SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)

SCHOOL OF MECHANICAL ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING

UNIT - I

MANUFACTURING TECHNOLOGY II – SPR1301

UNIT - I

THEORIES OF METAL CUTTING

Introduction - Material removal processes, Types of machine tools – Theory of metal cutting - chip formation, heat generation, cutting fluids, cutting tool life - Recent developments and applications (Dry machining and high speed machining).

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, etcc.

MATERIAL REMOVAL PROCESSES

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).

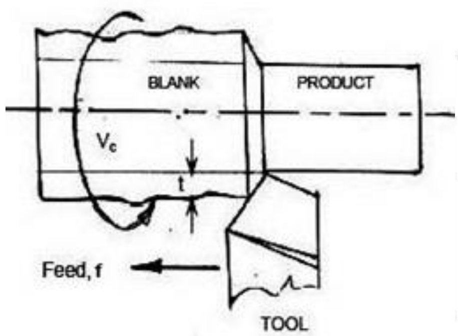


Fig. 1.1 Principle of machining (Turning)

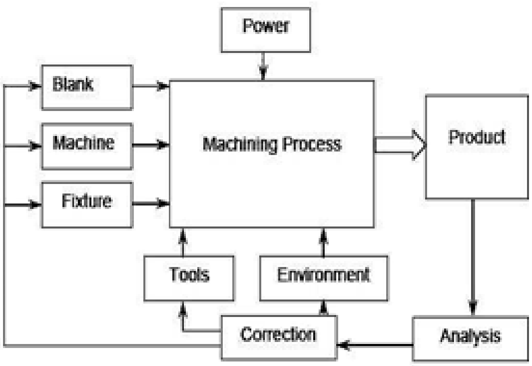


Fig. 1.2 Requirements for machining

Principle of machining

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

Purpose of machining

Most of the engineering components such as gears, bearings, clutches, tools, screws and nuts etc. need dimensional and form accuracy and good surface finish for serving their purposes.

Preforming like casting, forging etc. generally cannot provide the desired accuracy and finish. For that such preformed parts, called blanks, need semi-finishing and finishing and it is done by machining and grinding. Grinding is also basically a machining process.
Machining to high accuracy and finish essentially enables a product:

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

Requirements of machining

The essential basic requirements for machining a work are schematically illustrated in Fig. 1.2. The blank and the cutting tool are properly mounted (in fixtures) and moved in a powerful device called machine tool enabling gradual removal of layer of material from the work surface resulting in its desired dimensions and surface finish. Additionally, some environment called cutting fluid is generally used to ease machining by cooling and lubrication.

TYPES OF MACHINE TOOLS

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.

Classification of machine tools

Number of types of machine tools gradually increased till mid 20th century and after that started decreasing based on group technology.
However, machine tools broadly classified as follows:

According to direction of major axis:

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

According to purpose of use:

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

According to degree of automation:

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

According to size:

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

According to blank type:

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

According to precision:

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

According to number of spindles:

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

According to type of automation:

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

According to configuration:

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

Specification of machine tools

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

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

Centre lathe:

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

Shaper:

- Length, breadth and depth of the bed.

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

Drilling machine (column type):

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

Milling machine (knee type and with arbor):

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

THEORY OF METAL CUTTING

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.*

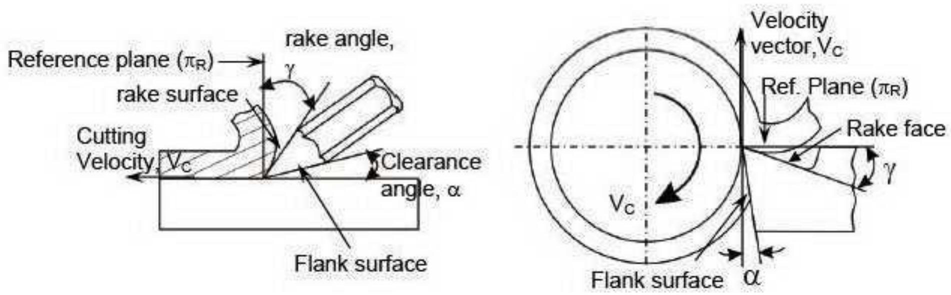


Fig. 1.3 Rake and clearance angles of cutting tools

Definition

Rake angle (γ): Angle of inclination of rake surface from reference plane.

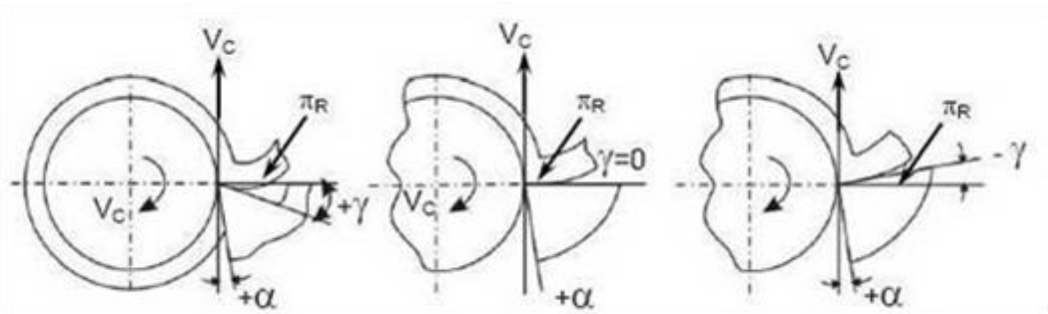


Fig. 1.4 Three possible types of rake angles (a) Positive rake (b) Zero rake (c) Negative rake

Clearance angle (α): Angle of inclination of clearance or flank surface from the finished surface. Rake angle is provided for ease of chip flow and overall machining. Rake angle may be positive, or negative or even zero *as shown in Fig. 1.4 (a, b and c).*

Relative advantages of such rake angles are:

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

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

Systems of description of tool geometry

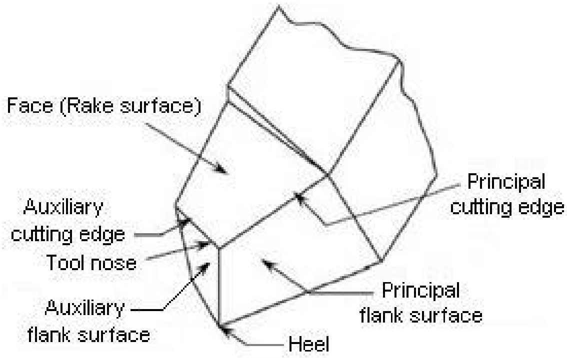
- Tool-in-Hand System - where only the salient features of the cutting tool point are identified or visualized *as shown in Fig. 1.5 (a).* There is no quantitative information, i.e., value of the angles.
  - Machine Reference System
  - Tool Reference System

- Normal Rake System- NRS
- ASA system.
- Orthogonal Rake System- ORS

Description of tool geometry in Machine Reference System

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

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



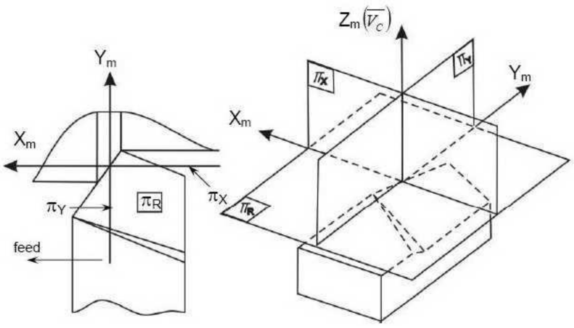


Fig 1.5 (a) Basic features of single point Fig. 1.5 (b) Planes and axes of reference cutting (turning) tool in ASA system

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

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

$\boldsymbol{\Pi_R}$ = Reference plane; plane perpendicular to the velocity vector. Shown in Fig. 1.5 (b).

$\boldsymbol{\Pi_X}$ = Machine longitudinal plane; plane perpendicular to Π_R and taken in the direction of assumed longitudinal feed.

$\boldsymbol{\Pi_Y}$ = 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.*

Definition of:

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

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

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

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

Rake angles: [Fig. 1.6]

γ_x = Side rake angle (axial rake): angle of inclination of the rake surface from the reference plane (Π_R) and measured on machine reference plane, Π_X.
γ_y = Back rake angle: angle of inclination of the rake surface from the reference plane and measured on machine transverse plane, Π_Y.
Clearance angles: [Fig. 1.6]

α_x = Side clearance angle (Side relief angle): angle of inclination of the principal flank from the machined surface (or CV) and measured on Π_X plane.
α_y = Back clearance angle (End relief angle): same as α_x but measured on Π_Y plane.
Cutting angles: [Fig. 1.6]

φ_s = Side cutting edge angle (Approach angle): angle between the principal cutting edge (its projection on Π_R) and Π_Y and measured on Π_R.
φ_e = End cutting edge angle: angle between the end cutting edge (its projection on Π_R) from Π_X and measured on Π_R.

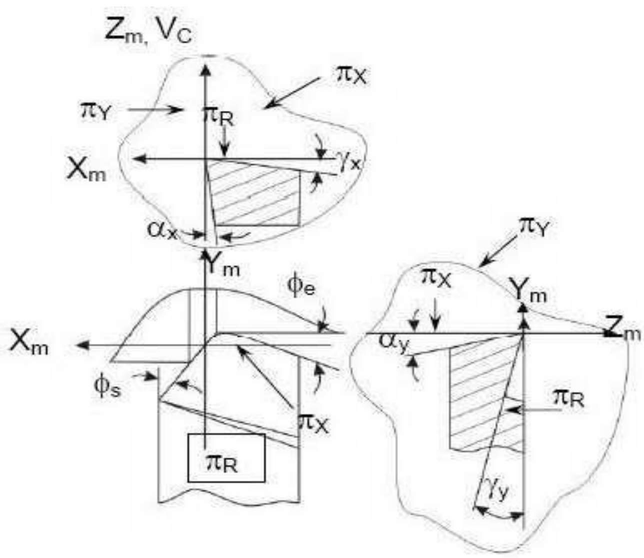


Fig. 1.6 Tool angles in ASA system

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 - γ_y, γ_x, α_y, α_x, φ_e, φ_s, **r** (in inch)

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

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

Types of metal cutting processes

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

1. ***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.
2. ***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.

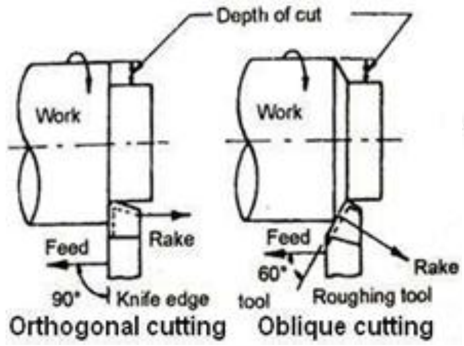
Orthogonal and oblique cutting

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

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

When $\lambda = 0^0$, the chip flows along orthogonal plane, i.e, $\rho_c = 0^0$.

When $\lambda \neq 0^0$, the chip flow is deviated from π_o and $\rho_c = \lambda$ where ρ_c is chip flow deviation (from π_o) angle.



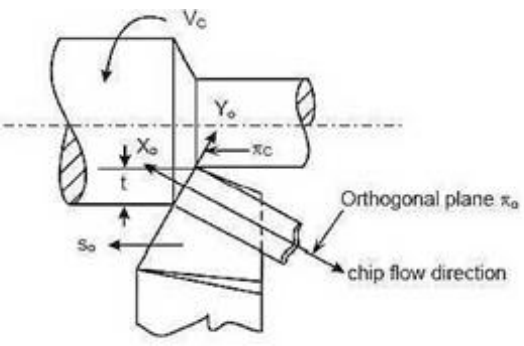


Fig. 1.7 (a) Setup of orthogonal and oblique cutting Fig. 1.7 (b) Ideal direction of chip flow

in turning

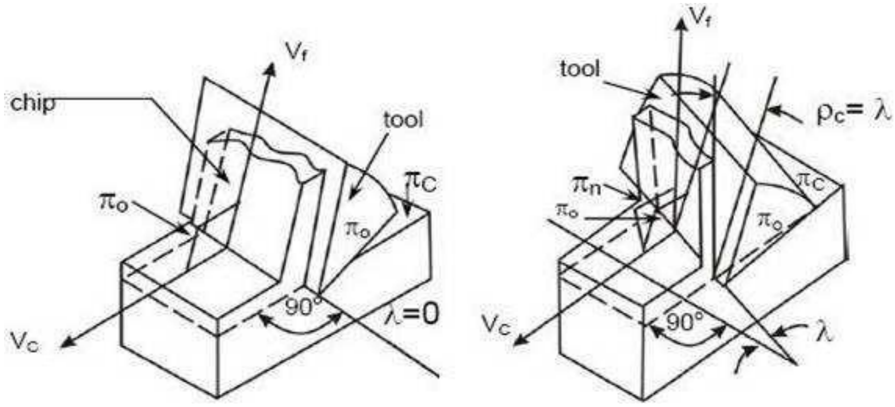


Fig. 1.8 Role of inclination angle, λ on chip flow direction

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

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

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

Pure orthogonal cutting

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

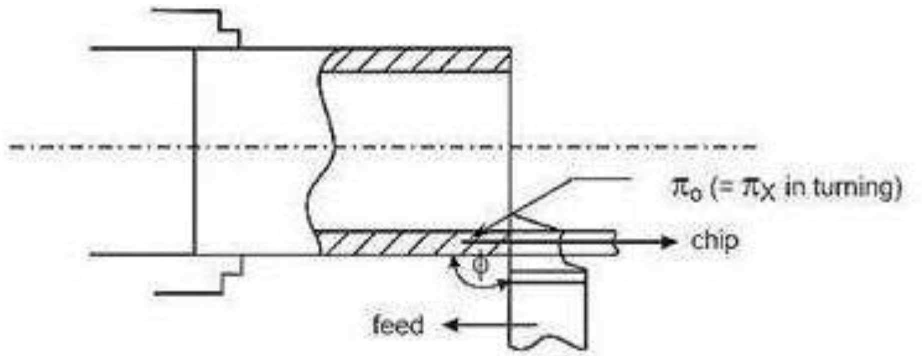


Fig. 1.9 Pure orthogonal cutting (pipe turning)

Comparison between Orthogonal and Oblique cutting

S.No	Orthogonal Cutting	Oblique Cutting
1	The cutting angle of tool make right angle (90 degrees) to the direction of motion	The cutting angle of tool make an acute angle (> 90 degrees)to the direction of motion
2	The flow of chip is perpendicular to cutting edge.	The flow of chip is not perpendicular to cutting edge.

3	The tool has lesser cutting life.	The tool has higher cutting life.
4	The shear force per unit area is high which increases the heat per unit area.	The shear force per unit area is low which decrease heat per unit area .
5	In this cutting, chip flow over the tool.	In this cutting, chip flow along the sideways.
6	In orthogonal cutting, surface fiish is poor.	In oblique cutting surface finish is good.
7	Cutting edge is longer than edge of cut.	Cutting may or may not be longer than edge of cut.
8	Two mutually perpendicular cutting force act on the workpiece	Three mutually perpendicular forces are involved .

CHIP FORMATION

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:

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

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

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

The form of machined chips depends mainly upon:

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

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

Mechanism of chip formation in machining ductile materials

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

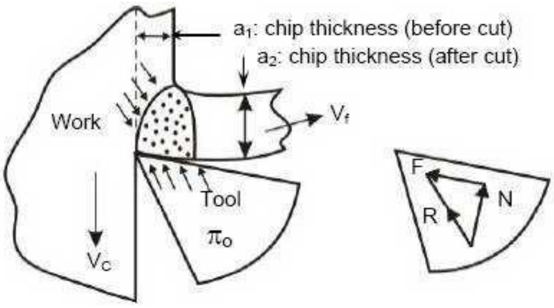


Fig. 1.10 Compression of work material (layer) ahead of the tool tip

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

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

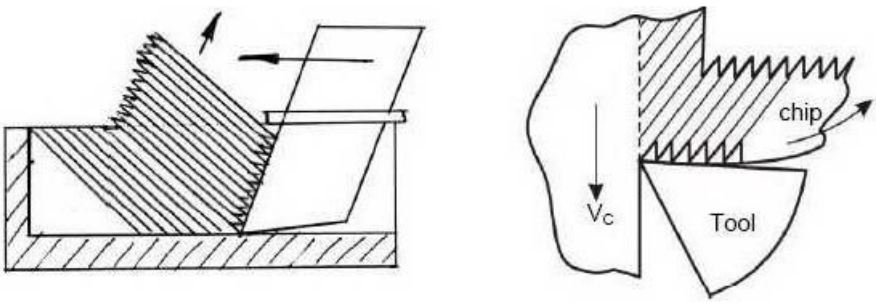


Fig. 1.11 Piispannen model of card analogy to explain chip formation in machining ductile materials (a) Shifting of the postcards by partial sliding against each other (b) Chip formation by shear in lamella

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

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

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

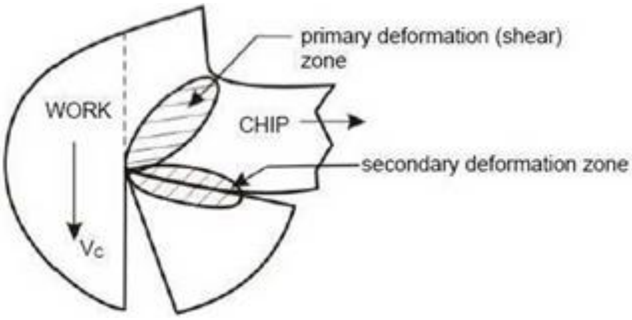
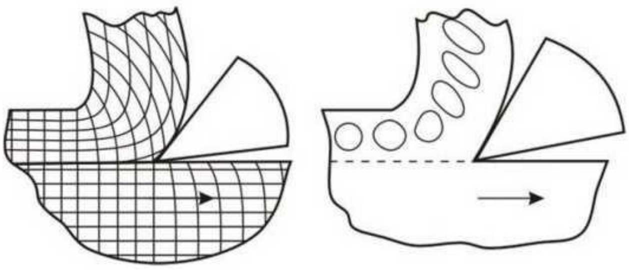


Fig. 1.12 Primary and secondary deformation zones in the chip

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

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

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



(a) Rectangular grids (b) Circular grids

Fig. 1.13 Pattern of grid deformation during chip formation

Mechanism of chip formation in machining brittle materials

The basic two mechanisms involved in chip formation are:

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

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

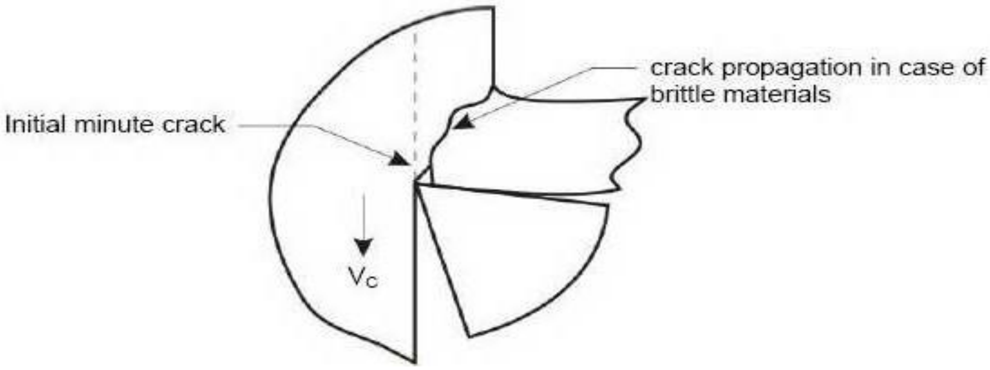
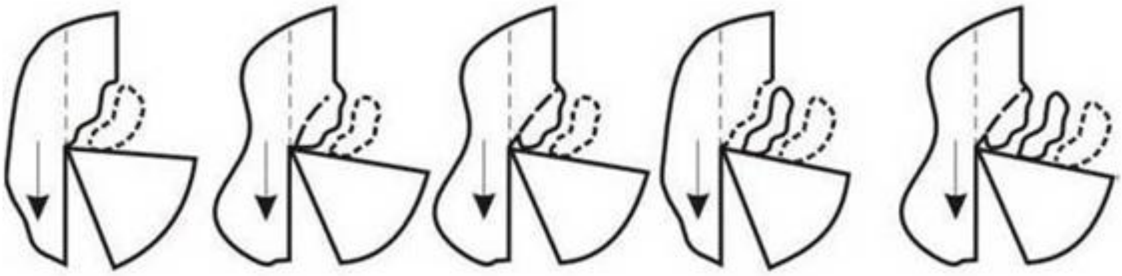


Fig. 1.14 Development and propagation of crack causing chip separation.

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



(a) Separation (b) Swelling (c) Further swelling (d) Separation (e) Swelling again Fig. 1.15 Schematic view of chip formation in machining brittle materials

Chip thickness ratio

Geometry and characteristics of chip forms

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

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

Chip reduction coefficient or cutting ratio

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

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

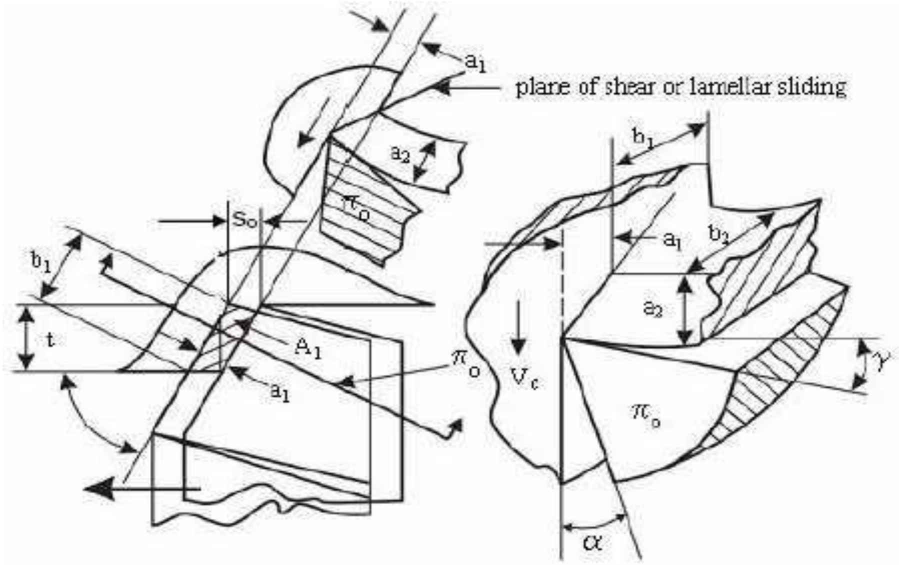


Fig. 1.16 Geometrical features of continuous chip formation.

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

t = depth of cut (mm) - perpendicular penetration of the cutting tool tip in work surface. f = feed (mm/rev) - axial travel of the tool per revolution of the job.

b_1 = width (mm) of chip before cut. b_2 = width (mm) of chip after cut.

a_1 = thickness (mm) of uncut layer (or chip before cut). a_2 = chip thickness (mm) - thickness of chip after cut. A_1 = cross section (area, mm2) of chip before cut.

The degree of thickening of the chip is expressed by

$$\mathbf{r_c = a_2 / a_1 > 1.00} \qquad \text{(since } a_2 > a_1\text{)} \qquad 1.$$

where, r_c = chip reduction coefficient.

$$\mathbf{a_1 = f \sin\varphi} \qquad 1.$$

where φ = principal cutting edge angle.

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

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

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

where r = cutting ratio.

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

Tool rake angle, Chip-tool interaction, mainly friction,

the value of r_c can be desirably reduced by

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

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

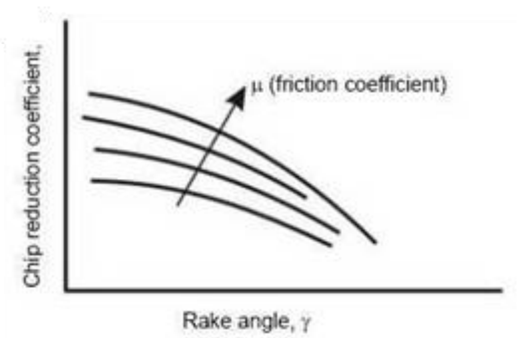


Fig. 1.17 Role of rake angle and friction on chip reduction coefficient

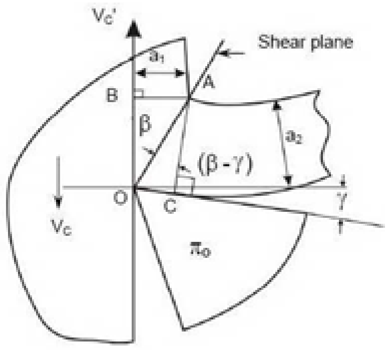


Fig. 1.18 Shear plane and shear angle in chip formation

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

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

Considering total volume of chip produced in a given time,

$$\mathbf{a_1 b_1 L_1 = a_2 b_2 L_2} \qquad 1.5$$

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

$$\mathbf{r_c = a_2 / a_1} = L_1 / L2 \qquad 1.6$$

Again considering unchanged material flow (volume) ratio, Q

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

Taking $b_1=b_2$,

$$\mathbf{r_c = a_2 / a_1 = V_C/Vf \qquad 1.8}$$

Equation 1.8 reveals that the chip velocity, V_f will be lesser than the cutting velocity, V_C and the ratio is equal to the cutting ratio, $\mathbf{r = 1 / r_c}$

Shear angle

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

Shear plane

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

Shear angle

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

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

- Chip thickness before cut and after cut i.e. r_c.
- Rake angle, γ (in orthogonal plane). From Fig. 1.18,

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

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

or

$$\mathbf{\tan\beta = \cos\gamma / rc - \sin\gamma} \qquad 1.10$$

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

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

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

Cutting strain

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

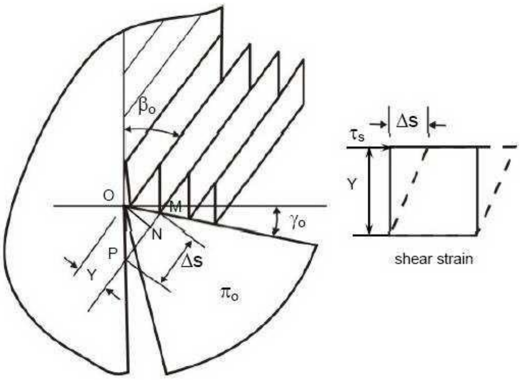


Fig. 1.19 Cutting strain in machining

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

Cutting strain (average), **ε = Δs / Y = PM / ON**

Or **ε = PN + NM / ON**

ε = PN / ON + NM / ON or $\varepsilon = \cot\beta + \tan(\beta - \gamma)$ 1.12

Built-up-Edge (BUE) formation

Causes of formation

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

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

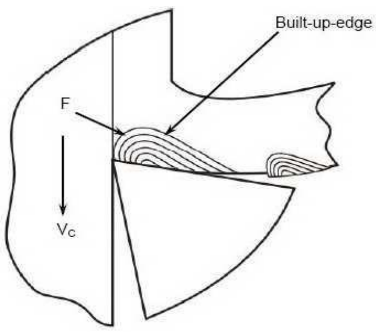


Fig. 1.20 Scheme of built-up-edge formation

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

Characteristics of BUE

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

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

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

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

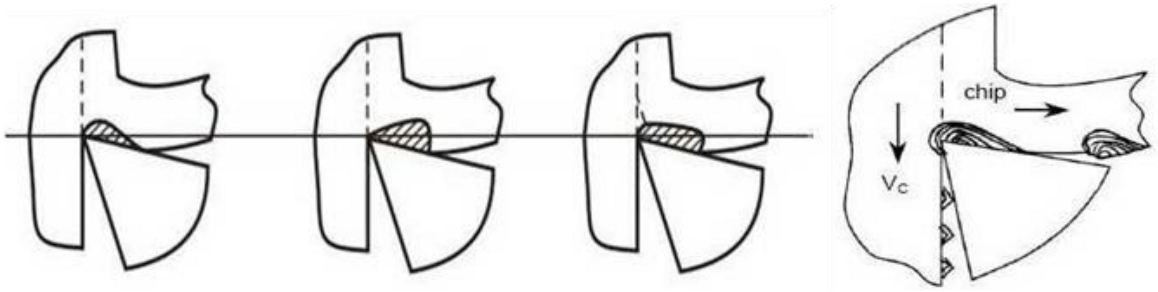


Fig. 1.22 Overgrowing and Fig. 1.21 Different forms of built-up-edge.

In machining too soft and ductile metals by tools like high speed steel or uncoated carbide the overflowing of BUE causing surface roughness

BUE may grow larger and overflow towards the finished surface through the flank as shown in Fig. 1.22. While the major part of the detached BUE goes away along the flowing chip, a small part of the BUE may remain stuck on the machined surface and spoils the surface finish. BUE formation needs certain level of temperature at the interface depending upon the mutual affinity of the work-tool materials. With the increase in V_C and so the cutting temperature rises and favors BUE formation.

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

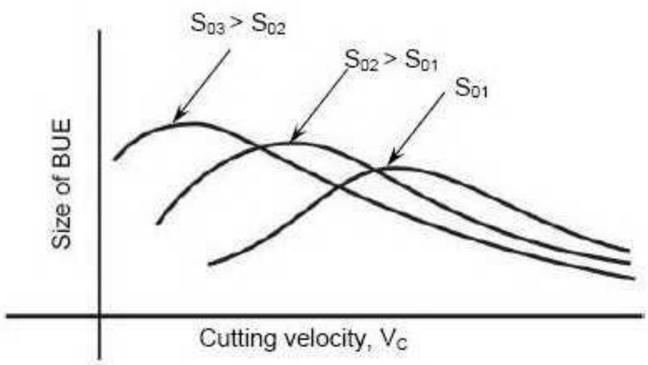


Fig. 1.23 Role of cutting velocity and feed on BUE formation

Effects of BUE formation

Formation of BUE causes several harmful effects, such as:

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

Types of chips

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

upon:

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

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

Continuous chips without BUE

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

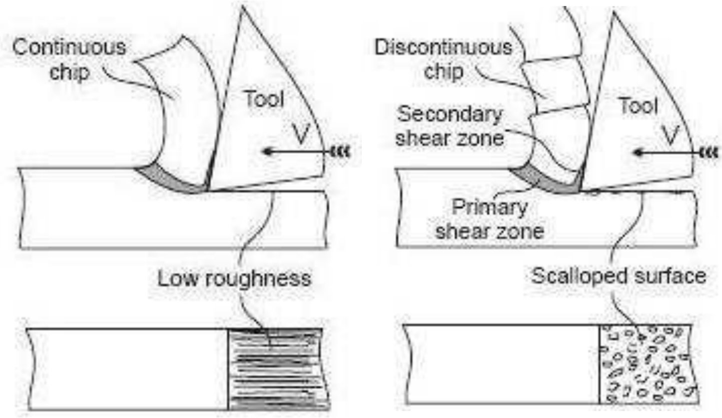


Fig. 1.24 Formation of continuous chips Fig. 1.25 Formation of discontinuous chips

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

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

Discontinuous chips

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

The following condition favors the formation of discontinuous chips:

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

Continuous chips with BUE

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

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

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

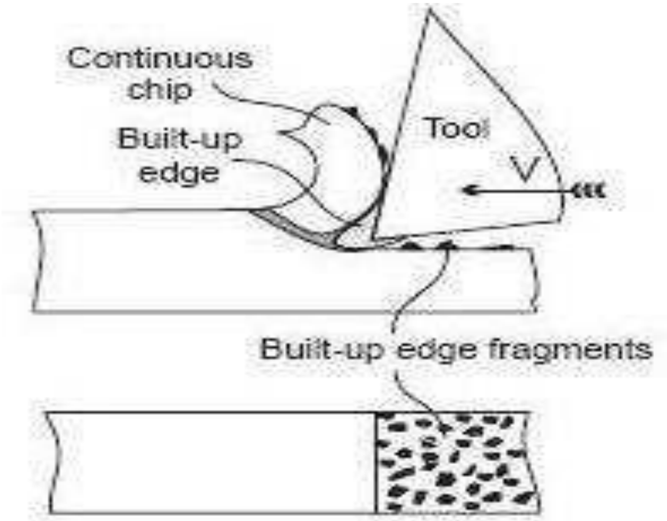


Fig. 1.26 Formation of continuous chips with BUE

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

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

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

Chip breakers

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 machining of ductile metals and alloys at high speed.

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

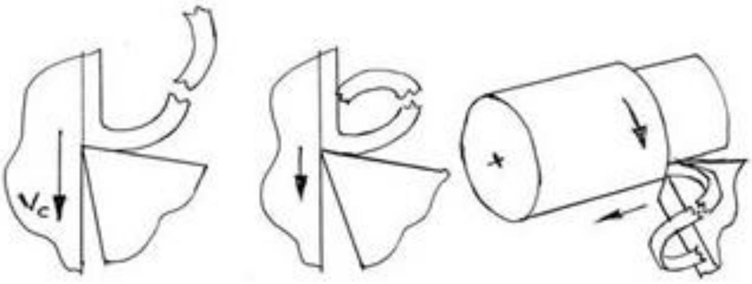
- Self chip breaking - This is accomplished without using a separate chip-breaker either as an attachment or an additional geometrical modification of the tool.
- Forced chip breaking - This is accomplished by additional tool geometrical features or devices.

a) Self breaking of chips

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

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

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



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

Fig. 1.27 Principles of self breaking of chips

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

b) Forced chip-breaking

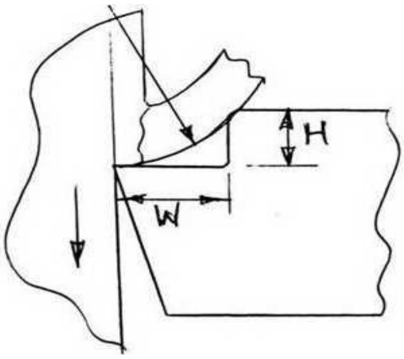
The hot continuous chip becomes hard and brittle at a distance from its origin due to work hardening and cooling. If the running chip does not become enough curled and work hardened, it may not break. In that case the running chip is forced to bend or closely curl so that it breaks into pieces at regular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

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

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

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

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



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

Fig. 1.28 Principle of forced chip breaking

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

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

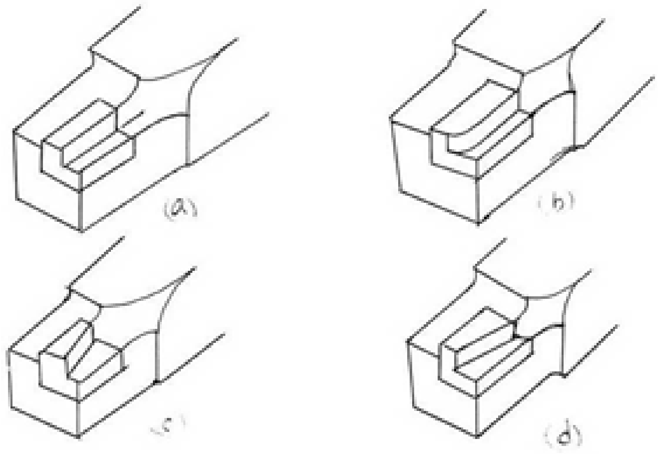
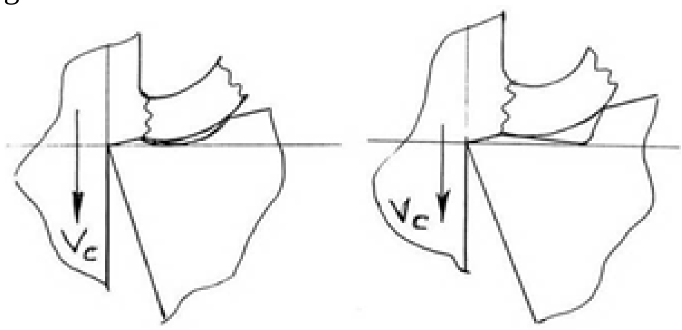


Fig. 1.29 Step type in-built chip breaker (a) Parallel step (b) Parallel and radiused (c) Positive angular (d) Negative angular

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

- Circular groove.
- Tilted Vee groove.



(a) Circular groove (b) Tilted Vee groove

Fig. 1.30 Groove type in-built chip breaker

The unique characteristics of in-built chip breakers are:

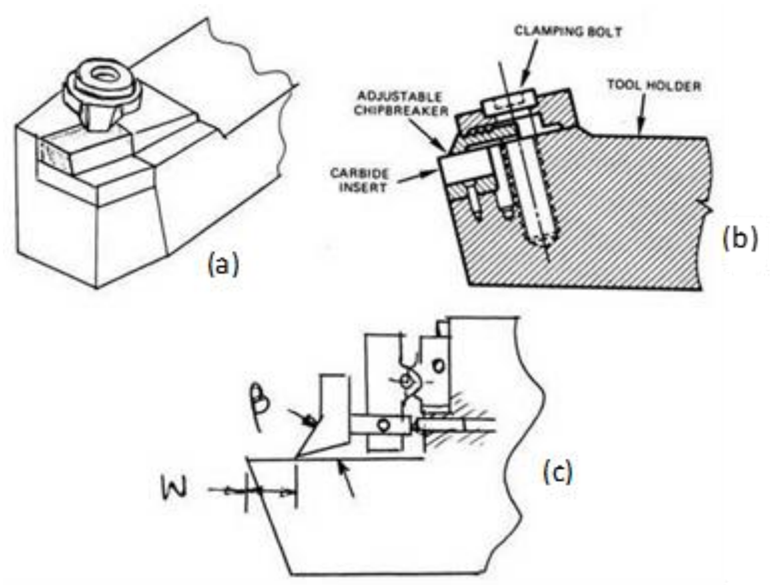
- The outer end of the step or groove acts as the heel that forcibly bends and fractures the running chip.
- Simple in configuration, easy manufacture and inexpensive.

- The geometry of the chip-breaking features is fixed once made. (i.e., cannot be controlled)
- Effective only for fixed range of speed and feed for any given tool-work combination.

(a) Clamped type chip-breaker

Clamped type chip breakers work basically in the principle of stepped type chip-breaker but have the provision of varying the width of the step and / or the angle of the heel.
Fig. 1.31 (a, b and c) schematically shows three such chip breakers of common use:

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



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

(b) Chip breakers in solid HSS tools

Despite advent of several modern cutting tool materials, HSS is still used for its excellent TRS (transverse rupture strength) and toughness, formability, grindability and low cost. The cutting tools made of solid HSS blanks, such as form tools, twist drills, slab milling cutters, broaches etc, are also often used with suitable chip breakers for breaking the long or wide continuous chips.
The handling of wide and long chips often becomes difficult particularly while drilling large diameter and deep holes. Grooves, either on the rake faces or on the flanks *as shown in Fig. 1.32* help to break the chips both along the length and breadth in drilling ductile metals. The

locations of the grooves are offset in the two cutting edges.

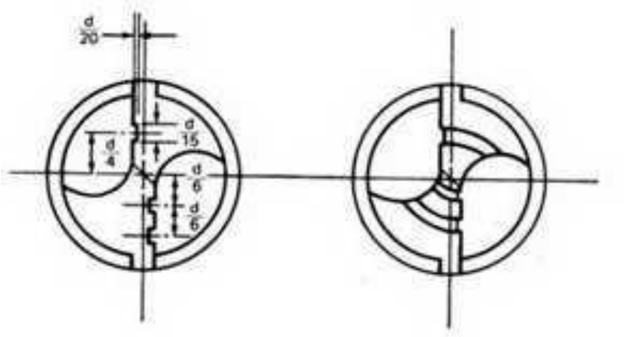
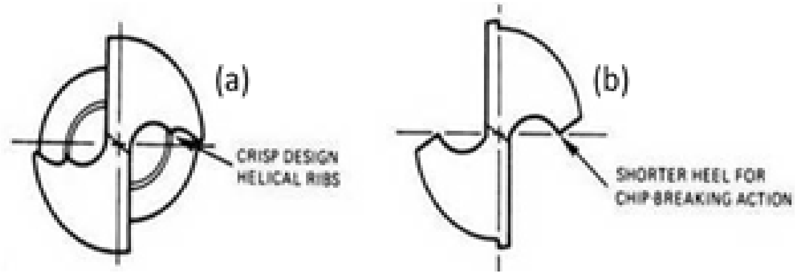


Fig. 1.32 Chip breaking grooves.



(a) Crisp design of chip-breaking drill (b)US industrial design of chip-breaking drill

Fig. 1.33 Designs of chip-breaking drill

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

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

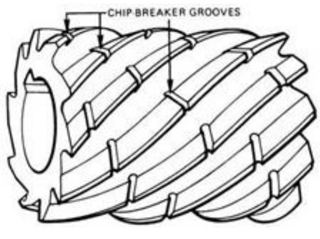


Fig. 1.34 Chip breaking grooves on a plain helical milling cutter

(c) Dynamic chip breaker

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

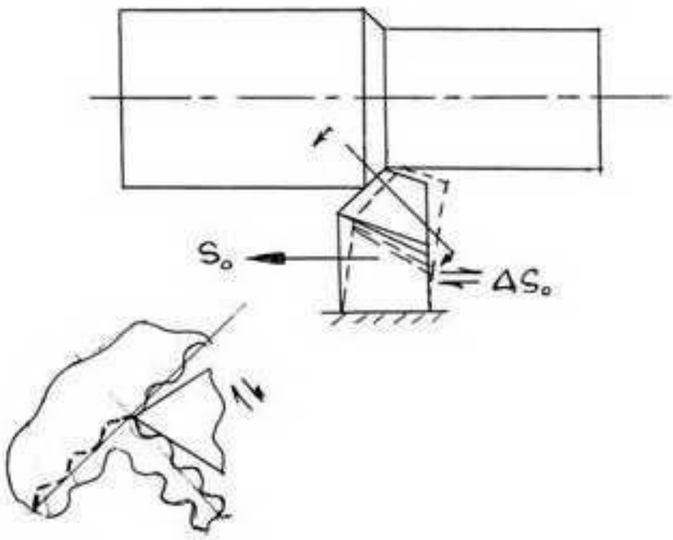


Fig 1.35 Self chip breaking in dynamic turning

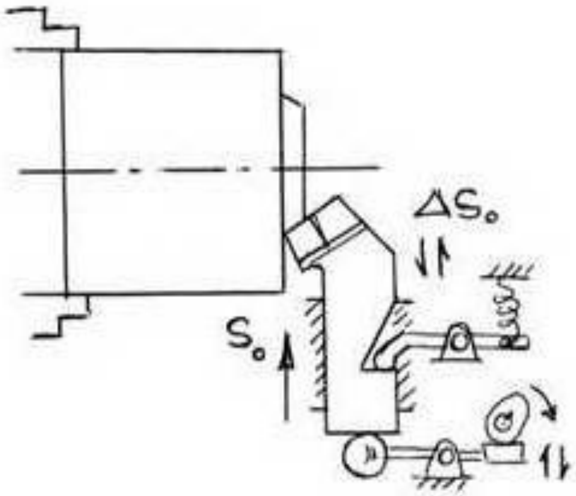


Fig 1.36 Dynamic chip breaking in radial operations in lathe

Overall effects of chip breaking

Favorable effects:

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

Unfavorable effects:

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

ORTHOGONAL METAL CUTTING

Benefit of knowing and purpose of determining cutting forces

The aspects of the cutting forces concerned:

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

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

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

Cutting force components and their significances

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

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

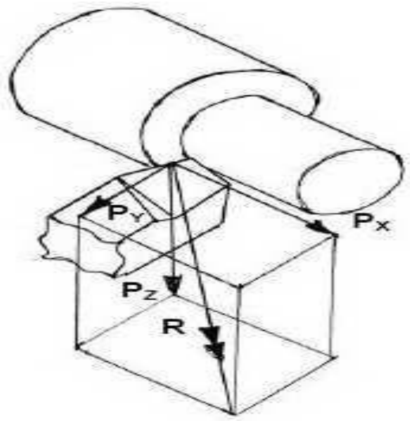


Fig. 1.37 Cutting force R resolved into P_X, P_Y and P_Z

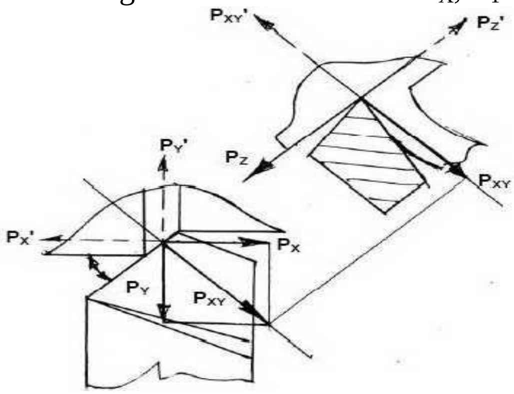


Fig. 1.37 Cutting force R resolved into P_X, P_Y and P_Z

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

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

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

and $\mathbf{P_Y = P_{XY} \cos\varphi}$ 1.1

P_Z - Tangential component taken in the direction of Z_m axis.
P_X - Axial component taken in the direction of longitudinal feed or X_m axis. P_Y - Radial or transverse component taken along Y_m axis.
In Fig. 1.37 and Fig. 1.38 the force components are shown to be acting on the tool. A similar set of forces also act on the job at the cutting point but in opposite directions *as indicated by P_Z', P_{XY}', P_X' and P_Y' in Fig. 1.38.*

Significance of P_Z, P_X and P_Y

➢ P_Z: Called the main or major component as it is the largest in magnitude. It is also called power component as it being acting along and being multiplied by V_C decides cutting power ($P_Z.V_C$) consumption.

➢ P_Y: May not be that large in magnitude but is responsible for causing dimensional inaccuracy and vibration.

➢ P_X: It, even if larger than PY, is least harmful and hence least significant.

Merchant's Circle Diagram and its use

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

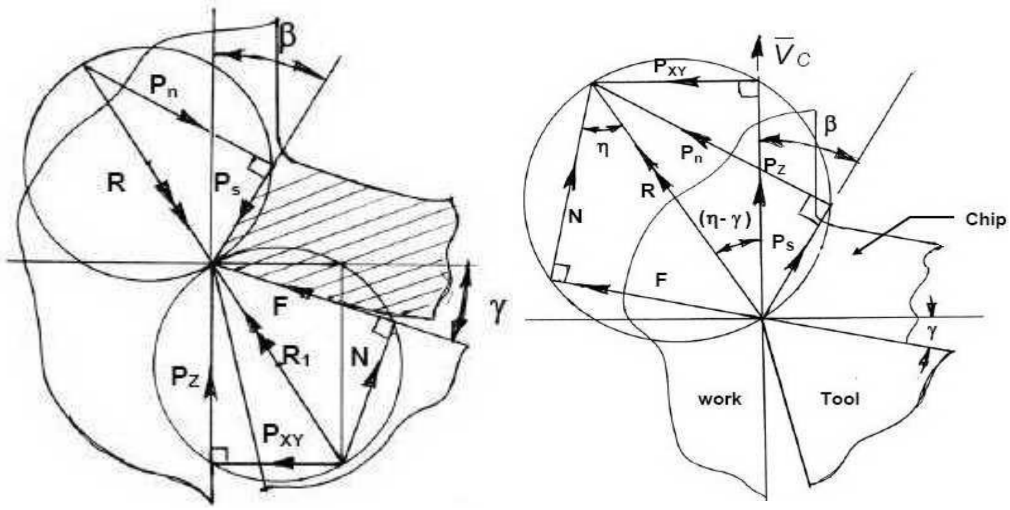


Fig 1.39 Development of Merchant's circle diagram with cutting forces

Fig. 1.40 Merchant's Circle Diagram

The forces in the chip segment are:

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

$R_1 = P_Z + P_{XY}$ where, P_Z - Force along the velocity vector.
P_{XY} - force along orthogonal plane.
The circle(s) drawn taking R or R_1 as diameter is called Merchant's circle which contains all the force components concerned as intercepts. The two circles with their forces are combined into one circle having all the forces contained in that *as shown by the diagram called Merchant's Circle Diagram (MCD) in Fig. 1.40.*

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

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

N - Force acting normal to the rake surface.

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

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

Advantageous use of Merchant's circle diagram

Proper use of MCD enables the followings:

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

Some limitations of use of MCD:

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

Development of equations for estimation of cutting forces

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

- Analytical method: Enables estimation of cutting forces.

