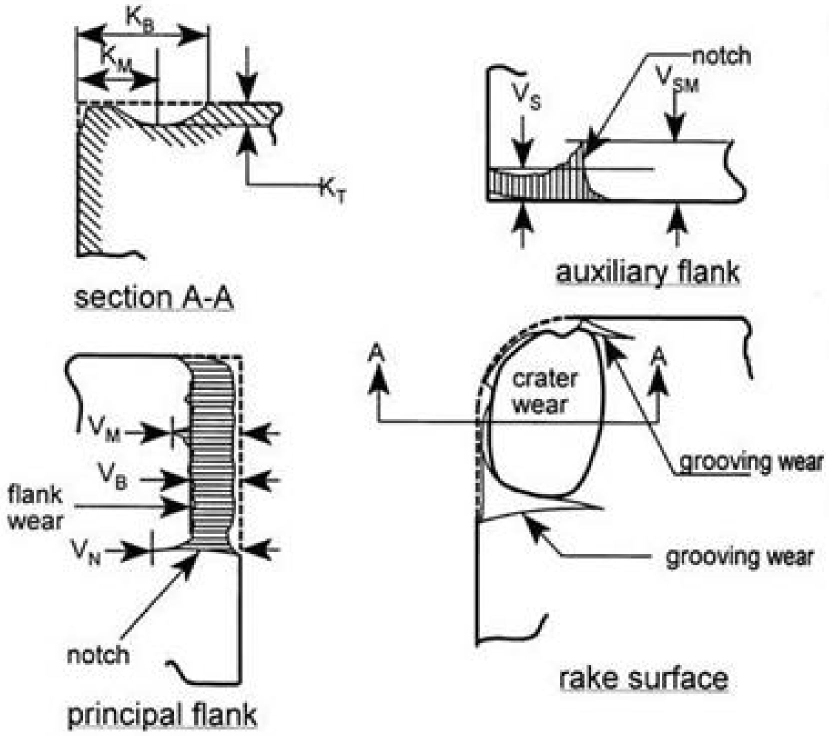
Chemical wear, leading to damages like grooving wear may occur if the tool material is not enough chemically stable against the work material and/or the atmospheric gases.

(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

Schematic view of wear pattern of face milling insert



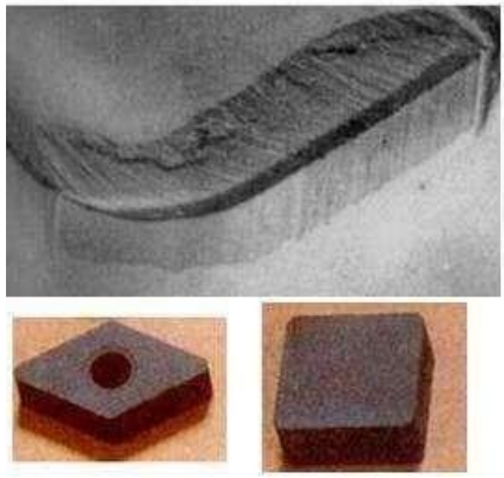


Fig. 1.49 (b) Geometry and major featuresof wear of turningtools

Fig. 1.49 (c) Photographic view of the wear pattern of a turning too linsert

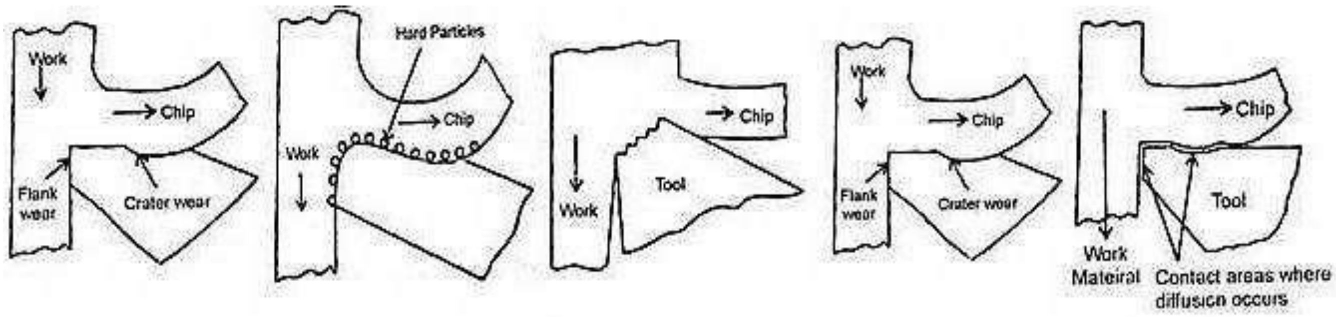


Fig. 1.49 (d) Different types of wears of turning tools

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 tooltip.

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.

TOOLLIFE

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 0.15mm.

(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

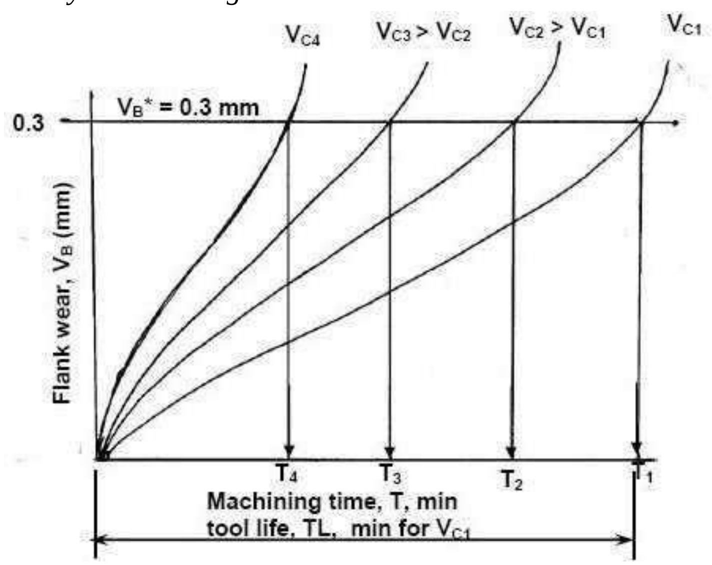
For R & D purposes, tool life is always assessed or expressed by span of machining time in minutes, whereas, in industries besides machining time in minutes some other means are also used to assess tool life, depending upon the situation, such as:

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

Taylor's tool life equation

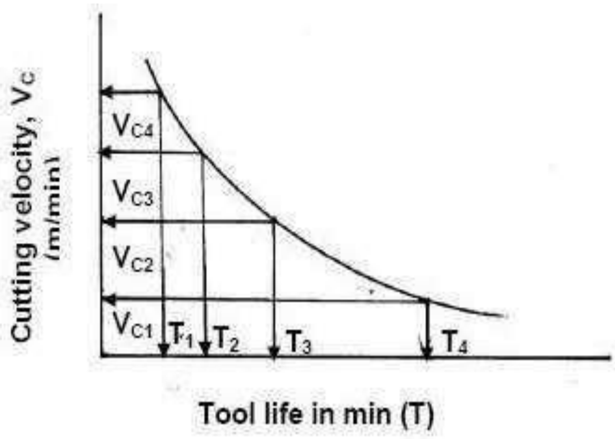
Wear and hence tool life of any tool for any work material is governed mainly by the level of the machining parameters i.e., cutting velocity (V_C), feed (f) and depth of cut (t). Cutting velocity affects maximum and depth of cut minimum.

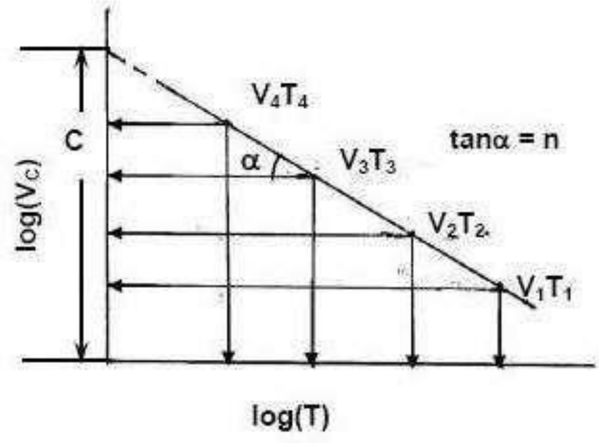
The usual pattern of growth of cutting tool wear (mainly V_B), principle of assessing tool life and its dependence on cutting velocity are schematically shown in Fig. 1.50.



Growth of flank wear and assessment of tool life

The tool life obviously decreases with the increase in cutting velocity keeping other conditions unaltered 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*, 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.*





Cutting velocity – tool life relationship

Cutting velocity - tool life on a log-log scale

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

$$V_C T^n = C \qquad 1.53$$

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.).

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,

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

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.

Effect of tool geometry on toollife

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

Effect of side cutting edge angle on toollife

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

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

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

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

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

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

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

Factors affecting toollife

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

- Cuttingspeed.
- Feed and depth ofcut.
- Toolgeometry.
- Toolmaterial.
- Cuttingfluid.
- Work piecematerial.
- Rigidity of work, tool andmachine.

Machinability

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.

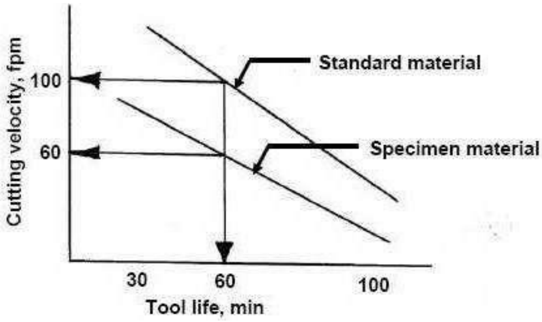
Often cutting temperature and chip form are also considered for assessing machinability.

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

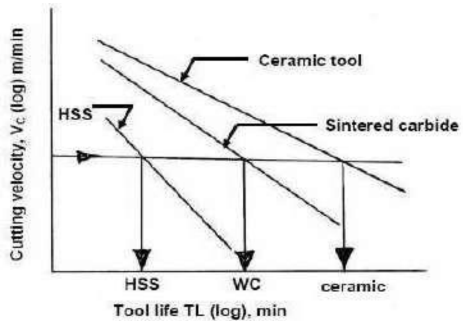
But usefulness and reliability of such practice faced several genuine doubts and questions:

- 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 variationin:
    - Material and geometry of the cutting tool.
    - Level of process parameters (Vc, f,t).
    - Machining environment (cutting fluid application).
    - Machine tool condition.



Machinability rating intermsof velocity giving 60 mintool life



Role of cutting toolmaterial cutting on machinability (toollife)

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 cuttingforces.
- Tool wear or toollife.
- Surface finish.
- Magnitude of cuttingtemperature.
- Chipforms.

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.

Role of the properties of the work material onmachinability

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.

SURFACEFINISH

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

- Cuttingspeed.
- 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.

CUTTINGFLUIDS

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.

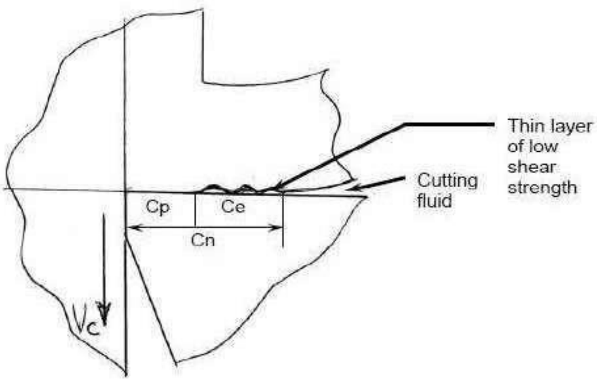
Essential properties of cutting fluids

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 flashpoint.
- High resistance to bacterial growth.
- Odourless and also preferably colourless.
- Non toxic in both liquid and gaseous stage.
- Easily available and low cost.

Principles of cutting fluidaction

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. 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



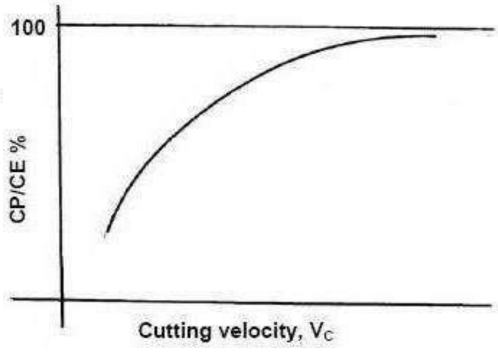


Fig. 1.55 Cutting fluid action in machining

Fig. 1.56 Apportionment of plastic andelastic

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.

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 work piece 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.

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.*

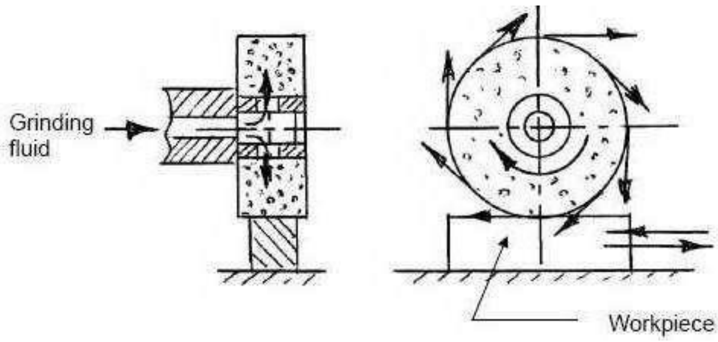


Fig 1.57 Z-Z method of cutting fluid application in grinding

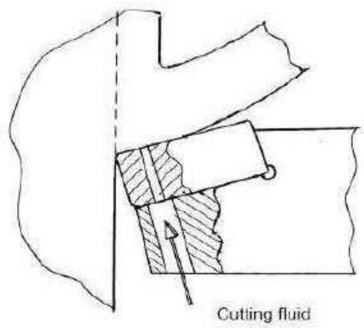


Fig. 1.58 Application of cutting fluid at high pressure through the hole in the tool. The direction of application also significantly governs the effectiveness of the cutting fluid in respect of reaching at or near the chip-tool and work-tool interfaces. Depending upon the requirement and accessibility 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.*

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

MACHINE TOOLS –I

CENTRE LATHE AND SPECIAL PURPOSE LATHES

CENTRELATHE

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.

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 faceplate.

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.

CONSTRUCTIONALFEATURES

Major parts of a centre lathe

Amongst the various types of lathes, centre lathes are the most versatile and commonly used.

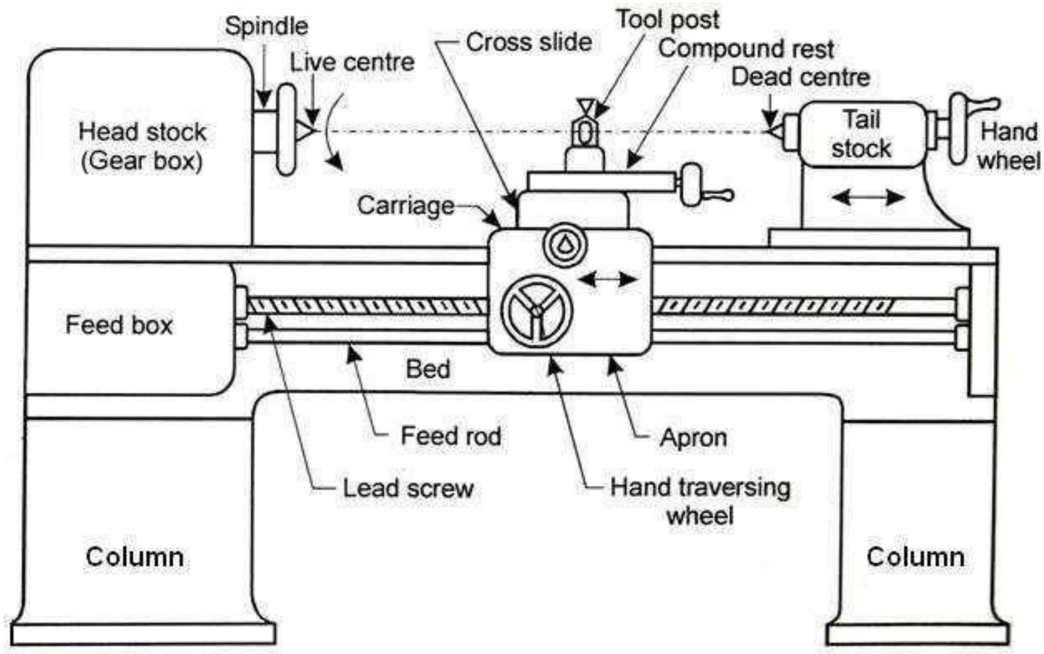


Fig. 2.1 shows the basic configuration of a center lathe. The major parts are:

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 unit.

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.

2.1.1 Kinematic system and working principle of a centre lathe

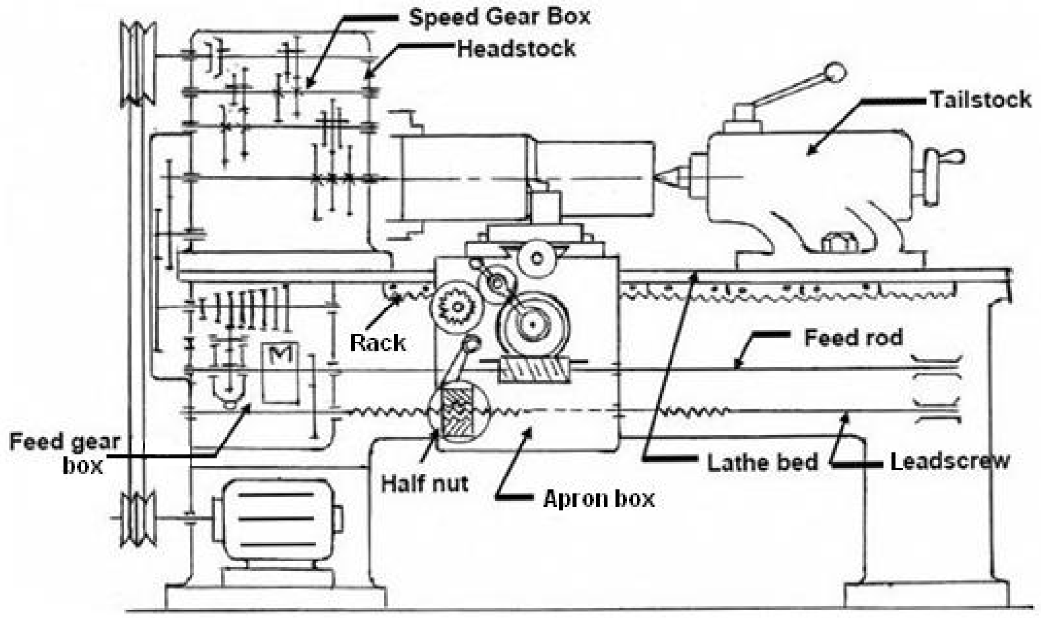


Fig. 2.2 schematically shows the kinematic system of a 12 speed centre lathe.

For machining in machine tools the job and the cutting tool need to be moved relative to each other.

The tool-work motions are:

- Formativemotions: - cutting motion, feedmotion.

Auxiliarymotions: - indexing motion, relievingmotion

Mounting of jobs in centrelathe

Without additional support from thetailstock

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

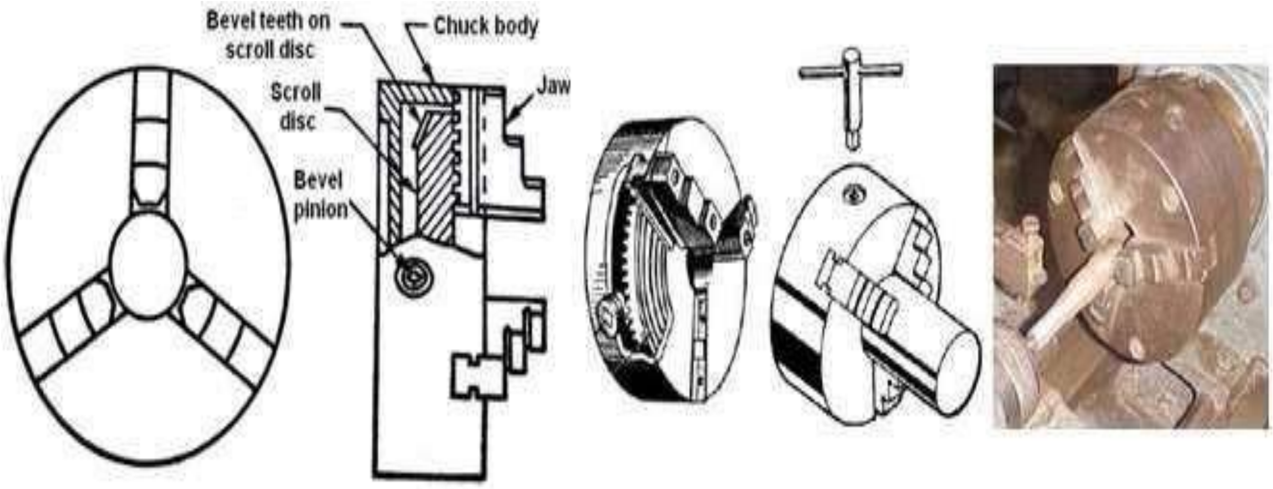


Fig. 2.10 (a) 3-jaw self centering chuck or universal chuck

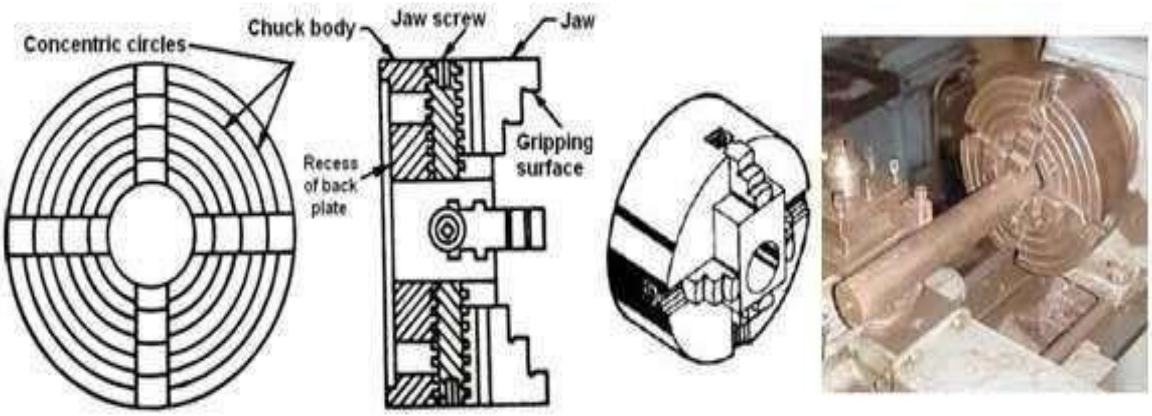
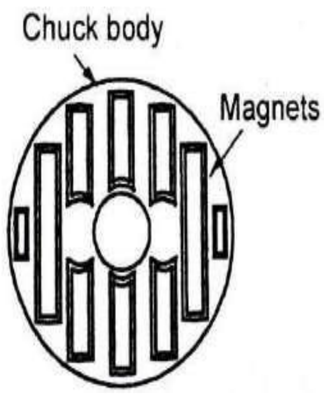


Fig. 2.10 (b) 4-jaw independent chuck

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.*



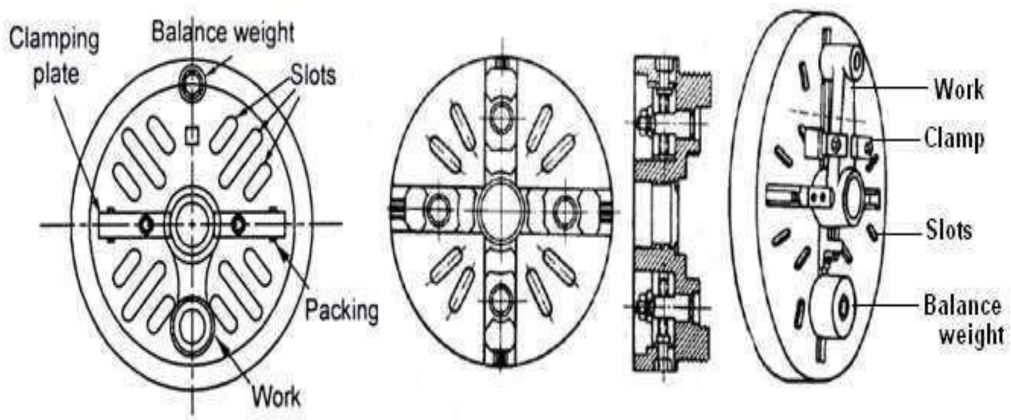


Fig. 2.11Magnetic chuck

Fig. 2.12 Faceplate

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).*

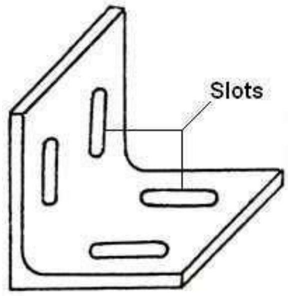


Fig. 2.13 (a)Angleplate

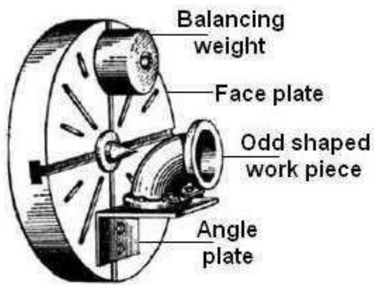


Fig. 2.13 (b) Angle plate used along with faceplate

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 catchplate.*

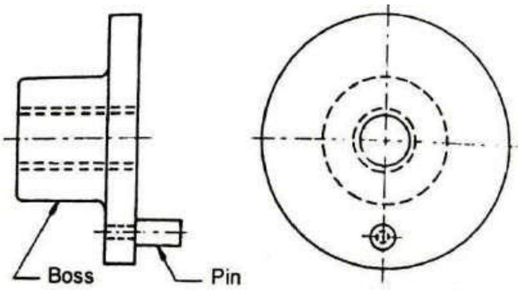


Fig. 2.14Catchplate

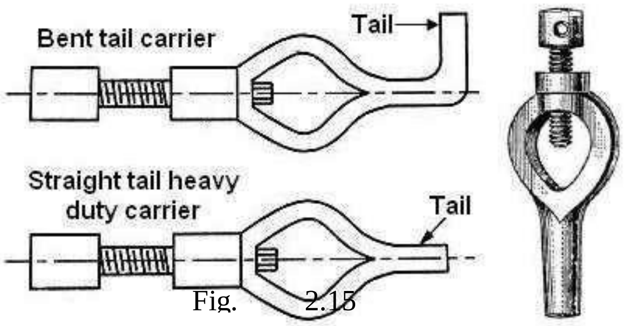


Fig. 2.15

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.

Mandrels

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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.

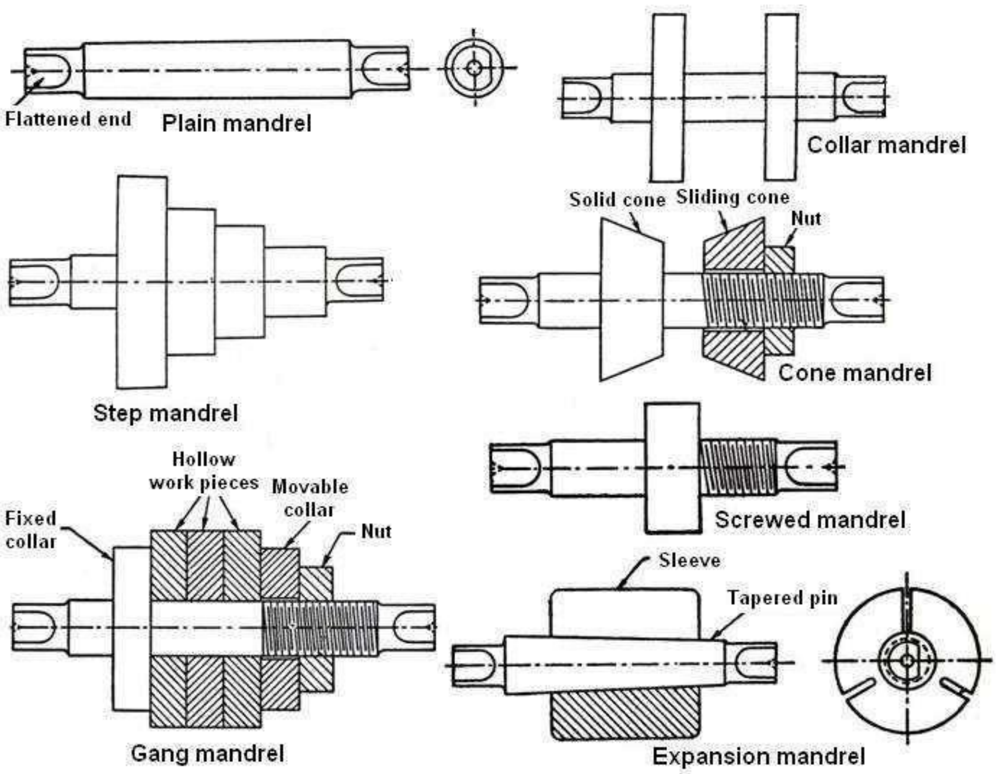


Fig. 2.16 Types of mandrels

Fig. 2.17 Work held between centres

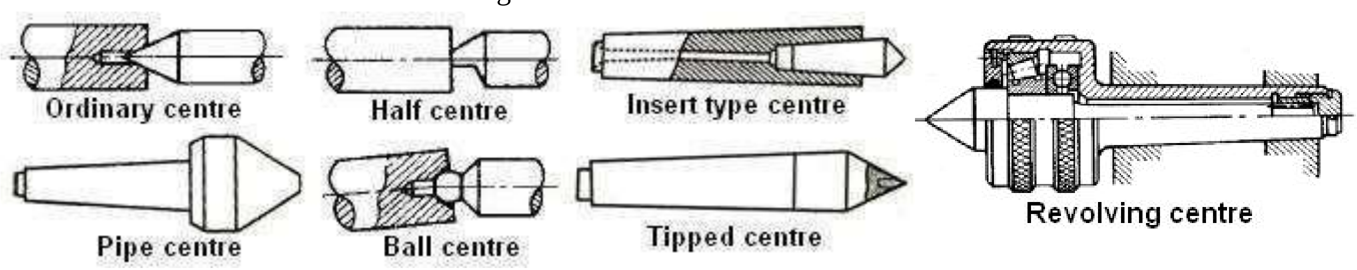


Fig. 2.18 Types of centres

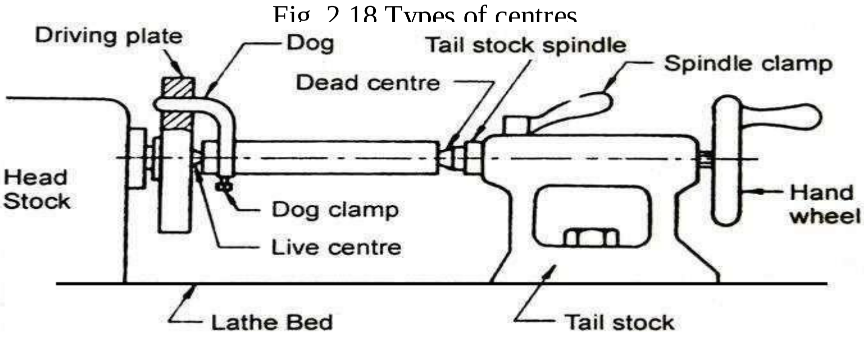


Fig. 2.10 (a and b) visualizes 3-jaw and 4-jaw chucks which are mounted at the spindle nose and firmly hold the job in centre lathes. Premachined round bars are quickly and coaxially mounted by simultaneously moving the three jaws radially by rotating the scroll (disc with radial threads) by a key *as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

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.

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 tail stock 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.*

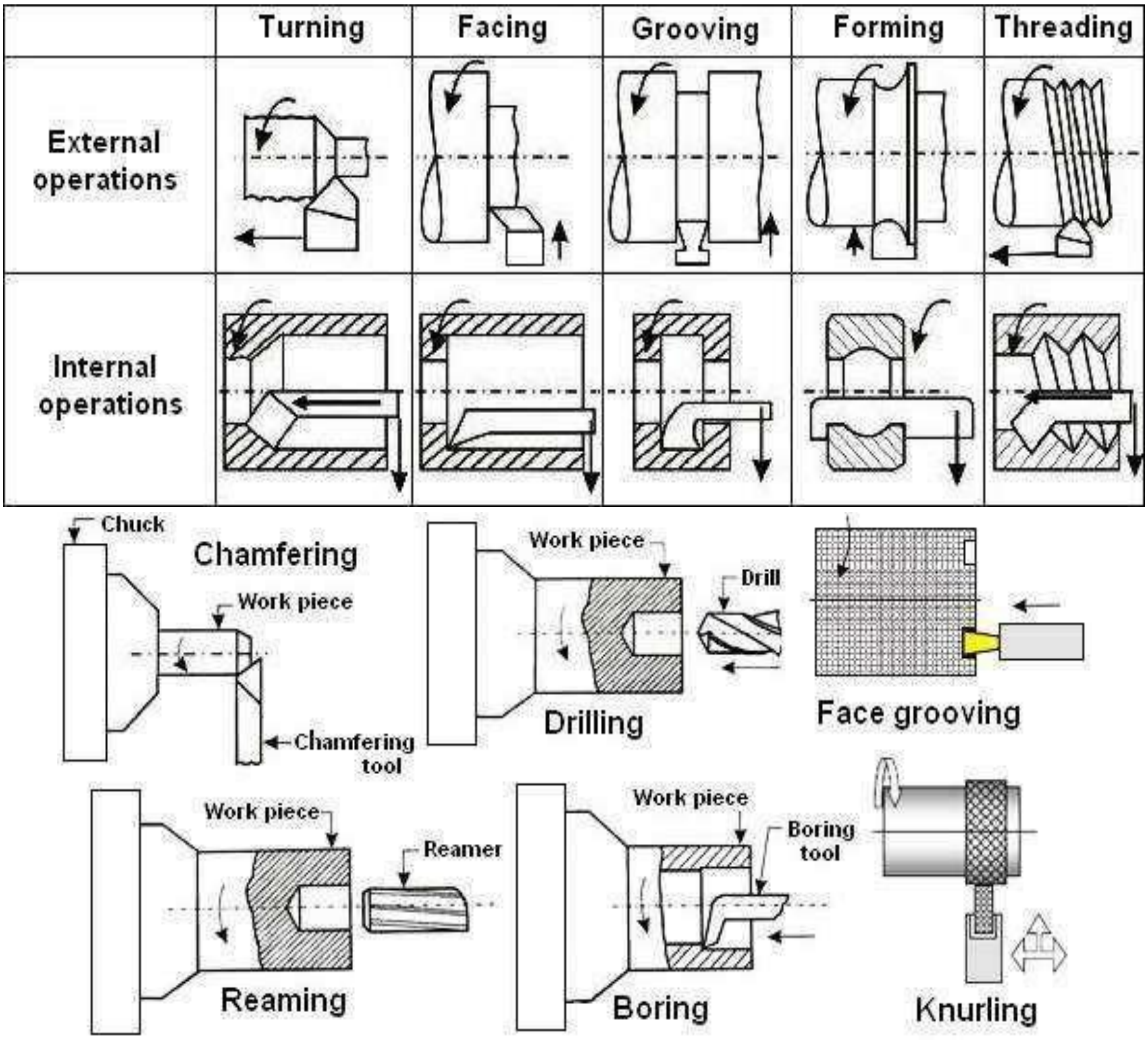


Fig. 2.30 some common machining operations carried out in a centre lathe

TAPER TURINGMETHODS

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 thelength.
- In degrees of half the includedangle.