Characteristics:

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

Experimental methods: Direct measurement.

Characteristics:

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

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

Development of mathematical expressions for cutting forces

Tangential or main component, P_Z

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

From the MCD shown in Fig. 1.40,

$P_Z = R\cos(\eta - \gamma)$ 1.1

$P_s = R\cos(\beta + \eta - \gamma)$ 1.1

Dividing Eqn. 1.17 by Eqn. 1.18,

$P_Z = P_s \cos(\eta - \gamma) / \cos(\beta + \eta - \gamma)$ 1.1

It was already shown that, $P_s = t.f.\ \tau_s / \sin\beta$ 1.2

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

Thus, $P_Z = t.f.\ \tau_s \cos(\eta - \gamma) / \sin\beta \cos(\beta + \eta - \gamma)$ 1.2

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

Then for turning brittle material,

PZ = t.f. τs cos(900 – 2β) / sinβ cos(900 – β) 1.2

or

PZ = 2 t.f. τs cotβ 1.2

Where, $\cot\beta = r_c - \tan\gamma\ r_c = a_2 / a_1 = a_2 / f \sin\varphi$

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

τs = 0.175 BHN 1.2

where, BHN - Brinnel's Hardness number.

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

$\beta + \eta - \gamma = 45^0$ 1.2

and the value of τ_s is obtained from,

τs = 0.186 BHN (approximate) 1.2

or

τs = 0.74σuε0.6Δ (more suitable and accurate) 1.2

where, σ_u - Ultimate tensile strength of the work material

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

Δ - % elongation Substituting Eqn. 1.25 in Eqn. 1.21,

PZ = t.f. τs(cot β + 1) 1.2

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

So,

$\mathbf{P_Z = t.f.\tau_s(r_c - \tan\gamma + 1)}$ 1.2

Axial force, P_X and transverse force, P_Y
From the MCD shown in Fig. 1.40,

$P_{XY} = P_Z \tan(\eta - \gamma)$1.30
Combining Eqn. 1.21 and Eqn. 1.30,
$P_{XY} = t.f.\tau_s \sin(\eta - \gamma) / \sin\beta \cos(\beta + \eta - \gamma)$1.31
Again, using the angle relationship $\beta + \eta - \gamma = 45^0$, for ductile material
$P_{XY} = t.f.\tau_s(\cot\beta - 1)$ 1.32
or $\mathbf{P_{XY} = t.f.\tau_s(r_c - \tan\gamma - 1)}$1.33
where, $\tau_s = 0.74\sigma_u\varepsilon^{0.6\Delta}$ or $\tau_s = 0.186$ BHN It is already known,
Therefore, $\mathbf{P_X = t.f.\tau_s(r_c - \tan\gamma - 1)\sin\varphi}$ 1.34
and $\mathbf{P_Y = t.f.\tau_s(r_c - \tan\gamma - 1)\cos\varphi}$ 1.35

Friction force, F, normal force, N and apparent coefficient of friction μ_a
From the MCD shown in Fig. 1.40,

$F = P_Z \sin\gamma + P_{XY} \cos\gamma$ 1.36
and $N = P_Z \cos\gamma - P_{XY} \sin\gamma$ 1.37
$\mu_a = F / N = P_Z \sin\gamma + P_{XY} \cos\gamma / P_Z \cos\gamma - P_{XY} \sin\gamma$ 1.38
or $\mathbf{\mu_a = P_Z \tan\gamma + P_{XY} / P_Z - P_{XY} \tan\gamma}$ 1.39

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

Shear force P_s and P_n
From the MCD shown in Fig. 1.40,

$\mathbf{P_s = P_Z \cos\beta - P_{XY} \sin\beta}$ 1.4
and $\mathbf{P_n = P_Z \sin\beta + P_{XY} \cos\beta}$ 1.4

From P_s, the dynamic yield shear strength of the work material, τ_s can be determined by using the relation,
$\mathbf{P_s = A_s\tau_s}$
where, $A_s = t.f / \sin\beta$ = Shear area Therefore,$\tau_s = P_s \sin\beta / t.f$
$\tau s = (PZ \cos\beta - PXY \sin\beta)\sin\beta / t.f$ 1.4

Metal cutting theories
Earnst - Merchant theory
Earnst and Merchant have developed a relationship between the shear angle β, the cutting rake angle γ, and the angle of friction η as follows:
$\mathbf{2\beta + \eta - \gamma = C}$ where C is a *machining constant* for the work material dependent on the rate of change of the shear strength of the metal with applied compressive stress, besides taking the internal coefficient of friction into account.

Modified - Merchant theory

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

Merchant Theory:

Merchant has carried out lot of practical experiments on metal cutting and he found that the relationship, does not hold good practically.

$$\emptyset = \frac{\pi}{4} + \frac{\beta}{2} + \frac{\alpha}{2}$$

He then modified his theory by assuming that shear stress y along the shear plane varies linearly with normal stress, i.e. $y = y_0 + K\sigma$, y_0 is the value of y when normal stress $\sigma = 0$

He then derived $2\phi = C + a = \beta$,
where C = machining constant = arc cot k
Its value varies from 70° to 80° for various steels. i.e. it measures the dependence of shear strength on various steels.

$$\therefore \qquad \psi = \frac{\text{arc cot } k}{2} - \frac{\beta}{2} + \frac{\alpha}{2}.$$

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

Lee and Shaffer's theory

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

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

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

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

Velocity relationship

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

$Vs = VC \cos\gamma / \cos(\beta - \gamma)$ 1.4

and

$Vf = \sin\beta / \cos(\beta - \gamma)$ 1.4

From equation $V_f = V_C / r_c$

It can be inferred from the principle of kinematics that the relative velocity of two bodies (here tool and the chip) is equal to the vector difference between their velocities relative to the reference body (the workpiece). So,

VC = Vs + Vf 1.4

Metal removal rate

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

Metal removal rate (MRR) = t. f.VC 1.4

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

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

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

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

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

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

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

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

Evaluation of cutting power consumption and specific energy requirement

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

Cutting power consumption **(P_C)** can be determined from,

$P_C = P_Z.V_C + P_X.V_f$ 1.5

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

Since both P_X and V_f, specially V_f are very small, $P_X.V_f$ can be neglected and then

PC ≅ PZ.VC **1.5**

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

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

Us = PZ.VC / MRR = PZ/ t.f **1.5**

CUTTING TOOL MATERIALS

Essential properties of cutting tool materials

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

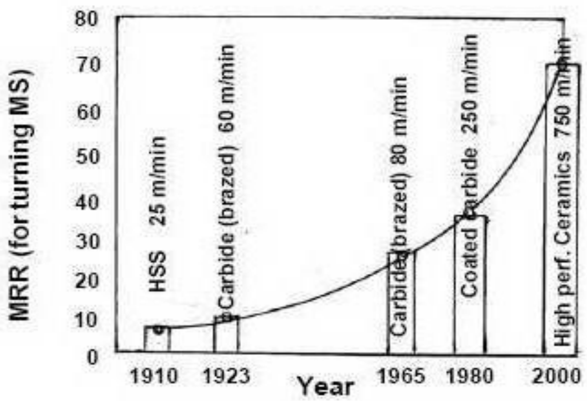
- High mechanical strength; compressive, tensile, and TRA.
- Fracture toughness - high or at least adequate.
- High hardness for abrasion resistance.
- High hot hardness to resist plastic deformation and reduce wear rate at elevated temperature.
- Chemical stability or inertness against work material,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

Needs and chronological development of cutting tool materials

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

- To meet the growing demands for high productivity, quality and economy of machining.
- To enable effective and efficient machining of the exotic materials those are coming up with the rapid and vast progress of science and technology.
- For precision and ultra-precision machining.
- For micro and even nano machining demanded by the day and future.
- It is already stated that the capability and overall performance of the cutting tools depend upon:
- The cutting tool materials.
- The cutting tool geometry.
- Proper selection and use of those tools.
- The machining conditions and the environments.

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



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

Fig. 1.41 Productivity raised by cutting tool materials

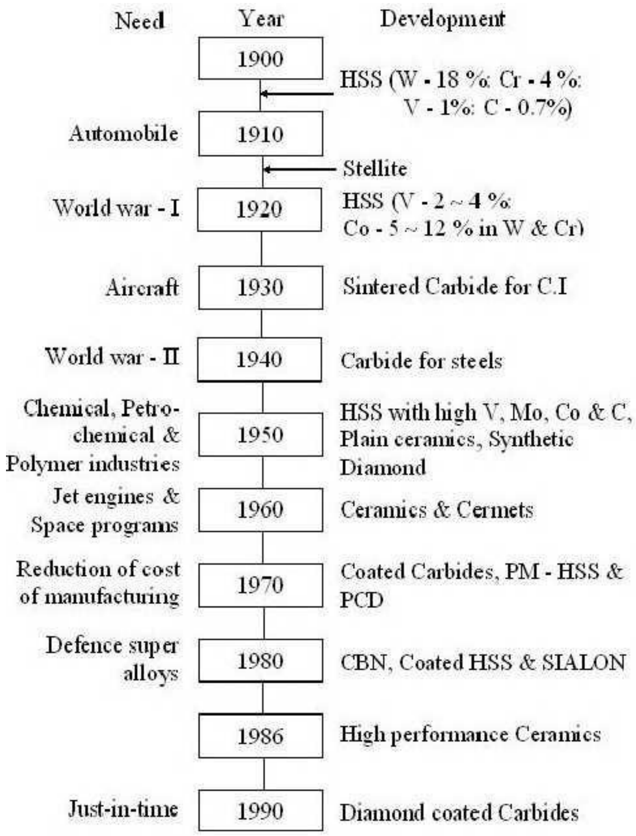


Fig 1.42 Chronological development of cutting tool materials

Characteristics and applications of cutting tool materials

a) High Speed Steel (HSS)

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

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

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

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

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

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

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

Table 1.1 Compositions and types of popular high speed steels

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

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

b) Stellite

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

c) Sintered Tungsten carbides

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

i) Straight or single carbide

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

ii) Composite carbides

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

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

iii) Mixed carbides

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

Gradation of cemented carbides and their applications

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

Table 1.2 Broad classifications of carbide tools

ISO Code	Colour Code	Application
P	Sky blue	For machining long chip forming common materials like plain carbon and low alloy steels.
M	Yellow	For machining long or short chip forming ferrous materials like Stainless steel.

K	Red	For machining short chipping, ferrous and non-ferrous material and non- metals like Cast Iron, Brass etc.

K-group is suitable for machining short chip producing ferrous and non-ferrous metals and also some non metals.
P-group is suitably used for machining long chipping ferrous metals i.e. plain carbon and low alloy steels.
M-group is generally recommended for machining more difficult-to-machine materials like strain hardening austenitic steel and manganese steel etc.
Each group again is divided into some subgroups like P10, P20 etc., as shown in Table 1.3 depending upon their properties and applications.

Table 1.3 Detail grouping of cemented carbide tools

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

M10	Steel, steel castings, manganese steel, grey C.I.	Turning at medium or high cutting speed, medium chip section
M20	Steel casting, austenitic steel, manganese steel, spherodized C.I., Malleable C.I.	Turning, milling, medium cutting speed and medium chip section
M30	Steel, austenitic steel, spherodized C.I. heat resisting alloys	Turning, milling, planning, medium cutting speed, medium or large chip section
M40	Free cutting steel, low tensile strength steel, brass and light alloy	Turning, profile turning, especially in automatic machines.

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

d) Plain ceramics

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

Table 1.4 Cutting tool properties of alumina ceramics

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

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

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

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

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

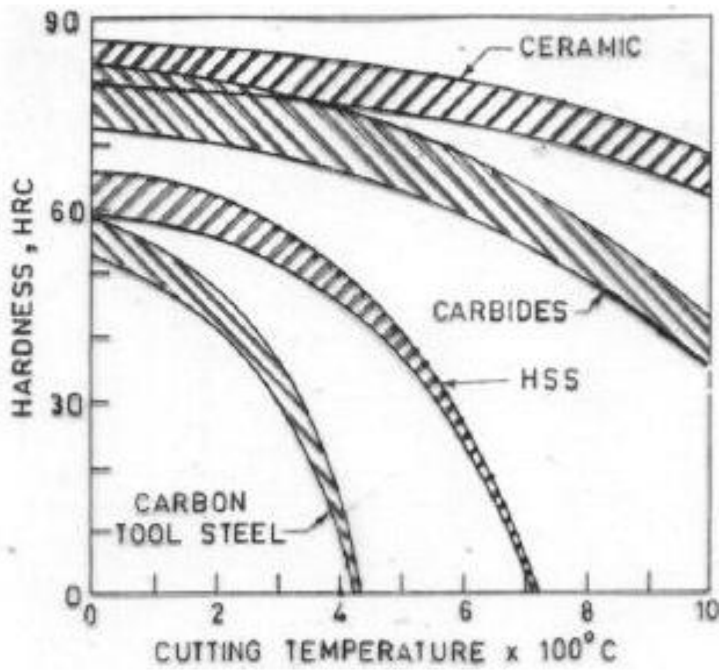


Fig. 1.43 Hot hardness of the different commonly used tool materials (Ref. Book by A. Bhattacharya)

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

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

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

Development and applications of advanced tool materials

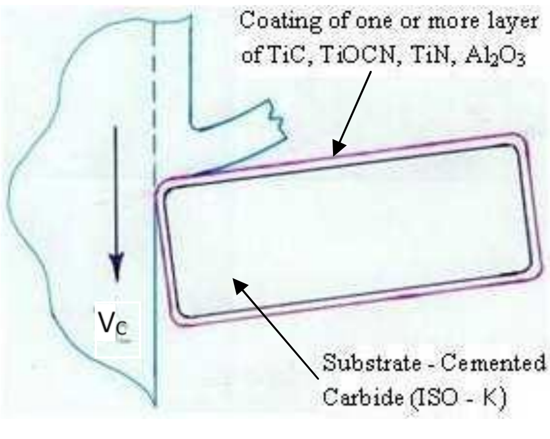
a) Coated carbides

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



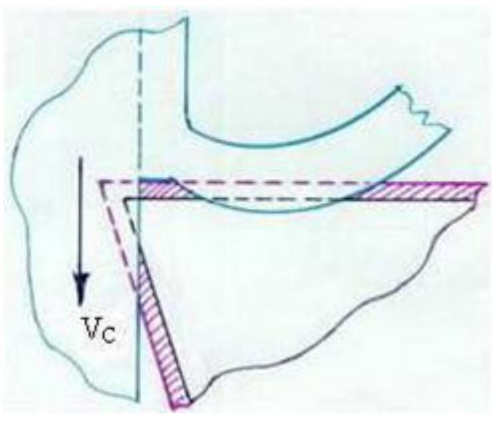


Fig. 1.44 Machining by coated carbide insert. Fig. 1.45 Role of coating even after its wear and rupture

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

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

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

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

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

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

b) Cermets

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

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

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

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

c) Coronite

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

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

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

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

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

d) High Performance ceramics (HPC)

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

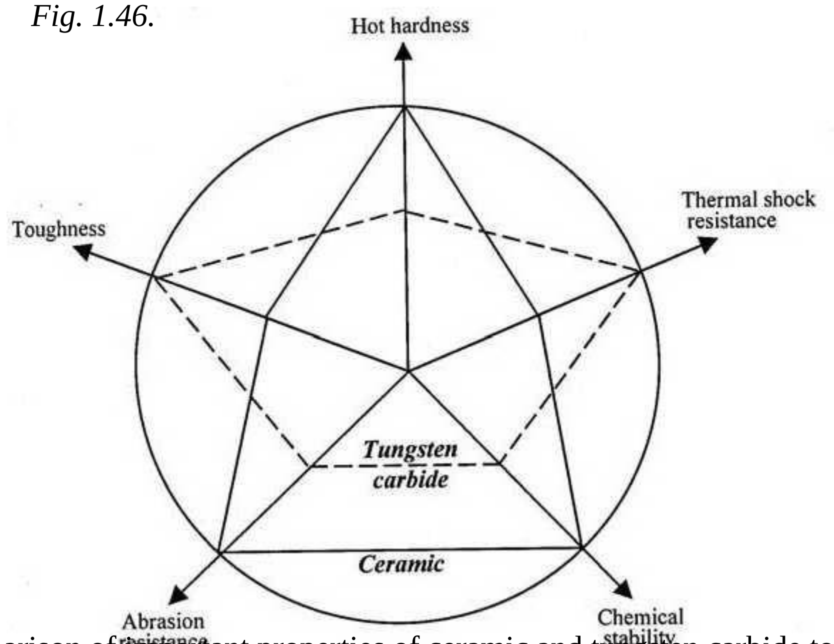


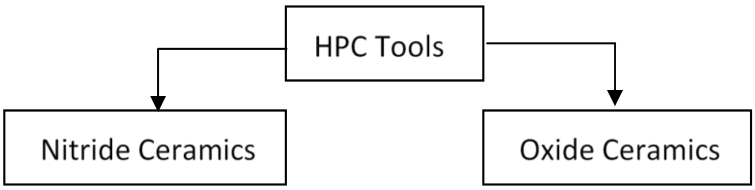
Fig. 1.46 Comparison of important properties of ceramic and tungsten carbide tools

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

- Sinterability, microstructure, strength and toughness of Al_2O_3 ceramics were improved to some extent by adding TiO_2 and MgO.
- Transformation toughening by adding appropriate amount of partially or fully stabilized zirconia in Al_2O_3 powder.
- Isostatic and hot isostatic pressing (HIP) - these are very effective but expensive route.
- Introducing nitride ceramic (Si_3N_4) with proper sintering technique - this material is very tough but prone to built-up-edge formation in machining steels.
- Developing SIALON - deriving beneficial effects of Al_2O_3 and Si_3N_4.

- Adding carbide like TiC (5 ~ 15%) in Al_2O_3 powder - to impart toughness and thermal conductivity.
- Reinforcing oxide or nitride ceramics by SiC whiskers, which enhanced strength, toughness and life of the tool and thus productivity spectacularly. But manufacture and use of this unique tool need especially careful handling.
- Toughening Al_2O_3 ceramic by adding suitable metal like silver which also impart thermal conductivity and self lubricating property; this novel and inexpensive tool is still in experimental stage.

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



The successful and commonly used high performance ceramic tools have been discussed here: The HPC tools can be broadly classified into two groups as:

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

i) Plain nitride ceramics tools

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

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

ii) SIALON tools

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

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

iii) SiC reinforced Nitride tools

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

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

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

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

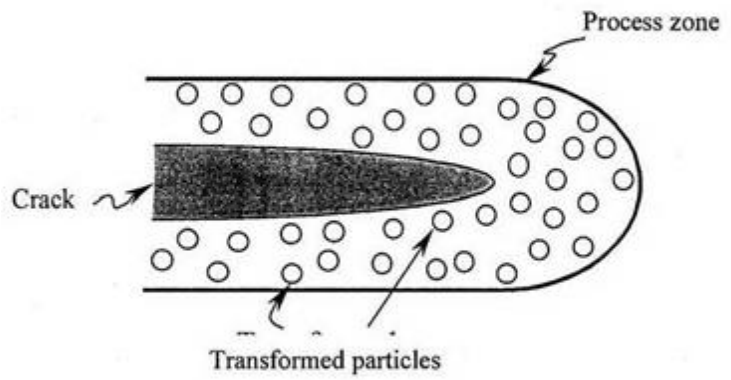


Fig. 1.47 The method of crack shielding by a transformation zone

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

v) Alumina ceramic reinforced by SiC whiskers

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

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

vi) Silver toughened alumina ceramic

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

All such potential characteristics of silver-toughened alumina ceramic have already been exploited in making some salient parts of automobiles and similar items. Research is going on to develop and use silver-toughened alumina for making cutting tools like turning inserts..

The toughening of the alumina matrix by the addition of metal occurs mainly by crack deflection and crack bridging by the metal grains as schematically shown in Fig. 1.48.

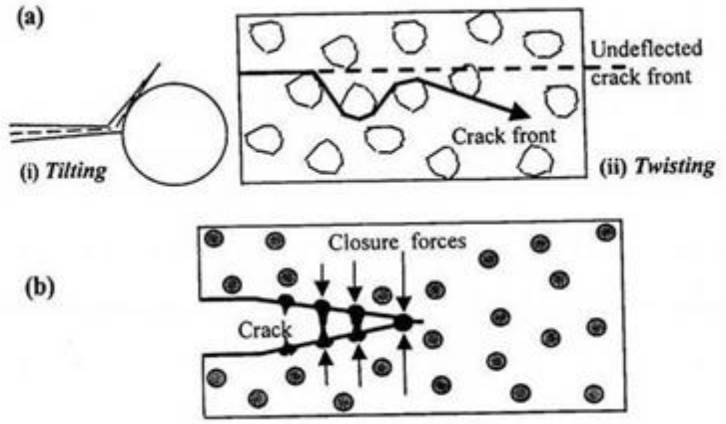


Fig. 1.48 Toughening mechanism of alumina by metal dispersion

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

e) Cubic Boron Nitride

Next to diamond, cubic boron nitride is the hardest material presently available. Only in 1970 and onward CBN in the form of compacts has been introduced as cutting tools. It is made by bonding a

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

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

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

(f) Diamond Tools

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

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

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

i) Polycrystalline Diamond (PCD)

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

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

But such unique PCD also suffers from some limitations like:

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

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

ii) Diamond coated carbide tools

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

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

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

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

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

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

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

TOOL WEAR

Failure of cutting tools

Smooth, safe and economic machining necessitates:

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

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

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

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

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

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

(a) In R&D laboratories

- Total breakage of the tool or tool tip(s).
- Massive fracture at the cutting edge(s).
- Excessive increase in cutting forces and/or vibration.
- Average wear (flank or crater) reaches its specified limit(s).

(b) In machining industries

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

Mechanisms and pattern (geometry) of cutting tool wear

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

The common mechanisms of cutting tool wear are:

(a) Mechanical wear

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

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

(b) Thermo chemical wear

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

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

(c) Chemical wear

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

(d) Galvanic wear

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

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

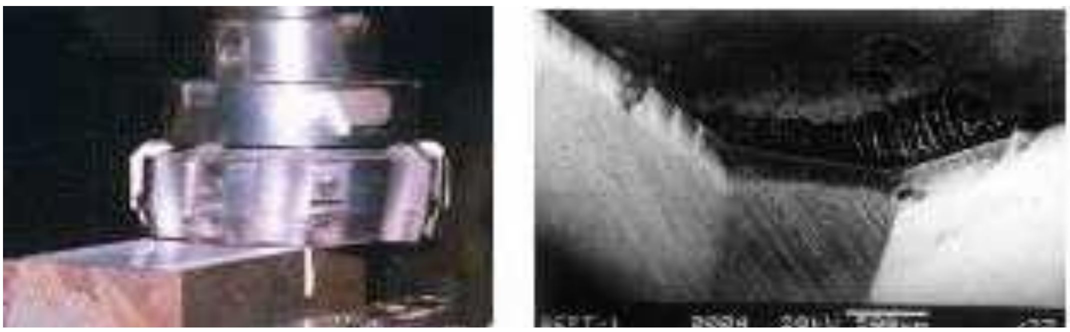
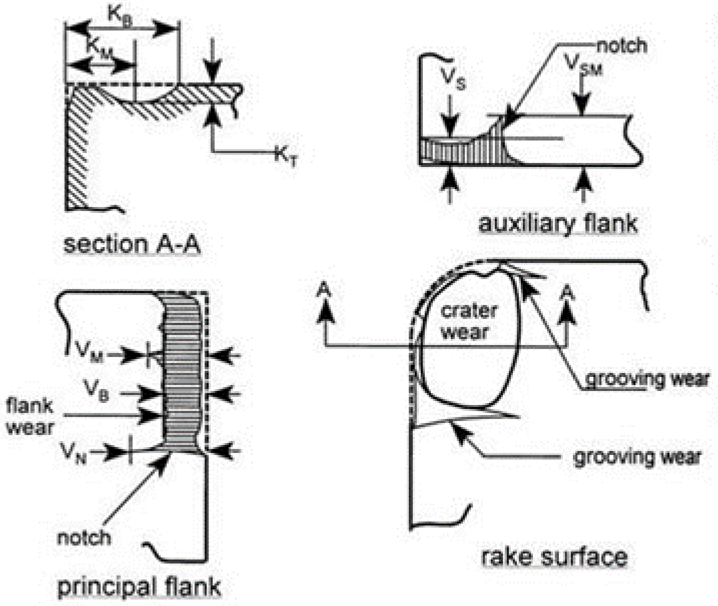


Fig. 1.49 (a) Schematic view of wear pattern of face milling insert



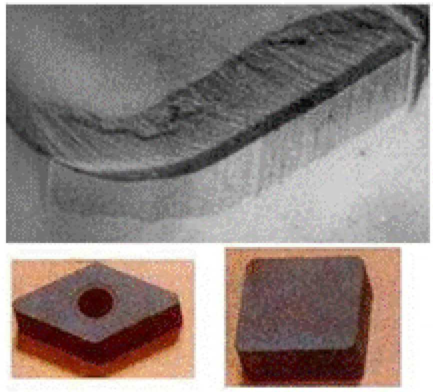


Fig. 1.49 (b) Geometry and major features of Fig. 1.49 (c)
Photographic view of the wear of turning tools wear pattern of a
turning tool insert

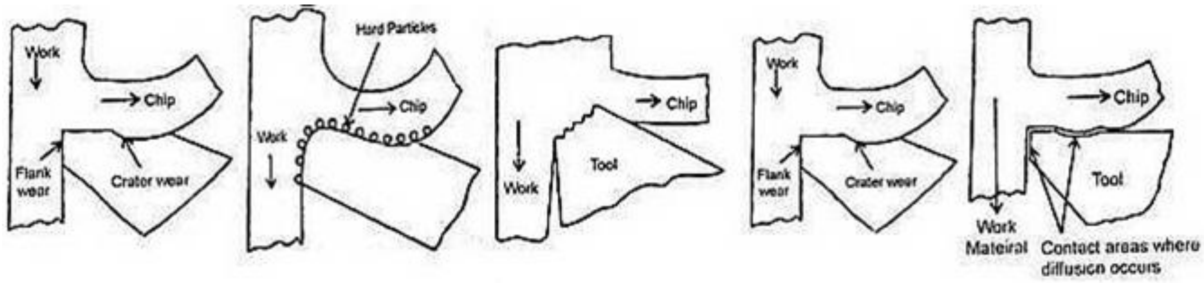


Fig. 1.49 (d) Different types of wears of turning tools

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

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

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.

TOOL LIFE

Definition:

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

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

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

Assessment of tool life

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

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

Taylor's tool life equation

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

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

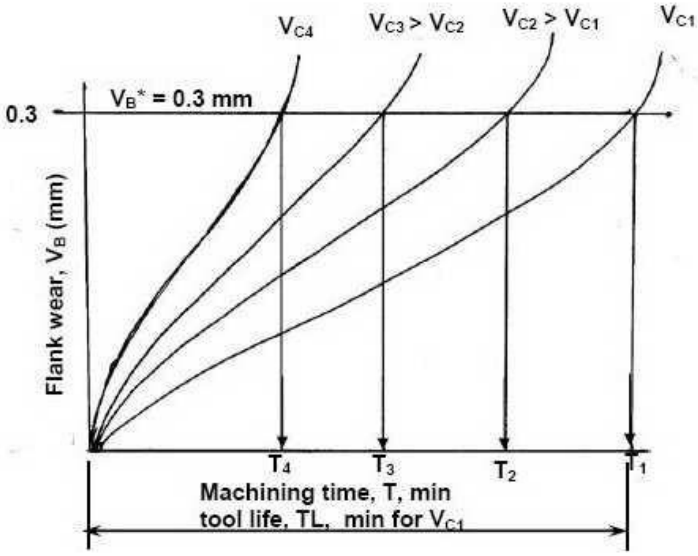
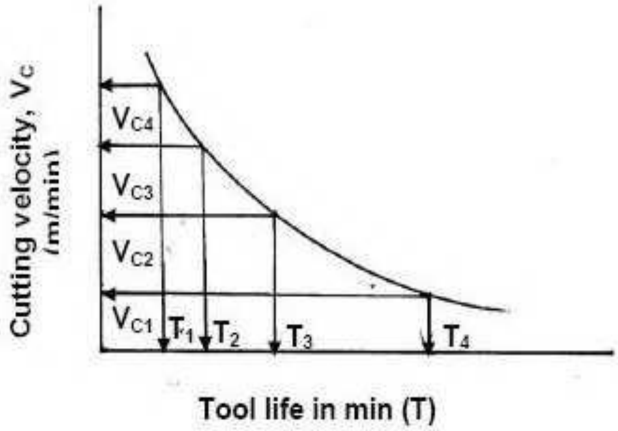


Fig. 1.50 Growth of flank wear and assessment of tool life

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



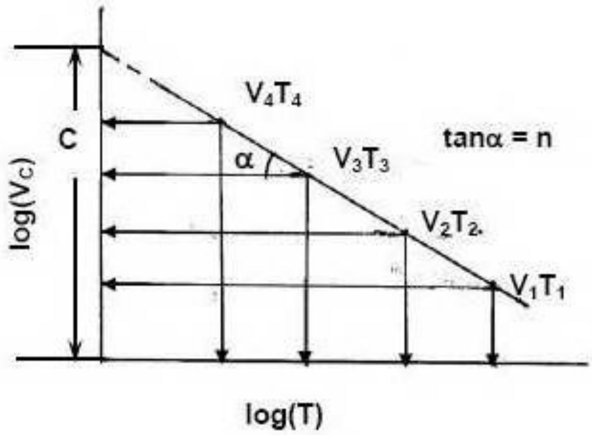


Fig. 1.51 Cutting velocity - tool life relationship

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

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

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

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,

$T = C_T / V_C^x \cdot f^y \cdot t^z$ 1.54

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

Effect of tool geometry on tool life

The tool life is also affected by tool geometry. The nose radius (R) tends to improve tool life and is evident from the relation:

$V_C T^{0.0927} = 331 R^{0.244}$ 1.55

Effect of side cutting edge angle on tool life

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

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

Tool life in terms of metal removal

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

Cutting speed $V_C = \pi DN / 1000$ m/min 1.57
where D - Diameter of work piece (mm).
N - Rotation speed of work piece (rpm).
Let t - Depth of cut (mm).
f - Feed rate (mm/min).
t_{tf} - Time of tool failure (min).
T - Tool life in 1 mm^3 of metal removal.

Volume of metal removed per revolution = $\pi.D.t.f$ mm^3 1.5

Volume of metal removed per minute = $\pi.D.t.f.N$ mm^3 1.5

Volume of metal removed in 't_{tf}' minute = $\pi.D.t.f.N.t_{tf}$ mm^3 1.6

Therefore, Volume of metal removed between tool grinds = $\pi.D.t.f.N.t_{tf}$ mm^3 1.6

$T = \pi.D.t.f.N.t_{tf}$ mm^3 = $1000.V_C.t.f.t_{tf}$ mm^3 1.6

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

1.6

Factors affecting tool life

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

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

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.

Machinability rating (MR) = [(C. Speed (fpm) of machining the work giving 60 min tool life / C. Speed(fpm)of machining the standard metal giving 60 min s tool life)X100] 1.64

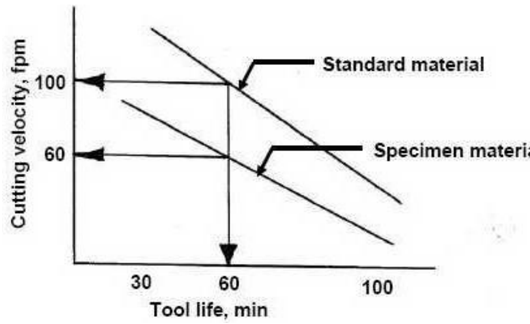
The free cutting steel, AISI - 1112, when machined (turned) at 100 fpm, provided 60 min of tool life. If the work material to be tested provides 60 min of tool life at cutting velocity of 60 fpm (say), as indicated in Fig. 1.53, under the same set of machining condition, then machinability (rating) of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

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

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

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

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



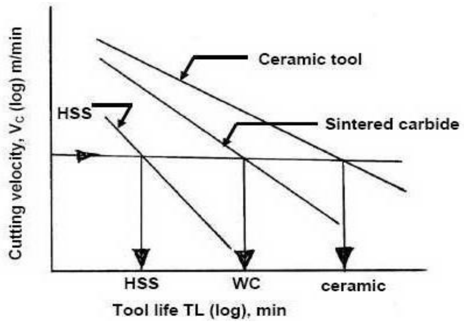


Fig. 1.53 Machinability rating in terms of material cutting velocity giving 60 min tool life

Fig. 1.54 Role of cutting tool on machinability (tool

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

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

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

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

Role of the properties of the work material on machinability
The work material properties that generally govern machinability in varying extent are:

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

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

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

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

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

Depth of cut

Lighter cuts provide good surface finish to the work piece. If depth of cut increases during machining, the quality of surface finish will reduce.
Therefore, higher cutting speeds, fine feeds and low depth of cuts or applied to ensure good surface finish. Usually, it is done in finishing cuts. But, lower cutting speeds, coarse feeds and heavier depth of cuts are applied in rough cutting operations.

CUTTING FLUIDS

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 flash point.
- High resistance to bacterial growth.
- Odourless and also preferably colourless.

- Non toxic in both liquid and gaseous stage.
- Easily available and low cost.

Principles of cutting fluid action

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

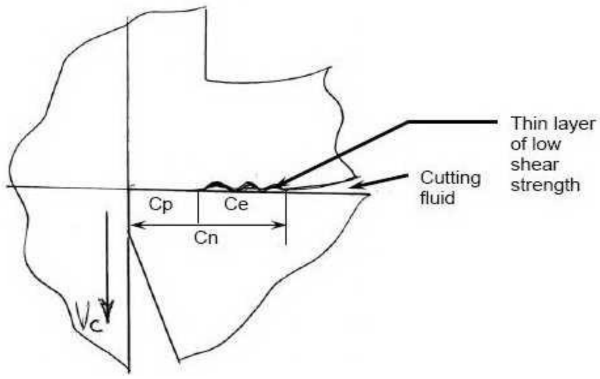


Fig. 1.55 Cutting fluid action in machining

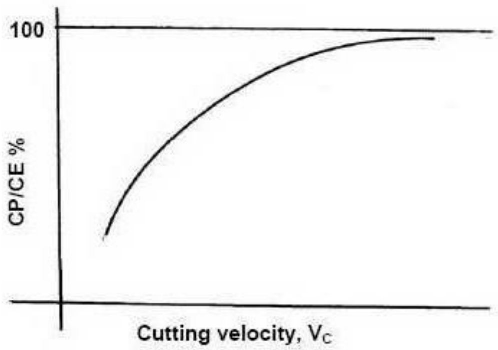


Fig. 1.56 Apportionment of plastic and elastic contact zone with increase in cutting velocity The cutting fluid cannot penetrate or reach the plastic contact zone but enters in the elastic contact zone by capillary effect. With the increase in cutting velocity, the fraction of plastic contact zone gradually increases and covers almost the entire chip-tool contact zone *as indicated in Fig. 1.56.*

Therefore, at high speed machining, the cutting fluid becomes unable to lubricate and cools the tool and the job only by bulk external cooling.

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

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

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

Types of cutting fluids and their application

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

The cutting fluids, which are commonly used, are:

Air blast or compressed air only

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

Solid or semi-solid lubricant

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

Water

For its good wetting and spreading properties and very high specific heat, water is considered as

the best coolant and hence employed where cooling is most urgent.

Soluble oil

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

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

Cutting oils

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

Chemical fluids

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

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

Cryogenic cutting fluid

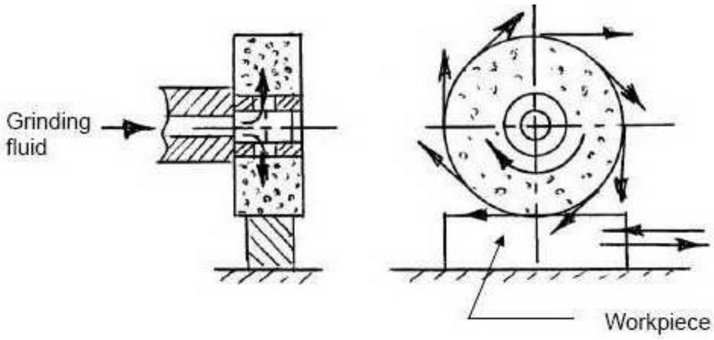
Extremely cold (cryogenic) fluids (often in the form of gases) like liquid CO_2 or N_2 are used in some special cases for effective cooling without creating much environmental pollution and health hazards.

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.*



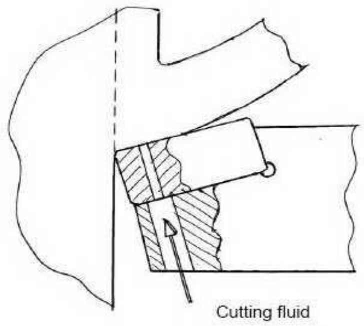


Fig 1.57 Z-Z method of cutting fluid application in grinding

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.

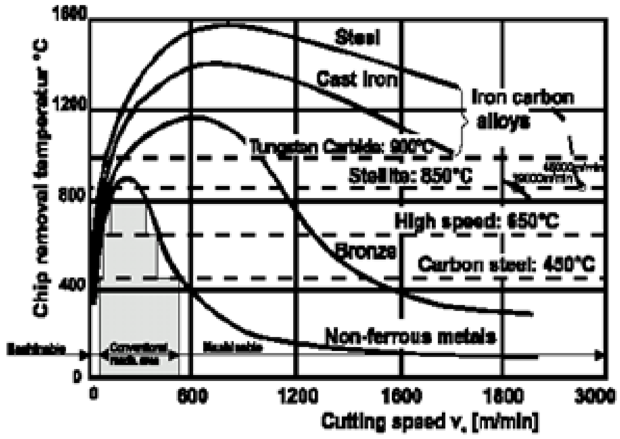
Grinding at high speed needs cooling (1: 50 ~ 100) soluble oil. For finish grinding of metals and alloys low viscosity neat oil is also used.

HIGH SPEED MACHINING

Definitions :

“HSM is a powerful machining method that combines high feed rates with high spindle speeds, specific tools and specific tool motion.”

- High cutting speed machining, High rotational speed machining, High feed machining, High speed and feed machining, High productive machining
- Carl Salomon assumes that “At a certain cutting speed which is 5-10 times higher than in conventional machining the chip removal temperature at the cutting edge will start to decrease”.



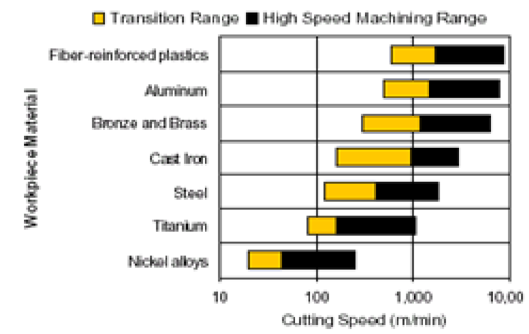


Fig. 1 High-speed cutting ranges in machining of various materials [3]

CUTTING TOOLS

- TiN and TiCN coated Carbide for materials with hardness less than 42 HRC
- TiALN coated Carbide for materials with hardness 42 HRC and above
- For special applications like hard turning (HRC 60-65) PCBN is used
- Cubic boron nitrite (CBN) and ceramic for cast iron
- Poly crystalline diamonds (PCD) and Cermets are used for aluminum

Advantages

- High material removal rate, High surface finish, Increased productivity,
- Possibility of machining of very thin walls,
- Reduction in lead times, Reduction of production process, Low cutting force,
- It eliminates the need of coolant, Cutting tool and work piece temperature are kept low, Connection time between the cutting edge and work piece is short

Disadvantages

- Need for expensive and special machine tools with advanced spindle and controllers

- Excessive tool wear
- Good work and process planning necessary
- It can be difficult to find and recruit advanced staff

Applications

- Industry which deals with the machining of Al to produce automotive components, small computer parts or medical devices,
- Aircraft industry involves machining of Al often with thin walls, Die mould industry which requires dealing with finishing of hard materials.
- Used to machine such parts as die casting dies, forging dies, injection moulds and blow moulds, milling of electrodes in graphite and copper, modeling and prototyping of dies and moulds.

FEATURES	EFFECTS
Reduced heat transfer in to the work piece	Part accuracy
Reduction of cutting forces	Part accuracy, Surface quality
Increased cutting speed	Stability of rotating, cutting tool feed rate, Increased material removal

RECOMMENDED PARAMETERS

1.True cutting speed

As the speed is dependent on both spindle speed and diameter of tools

HSM should be defined as “true cutting speed” above a certain level

2.**Material removal rate**

$$Q = (a_p * a_e * v_f)/1000 \ \ cm^3/min$$

where a_p = vertical dist from tool tip to the reference point mm

a_e = step over distance mm, v_f = feed speed mm/min

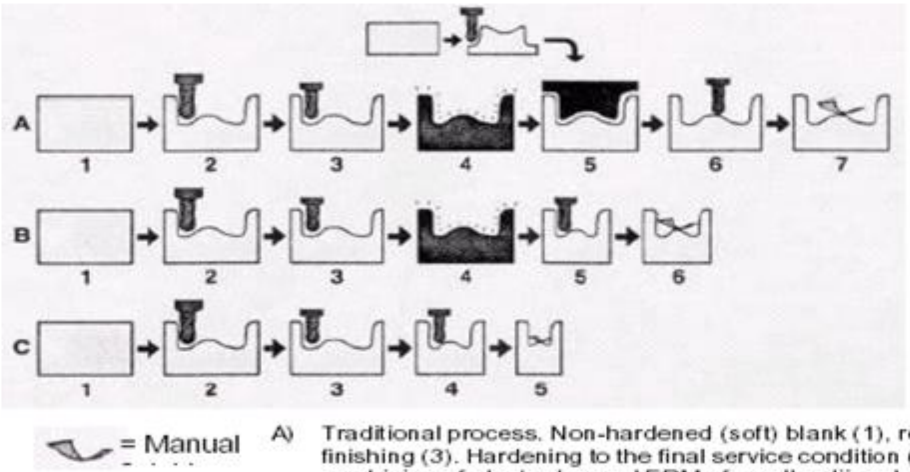
3. Surface finish

Surface finish is depends upon cutting tool geometry, coating of the cutting tool, wear status of the cutting tool etc.

$$R_{th} = \frac{D}{2} - \sqrt{\frac{D^2 + a_e^2}{4}}$$

- HSM is not simply high cutting speed .It should be regarded as a process where the operations are performed with very specific methods and precision equipment
- HSM is not necessarily high spindle speed machining. Many HSM applications are performed with moderate spindle speeds and large sized cutters
- HSM is performed in finishing in hardened steel with high speeds and high feeds often with 4-6 times conventional cutting speeds
- HSM is high productive machining in small sized components in roughing to finishing and in finishing to super finishing in components of all sizes.
- Even though HSM is known for a long time, the research are still being developed for further improvement of quality and optimization of cost.

Conventional machine	High speed machine
Max speed 600 m/min	Speed starts at 600 m/min
Max feed ~40 ipm	Feed starts at 100 ipm
Require high levels coolant	With coolant ,feed rate can go more than 2000 ipm No need for coolant for low feed rate
HSM	**EDM**
Material removal rate high	Material removal rate is low
Dimensional tolerance 0.02 mm	Dim tolerance 0.1- 0.2 mm
There is no need of making cutting tool according to the contour to be machined	Cutting tool has to be made according to the contour to be machined

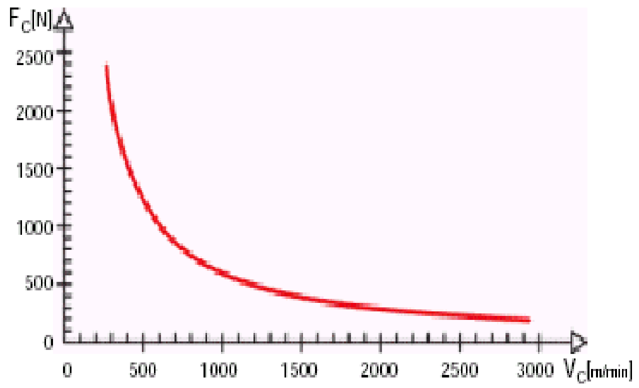


A) Traditional process. Non-hardened (soft) blank (1), roughing (2) and semi-finishing (3). Hardening to the final service condition (4). EDM process – machining of electrodes and EDM of small radii and corners at big depths (5). Finishing of parts of the cavity with good accessability (6). Manual finishing (7).

B) Same process as (A) where the EDM-process has been replaced by finish machining of the entire cavity with HSM (5). Reduction of one process step.

C) The blank is hardened to the final service condition (1), roughing (2), semi-finishing (3) and finishing (4). HSM most often applied in all operations (especially in small sized tools). Reduction of two process steps. Normal time reduction compared with process (A) by approximately 30 – 50%.

Fig. 2. Improvement of production process when using HSM [2].



Cutting force (F_c) vs cutting speed (v_c) for a constant cutting power of 10 kW. $F_c = \frac{P_c}{V_c}$

DRY MACHINING

Introduction

Manufacturing activity is a major consumer of energy and natural resources. In machining process, a large amount of heat is produced whose removal requires the use of suitable cooling agents or cutting fluids. These cutting fluids are a major source of waste generation and environmental damage.

To eliminate hazardous cutting fluids during machining operations, researchers have tried machining components without applying cutting fluids, which is known as dry machining.

Purpose of using Cutting Fluid

Metal Working fluids

- Removal of heat generated during Cutting, Removal of chips, Reduction of tool wear
- Better surface finish, Conventional Wet Machining
- Conventional wet machining process involves use of cutting fluid

Cost of Wet Machining

Environmental pollutions and health hazards.¬ Need of storage, additional floor space, pumping system, recycling and disposal ¬ Corrosion and contamination of the lubricating system ¬ Wetting and dirtiness ¬ Major Problems with Conventional Process

Dry Machining

Challenges Dry machining often causes excessive temperature rise leading to poor tool life and machined surface damage.

The main issues which restricts the practical implementation of dry machining are

1. Tool Life

2. Work-piece Geometrical Accuracies

3. Work-piece Surface Integrity

4. Machinability of Materials

1.Tool life:

Average temperature near cutting tool edge is much higher ¬

It causes softening of tool cutting edge since the tool materials lose their hardness at elevated temperature.

2. Work-piece Geometrical Accuracies

Heat retention in work piece material

Retained heat cause thermal deformations in machined parts

3. Work-piece Surface Integrity

Excessive heat built up during dry machining raises the temperature of the surface layer to level where phase transformation and microstructure alteration.

It also cause the formation of hard layer on surface (white layer when observed under microscope)

4.Machinability of Materials

Most commonly used metals in engineering applications are LCS, MCS, Austenitic stainless steel, CI, nickel, titanium, copper and aluminium alloys etc.

Some of these materials exhibits difficulties in machining without aid of cutting fluids due to excessive generation of heat and high interfacial temperature. ¬

Strategies and Solution for Successful Dry Machining

1. Tool Materials

2. Tool Coatings

3. Hybrid Machining

4. MQL Machining

5. Cryogenic Machining

6. Under-Cooling Machining

7. Internal cooling by a vapourisation system

8. Thermoelectric Cooling System

1.Tool Materials

¬ Dry cutting typically results in elevated tool temperature as compared to wet machining

Primary requirement of a suitable tool for dry machining is the ability to retain hardness at high temperature or hot hardness. The tool should be able to resist high stresses

Most widely used tool materials in dry machining are:

a. Carbide of tungsten, titanium and tantalum

b. Ceramics

c. Cubic boron nitride

d. Diamond

A. Carbide of tungsten, titanium and tantalum grain size in range 10µm- 1µm, high hot hardness and wear resistance
B. Ceramics

high hardness and wear resistance ¬ withstand at higher temperature and retain the sharpness of cutting edge for longer duration even at elevated temperature ¬ suitable for high speed dry machining

C. Cubic Boron Nitride

high wear resistance, chemically inert at high temperature, harder than cemented carbide and ceramics at high temperature

D. Diamond

very high wear resistance to abrasive wear , high thermal conductivity, hardest material

2. Tool Coatings

coating helps to reduce friction at tool-work interface and hence compensate for lubricating effects of cutting oils,coatings are made from hard materials such as TiN, TiCN, CrN, CBN and Diamond

a. Multilayered nano-coatings : avoid catastrophic fracture

b. Self lubricating coatings

c. cubic boron nitride and diamond coatings

3. Hybrid Machining

a. Vibration assisted machining

b. laser and plasma assisted machining

4. MQL Machining

Very small quantity of lubricant is applied to the cutting area in the form of drops or as a mixture with compressed air or other gasses, forming a fine spray. Normal consumption of cutting oil is restricted in the range 10-100 ml per hour

5.Cryogenic Machining

Machining with liquid nitrogen at cryogenic temperatures at about -196ºC

Liquid nitrogen evaporates into the air as it comes in contact with the tool and work-piece leaving no trace of any harmful agents

It provides an excellent cooling effect in machining due to its very low temperature

6.Under-cooling System

The coolant flows through channels located under the insert, then out to the environment, without any direct contact with the cutting zone

7.Internal cooling by a vapourisation system

In which a vapourisable liquid is introduced inside the shank of the tool and vapourised on the underside surface of the insert

8.Thermoelectric cooling systems

Using a module of couples of thermoelectric material elements. When an electric current is passed through the thermoelectric elements, a cold junction and a hot junction is produced at the opposite ends of each of these elements.