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 angleoftaper.

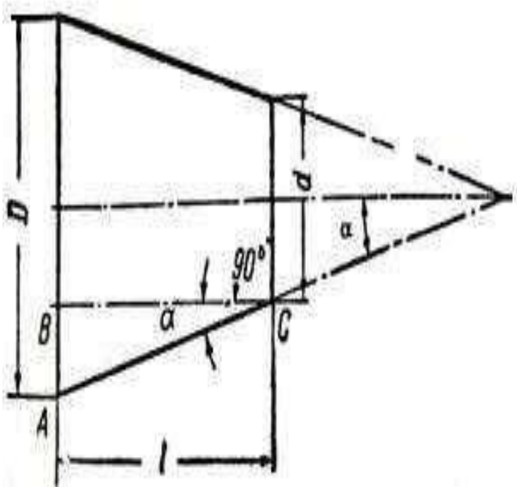


Fig. 2.31 Detail of at aper Generally, taper is specified by the termconicity .*Conicityis defined as the ratio of the difference in*

diameters of the taper to its length. Conicity,

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

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.

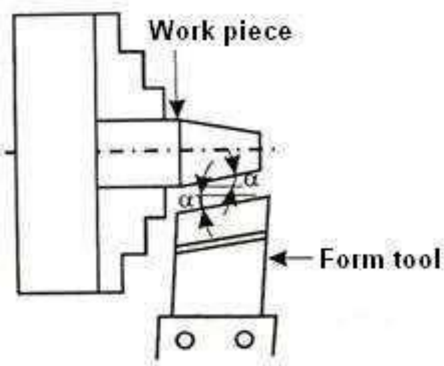


Fig. 2.32 Taper turning by aform tool

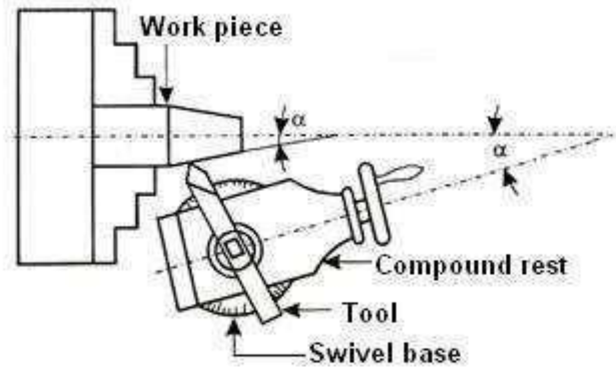


Fig. 2.33 Taper turning by swiveling the compoundrest

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, **tanα=**$^{D–d}$

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.

Taper turning by offsetting thetai lstock

Fig. 2.34 illustrates the method of turning taper by offsetting the tails tock. 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 notconstant.

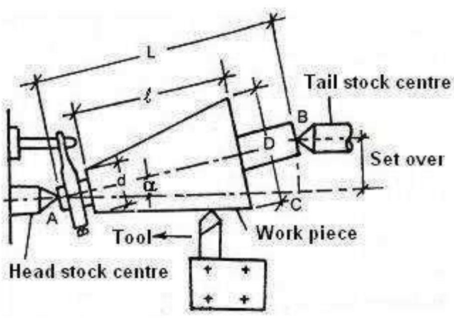


Fig. 2.34 Taper turning by offsetting the tail stock

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 ma y be swiveled is 10^0 to 12^0 on either sideof the centre line. *The angle of swiveling the guide bar can be determined from the equation2.2.*

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 oftime.
- Once the taper is set, any length of work piece may be turned taper within itslimit.
- 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 beturned.
- Internal tapers can be turned withease.

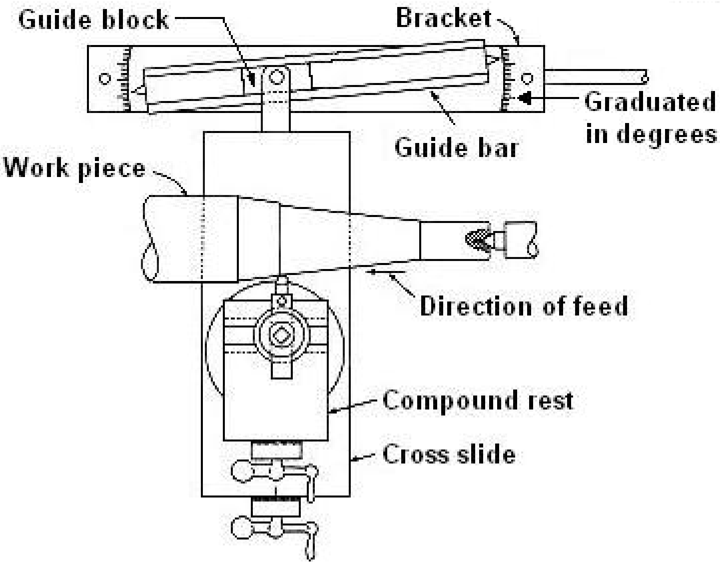


Fig. 2.35 Taperturningattachment

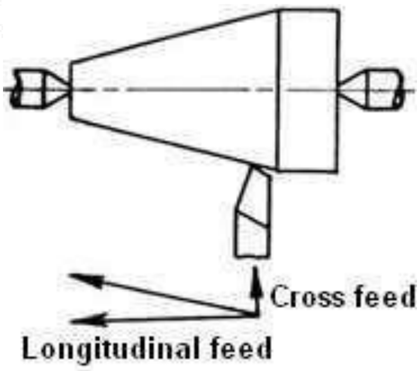


Fig. 2.36 Taper turning by combiningfeed

Taper turning by combining longitudinal feed and crossfeed

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.

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.

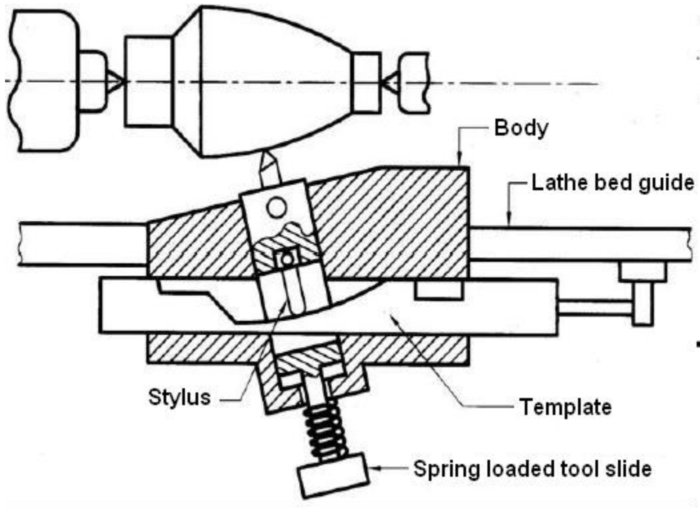


Fig. 2.50 Mechanical type copying attachment

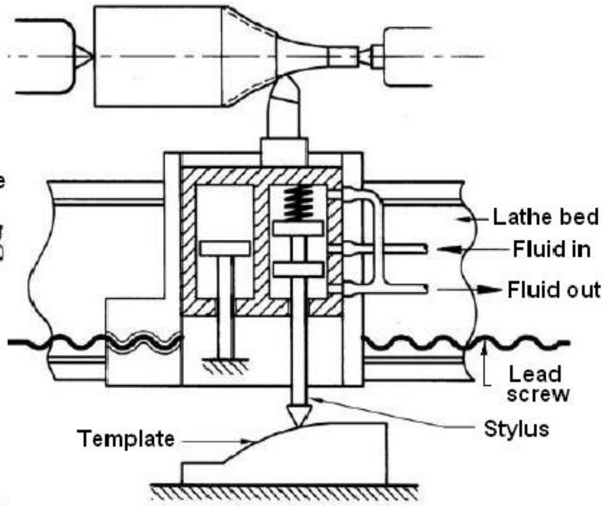


Fig. 2.51 Hydraulic copying attachment

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 Fig2.51.*

SPECIAL PURPOSELATHES

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 islarge.
- Only one tool can be used in the normal course. Sometimes the conventional tool post can be replaced by a square tool post with fourtools.
- The idle times involved in the setting and movement of tools between the cuts islarge.
- Precise movement of the tools to destined places is difficult to achieve if proper care is not taken by theoperator.

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 th etools.
- Automatic stopping of tools at precisel ocations.
- Automatic control of the proper sequence of operations.

CAPSTAN AND TURRETLATHES

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 oftail stock.
- 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.

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:

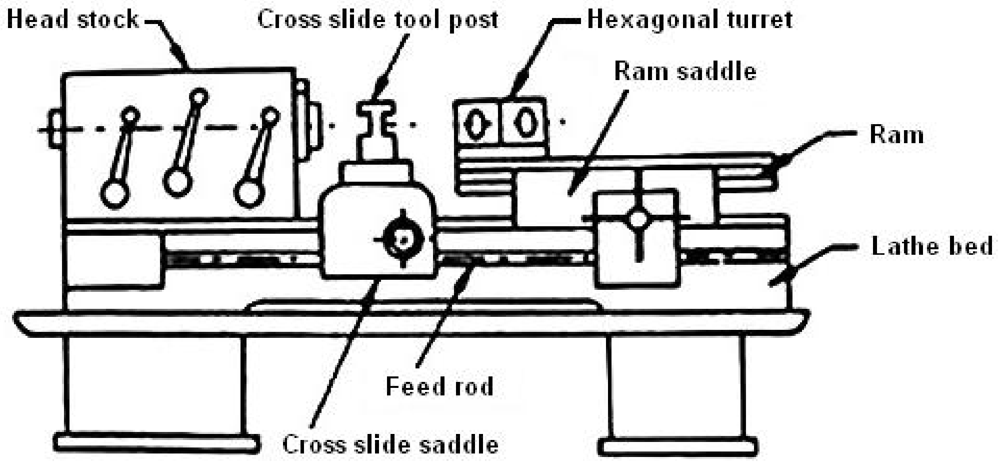


Fig. 2.60 Basic configuration of a Capstan lathe

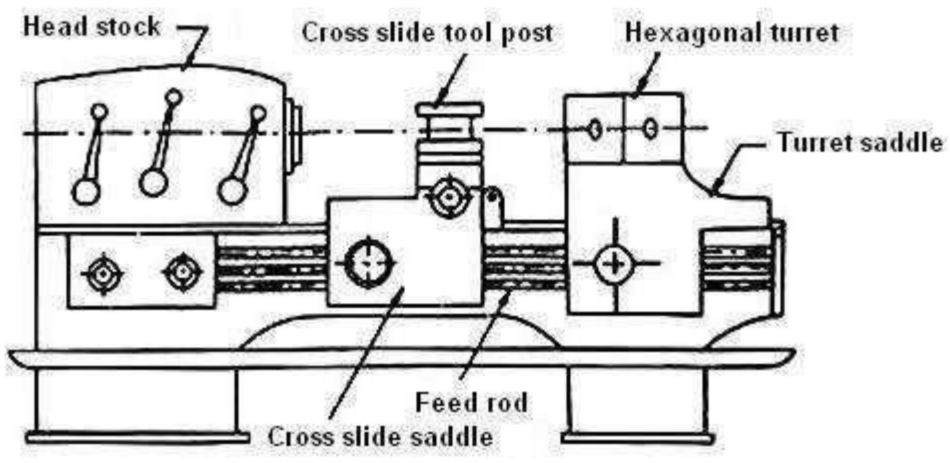


Fig. 2.61 Basic configuration of a Turret lathe

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.

Step cone pulleydriven 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 footpedal.

Electric motordriven 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 highspeeds.

Allgearedheadstock: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 themachine.

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 frictionclutches.

Cross slideand 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 ofcarriage.

- Conventional typecarriage.
- Side hung typecarriage.

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.*

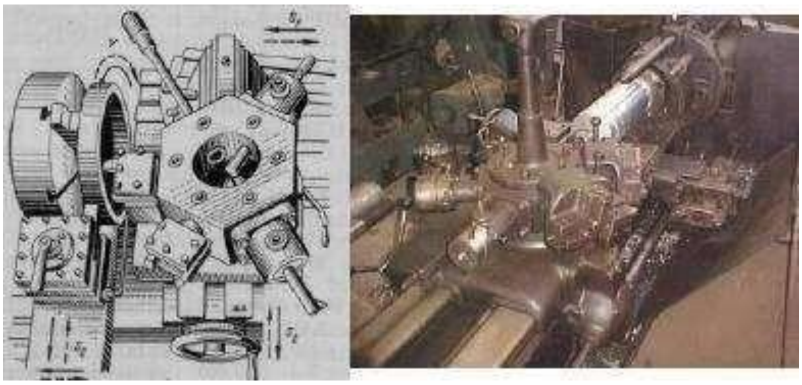


Fig. 2.62 Photographic view of a hexagonal turret

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.

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.

Type1: *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.

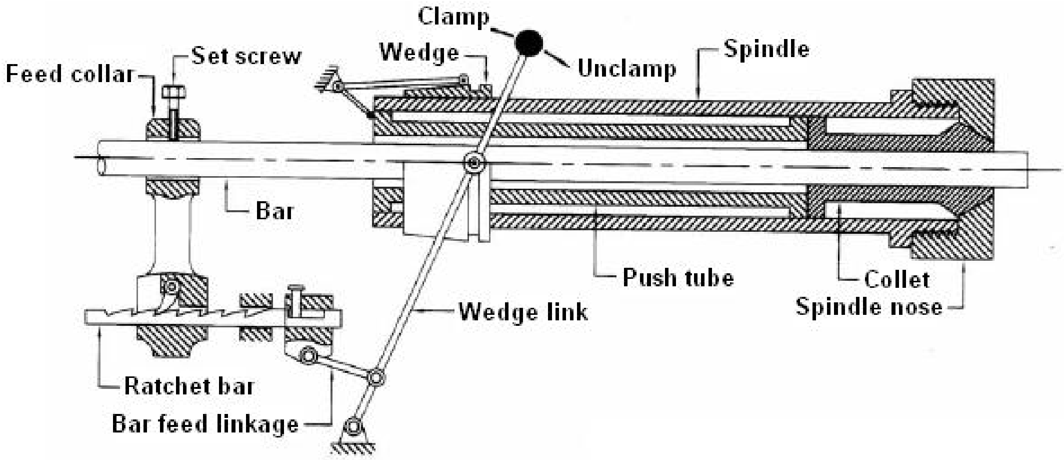


Fig. 2.63 Bar feeding mechanism

Type2: *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.

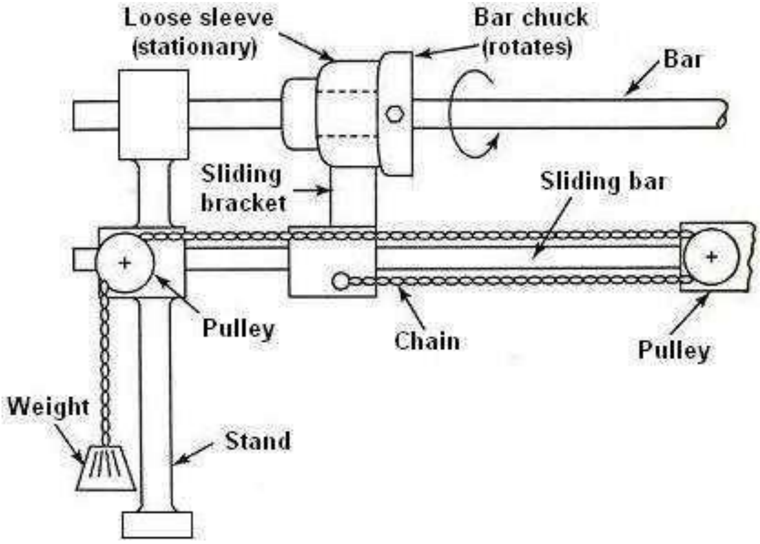


Fig. 2.64 Bar feeding mechanism

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.

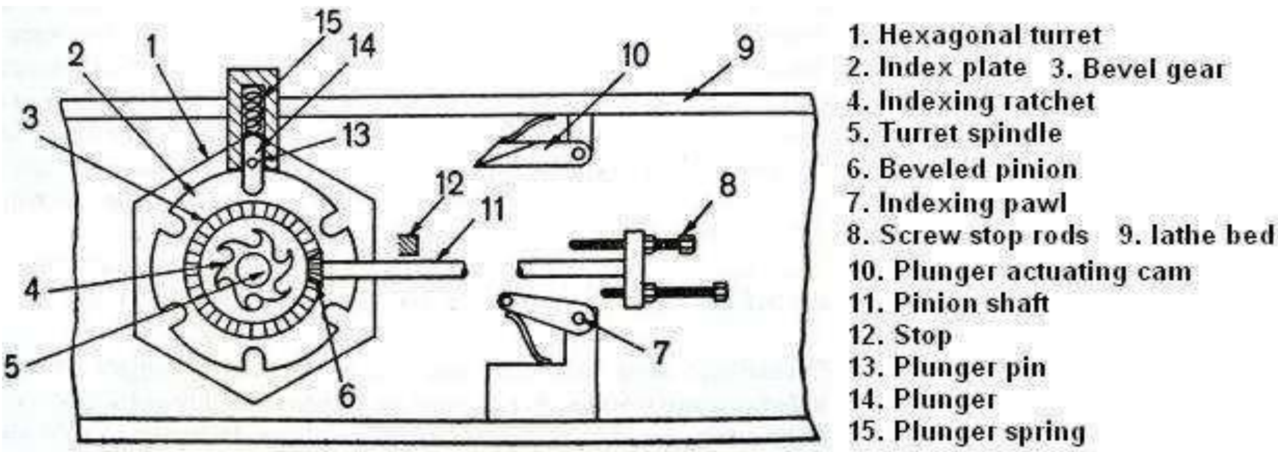


Fig. 2.65 Turret indexing mechanism

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 springpressure.

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.

AUTOMATICLATHES

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.

2.10.1 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).

SEMIAUTOMATICS

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.

Classification of semiautomatics

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 work piece 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:

- Centretype.

- Chuckingtype.

These multi spindle semi automatics are classified as:

- Parallel action or single station type.
- Progressive action or multi station type.

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.

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.

According to the type of mechanism used Crank shape

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.

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 Key seater.

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.

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.

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.

Major parts 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.

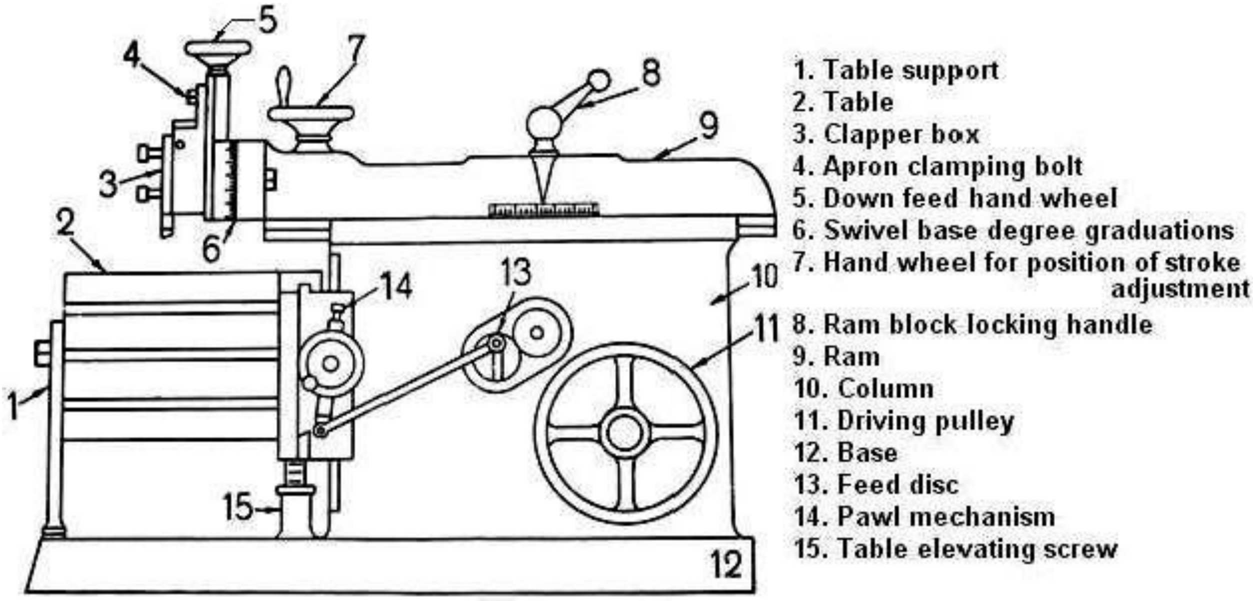


Fig. 3.1 shows the basic configuration of a standard shaper. The major parts are:

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 cross wise direction.

Saddle It is mounted on the cross rail which holds the table firmly onits 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 forwardend.

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 ashaper.*

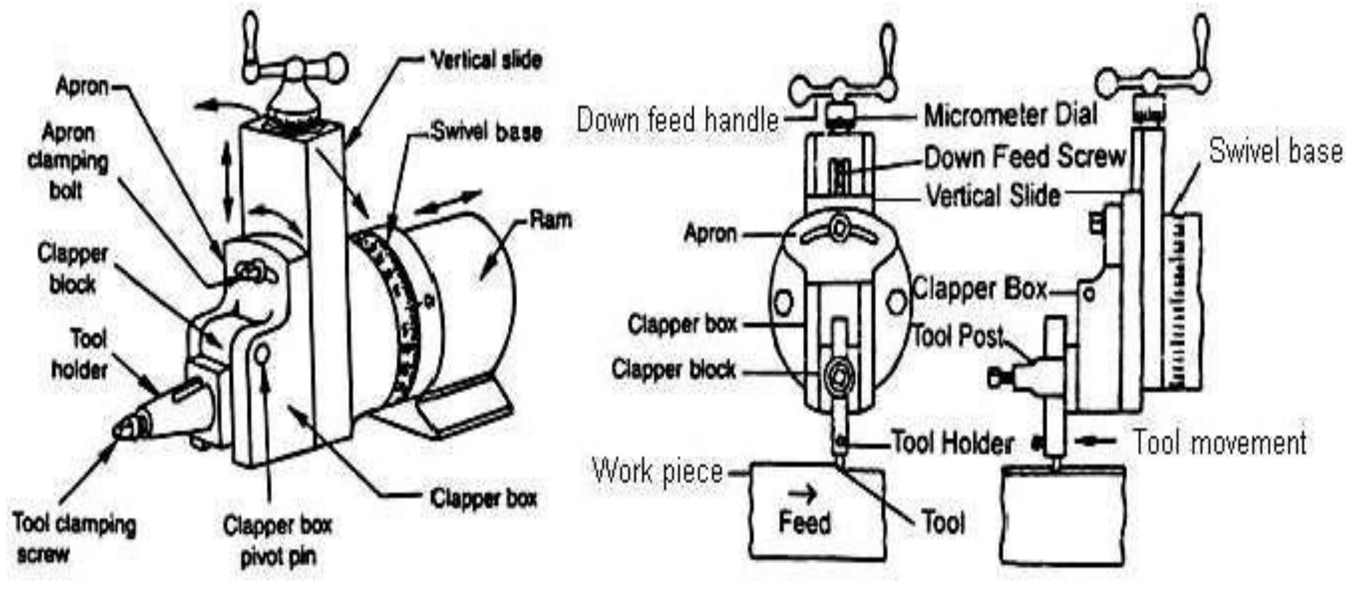


Fig. 3.2 Tool head of a shaper

Working principle of a standard shaper

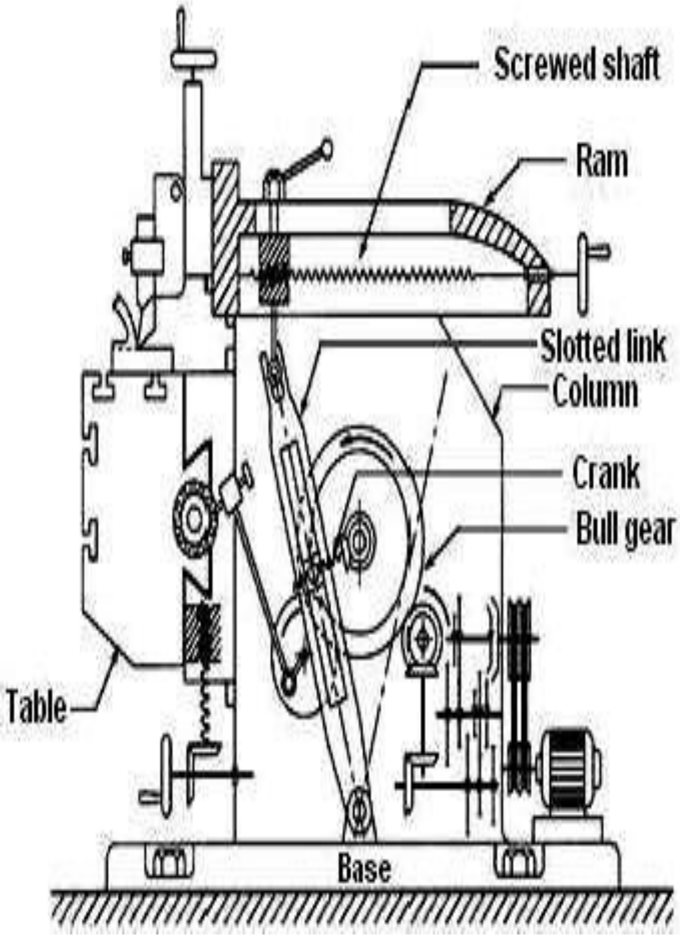


Fig. 3.3 (a) Kinematic system of a shaper

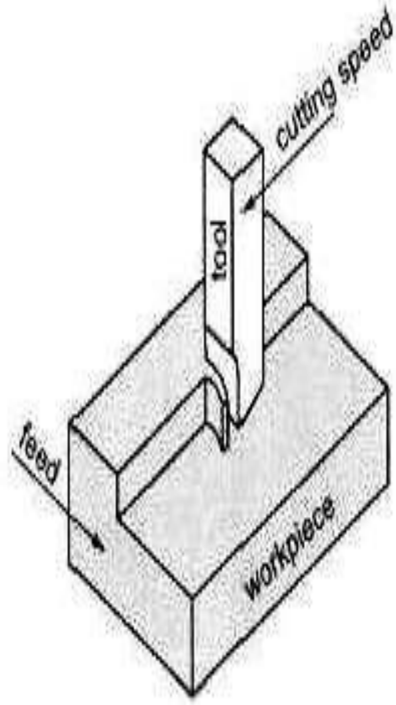


Fig. 3.3 (b) Principle of producing flat surface

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 in feed 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 bullgear.
- Shifting the ram block nut by rotating the leads crew.

Ram drive mechanism of ashaper

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.

Crank and slotted link quick returnmechanism

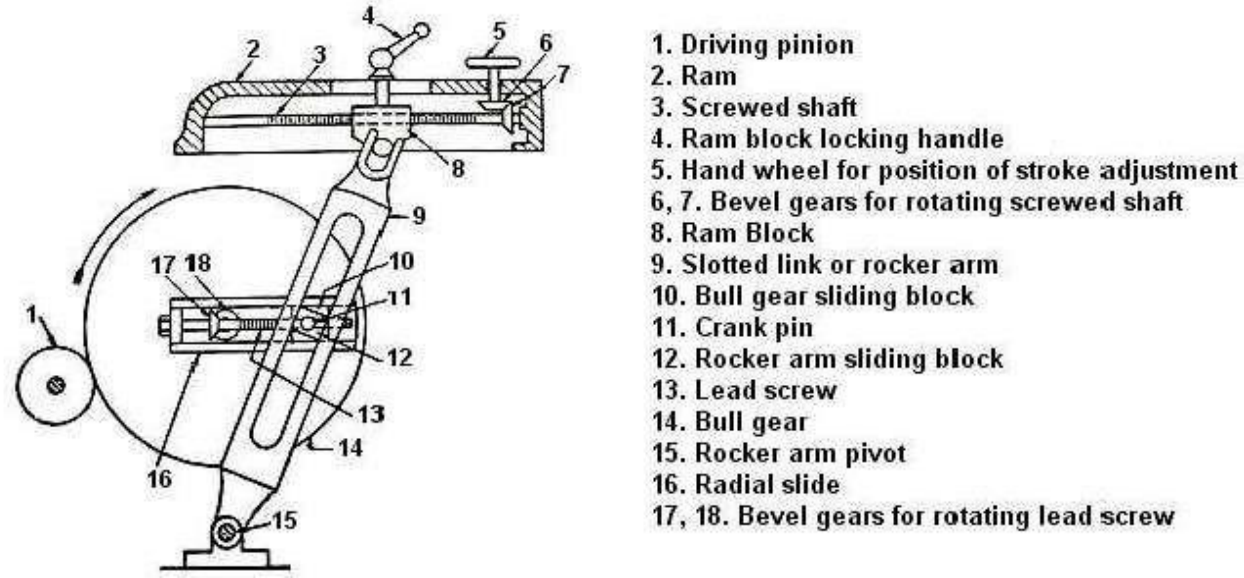


Fig. 3.4 Crank and slotted link quick return mechanism

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

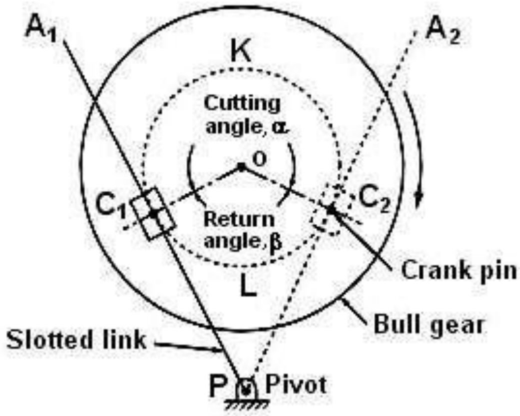


Fig. 3.5 Principle of quick return motion

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.

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.*

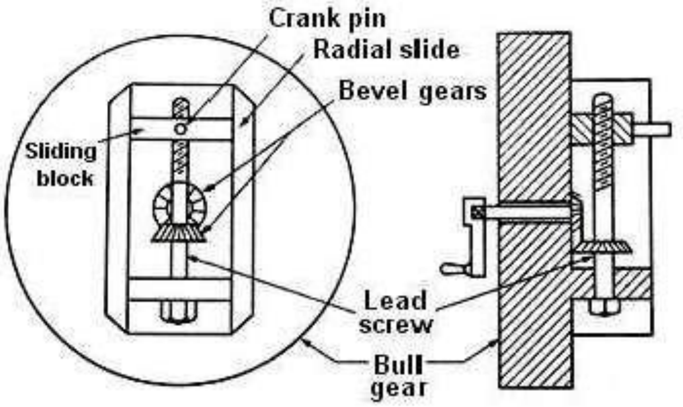


Fig. 3.6 (a) Arrangement of bull gear sliding block

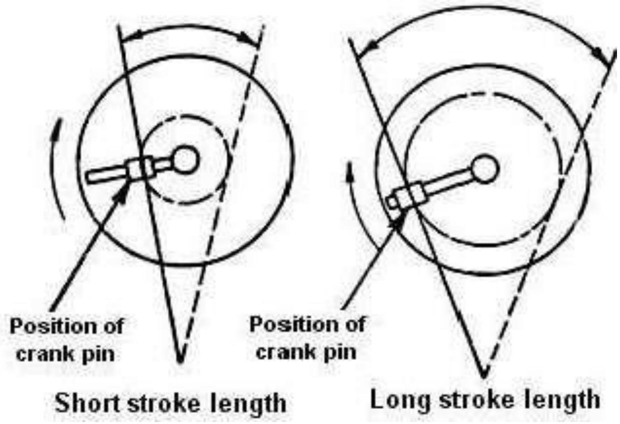


Fig. 3.6 (b) Short and long stroke length

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.