Application of Dry Machining Technology

1. Machining of different work piece materials in dry and semi dry conditions

Nickel and Titanium alloys¬ Alloy steels ¬ Aluminium alloys ¬

Cast iron ¬ Copper alloys ¬ Magnesium and its alloys ¬

2. Adaptation of machining processes for dry and MQL machining

Grinding ¬ Drilling ¬ Turning ¬ Milling ¬

Advantages

- Reduction in overall production time and improved working conditions
- High cutting speeds can be achieved with improved surface finish
- It eliminates cost involved in purchase, storage, handling, utilizing and safe disposal of the fluid
- Complete elimination of harmful cutting fluid

Green machining is desirable for environment and it will be considered as a need in the upcoming future for manufacturing companies. For the protection of environmental laws and health regulations industries will be forced to consider dry machining. The benefits of dry machining includes: non-pollution of the atmosphere (or water); no left over on the swarf which will be displayed in reduced disposal and cleaning costs; no threat to health; and it is non-injurious to skin and is allergy free. And it also offers cost reduction in machining as shown in fig. 1.

Fig. 1. Benefits of green machining.

Hence to reduce manufacturing costs dry machining has to be implemented. Cutting fluids play a very important role in manufacturing industry, for the removal of heat which is generated because of friction during cutting; to get better tool life, surface finish and dimensional tolerances; to stop the formation of built-up edge and to facilitate the transportation of chips. It is dependent on the work piece, the production structure, and the location of the production the costs related to the need of cooling lubricants vary from 7 - 17% of the overall costs of the produced work piece. By discarding conventional cooling lubricants and making the use of technologies of dry machining or minimum quantity lubrication (MQL), this cost component can be minimized significantly.

In machining process there is a relative motion between cutting tool and work piece, there is friction as well as heat is generated in the cutting zone. Cutting fluids are used to control friction, minimize the cutting temperature, prevent adhesion between work piece and tool and clear away chips.

Toxic vapours are caused by cutting fluids, unpleasant odours, smoke fumes, skin irritations and its bacteria has its effects on environment and operator. Mist lubrication is used in manufacturing industries to minimize cutting fluids and were beneficial to some extent. However mist in the manufacturing environment may have serious respiratory effect on the operator. The high temperature hardness and wear resistance of cemented carbides, ceramics, CBN and PCD based cutting tool materials make these materials eminently suitable for use in dry cutting operations. These materials are thus highly suitable for dry machining operations. A dry cutting process must be designed to minimize the amount of heat flowing into the part. This may be achieved by minimizing the cutting forces, and also by influencing the heat distribution. Cutting forces can be reduced by positive cutting edge geometries, while heat distribution towards the part may be positively influenced by using high cutting speeds. Temperature distribution on the tool-chip interface was attributed to the primary heat source due to shear deformation in the shear zone and secondary heat source due to friction on the tool-chip interface as specified in a moving oblique heat source model or a stationary square heat source model. For example, the heat generated by the friction on the tool-chip interface was considered as a moving heat source for any fixed point in the chip, while it was considered as a stationary heat source for any fixed point in the tool. Near dry machining refers to the use of a very small amount of cutting fluid in the machining process, typically on the order of 100 ml/h, which is about ten-thousandths of cutting fluid used in flood-cooling machining. The concept of near dry machining, also known as "minimal quantity lubrication" or"extremely low quantity of lubricant" was regarded as a solution to the negative impact of the cutting fluids on the environment.

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UNIT - II

MANUFACTURING TECHNOLOGY II – SPR1301

UNIT – II

CENTRE LATHE AND SPECIAL PURPOSE LATHES

Centre lathe – Constructional features – Cutting tool geometry – Various operations – Taper turning methods – Thread cutting methods – Special attachments – Machining time and power estimation –Capstan and turret lathes – Automats – Single spindle – Swiss type – Automatic screw type – Multi spindle – Turret Indexing mechanism – Bar feed mechanism.

CENTRE LATHE

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

Classification of lathes

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

According to configuration:

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

According to purpose of use:

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

According to size or capacity:

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

According to configuration of the jobs being handled:

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

According to precision:

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

According to number of spindles:

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

According to type of automation:

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

According to degree of automation:

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

CONSTRUCTIONAL FEATURES

Major parts of a centre lathe

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

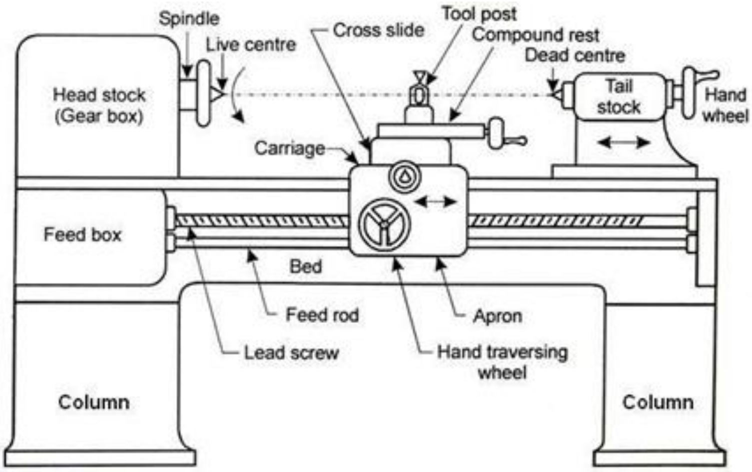


Fig. 2.1 shows the basic configuration of a center lathe. The major parts are:

Fig. 2.1 Schematic view of a center lathe

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

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

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

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

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

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

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

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

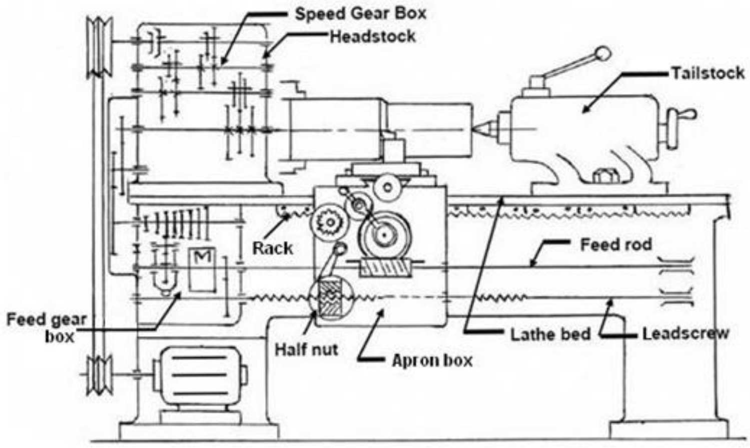
Apron Lower part of the carriage is termed as the apron. It is attached to the saddle and hangs in front of the bed. It contains gears, clutches and levers for moving the carriage by a hand wheel or power feed.

Feed mechanism The movement of the tool relative to the work piece is termed as “feed”. The lathe tool can be given three types of feed, namely, longitudinal, cross and angular.
When the tool moves parallel to the axis of the lathe, the movement is called longitudinal feed. This is achieved by moving the carriage.
When the tool moves perpendicular to the axis of the lathe, the movement is called cross feed. This is achieved by moving the cross slide.
When the tool moves at an angle to the axis of the lathe, the movement is called angular feed. This is achieved by moving the compound slide, after swiveling it at an angle to the lathe axis.

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

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

Kinematic system and working principle of a centre lathe



F

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

Fig. 2.2 Kinematic system of a 12 speed centre lathe
For machining in machine tools the job and the cutting tool need to be moved relative to each other. ***The tool-work motions are:***

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

In lathes: Cutting motion is attained by rotating the job and feed motion is attained by linear travel of the tool either axially for longitudinal feed or radially for cross feed.
It is noted, in general, from Fig. 2.2. The job gets rotation (and power) from the motor through the belt- pulley, clutch and then the speed gear box which splits the input speed into a number (here 12) of speeds by operating the cluster gears.
The cutting tool derives its automatic feed motion(s) from the rotation of the spindle via the gear quadrant, feed gear box and then the apron mechanism where the rotation of the feed rod is transmitted:

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

While cutting screw threads the half nuts are engaged with the rotating lead screw to positively cause travel of the carriage and hence the tool parallel to the lathe bed i.e., job axis.
The feed-rate for both turning and threading is varied as needed by operating the Norton gear and the Meander drive systems existing in the feed gear box (FGB). The range of feeds can be augmented by changing the gear ratio in the gear quadrant connecting the FGB with the spindle.
As and when required, the tailstock is shifted along the lathe bed by operating the clamping bolt and the tailstock quill is moved forward or backward or is kept locked in the desired location. *The versatility or working range of the centre lathes is augmented by using several special attachments.*

Headstock driving mechanisms

There are two types of headstock driving mechanisms as follows:

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

Back geared headstock

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

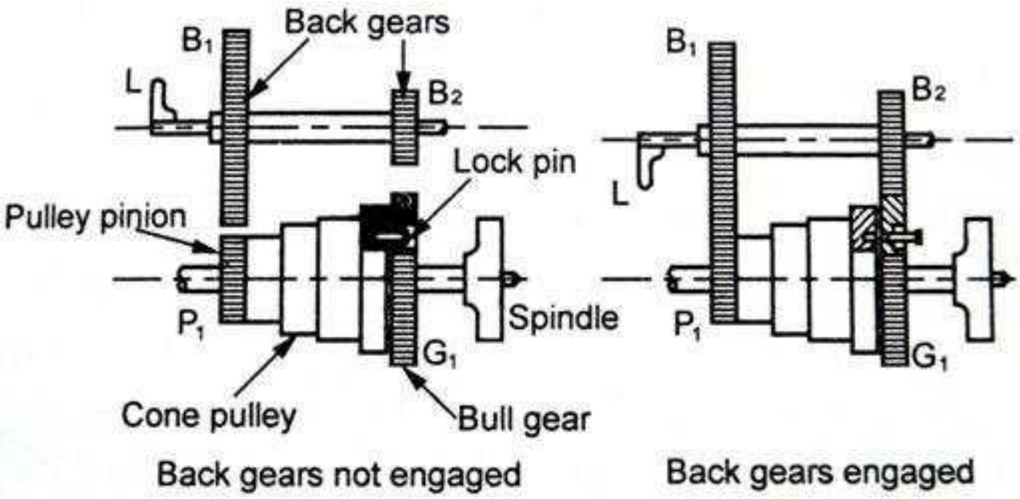


Fig. 2.3 Back gear arrangement

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

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

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

All geared headstock

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

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

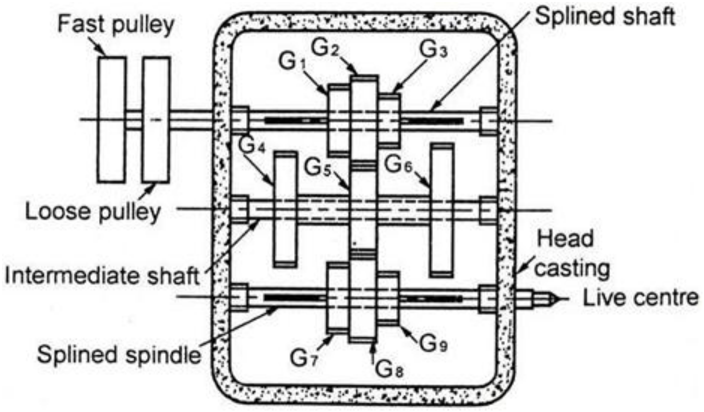


Fig. 2.4 All geared headstock

The all geared headstock is shown in Fig 2.4.

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

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

Feed mechanisms

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

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

Tumbler gear reversing mechanism

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

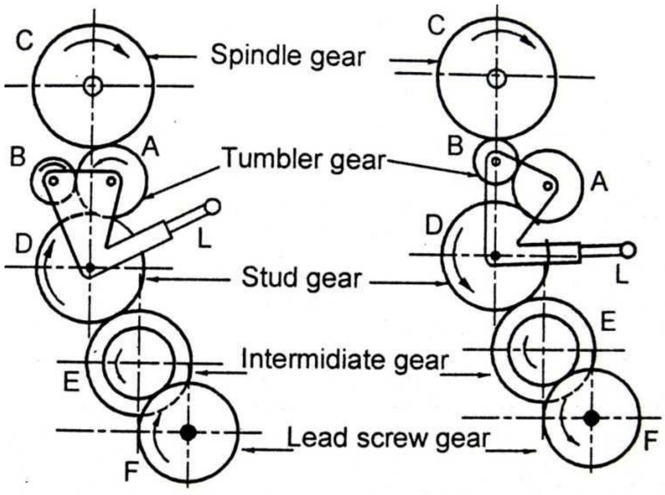


Fig. 2.5 Tumbler gear reversing mechanism

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

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

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

Quick-change gear box

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

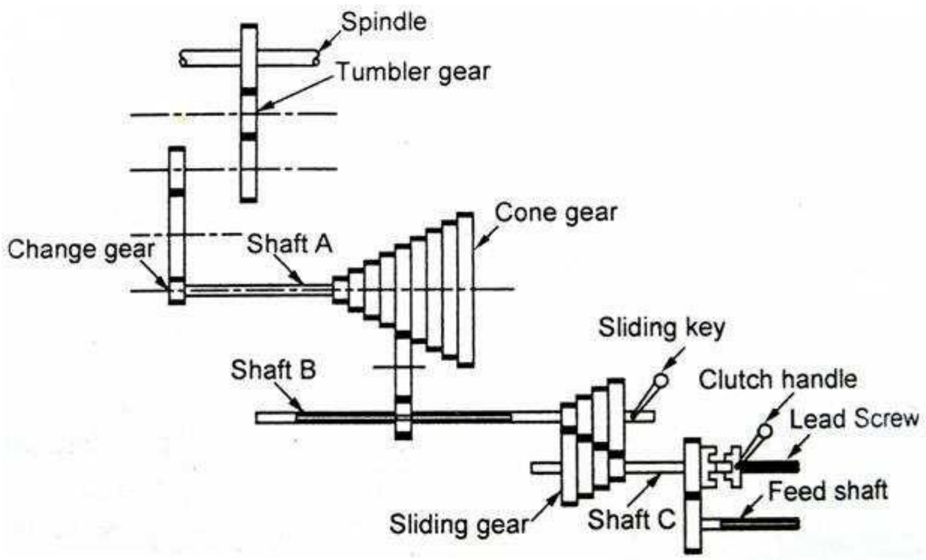


Fig. 2.6 quick-change gear box

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

Tumbler gear quick-change gear box

The different speed of the driving shaft is obtained by a tumbler gear and cone gear arrangement.

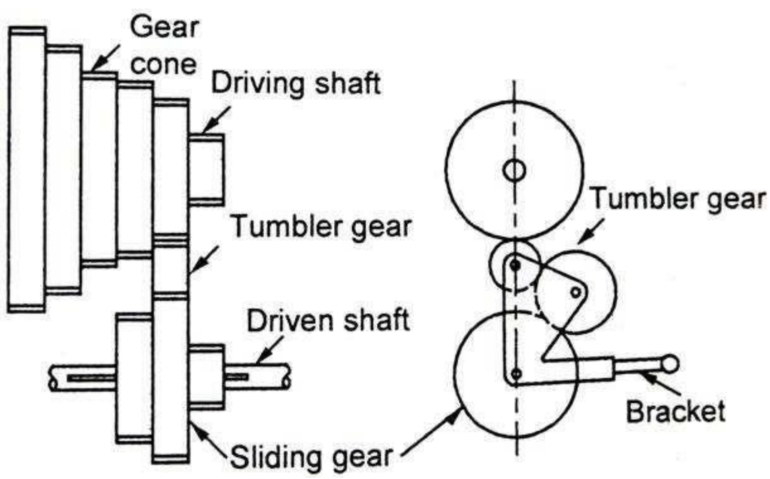


Fig. 2.7 shows the schematic arrangement of tumbler gear quick-change gear box.

Fig. 2.7 Tumbler gear quick-change gearbox

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

Apron mechanism

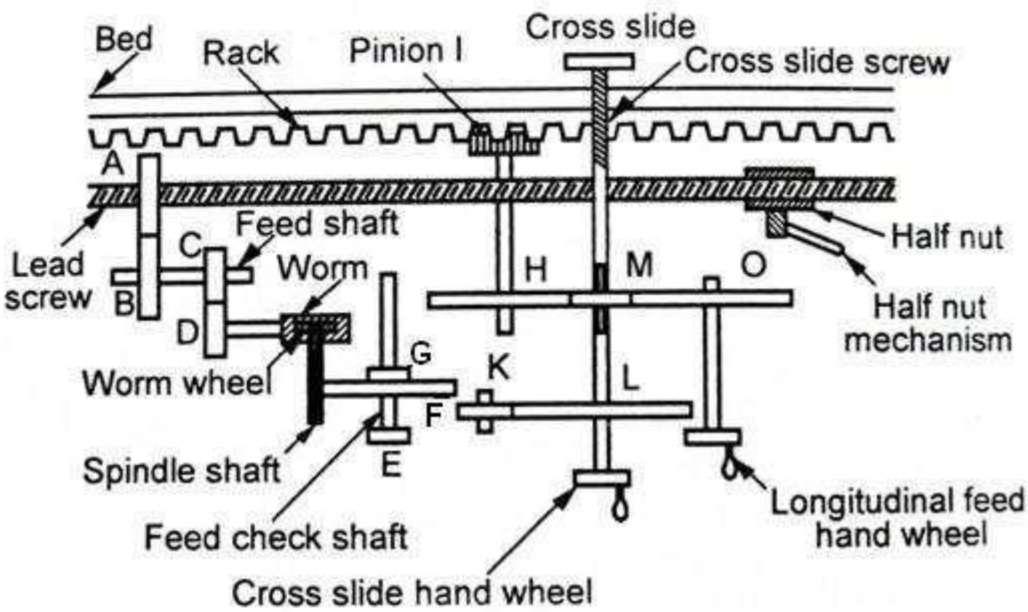


Fig. 2.8 shows the schematic arrangement of apron mechanism.

Fig. 2.8 Apron mechanism

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

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

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

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

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

Bevel gear feed reversing mechanism

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

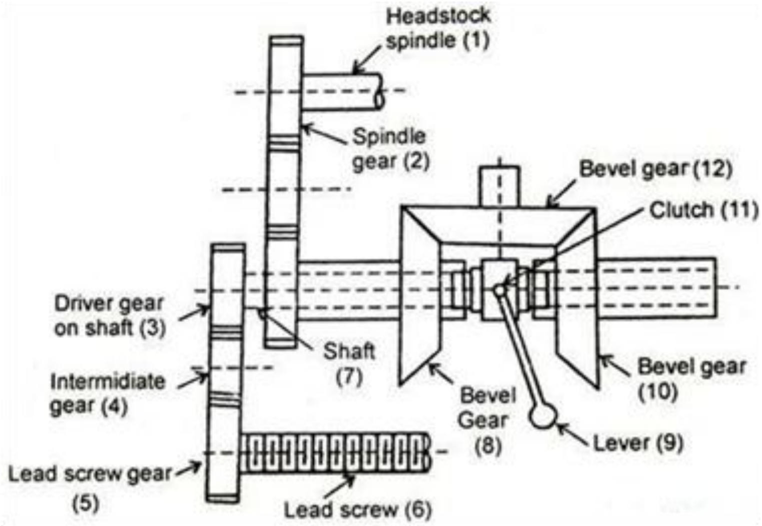


Fig. 2.9 Bevel gear feed reversing mechanism

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

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

Mounting of jobs in centre lathe

Without additional support from the tailstock

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

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

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

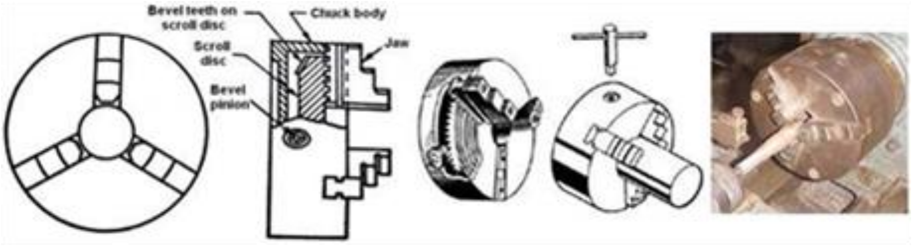


Fig. 2.10 (a) 3-jaw self centering chuck or universal chuck

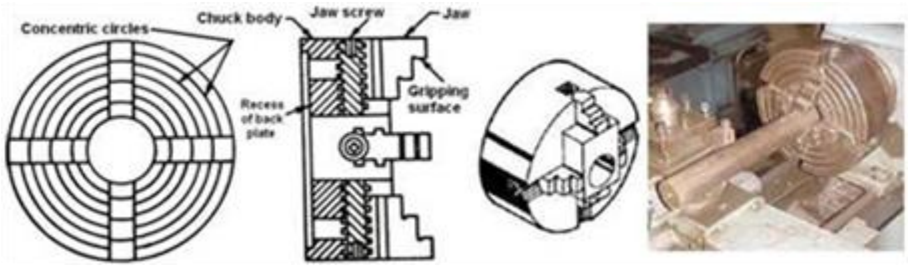
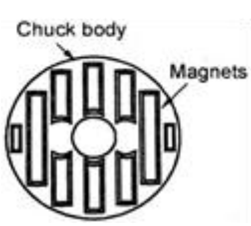


Fig. 2.10 (b) 4-jaw independent chuck

Magnetic chuck

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



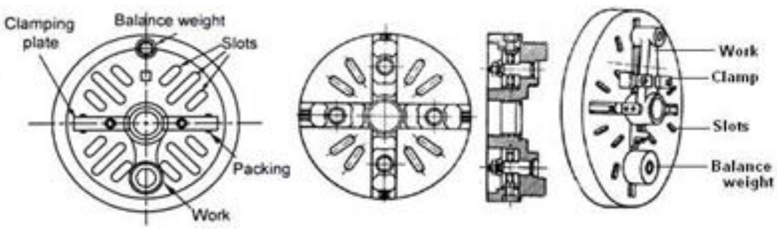


Fig. 2.11 Magnetic chuck

Fig. 2.12 Face plate

Face plate

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

Angle plate

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

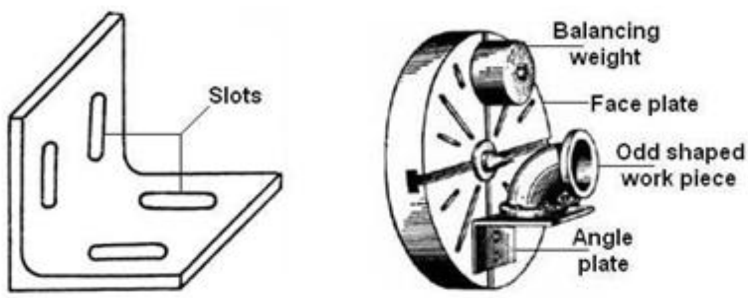


Fig. 2.13 (a) Angle plate   Fig. 2.13 (b) Angle plate used along with face plate

With additional support from the tailstock

Catch plate or driving plate

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

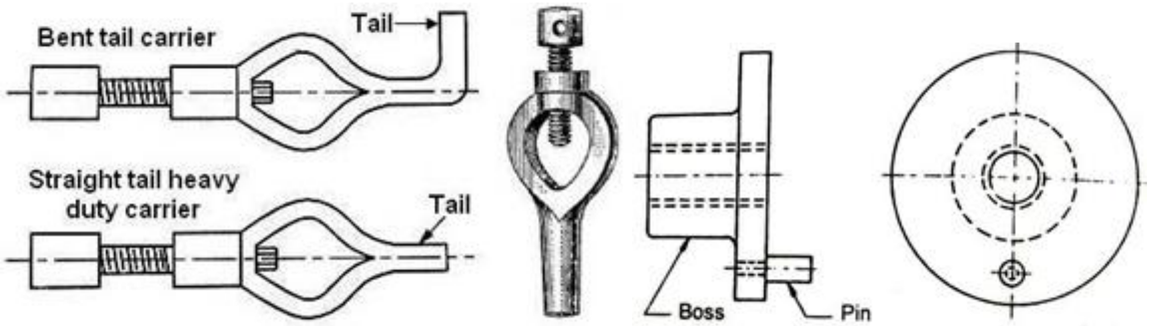


Fig. 2.14 Catch plate   Fig. 2.15 Types of carriers

Carriers or Dogs

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

Mandrels

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

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

In-between centres (by catch plate and carriers)

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

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

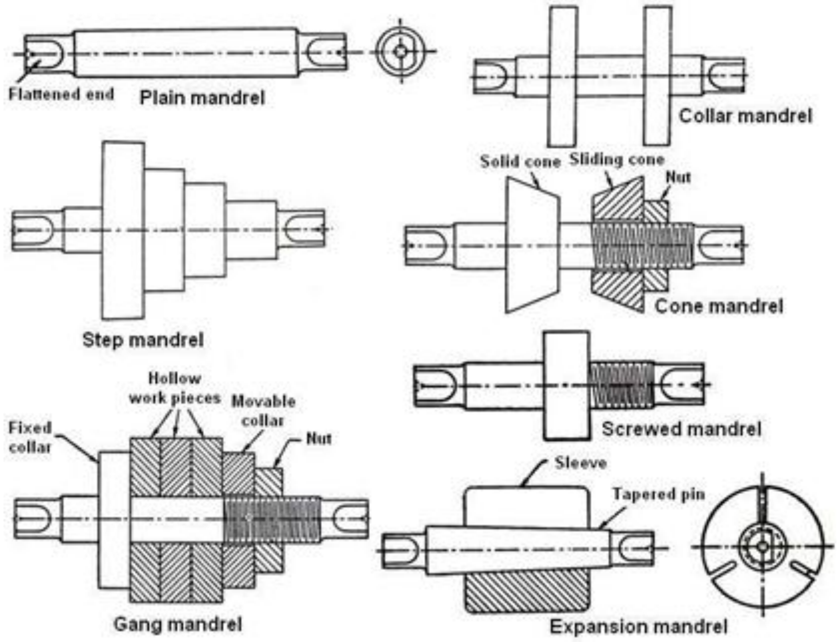


Fig. 2.16 Types of mandrels

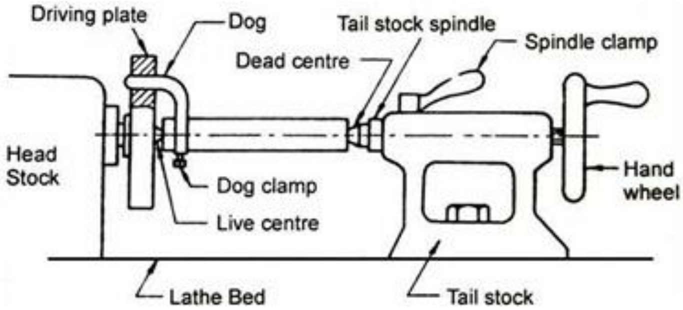


Fig. 2.17 Work held between centres

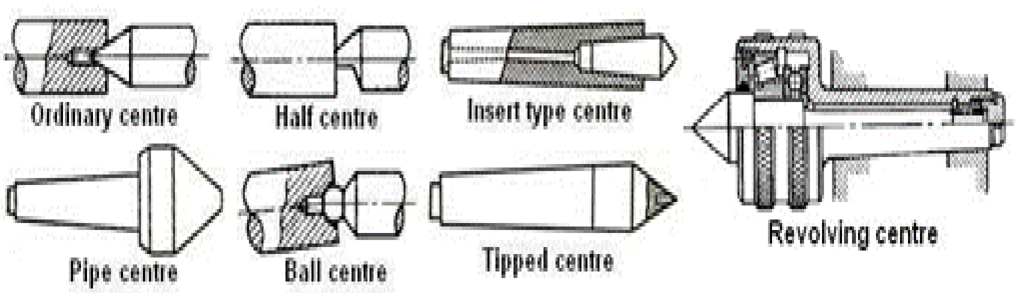


Fig. 2.18 Types of centres

Ordinary centre: It is used for general works.

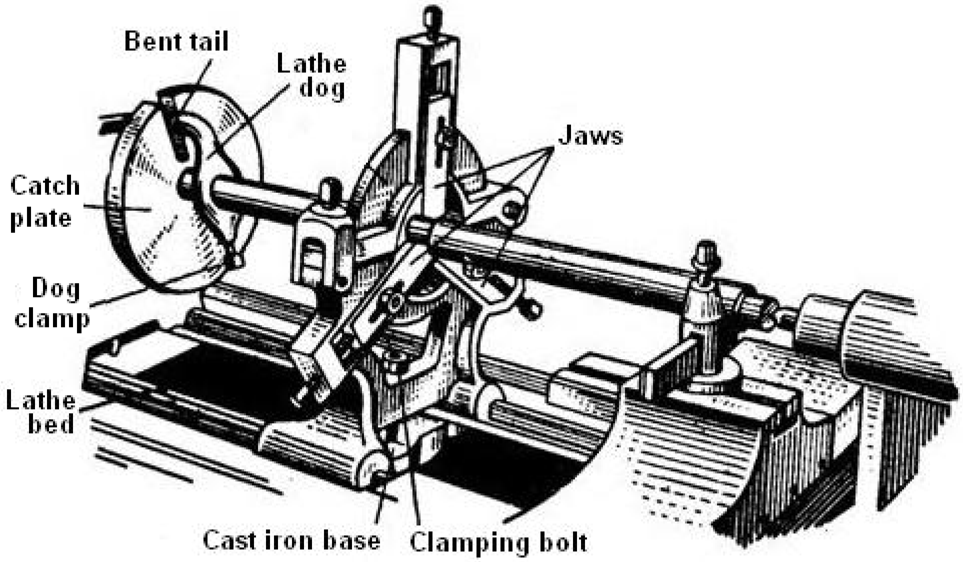
Insert type centre: In this the steel “insert” can be replaced instead of replacing the whole centre. *Half centre:* It is similar to ordinary centre and used for facing bar ends without removal of the centre. *Pipe centre:* It is used for supporting pipes and hollow end jobs.
Ball centre: It has ball shaped end to minimize the wear and strain. It is suitable for taper turning.
Tipped centre: Hard alloy tip is brazed into steel shank. The hard tip has high wear resistant.
Revolving centre: The ball and roller bearings are fitted into the housing to reduce friction and to take up end thrust. This is used in tail stock for supporting heavy work revolving at a high speed.

In-between chuck and centre

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

In-between headstock and tailstock with additional support of rest

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



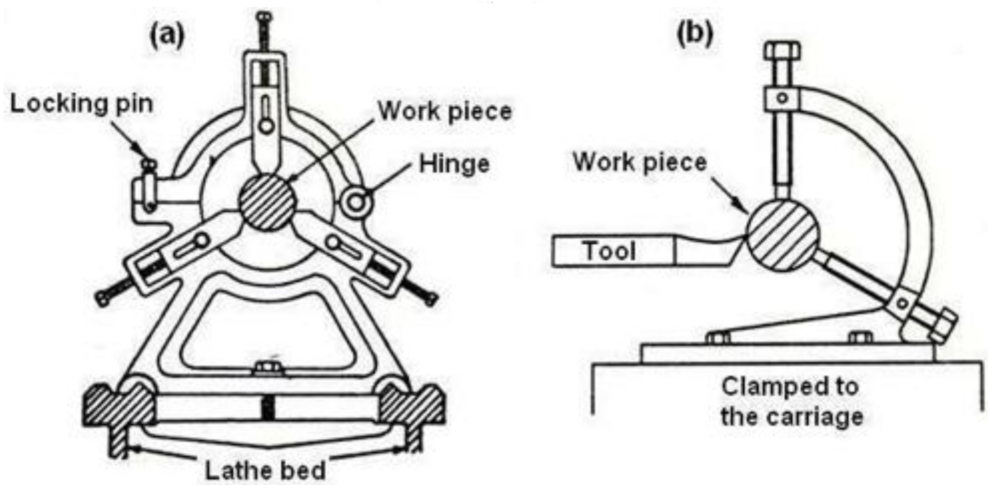


Fig. 2.20 Slender job held with extra support by steady rest
Fig. 2.21 (a) Steady rest and (b) Follower rest

Mounting of tools in centre lathe

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

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

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

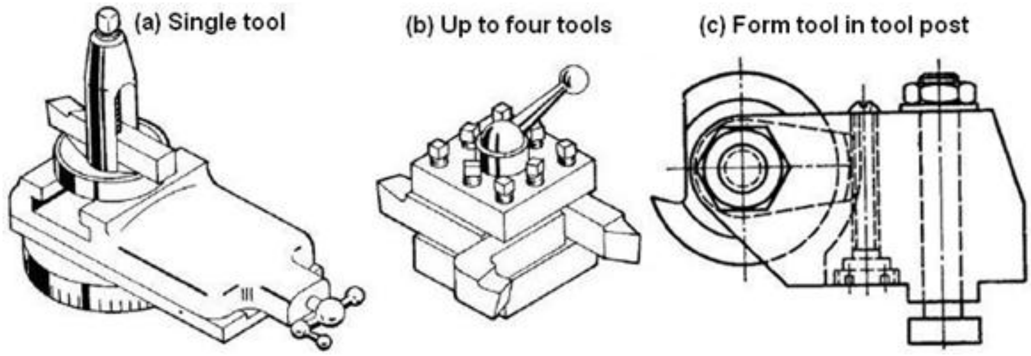


Fig. 2.22 Mounting of (a and b) shank type tools in tool post and (c) form tool in tool

post Carbide, ceramic and cermet inserts of various size and shape are mechanically

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

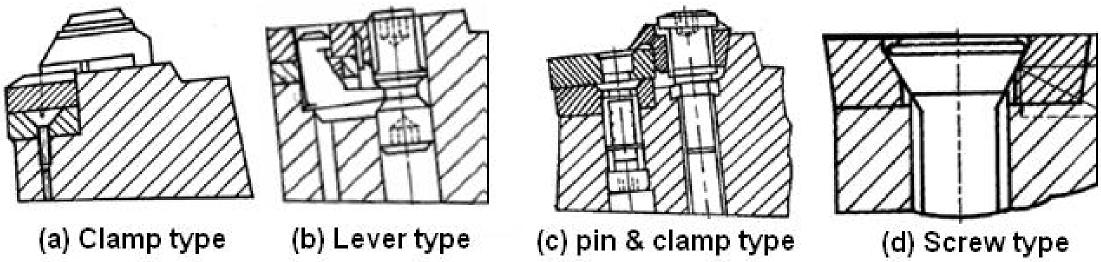


Fig. 2.23 Mounting of tool inserts in tool holders by mechanical clamping

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

Fig. 2.24 Holding drill chuck and drill in tailstock

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

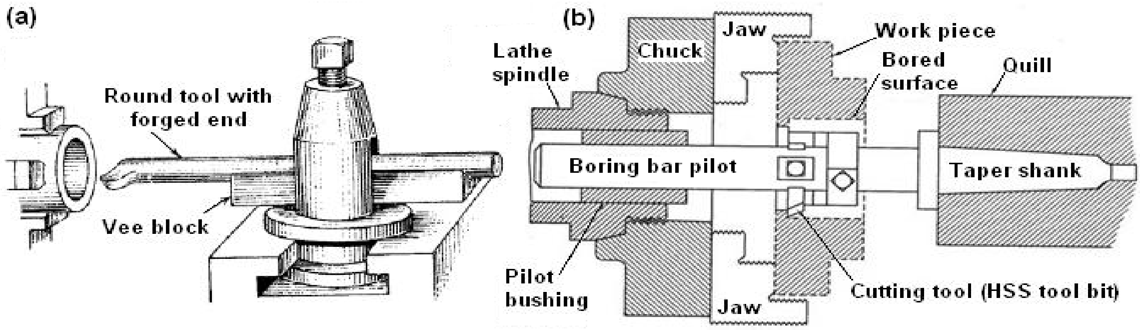


Fig. 2.25 (a) Boring tool mounted in the tool post   Fig. 2.25 (b) Precision boring in centre lathe

CUTTING TOOLS

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

According to the method of manufacturing the tool

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

According to the method of holding the tool

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

According to the method of using the tool

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

According to the method of applying feed

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

According to the method of manufacturing the tool

Forged tool

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

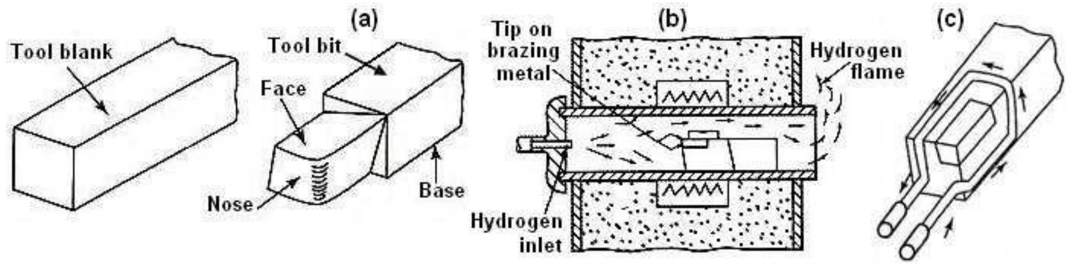


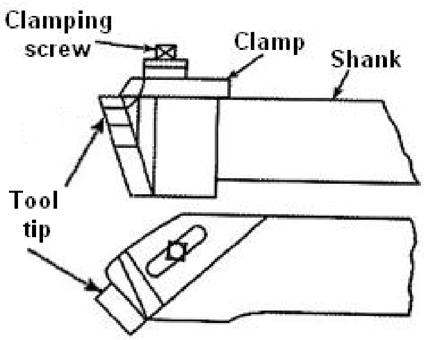
Fig. 2.26 (a) Forged tool (b) Furnace bracing of a tool tip (c) Induction brazing of a tool tip

Tipped tool brazed to the carbon steel shank

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

Tipped tool fastened mechanically to the carbon steel shank

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



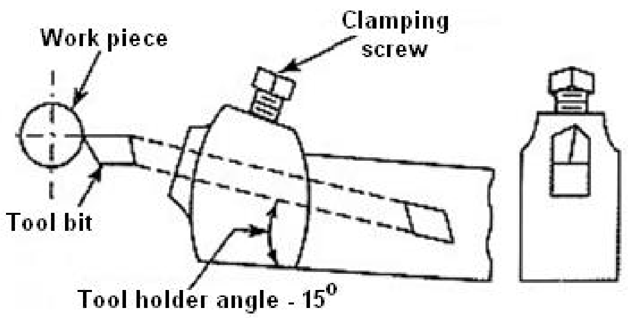


Fig. 2.27 Mechanically fastened tool tip   Fig. 2.28 Tool holder and tool bit

According to the method of holding the tool

Solid tool

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

Tool bit inserted in the tool holder

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

According to the method of using the tool

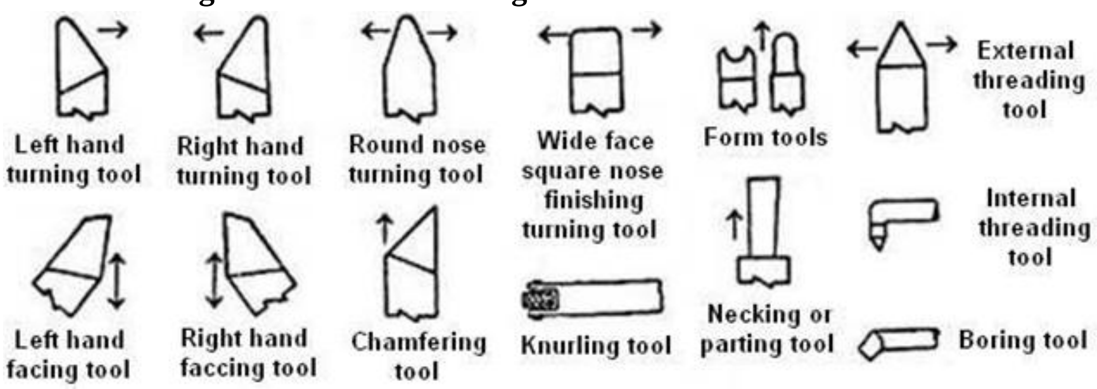


Fig. 2.29 shows the various tools used in centre lathe according to the method of using the tool.

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

VARIOUS OPERATIONS

The machining operations generally carried out in centre lathe are:

- Rough and finish turning - The operation of producing cylindrical surface.
- Facing - Machining the end of the work piece to produce flat surface.

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

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

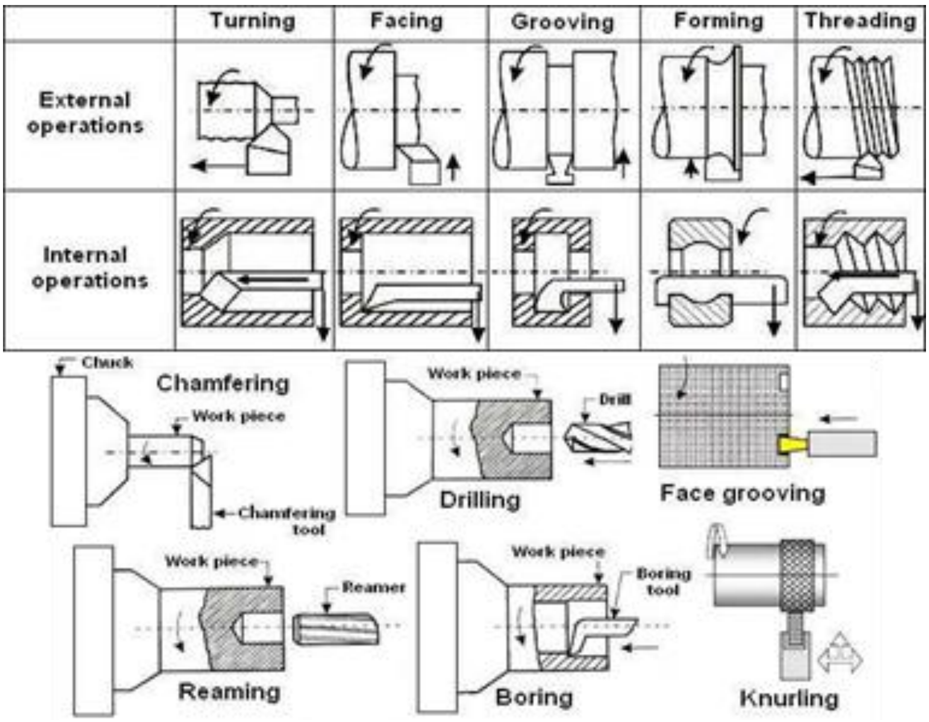


Fig. 2.30 Some common machining operations carried out in a centre lathe

TAPER TURING METHODS

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

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

Fig. 2.31 shows the details of a taper. D - Large diameter of the taper. d - Small diameter of the taper. l - Length of tapered part.

α - Half angle of taper.

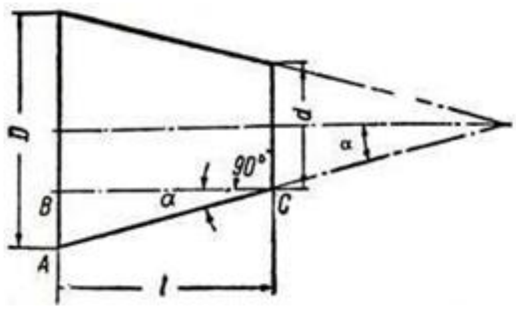
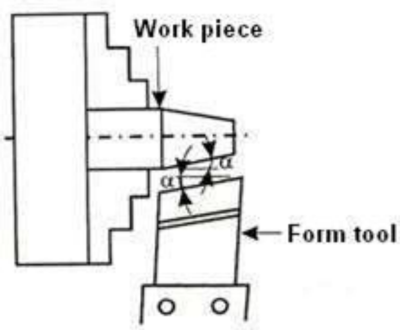


Fig. 2.31 Details of a taper Generally, taper is specified by the term conicity. *Conicity is defined as the ratio of the difference in diameters of the taper to its length.* Conicity, $K = \frac{D - d}{l}$ 2.1

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.



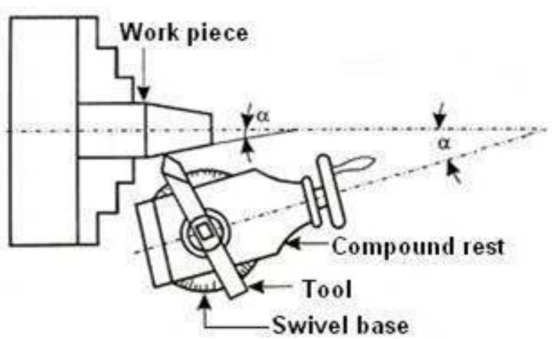


Fig. 2.32 Taper turning by a form tool Fig. 2.33 Taper turning by swiveling the compound rest

Taper turning by swiveling the compound rest

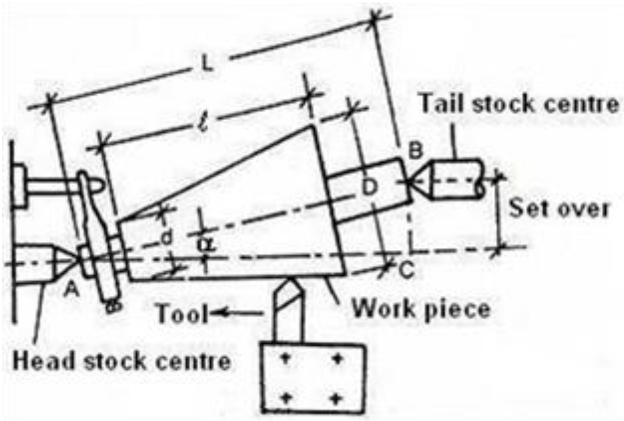
Fig. 2.33 illustrates the method of turning taper by swiveling the compound rest. This method is used to produce short and steep taper. In this method, work is held in a chuck and is rotated about the lathe axis. The compound rest is swiveled to the required angle and clamped in position.