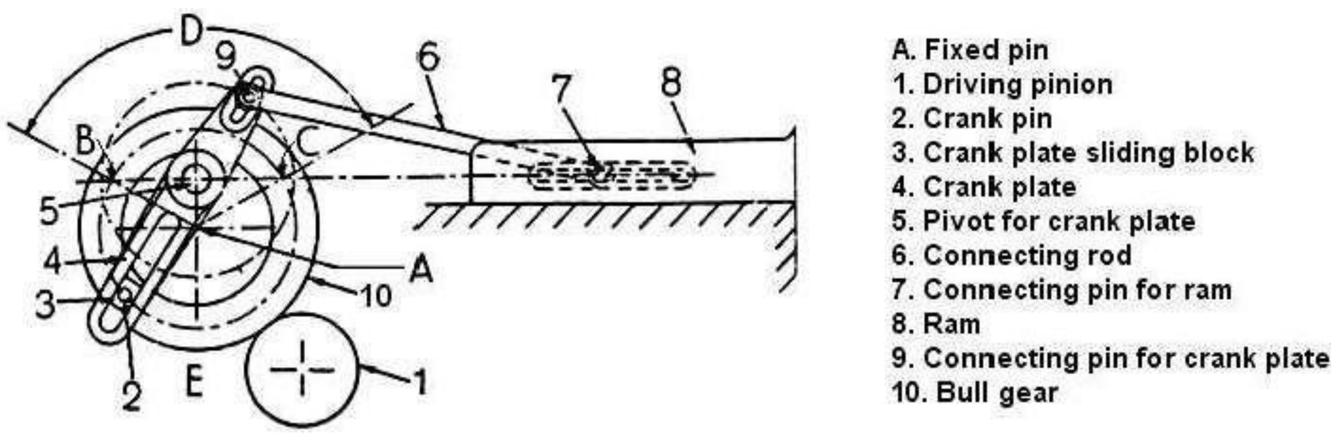


Fig. 3.7 Whitworth quick return mechanism

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 in toreciprocating 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.

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 screwis engaged with a nut fitted in thetable. 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.*

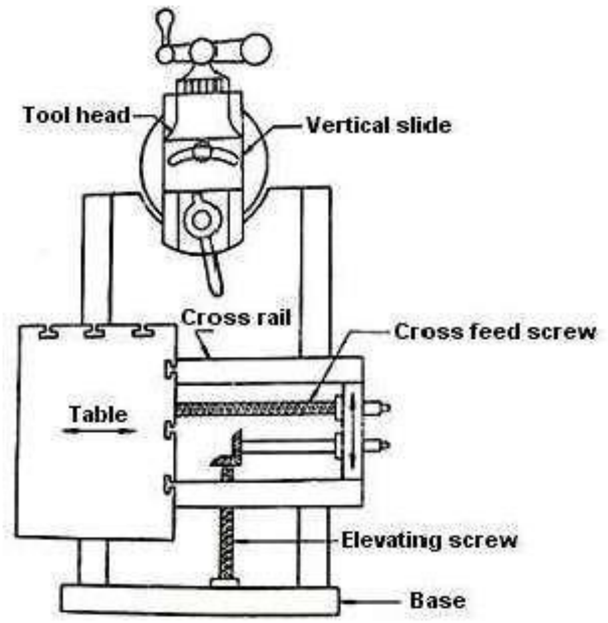


Fig. 3.10 Down feed and cross feed mechanism

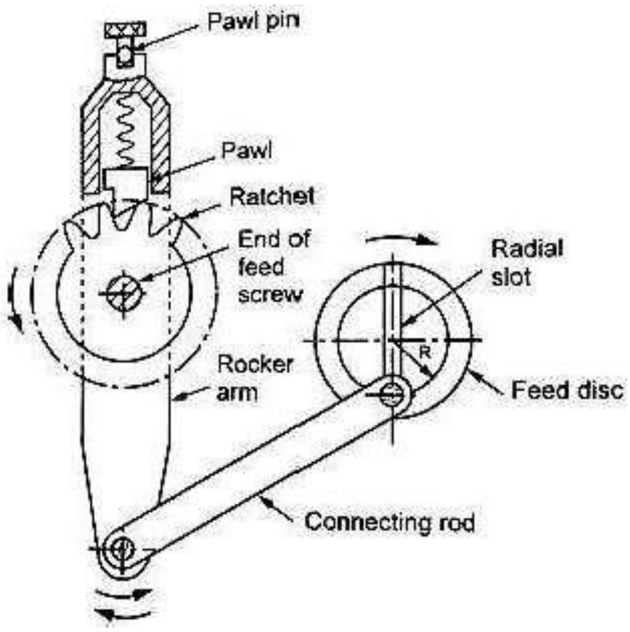


Fig. 3.11 Automatic feed mechanism

Automatic feed mechanism of ashaper

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.

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.

Types of planer

The different types of planer which are most commonly used are:

- Standard or double housing planer.
- Open side planer.
- Pitp laner.
- Edge or plate planer.
- Divided or latching table planer.

Standard or double housing planer

It is most widely used in workshops. It has a long, heavy base on which a table reciprocates on accurate guide ways. It has one drawback. 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.*

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.*

Pit planer

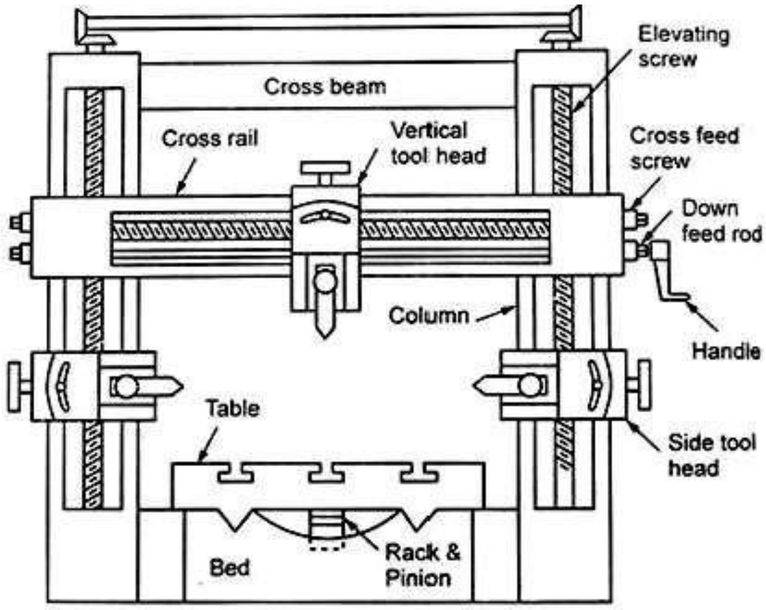
It is massive in construction. It differs from an ordinary planer in that the table is stationary and the column carrying the cross rail reciprocates on massive horizontal rails mounted on both sides of the table. This type of planer is suitable for machining a very large work which cannot be accommodated 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.*

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.*

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.*



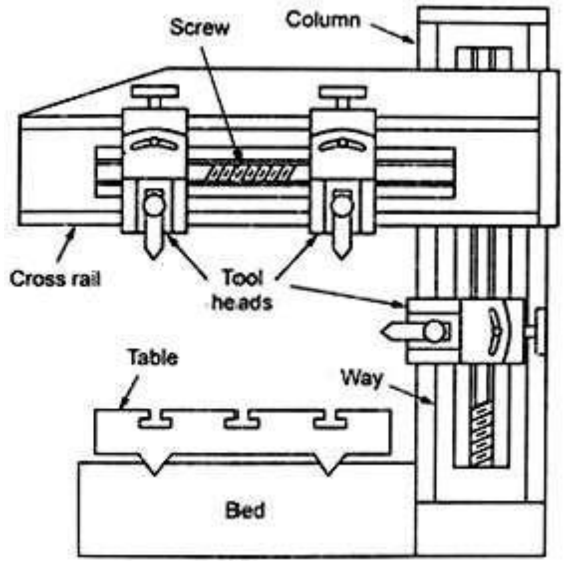
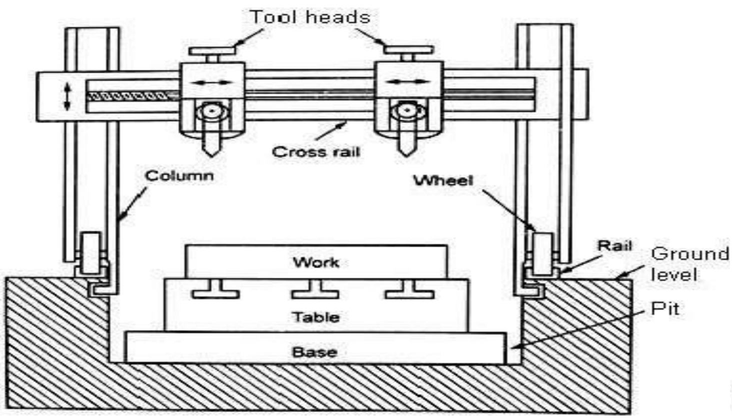


Fig. 3.30 Schematic view of a double housing planer Fig. 3.31 Schematic view of an open side planer



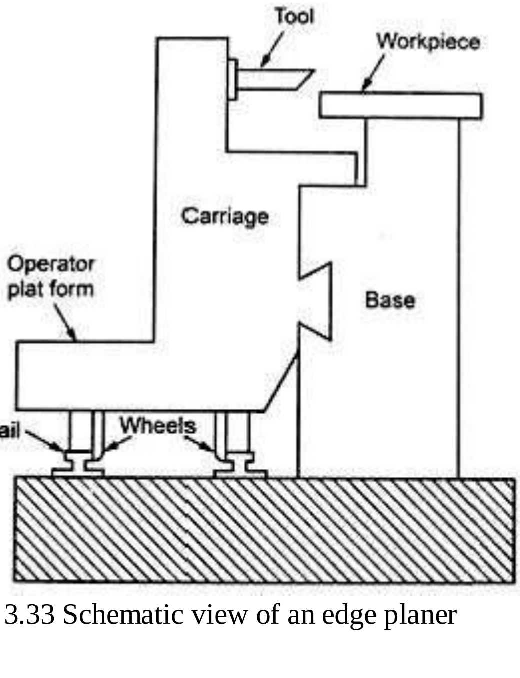


Fig. 3.32 Schematic view of apit planer

Fig. 3.33 Schematic view of an edge planer

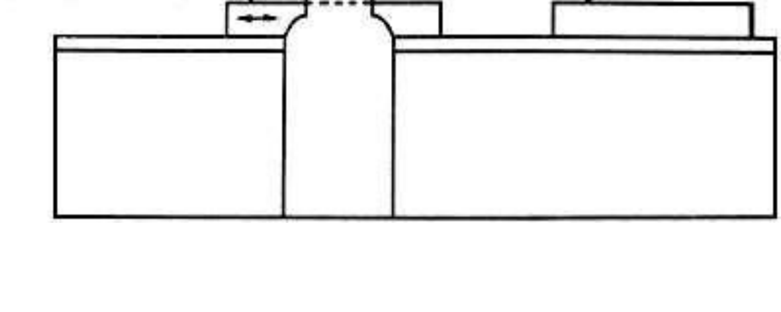


Table drive mechanism of a planer

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.*

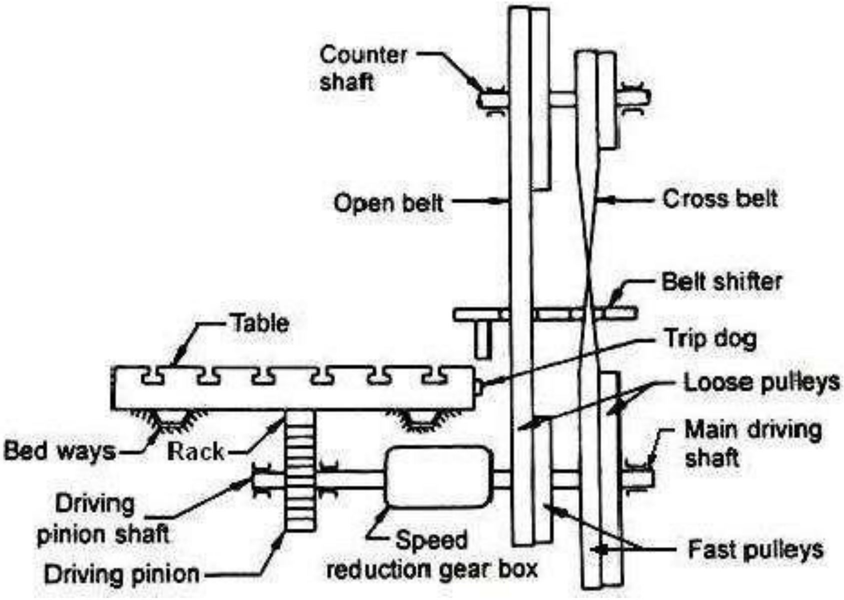


Fig. 3.37 Open and cross belt drive quick return mechanism

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.

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.*

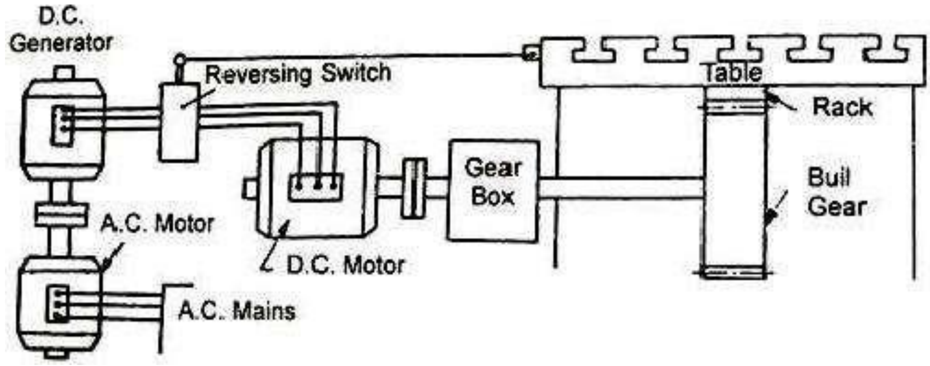


Fig. 3.38 Reversible motor drive quick return mechanism

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 themachine.
- Large number of cutting speeds and return speeds areavailable.
- 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.

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.

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.

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. 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, he 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.

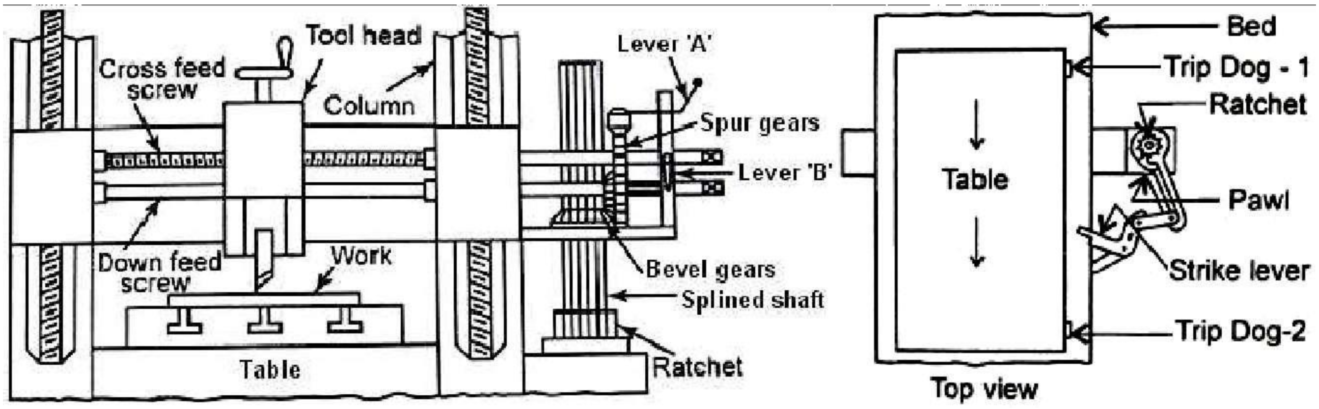


Fig. 3.39 Front and top view of the automatic feed mechanism of a planer

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.

Types of slotter

The different types of slotter which are most commonly used are:

- Puncherslotter.
- Precisionslotter.

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.

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 Whit worth quick return mechanism.

Major parts of a slotter

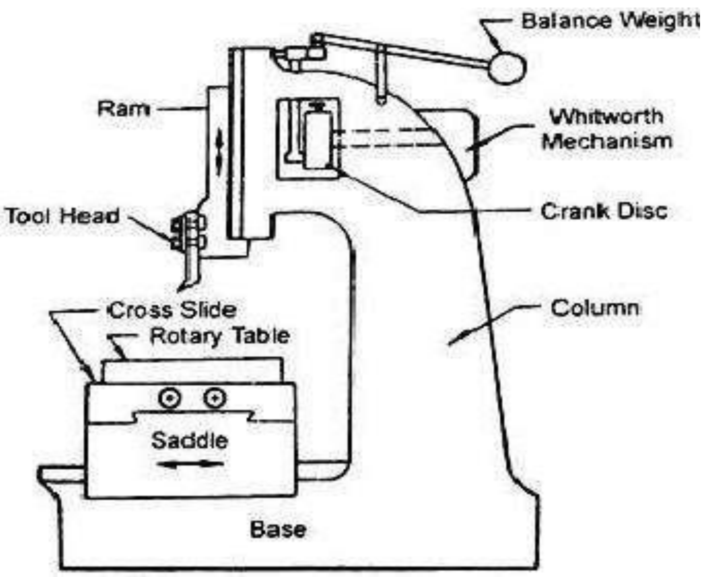


Fig. 3.46 shows the basic configuration of a slotter. The major parts are:

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 finished for the column is accurately providing ways on which the ram reciprocates the column is accurately.

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.

3.3.1 Working principle of a slotter

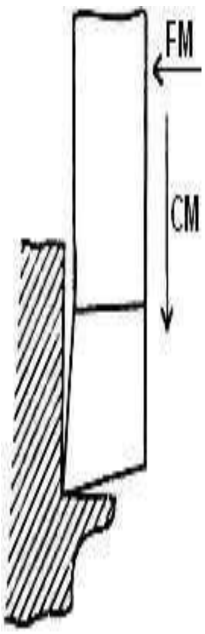


Fig. 3.47 Principle of producing vertical flat surface

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).

UNIT-III

MACHINE TOOLS –II

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 year1782. The first successful plain milling machine was designed by Eli Whitney in the milling machine was invented in the year 1861 by Joseph R Brown.

TYPES OF MILLINGMACHINE

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.

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 slide ways 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).

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

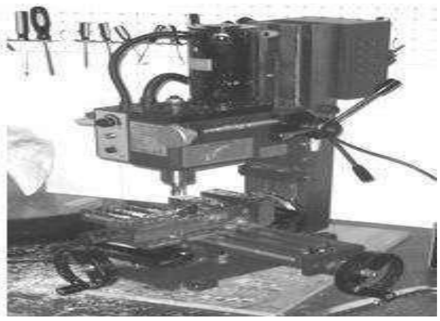


Fig. 3.52 (b) Vertical hand milling machine

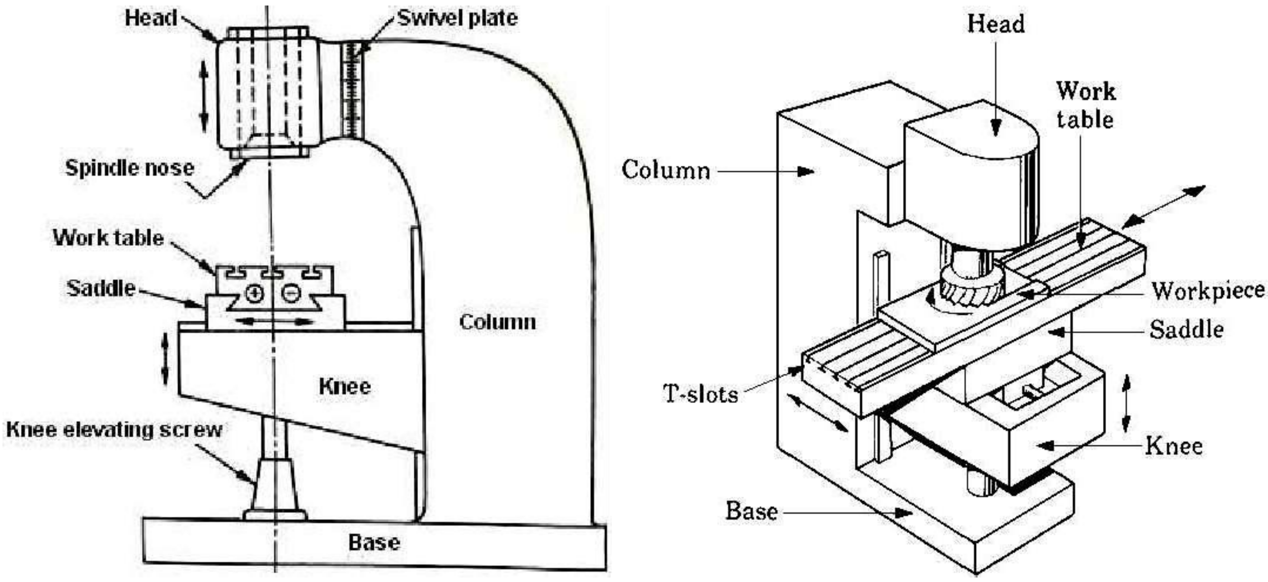


Fig. 3.56 schematically shows the basic configuration of a vertical milling machine.

MILLINGCUTTERS

Milling machines are mostly general purpose and have wide range 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.

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.

Types of milling cutters

Many different kinds of milling cutters are used in milling machines. They are:

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.*

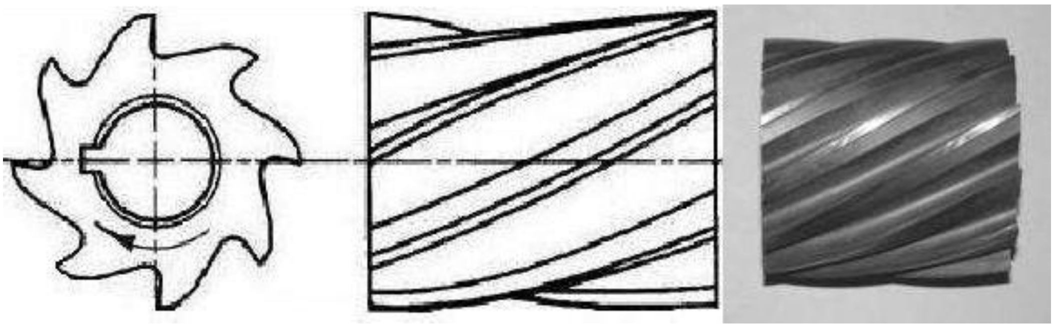


Fig. 3.74 Slab or plain milling cuttrer

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.*

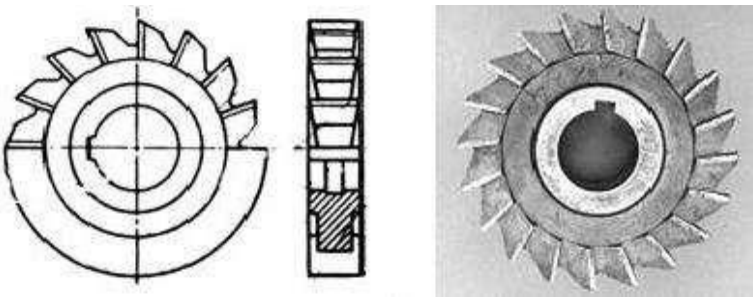


Fig. 3.75 Side milling cutter

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.

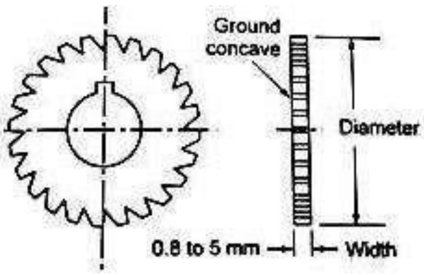


Fig. 3.76Slittingsaw

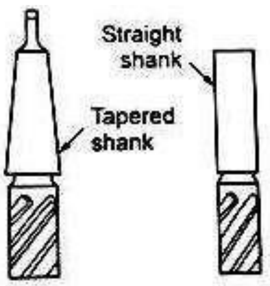


Fig. 3.77 End milling cutters

Fig. 3.78 Face milling cutter

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 40mm.
- 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).

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.

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.*

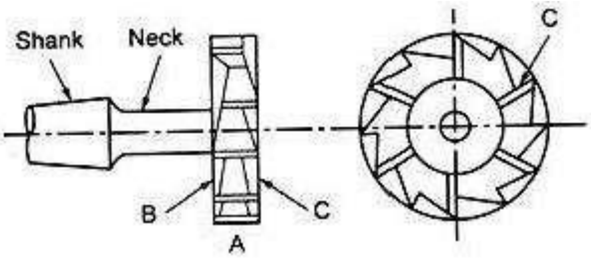


Fig. 3.79 T-slot milling cutter

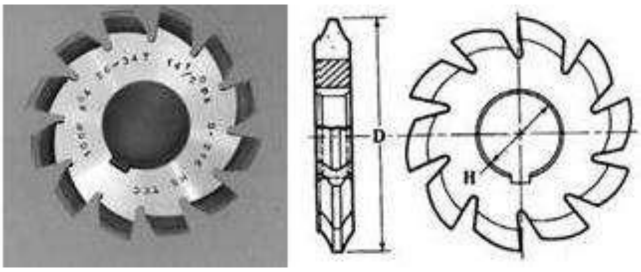


Fig. 3.80 Involute gear milling cutter

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.*

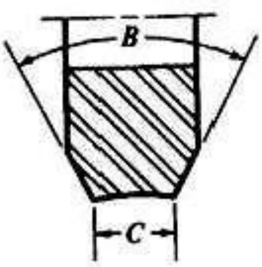


Fig. 3.81 Tooth section of a spline shaft cutter

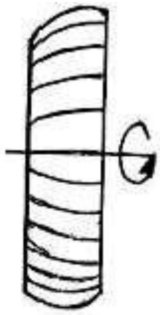


Fig. 3.82 Tool form cutter

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.

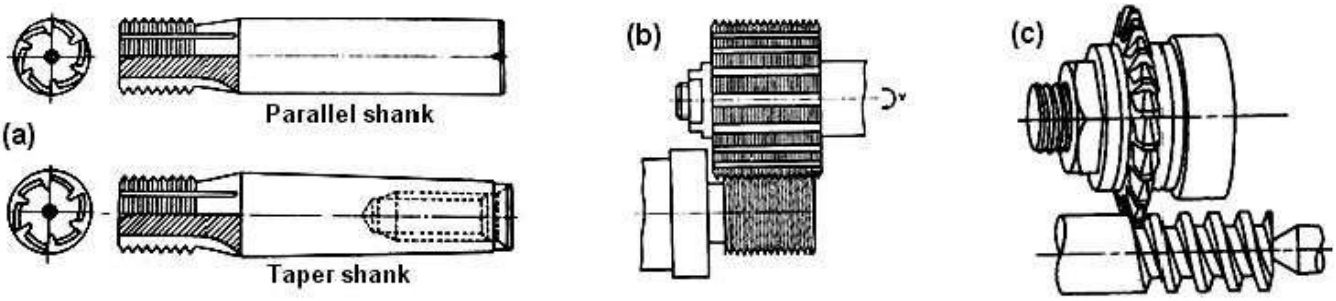


Fig. 3.83 (a) Internal thread milling cutters (b) Short thread milling cutter (c) Long thread milling cutter

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.*

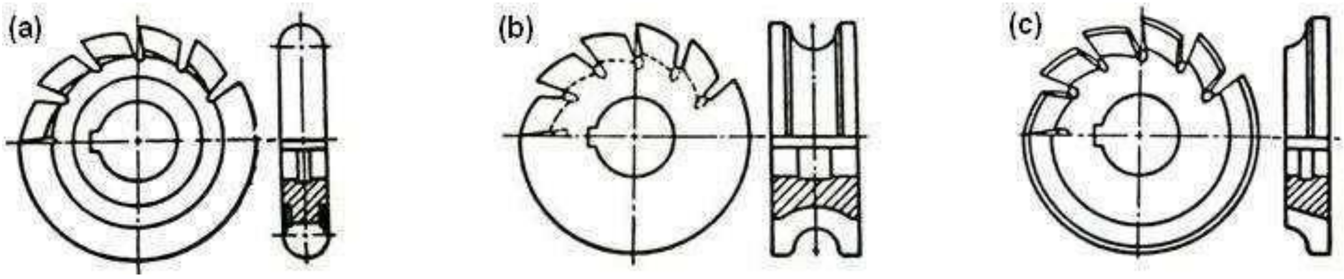


Fig. 3.84 (a) Convex milling cutter (b) Concave milling cutter and (c) Corner rounding milling cutter

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.*

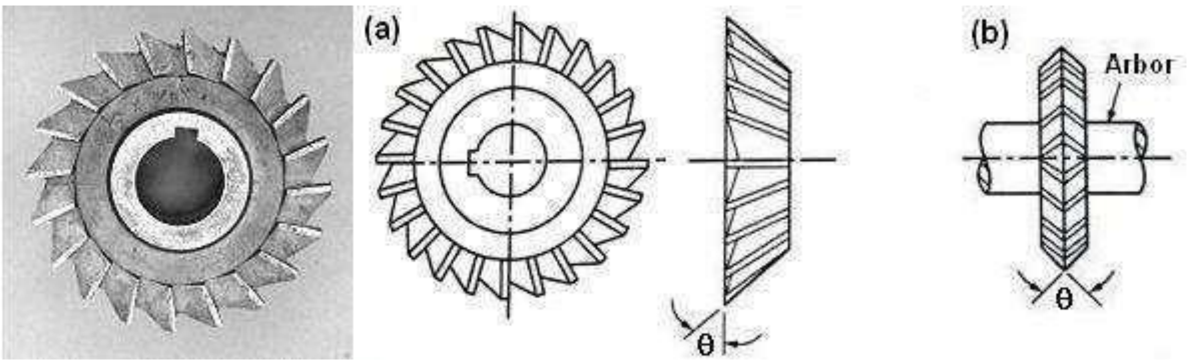


Fig. 3.85 (a) Single angle milling cutter and (b) Double angle milling cutter

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.*

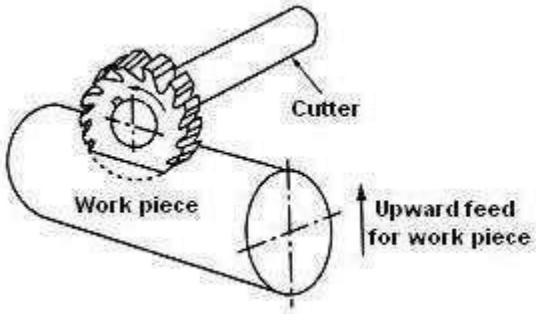


Fig. 3.86 Woodruff key slot milling cutter

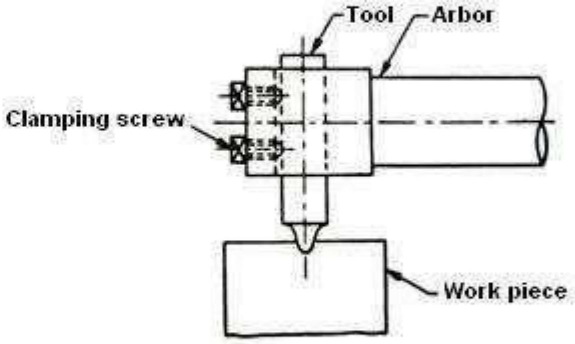


Fig. 3.87 Schematic view of a fly cutter

Fly cutter

These are simp lest 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.*

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.*

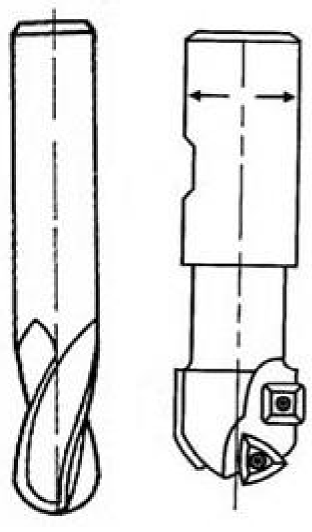


Fig. 3.88 Ball nose end mills

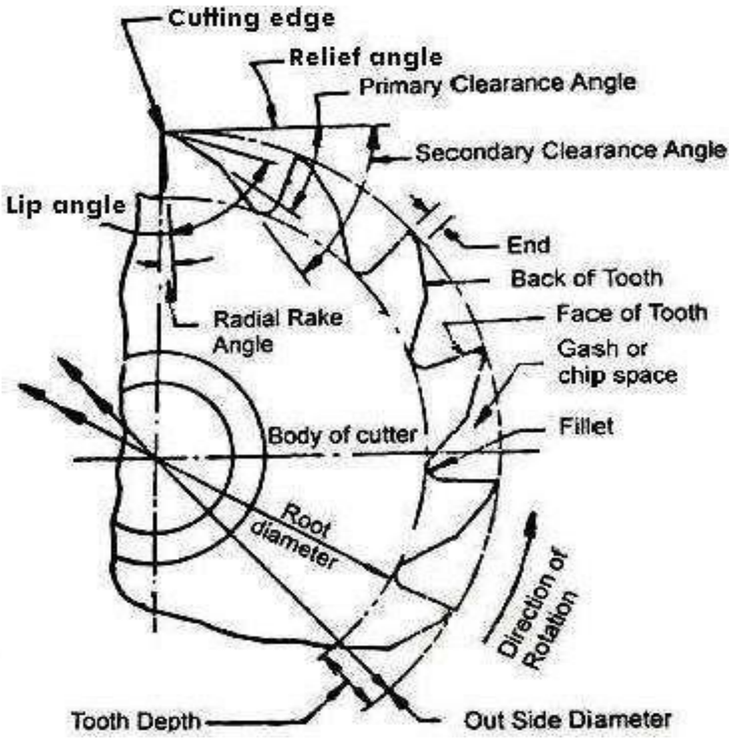


Fig. 3.89 Elements of a plain milling cutter

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 thenext tooth.

Land The part of the back of tooth adjacent to the cutting edge which is relieved to avoid interference between the surfac

Out side diameter The diameter of the circle passing through the peripheral cutting edge.

Root diameter The diameter of the circle passing through the bottom of thef illet

Cutter angles imilar 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.

Rel 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 ofthe tooth.

Primary clearan ceangle 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 clearan ceangle 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.*

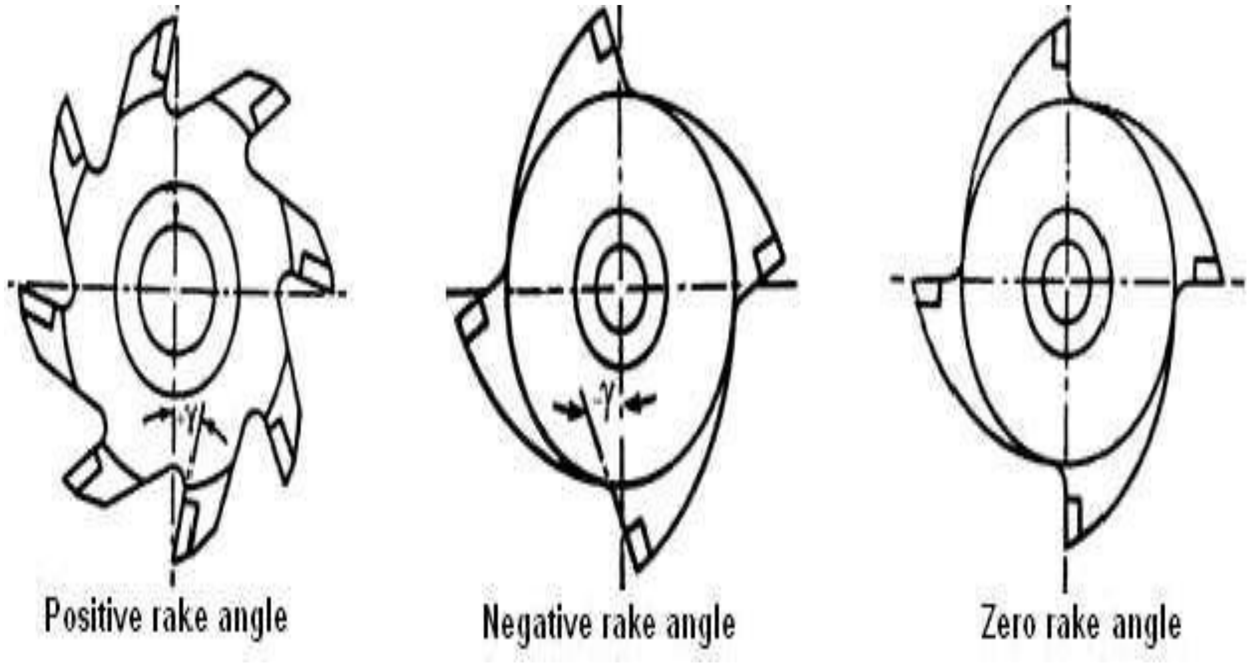


Fig. 3.90 Three types of rake angle of a plain milling cutter

MILLINGOPERATIONS

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.*

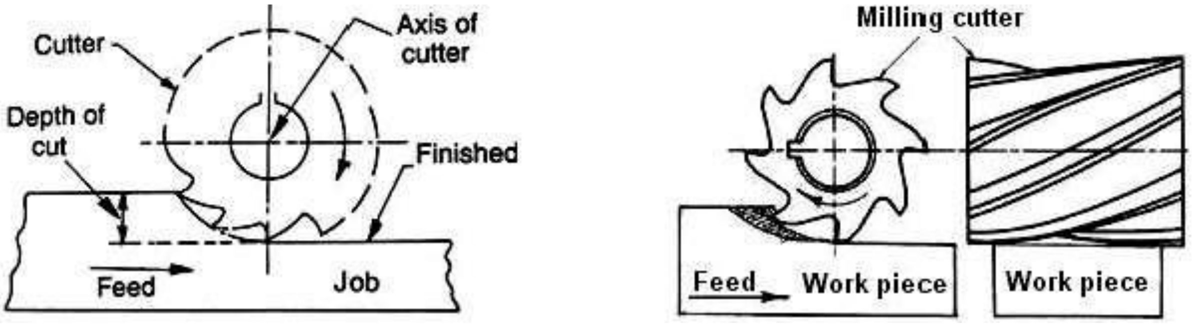


Fig. 3.91 Schematic view of the peripheral milling operation

Face milling Here, the finished surface is perpendicular to the axis of rotation of the cutter and is machined by cutter teeth on the peripheral and the flatened 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.

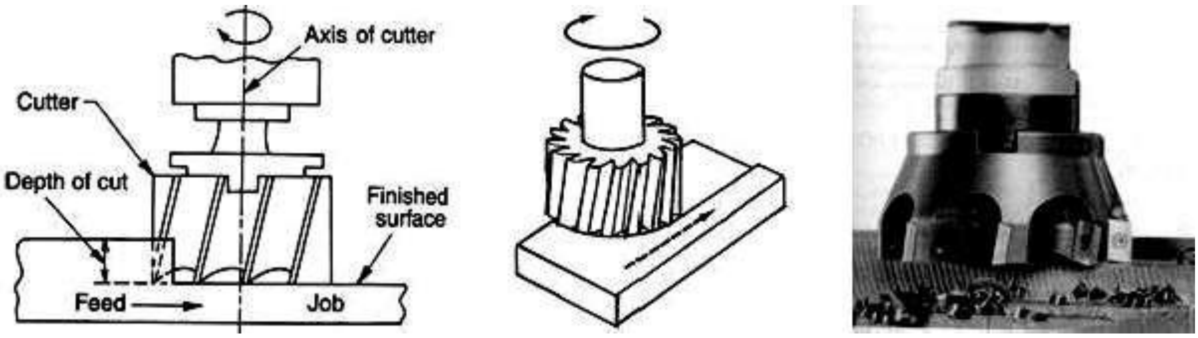


Fig. 3.92 Schematic view of the face milling operation

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.*

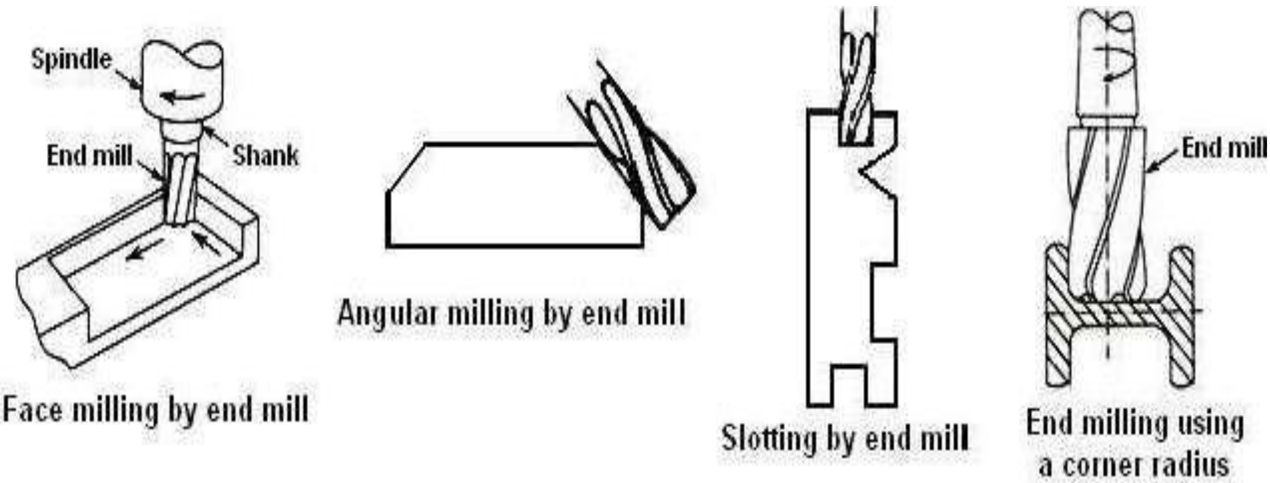


Fig. 3.93 Schematic views of the different end milling operations

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.

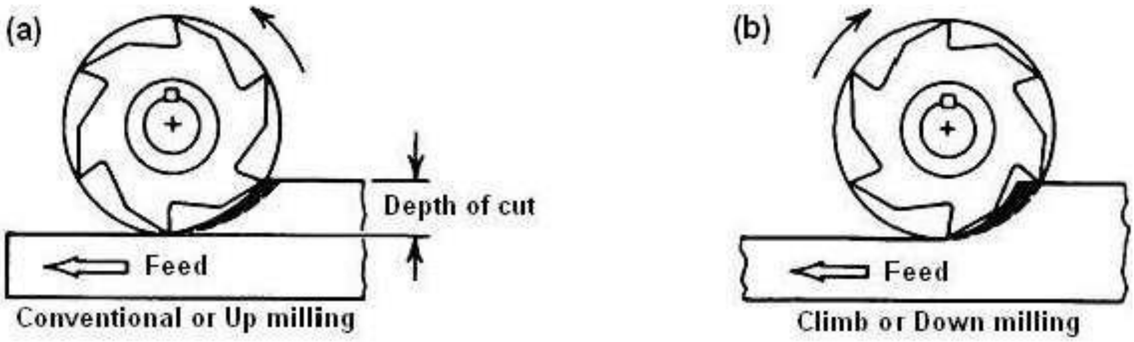


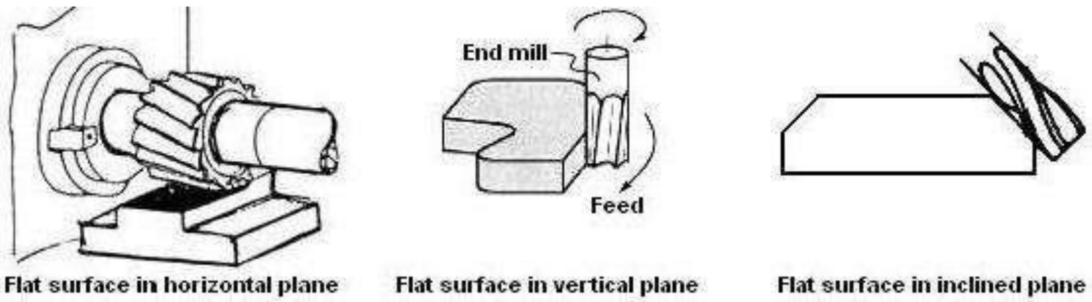
Fig. 3.94 (a) schematically shows the up milling or conventional milling process.

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.*

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.*

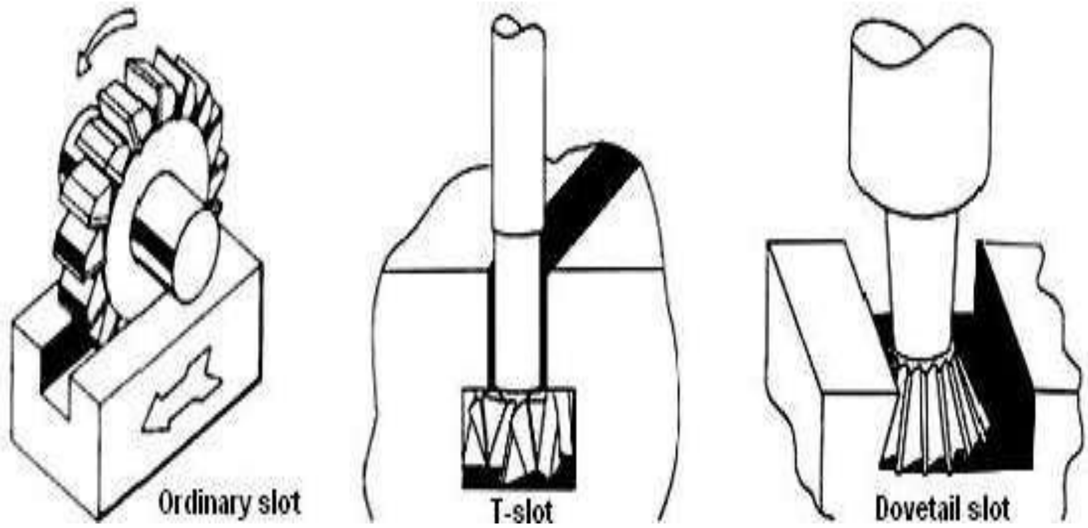


Fig. 3.96 Machining slots of various cross sections

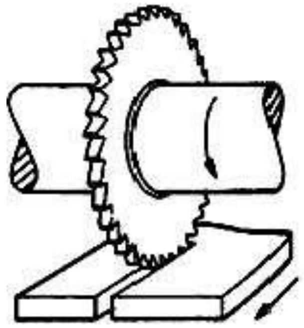


Fig. 3.97 Parting byslittingsaw

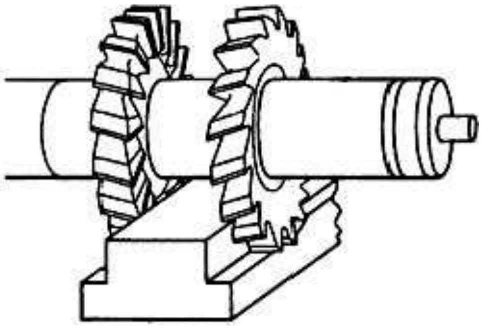
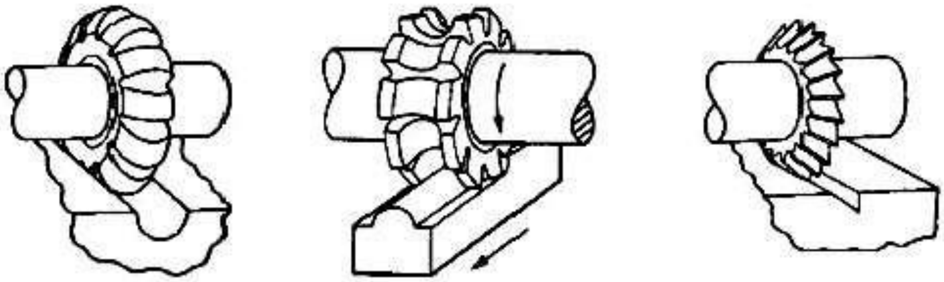


Fig. 3.98 Straddlemilling

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.*

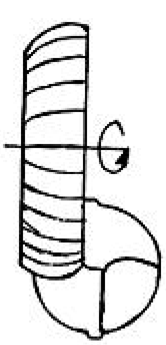


Fig. 3.100 Cutting of drill flutes

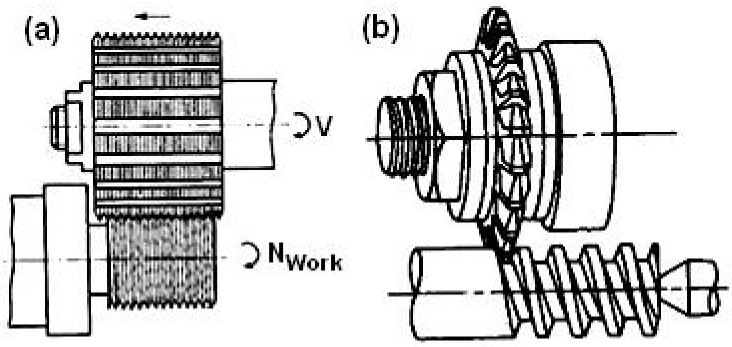


Fig. 3.101 (a) Short thread milling (b) Long thread milling

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).*

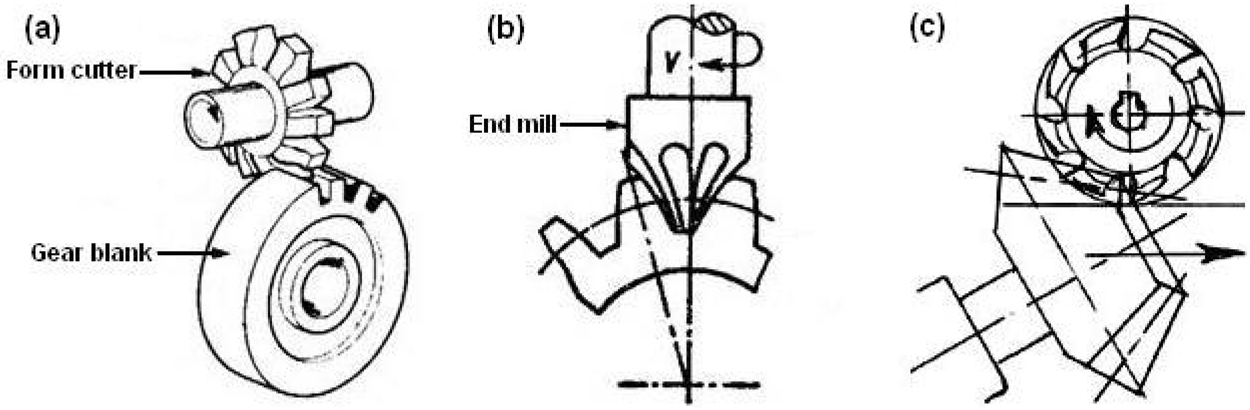


Fig. 3.102 (a) Cutting teeth of spur gear by disc type cutter (b) Cutting teeth of spur gear by end mill

(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.*

(d)

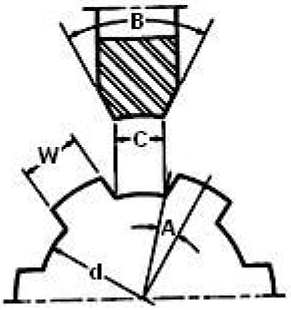


Fig. 3.103 Cutting slots of externalsplineshaft

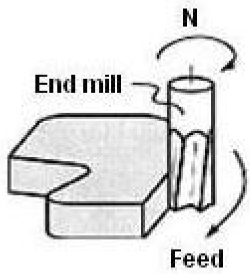
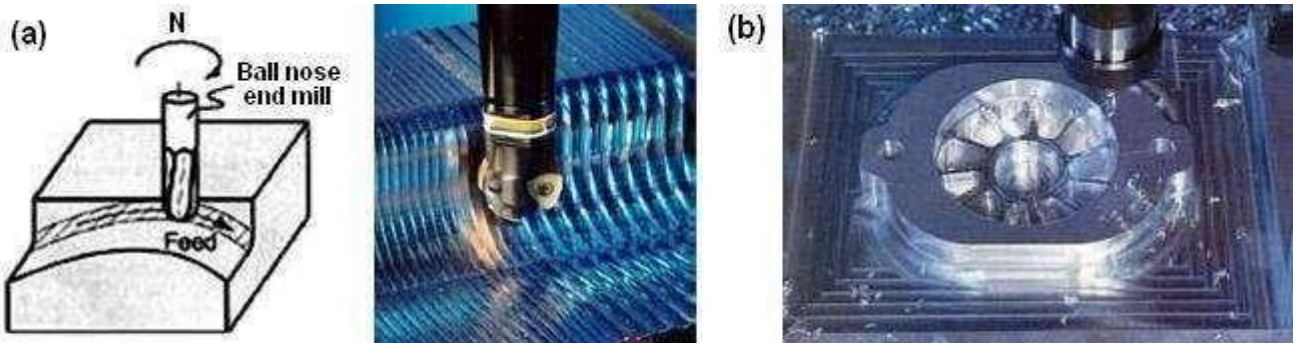


Fig. 3.104 Profile milling of acam

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.*

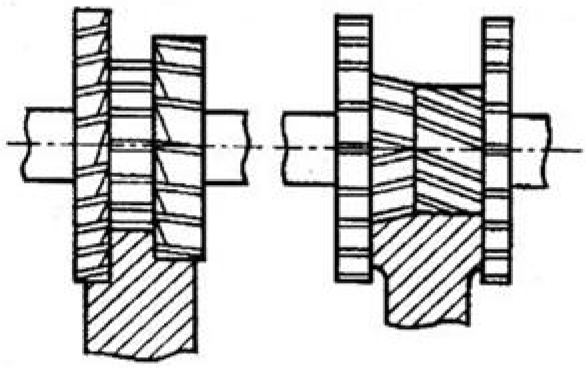


Fig. 3.106 Gang milling

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 andc).*

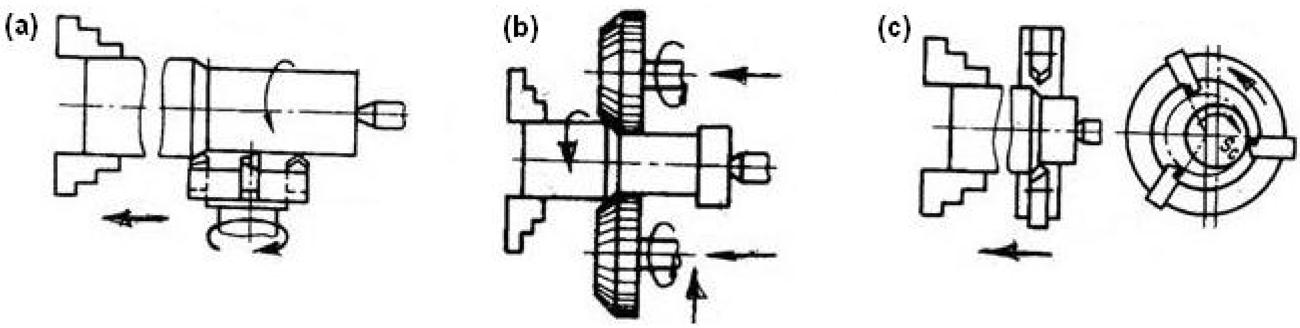


Fig. 3.107 (a, b and c) Turning by rotary milling cutters

HOLEMAKING

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.*

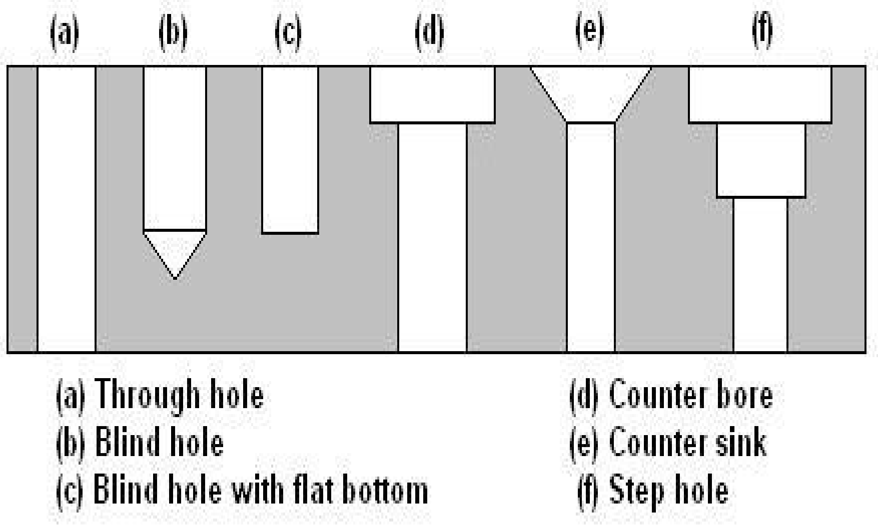


Fig. 3.108 Various types of holes

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.

Types of drilling machine

The different types of drilling machine which are most commonly used are:

- Portable drillingmachine.
- Sensitive drilling machine (Bench mounting or table top and Floormounting).
- Upright drilling machine (Pillar or Round column section and Box columnsection).
- Radial drilling machine (Plain, Semi-universal andUniversal).
- Gang drillingmachine.
- Multiple spindle drillingmachine.
- Deep hole drillingmachine.
- Turret type drillingmachine

But in working principle all are more or less the same.

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.*

Bench mounting or table top sensitive drilling machine

This small capacity ($\leq$ 0.5 kW) upright (vertical) single spindle drilling machine is mounted on rigid table and manually operated using usually small size ($\varphi \leq 10$ mm) drills. *Fig. 3.110 illustrates a table top sensitive drilling machine.*

Fig. 3.109 Handdrillingmachine   Fig. 3.110 Table top sensitive drillingmachine

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 drillingmachinesarecapableofrotatingdrillsofdiameterfrom1.5to15.5mm.Super sensitivedrilling 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.*

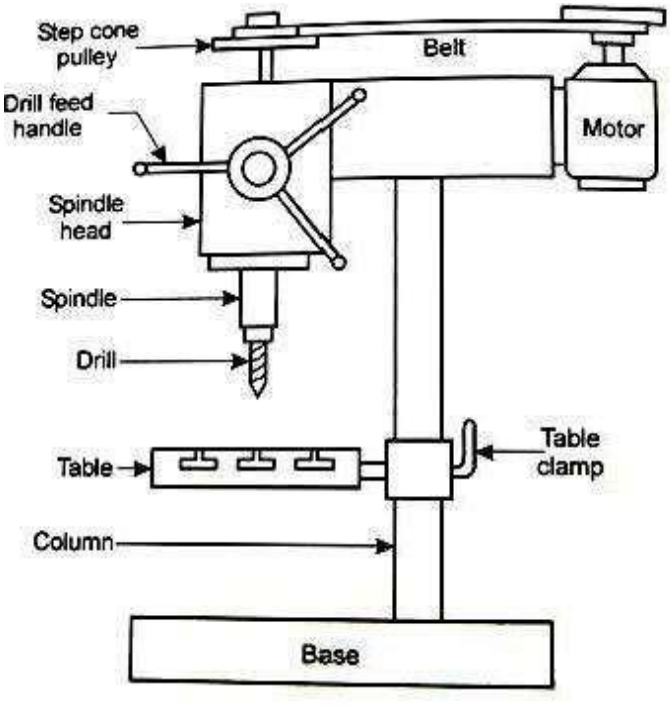


Fig. 3.111 Floor mounting sensitive drilling machine,   Fig. 3.112 Pillar drilling machine

Pillar or Round column section upright drillingmachine

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 50mm.

Box column section upright drilling machine

Fig. 3.113 illustrates a box column section upright drilling machine. The major parts are:

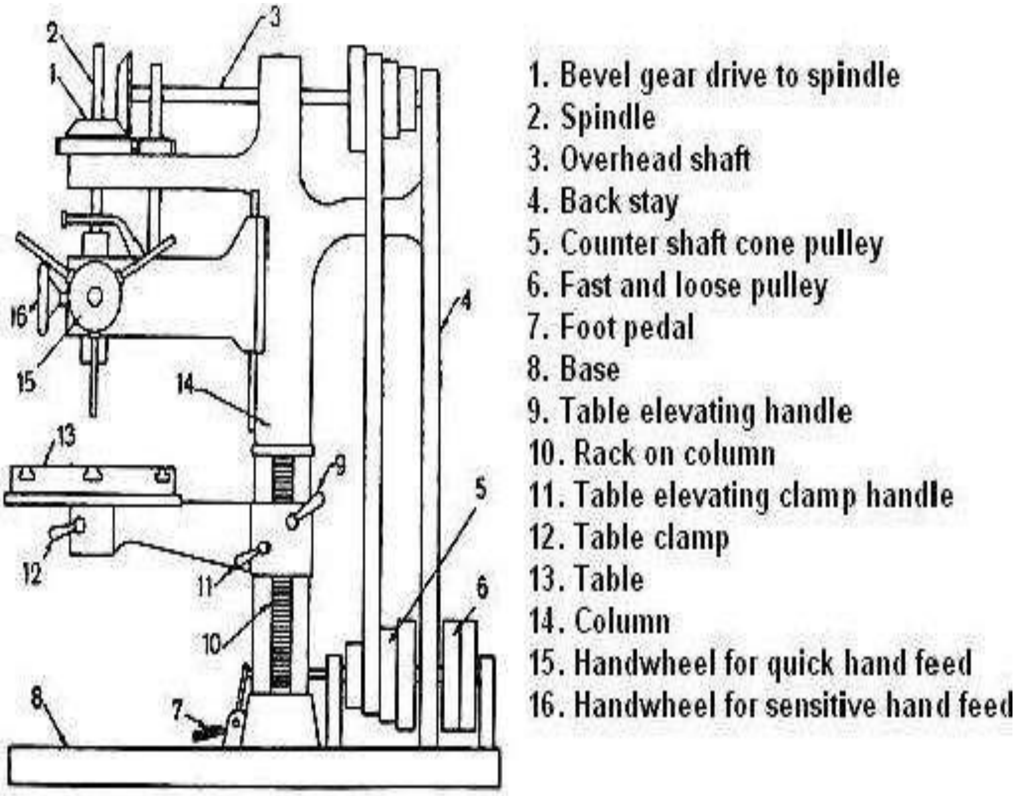


Fig. 3.113 Box column section upright drilling machine

Twist drill elements

Axis	The longitudinal centre line of thedrill.
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 theshank.
Bodyclearance	That portion of the body surface which is reduced in diameter to provide diametral clearance.
Chiseledge	The edge formed by the intersection of the flanks. The chisel edge is also sometimes called deadcentre.
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 provideslip.

The functions of the flutes are:

- To form the cutting edges.
- To allow the chips to escape.
- To cause the chips tocurl.
- To permit the cutting fluid to reach the cuttingedges.

Heel The edge formed by the intersection of the flute surface and the bodyclearance.

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 flutehelix.

Lip(cuttingedge) The edge formed by the intersections of the flank andface.

The requirements of the drill lip are:

- Both lips should be at the same angle of inclination (59^0) with the drillaxis.
- Both lips should be of equallength.
- Both lips should be provided with the correctclearance.

Neck The diametrically undercut portion between the body and the shank of thedrill. Diameter and other particulars of the drill are engraved at the neck.

Outercorner The corner formed by the intersection of the flank andface.

Point The sharpened end of the drill, which is shaped to produce lips, faces, flanksand chiseledge.

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 straightshank.

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 thespindle.

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 largerdiameters.

Bodyclearancediameter The diameter over the surface of the drill body which issituated behind the lands.

Depth ofbodyclearance The amount of radial reduction on each side to provide bodyclearance.

Diameter The measurement across the cylindrical lands at the outer corners of thedrill.

Flutelength The axial length from the extreme end of the point to the termination of the flute atthe shank end of thebody.

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.

Liplength The minimum distance between the outer corner and the chisel edge corner of thelip.

Overalllength The length over the extreme ends of the point and the shank of thedrill.

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 pointend.

Webthickness The minimum dimension of the web or core measured at the point end of thedrill.

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.

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 (co axially) 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.