The angle is determined by using the formula, **$\tan\alpha = D - d/2l$** 2.2

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

Taper turning by offsetting the tailstock

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



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

Fig. 2.34 Taper turning by offsetting the tailstock

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

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

Set over = L sinα 2.3

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

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

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

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

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

Taper turning by using taper turning attachment

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

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

The advantages of using a taper turning attachment are:

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

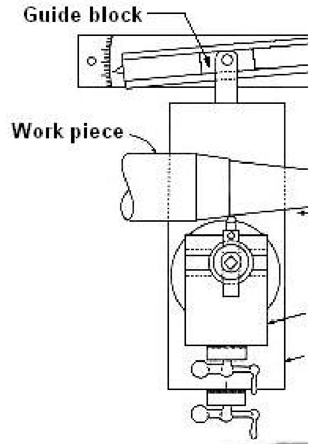
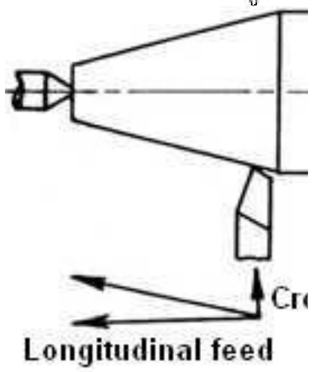


Fig. 2.35 Taper turning attachment



Taper turning by combining longitudinal feed and cross feed

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

THREAD CUTTING METHODS

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

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

Fig. 2.36 Taper turning by combining feed

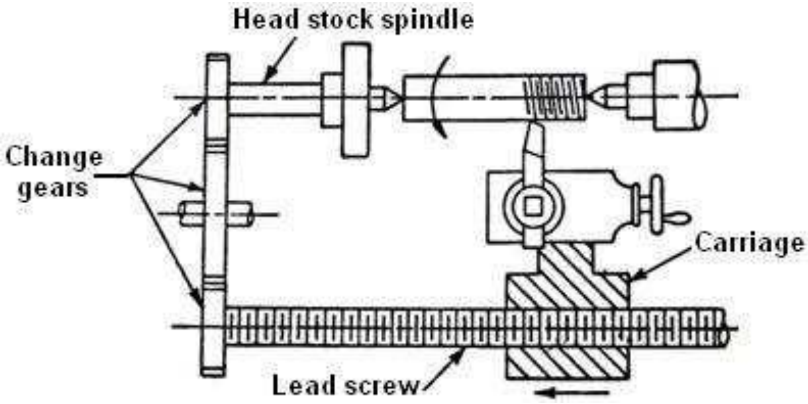


Fig. 2.37 Principles of thread cutting

Change gear ratio

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

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

Pitch of the lead screw

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

Thread cutting procedure

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

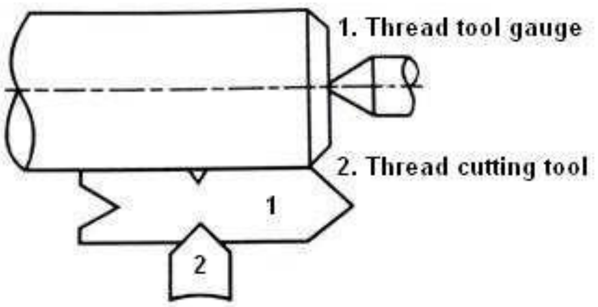


Fig. 2.38 Checking of the cutting edge

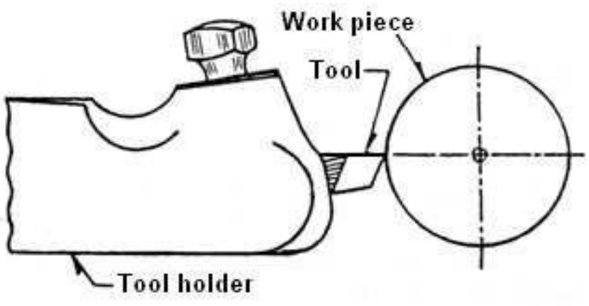


Fig. 2.39 Mounting of the cutting tool

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

Depth of cut in thread cutting

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

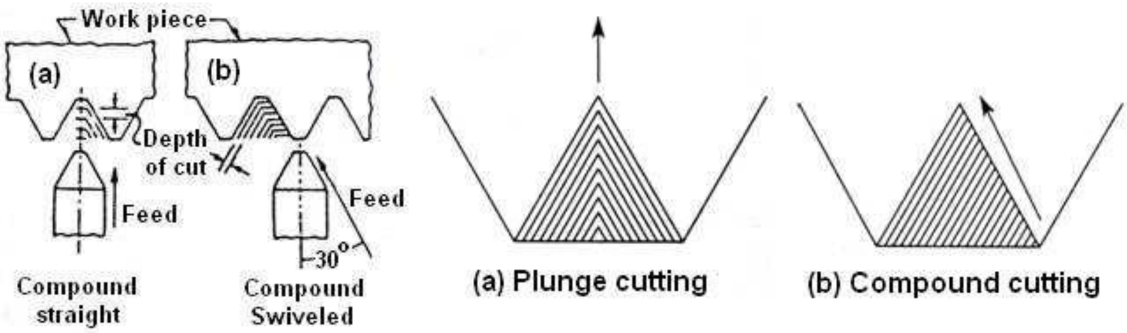


Fig. 2.40 *schematic view of the method of applying plunge cut and compound cut*

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

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

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

So compound cutting is more preferred compared with plunge cutting.

Picking up the thread

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

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

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

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

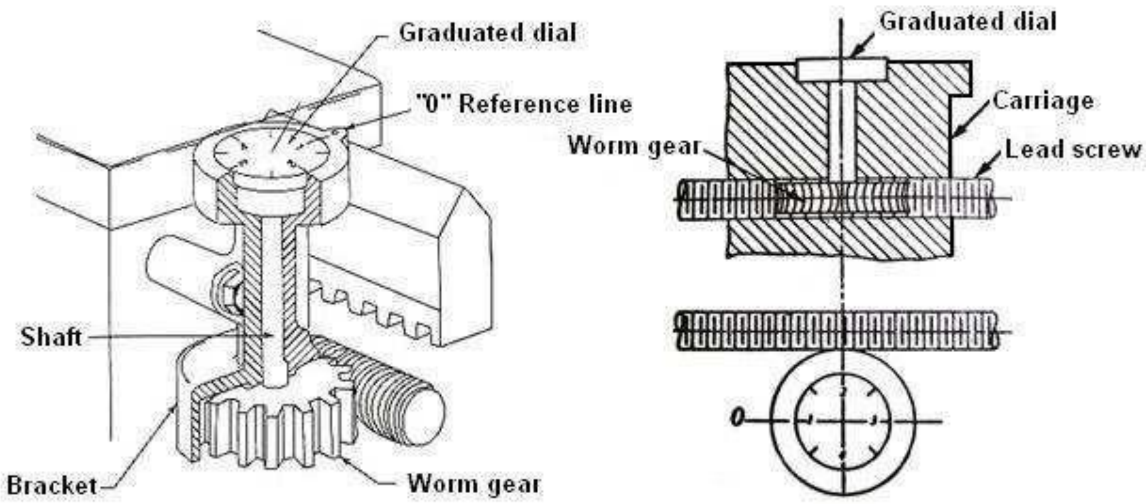


Fig. 2.41 Thread chasing dial

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

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

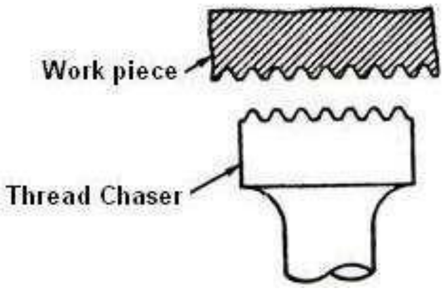


Fig. 2.42 (a) External thread chaser thread

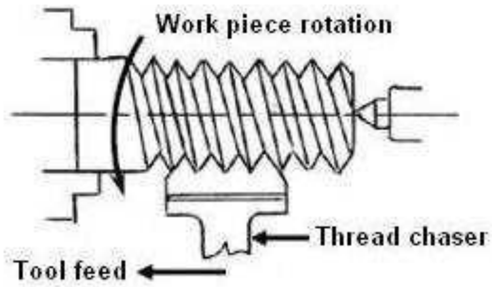


Fig. 2.42 (b) Finishing of a partly cut

Other methods for cutting external threads

External thread cutting by dies

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

Different types of dies used for cutting external threads are:

- ***(a) Solid die:*** It is used for making threads of usually small pitch and diameter in one pass.
- ***(b) Spring die:*** The die ring is provided with a slit, the width of the slit is adjustable by a screw to enable elastically slight reduction in the bore and thus cut the thread in number of passes with lesser force on hands.
- ***(c) Split die:*** The die is made in two pieces, one fixed and one movable (adjustable) within the cavity of the handle or wrench to enable cut relatively larger threads or fine threads on harder blanks easily in number of passes, the die pieces can be replaced by another pair for cutting different threads within small range of variation in size and pitch.
- ***(d) Pipe die:*** Pipe threads of large diameter but smaller pitch are cut by manually rotating the large wrench (stock) in which the die is fitted through a guide bush.

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

Fig. 2.43 shows the hand operated dies of common use.

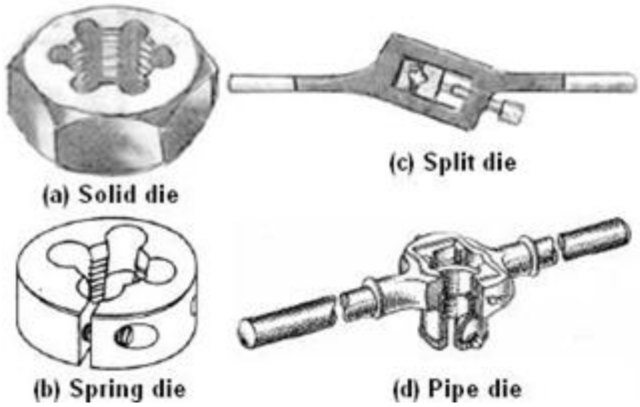


Fig. 2.43 Hand operated dies

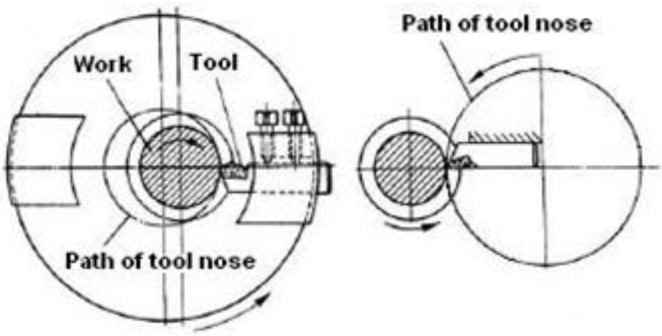


Fig. 2.44 Thread cutting by rotating tool

External thread cutting by rotating tools

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

External thread cutting by milling cutters

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

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

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

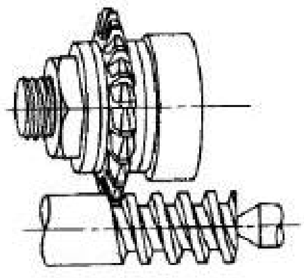


Fig. 2.45 (a) Long thread milling

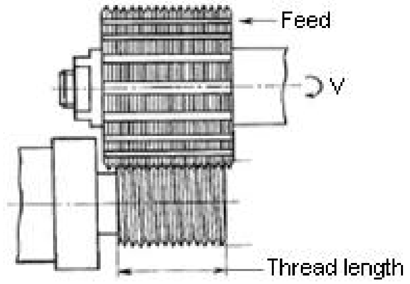


Fig. 2.45 (b) Short thread milling

External thread cutting on tapered surface

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

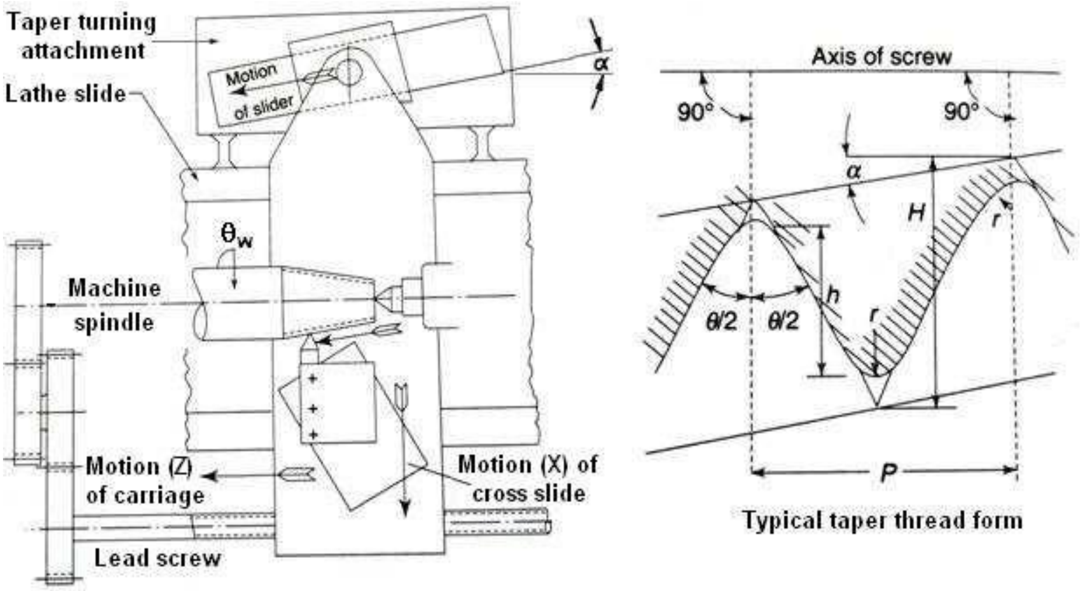
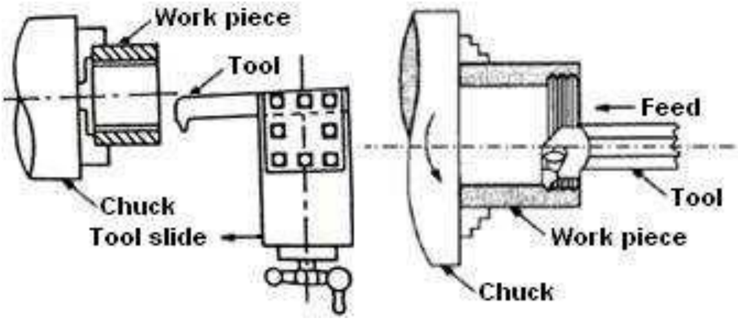


Fig. 2.46 Setup for thread cutting on a taper

Internal thread cutting

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



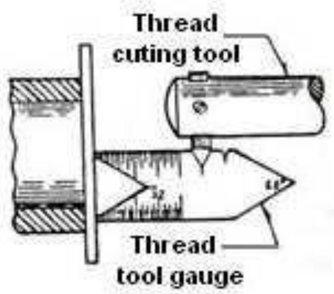


Fig. 2.47 (a) Internal thread cutting operation Fig. 2.47 (b) Setting of cutting edge

Other methods for cutting internal threads

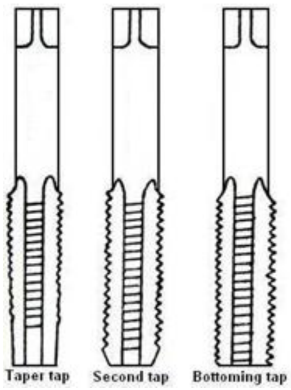
Internal thread cutting by taps

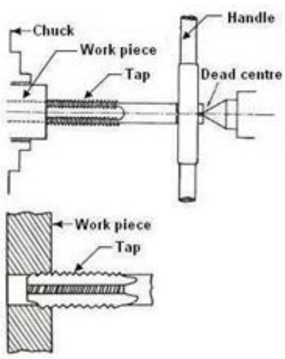
Internal screw threads of usually small size are cut manually, if needed, in plates, blocks, machine parts etc. by using taps which look and behave like a screw but made of tool steel or HSS and have sharp cutting edges produced by axial grooving over the threads *as shown in Fig. 2.48 (a).* Three taps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

Different types of taps used for cutting internal threads are:

- ***Straight solid taps:*** Used for small jobs.
- ***Taps with adjustable blades:*** Usually for large diameter jobs.
- ***Taper or nut taps*****:** Used for cutting threads in nuts.
- However the quality of the threads will depend upon the perfection of the taps and skill of the operator.

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





Internal thread cutting by milling cutters

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

Fig. 2.49 Internal thread milling cutters

SPECIAL ATTACHMENTS

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

Conditions and places suitable for application of attachments in machine tools

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

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

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

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

Taper turning attachment

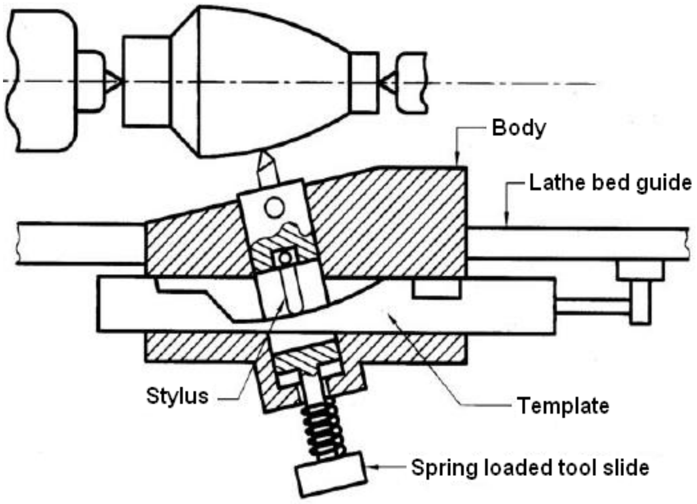
The construction and working principle of the taper turning attachment has been described in Article 2.5.4, Page 66 and illustrated in Fig. 2.35.

Copy turning attachments

The two common types of copy turning attachments are:

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.



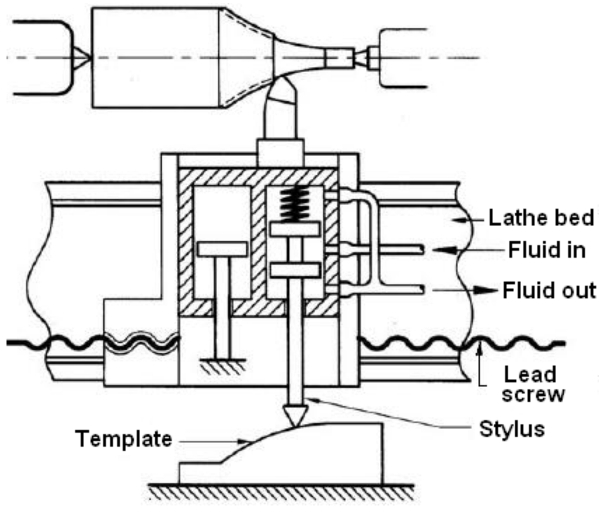


Fig. 2.50 Mechanical type copying attachment Fig. 2.51 Hydraulic copying attachment

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 Fig 2.51.*

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

Radius turning attachment

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

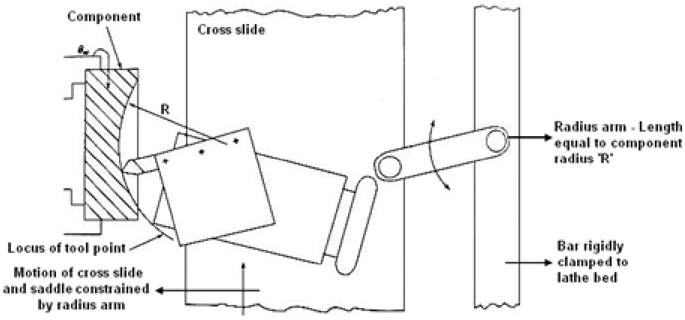


Fig. 2.52 Radius turning attachment

Spherical turning attachment

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

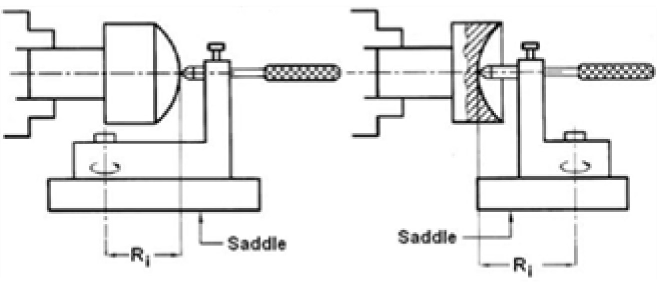


Fig. 2.53 (a) Spherical turning without template

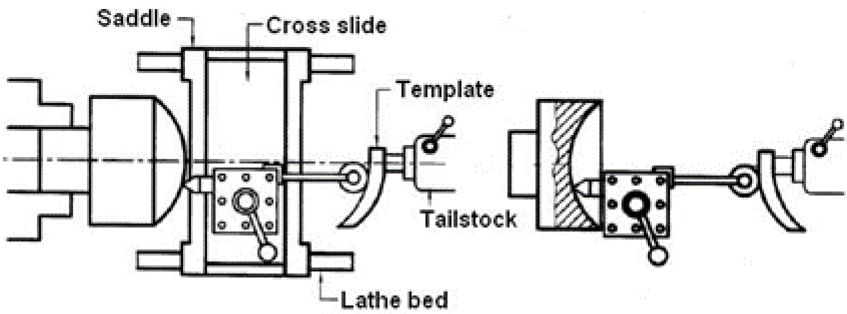


Fig. 2.53 (b) Spherical turning using template

Milling attachment

For cutting grooves or keyways

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

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

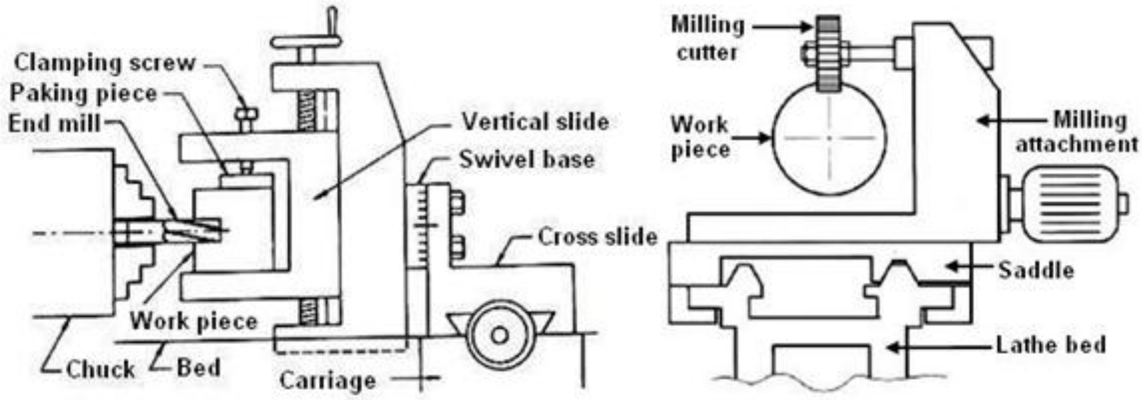
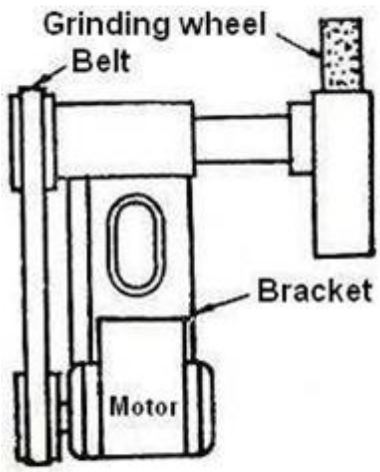


Fig. 2.54 (a) End milling attachment Fig. 2.54 (b) Milling attachment

Cylindrical grinding attachment

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



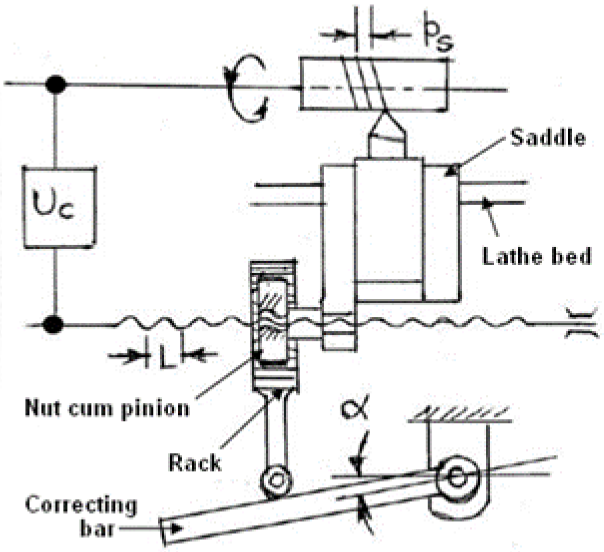


Fig. 2.55 Cylindrical grinding attachment

Fig. 2.56 Thread pitch correcting attachment

Thread pitch correcting attachment

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

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

$\mathbf{p_a = U_C.L}$ 2.11

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

where, UC - Transmission ratio.

L - Lead of the lead screw. M - Module of teeth.

Z - No. of teeth of the gear fixed with the nut and is additionally rotated slightly by the movement of the rack along the bar.

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

Relieving attachment

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

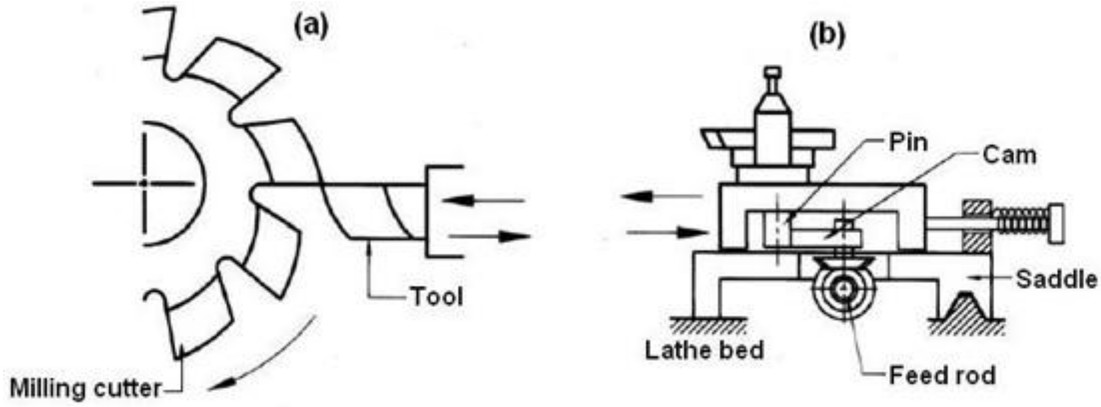


Fig. 2.57 Relieving attachment used in lathe

Super finishing attachment

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

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

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

Stone holder: The stone holders are fastened in the position rod of the stone guide by means of their spherical head part. The universal movability allows the stone to be set precisely in the work piece. ***Stroke regulation valve:*** This Valve is used for regulating the oscillation stroke. The stroke is lengthened by turning the valve to the left and reduced by turning to the right up to its complete stop.

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

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

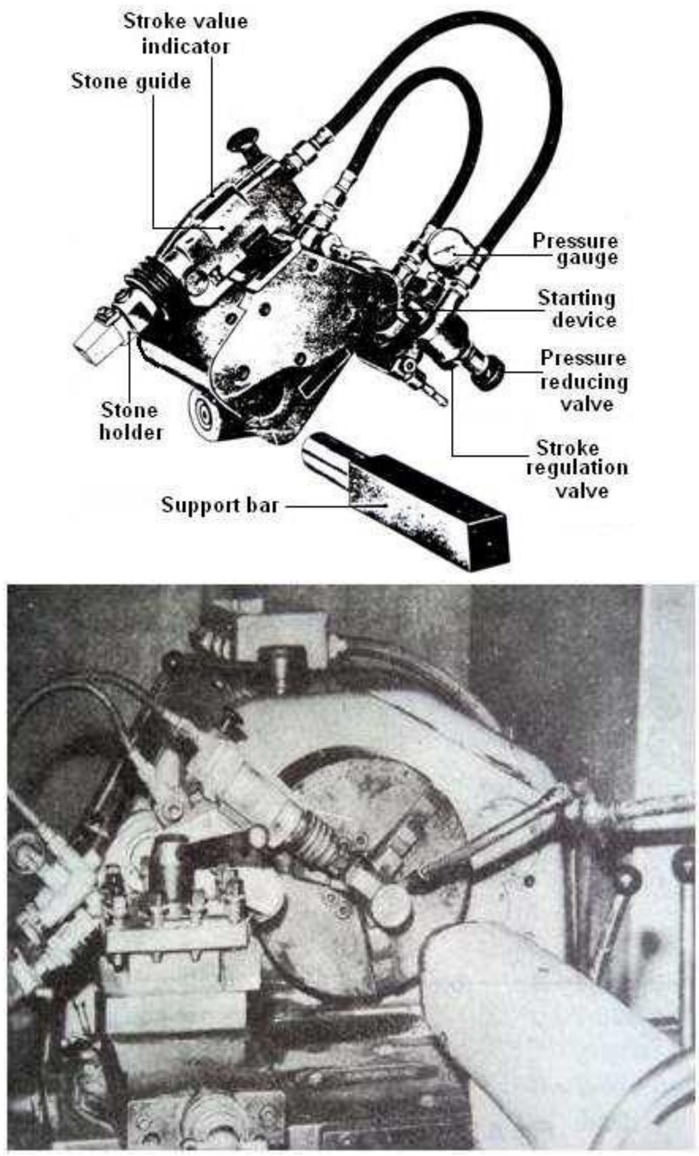


Fig. 2.58 (a) Super finishing attachment Fig. 2.58 (b) Super finishing attachment on a centre lathe

MACHINING TIME AND POWER ESTIMATION

Machining time

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

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

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

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

where, L – Length of the work piece (mm). L_o – Over travel of the tool (mm).

f – Feed rate (mm / rev).

The number of roughing passes (P_r) is given by

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

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

The number of finishing passes (P_f) is given by 2.16

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

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

Power estimation

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

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

where, V – Cutting speed (m/min) and F_C – Force in the direction of cutting speed (N).
Due to shear and friction, the total power is divided into two components. They are;

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

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

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

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

Tool force dynamometers

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

Design requirements for Tool force Dynamometers

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

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

Construction and working principle of turning dynamometers

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

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

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

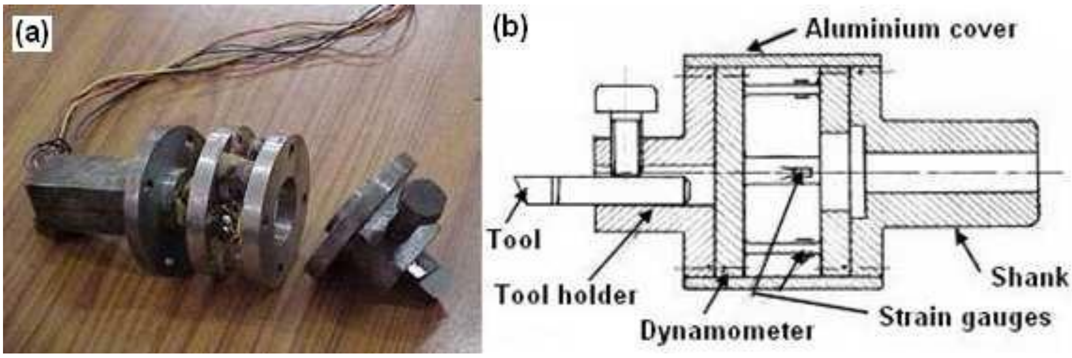


Fig. 2.59 (a and b) Construction of a strain gauge type 2D turning dynamometer

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

SPECIAL PURPOSE LATHES

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

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

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

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

CAPSTAN AND TURRET LATHES

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

In contrast to centre lathes, capstan and turret lathes:

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

Major parts of capstan and turret lathes

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

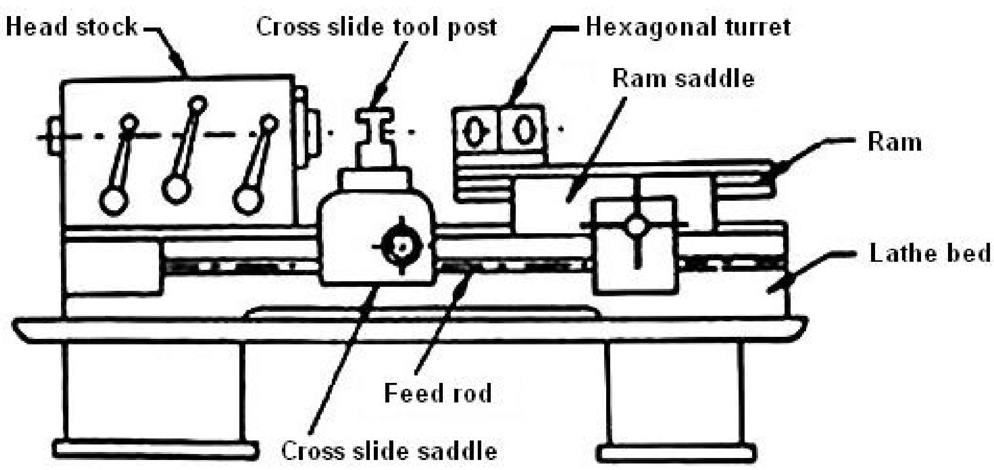


Fig. 2.60 Basic configuration of a Capstan lathe

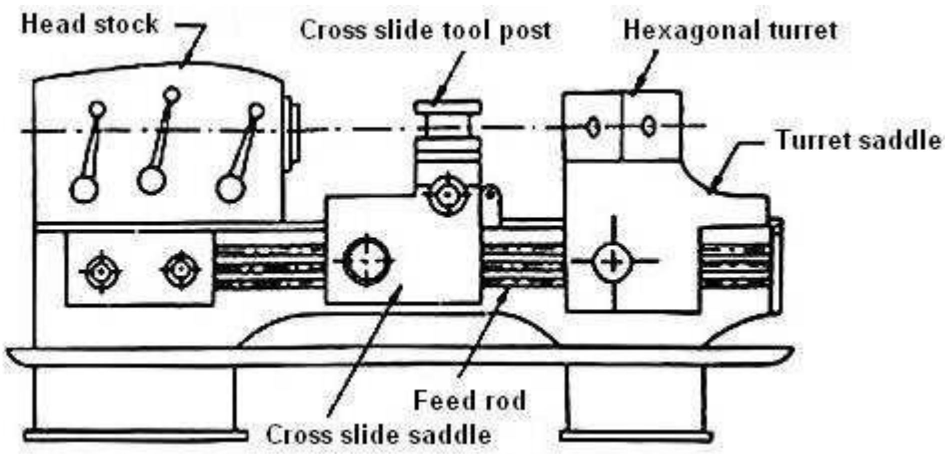


Fig. 2.61 Basic configuration of a Turret lathe

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

Headstock The head stock is a large casting located at the left hand end of the bed.

The headstock of capstan and turret lathes may be of the following types:

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

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

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

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

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

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

- Conventional type carriage.
- Side hung type carriage.

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

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

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

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

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

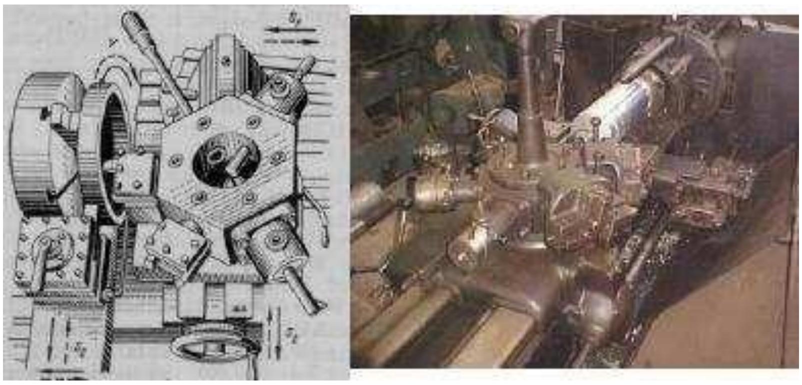


Fig. 2.62 Photographic view of a hexagonal turret

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.

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

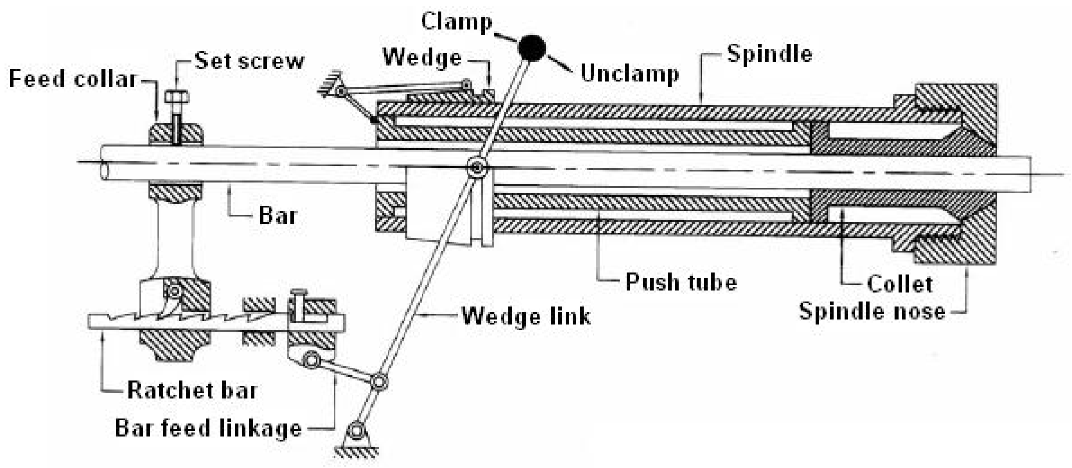


Fig. 2.63 Bar feeding mechanism

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

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

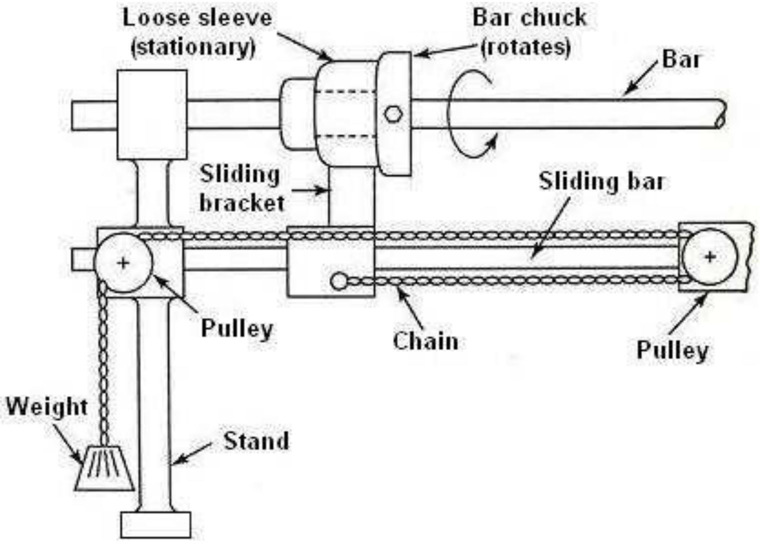


Fig. 2.64 Bar feeding mechanism

Turret indexing mechanism

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

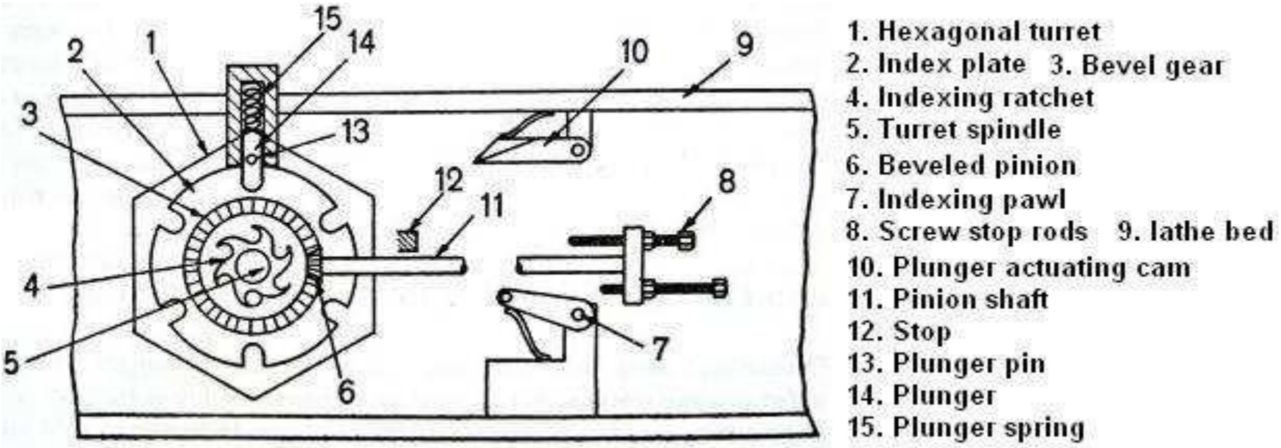


Fig. 2.65 Turret indexing mechanism

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

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

Work holding devices used in capstan and turret lathes

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

1. Jaw chucks

The jaw chucks are used in capstan lathes having two, three or four jaws depending upon the shape of the work piece. The jaw chucks are used to support odd sized jobs or jobs having larger diameter which cannot be introduced through the headstock spindle and gripped by collet chucks.

2-jaw chuck self centering chuck

It is used for bar work. The two jaws hold the irregular work more readily since the clamping is at two points which are diametrically opposite. It is available in size from about 125 mm to 250 mm outside diameter to hold bar stock of diameter from about 20 mm to 45 mm.

3-jaw chuck self centering chuck

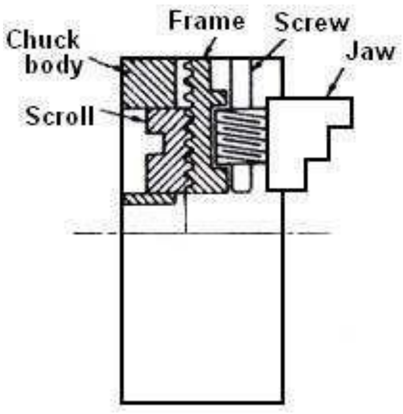
It is used for holding round or hexagonal bar stock or other symmetrical work. It is suitable for gripping larger diameter bars, circular castings, forgings etc. It is available in size from about 100 mm to 750 mm outside diameter and they can hold work up to about 650 mm diameter. The 3-jaw chuck has been described in Article 2.2.5.1, Page 57 and illustrated in Fig. 2.10 (a).

4- jaw independent chuck

It is used occasionally for gripping irregular shaped workpieces, where the number of articles required does not justify the manufacture of special fixtures. It is used for holding rough castings and square or octagonal work. Each jaw can be operated independently and is reversible. It is available in sizes up to about 1000 mm diameter. The 4-jaw chuck has been described in Article 2.2.5.1, Page 57 and illustrated in Fig. 2.10 (b).

Combination chuck

The combination chuck is shown in Fig. 2.66. As the name implies, a combination chuck may be used both as a self centering and an independent chuck to take advantage of both the types. The jaws may be operated individually by separate screws or simultaneously by the scroll disc. The screws mounted on the frame have teeth cut on its underside which meshes with the scroll and all the jaws together with the screws move radially when the scroll is made to rotate by a pinion.



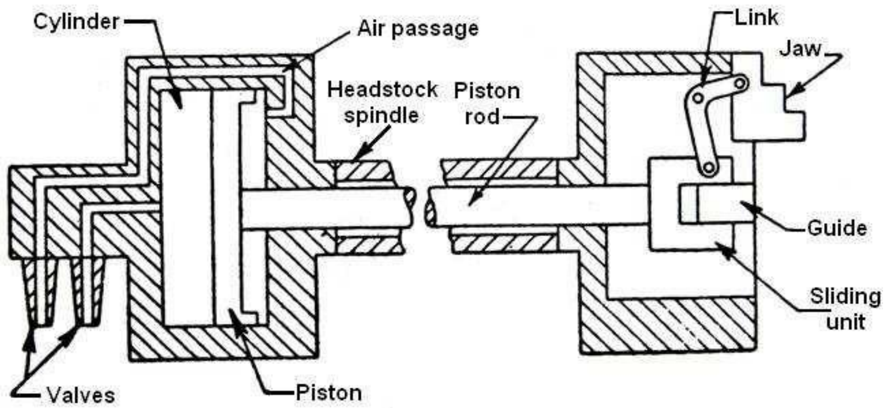


Fig. 2.66 Combination chuck   Fig. 2.67 Air operated chuck

Air operated chuck

The air operated chuck is shown in Fig. 2.67. Heavy duty turret lathes and capstan lathes engaged in mass production work are equipped with air operated chucks for certain distinct advantages. The chuck grips the work piece quickly and is capable of taking powerful grip with least manual exertion. The chucks are operated by air at a pressure of 5.5 kg/cm^2 to 7 kg/cm^2.

The mechanism incorporates an air cylinder mounted at the back end of the headstock spindle and rotates with it. Fluid pressure may be communicated to the cylinder by operating a valve with a lever and the piston will slide within the cylinder. The movement of the piston is transmitted to the jaws by means of connecting rod and links. A guide is provided for the movement of the connecting rod.

To clamp the work piece, compressed air is admitted to the cylinder at the right side of the piston. The piston slides to the left side and the jaws grip the work piece securely. To release the work piece, the air is admitted to the left side of the piston. Then the piston slides to the right side and the jaws unclamp the work piece.

2. Collet chucks

Collet chucks or collets are used mainly to hold bar stock, especially in the smaller sizes. A collet is a circular steel shell having three or four equally spaced slits extending the greater part of its length. These slits impart springing action to the collet. That is why, collets are also known as “spring collets”. The collet nose is made thicker to form the jaws. The outside surface of the nose fits in the taper hole of the hood. The inside of the collet is made according to the shape of the work to be held.

Collets are much more suitable than a self centering chuck in mass production work due to its quickness in action and accurate setting. The collets may be operated by hand or by power. The collets are classified by the methods used to close the jaws on the work.

Push out type Collet chuck

The push out type collet chuck is shown in Fig. 2.68 (a). In this type the taper of the collet nose and hood converge towards the right. To grip the work, the tapered portion of the spring collet is pushed into the mating taper of the hood. There is a tendency of the bar to be pushed slightly outward when the collet is pushed for gripping. If the bar is fed against a stop bar fitted on the turret head, this slight outward movement of the bar ensures accurate setting of the length for machining.

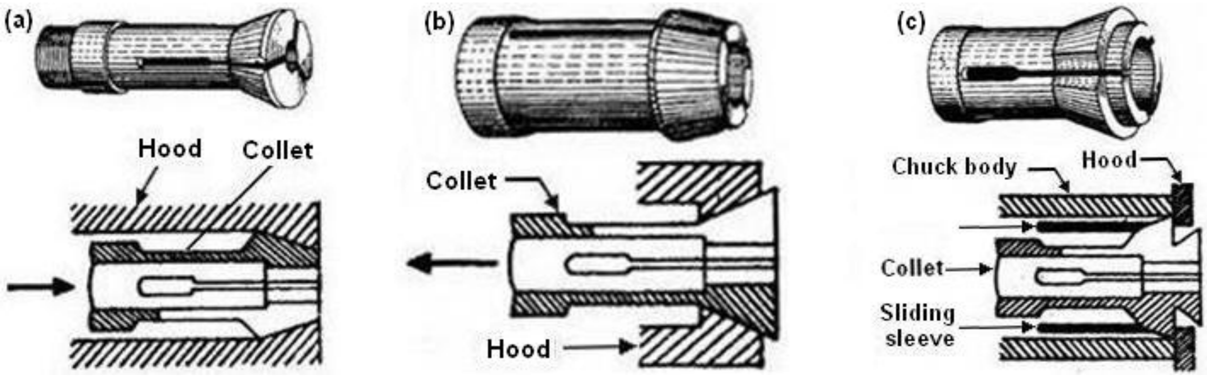


Fig. 2.68 Collet chucks (a) Push out type (b) draw back type (c) Dead length type

Draw back or Draw in type Collet chuck

The draw back type collet chuck is shown in Fig. 2.68 (b). In this type the taper of the collet nose and hood converge towards the left. To grip the work, the tapered portion of the spring collet is pulled back into the mating taper of the hood which causes the split end of the collet to close in and grip the bar. The machining length of the bar in this type of chuck cannot be accurately set as the collet while closing will draw the bar slightly inward towards the spindle.

Dead length type Collet chuck

The dead length type collet chuck is shown in Fig. 2.68 (c). For accurate positioning of the bar, both the push out and draw in type collet present some error due to the movement of the bar along with the collet while gripping. This difficulty is removed by using a stationary collet on the bar. In this type the taper of the collet nose converge towards the left. A sliding sleeve is placed between the collet and the hood. This sliding sleeve has a tapered edge which fits on the taper of the collet nose. To grip the work, the sliding sleeve is pushed towards the right. This makes the collet to close in and grip the bar. The end movement of the collet is prevented by the shoulder stop.

3. Fixtures

A fixture may be described as a special chuck built for the purpose of holding, locating and

machining a large number of identical pieces which cannot be easily held by conventional gripping devices. Fixtures also serve the purpose of accurately locating the machining surface.
The main functions of a fixture are as follows:

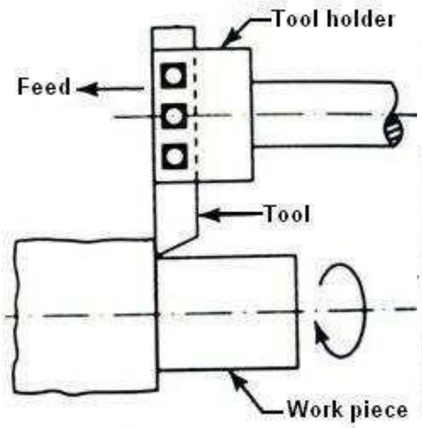
- It accurately locates the work.
- It grips the work properly, preventing it from bending or slipping during machining operations.
- It permits rapid loading and unloading of workpieces.

Tool holding devices used in capstan and turret lathes

The wide variety of work performed in a capstan or turret lathe in mass production necessitated designing of many different types of tool holders for holding tools for typical operations. The tool holders may be mounted on turret faces or on cross-slide tool post and may be used for holding tools for bar and chuck work. Certain tool holders are used for holding tools for both bar and chuck work while box tools are particularly adapted in bar work.

Straight cutter holder

This is a simple tool holder constructed to take standard section tool bits. The shank of the holder can be mounted directly into the hole of the turret face or into a hole of a multiple turning head. In this type of holder, the tool is held perpendicular to the shank axis. The tool is gripped in the holder by three set screws. Different operations like turning, facing, boring, counter boring, chamfering, etc. can be performed by holding suitable tools in the holder. *Fig.2.69 illustrates a straight cutter holder.*



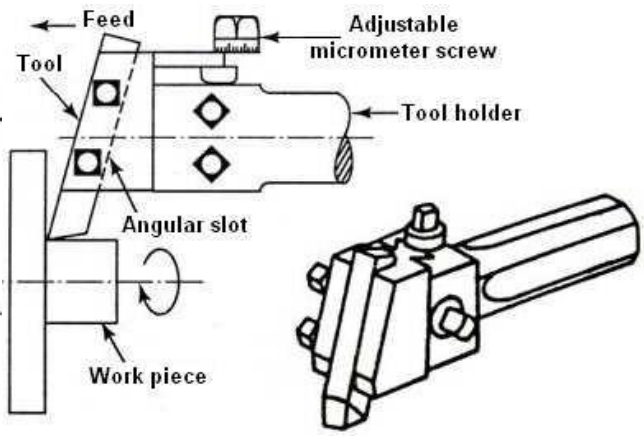


Fig. 2.69 straight cutter holder

Fig. 2.70 Adjustable angle cutter holder

Plain or adjustable angle cutter holder

It is similar as that of a straight cutter holder but having an angular slot. The tool is fitted in this slot by means of setscrews. The inclination of the tool helps in turning or boring operations close to the chuck jaws or up to the shoulder of the work piece without any interference. In plain type of holder, the setting of the cutting edge relative to the work is effect by opening the set screws and then adjusting the tool by hand. In adjustable type of holder, the accurate setting of the tool can be effect by rotating a micrometer screw. *Fig.2.70 illustrates an adjustable angle cutter* *holder.*

Multiple cutter holder

This holder can accommodate two or more tools in its body. This feature enables turning of two different diameters simultaneously. This will reduce the time of machining. Turning and boring tools can also be set in the holder to perform two operations at a time. *Fig.2.71 illustrates a multiple cutter holder.*

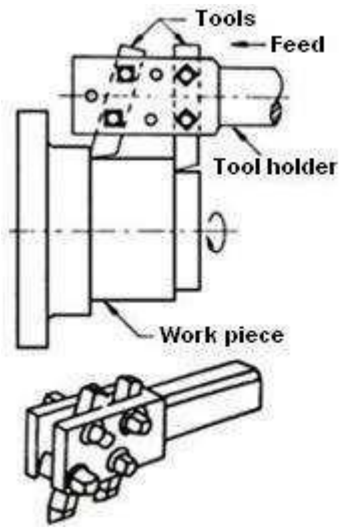


Fig. 2.71 Multiple cutter holder

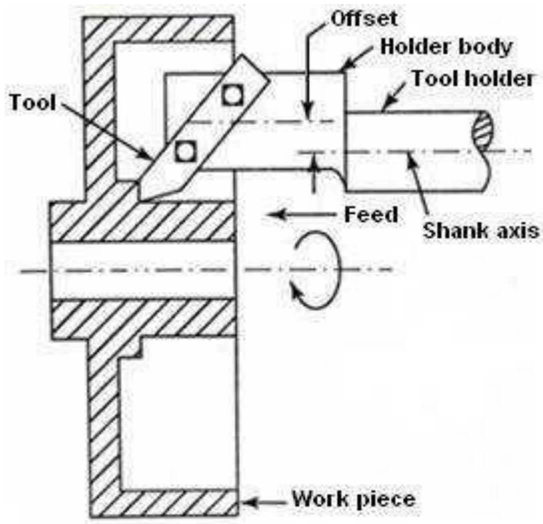


Fig. 2.72 Offset cutter holder

Offset cutter holder

In this type, the holder body is made offset with the shank axis. Larger diameter work can be turned or bored by this type of holder. *Fig.2.72 illustrates an offset cutter holder.*

Combination tool holder or multiple turning head

It is used for holding straight, angular, multiple or offset cutter holders, boring bars, etc. for various turning and boring operations, so that it may be possible to undertake a number of operations simultaneously. The tools are set at different positions on the work surface by inserting the shank of tool holders in different holes of the multiple head body, and they are secured to it by tightening separate set screws. A boring bar is held at the central hole of the head which is aligned with the axis of the supporting flange. The head is supported on the turret face by tightening four bolts passing through the holes of the flange. The tool holder has a guide bush. The pilot bar projecting from the head stock of the machine; slides inside the guide bush. This gives additional support to the tool while cutting and prevents any vibration or deflection. Fig.2.73 illustrates a combination tool holder.

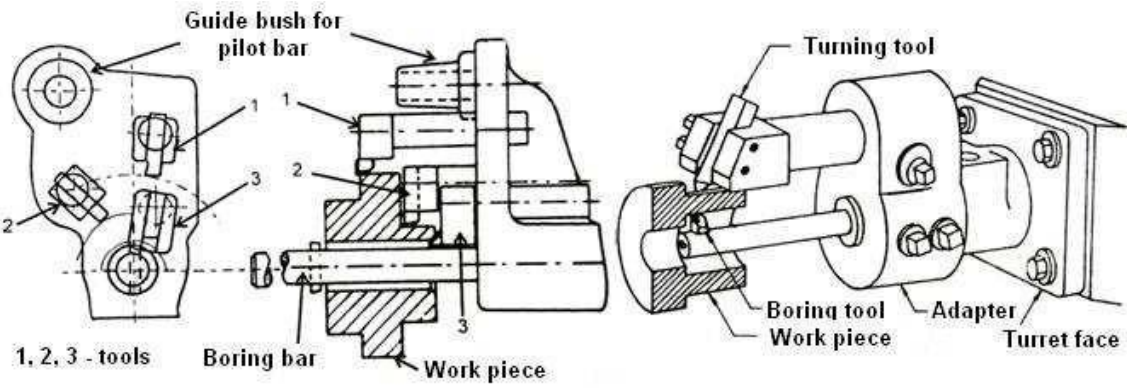
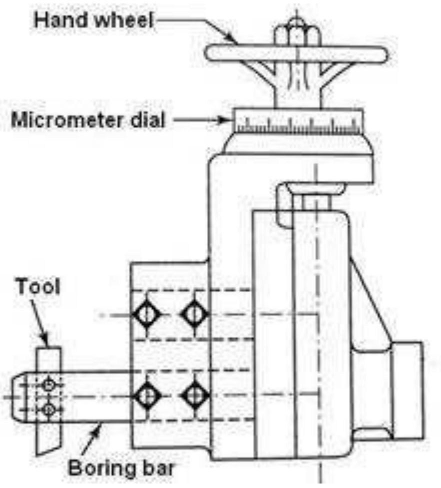


Fig. 2.73 Combination tool holder

Sliding tool holder

It is useful for rough and finish boring, recessing, grooving, facing, etc. The holder consists of a vertical base on which a slide is fitted. The slide may be adjusted up or down accurately by rotating a hand wheel provided with a micrometer dial. Two holes are provided on the sliding unit for holding tools. The lower hole which is aligned with the lathe axis is used for holding boring bars, drills, reamers, etc. The upper hole accommodates a turning tool holder. After necessary adjustments the slide is clamped to the base by a clamping lever for turning or boring operations. For facing or recessing operations, the crosswise movement of the tool is obtained in the vertical plane. The slide is equipped with two adjustable stops for facing or similar operations in order to be able to duplicate the workpiece. The holder base is clamped directly on the turret face by studs. Fig.2.74 illustrates a sliding tool holder.



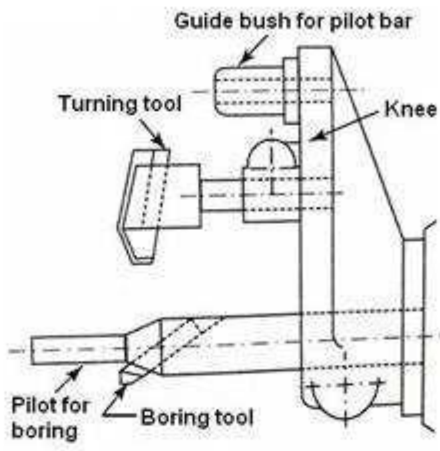


Fig. 2.74 Sliding tool holder

Fig. 2.75 Knee tool holder

Knee tool holder

It is useful for simultaneous turning and boring or turning and drilling operations. The knee holder is bolted directly on the turret face. The axis of the lower hole coincides with the lathe axis and is used for holding boring bars, drills, etc. The turning tool holder is fitted in to the centre hole. A guide bush is provided at the top of the holder for running of pilot bar. *Fig.2.75 illustrates a knee tool holder.*

Flange tool holder

This holder is also called as extension holder, drill holder or boring bar holder. These holders are intended for holding drills, reamers, boring bars, etc. The twist drills having Morse taper shanks are usually held in a socket which is parallel outside and tapered inside. The socket is introduced in the hole of the flange tool holder and clamped to it by set screws. The flanged end of the holder is bolted directly to the face of the turret and is accurately centered. *Fig.2.76 illustrates a flange tool holder.*

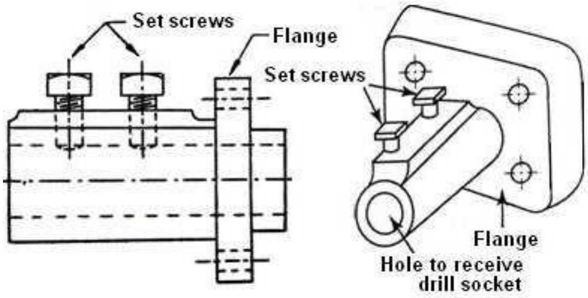


Fig. 2.76 Flange tool holder

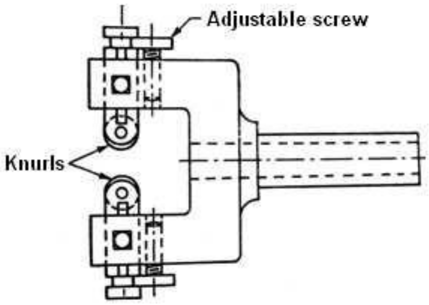


Fig. 2.77 Knurling tool holder

Knurling tool holder

It may be mounted on the turret face or on the tool posts of the cross-slide. The holders with knurls mounted on the cross-slide can perform knurling operation on any diameter work. *Fig 2.77 illustrates a knurling tool holder which is fitted on the turret face.* The position of knurls can be adjusted in a vertical plane to accommodate different diameters of work, while the relative angle between them can also be varied to produce different patterns of knurled surface.

Form tool holder

Two sets of form tool holders have been designed for holding straight and circular form cutters. The usual procedure of holding a form tool holder is on the cross-slide. In the straight form tool holder, the tool is mounted on a dovetail slide and the height of the cutting edge may be adjusted by moving the tool within the slide. The height of the circular form tool may be adjusted by rotating the circular cutter. *Fig.2.78 illustrates a form tool holder.*

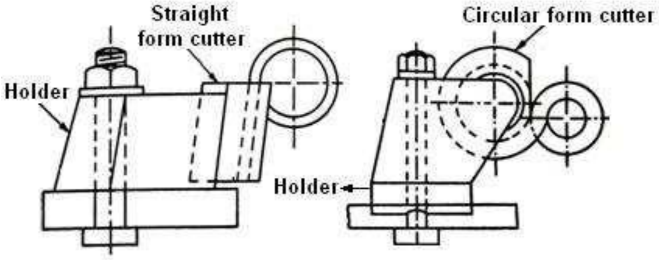


Fig. 2.78 Form tool holder

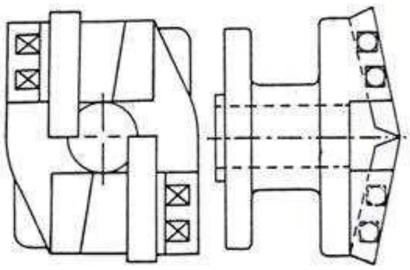


Fig. 2.79 Balanced tool holder

Balanced tool holder

Its name is derived from the fact that the tools mounted on the holder are so arranged that the cutting thrust exerted by one of the tools on the work is balanced by the cutting thrust developed by the other tool fitted on the holder. This prevents any bending of the work and obviates the use of any other work support. *Fig.2.79 illustrates a balanced tool holder.*

V- Steady tool holder

The V-steady box tool holders are used for lending support to the workpiece while cutting action progresses from the end of a bar stock. Both the tool and V-steady are mounted on the adjustable slide in order to set the required diameter of the machined part and to position the tool relative to the V-steady. The V-steady tool holder is mainly used in brass work. *Fig.2.80 illustrates a V-Steady tool holder.*

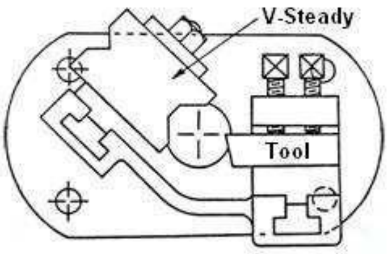


Fig. 2.80 V-Steady tool holder

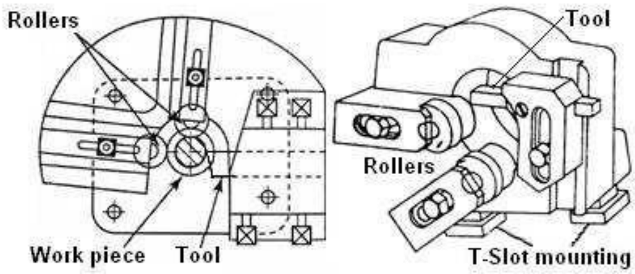


Fig. 2.81 Roller steady box tool holder

Roller steady box tool holder

It is commonly used in bar work for turning steel rods. In construction, it replaces V-steady and in its place two rollers are used to provide support to the work. The tool and the rollers can be adjusted in the holder for proper setting. A high class finish is obtained on the work surface due to burnishing action of the rollers on the work. The rollers acting against the cutting pressure remove the feed marks on the workpiece. *Fig.2.81 illustrates a roller steady box tool holder*.

Comparison of capstan and turret lathes

Sl . No.	Capstan lathe	Turret lathe
1	Turret head is mounted on a ram which slides over the saddle.	Turret head is directly mounted on saddle. But it slides on the bed.
2	The turret movement is limited.	The turret moves on the entire length of the bed without any restriction.
3	Hence shorter work piece can be machined.	Longer work piece can be machined.
4	Its construction does not provide rigidity due to overhanging of ram beyond the bed.	It provides rigidity and strong.
5	It is suitable for light duty applications.	It is suitable for heavy duty applications.
6	Turret head can be moved manually.	Turret head cannot be moved manually.
7	The maximum size of 60 mm diameter work can be accommodated.	It can accommodate only from 125 to 200mm.
8	No cross-wise movement to turret.	Facing and turning are usually done by cross-wise movement of turret.
9	Overhung type of cross-slide is not used.	Overhung type of cross-slide is provided for some specific operations.

Specifications of capstan and turret lathes

The main sizes to be specified in any capstan and turret lathes are:

- Maximum diameter of the workpiece that can be machined.
- Swing over cross slide.
- Swing over bed.

100-200-250 refers to the maximum diameter that can be machined by using this size of lathe is 100 mm, the size of swing over cross slide is 200 mm and the size of swing over bed is 250 mm.

In addition to the above sizes, the following details are also needed to specify the full description about the machine:

- Power of the main drive motor.
- Range of spindle speeds.
- Range of feeds for the carriage.
- Range of feeds for the turret or saddle.
- Total weight of the machine.
- Floor space required.

AUTOMATIC LATHES

Highly automated machine tools especially of the lathe family are ordinarily classified as semi automatics and automatics. Automatics as their name implies are machine tools with a fully automatic work cycle. Semi automatics are machine tools in which the actual machining operations are performed automatically in the same manner as on automatics. In this case however, the operator loads the blank into the machine, starts the machine, checks the work size and removes the completed piece by hand.

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).

SEMI AUTOMATICS

Semi automatics are employed for machining work from separate blanks. The operator loads and clamps the blanks, starts the machine and unloads the finished work. *The characteristic features of semi automatic lathes are:*

- Some major auxiliary motions and handling operations like bar feeding, speed change, tool change etc. are done quickly and consistently with lesser human involvement.
- The operators need lesser skill and putting lesser effort and attention.

- Suitable for batch or small lot production.
- Costlier than centre lathes of same capacity.

Classification of semi automatics

Depending upon the number of work spindle, these machines are classified as:

Single spindle semi automatics

- ***Centre type:*** In this type, the workpiece is held between centres, for which a head stock and a tail stock are mounted on the bed of the machine. Usually, external stepped or formed surfaces are machined on this machine. The work is machined by two groups of cutting tools. The front tool slide holds the cutting tools which require a longitudinal feed motion to turn the steps of a shaft, while the rear tool slide carries the tools that require a transverse feed motion to perform operations such as facing, shouldering, necking, chamfering etc.
- ***Chucking type:*** In this type, the workpiece is held in a chuck. Such a machine may be equipped with various tool slide arrangements. In addition to longitudinal and transverse feed tool slides, these machines may also be equipped with a central end working tool slide or a turret if internal surfaces are also to be machined in addition to the external surfaces.

Multi spindle semi automatics

The machine may also be built in two designs:

- Centre type.
- Chucking type.

These multi spindle semi automatics are classified as:

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

AUTOMATS

These are machine tools in which the components are machined automatically. The working cycle is fully automatic that is repeated to produce identical parts without participation of the operator. All the working and idle operations are performed in a definite sequence by the control system adopted in the automats which is set up to suit a given work.

Classification of Automats

The automats can be classified as follows:

According to the type of work materials used:

- Bar stock machine.
- Chucking machine.

According to the number of spindles:

- Single spindle machine.
- Multi spindle machine.

According to the position of spindles:

- Horizontal spindle type.
- Vertical spindle type.

According to the use:

- General purpose machine.
- Single purpose machine.

According to the feed control:

- Single cam shaft rotating at constant speed.
- Single cam shaft with two speeds.
- Two cam shafts.

Advantages of automats over conventional lathes

- Mass production of identical parts.
- High accuracy is maintained.
- Time of production is minimized.
- Less floor space is required.
- Unskilled labor is enough. It minimizes the labor cost.
- Constant flow of production.
- One operator can be utilized to operate more than one machine.
- The bar stock is fed automatically.
- Scrap loss is reduced by eliminating operator error.

Comparison of automats and semiautomatics

Sl.	Automats	Semi automatics

No.		
1	Loading and unloading of work piece are done automatically by the machine.	Loading and unloading manually.
2	Feeding of bar stock and bringing the tools to correct machining positions are done automatically.	These are done manually.
3	A single operator can attend a number of machines when they are arranged together as a group.	An operator can attend to only one or two machines at a line.
4	Production time and cost less.	Not so less.
5	Best suitable for production of components.	Suitable for large size components.
6	Initial cost of machine is high.	Initial cost is lower tha automatic lathe.

SINGLE SPINDLE AUTOMATS

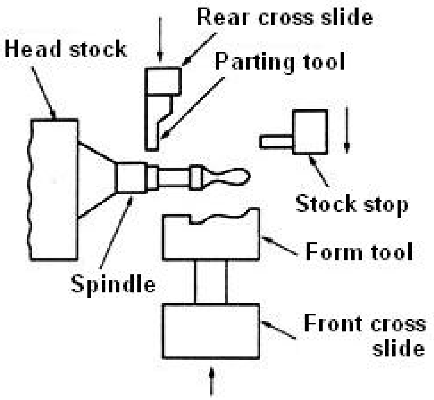
These machines have only one spindle. So, one component can be machined at a time. These are modified form of turret lathe. These machines have maximum of 4 cross slides in addition to a 6 station or 8 station turret. These cross slides are operated by disc cams which draws the power from the main spindle through cycle time change gears. The single spindle automats are of the following types:

SINGLE SPINDLE AUTOMATIC CUTTING OFF MACHINE

This machine produces large quantities of workpieces of smaller diameter and shorter lengths.

Components with simple form are produced in this machine by means of cross sliding tools.

Construction This machine is simple in design. The head stock with the spindle is mounted on the bed. Two cross slides are located on the bed at the front end of the spindle. The front cross slides are used for turning and forming operations. The rear tool slide is used for facing, chamfering, recessing, under cutting and cutting off operations. Cams on a camshaft actuate the movements of the cross slides through a system of levers.



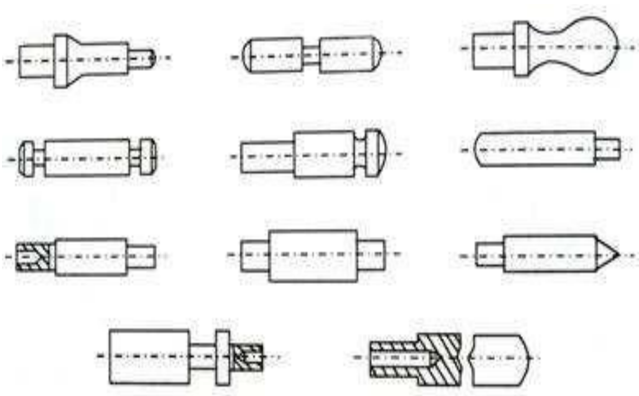


Fig. 2.82 Arrangement of tool slide   Fig. 2.83 Simple parts produced on cutting off machine

Working principle *Typical arrangement of tool slide in an automatic cutting off machine is illustrated in Fig. 2.82.* The required length of work piece (stock) is fed out with a cam mechanism, up to the stock stop which is automatically advanced in line with the spindle axis, at the end of each cycle. The stock is held in the collect chuck of the rotating spindle. The machining is done by tools held in cross slides operating only in the crosswise direction. The form tool held in the front tool slide produces the required shape of the component. The parting off tool in the rear tool slide is used to cut off the component after machining. Special attachments can be employed if holes or threads are required on the simple parts.

This machine has a single cam shaft which controls the working and idle motions of the tools. The cam shaft runs at constant speed. Therefore working motions and idle motions takes place at the same speed. Hence the cycle time is more. *Typical simple parts (from 3 mm to 20 mm in diameter) produced on this machine are shown in Fig. 2.83.*

SWISS TYPE AUTOMATIC SCREW MACHINE

This machine was designed and developed in Switzerland. So it is often called as Swiss auto lathe. This machine is also known as 'Sliding head screw machine', or 'Movable headstock machine', because the head stock is movable and the tools are fixed. This machine is used for machining long accurate parts of small diameter (2 mm to 25 mm).

Construction *Fig. 2.84 schematically shows the basic configuration of a Swiss type automatic screw machine.* This machine has the following parts:

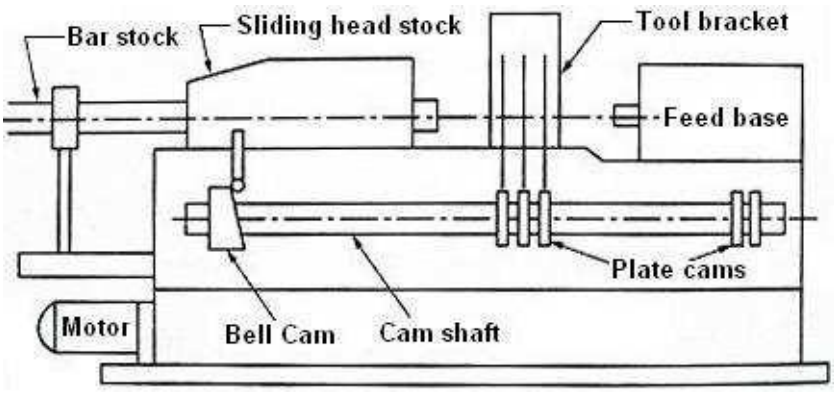


Fig. 2.84 Swiss type automatic screw machine

Sliding Head Stock: This head stock has a collet. The bar stock is held in this collet. The headstock slides along the guide ways of the bed. A bell cam connected to the cam shaft controls this sliding motion.

Tool Bracket: The tool bracket is mounted on the bed way near the head stock. The tool bracket supports 4 or 5 toll slides. It also has a bush for supporting and guiding the bar stock. Two slides are positioned horizontally (front and rear) on which the turning tools are normally clamped. The other slides are arranged above these slides. These slides can move radially. All the slides can move back and forth. These slides are actuated independently by sets or rocker arms and plate cams. Plate cams are fitted to the cam shaft. *The tool bracket is shown schematically in Fig. 2.85 (a) and photographically in Fig. 2.85 (b).*

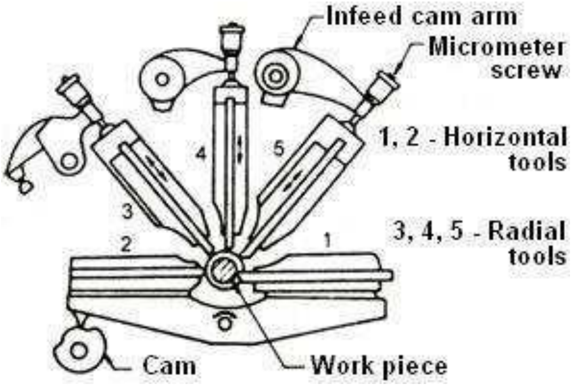


Fig. 2.85 (a) Schematic view of a tool bracket

Feed Base: The feed base is a special attachment mounted at the right hand side of the bed. This can move along the bed. Using this attachment, operations like drilling, boring, thread cutting with taps or dies etc., are done. The movement of the feed base is controlled by the plate cam fitted to the cam shaft.

Cam Shaft: The cam shaft is mounted at the front of the machine. It has a bell cam at the left end. This controls the sliding movement of the head stock. Plate cams fitted at the centre of the shaft controls the movement of the tool slides. Plate cam at the right end of the cam shaft controls the movement of the feed base.

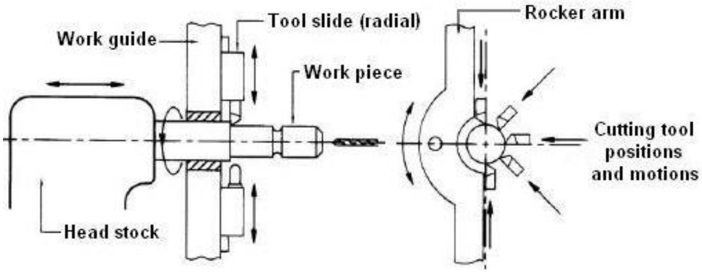


Fig. 2.86 Working principle of the Swiss type automatic screw machine

Working principle *Fig. 2.86 shows the working principle of the Swiss type automatic screw machine.* The stock is held by a rotating collet in the head stock and all longitudinal feeds are obtained by a cam which moves the head stock as a unit. Most diameters turning are done by two horizontal tool slides while the other three slides are used principally for such operations as knurling, chamfering, recessing and cutting off. The tools are controlled and positioned by cams that bring the tools in as needed to turn, face, form, and cut off the workpiece from the bar as it emerges from the bushing.

The cutting action is confined close to the support bushing reducing the overhang to a minimum. As a result, the work can be machined to very close limits. All tools can work at a time. After the work piece is machined, the head stock slides back to the original position. One revolution of the cam shaft produces one component.

A wide variety of formed surfaces may be obtained on the workpiece by synchronized alternating or simultaneous travel of the headstock (longitudinal feed) and the cross slide (approach to the depth of cut). The bar stock used in these machines has to be highly accurate and is first ground on centreless grinding machines to ensure high accuracy. *Parts produced on this machine are shown in Fig. 2.87.*

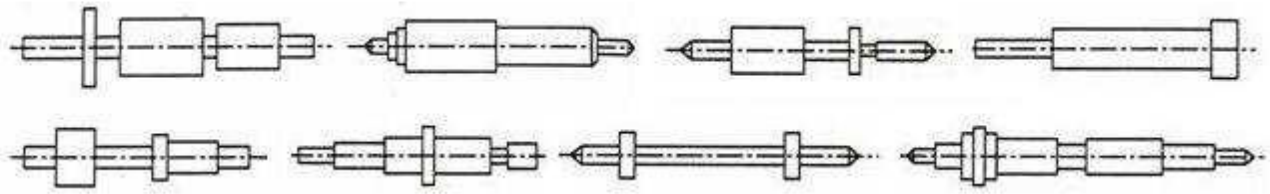


Fig. 2.87 Simple parts produced on Swiss auto lathe

Advantages

- It is used to precision turning of small parts.
- Wide range of speeds is available.
- It is rigid in construction.
- Micrometer tool setting is possible.
- Interchangeability of cams is possible.
- Tolerance of 0.005 mm to 0.0125 mm is obtained.

SINGLE SPINDLE AUTOMATIC SCREW TYPE MACHINE

This is essentially wholly automatic bar type turret lathe. This is very similar to capstan and turret lathes with reference to tool layout, but all the tool movements are cam controlled, such that full automation in manufacturing is achieved. This is designed for machining complex external and internal surfaces on parts made of bar stock or of separate blanks. These machines are made in several sizes for bar work from 12.7 mm to 60 mm diameter.

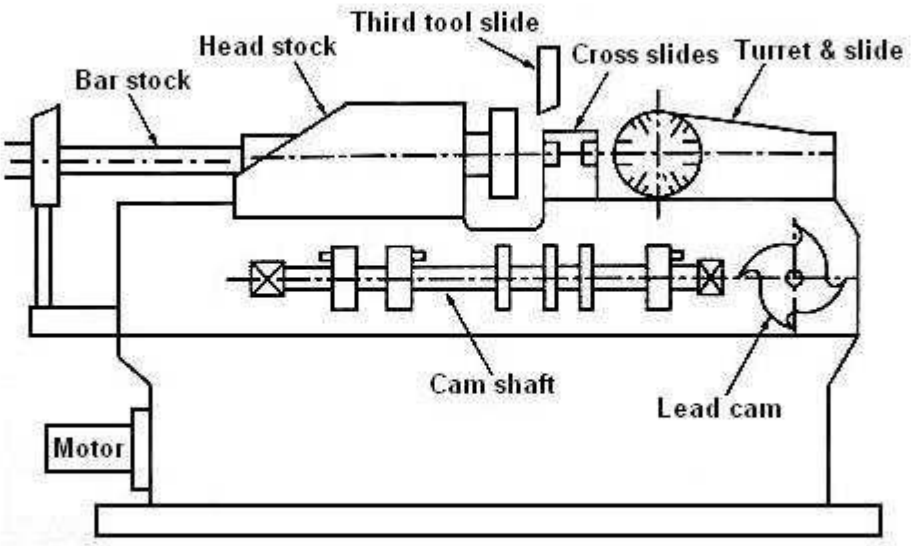


Fig. 2.88 Single spindle automatic screw cutting machine

Construction *Fig. 2.88 schematically shows the basic configuration of a single spindle automatic screw cutting machine.* Up to ten different cutting tools may be employed at a time in this machine. The tools are fixed in indexing turret and in cross-slides. The turret carries six tools. Two cross-slides (front and rear) are employed for cross-feeding tools. A vertical slide for parting off operation may also be provided. It is installed above the work spindle. The stationary headstock, mounted on the left end of the bed, houses the spindle which rotates in either direction.

Working principle The bar stock is held in a collet chuck and advanced by a feed finger after each piece is finished and cut off. All movements of the machine units are actuated by cams mounted on the camshaft. The bar stock is pushed through stock tube in a bracket and its leading end is clamped in rotating spindle by means of a collet chuck. The bar is then fed out for the next part by stock feeding mechanism. Longitudinal turning and machining of the central hole are performed by tools mounted on turret slide. The cut off and form tools are mounted on the cross-slides. At the end of each cut, turret slide is withdrawn automatically and indexed to bring the next tool into position. One revolution of camshaft produces one component. It is used for producing small jobs, screws, stepped pins, taper pins, bolts, etc. *Typical parts produced on this machine are shown in Fig. 2.89.*

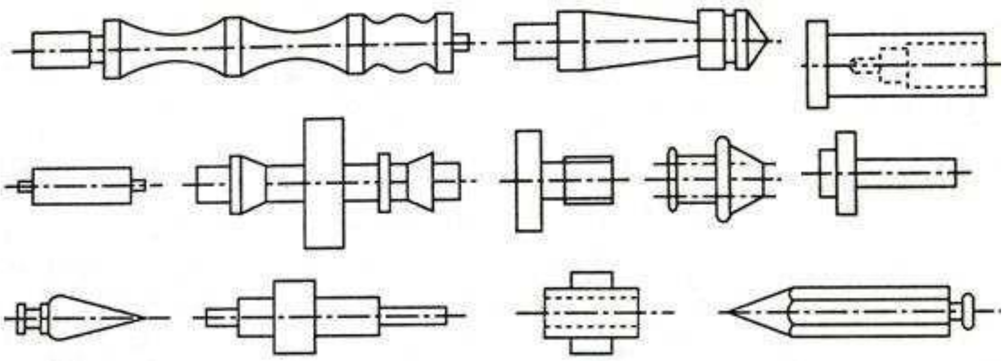


Fig. 2.89 Parts produced on single spindle automatic screw cutting machine

MULTI SPINDLE AUTOMATS

The multi spindle automats are the fastest type of production machines and are made in a variety of models with 2, 4, 5, 6 or 8 spindles. Each of the spindles is provided with its own set of tools for operation. As a result, more than one work piece can be machined simultaneously in these machines. In contrast to the single spindle automat, where one turret face at a time is working on one spindle, the multi spindle automat has all turret faces working on all spindles at the same time. The production rate of a multi spindle automat, however, is less than that of the corresponding number of single spindle automats. E.g. the production rate of a 4 spindle automat is not four times but only 2½ to 3 times more than that of a single spindle automat.

Classification of multi spindle automats

The multi spindle automats can be classified as follows:

According to the type of stock used:

- Bar stock machine.
- Chucking type machine.

According to the position of spindles:

- Horizontal spindle type.
- Vertical spindle type.

According to the principle of operation:

- Parallel action type.
- Progressive action type.

Comparison of single spindle automat and multi spindle automat

Sl . No.	Single spindle automat	Multi spindle automat
1	There is only one spindle.	There are 2,4,5,6 or 8 spindles.

2	**Only one work piece can be machined at a time.**	**More number of work pieces can be machined at a time.**
3	**The rate of production is low.**	**The rate of production is high.**
4	**Machining accuracy is higher.**	**Machining accuracy is lower.**
5	**Tool setting time is less.**	**Tool setting time is more.**
6	**Tooling cost is less.**	**Tooling cost is more.**
7	**Economical for shorter as well as longer runs.**	**Economical for longer runs only.**
8	**The time required to produce one job is the sum of all turret operation times.**	**The time required to produce one job is the time of the longest cut in any one spindle.**
9	**Tools in turret are indexed.**	**Work pieces held in spindles are indexed (Progressive action machine)**

PARALLEL ACTION MULTI SPINDLE AUTOMAT

These machines are usually automatic cutting off bar type machines. This is also called as ‘multiple-flow’ machine. In this machine, the same operation is performed on each spindle and a workpiece is finished in each spindle in one working cycle. The rate of production is very high, but the machine can be employed to machine simple parts only since all the machining processes are done at one position. *Fig. 2.90 shows the basic configuration of a parallel action multi spindle automat.*

They are used to perform the same work as single spindle automatic cutting off machines. Centering or a single drilling operation can also be performed on certain models. The machine consists of a frame with a head stock. The horizontal work spindles which are arranged in a line, one above the other, are housed in this headstock. Cross slides are located at the right and left hand sides of the spindles and carry the cross feeding tools. All the working and the auxiliary motions of the machine units are obtained from the cam mounted on the cam shaft.

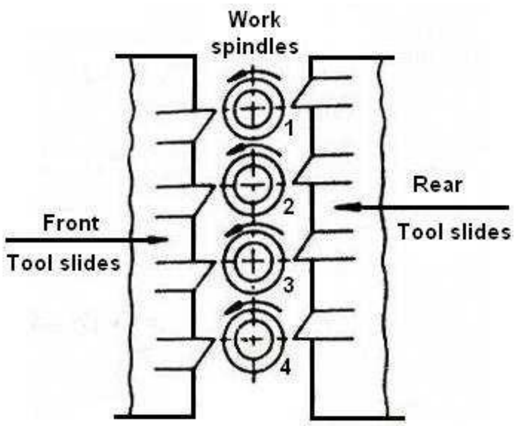


Fig. 2.90 Parallel action multi spindle automat

PROGRESSIVE ACTION MULTI SPINDLE AUTOMAT

In this machine the blanks clamped in each spindle are machined progressively in station after station.

Construction *Fig. 2.91 shows the basic configuration of a six-spindle progressive action automat.* The headstock is mounted at the left end of the base of the machine. It contains a spindle carrier which periodically indexes through a definite angle (360^0 divided by the number of spindles) about a horizontal axis through the centre of the machine at each tool retraction. The main tool slide (end tool slide), which accommodates tooling for all of the spindles, travels on the spindle carrier stem. The number of tool slides or faces is equal to the number of spindles.

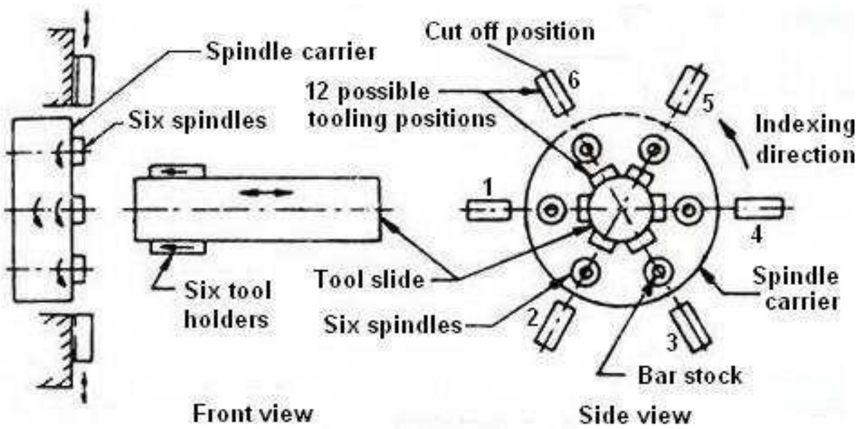


Fig. 2.91 Six-spindle progressive action automat

The working spindles are mounted in this spindle carrier. The working spindles carry the collets on which the workpieces are held. The bar stock is fed to the working spindle from the rear.

Cross slides which carry tools for operations such as cut off, turning, facing, forming, chamfering etc. are mounted in a frame above the face of the spindle carrier. These cross slides travel radially inward for cutting operation. The number of cross slides is equal to the number of spindles. The feed of each tool, both cross slide tools and end slide tools, is controlled by its own individual cam.

Working principle The spindle carrier indexes on its own axis by 60^0 ($360^0/6$) at each tool retraction. As the spindle carrier indexes, it carries the work from station to station, where various tools operate on it. The stock moves around the circle in counter clockwise direction and comes to the station number 6 for cutting off. A finished component is obtained for one full revolution of the spindle carrier. *Typical parts produced on this machine are shown in Fig. 2.92.*

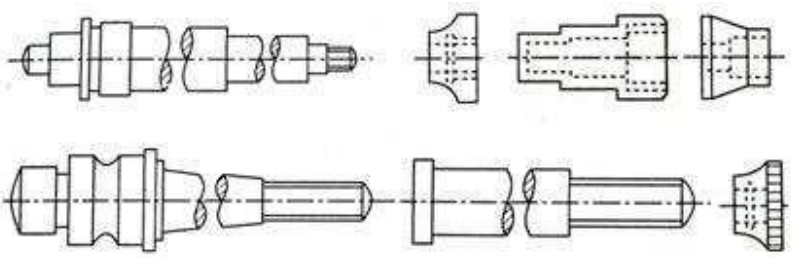


Fig. 2.92 Parts produced on multi spindle automatic lathe

Comparison of parallel action and progressive action multi spindle automat

Sl . No.	Parallel action multi spindle automat	Progressive action multi spindle automat
1	Same operation is done on all jobs in all the spindles.	Different operations are done on jobs at each station one after another.
2	In one cycle the number of components produced simultaneously is equal to the number of spindles.	It is not so. (i.e.) The number of components produced in one cycle is not equal to the number of spindles. For every indexing of component (spindle) one component is produced.
3	Rate of production is very high.	Rate of production is moderate.
4	If anything goes wrong in one station, the production in that particular station only is affected.	If anything goes wrong in one station, the production is completely affected in all the stations.
5	Small parts of simple shapes are produced.	Parts of complicate shapes can be produced.

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)

SCHOOL OF MECHANICAL ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING

UNIT - III

MANUFACTURING TECHNOLOGY II – SPR1301

UNIT - III

OTHER MACHINE TOOLS

Reciprocating machine tools: shaper, planer, slotter - Milling: types, milling cutters, operations – Hole making: Drilling - Quill mechanism, Reaming, Boring, Tapping - Sawing machine: hack saw, band saw, circular saw; broaching machines: broach construction – push, pull, surface and continuous broaching machines

RECIPROCATING MACHINE TOOLS

In lathes the work piece is rotated while the cutting tool is moved axially to produce cylindrical surfaces. But in reciprocating machine tools the single point cutting tool is reciprocates and produces flat surfaces. The flat surfaces produced may be horizontal, vertical or inclined at an angle. These machine tools can also be arranged for machining contoured surfaces, slots, grooves and other recesses. The major machine tools that fall in this type are: Shaper, Planer and Slotter. The main characteristic of this type of machine tools is that they are simple in construction and are thus economical in operation.

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. 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 and Hydraulic shaper.

According to the position and travel of ram:

- Horizontal shaper, Vertical shaper and Traveling head shaper.

According to the type of design of the table:

- Standard or plain shaper and Universal shaper.

According to the type of cutting stroke:

- Push type shaper and Draw type shaper.

According to the type of mechanism used

Crank shaper

This is the most common type of shaper in which a single point cutting tool is given a reciprocating motion equal to the length of the stroke desired while the work is clamped in position on an adjustable table. In construction, the crank shaper employs a crank mechanism to change circular motion of “bull gear” to reciprocating motion of the ram.

Geared type shaper

The reciprocating motion of the ram is some type of shaper is effect by means of a rack and pinion. The rack teeth which are cut directly below the ram mesh with a spur gear. The pinion meshing with the rack is driven by a gear train. The speed and the direction in which the ram will traverse depend on the number of gears in the gear train. This type of shaper is not very widely used.

Hydraulic shaper

In a hydraulic shaper, reciprocating movement of the ram is obtained by hydraulic power. Oil under high pressure is pumped into the operating cylinder fitted with a piston. The end of the piston rod is connected to the ram. The high pressure oil first acts on one side of the piston and then on the other causing the piston to reciprocate and the motion is transmitted to the ram. The speed of the ram is changed by varying the amount of liquid delivered to the piston by the pump.

According to the position and travel of ram

Horizontal shaper

In a horizontal shaper, the ram holding the tool reciprocates in a horizontal axis. Horizontal shapers are mainly used to produce flat surfaces.

Vertical shaper

In a vertical shaper, the ram holding the tool reciprocates in a vertical axis. The work table of a vertical shaper can be given cross, longitudinal, and rotary movement. Vertical shapers are very convenient for machining internal surfaces, keyways, slots or grooves. Large internal and external gears may also be machined by indexing arrangement of the rotary table. The vertical shaper which is specially designed for machining internal keyway is called as Keyseater.

Travelling head shaper

The ram carrying the tool while it reciprocates moves crosswise to give the required feed. Heavy jobs which are very difficult to hold on the table of a standard shaper and fed past the tool are held static on the basement of the machine while the ram reciprocates and supplies the feeding movements.

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

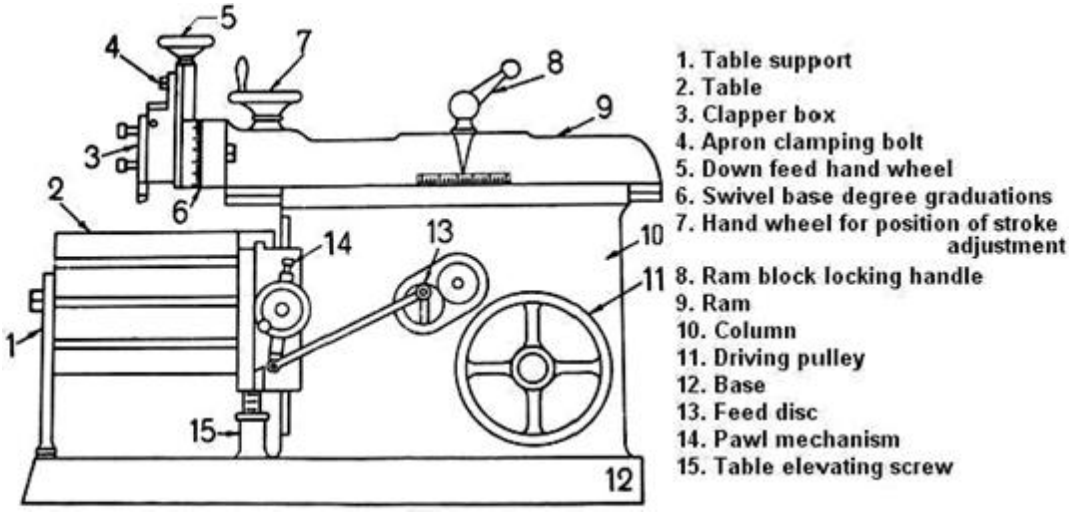


Fig. shows the basic configuration of a standard shaper. The major parts are:
Fig. Schematic view of a standard shaper

Base It provides the necessary support to the machine tool. It is rigidly bolted to the shop floor. All parts are mounted on the base. It is made up of cast iron to resist vibration and take up high compressive load. It takes the entire load of the machine and the forces set up by the cutting tool during machining.

Column It is a box like casting mounted upon the base. It encloses the drive mechanisms for the ram and the table. Two accurately machined guide ways are provided on the top of the column on which the ram reciprocates. The front vertical face of the column which serves as the guide ways for the cross rail is also accurately machined.

Cross rail It is mounted on the front vertical guide ways of the column. It has two parallel guide ways on its top in the vertical plane that is perpendicular to the ram axis. The table may be raised or lowered to accommodate different sizes of jobs by rotating an elevating screw which causes the cross rail to slide up and down on the vertical face of the column. A horizontal cross feed screw which is fitted within the cross rail and parallel to the top guide ways of the cross rail actuates the table to move in a crosswise direction.

Saddle It is mounted on the cross rail which holds the table firmly on its top. Crosswise movement of the saddle by rotating the cross feed screw by hand or power causes the table to move sideways.

Table It is bolted to the saddle receives crosswise and vertical movements from the saddle and cross rail. It is a box like casting having T-slots both on the top and sides for clamping the work. In a universal shaper the table may be swiveled on a horizontal axis and the upper part of the table may be tilted up or down. In a heavier type shaper, the front face of the table is clamped with a table support to make it more rigid.

Ram It holds and imparts cutting motion to the tool through reciprocation. It is connected to the reciprocating mechanism contained within the column. It is semi cylindrical in form and heavily ribbed inside to make it more rigid. It houses a screwed shaft for altering the position of the ram with respect to the work and holds the tool head at the extreme forward end.