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.*

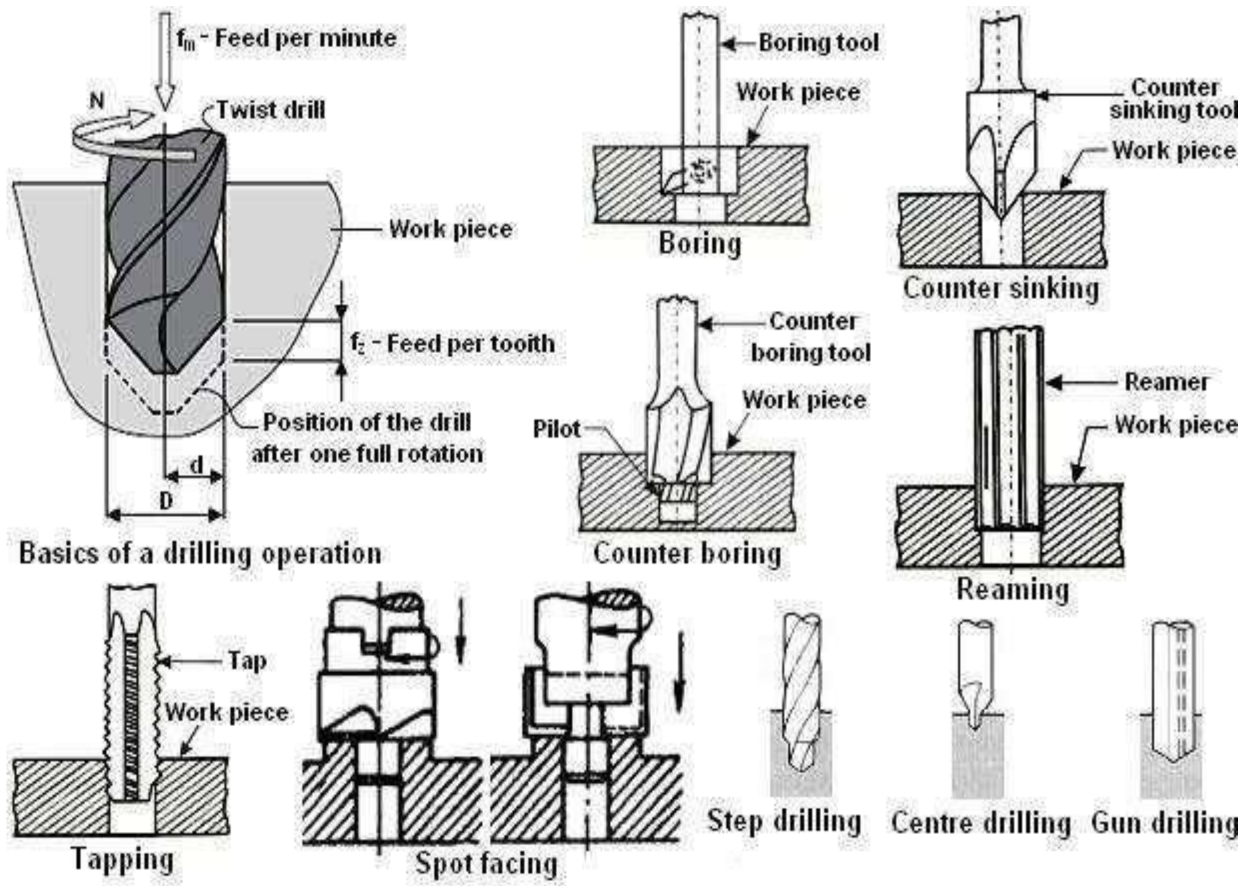
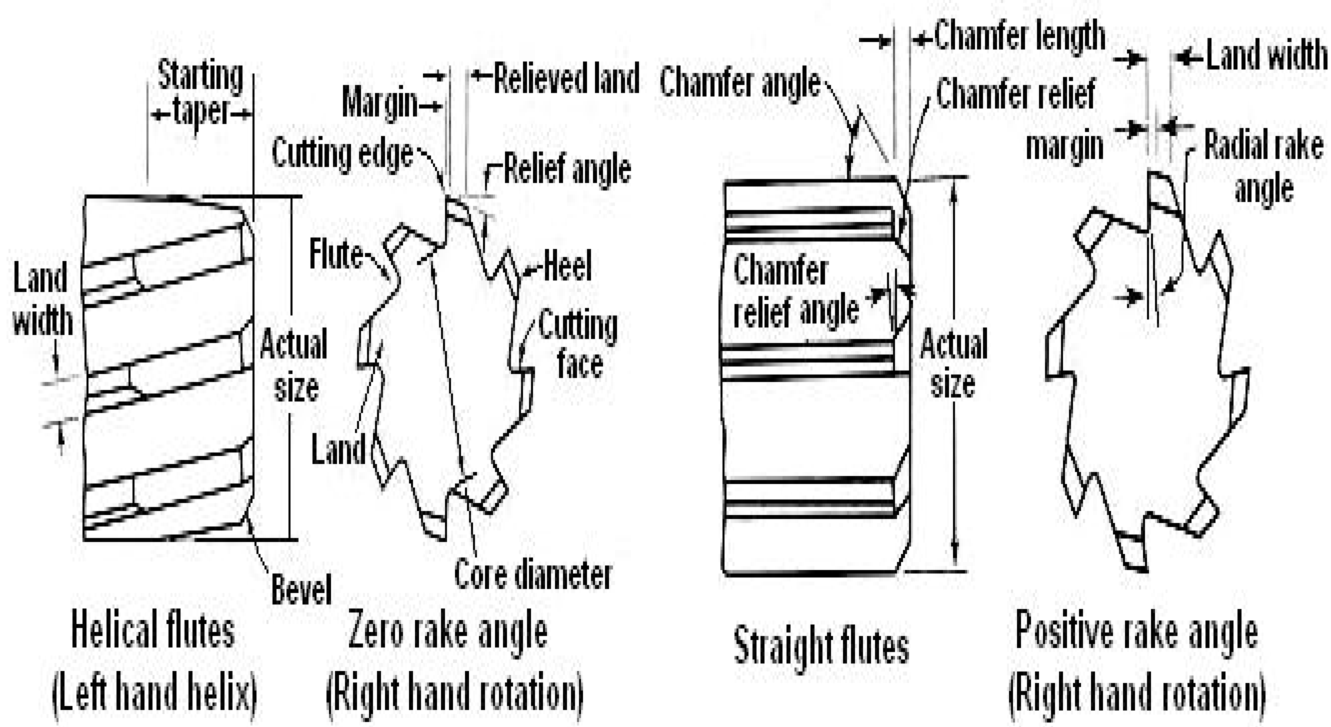


Fig. 3.128 Different operations performed in a drilling machine



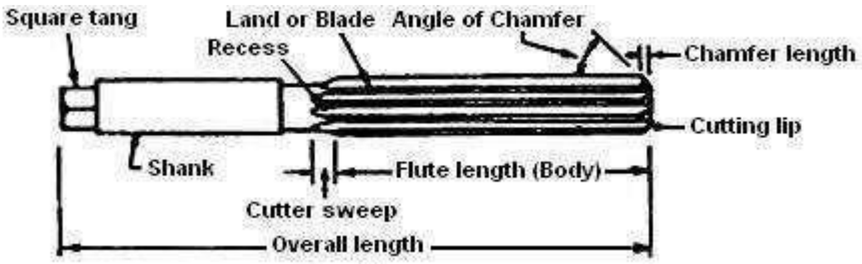


Fig. 3.129 Elements of a reamer

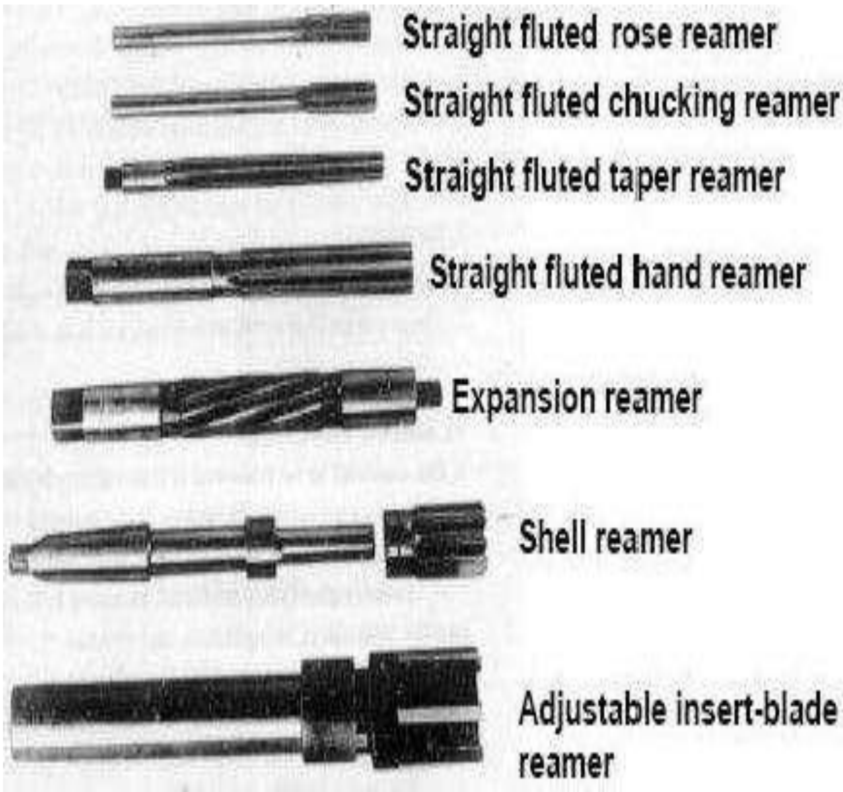


Fig. 3.130 Different typesofreamers

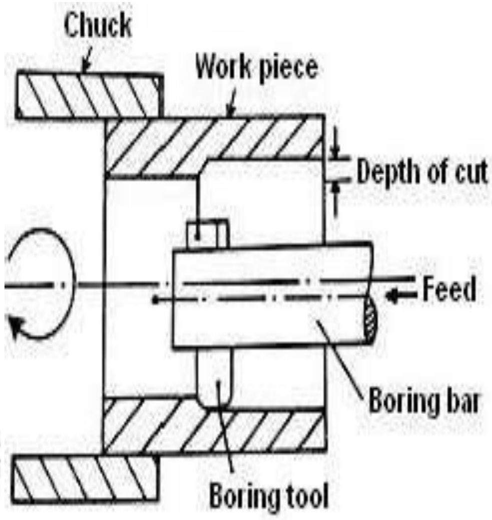


Fig. 3.131 Principle of boringoperation

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.

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.

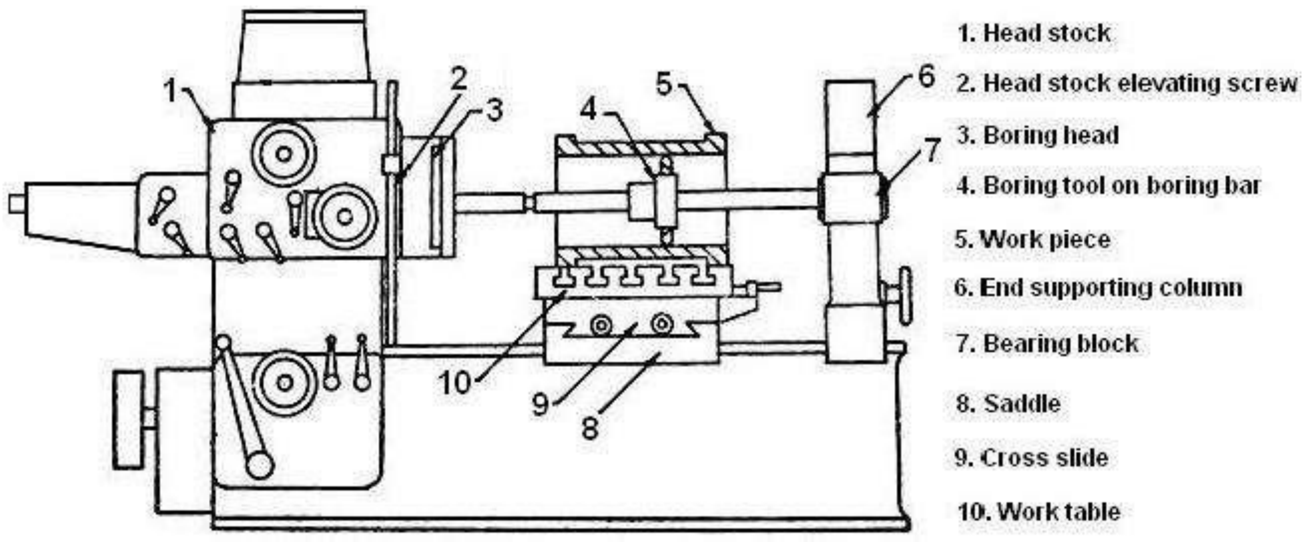


Fig. 3.132 schematically shows the basic configuration of a horizontal boring machine.

Fig. 3.132 Basic configuration of a horizontal boring machine

Types of horizontal boring machine

Different types of horizontal boring machines have been designed to suit different purposes.

They are:

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.*

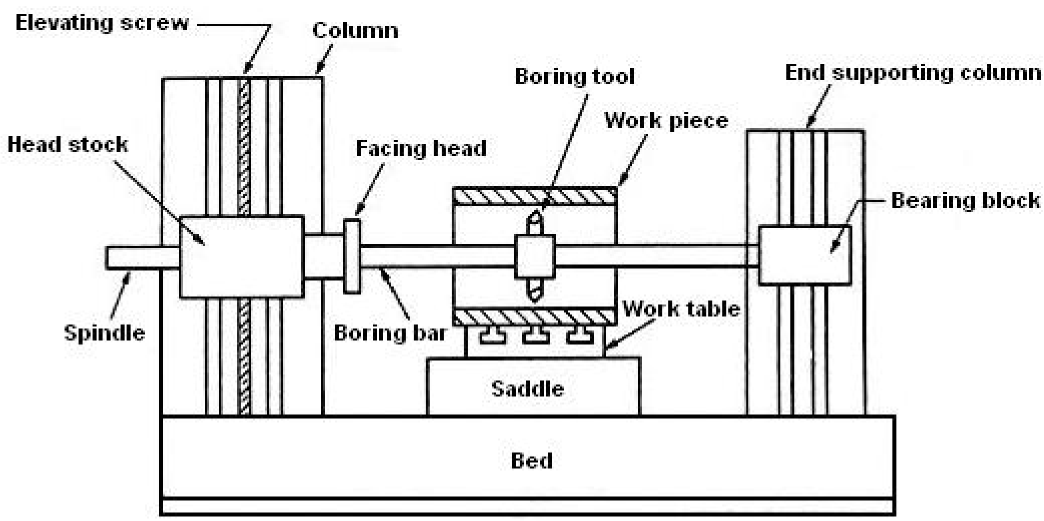


Fig. 3.133 Table type horizontal boring machine

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.*

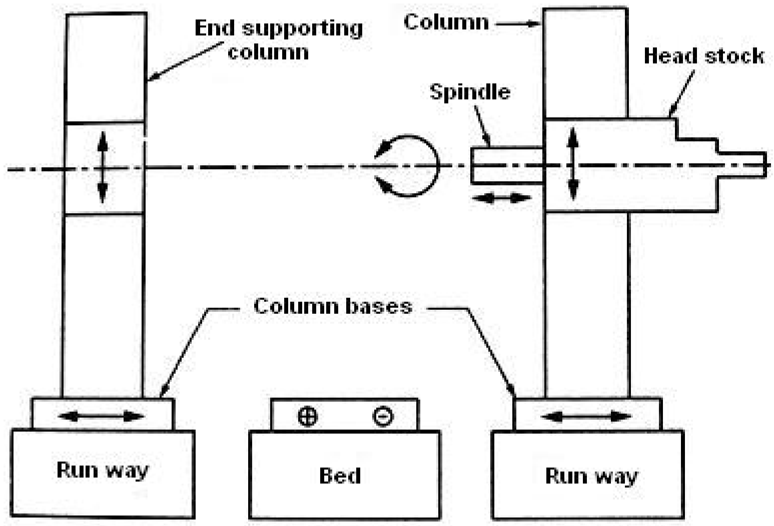


Fig. 3.134 Planer type horizontal boring machine

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.*

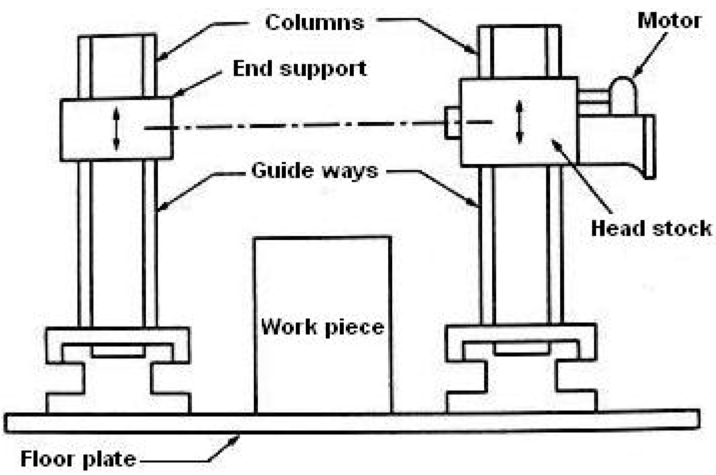


Fig. 3.135 Floor type horizontal boring machine

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.*

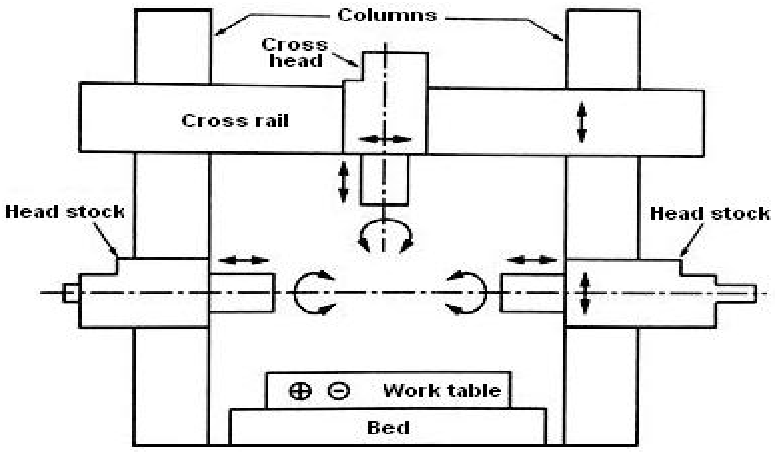


Fig. 3.136 Multiple head type horizontal boring machine

Vertical boringmachines

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 tablerevolves.

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.*

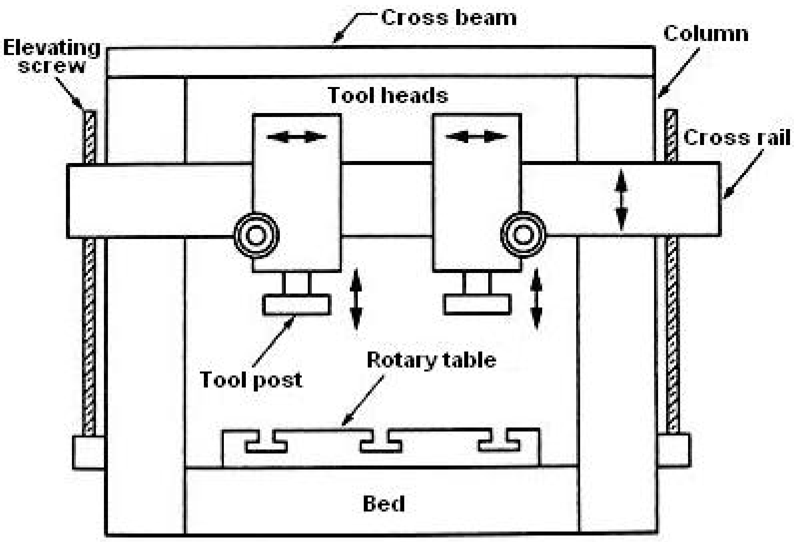


Fig. 3.137 Double column verticalboringmachine

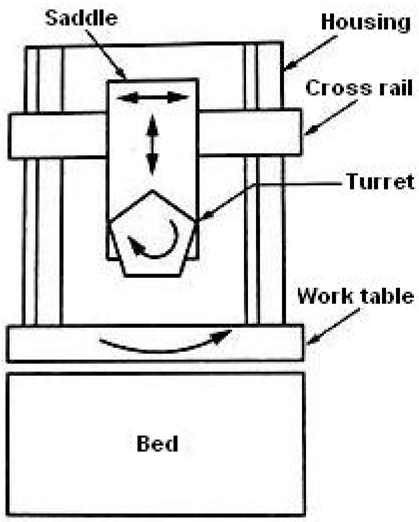


Fig. 3.138 Turret boringmachine

Jig borers or jig boringmachines

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 boringmachine.*

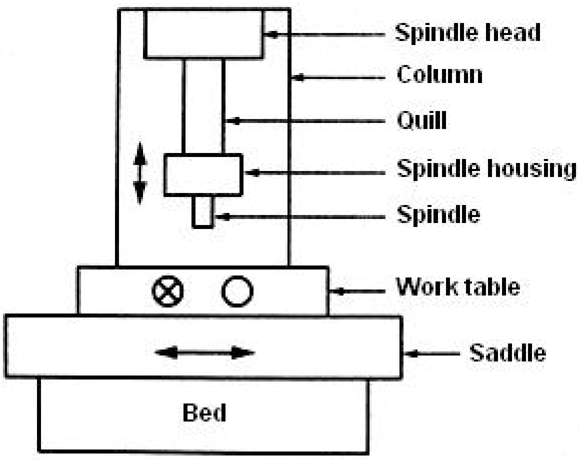


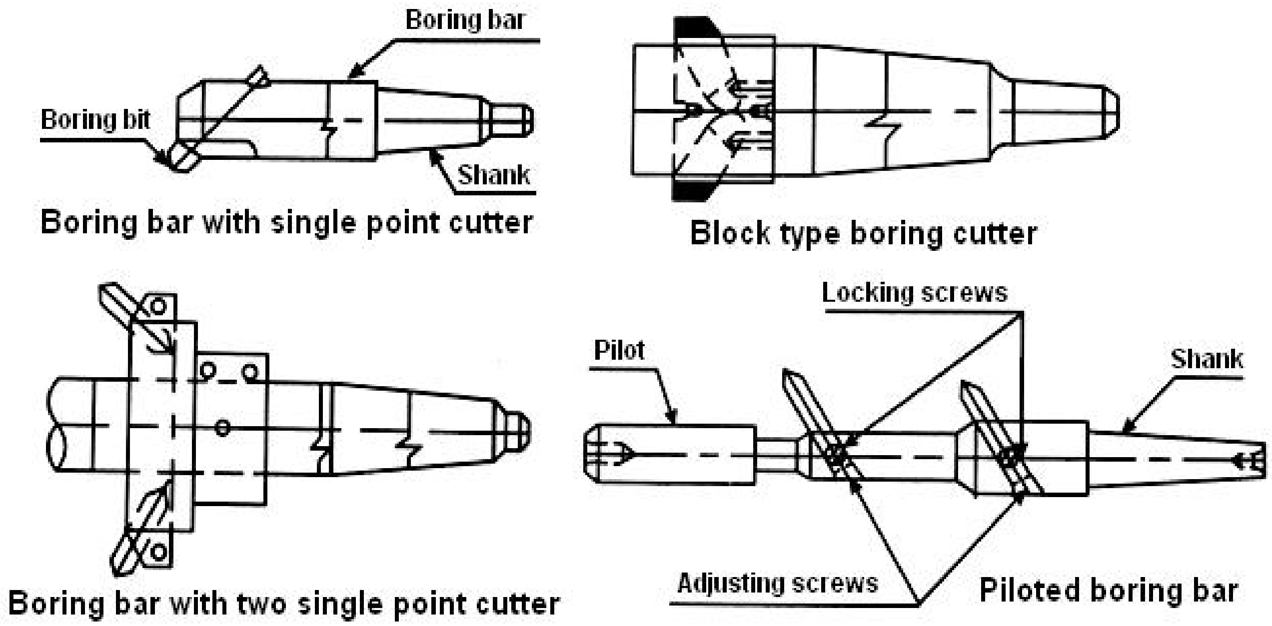
Fig. 3.139 Block diagram of a jig boring machine

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 solidtap.*



UNIT – IV

SYSTEM OF LIMITS, FITS, TOLERANCE AND GAUGING

Limits & Fits: Why study Limits & Fits??

- Exact size is impossible to achieve.
- Establish boundaries within which deviation from perfect form is allowed but still the design intent is fulfilled.
- Enable interchangeability of components during assembly

Definition of Limits:

The maximum and minimum permissible sizes within which the actual size of a component lies are called Limits.

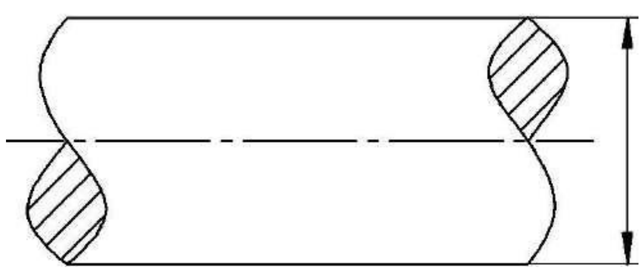
Tolerance:

It is impossible to make anything to an exact size, therefore it is essential to allow a definite tolerance or permissible variation on every specified dimension.

Why Tolerances are specified?

- Variations in properties of the material being machined introduce errors.
- The production machines themselves may have some inherent inaccuracies.
- It is impossible for an operator to make perfect settings. While setting up the tools and workpiece on the machine, some errors are likely to creep in.

+0.05
–0.05



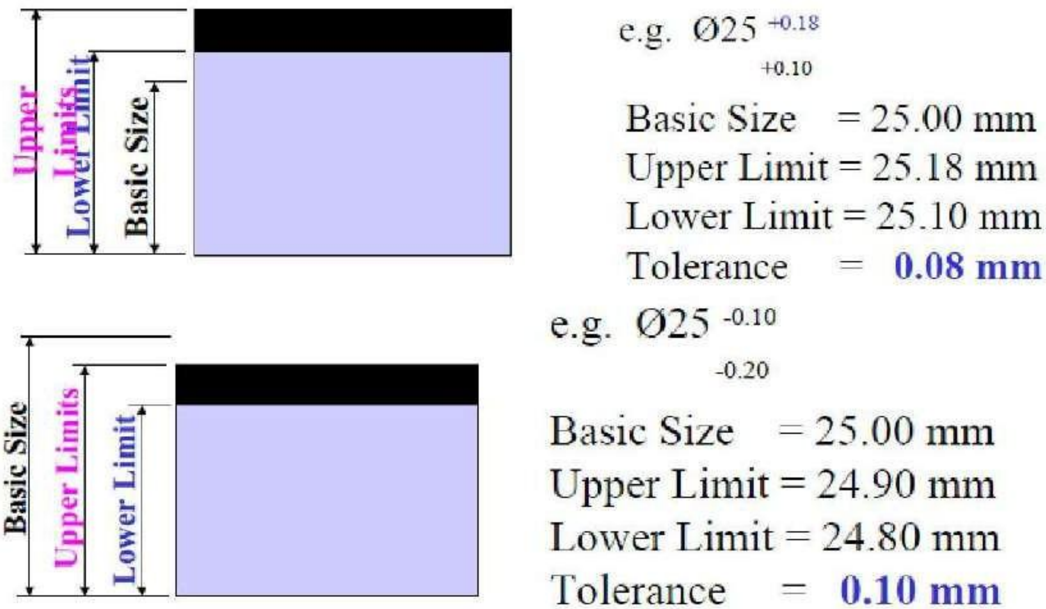
Consider the dimension shown in fig. When trying to achieve a diameter of 40 mm (Basic or Nominal diameter), a variation of 0.05 mm on either side may result.

If the shaft is satisfactory even if its diameter lies between 40.05 mm & 39.95 mm, the dimension 40.05 mm is known as Upper limit and the dimension 39.95 mm is known as Lower limit of size. Tolerance in the above example is (40.05-39.95)

=0.10 mm Tolerance is always a positive quantitative number.

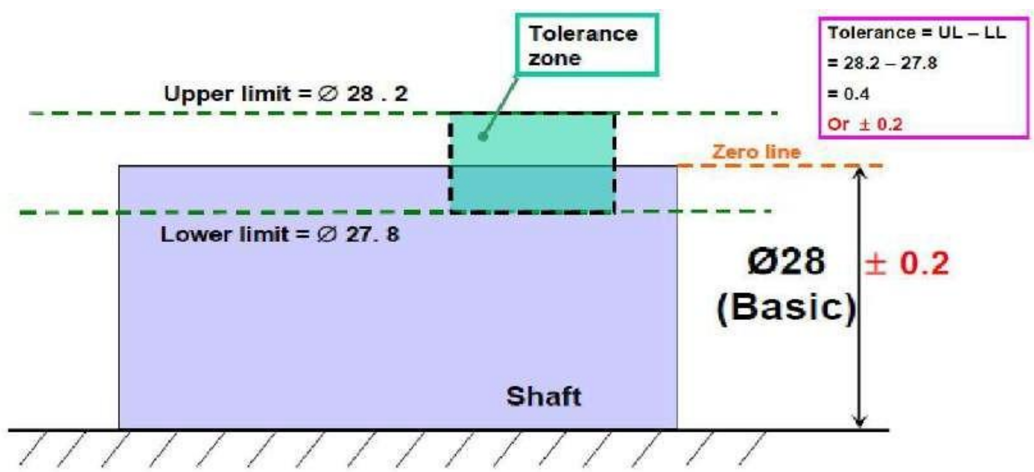
Unilateral Tolerance:

- Tolerances on a dimension may either be unilateral or bilateral.
- When the two limit dimensions are only on one side of the nominal size, (either above or below) the tolerances are said to be unilateral.
- For unilateral tolerances, a case may occur when one of the limits coincide with the basic size.

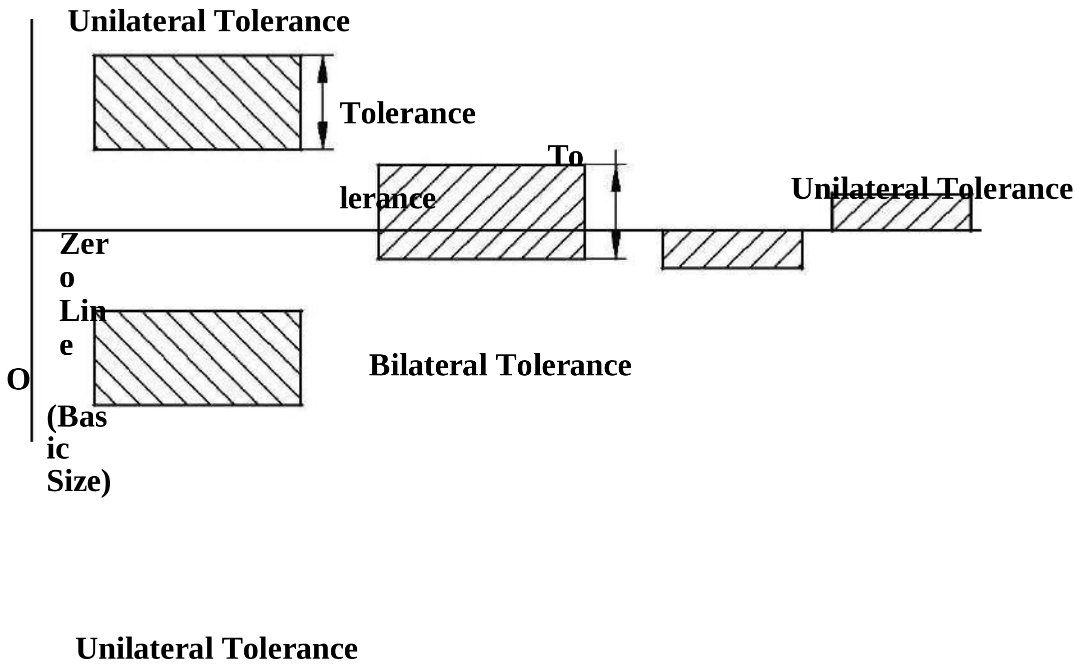


Bilateral Tolerance: When the two limit dimensions are above and below nominal size,(i.e. on either side of the nominal size) the tolerances are said to be bilateral.

Unilateral tolerances, are preferred over bilateral because the operator can machine to the upper limit of the shaft (or lower limit of a hole) still having the whole tolerance left for machining to avoid rejection of parts.



Schematic representation of tolerances:



Tolerance Accumulation (or) Tolerance Build up:

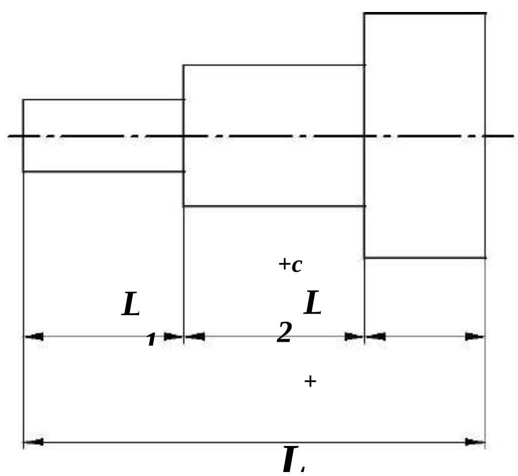


Fig (a)

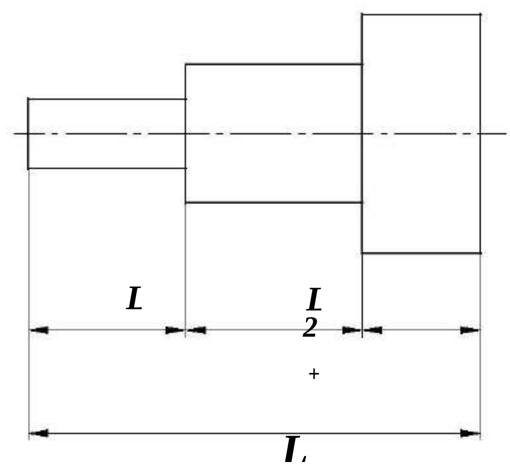


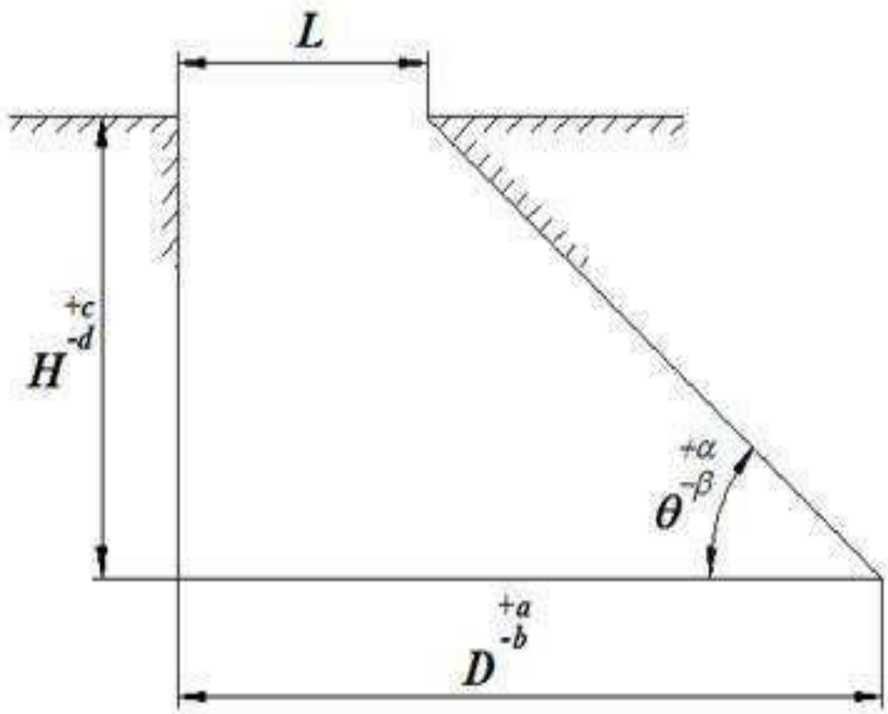
Fig (b)

If a part comprises of several steps, each step having some tolerance specified over its length, then the overall tolerance on the complete length will be the sum of tolerances on individual lengths as shown in fig (a).

The effect of accumulation of tolerances can be minimized by adopting progressive dimensioning from a common datum as shown in fig (b).

Another example of tolerance build up is shown below.

Compound Tolerances: A compound tolerance is one which is derived by consideringthe effect of tolerances on more than one dimension.



For ex, the tolerance on the dimension L is dependent on the tolerances on D, H &θ.

The dimension L will be maximum when the base dimension is (D+a), the angle is (θ+a), and the vertical dimension is (H-d).

The dimension L will be minimum when the base dimension is (D-b), the angle is (θ-b), and the vertical dimension is (H+c).

LIMITS OF SIZE & TOLERANCE

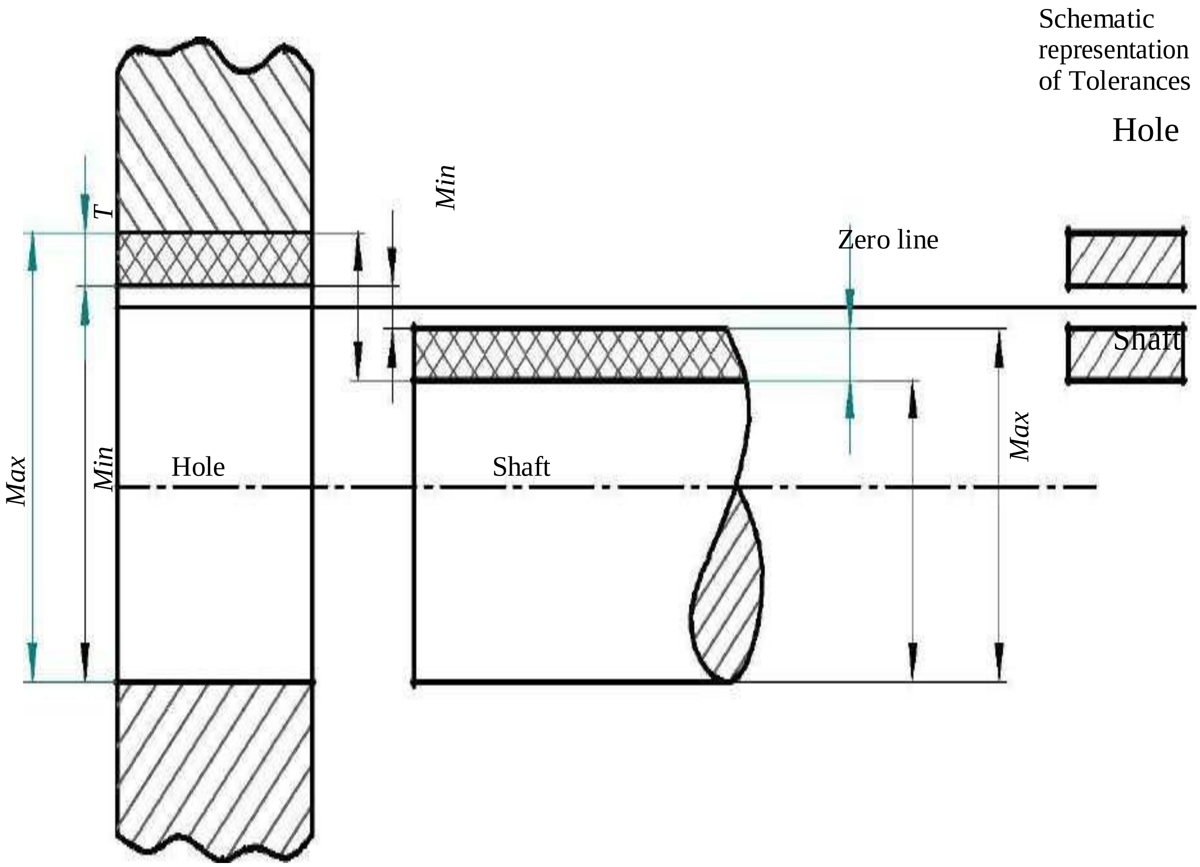
Terminology of limit systems:

Limits of size: The two extreme permissible sizes of a component between which theactual size should lie including the maximum and minimum sizes of the component.