Tool head It holds the tool rigidly, provides the feed movement of the tool and allows the tool to have an automatic relief during its return stroke. The vertical slide of the tool head has a swivel base which is held on a circular seat on the ram. So the vertical slide may be set at any desired angle. By rotating the down feed screw handle, the vertical slide carrying the tool executes the feed or depth of cut. The amount of feed or depth of cut may be adjusted by a micrometer dial on the top of the down feed screw. Apron consisting of clapper box, clapper block and tool post is clamped upon the vertical slide by a screw. By releasing the clamping screw, the apron may be swiveled upon the apron swivel pin with respect to the vertical slide. This arrangement is necessary to provide relief to the tool while making vertical or angular cuts. The two vertical walls on the apron called clapper box houses the clapper block which is connected to it by means of a hinge pin. The tool post is mounted upon the clapper block. On the forward cutting stroke the clapper block fits securely to the clapper box to make a rigid tool support. On the return stroke a slight frictional drag of the tool on the work lifts the block out of the clapper box a sufficient amount preventing the tool cutting edge from dragging and consequent wear. The work surface is also prevented from any damage due to dragging. *Fig. illustrates the tool head of a shaper*.

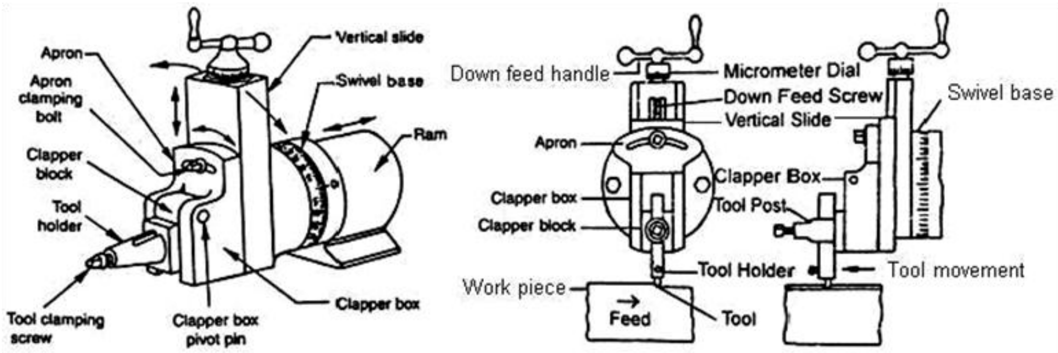
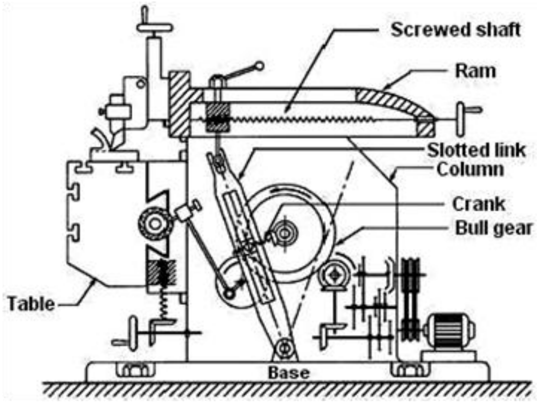


Fig. Tool head of a shaper

Working principle of a standard shaper



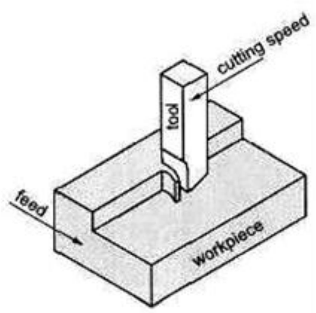


Fig. (a) Kinematic system of a shaper Fig. (b) Principle of producing flat surface

Fig. (a) schematically shows the kinematic system of a standard shaper. Fig (b) shows the basic principle of producing flat surface in a standard shaper. The bull gear receives its rotation from the motor through the pinion. The rotation of the crank causes oscillation of the link and thereby reciprocation of the ram and hence the tool in straight path. The cutting motion provided by the reciprocating tool and the intermittent feed motion provided by the slow transverse motion of the work at different rate by using the ratchet - pawl system along with the saddle result in producing a flat surface by gradual removal of excess material layer by layer in the form of chips.

The vertical infeed is given either by descending the tool holder or raising the cross rail or both. Straight grooves of various curved sections are also made in shaper by using specific form tools. The single point straight or form tool is clamped in the vertical slide of the tool head, which is mounted at the front face of the reciprocating ram. The work piece is clamped directly on the table or clamped in a vice which is mounted on the table. *The changes in length of stroke and position of the stroke required for different machining are accomplished respectively by:*

- Adjusting the crank length by rotating the bevel gear mounted coaxially with the bull gear.
- Shifting the ram block nut by rotating the lead screw.

Ram drive mechanism of a shaper

In a shaper, rotary movement of the drive is converted into reciprocating movement of the ram by the mechanism contained within the column of the machine. In a standard shaper metal is removed in the forward cutting stroke and during the return stroke no metal is removed. To reduce the total machining time it is necessary to reduce the time taken by the return stroke. Thus the shaper mechanism should be so designed that it can allow the ram to move at a comparatively slower speed during the forward cutting stroke and during the return stoke it can allow the ram to move at a faster rate to reduce the idle return time. This mechanism is known as quick return mechanism. The reciprocating movement and the quick return of the ram are usually obtained by using any one of the following mechanisms.

Crank and slotted link quick return mechanism

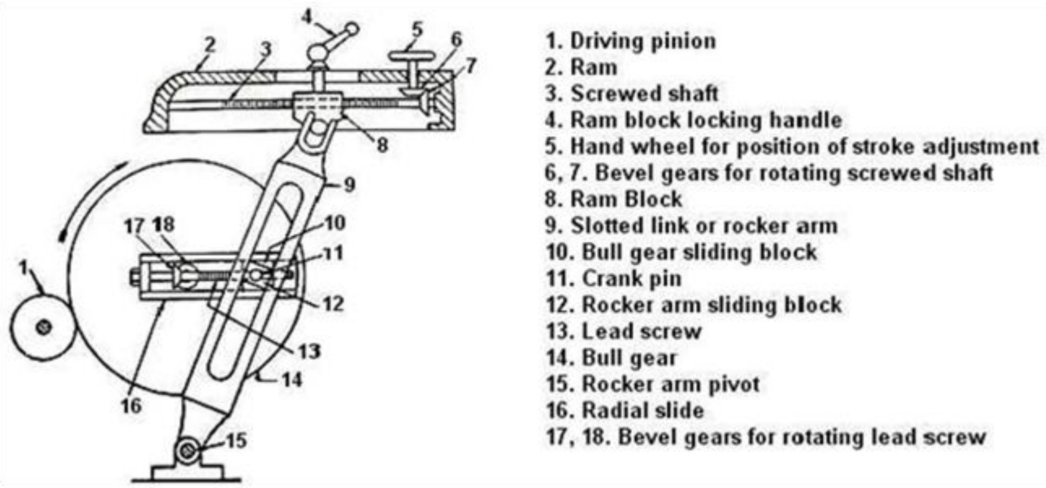
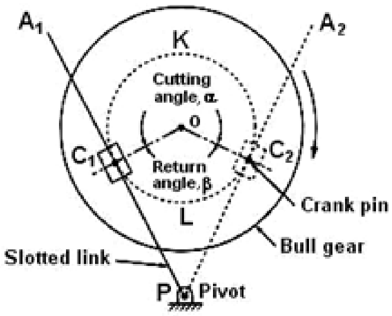


Fig. Crank and slotted link quick return mechanism

The crank and slotted link quick return mechanism is shown in Fig. 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. Principle of quick return motion

The principle of quick return motion is illustrated in Fig. 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. 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. (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. (b) shows the short and long stroke of the ram, effect by altering the position of the crank pin.*

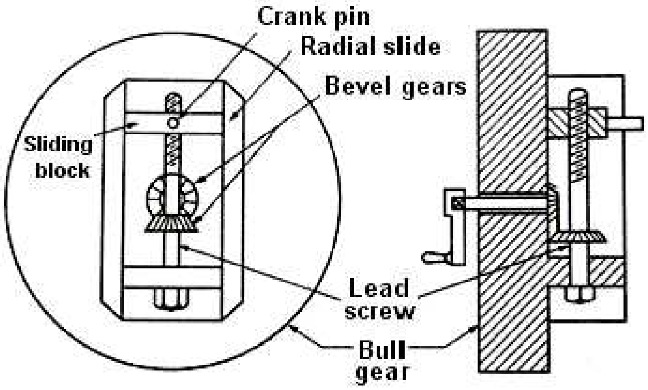


Fig. (a) Arrangement of bull gear sliding block

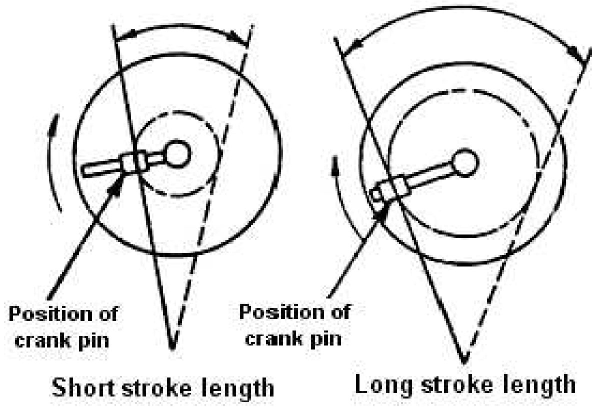
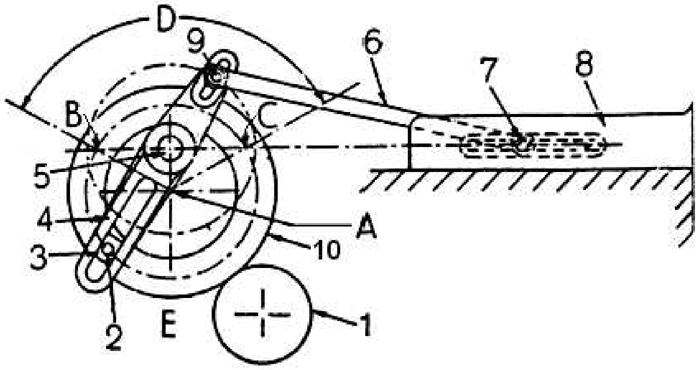


Fig. (b) Short and long stroke length

Adjusting the position of stroke

The position of the ram relative to the work can also be adjusted. *Referring to the Fig.,* 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.

Whitworth quick return mechanism



A. Fixed pin
1. Driving pinion
2. Crank pin
3. Crank plate sliding block
4. Crank plate
5. Pivot for crank plate
6. Connecting rod
7. Connecting pin for ram
8. Ram
9. Connecting pin for crank plate
10. Bull gear

Fig. Whitworth quick return mechanism

The Whitworth quick return mechanism is shown in Fig. The bull gear is mounted on a large fixed pin A upon which it is free to rotate. The motion or power is transmitted to the bull gear through a pinion which receives its motion from an individual motor. The crank plate is pivoted eccentrically upon the fixed pin at 5. The crank pin is fitted on the face of the bull gear. The crank plate sliding block is mounted upon the crank pin and it fits into the slot provided on the crank plate. The crank plate sliding block can slide inside the slot. At the other end of the crank plate, a connecting rod connects the crank plate and the ram by two pin 9 and 7. When bull gear will rotate at a constant speed the crank pin with the sliding block will rotate on a crank circle of radius A2 and the sliding block will cause the crank plate to rotate about the point 5 with a variable angular velocity. Pin 9 fitted on the other end of the crank plate will rotate in a circle and the rotary motion of the pin 9 will be converted into reciprocating movement of the ram similar to the crank and connecting rod mechanism. The axis of reciprocating of the ram passes through the pin 5 and is normal to the line A5.

When the crank pin 2 is at the point C the ram will be at the extreme backward position of its stroke. When the crank pin 2 is at the point B the ram will be at the extreme forward position of its stroke. Therefore the forward cutting stroke takes place when the crank pin rotates through the angle CEB (α) and the return stroke takes place when the crank pin rotates through the angle BDC (β). It is clear that the angle α made by the forward or cutting stroke is greater than the angle β described by the return stroke. The angular velocity of the crank pin being constant, therefore the return stroke is completed within a shorter time for which it is known as quick return motion. The length of stroke of the ram may be changed by shifting the position of pin 9 closer or away from the pivot 5. The position of stroke may be altered by shifting the position of pin 7 on the ram.

Hydraulic drive quick return mechanism

A typical hydraulic drive for horizontal shaper is shown in Fig. A constant speed motor drives a hydraulic pump which delivers oil at a constant pressure to the line. A regulating valve admits oil under pressure to each end on the piston alternately, at the same time allowing oil from the opposite end of the piston to return to the reservoir.

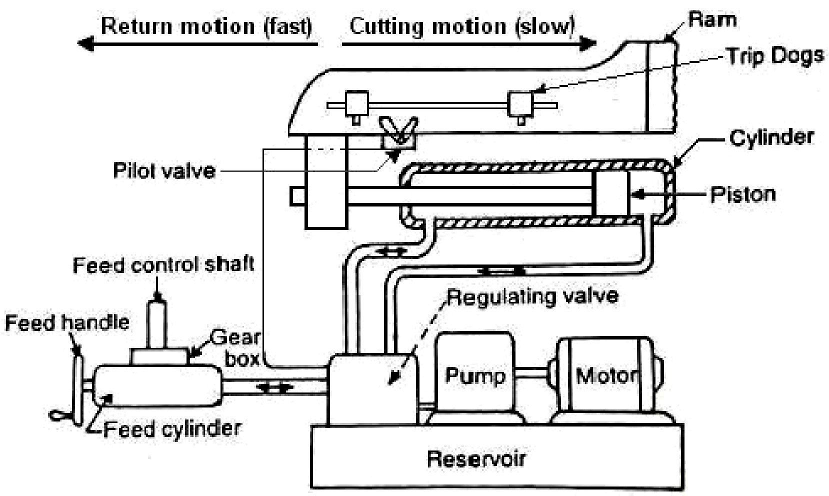


Fig. Hydraulic drive for horizontal shaper

The piston is pushed by the oil and, being connected to the ram by the piston rod, pushes the ram carrying the tool. The admission of oil to each end of the piston, alternately, is accomplished with the help of trip dogs and pilot valve. As the ram moves and completes its stroke (forward or return) a trip dog will trip the pilot valve which operates the regulating valve. The regulating valve will admit the oil to the other side of the piston and the motion of the ram will get reversed. It is clear that the length of the ram stroke will depend upon the position of the trip dogs. The length of the ram stroke can be changed by unclamping and moving the trip dogs to the desired positions.

The above system is a constant pressure system. The velocity of the ram travel will be directly proportional to the oil pressure and the piston area to which it is applied. The return stroke is quicker, since the piston area on which the oil pressure acts is greater as compared to the other end for which it gets reduced because of the piston rod. Another oil line is connected to a smaller feed cylinder to change the hydraulic power to mechanical power for feeding the work past the tool.

Advantages of Hydraulic drive

- Does not make any noise and operates very quietly.
- Ability to stall against an obstruction without damage to the tool or the machine.
- Ability to change length and position of stroke or speed while the machine is running.
- The cutting and return speeds are practically constant throughout the stroke. This permits the cutting tool to work uniformly during cutting stroke.
- The reversal of the ram is obtained quickly without any shock as the oil on the other end of the cylinder provides cushioning effect.
- Offers great flexibility of speed and feed and the control is easier.
- The hydraulic drive shows a very nearly constant velocity as compared with a mechanical drive, which has a constantly changing velocity because the horizontal component of the crankpin moving about its circle is constantly changing. *The velocity diagram is shown in Fig.*

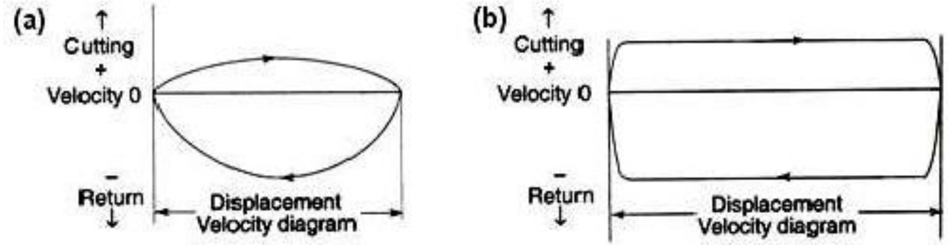


Fig. Velocity diagram of (a) Crank shaper and (b) Hydraulic shaper

On the other hand, a mechanical shaper has the following plus points: Lower first cost and simpler in operation. The cutting stroke has a definite stopping point.

F

eed mechanism of a shaper

The mechanism used for providing feed is known as feed mechanism. In a shaper both down Feed and cross feed movements may be obtained. Unlike a lathe, these feed movements are provided intermittently and during the end of return stroke only. Vertical or bevel surfaces are produced by rotating the down feed screw of the tool head by hand. This movement of the tool is called down feed.

The horizontal movement of table is called cross feed. Cross feed movement is used to machine a flat horizontal surface. The cross feed of the table is effect by rotating the cross feed screw. This screw is

engaged with a nut fitted in the table. Rotation of the cross feed screw causes the table mounted upon the saddle to move sideways on the cross rail. Cross feed is given either by hand or power. If this screw is rotated manually by handle, then it is called hand feed. If this screw is rotated by power, then it is called automatic feed. The power is given through an automatic feed mechanism. *The down feed and cross feed mechanism of a shaper is schematically shown in Fig.*

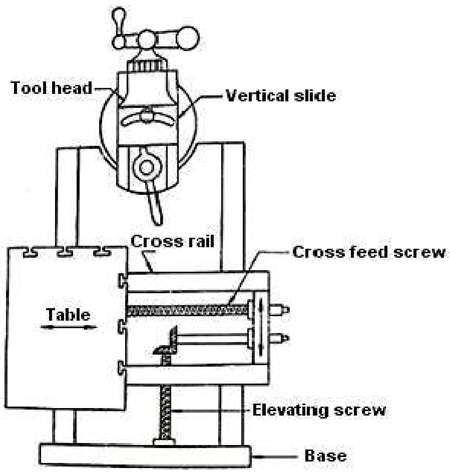


Fig. Down feed and cross feed mechanism

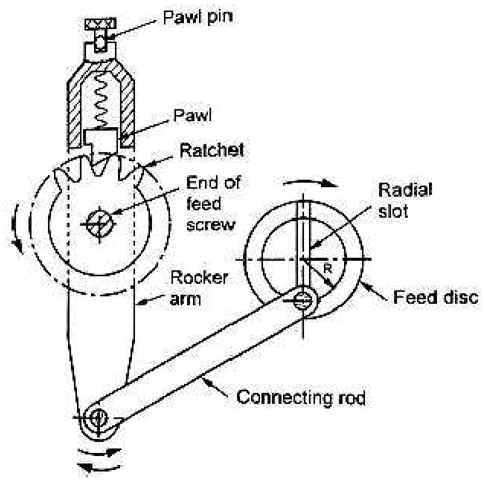


Fig. Automatic feed mechanism

Automatic feed mechanism of a shaper

Fig. 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.

Work holding devices used in a shaper

The top and side of the table of a shaper have T-slots for clamping the work piece. The work piece may be supported on the shaper table by using any one of the following work holding devices depending upon the geometry of the work piece and nature of the operation to be performed.

- Machine vise.
- Clamping work on the table.
- Angle plate.
- V-blocks.
- Shaper centre.

Machine vise

A vise is a quick method of holding and locating small and regular shaped work pieces. It consists of a base, screw, fixed jaw and movable jaw. The work piece is clamped between fixed and movable jaws by rotating the screw. Types of machine vise are plain vise, swivel vise and universal vise.

A plain vise is the most simple of all the types. The vise may have a single screw or double screws for actuating the movable jaw. The double screws add gripping strength while taking deeper cuts or handling heavier jobs. *Fig. (a) illustrates a plain vise.*

In a swivel vise the base is graduated in degrees, and the body of the vise may be swiveled at any desired angle on a horizontal plane. The swiveling arrangement is useful in beveling the end of work piece. *Fig. (b) illustrates a swivel vise.*

A universal vise may be swiveled like a swivel vise. In addition to that, the body may be tilted in a vertical plane up to 90 degrees from the horizontal. An inclined surface may be machined by a universal vise. *Fig. (c) illustrates a universal vise.*

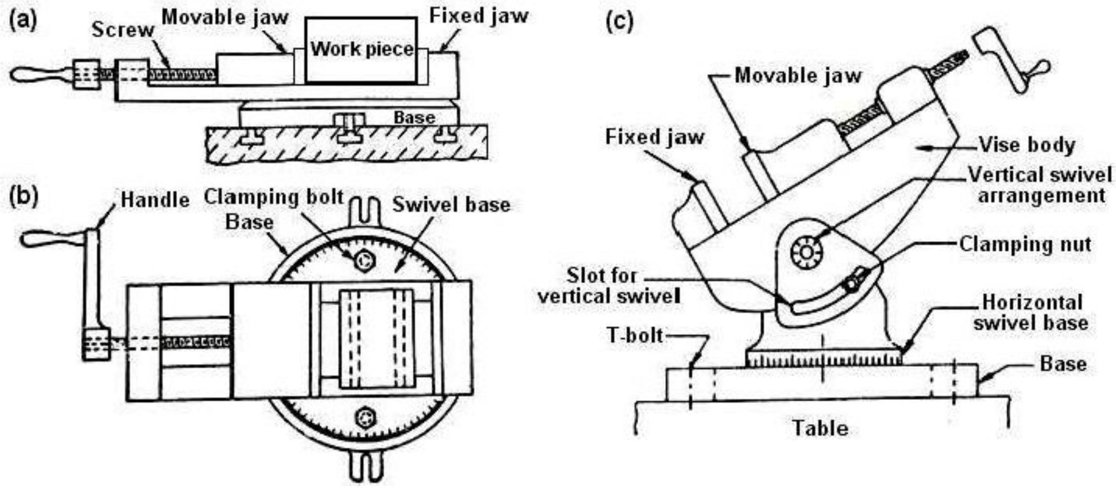


Fig. Machine vise (a) Plain vise (b) Swivel vise and (c) Universal vise

Parallels When the height of the job is less than the height of the jaws of the vise, parallels are used to raise and seat the work piece above the vise jaws and parallel with the vise bottom. Parallels are square or rectangular hardened bars of steel or cast iron. *Fig 3.13 illustrates the use of parallels.*

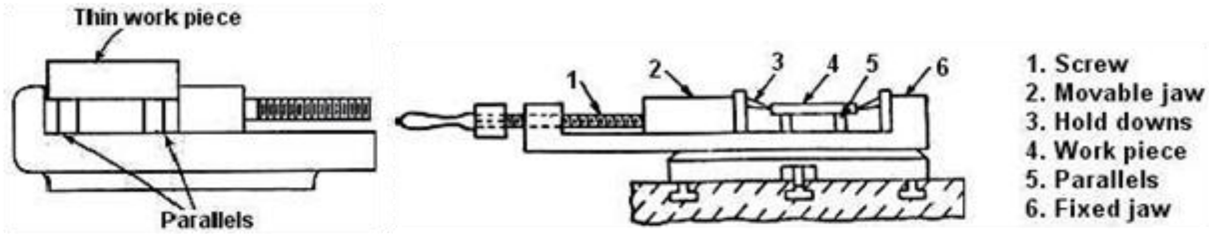


Fig. Use of parallels and Use of hold downs

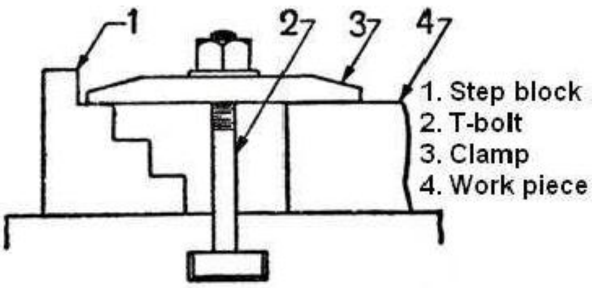
Hold downs *Fig illustrates the use of hold downs.* Hold downs or grippers are used for holding thin pieces of work in a shaper vise. These are also used for holding work of smaller height than the vise jaws. These are hardened wedge shaped piece with a taper angle of 5^0. These are placed between two jaws of the vise and the work piece. When the screw is tightened the typical shape of the hold down exerts downward pressure on the work to hold it tight on the parallels or on the vise table.

Clamping work on the table

When the work piece is too large to be held in a vise it must be fastened directly on the shaper table. The different methods employed to clamp different types of work on a shaper table are:

- T-bolts, step blocks and clamps.
- Stop pins.
- Stop pins and toe dogs.
- Strip and stop pins.

T-bolts, step blocks and clamps *Fig. illustrates the use of T-bolt and clamp for holding the work.* T-bolt having T-head is fitted in the T-slot of the table. The length of the threaded portion is sufficiently long in order to accommodate different heights of work. One end of the clamp rests on the side of the work while the other end rests on a fulcrum block or step block. The fulcrum block should be of the same height as the part being clamped. To hold a large work on the table a series of clamps and T- bolts are used all round the work.



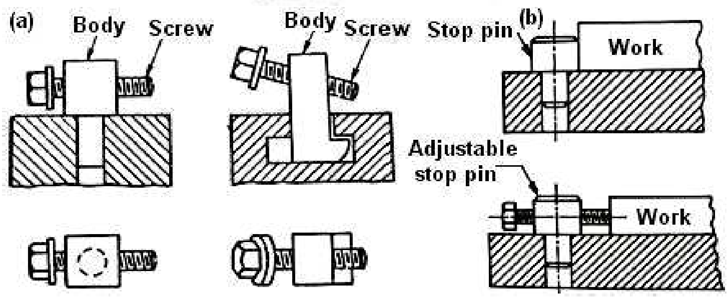
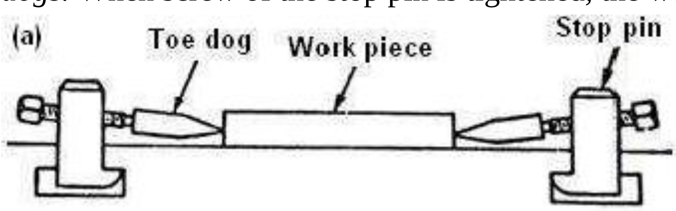


Fig. Use of T-bolt, step block and clamp

Fig. (a) Stop pins and (b) Use of stop pins

Stop pins *Fig. (a) illustrates the stop pins and Fig. (b) illustrates the use of stop pins.* A stop pin is a one-leg screw clamp. Stop pins are used to prevent the work piece from coming out of position during the cutting stroke. The body of the stop pin is fitted in the slot on the table and the screw is tightened till it forces against the work.

Stop pins and toe dogs *Fig. (a) illustrates the use of stop pins and toe dogs.* While holding thin work on the table stop pins in conjunction with toe dogs are used. A toe dog is similar in shape to that of a centre punch or a cold chisel. *Fig. (b) shows the two types of toe dogs.* When screw of the stop pin is tightened, the work is gripped down on the table.



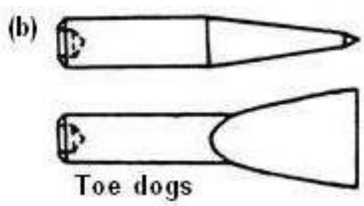
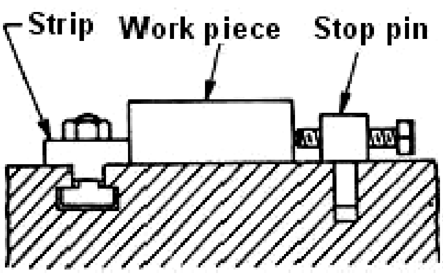


Fig. (a) Use of stop pins and toe dogs

Fig. (b) Toe dogs

Strip and stop pin Work having sufficient thickness is held on the table by strip and stop pin. A strip is a long bar having a tongue with holes for fitting the T-bolts. The strip with bolts is fitted in the T-slot of the table. *Fig. illustrates the use of strip and stop pin for holding the work.*



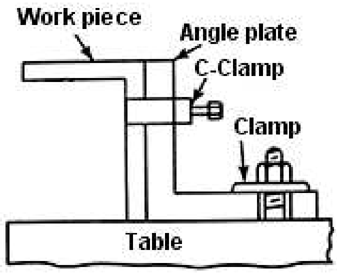


Fig. Use of strip and stop pin

Fig. Use of angle plate

Angle plate *Fig. illustrates the use of angle plate.* For holding "L" shaped work piece, angle plate is used. Angle plate is made of cast iron and is accurately planed on two sides at right angles. One of the sides is clamped to the table by T-bolts while the other side holds the work by clamps.

V-blocks *Fig. illustrates the use of V-blocks.* V-blocks are used for holding round rods. Work piece may be supported on two V-blocks at its two ends and is clamped to the table by T-bolts and clamps. V-blocks are made of cast iron or steel and are accurately machined.

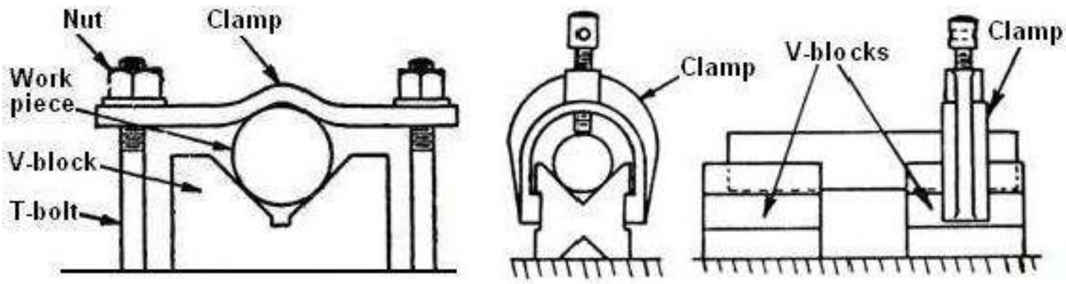


Fig. Use of V-blocks

Shaper centre

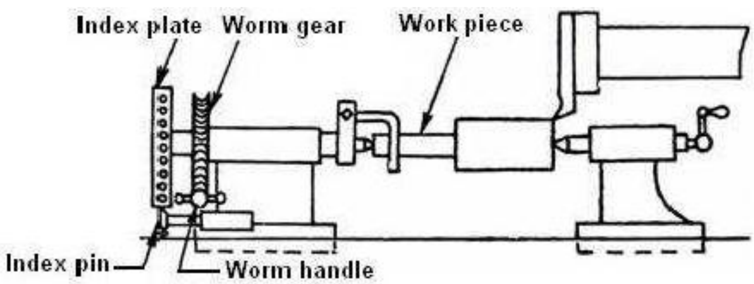


Fig. Use of shaper centre

Fig. illustrates the shaper center. This is a special attachment used for cutting equally spaced grooves or splines and gears. A shaper centre consists of a headstock and a tailstock, and the work is mounted between two centres. The worm gear is mounted upon the head stock spindle and it meshes with the worm. The handle is connected with the worm shaft. Rotation of the handle causes the worm gear to rotate and the motion is transmitted to the work through a catch plate and carrier. After cutting a slot or groove on the top of the work, it may be turned to a predetermined amount by an index plate. The index plate is mounted on the worm gear shaft. The index plate has a series of holes around itscircumference and is locked in any desired position by engaging the index pin in the corresponding hole.

Shaper tools

The cutting tool used in a shaper is a single point cutting tool having rake, clearance and other tool angles similar to a lathe tool. It differs from a lathe tool in tool angles. Shaper tools are much more rigid and heavier to withstand shock experienced by the cutting tool at the commencement of each cutting stroke. In a shaper tool the amount of side clearance angle is only 2^0 to 3^0 and the front clearance angle is 4^0 for cast iron and steel. Small clearance angle adds strength to the cutting edge.

As the tool removes metal mostly from its side cutting edge, side rake of 10^0 is usually provided with little or no rake. A shaper can also use a right hand or left hand tool. High speed steel is the most common material for a shaper tool but shock resistant cemented carbide tipped tool is also used where harder material is to be machined. As in a lathe, tool holders are also used to hold the tool bits.

Classification of shaper tools The shaper tools are classified as follows: ***According to the shape:***

- Straight tool.
- Cranked tool.
- Goose necked tool.

According to the direction of cutting:

- Left hand tool.
- Right hand tool.

According to the finish required:

- Roughing tool.
- Finishing tool.

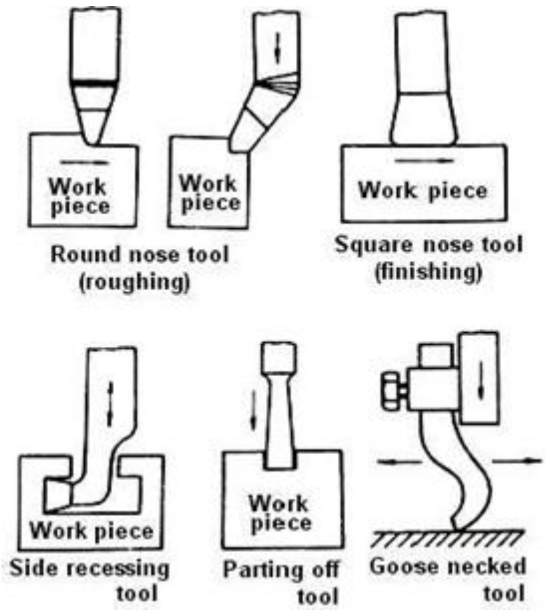
According to the type of operation:

- Down cutting tool.
- Parting off tool.
- Squaring tool.
- Side recessing tool.

According to the shape of the cutting edge:

- Round nose tool.
- Square nose tool.

Commonly used shaper tools are shown in Fig.



Round nose tool: This is used for roughing operations. The tool has no top rake. It has side rake angle, in between 10 to 20^0. Round tool is of two types - plain and bent types. The plain straight type is used for rough machining of horizontal surface. Round nose tool can be left handed or right handed. Another type of round nose tool which is cranked or bent is used for machining vertical surfaces. It is known as round nose cutting down tool.

Square nose tool: This tool is used for finishing operations. The cutting edge may have different widths. It is also used to machine the bottom surfaces of key ways and grooves.

Side recessing tool: This is a special tool used for machining T-slots and narrow vertical surfaces. This tool can be both left handed and right handed.

Parting off tool: This is used for parting off operation. It is also used for cutting narrow slots. It has no side rake angle. It has front and side clearance angle of 3^0.

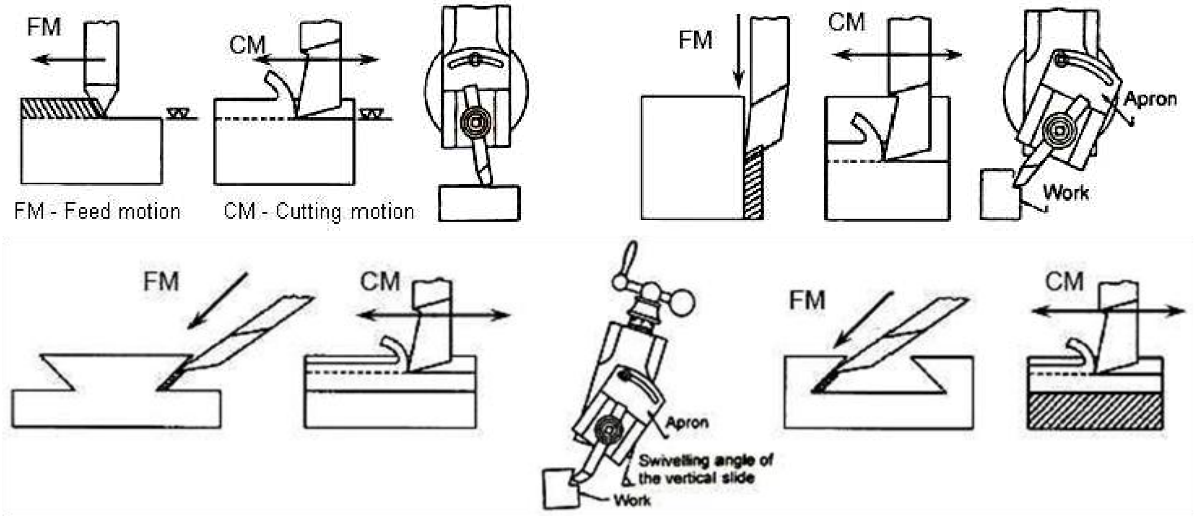
Goose necked tool: This is also known as spring tool. The special shape of tool reduces chatter and prevents digging of tool into the work piece. This tool is generally used for finishing cast iron.

Shaper operations

A shaper is a versatile machine tool primarily designed to generate a flat surface by a single point cutting tool. But it may also be used to perform many other operations. The different operations which a shaper can perform are as follows:

Machining flat surfaces in different planes

Fig. shows how flat surfaces are produced in a shaper by single point cutting tools in (a) Horizontal (b) Vertical and (c) Inclined planes.



(a) Horizontal surface (b) Vertical surface
(c) Inclined surfaces (dovetail slides and guides)
Fig. Machining of flat surfaces in a shaper

Making features like slots, steps etc. which are also bounded by flat surfaces

Fig. visualizes the methods of machining (a) Slot (b) Pocket (c) T-slot and (d) V-block in a shaper by single point cutting tools.

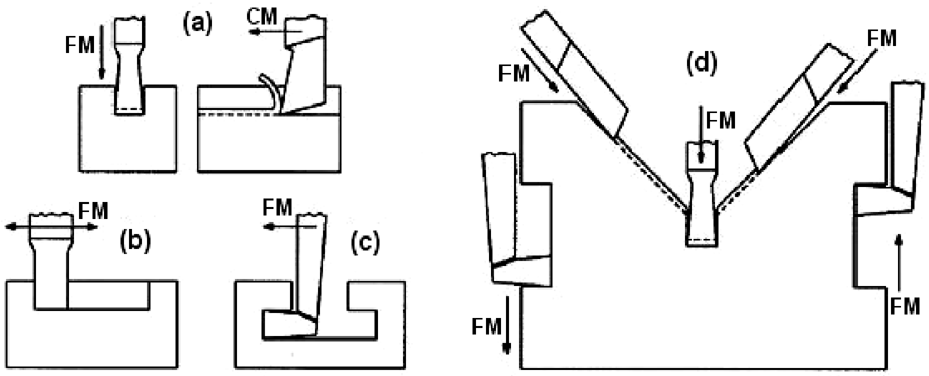


Fig. Machining (a) Slot (b) Pocket (c) T-slot and (d) V-block in a shaper

Forming grooves bounded by short width curved surfaces

Fig. typically shows how oil groove and contour form are made in a shaper by using single point form tools.

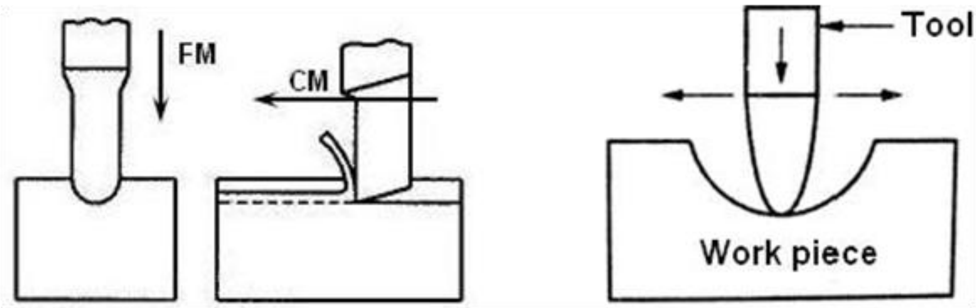


Fig. Making grooves in a shaper by form tools

Cutting external and internal keyways

Fig visualizes the methods of machining (a) External keyway and (b) Internal keyway in a shaper by using single point tools.

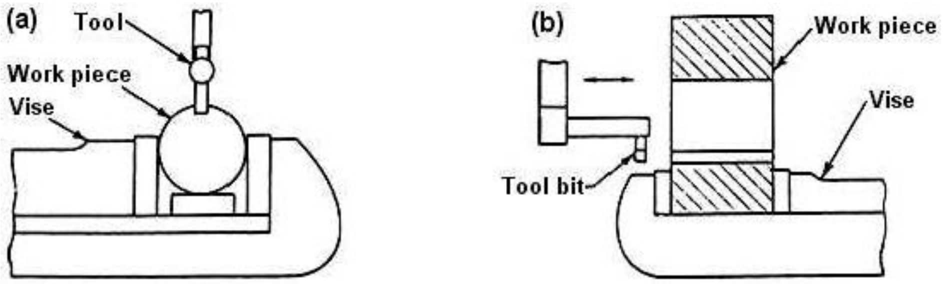
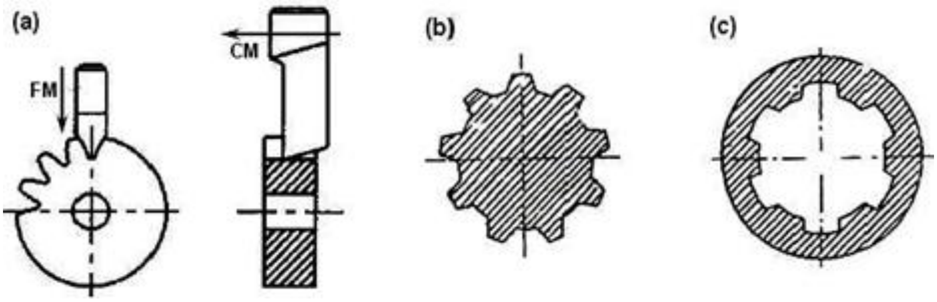


Fig. Machining of (a) External keyway and (b) Internal keyway in a shaper

Machining of external gears, external and internal splines

Fig. visualizes the methods of machining (a) External gear (b) External splines and (c)



Internal splines by using a shaper centre with single point tools.

Fig. Machining of (a) External gear (b) External splines and (c) Internal splines in a shaper

Some other machining applications of shaper are smooth slitting or parting, cutting teeth of rack for repair etc. using simple or form type single point cutting tools. Some unusual work can also be done, if needed, by developing and using special attachments. However, due to very low productivity, less versatility and poor process capability, shapers are not employed for lot and batch production. Such low cost primitive machine tools may be reasonably used only for little or few machining work on one or few work pieces required for repair and maintenance work in small machine shops.

Special attachments used in a shaper

Some special attachments are often used for extending the processing capabilities of a shaper and also for getting some unusual work in an ordinary shaper.

Double cut attachment

This simple attachment is rigidly mounted on the vertical face of the ram replacing the clapper box. It is comprised of a fixed body with two working flat surfaces and a swing type tool holder having two tools on either faces. The tool holder is tilted by a spring loaded lever which is moved by a trip dog at the end of its strokes. Such attachment simply enhances the productivity by utilizing both the strokes in shaping machines.

Thread rolling attachment

The thread of fasteners is done by mass production methods. Thread rolling is hardly done nowadays in shaping machines. However the configuration, mounting and the working principle of the thread rolling attachment are *visualized in Fig. 3.29.* In between the flat dies

, one fixed and one reciprocating, the blanks are pushed and thread - rolled one by one.

P

LANER

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. Types of planer

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

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

S

tandard 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. 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. shows an open side planer.*

Pit planer

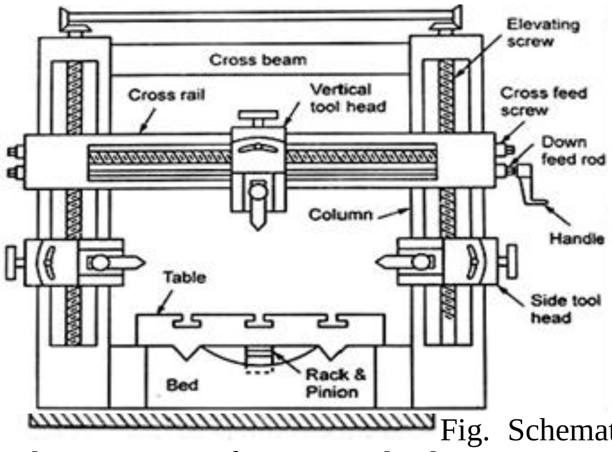
It is massive in construction. It differs from an ordinary planer in that the table is stationary and the column carrying the cross rail reciprocates on massive horizontal rails mounted on both sides of the table. This type of planer is suitable for machining a very large work which cannot be accommodated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



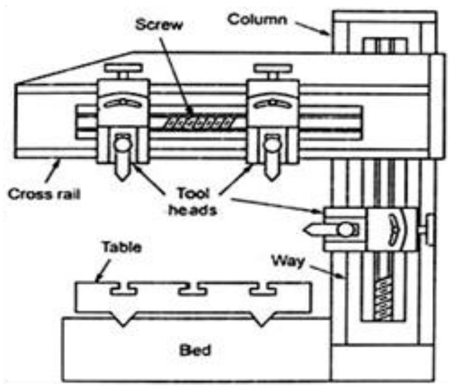


Fig. Schematic view of a double housing planer Fig. Schematic view of an open side planer

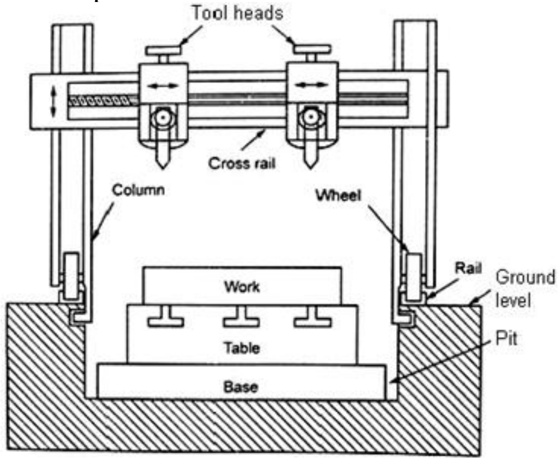


Fig. Schematic view of a pit planer Fig. Schematic view of an edge planer

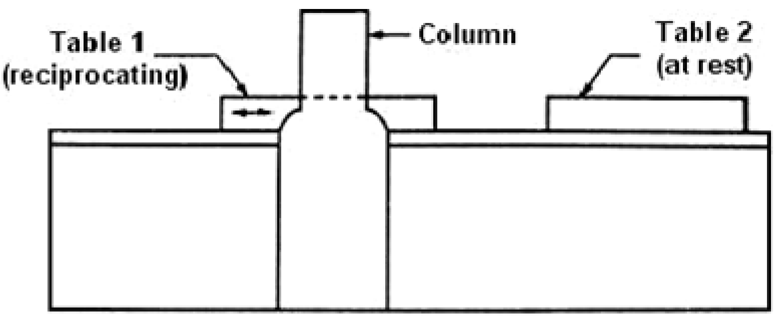


Fig. Schematic view of a divided table planer

Major parts of a double housing planer

Fig shows the basic configuration of a double housing planer. The major parts are:

Bed It is box like casting having cross ribs. It is a very large in size and heavy in weight and it supports the column and all other moving parts of the machine. The bed is made slightly longer than twice the length of the table so that the full length of the table may be moved on it. It is provided with precision ways over the entire length on its top surface and the table slides on it. The hollow space within the box like structure of the bed houses the driving mechanism for the table.

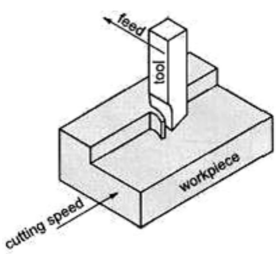
Table It supports the work and reciprocates along the ways of the bed. The top face of the planer table is accurately finished in order to locate the work correctly. T-slots are provided on the entire length of the table so that the work and work holding devices may be bolted upon it. Accurate holes are drilled on the top surface of the planer table at regular intervals for supporting the poppet and stop pins. At each end of the table a hollow space is left which acts as a trough for collecting chips. Long works can also rest upon the troughs. A groove is cut on the side of the table for clamping planer reversing dogs at different positions.

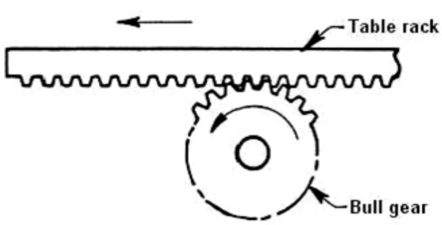
Housing It is also called columns or uprights are rigid box like vertical structures placed on each side of the bed and are fastened to the sides of the bed. They are heavily ribbed to trace up severe forces due to cutting. The front face of each housing is accurately machined to provide precision ways on which the cross rail may be made to slide up and down for accommodating different heights of work. Two side-tool heads also slide upon it. The housing encloses the cross rail elevating screw, vertical and cross feed screws for tool heads, counterbalancing weight for the cross rail, etc. these screws may be operated either by hand or power.

Cross rail It is a rigid box like casting connecting the two housings. This construction ensures rigidity of the machine. The cross rail may be raised or lowered on the face of the housing and can be clamped at any desired position by manual, hydraulic or electrical clamping devices. The two elevating screws in two housing are rotated by an equal amount to keep the cross rail horizontal in any position.

The front face of the cross rail is accurately machined to provide a guide surface for the tool head saddle. Usually two tool heads are mounted upon the cross rail which are called railheads. The cross rail has screws for vertical and cross feed of the tool heads and a screw for elevating the rail. These screws may be rotated either by hand or by power.

Tool head It is similar to that of a shaper both in construction and operation.





Working principle of a double housing planer

Fig. Principle of producing flat surface　　　Fig. Meshing of bull gear with table rack

Fig. shows the basic principle of producing flat surface in a planer. The work piece is mounted on the reciprocating table and the tools are mounted on the tool heads. The tool heads holding the cutting tools are moved horizontally along the cross rail by screw-nut system and the cross rail is again moved up and down along the vertical rails by another screw-nut pair. The simple kinematical system of the planer enables transmission and transformation of rotation of the main motor into reciprocating motion of the large work table and the slow transverse feed motions (horizontal and vertical) of the tool heads. The reciprocation of the table, which imparts cutting motion to the work piece, is attained by rack and pinion (bull gear) mechanism. *Fig. illustrates meshing of the bull gear with the table rack.* The rack is fitted with the table at its bottom surface and the pinion is fitted on the output shaft of the speed gear box. The feed to the tool is given at the end of the return stroke.

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. schematically shows the open and cross belt drive quick return mechanism of a planer.*

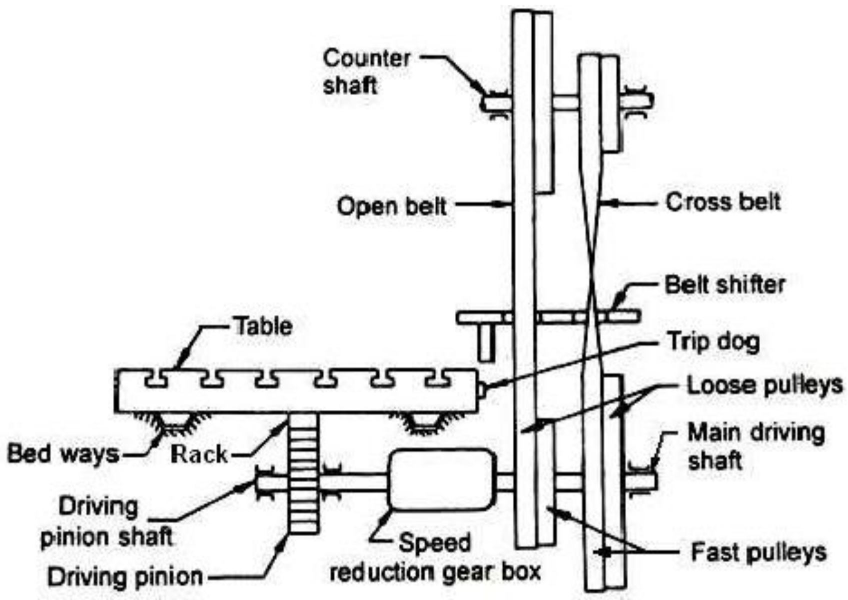


Fig. Open and cross belt drive quick return mechanism

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. 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. schematically shows the reversible motor drive quick return mechanism of a planer.*

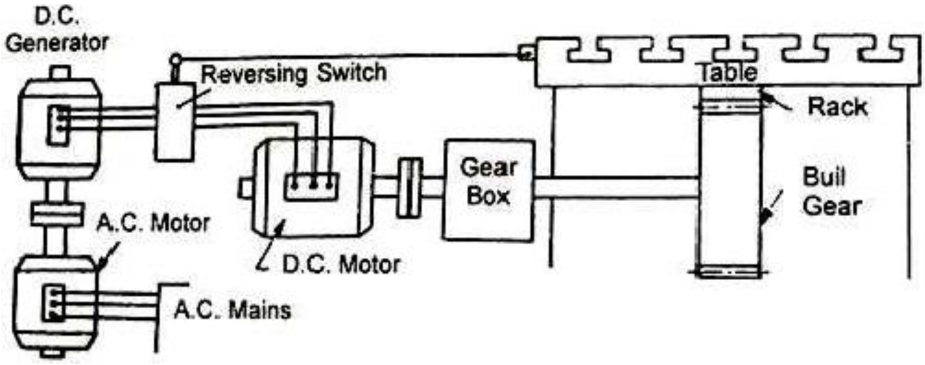


Fig. Reversible motor drive quick return mechanism

This system consists of an AC motor which is coupled with a DC generator, a DC motor and a reversing switch. When the AC motor runs, the DC motor will receive power from the DC generator. At that time, the table moves in forward direction. At the end of this stroke, a trip dog actuates an electrical reversing switch. Due to this action, it reverses the direction of current in DC generator with increased current strength. Now, the motor rotates in reverse direction with higher speed. So, the table moves in the reverse direction to take the return stroke with comparatively high speed. Thus the quick return motion is obtained by the mechanism.

The distinct advantages of electrical drive over a belt drive are:

- Cutting speed, stroke length and stroke position can be adjusted without stopping the machine.
- Large number of cutting speeds and return speeds are available.
- Quick and accurate control. Push button controls the start, stop and fine movement of the table.
- Return speed can be greatly increased reducing idle time.

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.

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. illustrates the front and top view of the automatic feed mechanism of a planer. A trip dog is fitted to the planer table. At the end of the return stroke, the trip dog strikes a lever. A pawl attached to this lever rotates a ratchet. So a splined shaft attached to the ratchet rotates. A bevel gear cast integral with a spur gear is fitted freely on the down feed screw. This bevel gear meshes with other bevel gear slides on the splined shaft.

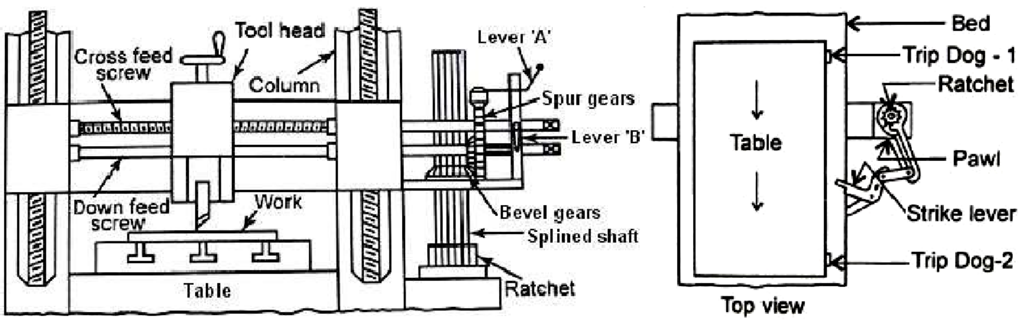


Fig. Front and top view of the automatic feed mechanism of a planer

The spur gear meshes with another spur gear which is keyed to the cross feed screw.

So the power from the splined shaft is transmitted to the cross feed screw. Then the rotation is transmitted to the tool head through a nut. The tool head moves horizontally. It is known a cross feed. At the end of the forward stroke, another trip dog strikes the lever. The lever comes to its original position. During this time, the pawl slips over the ratchet. The ratchet wheel does not rotate.

For giving automatic down feed, the spur gear keyed to the cross feed screw is disengaged. The bevel gear freely fitted to the down feed rod is keyed to the down feed rod. At the end of return stroke, the power is transmitted to the down feed rod through the lever, ratchet and bevel gears. Then the rotation is transmitted to the tool head though the bevel gears. The tool moves downward.

Work holding devices used in a planer

A planer table is used to hold very large, heavy and intricate work pieces, and in many cases, large number of identical work pieces together. Setting up of the work pieces on a planer table requires sufficient amount of skill. *The work piece may be held on a planer table by the following methods:*

- By standard clamping.
- By special fixtures.

Standard clamping devices

The standard clamping devices are used for holding most of the work pieces on a planer table.

The standard clamping devices are as follows:

- Heavy duty vises.
- T-bolts, step blocks and clamps.
- Stop pins and toe dogs.
- Angle plates.
- Planer jacks.
- Planer centres (similar to shaper centre).
- V-blocks.

A planer vise is much more robust in construction than a shaper vise as it is used for holding comparatively larger size of work. The vise may be plain or swiveled base type.

Large work pieces are clamped directly on the table by T- bolts and clamps. Different types of clamps are used for different types of work. *Fig. illustrates the method of clamping a large work piece on a planer table.* Step blocks are used to lend support to the other end of the clamp.

Planer jacks are used for supporting the overhanging part of a work to prevent it from bending.

Fig. illustrates the use of a planer jack.

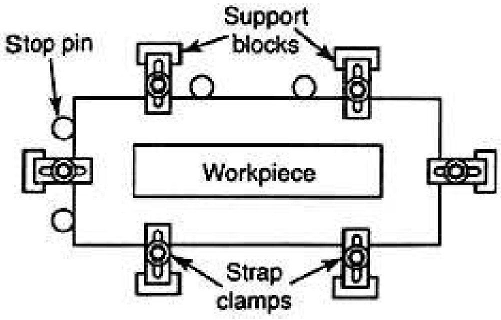
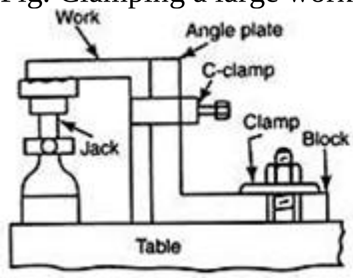


Fig. Clamping a large work piece on a planer table



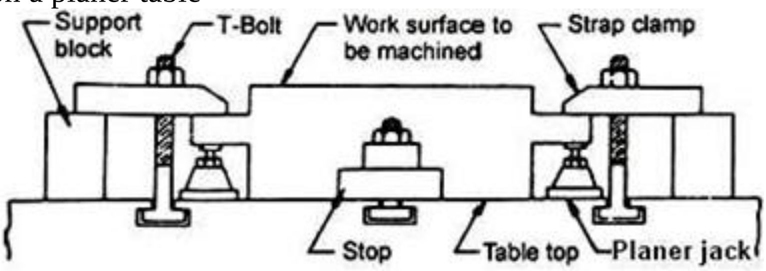


Fig. Use of planer jack

Special fixtures

These are used for holding a large number of identical pieces of work on a planer table. Fixtures are specially designed for holding a particular type of work. By using a fixture the setting time may be reduced considerably compared to the individual setting of work by conventional clamping devices. *Fig. illustrates the use of a fixture.*

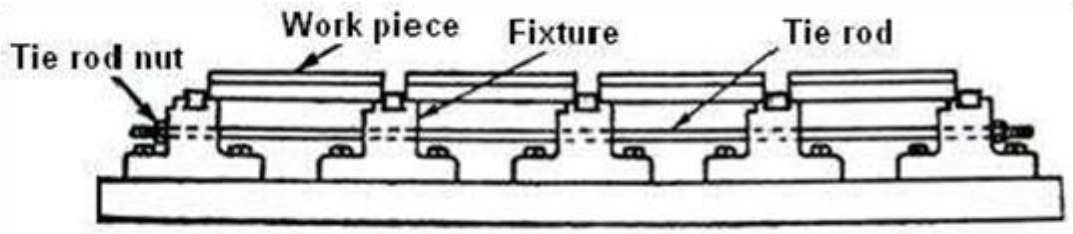


Fig. Use of a fixture

Planer tools

The cutting tools used on planers are all single point cutting tools. They are in general similar in shapes and tool angles to those used on a lathe and shaper. As a planer tool has to take up heavy cut and coarse feed during a long cutting stroke, the tools are made heavier and larger in cross-section. Planer tools may be solid, forged type or bit type. Bits are made of HSS, stellite or cemented carbide and they may be brazed, welded or clamped on a mild steel shank. Cemented carbide tipped tool is used for production work. *Fig. shows the typical tools used in a planer.*

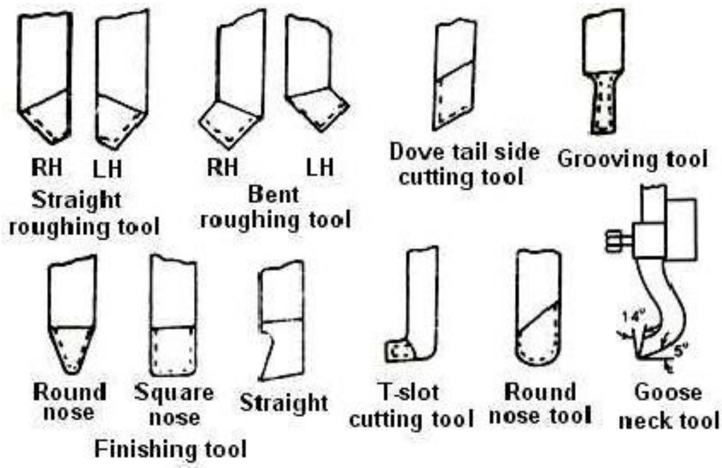


Fig. Typical tools used in a planer

Planer operations

All the operations done in a shaper can be done in a planer. But large size, stroke length and higher rigidity enable the planers do more heavy duty work on large jobs and their long surfaces. Simultaneous use of number of tools further enhances the production capacity of planers. The common types of work machined in a planer are: Beds and tables of various machine tools, large structures, long parallel T-slots, V and inverted V type guide ways, frames of different engines and identical pieces of work which may be small in size but large in number.

Machining the major surfaces and guide ways of beds and tables of various machines like lathes, drilling machines, milling machines, grinding machines, broaching machines and planers itself are the common applications of a planer *as illustrated in Fig.* Where the several parallel surfaces of typical machine bed and guide way are machined by a number of single point HSS or carbide tools.

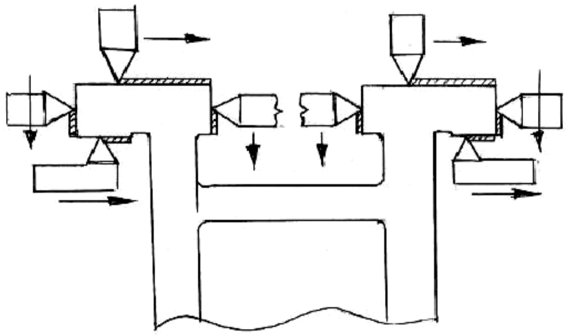


Fig. Machining of a machine bed in a planer

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

Special attachments used in a planer

Contour forming attachment

Fig. illustrates the contour forming attachment used in a planer. The machining operation is performed by using the attachment which consists of a radius arm and a bracket. The bracket is connected to the cross member attached to the two housings. One end of the radius arm is pivoted on the bracket and the other end to the vertical slide of the tool head. The down feed crew of the tool head is removed. The horizontal rail is kept delinked from the vertical lead screws. The tool which is guided by the radius arm planes a convex or a concave surface. The radius of convex or concave surface produced is dependent upon the length of the radius arm.

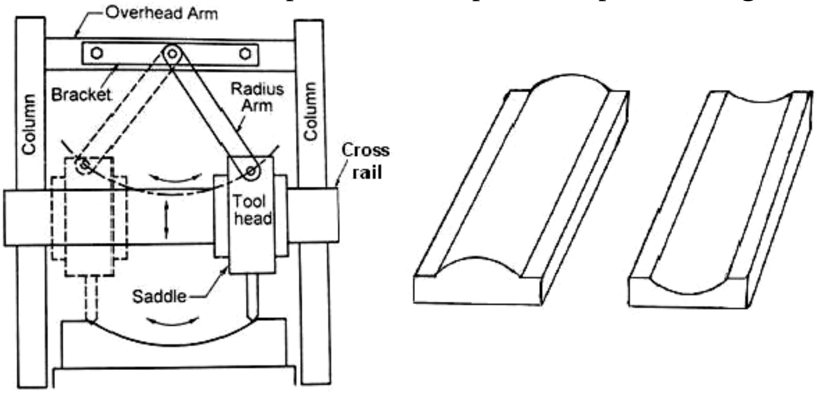


Fig. Contour forming attachment used in a planer

Specifications of a planer

The planer is specified by the following parameters:

- Radial distance between the top of the table and the bottom most position of the cross rail.
- Maximum length of the table and maximum stroke length of table.
- Power of the motor.
- Range of speeds and feeds available.
- Type of feed and type of drives required.
- Horizontal distance between two vertical housings.
- Net weight of machine and Floor area required.

Difference between shaper and planer

Sl. No.	Shaper	Planer
1	The tool reciprocates and the work is stationary.	The work reciprocates and the tool is stationary.
2	Feed is given to the work during the idle stroke of the ram.	Feed is given to the tool during the idle stroke of the work table.
3	It gives more accuracy as the tool is rigidly supported during cutting.	Less accuracy due to the over hanging of the ram.
4	Suitable for machining small work pieces.	Suitable for machining large work pieces.
5	Only light cuts can be applied.	Heavy cuts can be applied.
6	Only one tool can be used at a time. So machining takes longer time.	Vertical and side tool heads can be used at a time. So machining is quicker.
7	Setting the work piece is easy.	Setting the work piece is difficult.
8	Only one work piece can be machined at a time.	Several work pieces can be machined at a time.
9	Tools are smaller in size.	They are larger in size.
10	Shapers are lighter and smaller.	Planers are heavier and larger.

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:

- Puncher slotter.
- Precision slotter.

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 Whitworth quick return mechanism.

- **Major parts of a slotter**

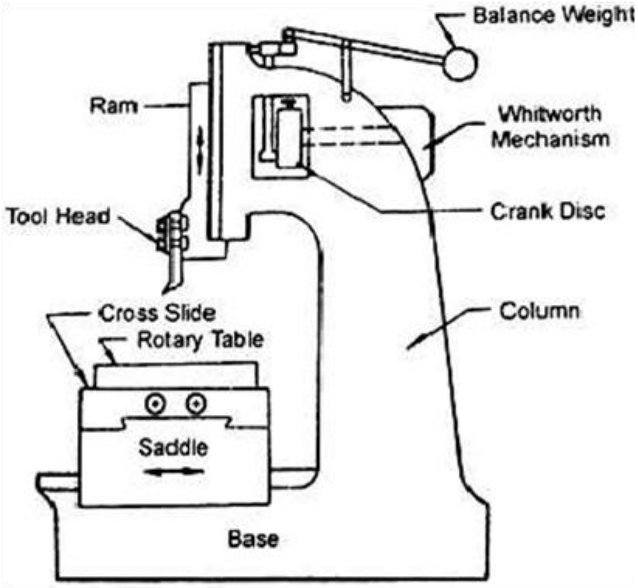


Fig. Schematic view of a slotter

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

Saddle It is mounted upon the guide ways and may be moved toward or away from the column either by power or manual control to supply longitudinal feed to the work. The top face of the saddle is accurately finished to provide guide ways for the cross-slide. These guide ways are perpendicular to the guide ways on the base.

Cross slide It is mounted upon the guide ways of the saddle and may be moved parallel to the face of the column. The movement of the slide may be controlled either by hand or power to supply cross feed.

Rotary table It is a circular table which is mounted on the top of the cross-slide. The table may be rotated by rotating a worm which meshes with a worm gear connected to the underside of the table. The rotation of the table may be effected either by hand or power. In some machines the table is graduated in degrees that enable the table to be rotated for indexing or dividing the periphery of a job in equal number of parts. T-slots are cut on the top face of the table for holding the work by different clamping devices. The rotary table enables a circular or contoured surface to be generated on the work piece.

Ram It is the reciprocating member of the machine mounted on the guide ways of the column. It is connected to the reciprocating mechanism contained within the column. A slot is cut on the body of the ram for changing the position of the stroke. It carries the tool head at its bottom end.

Tool head It holds the tool rigidly. In some machines, special types of tool holders are provided to relieve the tool during its return stroke.

Working principle of a slotter

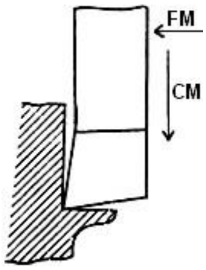


Fig. Principle of producing vertical flat surface

Fig. 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).

Ram drive mechanism of a slotter

A slotter removes metal during downward cutting stroke only whereas during upward return stroke no metal is removed. To reduce the idle return time, quick return mechanism is incorporated in the machine. The reciprocating movement and the quick return of the ram are usually obtained by using any one of the following mechanisms.

Whitworth quick return mechanism

The Whitworth quick return mechanism is most widely used in a medium sized slotter for driving the ram.

Hydraulic drive quick return mechanism

The hydraulic drive is adapted in slotters which are used in precision or tool-room work. In a hydraulic drive, the vibration is minimized resulting improved surface finish. The hydraulic drive has been described in Article 3.2.4.3, Page 107 and illustrated in Fig. 3.8.

Electrical drive quick return mechanism

Large slotters are driven by variable voltage reversible motor.

Feed mechanism of a slotter

In a slotter, the feed is given by the table. A slotting machine table may have three types of feed movements: Longitudinal, cross and circular.

If the table is fed perpendicular to the column toward or away from its face, the feed movement is termed as longitudinal. If the table is fed parallel to the face of the column the feed movement is termed as cross. If the table is rotated on a vertical axis, the feed movement is termed as circular.

Like a shaper or a planer, the feed movement of a slotter is intermittent and supplied at the beginning of the cutting stroke. The feed movement may be provided either by hand or power. If the feed screws are rotated manually by a handle, then it called hand feed. If the feed screws are rotated by power, then it is called automatic feed.

Automatic feed mechanism of a slotter

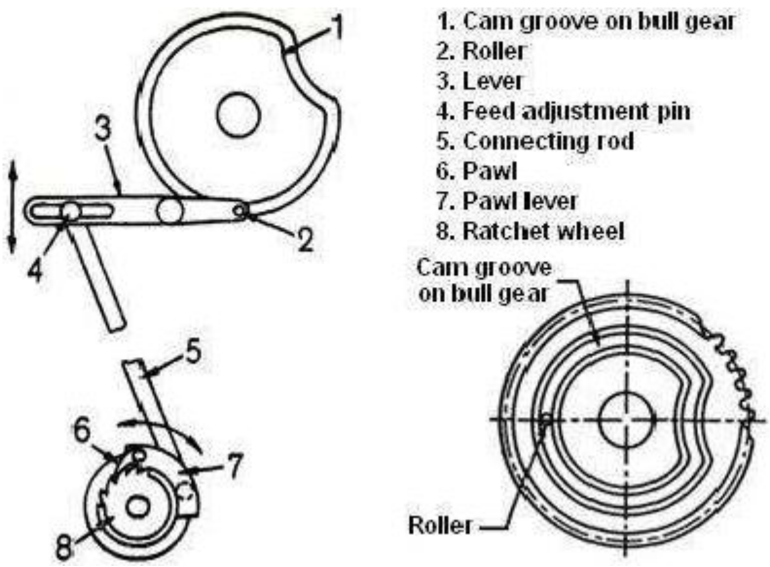


Fig. Automatic feed mechanism of a slotter

Fig. illustrates the automatic feed mechanism of a slotter. A cam groove is cut on the face of the bull gear in which a roller slides. As the bull gear rotates, the roller attached to a lever follows the contour of the cam groove and moves up and down only during a very small part of revolution of the bull gear. The cam groove may be so cut that the movement of the lever will take place only at the beginning of the cutting stroke. Fig. Shows the cam groove cut on a bull gear. The rocking movement of the lever is transmitted to the ratchet and pawl mechanism, so that the ratchet will move in one direction only during this short period of time. The ratchet wheel is mounted on a feed shaft which may be engaged with cross, longitudinal or rotary feed screws individually or together to impart power feed movement to the table.

Work holding devices used in a slotter

The work is held on a slotter table by a vise, T-bolts and clamps or by special fixtures. T-bolts and clamps are used for holding most of the work on the table. Before clamping, parallels are placed below the work piece so as to allow the tool to complete the cut without touching the table. Holding work by T-bolts and clamps. Special fixtures are used for holding repetitive work. *Fig. shows a typical slotting fixture.*

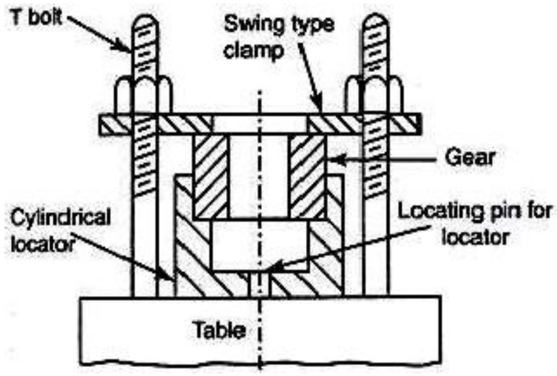


Fig. Slotting fixture

Slotter tools

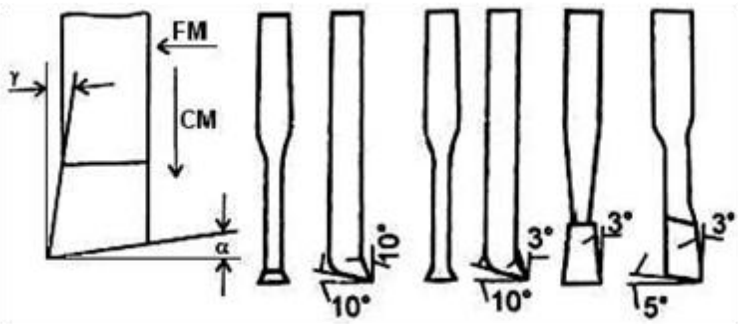


Fig. Different tools used in a slotter

Fig. illustrates different slotter tools used in different operations. A slotter tool differs widely from a shaper tool as the tool in a slotter removes metal during its vertical cutting stroke. This changed cutting condition presents a lot of difference in the tool shape. In a shaper tool the cutting pressure acts perpendicular to the tool length, whereas in a slotter tool the pressure acts along the length of the tool. The rake angle (α) and clearance angle (γ) of a slotter tool look different from a shaper tool. The slotter tools are robust in cross section and are usually of forged type: of course, bit type tools fitted in heavy tool holders are also used. Keyway cutting tools are thinner at the cutting edges. Round nose tools are used for machining contoured surfaces. Square nose tools are used for machining flat surfaces.

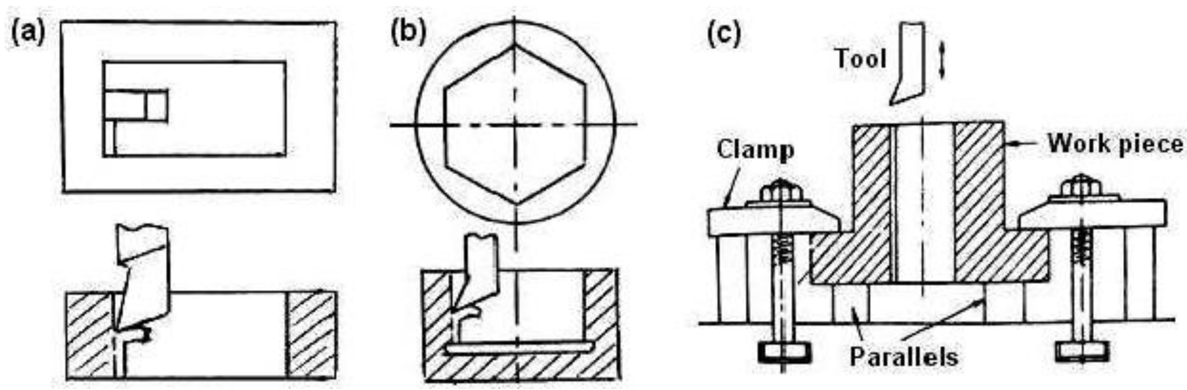
Slotter operations

Slotter is mostly used for machining internal surfaces. The usual operations of a slotter are:

Internal flat surfaces.and possible machining, Enlargement and / or finishing non-circular holes bounded by a number of flat surfaces *as shown in Fig. (a).*

Blind geometrical holes like hexagonal socket *as shown in Fig. (b).*

Internal grooves and slots of rectangular and curved sections. Internal keyways and splines, straight tooth of internal spur gears, internal curved surfaces, and internal oil grooves etc *as shown in Fig. (c),* which are not possible in shaper.



(a) Through rectangular hole (b) Hexagonal socket and (c) Internal keyway

Fig. Typical machining operations performed in a slotter

However, the productivity and process capability of slotters are very poor and hence used mostly for piece production required for maintenance and repair in small industries. Scope of use of slotter for production has been further reduced by more and regular use of broaching machines.

Shapers, planers and slotters are becoming obsolete and getting replaced by Plano-millers where instead of single point cutting tools more number of large size and high speed milling cutters are used.

Specifications of a slotter

The slotter is specified by the following parameters:

- The maximum stroke length.
- Diameter of rotary table.
- Maximum travel of saddle and cross slide.

- Type of drive used.
  - Power of the motor.
  - Net weight of machine.
  - Number and amount of feeds.
  - Floor area required.

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.

TYPES OF MILLING MACHINE

Milling machines are broadly classified as follows:

Column and knee type

- Hand milling machine.
- Plain or horizontal milling machine.
- Universal milling machine.
- Omniversal milling machine.
- Vertical milling machine.

Manufacturing or bed type

- Simplex milling machine.
- Duplex milling machine.
- Triplex milling machine.

Planer type Special type

- Drum milling machine.
- Rotary table milling machine.
- Profile milling machine.
- Pantograph milling machine.
- Planetary milling machine.

Column and knee type milling machines

This is the most commonly used machine in view of its flexibility and easier setup. In such small and medium duty machines the table with work travels above the saddle in horizontal direction (X axis) (left and right). The saddle with table moves on the slideways provided on the knee in transverse direction (Y axis) (front and back). The knee with saddle and table moves on a dovetail guide ways provided on the column in vertical direction (Z axis) (up and down).

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 (a) shows the photographic view of a horizontal hand milling machine and Fig. (b) shows that of a vertical* *hand milling machine.*

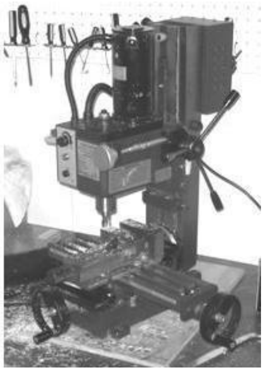
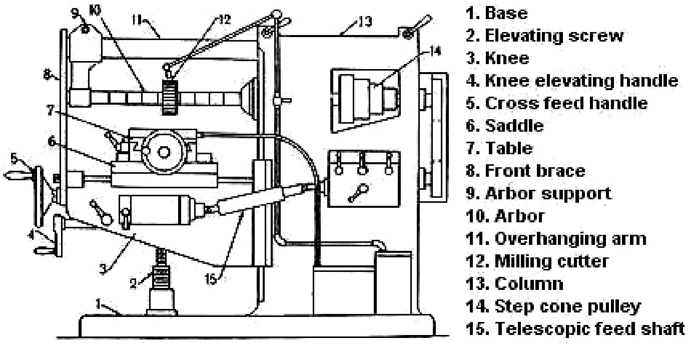


Fig. (a) Horizontal hand milling machine   Fig. (b) Vertical hand milling machine

Plain or horizontal milling machine

This non automatic general purpose milling machine of small to medium size possesses a single horizontal axis milling arbor. The work table can be linearly fed along three axes (X, Y, and Z) only. The table may be fed by hand or power. These machines are most widely used for piece or batch production of jobs of relatively simple design and geometry. *Fig. schematically shows the basic configuration of a horizontal milling machine.*



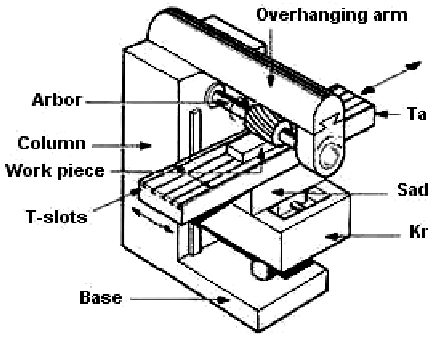
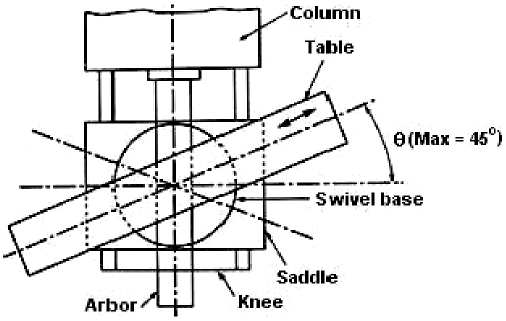


Fig. Plain or horizontal milling machine

Universal milling machine

It is so named because it may be adapted to a very wide range of milling operations. It can be distinguished from a plain milling machine in that the table of a universal milling machine is mounted on a circular swiveling base which has degree graduations, and the table can be swiveled to any angle up to 45^0 on either side of the normal position.

Thus in a universal milling machine, in addition to the three movements as incorporated in a plain milling machine, the table have a fourth movement when it is fed at an angle to the milling cutter. This additional feature enables it to perform helical milling operation which cannot be done on a plain milling machine unless a spiral milling attachment is used. The capacity of a universal milling machine is considerably increased by the use of special attachments such as dividing head or index head, vertical milling attachment, rotary attachment, slotting attachment, etc. The machine can produce spur, spiral, bevel gears, twist drills, reamers, milling cutters, etc. besides doing all conventional milling operations. *Fig. schematically shows the basic configuration of a universal milling machine.*



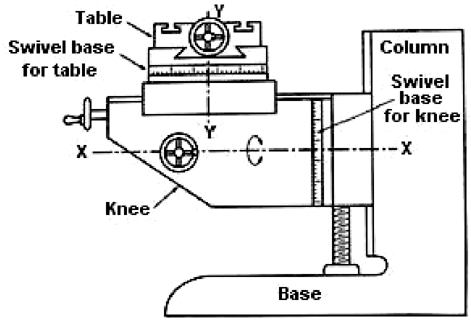


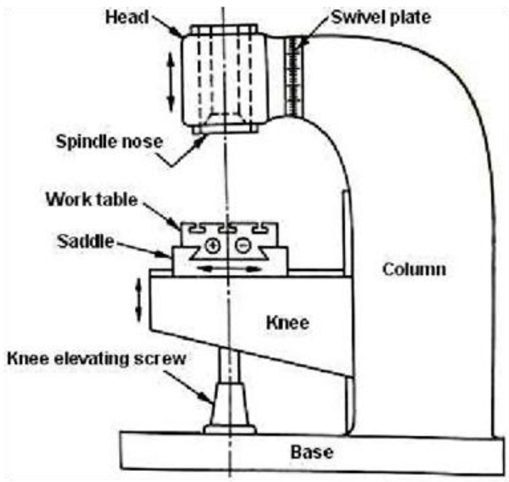
Fig. Universal milling machine Fig. Omniversal milling machine

Omniversal milling machine

Fig. schematically shows the basic configuration of an omniversal milling machine. In this machine, the table besides having all the movements of a universal milling machine can be tilted in a vertical plane by providing a swivel arrangement at the knee. Also the entire knee assembly is mounted in such a way that it may be fed in a longitudinal direction horizontally. The additional swiveling arrangement of the table enables it to machine taper spiral grooves in reamers, bevel gears, etc. It is essentially a tool room and experimental shop machine.

Vertical milling machine

This machine is very similar to a horizontal milling machine. The only difference is the spindle is vertical. The work table may or may not have swiveling features. The spindle head may be swiveled at an angle, permitting the milling cutter to work on angular surfaces. In some machines, the spindle can also be adjusted up or down relative to the work piece. This machine works using end milling and face milling cutters. This machine is adapted for machining grooves, slots and flat surfaces.



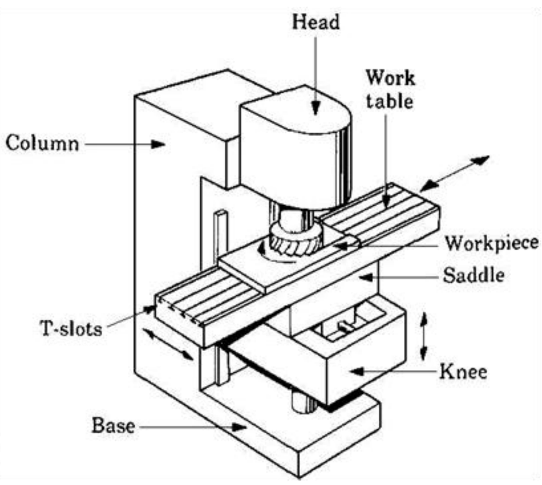


Fig. schematically shows the basic configuration of a vertical milling machine.
Fig. Vertical milling machine

Manufacturing or bed type milling machines

The fixed bed type milling machines are comparatively large, heavy, and rigid and differ radically from column and knee type milling machines by the construction of its table mounting. The table is mounted directly on the guide ways of the fixed bed. The table movement is restricted to reciprocation at right angles to the spindle axis with no provision for cross or vertical adjustment. The cutter mounted on the spindle head may be moved vertically on the column, and the spindle may be adjusted horizontally to provide cross adjustment. The name simplex, duplex and triplex indicates that the machine is provided with single, double and triple spindle heads respectively. In a duplex machine, the spindle heads are arranged one on each side of the table. In triplex type the third spindle (vertical) is mounted on a cross rail. The usual feature of these machines is the automatic cycle of operation for feeding the table, which is repeated in a regular sequence. The feed cycle of the table includes the following: Start, rapid approach, slow feed for cutting, rapid traverse to the next work piece, quick return and stop. This automatic control of the machine enables it to be used with advantage in repetitive types of work. *Fig. (a) and (b) shows the simplex milling machine and duplex milling machine.*

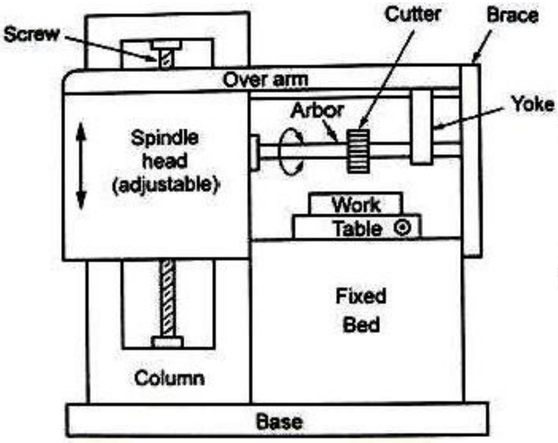


Fig. (a) Simplex milling machine

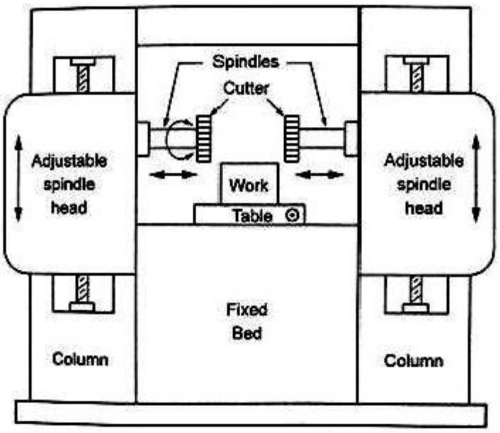


Fig. (b) Duplex milling machine

Planer type milling machine

This heavy duty large machine, called Plano-miller, look like planer where the single point tools are replaced by one or a number of milling heads. This is generally used for machining a number of longitudinal flat surfaces simultaneously, such as lathe beds, table and bed of planer etc. Modern Plano-millers are provided with high power driven spindles powered to the extent of 100 hp. and the rate of metal removal is tremendous. The use of this machine is limited to production work only and is considered ultimate in metal removing capacity. *Fig. shows a planer type milling machine.*

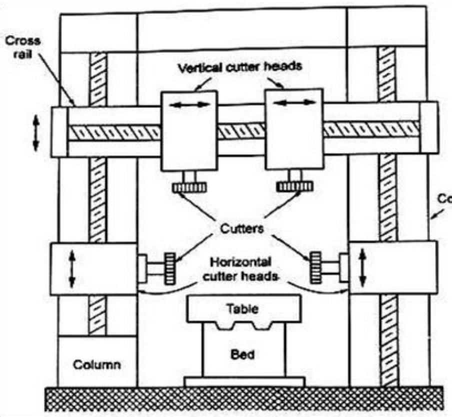


Fig. Planer type milling machine

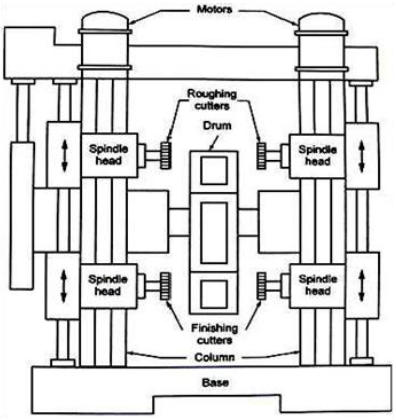


Fig. Drum type milling machine

Special type milling machines

Drum milling machine

Fig. schematically shows a drum milling machine. These machines are of the continuous-operation type. They are mostly found in large-lot and mass production shops for production of large parts such as motor blocks, gear cases, and clutch housings. Two flat surfaces of the workpiece can be milled simultaneously.

A square drum (sometimes it may be a regular pentagon or hexagon), is mounted on a shaft passing through the frame. Parts are carried in fixtures mounted on the drum faces. The drum rotates continuously in a horizontal axis, carrying the parts between face milling cutters. The milling cutters are mounted on three or four spindle heads and rotates in a horizontal axis. The milling heads can be adjusted along the housing and clamped as required for the set up. In addition to rotation, the milling spindles also have axial adjustment to set the cutters to the depth of cut. The output of such machines depends upon the number of simultaneously machined parts and the speed of rotation of the drum (rate of feed). The machined parts are removed after one complete turn of the drum, and then the new ones are clamped to it.

Rotary table milling machine

The construction of this machine is the modification of a vertical milling machine and is adapted for machining flat surfaces. Such open or closed ended high production milling machines possess one large rotary work table rotates about a vertical axis and one or two vertical spindles. The positions of the work piece(s) and the milling head are adjusted according to the size and shape of the work piece. A continuous loading and unloading of work pieces may be carried out by the operator while the milling is in progress. *Fig. schematically shows a rotary table milling machine.*

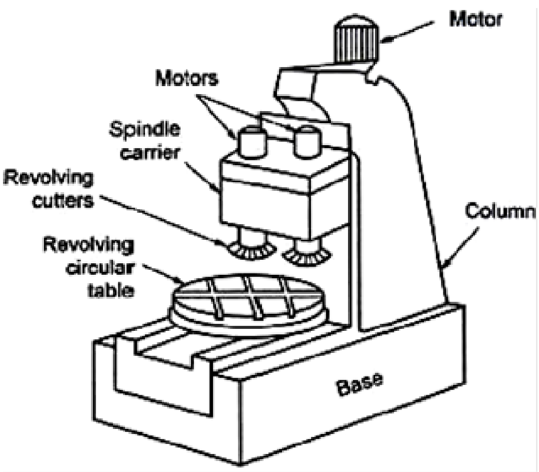


Fig. Rotary table milling machine

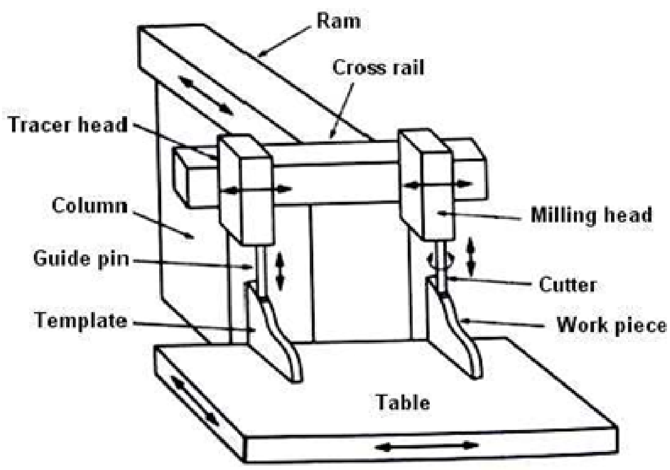


Fig. Profile milling machine

Profile milling machine

Fig. schematically shows a profile milling machine. This machine duplicates the full size of the template attached to the machine. This is practically a vertical milling machine of bed type in which the spindle can be adjusted vertically and the cutter head horizontally across the table. The movement of the cutter is regulated by a hardened guide pin. The pin is held against and follows outline or profile of a template mounted on the table at the side of the work piece. The longitudinal movement of the table and crosswise movement of the cutter head follow the movements of the guide pin on the template.

Pantograph milling machine

This machine can duplicate a work by using a pantograph mechanism which permits the size of the work piece reproduced to be smaller than, equal to or greater than the size of a template or model used for the purpose. Pantograph machines are available in two dimensional or three dimensional models. Two dimensional models are used for engraving letters or other designs, whereas three dimensional models are employed for copying any shape and contour of the work piece. The tracing stylus is moved manually on the contour of the model to be duplicated and the milling cutter mounted on the spindle moves in a similar path on the work piece.

Planetary milling machine

In this machine, the work is held stationary while the revolving cutter(s) move in a planetary path to finish a cylindrical surface on the work either internally or externally or simultaneously. This machine is particularly adapted, for milling internal or external threads of different pitches.

Major parts of a column and knee type milling machine

The general configuration of a column and knee type conventional milling machine with horizontal arbor is shown in Fig. The major parts are:

Base It is accurately machined on its top and bottom surface and serves as a foundation member for all other parts. It carries the column at its one end. In some machines, the base is hollow and serves as a reservoir for cutting fluid.

Column It is the main supporting frame mounted vertically on the base. The column is box shaped, heavily ribbed inside and houses all the driving mechanisms for the spindle and table feed. The front vertical face of the column is accurately machined and is provided with dovetail guide ways for supporting the knee. The top of the column is finished to hold an over arm that extends outward at the front of the machine.

Knee It slides up and down on the vertical guide ways of the column face. The adjustment of height is effected by an elevating screw mounted on the base that also supports the knee. The knee houses the feed mechanism of the table, and different controls to operate it. The top face of the knee forms a slideway for the saddle to provide cross travel of the table.

Table The table rests on ways on the saddle and travels longitudinally. The top of the table is accurately finished and T-slots are provided for clamping the work and other fixtures on it. A lead screw under the table engages a nut on the saddle to move the table horizontally by hand or power. The longitudinal travel of the table may be limited by fixing trip dogs on the side of the table. in universal machines, the table may also be swiveled horizontally.

Overhanging arm The overhanging arm that is mounted on the top of the column extends beyond the column face and serves as a bearing support for the other end of the arbor. The arm is adjustable so that the bearing support may be provided nearest to the cutter.

Front brace The front brace is and extra support that is fitted between the knee and the over arm to ensure further rigidity to the arbor and the knee. The front brace is slotted to allow for the adjustment of the height of the knee relative to the over arm.

Spindle The spindle of the machine is located in the upper part of the column and receives power from the motor through belts, gears, clutches and transmits it to the arbor. The front end of the spindle just projects from the column face and is provided with a tapered hole into which various cutting tools and arbors may be inserted. The accuracy in metal machining by the cutter depends primarily on the accuracy, strength, and rigidity of the spindle.