Nominal size: It is the size of the component by which it is referred to as a matter of convenience.

Basic size: It is the size of a part in relation to which all limits of variation are determined.

Zero Line: It is the line w.r.t which the positions of tolerance zones are shown**.**



Deviation: It is the algebraic difference between a limit of size and the corresponding basic size.

Upper Deviation: It is the algebraic difference between the maximum limit of size andthe corresponding basic size. It is denoted by letters ***„ES‟*** for a hole and ***„es‟*** for a shaft.

Lower Deviation: It is the algebraic difference between the minimum limit of size andthe corresponding basic size. It is denoted by letters ***„EI‟*** for a hole and ***„ei‟*** for a shaft.

Fundamental Deviation: It is the deviation, either upper or lower deviation, which isnearest to the zero line for either a hole or a shaft. It fixes the position of the tolerance zone in relation to the zero line.

Allowance: It is the intentional difference between the hole dimensions and shaftdimension for any type of fit.

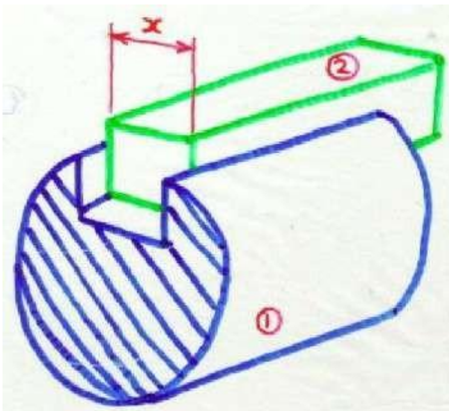
Size of tolerance: It is the difference between the maximum and minimum limits of size.

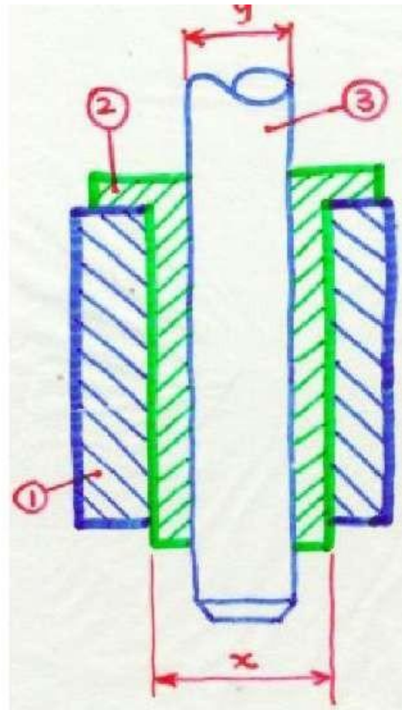
SYSTEM OF FITS

Fit is an assembly condition between _Hole‘ & _Shaft‘

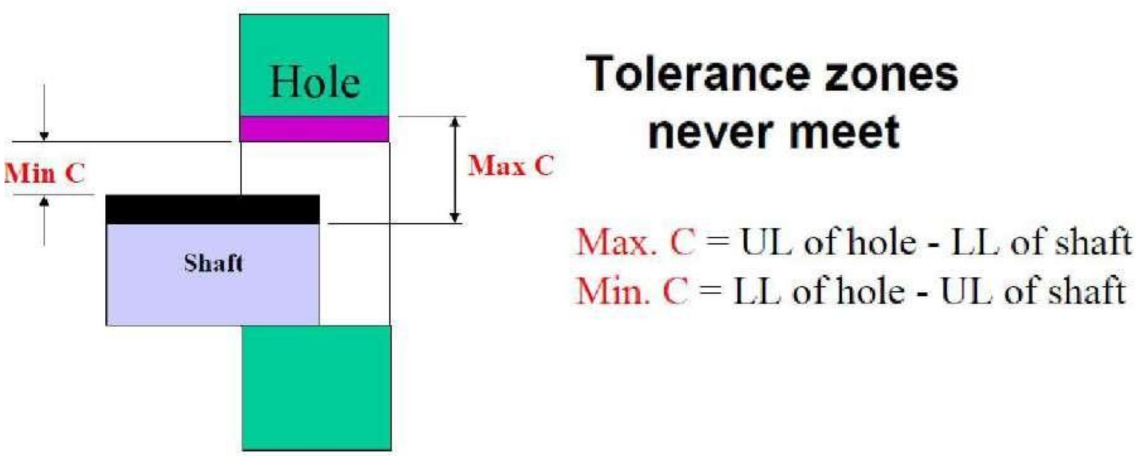
Hole: A feature engulfing a component.

Shaft: A feature being engulfed by a component.

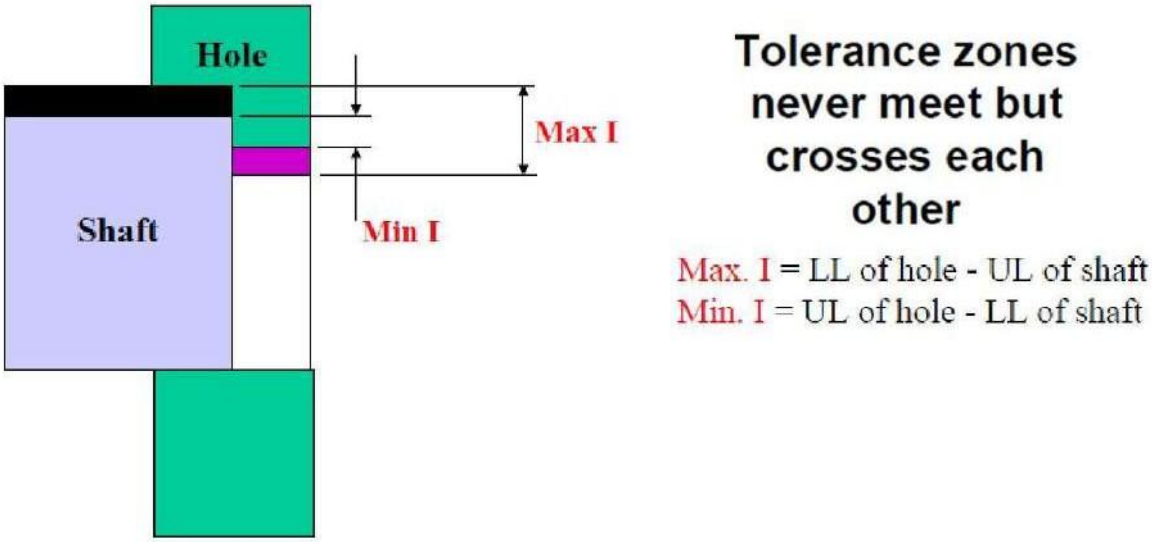




Clearance fit: In this type of fit, the largest permitted shaft diameter is less than thesmallest hole diameter so that the shaft can rotate or slide according to the purpose of the assembly.



Interfere

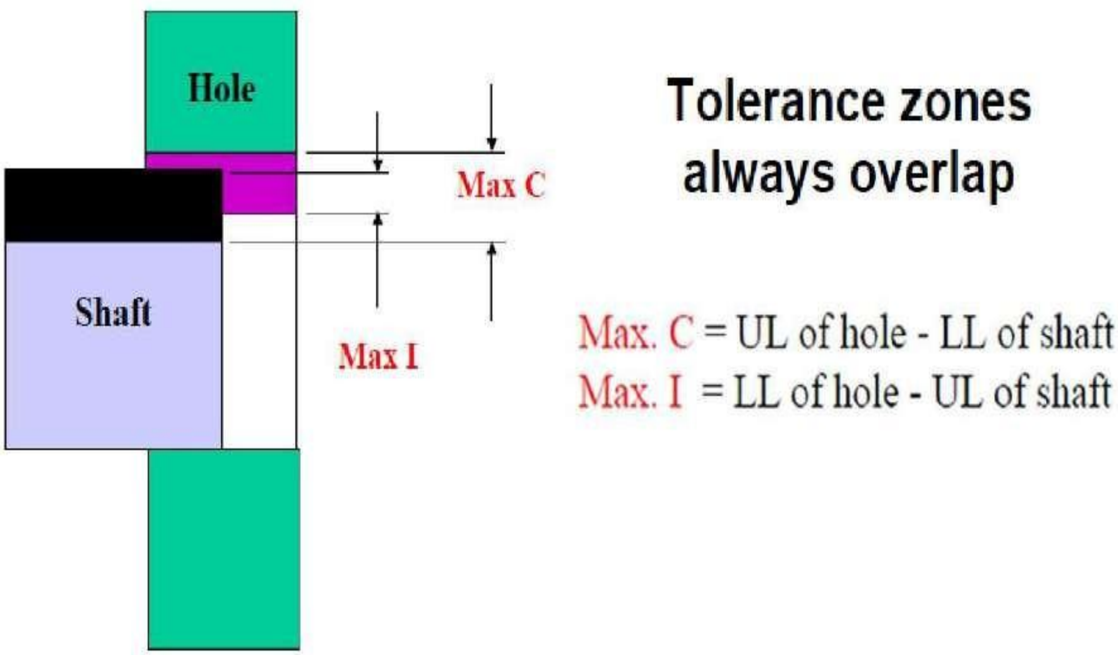


It is defined as the fit established when a negative clearance exists between the sizes of holes and the shaft. In this type of fit, the minimum permitted diameter of the shaft is larger than the maximum allowable diameter of the hole. In case of this type of fit, the members are intended to be permanently attached.

Ex: Bearing bushes, Keys & key ways

Transition Fit: In this type of fit, the diameter of the largest allowable hole is greaterthan the smallest shaft, but the smallest hole is smaller than the largest shaft, such that a small positive or negative clearance exists between the shaft & hole.

Ex: Coupling rings, Spigot in mating holes, etc.



Interchangeability occurs when one part in an assembly can be substituted for a similar part which has been made to the same drawing. Interchangeability is possible only when certain standards are strictly followed.

Universal interchangeability means the parts to be assembled are from two different manufacturing sources.

Local interchangeability means all the parts to be assembled are made in the same manufacturing unit.

Selective Assembly:

In selective assembly, the parts are graded according to the size and only matched grades of mating parts are assembled. This technique is most suitable where close fit of two components assembled is required.

Selective assembly provides complete protection against non-conforming assemblies and reduces machining costs as close tolerances can be maintained.

Suppose some parts (shafts & holes) are manufactured to a tolerance of 0.01 mm, then an automatic gauge can separate them into ten different groups of 0.001 mm limit for selective assembly of the individual parts. Thus high quality and low cost can be achieved.

Selective assembly is used in aircraft, automobile industries where tolerances are very narrow and not possible to manufacture at reasonable costs.

Geometrical Tolerances:

It is necessary to specify and control the geometric features of a component, such as straightness, flatness, roundness, etc. in addition to linear dimensions. Geometric tolerance is concerned with the accuracy of relationship of one component to another and should be specified separately.

Geometrical tolerance may be defined as the maximum possible variation of ***form***, or ***position of form*** or ***position of a feature.***

Geometric tolerances define the shape of a feature as opposed to its size. There are three basic types of geometric tolerances:

Form tolerances:

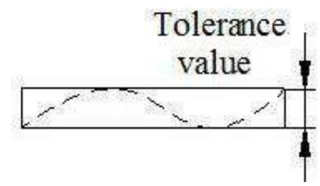
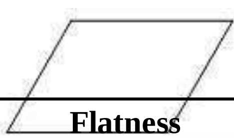
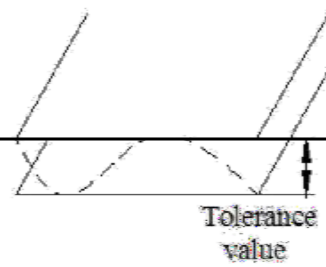
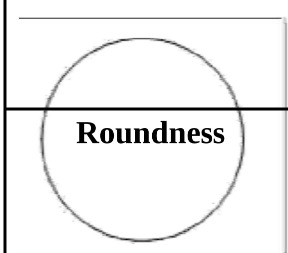
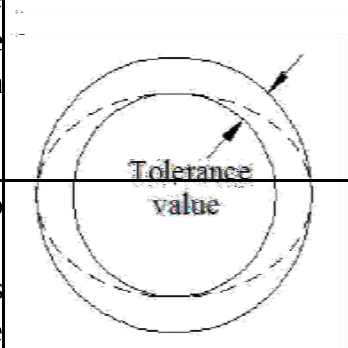
Straightness, flatness, roundness, cylindricity

Orientation tolerances:

Perpendicularity, parallelism, angularity

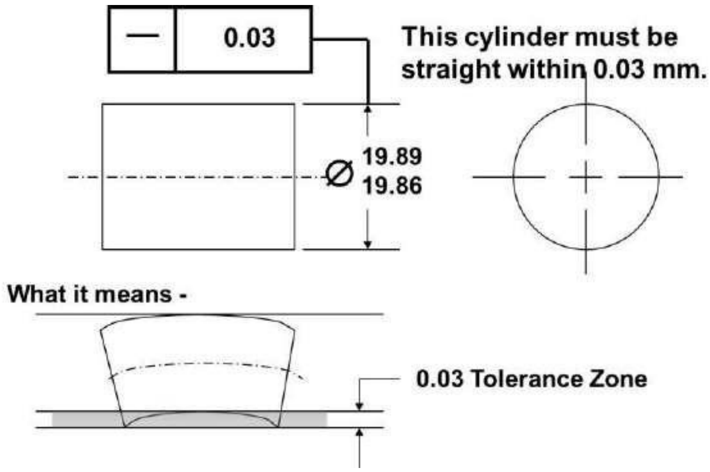
Position tolerances:

FORM TOLERANCES

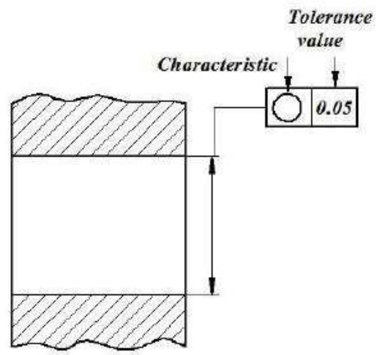
Characteristic or symbol	Function of geometric tolerance	Tolerance zone	Typical example
Straightness	To control the straightness of the line on a surface.	Area between two parallel straight lines in the plane containing the considered line or axis, Tolerance value is the distance between them.	
 **Flatness**	To control the flatness of a surface.	Area between two planes. Tolerance value is the distance between them.	
 **Roundness**	To control the errors of roundness of a circle in the plane in which it lies.	Area between two concentric circles. Tolerance value is the radial distance between them.	

Regardless of Feature Size (RFS): This is the default condition for all geometric tolerances.

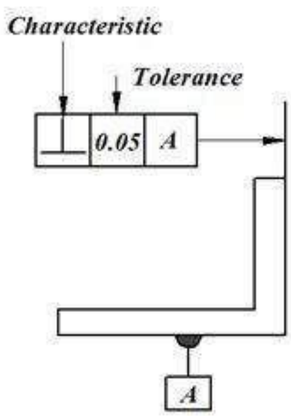
***Example*:STRAIGHTNESS**



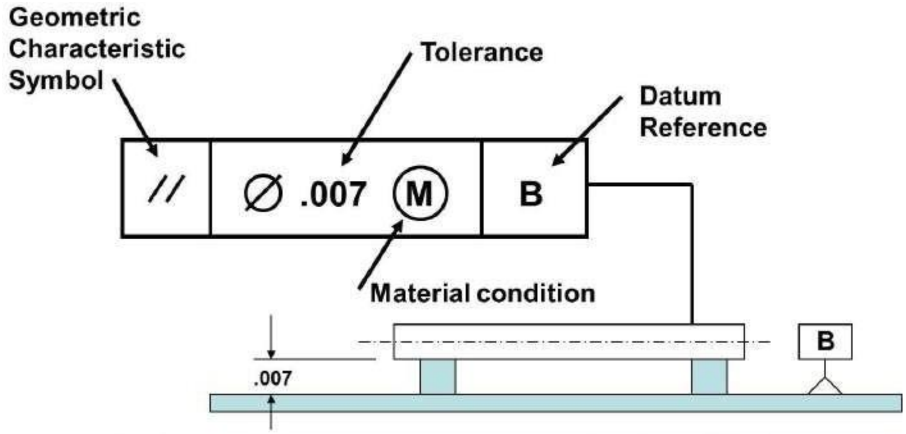
ROUNDNESS:



SQUARENESS:

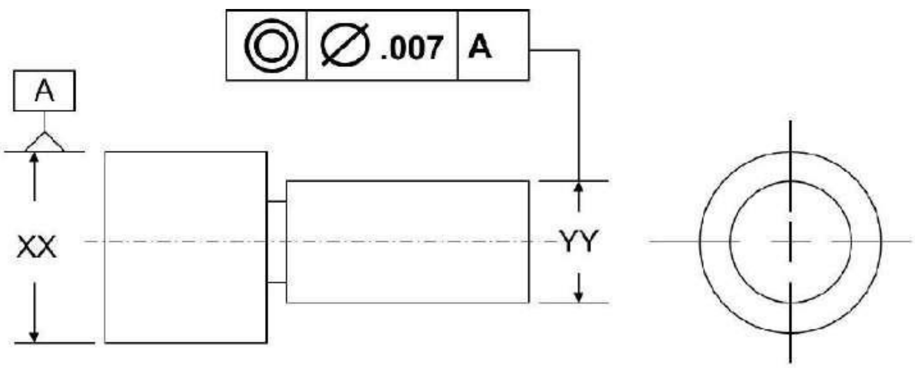


PARALLELISM:

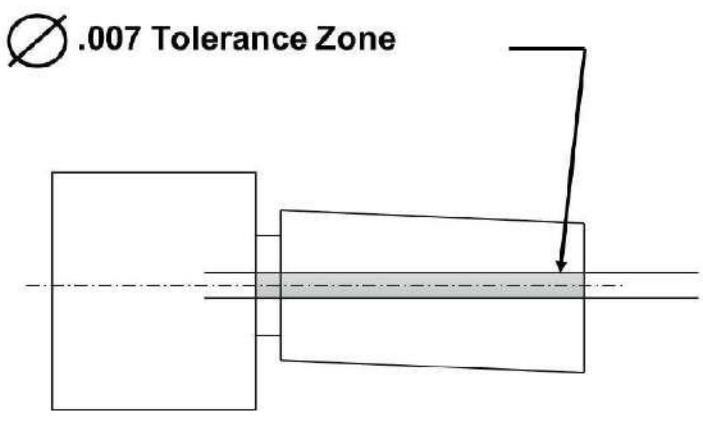


This feature must be parallel to Datum B within .007 at MMC (largest cylinder) as measured on the diameter

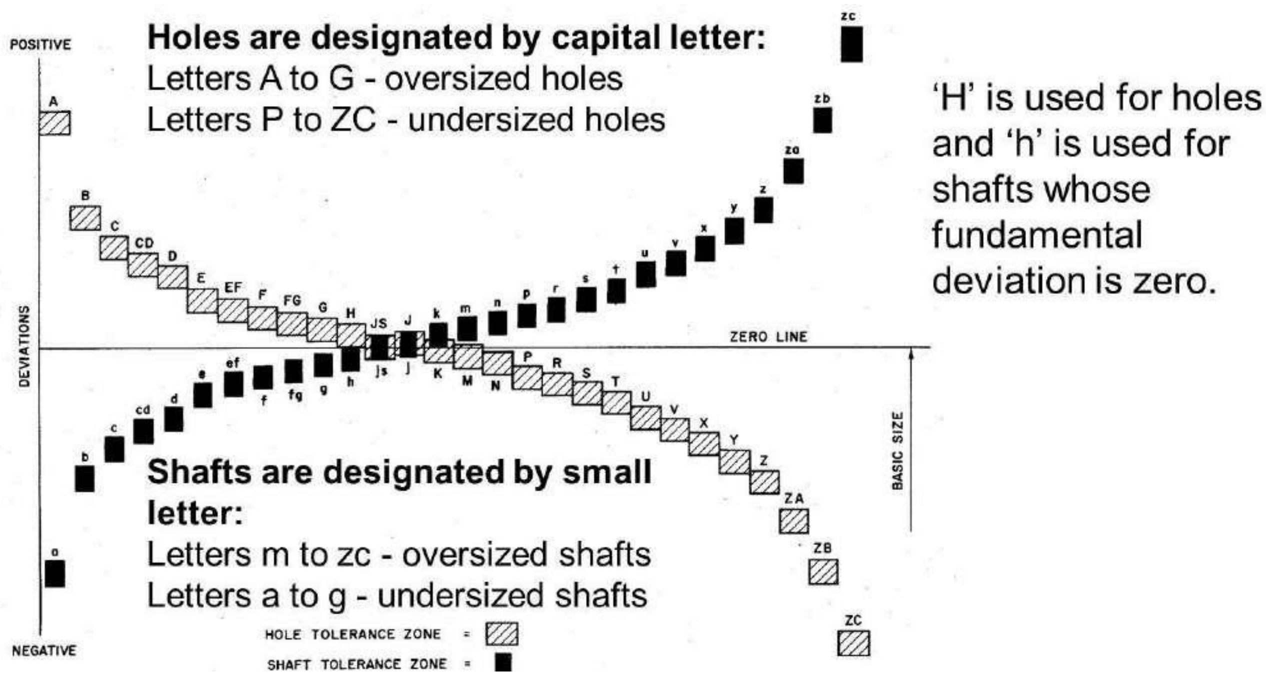
CONCENTRICITY:



This cylinder (the right cylinder) must be concentric within .007 with the Datum A (the left cylinder) as measured on the diameter



IS 919-1965 SYSTEM OF TOLERANCES



Terms & symbols used:

Basic shaft: It is a shaft whose upper deviation is zero. i.e. the maximum limit of shaftcoincides with the nominal size.(zero line). *Eg:* shaft ‗h‘

Basic hole: It is a hole whose lower deviation is zero. i.e. the minimum limit of holecoincides with the nominal size.(zero line). *Eg*: shaft ‗H‘

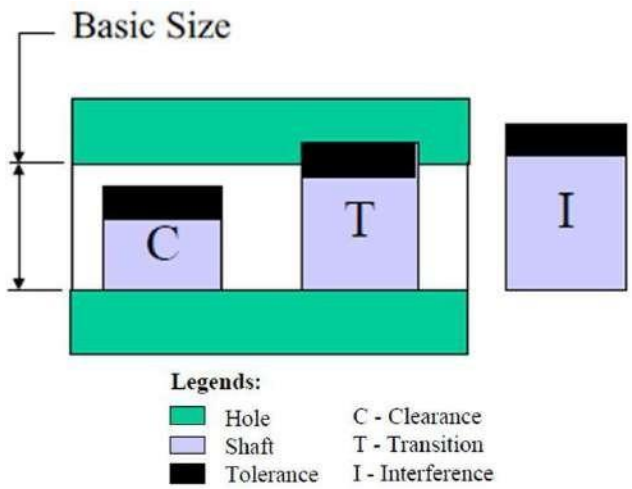
Basis of Fits

Hole Basis: In this system, the basic diameter of the hole is constant while the shaft sizeis varied according to the type of fit.

Significance of Hole basis system: The bureau of Indian Standards (BIS) recommendsboth hole basis and shaft basis systems, but their selection depends on the production methods. Generally, holes are produced by drilling, boring, reaming, broaching, etc. whereas shafts are either turned or ground.

If the shaft basis system is used to specify the limit dimensions to obtain various types of fits, number of holes of different sizes are required, which in turn requires tools of different sizes.

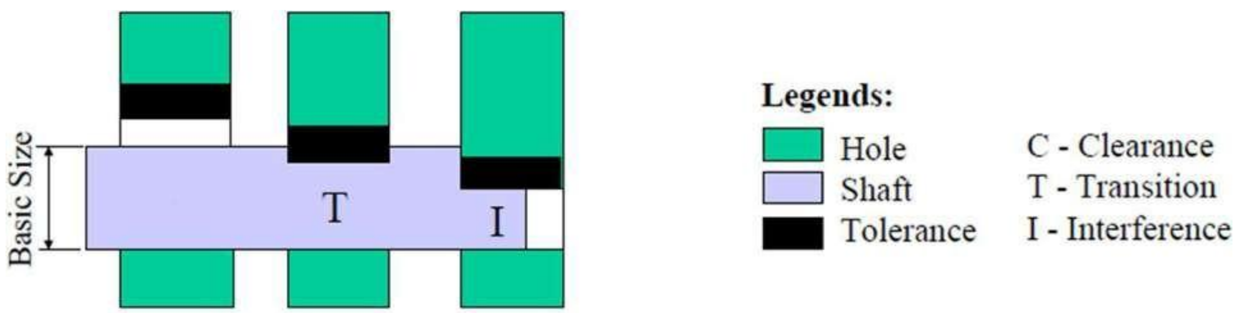
HOLE BASIS SYSTEM OF FITS



If the hole basis system is used, there will be reduction in production costs as only one tool is required to produce the ole and the shaft can be easily machined to any desired size. Hence hole basis system is preferred over shaft basis system.

Shaft Basis system:

In this system, the basic diameter of the shaft is constant while the hole size is varied according to the type of fit.



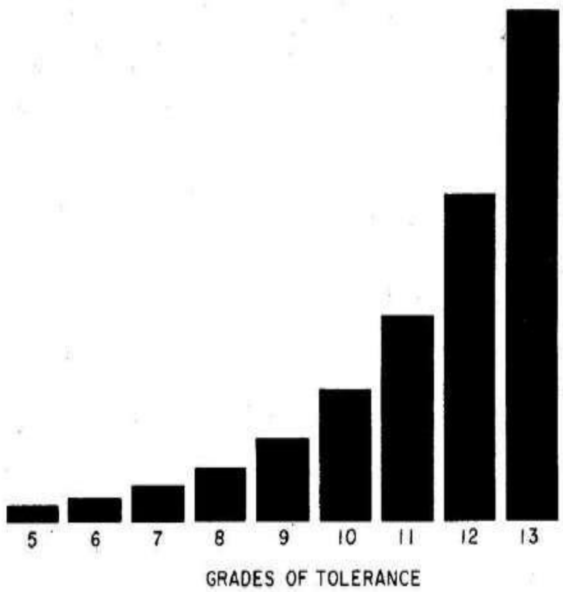
It may, however, be necessary to use shaft basis system where different fits are required along a long shaft.

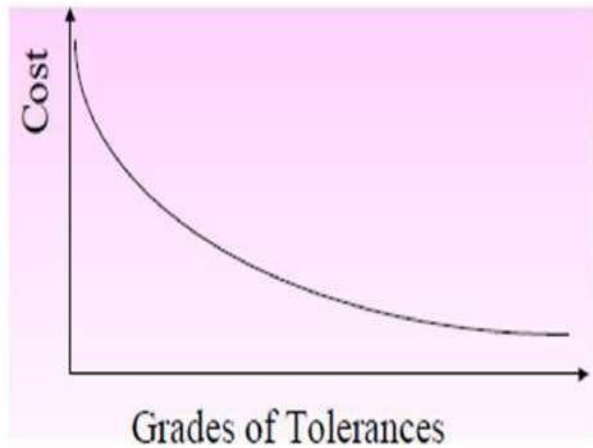
For example, in the case of driving shafts where a single shaft may have to accommodate to a variety of accessories such as couplings, bearings, collars, etc., it is preferable to maintain a constant diameter for the permanent member, which is the shaft, and vary the bore of the accessories.

GRADES OF TOLERANCES

Grade is a measure of the magnitude of the tolerance. Lower the grade the finer thetolerance. There are total of 18 grades which are allocated the numbers IT01, IT0, IT1, IT2. T16.

Fine grades are referred to by the first few numbers. As the numbers get larger, so the tolerance zone becomes progressively wider. Selection of grade should depend on the circumstances. As the grades get finer, the cost of production increases at a sharper rate.





TOLERANCE GRADE

The tolerance grades may be numerically determined in terms of the standard tolerance

unit _***i***‘ where ***i*** in microns is given by (for basic size upto and including 500 mm) and (for basic size above 500 mm upto and including 3150 mm), where D is in mm and it is the geometric mean of the lower and upper diameters of a particular step in which the component lies.

The above formula is empirical and is based on the fact that the tolerance varies more or less parabolically in terms of diameter for the same manufacturing conditions. This is so because manufacture and measurement of higher sizes are relatively difficult.

The various diameter steps specified by ISI are:

1-3, 3-6, 6-10, 10-18, 18-30, 30-50, 50-80, 80-120,180-250, 250-315, 315-400, and 400-500 mm. The value of _D‘ is taken as the geometric mean for a particular range of size to avoid continuous variation of tolerance with size.

The fundamental deviation of type d,e,f,g shafts are respectively $-16D^{0.44}$, $-11D^{0.41}$ $-5.5D^{0.41}$ & $-2.5D^{0.34}$

The fundamental deviation of type D,E,F,G shafts are respectively $+16D^{0.44}$, $+11D^{0.41}$ $+5.5D^{0.41}$ & $+2.5D^{0.34}$.

The relative magnitude of each grade is shown in the table below;

Tol. Grade	IT 5	IT 6	IT 7	IT 8	IT 9	IT 10	IT 11	IT 12	IT 13	IT 14	IT 15	IT 16
	7i	*10i*	*16i*	*25 i*	*40 i*	*64 i*	*100 i*	*160 i*	*250 i*	*400 i*	*640 i*	*1000 i*

It may be noted that from IT 6 onwards, every 5th step is 10 times the respective grade.
i.e. IT 11=10xIT6=10x10i=100 i, IT12=10xIT7=10x16i=160 i, etc.

LIMIT GAUGES

A ***Go-No GO*** gauge refers to an inspection tool used to check a workpiece against its allowed tolerances. It derives its name from its use: the gauge has two tests; the check involves the workpiece having to pass one test (Go) and fail the other (No Go).

It is an integral part of the quality process that is used in the manufacturing industry to ensure interchangeability of parts between processes, or even between different manufacturers.

A Go - No Go gauge is a measuring tool that does not return a size in the conventional sense, but instead returns a state. The state is either acceptable (the part is within tolerance and may be used) or it is unacceptable (and must be rejected).

They are well suited for use in the production area of the factory as they require little skill or interpretation to use effectively and have few, if any, moving parts to be damaged in the often hostile production environment.

PLAIN GAUGES

Gauges are inspection tools which serve to check the dimensions of the manufactured parts. Limit gauges ensure the size of the component lies within the specified limits. They are non-recording and do not determine the size of the part. Plain gauges are used for checking plain (Unthreaded) holes and shafts.

Plain gauges may be classified as follows;

According to their type:

(a) **Standard gauges** are made to the nominal size of the part to be tested and have themeasuring member equal in size to the mean permissible dimension of the part to be checked. A standard gauge should mate with some snugness.

(b) ***Limit Gauges*** These are also called**'go'**and**'no go'**gauges. These are made to thelimit sizes of the work to be measured. One of the sides or ends of the gauge is made to correspond to maximum and the other end to the minimum permissible size. The function of limit gauges is to determine whether the actual dimensions of the work are within or outside the specified limits.

According to their purpose:

(a) Work shop gauges: Working gauges are those used at the bench or machine in gauging the work as it being made.

(b) Inspection gauges: These gauges are used by the inspection personnel to inspect manufactured parts when finished.

(c) Reference or Master Gauges: These are used only for checking the size or condition of other gauges.

According to the form of tested surface:

Plug gauges: They check the dimensions of a hole

Snap & Ring gauges: They check the dimensions of a shaft.

According to their design:

Single limit & double limit gauges

Single ended and double ended gauges

Fixed & adjustable gauges

LIMIT GAUGING

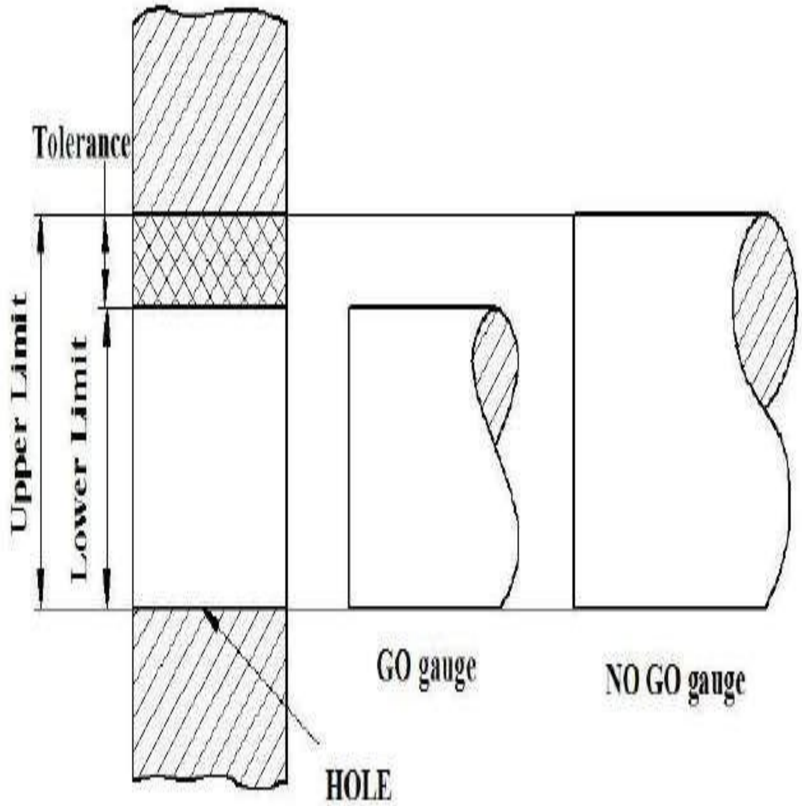
Limit gauging is adopted for checking parts produced by mass production. It has the advantage that they can be used by unskilled persons.

Instead of measuring actual dimensions, the conformance of product with tolerance specifications can be checked by a _GO' and _NO GO' gauges.

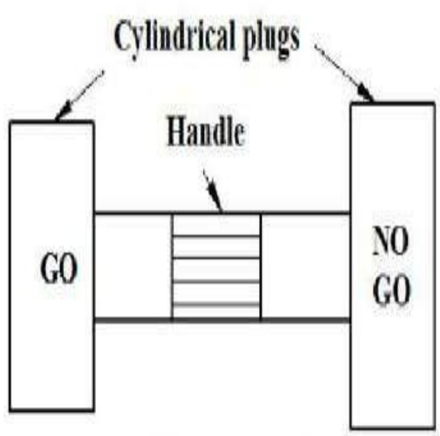
A _GO' gauge represents the maximum material condition of the product (i.e. minimum hole size or maximum shaft size) and conversely a _NO GO' represents the minimum material condition (i.e. maximum hole size or minimum shaft size)

Plug gauges:

Plug gauges are the limit gauges used for checking holes and consist of two cylindrical wear resistant plugs. The plug made to the lower limit of the hole is known as _GO‘ end and this will enter any hole which is not smaller than the lower limit allowed. The plug made to the upper limit of the hole is known as _NO GO‘ end and this will not enter any hole which is smaller than the upper limit allowed. The plugs are arranged on either ends of a common handle.



Plug gauges are normally double ended for sizes upto 63 mm and for sizes above 63 mm they are single ended type.

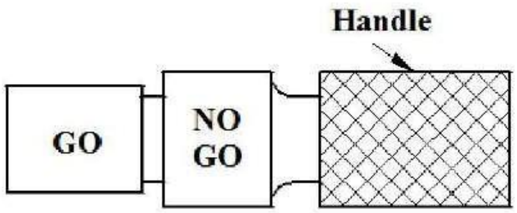


Double ended Plug Gauge

The handles of heavy plug gauges are made of light metal alloys while the handles of small plug gauges can be made of some nonmetallic materials.

Progressive plug gauges:

For smaller through holes, both GO & NO GO gauges are on the same side separated by a small distance. After the full length of GO portion enters the hole, further entry is obstructed by the NO GO portion if the hole is within the tolerance limits.



Progressive Plug Gauge

Ring gauges:

Ring gauges are used for gauging shafts. They are used in a similar manner to that of GO & NO GO plug gauges. A ring gauge consists of a piece of metal in which a hole of required size is bored.

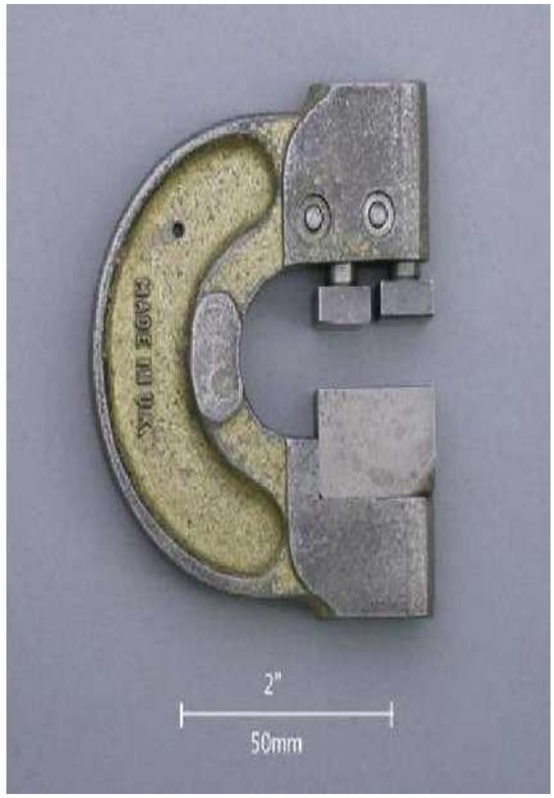
SNAP (or) GAP GAUGES:

A snap gauge usually consists of a plate or frame with a parallel faced gap of the required dimension. Snap gauges can be used for both cylindrical as well as non cylindrical work as compared to ring gauges which are conveniently used only for cylindrical work.

Double ended snap gauges can be used for sizes ranging from 3 to 100 mm.

For sizes above 100 mm upto 250 mm a single ended progressive gauge may be used.

Double Ended gap gauge



Progressive gap gauge

Desirable properties of Gauge Materials:

The essential considerations in the selection of material of gauges are;

1 Hardness to resist wear.

2 Stability to preserve size and shape

3 Corrosion resistance

4 Machinability for obtaining the required degree of accuracy.

5 Low coefficient of friction of expansion to avoid temperature effects.

Materials used for gauges:

High carbon steel: Heat treated Cast steel (0.8-1% carbon) is commonly used for most gauges.

Mild Steel: Case hardened on the working surface. It is stable and easily machinable.

Case hardened steel: Used for small & medium sized gauges.

Chromium plated & Hard alloys: Chromium plating imparts hardness, resistance toabrasion & corrosion. Hard alloys of tungsten carbide may also be used.

Cast Iron: Used for bodies of frames of large gauges whose working surfaces are hardinserts of tool steel or cemented carbides.

Glass: They are free from corrosive effects due to perspiration from hands. Also they arenot affected by temperature changes.

Invar: It is a nickel-iron alloy (36% nickel) which has low coefficient of expansion butnot suitable for usage over long periods.

(The name, Invar, comes from the word invariable, referring to its lack of expansion or contraction with temperature changes. It was invented in 1896 by Swiss scientist Charles Eduard Guillaume. He received the Nobel Prize in Physics in 1920 for this discovery, which enabled improvements in scientific instruments.)

Taylor's Principle of Gauge Design:

According to Taylor, _Go' and _No Go' gauges should be designed to check maximum and minimum material limits which are checked as below;

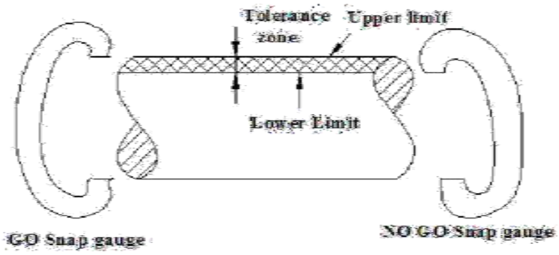
„GO" Limit. This designation is applied to that limit of the two limits of size whichcorresponds to the maximum material limit considerations, i.e. upper limit of a shaft and lower limit of a hole.

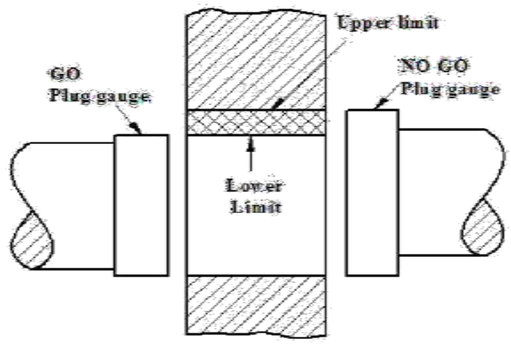
The GO gauges should be of full form, i.e. they should check shape as well as size.

No Go" Limit:

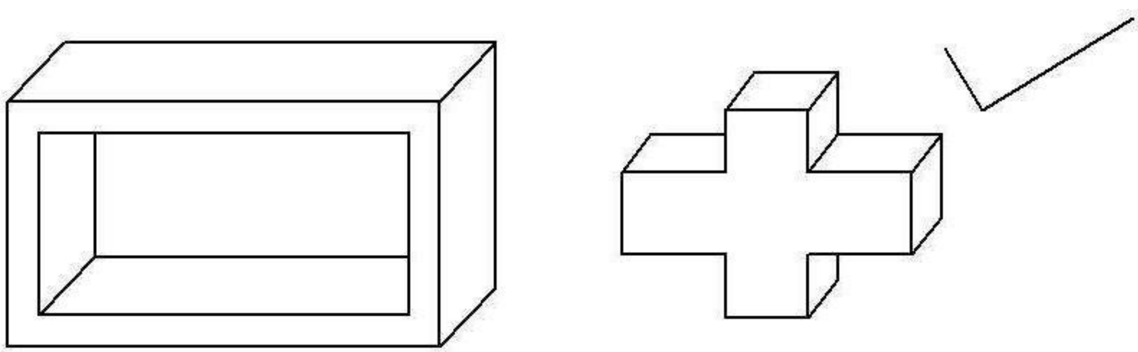
This designation is applied to that limit of the two limits of size which corresponds to the minimum material condition. i.e. the lower limit of a shaft and the upper limit of a hole.

_No Go' gauge should check only one part or feature of the component at a time, so that specific discrepancies in shape or size can be detected. Thus a separate _No Go' gauge is required for each different individual dimension.





Example to illustrate Taylor"s Principle of Gauge Design:

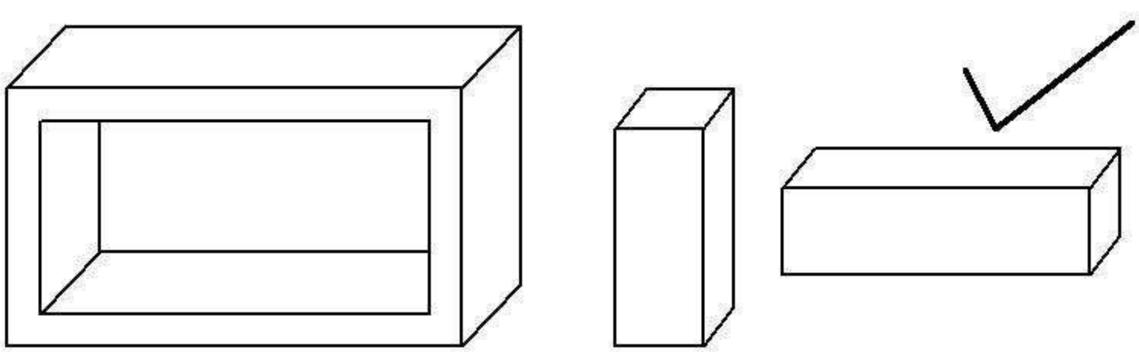


The slot is to be checked for height & Width

GO Gauge

A GO gauge must check the dimensions as well as form (perpendicularity) of the slot at a time. Hence the GO gauge must be as shown in fig on the right.

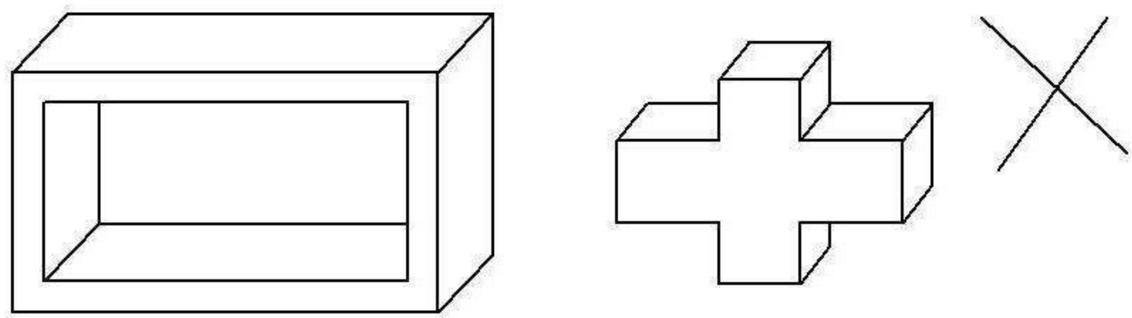
A NO GO gauge must check the dimensions of the slot one at a time and hence two separate gauges must be used.



The slot is to be checked for height & Width

NO GO Gauge

If the single gauge as shown is used, the gage is likely to pass a component even if one of the dimensions is less than desirable limit because it gets stuck due to the other dimension which is within correct limit.



The slot is to be checked for height & Width

NO GO Gauge

Gauge Tolerance:

Gauges, like any other jobs require a manufacturing tolerance due to reasonable imperfections in the workmanship of the gauge maker. The gauge tolerance should be kept as minimum as possible though high costs are involved to do so. The tolerance on the GO & NO GO gauges is usually 10% of the work tolerance.

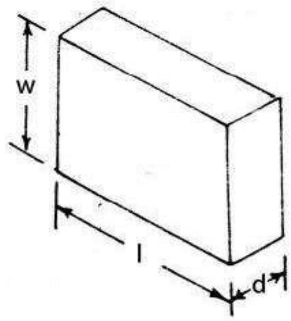
Wear Allowance:

The GO gauges only are subjected to wear due to rubbing against the parts during inspection and hence a provision has to be made for the wear allowance. Wear allowance is taken as 10% of gauge tolerance and is allowed between the tolerance zone of the gauge and the maximum material condition. *(i.e.* lower limit of a hole & upper limit of a shaft). If the work tolerance is less than 0.09 mm, wear allowance need not be given unless otherwise stated.

Construction of Slip Gauge

Slip gauges are rectangular in shape made up of *high-grade steels* with very close tolerances.

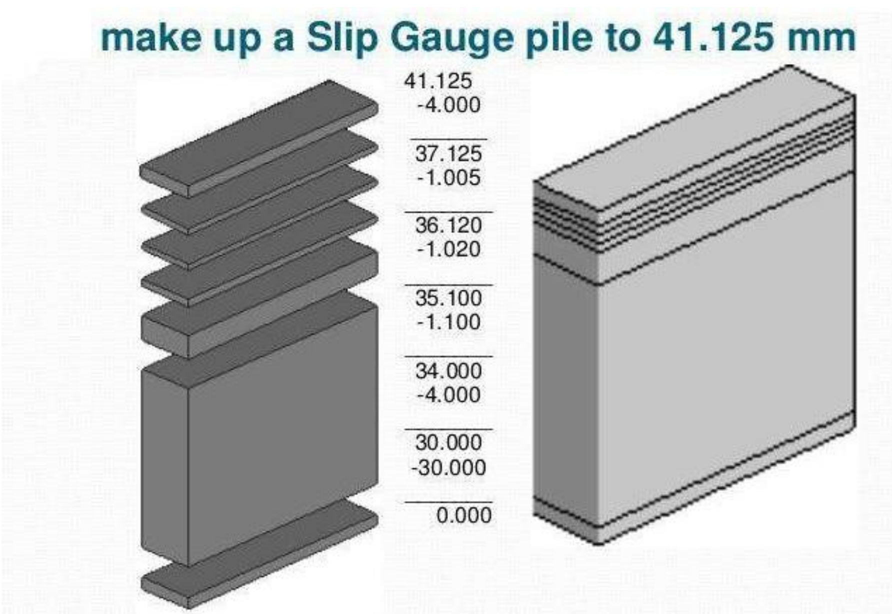
- The Working faces of any slip gauge will be made *truly flat* and parallel.
- The slip gauges will undergo *Hardening* to resist wear and tear.
- They will be further *heated and cooled down* successively to remove the hardening stresses induced during the hardening Process.
- The Slip Gauges can be made up of *Tungsten Carbide* because of it is extremely capable of hard and wear resistance.
- The size of the slip gauges is *permanently marked* on any of the measuring faces of individual slip gauge.

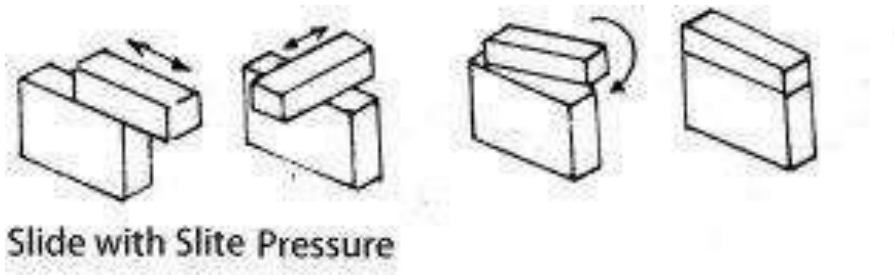


Wringing of Slip Gauges

1. Before using slip gauges the faces should be cleaned
2. Slide the one slip gauge over the other(With 90° as shown in the Fig: Pos2) with lite pressure. This way we can expel the air between the slip gauges faces.
3. Once placed the one gauge 90° to another gauge by using lite pressure, then rotate it by clockwise to make them in line as shown in below figure. (fourth position)
4. This wringing will helps to achieve a dimension by summation of the individual size of slip gauge. the need of clamping is also avoided.

To make any dimension with slip gauges, we will Wrung set of slip gauges to achieve the true dimension. See the following Example.





Uses Of Slip Gauge

1. Setting up a comparator to a specific dimension
2. Direct Precise measuring purpose.
3. To inspect the Vernier Calliper, Micrometers and some other linear measuring instruments.
4. Conjunction with sine bar to measure the angle of the workpiece.
5. Used to Check the distance between the parallel faces.

Dial indicator

In various contexts of science, technology, and manufacturing (such as machining, fabricating, and additive manufacturing), an indicator is any of various instruments used to accurately measure small distances and angles, and amplify them to make them more obvious. The name comes from the concept of indicating to the user that which their naked eye cannot discern; such as the presence, or exact quantity, of some small distance (for example, a small height difference between two flat surfaces, a slight lack of concentricity between two cylinders, or other small physical deviations).

Many indicators have a dial display, in which a needle points to graduations in a circular array around the dial. Such indicators, of which there are several types, are often called dial indicators.

Principal:

Indicators inherently provide relative measure only. But given that suitable references are used (for example, gauge blocks), they often allow a practical equivalent of absolute measure, with periodic recalibration against the references. However, the user must know how to use them properly and understand how in some situations, their measurements will still be relative rather than absolute because of factors such as cosine error

Applications:

- In a quality environment to check for consistency and accuracy in the manufacturing process.
- On the workshop floor to initially set up or calibrate a machine, prior to a production run.
- By toolmakers (such as moldmakers) in the process of manufacturing precision tooling.
- In metal engineering workshops, where a typical application is the centering of a lathe's workpiece in a four jaw chuck. The dial indicator is used to indicate the run out (the misalignment between the workpiece's axis of rotational symmetry and the axis of rotation of the spindle) of the workpiece, with the ultimate aim of reducing it to a suitably small range using small chuck jaw adjustments.
- In areas other than manufacturing where accurate measurements need to be recorded (e.g., physics).

MICROMETER

A micrometer sometimes known as a micrometer screw gauge, is a device incorporating a calibrated screw widely used for precise measurement of components in mechanical engineering and machining as well as most mechanical trades, along with other metrological instruments such as dial, vernier, and digital calipers. Micrometers are usually, but not always, in the form of calipers (opposing ends joined by a frame). The spindle is a very accurately machined screw and the object to be measured is placed between the spindle and the anvil. The spindle is moved by turning the ratchet knob or thimble until the object to be measured is lightly touched by both the spindle and the anvil.

Principal:

Micrometers use the principle of a screw to amplify small distances[8] (that are too small to measure directly) into large rotations of the screw that are big enough to read from a scale. The accuracy of a micrometer derives from the accuracy of the thread-forms that are central to the core of its design. In some cases it is a differential screw. The basic operating principles of a micrometer are as follows:

1. The amount of rotation of an accurately made screw can be directly and precisely correlated to a certain amount of axial movement (and vice versa), through the constant known as the screw's lead (/ˈliːd/). A screw's lead is the distance it moves forward axially with one complete turn (360°). (In most threads [that is, in all single-start threads], lead and pitch refer to essentially the same concept.)
2. With an appropriate lead and major diameter of the screw, a given amount of axial movement will be amplified in the resulting circumferential movement.

A micrometer is composed of:

Anvil

The shiny part that the spindle moves toward, and that the sample rests against.

Sleeve / barrel / stock

The stationary round component with the linear scale on it, sometimes with vernier markings. In some instruments the scale is marked on a tight-fitting but movable cylindrical sleeve fitting over the internal fixed barrel. This allows zeroing to be done by slightly altering the position of the sleeve.[12][13]

Lock nut / lock-ring / thimble lock

The knurled component (or lever) that one can tighten to hold the spindle stationary, such as when momentarily holding a measurement.

Screw

(not seen) The heart of the micrometer, as explained under "Operating principles". It is inside the barrel. This references the fact that the usual name for the device in German is Messschraube, literally "measuring screw".

Spindle

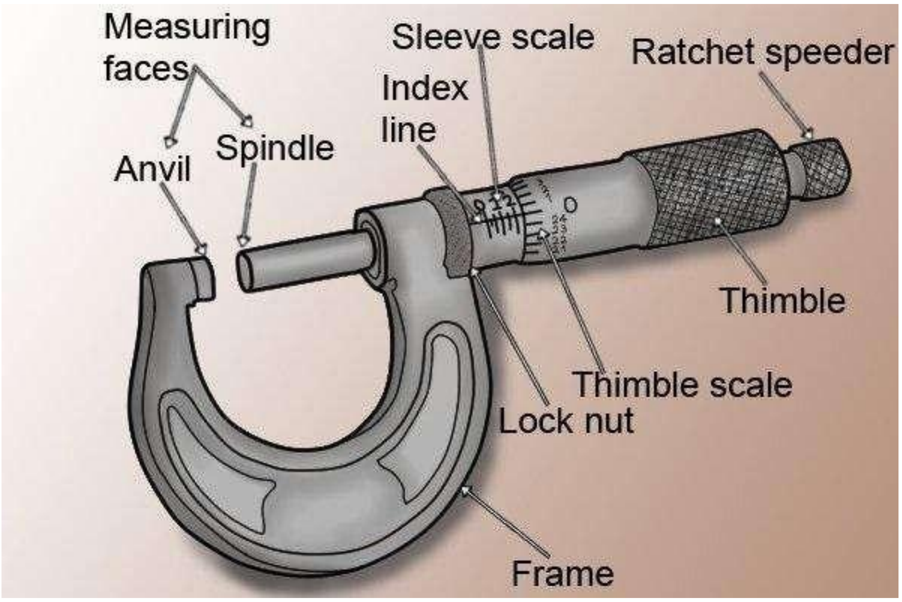
The shiny cylindrical component that the thimble causes to move toward the anvil.

Thimble

The component that one's thumb turns. Graduated markings.

Ratchet stop

(not shown in illustration) Device on end of handle that limits applied pressure by slipping at a calibrated torque.



MICROMETRE

BEVEL PROTRACTOR

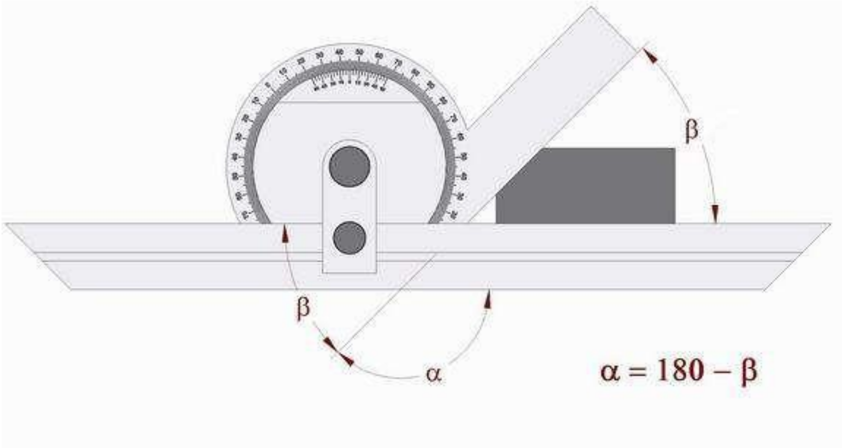
A bevel protractor is a graduated circular protractor with one pivoted arm; used for measuring or marking off angles. Sometimes Vernier scales are attached to give more precise readings. It has wide application in architectural and mechanical drawing, although its use is decreasing with the availability of modern drawing software or CAD.

Universal bevel protractors are also used by toolmakers; as they measure angles by mechanical contact they are classed as mechanical protractors.

The bevel protractor is used to establish and test angles to very close tolerances. It reads to 5 minutes or 1/12 and can measure any angle from 0° to 360°.

The bevel protractor consists of a beam, a graduated dial and a blade which is connected to a swivel plate (with Vernier scale) by thumb nut and clamp. When the edges of the beam and blade are parallel, a small mark on the swivel plate coincides with the zero line on the graduated dial. To measure an angle between the beam and the blade of 90° or less, the reading may be obtained direct from the graduation number on the dial indicated by the mark on the swivel plate. To measure an angle of over 90°, subtract the number of degrees as indicated on the dial from 180°, as the dial is graduated from opposite zero marks to 90° each way.

Since the spaces, both on the main scale and the Vernier scale, are numbered both to the right and to the left from zero, any angle can be measured. The readings can be taken either to the right or to the left, according to the direction in which the zero on the main scale is moved.



BEVEL PROTRACTOR

ANGLE SLIP GUAGES:

These designed for the inspection and calibration of angle, tapers, indexing plates, rotary scales, clinometers, dividing heads, rotary tables etc.

Material

Angle Gauge Blocks are made from High Carbon High Chromium Steel which has the properties of aging stability in dimensions and wear resistance. The working surfaces are hardened to 800HV. Also Angle Gauge Blocks available in Tungsten Carbide.

Scope

These angle gauges together with the square block used to obtain any angle between 0 and 360 degrees in steps of 6 seconds.

SPIRIT LEVEL

A spirit level, bubble level or simply a level is an instrument designed to indicate whether a surface is horizontal (level) or vertical (plumb). Different types of spirit levels may be used by carpenters, stonemasons, bricklayers, other building tradesworkers, surveyors, millwrightsand other metalworkers and insome photographic or video graphic work.

Early spirit levels had very slightly curved glass vials with constant inner diameter at each viewing point. These vials are incompletely filled with a liquid, usually a mercury colored spirit or alcohol, leaving a bubble in the tube. They have a slight upward curve, so that the bubble naturally rests in the center, the highest point. At slight inclinations the bubble travels away from the marked center position. Where a spirit level must also be usable upside-down or on its side, the curved constant-diameter tube is replaced by an uncurved barrel-shaped tube with a slightly larger diameter in its middle.

Alcohols such as ethanol are often used rather than water. Alcohols have low viscosity and surface tension, which allows the bubble to travel the tube quickly and settle accurately with minimal interference with the glass surface. Alcohols also have a much wider liquid temperature range and won't break the vial as water could due to ice expansion. A colorant such as fluorescein, typically yellow or green, may be added to increase the visibility of the bubble.

CALIBRATION:

To check the accuracy of a carpenter's type level, a perfectly horizontal surface is not needed. The level is placed on a flat and roughly level surface and the reading on the bubble tube is noted. This reading indicates to what extent the surface is parallel to the horizontal plane, according to the level, which at this stage is of unknown accuracy. The spirit level is then rotated through 180 degrees in the horizontal plane, and another reading is noted. If the level is accurate, it will indicate the same orientation with respect to the horizontal plane. A difference implies that the level is inaccurate.

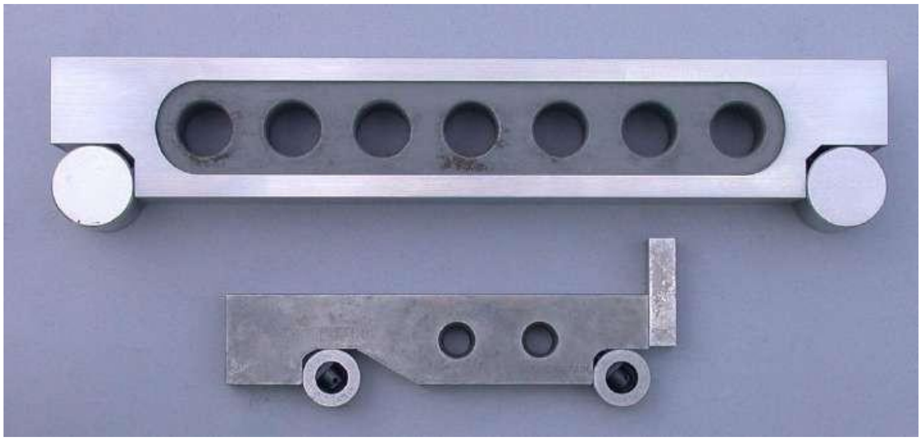
SINE BAR

A sine bar consists of a hardened, precision ground body with two precision ground cylinders fixed at the ends. The distance between the centers of the cylinders is precisely controlled, and the top of the bar is parallel to a line through the centers of the two rollers. The dimension between the two rollers is chosen to be a whole number (for ease of later calculations) and forms the hypotenuse of a triangle when in use.

When a sine bar is placed on a level surface the top edge will be parallel to that surface. If one roller is raised by a known distance, usually using gauge blocks, then the top edge of the bar will be tilted by the same amount forming an angle that may be calculated by the application of the sine rule.

- The hypotenuse is a constant dimension(100 mm or 10 inches in the examples shown).
- The height is obtained from the dimension between the bottom of one roller and the table's surface.

- The angle is calculated by using the sine rule. Some engineering and metalworking reference books contain tables showing the dimension required to obtain an angle from 0-90 degrees, incremented by 1minute intervals.



PRINCIPAL:

Angles are measured using a sine bar with the help of gauge blocks and a dial gauge or a spirit level. The aim of a measurement is to measure the surface on which the dial gauge or spirit level is placed horizontally. For example, to measure the angle of a wedge, the wedge is placed on a horizontal table. The sine bar is placed over the inclined surface of the wedge. At this position, the top surface of the sine bar is inclined the same amount as the wedge. Using gauge blocks, the top surface is made horizontal. The sine of the angle of inclination of the wedge is the ratio of the height of the gauge blocks used and the distance between the centers of the cylinders.

UNIT - V

TOOLMAKERS MICROSCOPES

The toolmakers microscopes include either manual micrometer measuring heads or digimaticmicrometer measuring heads. Toolmakers microscopes are used for inspection and measurement of machined parts and are often used in manufacturing quality control processes.

The Radical Toolmakers Precise Measuring Microscope is usedfor the purposes of measuring lengths, angles as well as diameter and distances. As such, it is commonly used by auto component manufacturers, tool manufacturers as well as in quality control or various tools and parts. A toolmakers microscope has a robust base that allows it to hold a wide range of objects for observations and measurements.

As multi functional devices, toolmaker tools will often be found in most of the manufacturing companies/factories involved in the manufacturing of machines, electronics and tools. In such places, they help in the measurement of shapes, sizes, angles and positions of small components which fall under the measuring range of the microscope. This makes the microscope particular suitable for such tasks as measuring the shapes of such components as milling cutters, thread gauge and guide screw among others.

In addition, the device finds use for measuring center to center distance of holes in a plane, linear measurements as well as accurate angular measurements.

TOOLMAKERS MICROSCOPES

Application

Determining relative positions

Here, the microscope is used elative positions of different points by simply measuring the travel that is necessary for bringing a second point to the position that was formerly occupied by the first and so forth.

Measuring angles

Using this microscope, it is possible to measure the angles by using the protractor eyepiece. This allows for the angles of the object to be viewed and determined.

Comparison measurement

This is where the microscope is used to do comparison of the thread forms, measuring of the pitch and diameter. Here, the microscope achieves this using the master profiles engravings in the eyepiece.

Comparing with a scale

This is where the images of the object are compared with the scale in the projection screen.

COLLIMATOR

A collimator is a device that narrows a beam of particles or waves. To narrow can mean either to cause the directions of motion to become more aligned in a specific direction (i.e., make collimated light or parallel rays), or to cause the spatial cross section of the beam to become smaller (beam limiting device).

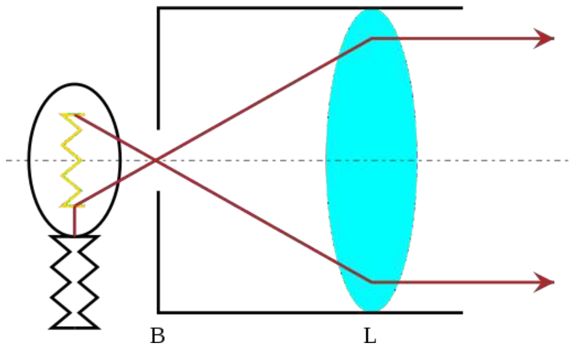
In optics, a collimator may consist of a curved mirror or lens with some type of light source and/or an image at its focus. This can be used to replicate a target focused at infinity with little or no parallax.

In lighting, collimators are typically designed using the principles of nonimaging optics.

Optical collimators can be used to calibrate other optical devices, to check if all elements are aligned on the optical axis, to set elements at proper focus, or to align two or more devices such as binoculars or gun barrels and gunsights. A surveying camera may be collimated by setting its fiduciary markers so that they define the principal point, as in photogrammetry.

Optical collimators are also used as gun sights in the collimator sight, which is a simple optical collimator with a cross hair or some other reticle at its focus. The viewer only sees an image of the reticle. They have to use it either with both eyes open and one eye looking into the collimator sight, with one eye open and moving the head to alternately see the sight and the target, or with one eye to partially see the sight and target at the same time. Adding a beam splitter allows the viewer to see the reticle and the field of view, making a reflector sight.

Collimators may be used with laser diodes and CO_2 cutting lasers. Proper collimation of a laser source with long enough coherence length can be verified with a shearing interferometer.



Optical collimator

OPTICAL PROJECTOR:

Optical Projector also known as an optical comparator, a profile projector is an optical instrument that can be used for measuring.

projector is an optical instrument that can be used for measuring. It is a useful item in a small parts machine shop or production line for the quality control inspection team.

A projector or image projector is an optical device that projects an image (or moving images) onto a surface, commonly a projection screen. Most projectors create an image by shining a light through a small transparent lens, but some newer types of projectors can project the image directly, by using lasers.

profile projector is used for measuring two-dimensionalcontours of precision specimens and other work pieces produced. The part to be measured is magnified by an optical system and projected on a screen.

The projector magnifies the profile of the specimen, and displays this on the built-in projection screen. On this screen there is typically a grid that can be rotated 360 degrees so the X-Y axis of the screen can be aligned with a straight edge of the machined part to examine or measure. This projection screen displays the profile of the specimen and is magnified for better ease of calculating linear measurements.

An edge of the specimen to examine may be lined up with the grid on the screen. From there, simple measurements may be taken for distances to other points. This is being done on a magnified profile of the specimen. It can be simpler as well as reduce errors by measuring on the magnified projection screen of a profile projector.

The typical method for lighting is by diascopic illumination, which is lighting from behind. This type of lighting is also called transmitted illumination when the specimen is translucent and light can pass through it. If the specimen is opaque, then the light will not go through it, but will form a profile of the specimen.

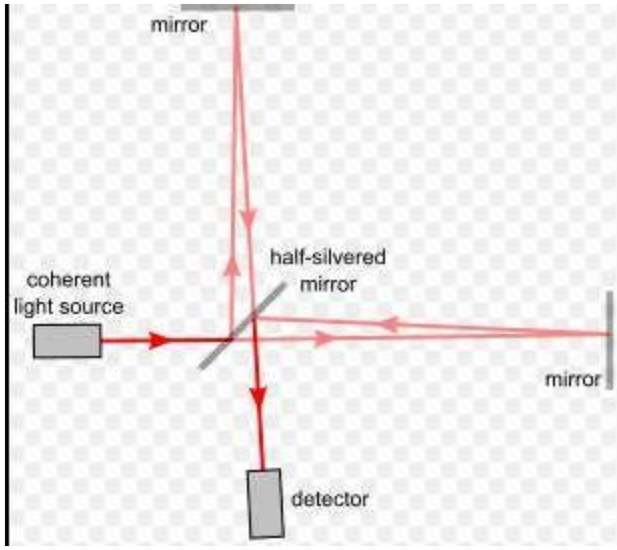
Measuring of the sample can be done on the projection screen. A profile projector may also have episcopic illumination (which is light shining from above). This useful in displaying bores or internal areas that may need to be measured.

Projector

Interferometre:

Interferometre is a family of techniques in which waves, usually electromagnetic waves, are superimposed causing the phenomenon of interference in order to extract information. Interferometry is an important investigative technique in the fields of astronomy, fiberoptics, engineering metrology, optical metrology, oceanography, seismology, spectroscopy(and its applications to chemistry), quantum mechanics, nuclear and particle physics, plasma physics, remote sensing, biomolecular interactions, surface profiling, microfluidics, mechanical stress/strain measurement, velocimetry, and optometry.

Interferometers are widely used in science and industry for the measurement of small displacements, refractive index changes and surface irregularities. In an interferometer, light from a single source is split into two beams that travel different optical paths, then combined again to produce interference. The resulting interference fringes give information about the difference in optical path length. In analytical science, interferometers are used to measure lengths and the shape of optical components with nanometer precision; they are the highest precision length measuring instruments existing. In Fourier transform spectroscopy they are used to analyze light containing features of absorption or emission associated with a substance or mixture. An astronomical interferometer consists of two or more separate telescopes that combine their signals, offering a resolution equivalent to that of a telescope of diameter equal to the largest separation between its individual elements.



Interferometer

PRINCIPAL:

Interferometry makes use of the principle of superposition to combine waves in a way that will cause the result of their combination to have some meaningful property that is diagnostic of the original state of the waves. This works because when two waves with the same frequency combine, the resulting intensity pattern is determined by the phase difference between the two waves—waves that are in phase will undergo constructive interference while waves that are out of phase will undergo destructive interference. Waves which are not completely in phase nor completely out of phase will have an intermediate intensity pattern, which can be used to determine their relative phase difference. Most interferometers use light or some other form of electromagnetic wave.

Typically (see Fig. 1, the well-known Michelson configuration) a single incoming beam of coherent light will be split into two identical beams by a beam splitter (a partially reflecting mirror). Each of these beams travels a different route, called a path, and they are recombined before arriving at a detector. The path difference, the difference in the distance traveled by each beam, creates a phase difference between them. It is this introduced phase difference that creates the interference pattern between the initially identical waves. If a single beam has been split along two paths, then the phase difference is diagnostic of anything that changes the phase along the paths. This could be a physical change in the path length itself or a change in the refractive index along the path.

SCREW THREAD MEASUREMENT

A screw thread, often shortened to thread, is a helical structure used to convert between rotational and linear movement or force. A screw thread is a ridge wrapped around a cylinder or cone in the form of a helix, with the former being called a straight thread and the latter called a tapered thread. A screw thread is the essential feature of the screw as a simple machine and also as a fastener.

The mechanical advantage of a screw thread depends on its lead, which is the linear distance the screw travels in one revolution. In most applications, the lead of a screw thread is chosen so that friction is sufficient to prevent linear motion being converted to rotary, that is so the screw does not slip even when linear force is applied, as long as no external rotational force is present. This characteristic is essential to the vast majority of its uses. The tightening of a fastener's screw thread is comparable to driving a wedge into a gap until it sticks fast through friction and slight elastic deformation.

APPLICATIONS:

- Fasteners such as wood screws, machine screws, nuts, and bolts.
- Connecting threaded pipes and hoses to each other and to caps and fixtures.
- Gear reduction via worm drives
- Moving objects linearly by converting rotary motion to linear motion, as in the leadscrew of a jack.
- Measuring by correlating linear motion to rotary motion (and simultaneously amplifying it), as in a micrometer.
- Both moving objects linearly and simultaneously measuring the movement, combining the two aforementioned functions, as in a leadscrew of a lathe.
- In all of these applications, the screw thread has two main functions:
- It converts rotary motion into linear motion.
- It prevents linear motion without the corresponding rotation.

Elements of measurements:

Most of the measurement systems contain three main functional elements are i) Primary sensing element ii) Variable conversion element & iii) Data presentationelement. Primary sensing element: The quantity under measurement makes its first contact with the primary sensing element of a measurement system.

Errors in Threads

Errors in screw threads are related to the five elements of the screw threads. They are major diameter, minor diameter, pitch diameter, pitch and thread angle. If any errors are taking place in these five elements the produced screw is rejected. So, these elements are also be checked with proper gauging system carefully. The threads are produced by a point cutting tools. The errors in major and minor diameter cause interference of the mating threads, less root section, less wall thickness and poor contact of the flanks, which ultimately cause the weak in strength of the component. The errors in effective diameter also cause the interference of the flanks.

The errors in pitch and thread angle also cause the progressive tightening of the mating parts due to the interference of the flank surfaces.

Let us discuss some important errors in thread forms. They are

1. Drunken error
2. Pitch errors

Drunken Error: It is error due to the irregular form of helical groove on a cylindrical surface. In this case pitch measured parallel to the axis is always same, but problem is with the thread is not cut to its true helix.

Due to this flank surface will not be as a straight edge, it will be as curved form.

Pitch errors:

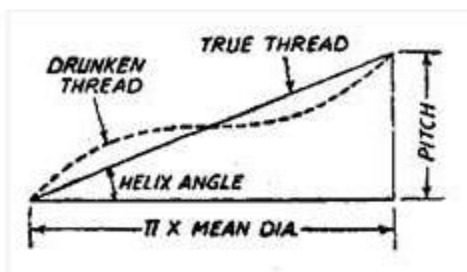
The pitch errors are due to improper ratios of cutting tool velocity to rotating velocity of the workpiece. these pitch errors are again classified as

Progressive pitch erros
Periodic pitch errors
Irregular errors

Progressive errors: In this the pitch error results increasing of major or minor diameter or decreasing of major or minor diameter. It means the error may either in increasing order or decreasing order.

Periodic errors: In this the pitch error causes the errors to repeat at certain time of interval.

Irregular errors: These are the errors randomly take place on threads without any specific reason. These are the combination of all the errors take place on threads.



MEASUREMENT OF EFFECTIVE DIAMETRE

The pitch diameter (often called the effective diameter) of a parallel thread is the diameter of the imaginary co-axial cylinder which intersects the surface of the thread in such a manner that theintercept on a generator of the cylinder, between the points where it meets the opposite flanks of a thread groove, is equal to half the nominal pitch of the thread.

The major diameter of a thread is the diameter of the imaginary co-axial cylinder that just touches the crest of an external thread or the root of an internal thread.

The minor diameter is the diameter of an imaginary cylinder that just touches the roots of an external thread and (or) the crests of an internal thread.

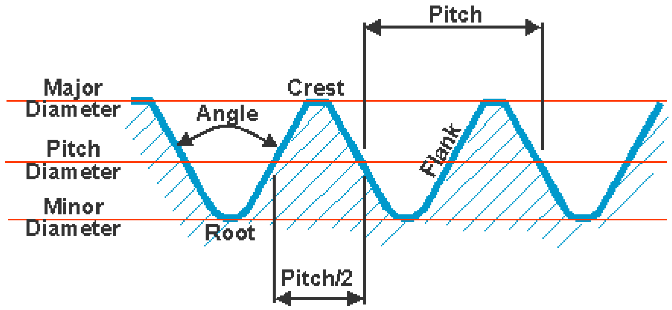
The crest of a thread is the prominent part of a thread, whether internal or external.

The root is the bottom of the groove between the two flanking surfaces of the thread whether internal or external.

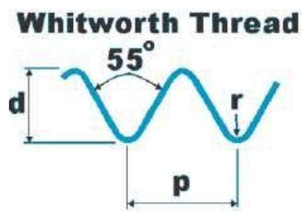
The flanks of a thread are the straight sides that connect the crest and the root.

The angle of a thread is the angle between the flanks, measured in an axial plane section.

The pitch of a thread is the distance, measured parallel to its axis, between corresponding points on adjacent surfaces, in the same axial plane.



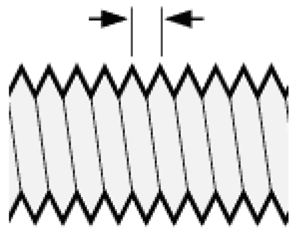
Sir Joseph Whitworth proposed this thread in 1841. This was the first standardised thread form. The form of the thread is shown in the diagram. The principal features of the British Standard Whitworth (BSW) thread form are that the angle between the thread flanks is 55 degrees and the thread has radii at both the roots and the crests of the thread. The relevant standard for this thread form is the British Standard BS 84 - 2007. The thread form is now redundant and has been replaced by Unified and Metric threads but there are many applications in which it is still used. The British Standard Fine (BSF) thread has the same profile as the BSW thread form but was used when a finer pitch was required for a given diameter.



If
p = pitch of the thread
d = depth of the thread
r = radius at the top and bottom of the threadsthen:
d = 0.640327 p
r = 0.137329 p

Thread pitch:

Metric fasteners are specified with a thread pitch instead of a thread count. The thread pitch is the distance between threads expressed in millimeters (measured along the length of the fastener). For example a thread pitch of 1.5 means that the distance between one thread and the next is 1.5mm. In general smaller fasteners have finer thread so they have lower thread pitch. For a table of standard metric thread pitchs please see our Metric Thead Pitch Table.



Metric - Thread pitch

Thread angle:

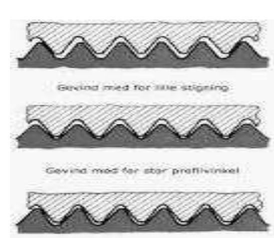
The thread angle of a screw is the included angle between the thread flanks, measured in a plane containing the thread axis.[1] This is a defining factor for the shape of a screw thread.

Thread angle

Name	Code	Angle
Acme thread		29°
Metric trapezoidal threads	Tr	30°
Buttress threads	S	45°
German buttress threads	S	30°

Profile thread gauges:

Thread Profile Gages are manufactured to industry standard tolerances using our state-of-the-art Wire EDM technology. Our Thread Profile Gages quickly identify tapered thread forms per the API Standards 5B and Spec 7 as well as Stub Acme, National Acme and others. All our Thread Profile Gages are in stock for immediate delivery and we offer specials made to your specifications.



Surface measurement

synonymous with surface metrology – determines surface topography, which is essential for confirming a surface's suitability for its function. Surface measurement conceptually includes surface shape, surface finish, surface profile roughness (R_a), or in surface area roughness (S_a), surface texture, asperity and structural characterization.

For example, engine parts may be exposed to lubricants to prevent potential wear, and these surfaces require precise engineering – at a microscopic level – to ensure that the surface roughness holds enough of the lubricants between the parts under compression, while it is smooth enough not to make metal to metal contact. For manufacturing and design purposes, measurement is critical to ensure that the finished material meets the design specification.

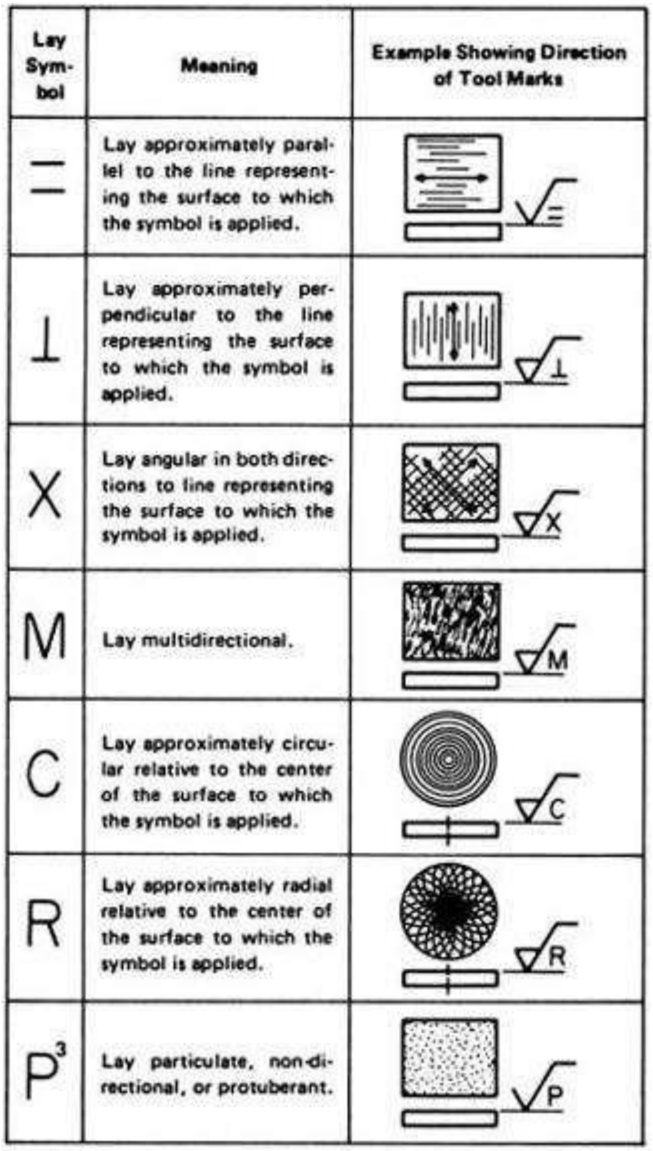
In the image above, a microscopic surface is measured in three dimensions using an interference microscope. For scale, the 3-D surface measurement above maps features within a 22 nanometer range of height, and the indicated pit defect is less than 12 nanometers deep. A nanometer (nm) is one one-thousandth of a micron (µm). There are about 80 microns (80,000 nm) in the thickness of a human hair. The area of the measured surface is 449 × 335 microns.

Surface Roughness Measurement **for Defect Analysis**

Defects may occur either in material surfaces during processing or after use, and defect analysis is often essential for providing the information to improve effectiveness, efficiency and durability of surfaces. For example, a product that requires long life in adverse conditions is prosthetic joints, such as hip joints. Being able to measure the surface material for wear, scratches, and the shape of a prosthetic joint after it has been removed for replacement can be beneficial for future hip replacement procedures. Optical surface measurement techniques have been used to measure these and other medical-quality surfaces such as stents, dental implants and artificial bone.

In the image of a 3-D surface map above, several pits appear in a step height calibration standard, which is made of quartz and then chrome plated. This type of standard is often used for calibration of profilometers of all types. The pits may be the result of impacts, wear, or chemical effects. If enough of these pits were present, the surface's suitability as a step height standard would be compromised. Depending on the application, the determination of pits versus asperities (bumps) is critical to the performance of the surface.

While computer hard disk surfaces can accommodate a certain number of pits, asperities can cause failures due to low flying height of the disk read/write heads. Optical profilers must be able to resolve the defect sufficiently to determine its polarity (pit or bump) and to characterize its height or depth.

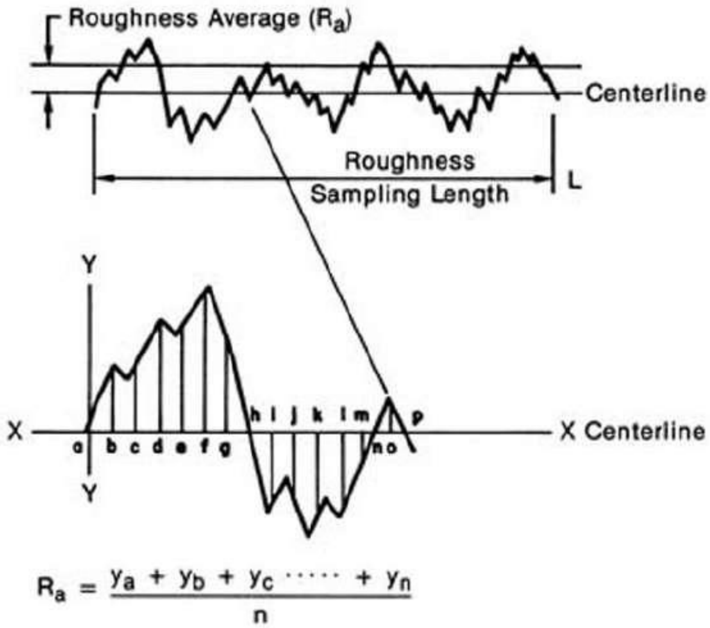


Lay Symbol	Meaning	Example Showing Direction of Tool Marks
=	Lay approximately parallel to the line representing the surface to which the symbol is applied.	
⊥	Lay approximately perpendicular to the line representing the surface to which the symbol is applied.	
X	Lay angular in both directions to line representing the surface to which the symbol is applied.	
M	Lay multidirectional.	
C	Lay approximately circular relative to the center of the surface to which the symbol is applied.	
R	Lay approximately radial relative to the center of the surface to which the symbol is applied.	
P[3]	Lay particulate, non-directional, or protuberant.	

chart categorizes the various lay configurations and shows the standardizes symbols used on drawing

NUMERICAL VALUES FOR ASSESSMENT

- Arithmetic roughness average
  - This method is also known as roughness average and by two earlier term; arithmetic average (AA) and center-line average (CLA)
  - The roughness average is the arithmetic average of the absolute values of the deviation from the profile height measured from the centerline along a specified sampling length
  - Two method for determining the value
    i. Graphical method
    ii. Electrical averaging

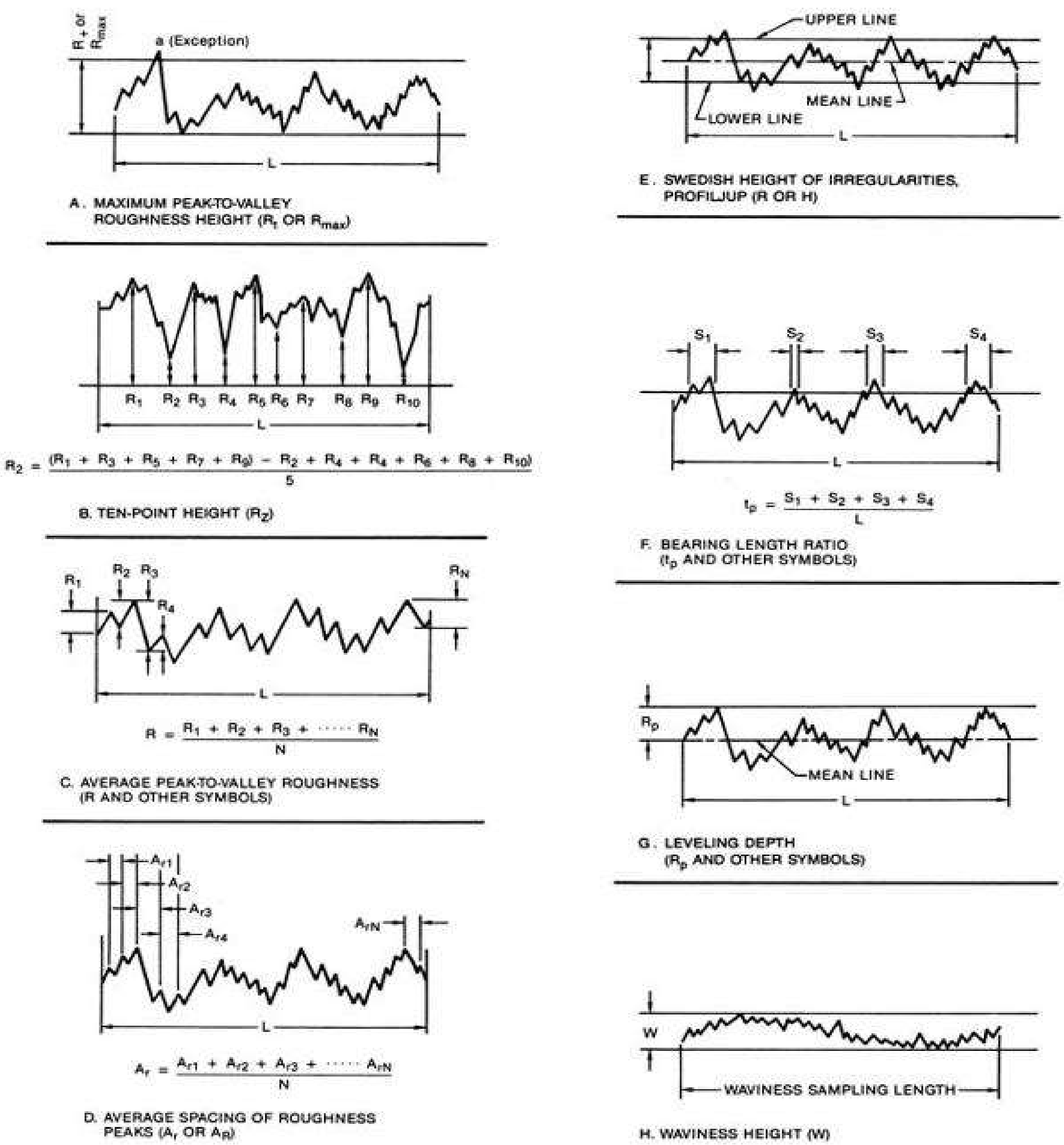


Other standardized assessment methods

1. Root-Means-Square roughness (R_a or RMS)
   - Closely related to the roughness average (Ra)
   - Square the distances, average them, and determine the square root of the result
   - The resulting value is the index for surface texture comparison
   - Usually 11% higher than the Ra value
2. Maximum Peak-Valley Roughness (R_{max} or R_t)
   - Determine the distance between the lines that contact the extreme outer and inner point of the profile
   - Second most popular method in industry
   - See figure A
3. Ten-Point Height (R_z)
   - Averages the distance between the five peaks and five deepest valleys within the sampling length
   - See figure B
4. Average Peak-to-Valley Roughness (R or H or H_{pl})
   - Average the individual peak-to-valley heights
   - See figure C
   - Use the height between adjacent peaks and valleys, not measure from a center line to peak valleys
5. Average Spacing of Roughness Peaks ($A_r$or A_R)
   - Average the distance between the peaks without regard to their height
   - See figure D
6. Swedish Height of Irregularities (R or H)
   - Also known as Profiljupmethos
   - Only standard in Sweden (H) and Denmark (R)
   - It assume that, in wear situation, the peaks are affected by wear, but the valleys are not.
7. Bearing Length Ration ($T_p$and others)
   - Create a reference line through some of the peaks

- This line is at a predetermined height from the mean line, and you have then divide the subtended length through the peaks by sampling length to arrive at the assessment value
- See figure F

8. Leveling Depth ($R_p$and others)
    - Measure the height between the highest peak and the mean line
    - See figure G
9. Waviness Height (W)
    - Assess the waviness without regard to roughness by determining the peak-to-valley distance of the total profile within the sampling length

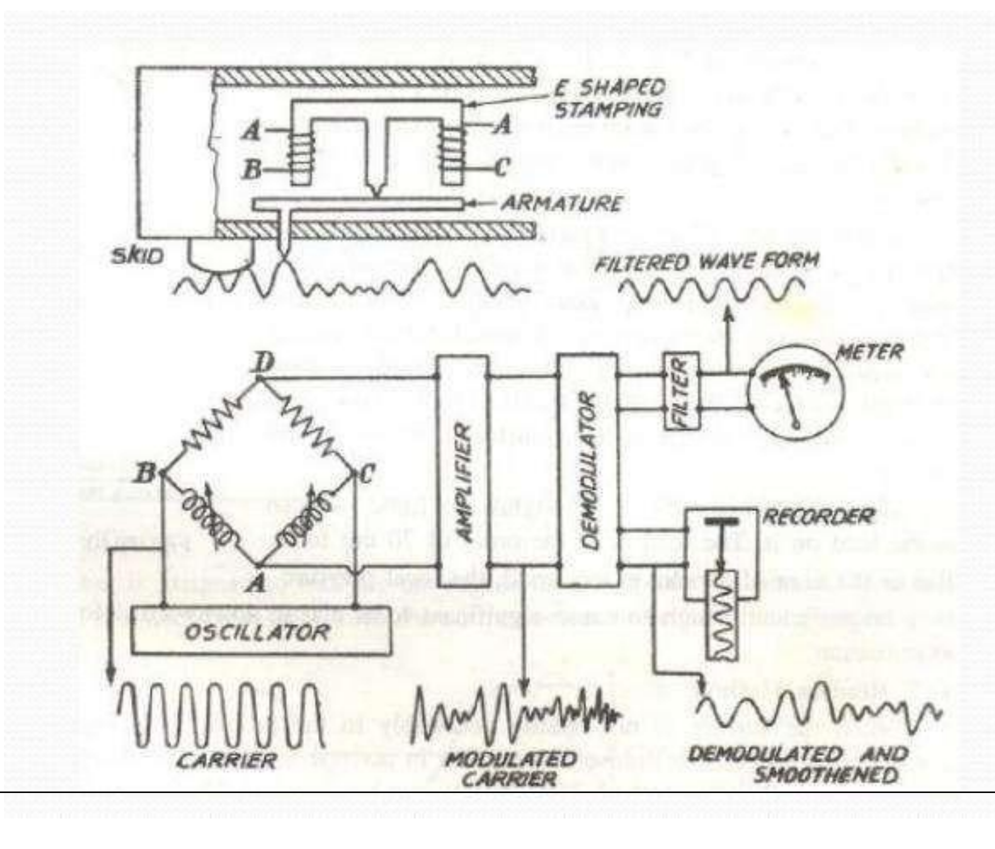


X	X^2
3	9
15	225
20	400
33	1089
25	625
18	324
5	25
10	100
15	225
15	225
5	25
11	121
14	196
13	169
27	729
8	64
Total 234	**4551**

AA = 234/16 = 14.6 micro in.

RMS = $(4551/16)^{1/2}$ = 16.9 micro in.

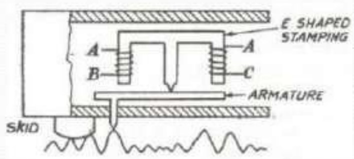
TAYLOR HOBSON TALYSURF



This instrument also gives the same information as the previous instrument, but much more rapidly and accurately.

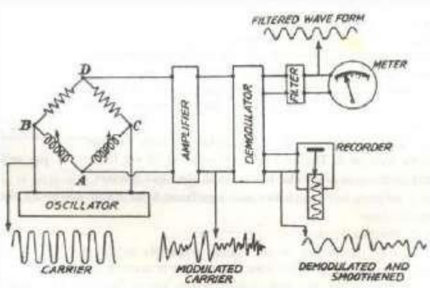
This instrument also as the previous one records the static displacement of the stylus and is dynamic instrument like profilometer.

The measuring head of this instrument consists of a diamond stylus of about 0.002 mm tip radius and skid or shoe which is drawn across the surface by means of a motorised driving unit. A neutral position in which the pick-up can be traversed manually is also provided.



The arm carrying the stylus forms an armature which pivots about the centre piece of E-shaped stamping. On two legs of (outer pole pieces) the E-shaped stamping there are coils carrying an a.c. current.

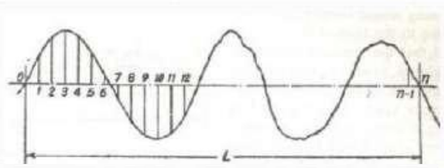
These two coils with other two resistances form an oscillator. The amplitude of the original a.c. current flowing in the coils is modulated because of air gap between the armature and E-shaped stamping. This is further demodulated so that the current now is directly proportional to the vertical displacement of the stylus only.



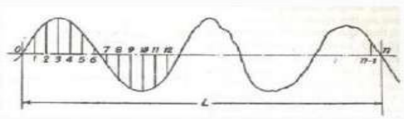
The demodulated output is caused to operate a pen recorder to produce a permanent record and a meter to give a numerical assessment directly. In recorder of this instrument the marking medium is an electric discharge through a specially treated paper which blackens at the point of the stylus.

Analysis of Surface Traces

- **Root Mean Square (R.M.S) Value**
- R.M.S. value is defined as the square root of the mean of the squares of

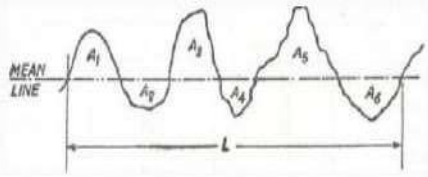


- **Centre Line Average (C.L.A) value.**
- This is defined as the average height from a mean line of all ordinates of the surface regardless of the sign



$$C.L.A = \frac{h_1 + h_2 + \ldots\ldots + h_n}{n}$$

- Things can be much simplified by using a planimeter which can find out the area of any curve. Then C.L.A. value



$$C.L.A = \frac{A_1 + A_2 + ... + A_n}{L} \times \frac{1}{Vertical\ magnification}$$

- *Calculate the CLA (Ra) value of a surface for which the sampling length was 0.8 mm. The graph was drawn to a vertical magnification of 10000 and a horizontal magnification of 100. and the areas above and below the datum line were :*

Above(mm2)	180	90	155	55
Below(mm2)	70	90	170	150

- Solution:

$$\frac{\text{Sum of areas } (mm^2)}{\text{Sampling length } (mm)} \times \frac{1000}{\text{Vertical magnification}} \times \frac{1}{\text{Horizontal magnification}}$$

- *In the measurement of surface roughness, heights of 20 successive peaks and troughs were measured from a datum and were 35, 25, 40, 22, 35, 18, 42, 25, 35, 22, 36, 18, 42, 22, 32, 21, 37, 18, 35, 20 microns.*
- *If these measurements were obtained over a length of 20 mm, determine the C.L.A. (Ra) and R.M.S value of the rough surface.*

Profilo graph This equipment is used for checking and recording the smoothness of profiles of pavements with accuracy and cost-effectiveness. The equipment, developed by Central Road Research Institute, comprises of a mobile trussed frame, four datum wheels which provide the plan of reference with respect to which the instrument, moves along the pavement surface during the test. The probing wheel undulates with the surface irregularities and the pen marker linked to probing wheel records the magnitude of the undulation on a graph sheet. The road roughness level is estimated using this equipment.

PROFILOGRAPH TESTING

accurately measures surface roughness through a computerized recorder capable of graphing a pavement profile both vertically and horizontally. The information it collects is used to calculate the International Roughness Index (IRI), which is expressed in units of inches/mile or millimeters/meters. An IRI value of 0 (zero) is equivalent to driving on a plate of glass. High ranges, upward to several hundred inches in a mile, indicate a very rough road. The Profilograph also measures a pavement‘s cross slope, allows bi-directional testing and multiple wheel path reporting, and can append data to existing files, which improves tracking and correlations throughout a project.

Another type of profilograph system is for measuring the surface texture of a road and how it relates to the coefficient of friction and thus to skid resistance. Pavement texture is divided into three categories; megatexture, macrotexture, and microtexture. Microtexture cannot currently be measured directly, except in a laboratory. Megatexture is measured using a similar profiling method as when obtaining IRI values, while macrotexture is the measurement of the individual variations of the road within a small interval of a few centimeters. For example, a road which has gravel spread on top followed by an asphalt seal coat will have a high macrotexture, and a road built with concrete slabs will have low macrotexture. For this reason, concrete is often grooved or roughed up immediately after it is laid on the road bed to increase the friction between the tire and road.

Equipment to measure macrotexture currently consists of a distance measuring laser with an extremely small spot size (< 1 mm) and data acquisition systems capable of recording elevations spaced at 1 mm or less. The sample rate is generally over 32 kHz. Macrotexture data can be used to calculate the speed-dependent part of friction between typical car tires and the road surface in both dry and wet conditions. Microtexture affects friction as well.

Lateral friction and cross slope are the key reaction forces acting to keep a cornering vehicle in steady lateral position, while it is subject to exiting forces arising from speed and curvature. Cross slope and curvature can be measured with a road profilograph, and in combination with friction-related measurements can be used to identify improperly banked curves, which can increase the risk of motor vehicle accidents.

ISI SYMBOL FOR INDICATION OF SURFACE FININSH

Roughness Values Ra µm	Roughness Grade Number	Roughness Triangle Symbols
50	N 12	~
25 12.5	N11 N10	▽
6.3 3.2 1.6	N9 N8 N7	▽▽
0.8 0.4 0.2	N6 N5 N4	▽▽▽
0.1 0.05 0.025	N3 N2 N1	▽▽▽▽