Arbor It may be considered as an extension of the machine spindle on which milling cutters are securely mounted and rotated. The arbors are made with taper shanks for proper alignment with the machine spindles having taper holes at their nose. The arbor may be supported at the farthest end from the overhanging arm or may be of cantilever type which is called stub arbor. The arbor shanks are properly gripped against the spindle taper by a draw bolt which extends throughout the length of the hollow spindle. The threaded end of the draw bolt is fastened to the tapped hole of the arbor shank and then the lock nut is tightened against the spindle. The spindle has also two keys for imparting positive drive to the arbor in addition to the friction developed in the taper surfaces. The cutter is set at the required position on the arbor by spacing collars or spacers of various lengths but of equal diameter. The entire assembly of the milling cutter and the spacers are fastened to the arbor by a long key. The end spacer on the arbor is slightly larger in diameter and acts as a bearing bush for bearing support which extends from the over arm. *Fig. 3.62 illustrates an arbor assembly used in a milling machine.*

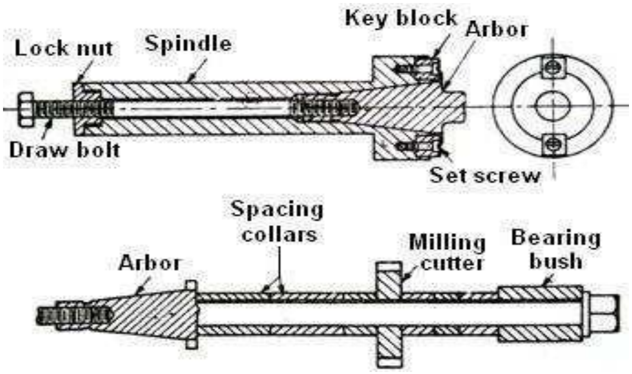


Fig. Arbor assembly

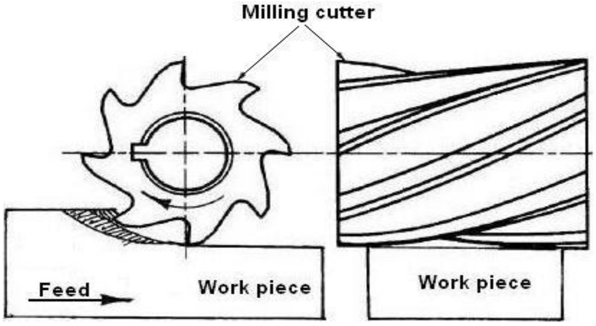


Fig. Principle of producing flat surface

Working principle of a column and knee type milling machine

Fig shows the basic principle of producing flat surface in a milling machine by a plain milling cutter. The kinematic system comprising of several mechanisms enables transmission of motion and power from the motor to the cutting tool for its rotation at varying speeds and to the work table for its slow feed motions along X, Y and Z directions. The milling cutter mounted on the horizontal milling arbor, receives its rotary motion at different speeds from the main motor through the speed gear box. The feeds of the work piece can be given by manually or automatically by rotating the respective wheels by hand or by power. The work piece is clamped on the work table by a work holding device. Then the work piece is fed against the rotating multipoint cutter to remove the excess material at a very fast rate.

Mechanism of a column and knee type milling machine

This mechanism is composed of spindle drive mechanism and table feed mechanism. The spindle drive mechanism is incorporated in the column. All modern machines are driven by individual motors housed within the column, and the spindle receives power from a combination of gears and clutch assembly. Multiple speed of the spindle may be obtained by altering the gear ratio. *Fig. 3.64 illustrates the power feed mechanism contained within the knee of the machine to enable the table to have three different feed movements, i.e. longitudinal, cross and vertical.*

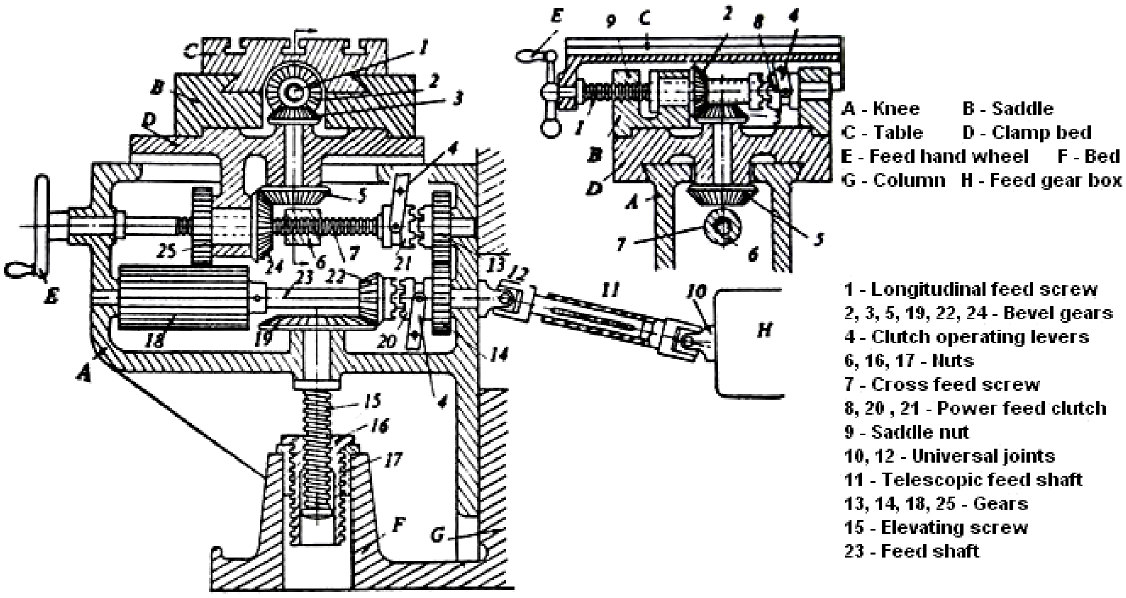


Fig. Power feed mechanism of a column and knee type milling machine

The power is transmitted from the speed gear box consisting of change gears to the feed shaft in the knee of the machine by a telescopic feed shaft. Both ends of the telescopic feed shaft are provided with universal joints. Telescopic feed shaft and universal joints are necessary to allow vertical movement of the knee, gear 14, attached to the jaw clutch 20. The jaw clutch 20 is keyed to the feed shaft and drives gear 13, which is free to rotate on the extreme end of the cross feed screw. Bevel gear 22 is free to rotate on feed shaft and is in mesh with gear 19 fastened to the evaluating screw. 16 serve as a nut for 15, and it is screwed in nut 17. Therefore, 15 and 16 serve as a telescopic screw combination and a vertical movement of the knee is thus possible. As soon as the clutch 20 is engaged with the clutch attached to the bevel gear 22 by means of a clutch operating lever, the bevel gear 22 rotates and this being in mesh with gear 19 causes the elevating screw to rotate in nut 16 giving a vertical movement of the knee.

Like-wise, when the clutch 21 attached to the cross feed screw, is engaged with the clutch attached to gear 13, power comes to the screw through gears 14 and 13. This causes the cross feed screw to rotate in nut 6 of the clamp bed giving a cross feed movement of the clamp bed and saddle.

Gear 18 is fastened to feed shaft, and meshes with gear 25 which is fastened to the bevel gear 24. The bevel gear 24 meshes with bevel gear 5 attached to a vertical shaft which carries one more bevel gear 3 at its upper end. The bevel gear 3 meshes with bevel gear 2 which is fastened to the table feed screw. Therefore, longitudinal feed movement of the table is possible through gears 18, 25, 24, 5, 3, & 2.

Work holding devices used in a milling machine

It is necessary that the work piece should be properly and securely held on the milling machine table for effective machining operations. The work piece may be supported on the milling machine table by using any one of the following work holding devices depending upon the geometry of the work piece and nature of the operation to be performed.

- T-bolts and clamps.

- Angle plate.
- V-blocks.
- Vises.
- Special fixtures.
- Dividing heads.

T-bolts and clamps Bulky work pieces of irregular shapes are clamped directly on the milling machine table by using T-bolts and clamps. *Fig. 3.15 illustrates the use of T-bolts and clamps.* Different designs of clamps are used for different patterns of work. *Fig. shows the different types of clamps.*

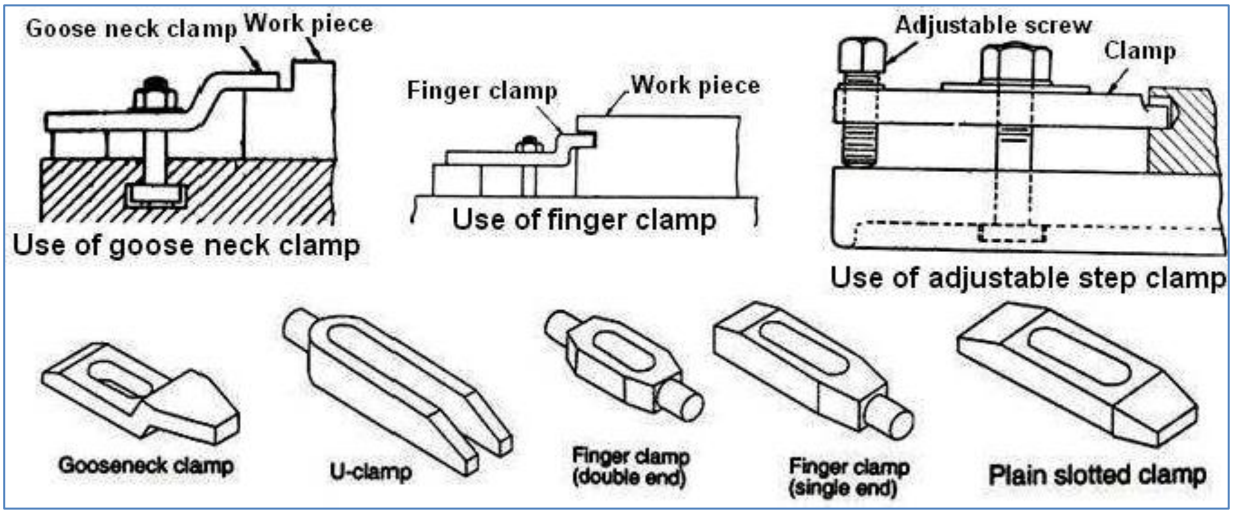


Fig. Different types of clamps

Angle plate The angle plate is illustrated in Fig. Sometimes a titling type angle plate in which one face can be adjusted relative to another face for milling at a required angle is also used. *Fig. 3.66 shows a tilting type angle plate.*

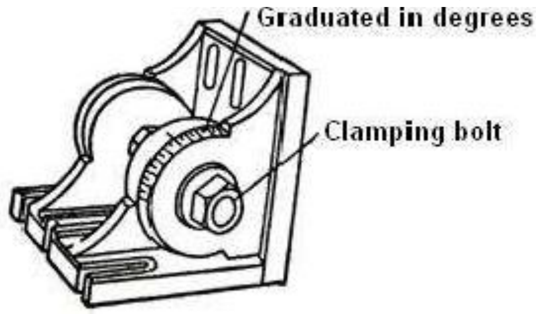


Fig. Tilting type angle plate

V-blocks The V-block has been illustrated in Fig. This is used for holding shafts on the table in which keyways, slots and flats are to be milled.

Vises The different types of vise has been illustrated in Fig. (a), (b) and (c). Vises are the most common appliances for holding work on milling machine table due to its quick loading and unloading arrangement.

Special fixtures The fixtures are special devices designed to hold work for specific operations more efficiently than standard work holding devices. Fixtures are especially useful when large numbers of identical parts are being produced. By using fixtures loading, locating, clamping and unloading time is greatly minimized.

Indexing head or dividing head

It is a special work holding device used in a milling machine. Dividing head can also be considered as a milling machine attachment. *Fig. shows a dividing head used in a milling machine.*

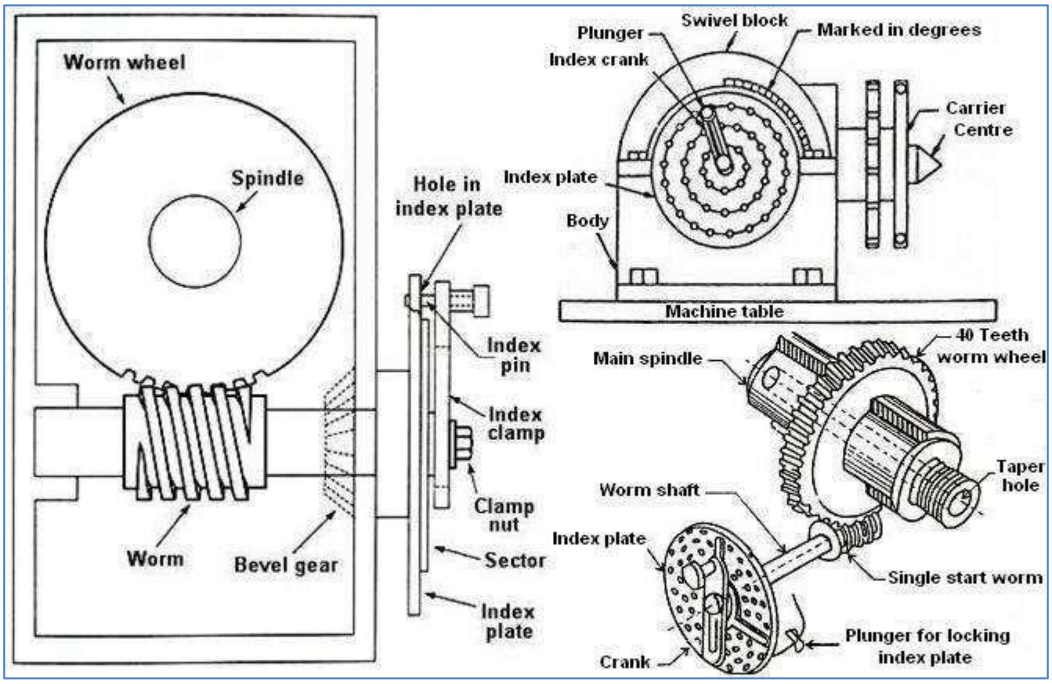


Fig. Dividing head

An important function and use of milling machines is for cutting slots, grooves etc. which are to be equally spaced around the circumference of a blank, for example, gear cutting, ratchet wheels, milling cutter blanks, reamers etc. This necessitates holding of the blank (work piece) and rotating it the exact amount for each groove or slot to be cut. This process is known as “indexing”. The dividing head is the device used for this purpose. It is lined and bolted to the machine table so that the axis passing through the head stock centre and tail stock centre is at right angle to the spindle axis of the machine. The head stock of the dividing head consists of a spindle to which a 40 tooth worm wheel is keyed. A single threaded worm meshes with this wheel. The worm spindle projects from the front of the head and has a crank and handle attached. The head spindle is bored with a tapered hole and is also screwed on its end.

The work piece is mounted between centres, one inserted into the dividing head spindle and the other into the tail stock. The work piece may also be mounted on a mandrel between these centres. A chuck may be mounted on the spindle nose for holding short work pieces having no centre holes. The work piece is rotated by turning the index crank by means of handle. Since the gear ratio of worm and worm wheel is 40:1, it takes 40 turns of the crank to rotate the spindle and hence the work piece through one complete revolution. Thus one turn of the crank rotates the work piece through 1/40th of a turn.

If divisions other than factors of 40 are required "index plates". An index plate has several circles of holes (each circle containing a different number of holes) and is mounted on the worm shaft. A pin on the crank can be adjusted to a radius such that it will fit in any desired circle of holes. By using different circles of holes and index plates, any fractional part of a turn of the index crank can be obtained. The two sector arms shown on front of the index plate are used for avoiding counting of holes during indexing.

Index plate It helps to accomplish indexing (dividing) of the work into equal divisions. It is a circular plate approximately 6 mm thick, with holes (equally spaced) arranged in concentric circles. The space between two subsequent holes is same for each circle; however it is different for different circles. A plate can have through holes or blind holes on its faces.

For a plain dividing head, the index plate is fixed to the body of the dividing head while in the case of universal dividing head it is mounted on the sleeve of the worm shaft. Various manufactures in
and other countries have produced index plates with different number of hole circles.

For example *The index plates available with the Brown and Sharpe milling machines are:*

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

The index plate used on the Cincinnati and Parkinson milling machine is:

- Obverse (A) - 24, 25, 28, 30, 34, 37, 38, 39, 41, 42, 43
- Reverse (B) - 46, 47, 49, 51, 53, 54, 57, 58, 59, 62, and 66

Index plates made in Germany are:
Plate No. 1 -
Plate No. 2 -
Plate No. 3 -

The high number index plates are used to increase the indexing capacity. These index plates are similar to those discussed earlier except that these contain very large number of holes. Cincinnati Milling Machine Co. U.S.A. produces a set of three plates with holes on both sides of the plate as given below:

Plate No. 1 Obverse (A) - 30, 48, 69, 91, 99, 117, 129, 147, 171, 177, 189

Reverse (B) - 36, 67, 81, 97, 111, 127, 141, 157, 169, 183, and 194

Plate No 2 Obverse (A) - 34, 46, 79, 93, 109, 123, 139, 153, 167, 181, 197
Reverse (B) - 32, 44, 77, 89, 107, 121, 137, 151, 163, 179, and 193

Plate No. 3 Obverse (A) - 26, 42, 73, 87, 103, 119, 133, 149, 161, 175, 191
Reverse (B) - 28, 38, 71, 83, 101, 113, 131, 143, 159, 173, and 187

It is importance to note that there is no standard followed internationally in this regard. The number of plates supplied varies with different manufacturers. However this does not change the principle of indexing. It should be put up with in mind that larger the number of plates, and more the hole circles and holes wider is the range of indexing and accuracy.

Types of dividing heads The various dividing heads used with milling machines are:

Plain indexing head A plain dividing head has a fixed spindle axis and the spindle rotates only about a horizontal axis.

Universal indexing head In this, the spindle can be rotated at different angles in the vertical plane from horizontal to vertical. This head performs the following functions: indexes the work piece, imparts a continuous rotary motion to the work piece for milling helical grooves (flutes of drills, reamers, milling cutters etc.) and setting the work piece in a given inclined position with reference to the table.

Optical indexing head These models are used for high precision angular setting of the work piece with respect to the cutter. For reading the angles, an optical system is built into the dividing head.

Methods of indexing The various methods of indexing are discussed below:

Direct indexing In this, the index plate is directly mounted on the dividing head spindle. The intermediate use of worm and worm wheel is avoided. For indexing, the index pin is pulled out on a hole, the work and the index plate are rotated the desired number of holes and the pin is engaged. Both plain and universal heads can be used in this manner. Direct indexing is the most rapid method of indexing, but fractions of a complete turn of the spindle are limited to those available with the index plate. With a standard indexing plate having 24 holes, all factors of 24 can be indexed, that is, the work can be divided into 2,3,4,6,8,12 and 24 parts.

Simple or plain indexing In this, the index plate selected for the particular application, is fitted on the worm shaft and locked through a locking pin. To index the work through any required angle, the index crank pin is withdrawn from a hole in the index plate. The work piece is indexed through the required angle by turning the index crank through a calculated number of whole revolutions and holes on one of the hole circles, after which the index pin is relocated in the required hole. If the number of divisions on the job circumference (that is number of indexing) needed is z, then the numberof turns (n) that the crank must be rotated for each indexing can be found from the formula: $\mathbf{n} = {}^{40}/z$ turns.

Compound indexing

When the available capacity of the index plates is not sufficient to do a given indexing, the compound indexing method can be used. First, the crank is moved in the usual fashion in the forward direction. Then a further motion is added or subtracted by rotating the index plate after locking the plate with the plunger. This is termed as compound indexing. For example, if the indexing is done by moving the crank by 5 holes in the 20 hole circle and then the index plate together with the crank is indexed back by a hole with the locking plunger registering in a 15 hole circle *as shown in Fig.*

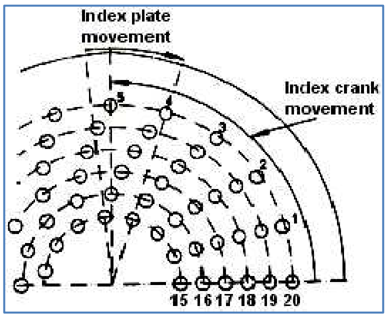


Fig. An example of compound indexing

Differential indexing

This is an automatic way to carry out the compound indexing method. In this the required division is obtained by a combination of two movements:

- The movement of the index crank similar to the simple indexing.
- The simultaneous movement of the index plate, when the crank is turned.

Fig. schematically shows the arrangement for differential indexing.

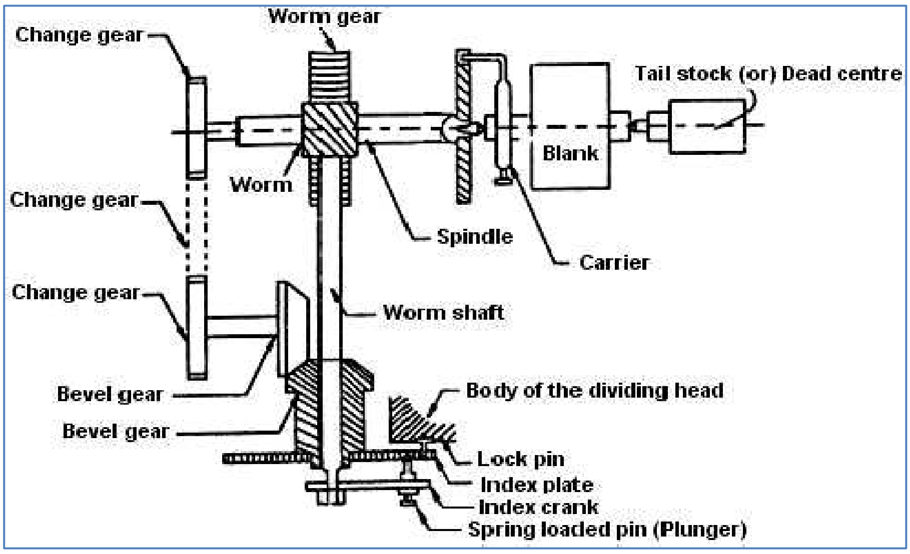


Fig. Arrangement for differential indexing

In differential indexing, the index plate is made free to rotate. A gear is connected to the back end of the dividing head spindle while another gear is mounted on a shaft and is connected to the shaft of the index plate through bevel gears *as shown in Fig.* When the index crank is rotated, the motion is communicated to the work piece spindle. Since the work piece spindle is connected to the index plate through the intermediate gearing as explained above, the index plate will also start rotating. If the chosen indexing is less than the required one, then the index plate will have to be moved in the same direction as the movement of the crank to add the additional motion. If the chosen indexing is more, then the plate should move in the opposite direction to subtract the additional motion.

The direction of the movement of the index plate depends upon the gear train employed. If an idle gear is added between the spindle gear and the shaft gear in case of a simple gear train, then the index plate will move in the same direction to that of the indexing crank movement. In the case of a compound gear train an idler is used when the index plate is move in the opposite direction. The procedure of calculation is explained with the following example.

The change gear set available is 24 (2), 28, 32, 40, 44, 48, 56, 64, 72, 86 and 100.

Angular indexing

Sometimes it is desirable to carry out indexing using the actual angles rather than equal numbers along the periphery. Here, angular indexing would be useful. The procedure remains the same as in the previous cases, except that the angle will have to be first converted to equivalent divisions. Since 40 revolutions of the crank equals to a full rotation of the work piece, which means 360^0, one revolution of the crank is equivalent to 9^0. The formula to find the index crank movement is given below.

Index crank movement = Angular displacement of work (in degrees) / 9
= Angular displacement of work (in minutes) / 540
= Angular displacement of work (in seconds) / 32400

Cutter holding devices used in a milling machine

There are several methods of holding and rotating milling cutters depending on the different designs of the cutters. They are: by the machine spindle

Arbors

The cutters have a bore at the centre are mounted and keyed on a short shaft called arbor.

Collets

A milling machine collet is a form of sleeve bushing for reducing the size of the taper hole at the nose of the spindle so that an arbor or a milling cutter having a smaller shank than the spindle taper can be fitted into it. *Fig. (a) illustrates a milling machine collet.*

Adapter

An adapter is a form of collet used on milling machine having standardized spindle end. Cutters having straight shanks are usually mounted on adapters. An adapter can be connected with the spindle by a draw bolt or it may be directly bolted to it. *Fig. 3.70 (b) illustrates a milling machine adapter.*

Spring collets

Straight shank cutters are usually held on a special adapter called “spring collet” or “spring chuck”. The cutter shank is introduced in the cylindrical hole provided at the end of the adapter and then the nut is lightened. This causes the split jaws of the adapter to spring inside, and grip the shank firmly. *Fig. (c) illustrates a spring collet.*

Bolted cutters

The face milling cutters of larger diameter having no shank are bolted directly on the nose of the spindle. For this purpose four bolt holes are provided on the body of the spindle. This arrangement of holding cutter ensures utmost rigidity. *Fig. (d) illustrates a face milling cutter bolted on the spindle.*

Screwed on cutters

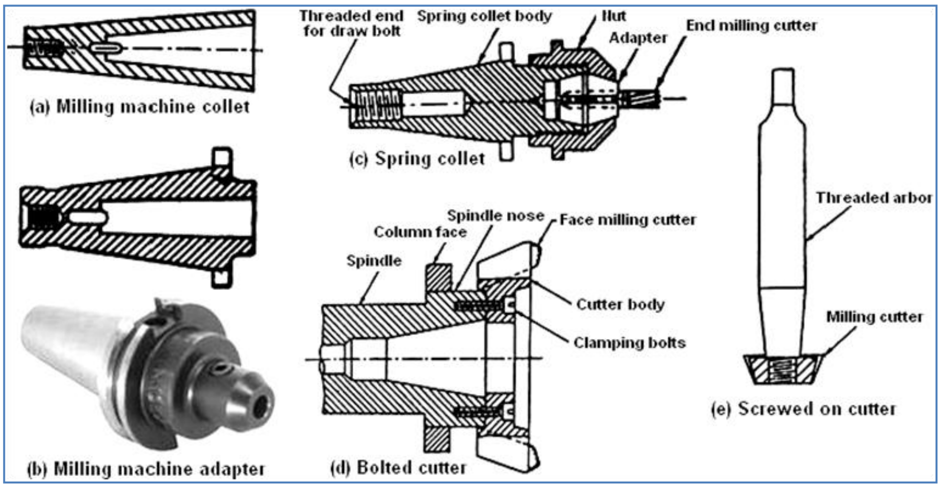


Fig. Different types of cutter holding devices used in milling

The small cutters having threaded holes at the centre are screwed on the threaded nose of an arbor which is mounted on the spindle in the usual manner. *Fig. (e) shows a screwed on cutter.*

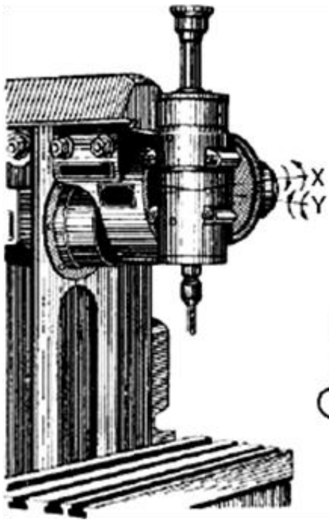
machines

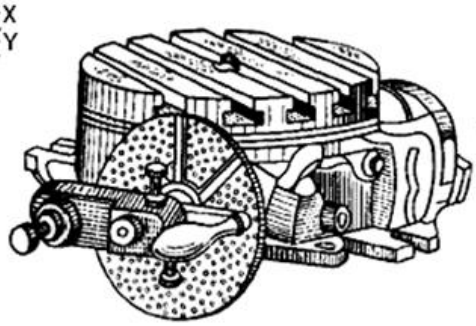
Special attachments used in milling machines

The attachments are intended to be fastened to or joined with one or more components of the milling machine for the purpose of enhancing the range, versatility, productivity and accuracy of operation. Some classes of milling machine attachments are used for positioning and driving the cutter by altering the cutter axis and speed, whereas other classes are used for positioning, holding and feeding the work along a specified geometric path. The following are the different attachments used on standard column and knee type horizontal milling machine.

Universal milling attachment

Amongst the column and knee type conventional milling machines, horizontal arbor type is very widely used, where various types and sizes of milling cutters having axial bore are mounted on the horizontal arbor. For milling by solid end mill type and face milling cutters, separate vertical axis type milling machines are available. But horizontal arbor type milling machines can also be used for those operations to be done by end milling and smaller size face milling cutters by using the universal milling attachment. The rotation of the horizontal spindle is transmitted into rotation about vertical axis and also in any inclined direction by this attachment which thus extends the processing capabilities and application range of the milling machine. *The universal milling attachment is shown in Fig.*





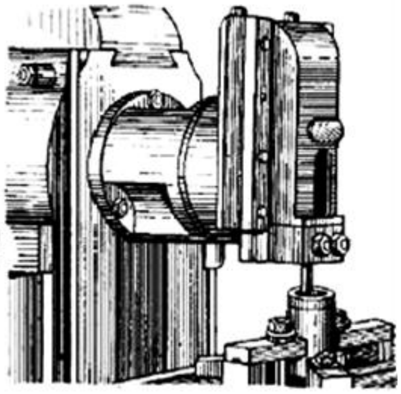


Fig.Universal milling attachment   Fig. Rotary table   Fig. Slotting attachment

Indexing head or dividing head
This attachment is also considered as an accessory.

Rotary table
This device may also be considered both accessory or attachment and is generally used in milling machines for both offline and online indexing / rotation of the work piece, clamped on it, about vertical axis. *Fig. 3.72 visualizes such a rotary table which is clamped or mounted on the machine bed / table.*

Slotting attachment
Such simple and low cost attachment is mounted on the horizontal spindle for producing keyways and contoured surface requiring linear travel of single point tool in milling machine where slotting machine and broaching machine are not available. *The configuration of such a slotting attachment and its mounting and operation can be seen in Fig.* The mechanism inside the attachment converts rotation of the spindle into reciprocation of the single point tool in vertical direction. The direction of the tool path can also be tilted by swiveling the circular base of the attachment body.

MILLING CUTTERS

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. illustrates a plain milling cutter.*

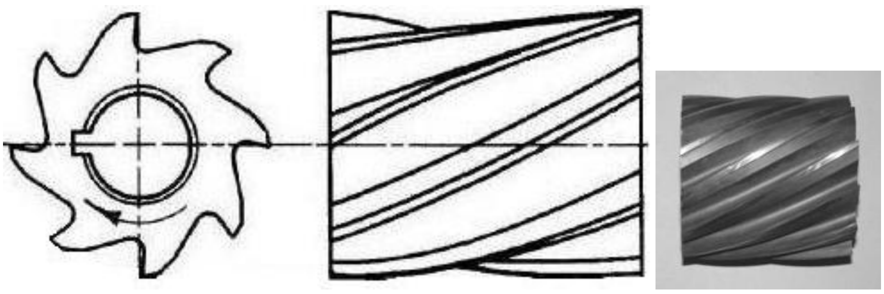


Fig. Slab or plain milling cuttre

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. illustrates a side milling cutter.*

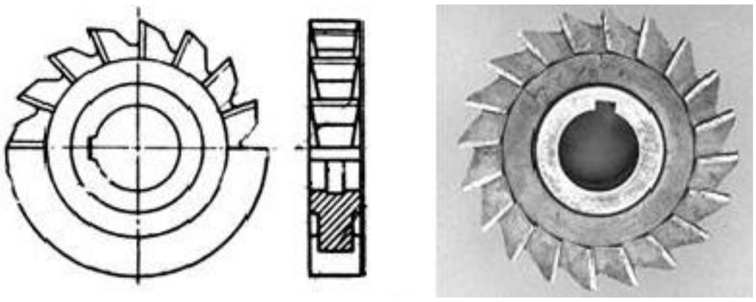
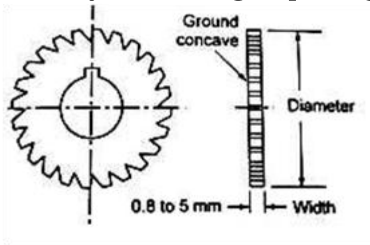


Fig. Side milling cutter

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.



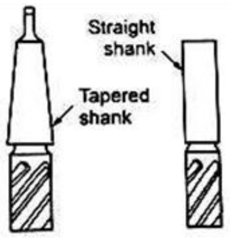


Fig. Slitting saw cutter

Fig. End milling cutters

FigFace milling

End milling cutters: With straight or taper shank

Fig. illustrates end milling cutters. The common characteristics of end milling cutters are:

- Mostly made of High Speed Steel.
- 4 to 12 straight or helical teeth on the periphery and face.
- Diameter ranges from about 1 mm to 40 mm.
- Very versatile and widely used in vertical spindle type milling machines.
- End milling cutters requiring larger diameter are made as a separate cutter body which is fitted in the spindle through a taper shank arbor (Shell end mills).

Face milling cutters

Fig. 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.*

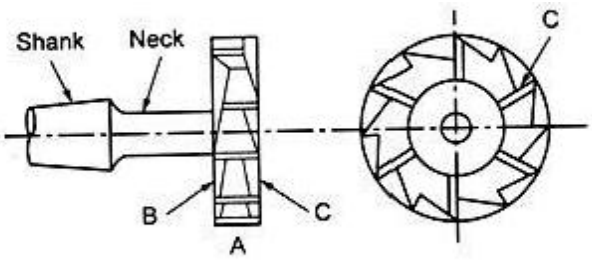


Fig. T-slot milling cutter

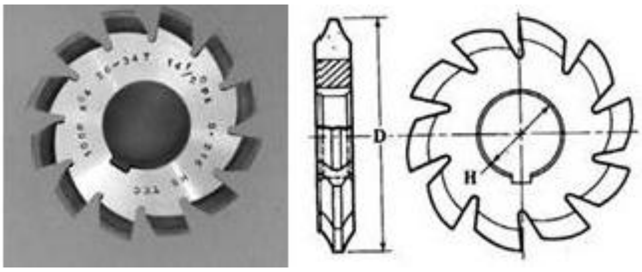


Fig. Involute gear milling cutter

Gear (teeth) milling cutters

Fig. 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. illustrates the tooth section of a spline shaft cutter.*

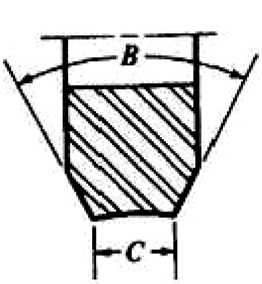


Fig. Tooth section of a spline shaft cutter

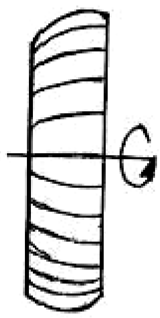


Fig. Tool form cutter

Tool form cutters

Fig. 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. (a) shows internal thread milling cutters, Fig. (b) shows a short thread milling cutter and Fig. (c) shows a long thread milling cutter.

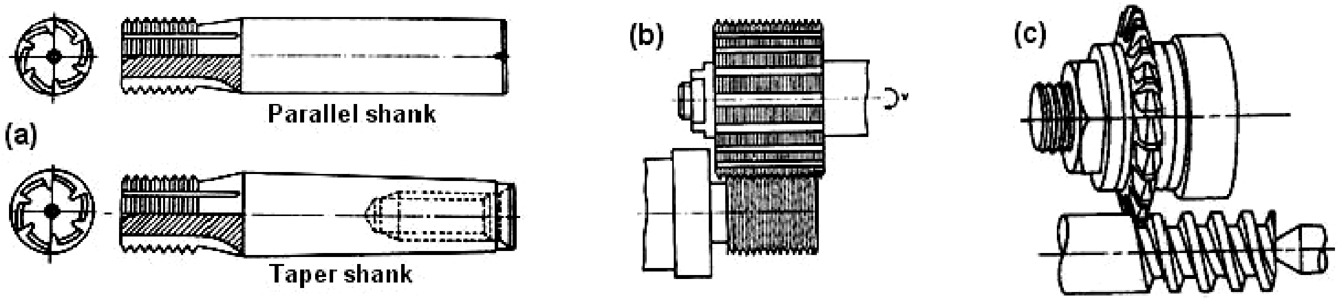


Fig. (a) Internal thread milling cutters (b) Short thread milling cutter (c) Long thread milling cutter

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. (a and b) illustrates the convex and concave milling cutters.*

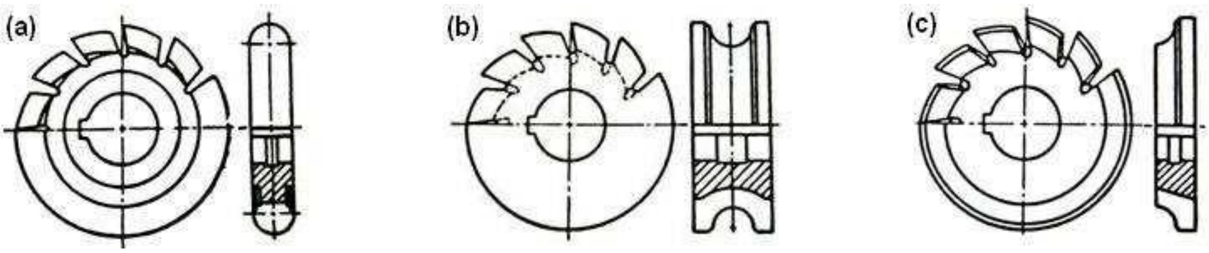


Fig. (a) Convex milling cutter (b) Concave milling cutter and (c) Corner rounding milling cutter

Corner rounding milling cutters

Fig (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 (a) shows a single angle milling cutters and Fig. (b) shows a* *double angle milling cutter.*

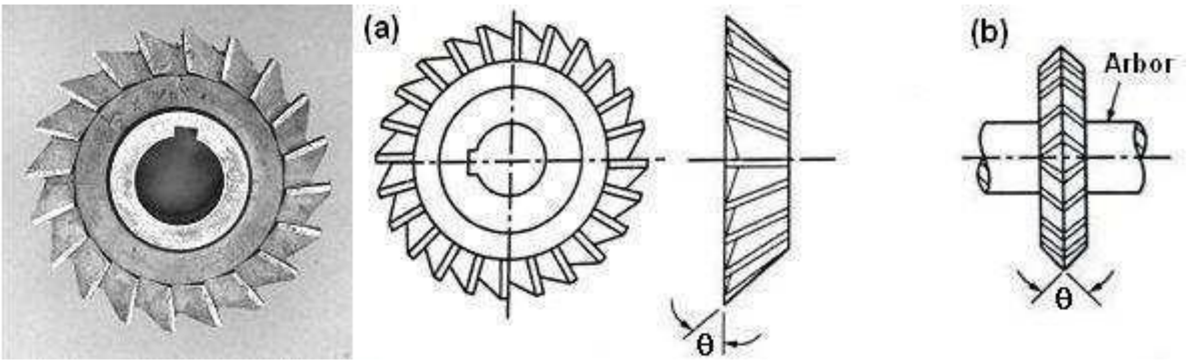
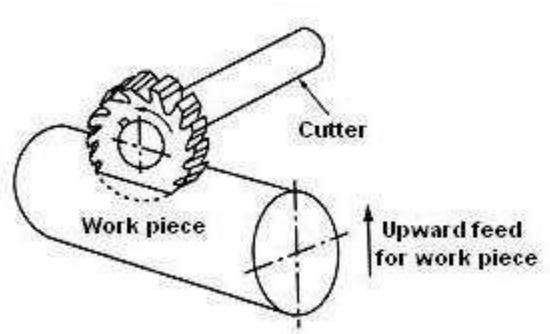


Fig. (a) Single angle milling cutter and (b) Double angle milling cutter

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. illustrates a woodruff key slot milling cutter.*



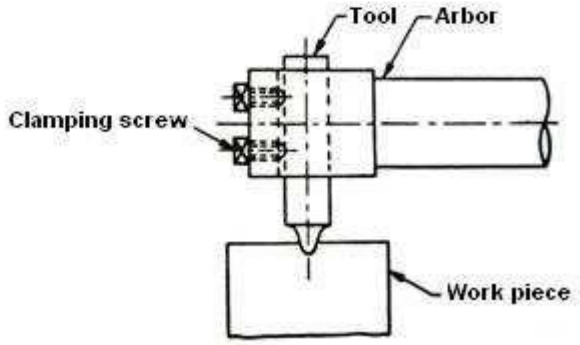


Fig. Woodruff key slot milling cutter

Fig. Schematic view of a fly cutter

Fly cutter

These are simplest form of cutters and are mainly used in experimental shops or in tool room works. The cutter consists of a single point cutting tool attached to the end of an arbor. This cutter may be considered as an emergency tool when the standard cutters are not available. The shape of the tool tip is the replica of the contour to be machined. *Fig. schematically shows a fly cutter.*

Ball nose end mill

Small end mill with balllike 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.*

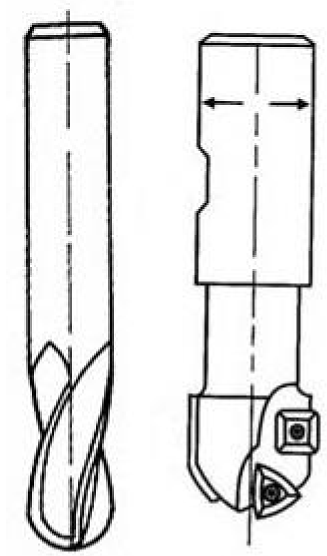


Fig. Ball nose end mills

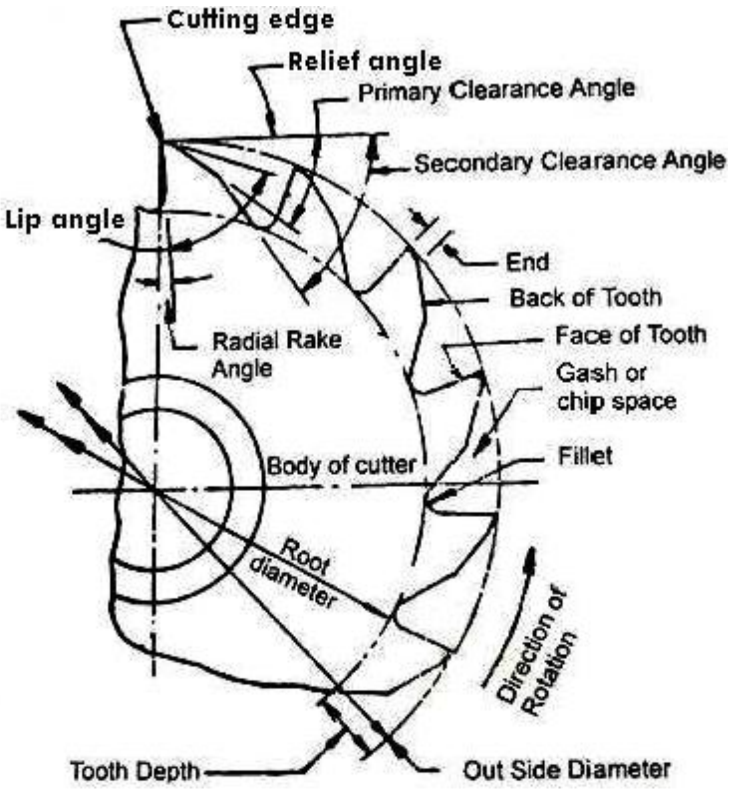


Fig. Elements of a plain milling cutter

Elements of a plain milling cutter

The major parts and angles of a plain milling cutter are illustrated in Fig.

Body of cutter The part of the cutter left after exclusion of the teeth and the portion to which the teeth are attached.

Cutting edge The edge formed by the intersection of the face and the circular land or the surface left by the provision of primary clearance.

Face The portion of the gash adjacent to the cutting edge on which the chip impinges as it is cut from the work.

Fillet The curved surface at the bottom of gash that joins the face of one tooth to the back of the tooth immediately ahead.

Gash The chip space between the back of one tooth and the face of the next tooth.

Land The part of the back of tooth adjacent to the cutting edge which is relieved to avoid interference between the surface being machined and the cutter.

Outside diameter The diameter of the circle passing through the peripheral cutting edge.

Root diameter The diameter of the circle passing through the bottom of the fillet.

Cutter angles Similar to a single point cutting tool, the milling cutter teeth are also provided with rake, clearance and other cutting angles in order to remove metal efficiently.

Relief angle The angle in a plane perpendicular to the axis. The angle between land of a tooth and tangent to the outside diameter of cutter at the cutting edge of that tooth.

Lip angle The included angle between the land and the face of the tooth, or alternatively the angle between the tangent to the back at the cutting edge and the face of the tooth.

Primary clearance angle The angle formed by the back of the tooth with a line drawn tangent to the periphery of the cutter at the cutting edge.

Secondary clearance angle The angle formed by the secondary clearance surface of the tooth with a line drawn tangent to the periphery of the cutter at the cutting edge.

Rake angle (Radial) The angle measured in the diametral plane between the face of the tooth and a radial line passing through the tooth cutting edge. *The rake angle which may be positive, negative or zero is illustrated in Fig..*

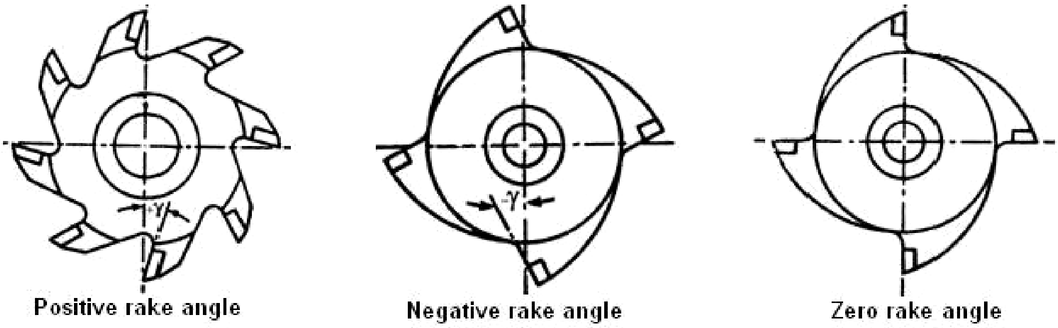


Fig. Three types of rake angle of a plain milling cutter

MILLING OPERATIONS

Milling machines are mostly general purpose machine tools and used for piece or small lot production. In general, all milling operations can be grouped into two types.
They are: peripheral milling and face milling.

Peripheral milling Here, the finished surface is parallel to the axis of rotation of the cutter and is machined by cutter teeth on the periphery of the cutter. *Fig. schematically shows the peripheral milling operation.*

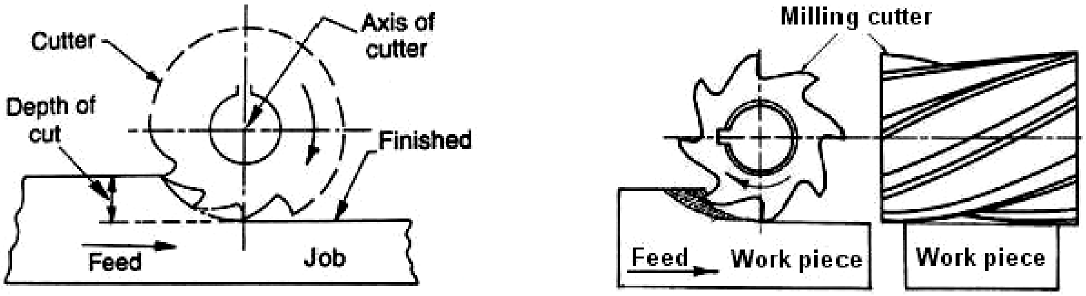


Fig. Schematic view of the peripheral milling operation

Face milling Here, the finished surface is perpendicular to the axis of rotation of the cutter and is machined by cutter teeth on the periphery and the flat end of the cutter. The peripheral cutting edges do the actual cutting, whereas the face cutting edges finish up the work surface by removing a very small amount of material. *Fig. schematically shows the face milling operation.*

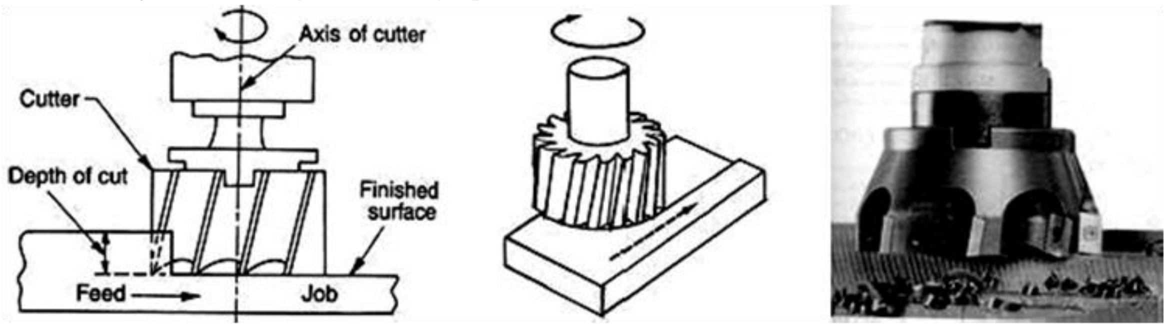


Fig. Schematic view of the face milling operation

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. schematically shows the different end milling operation.*

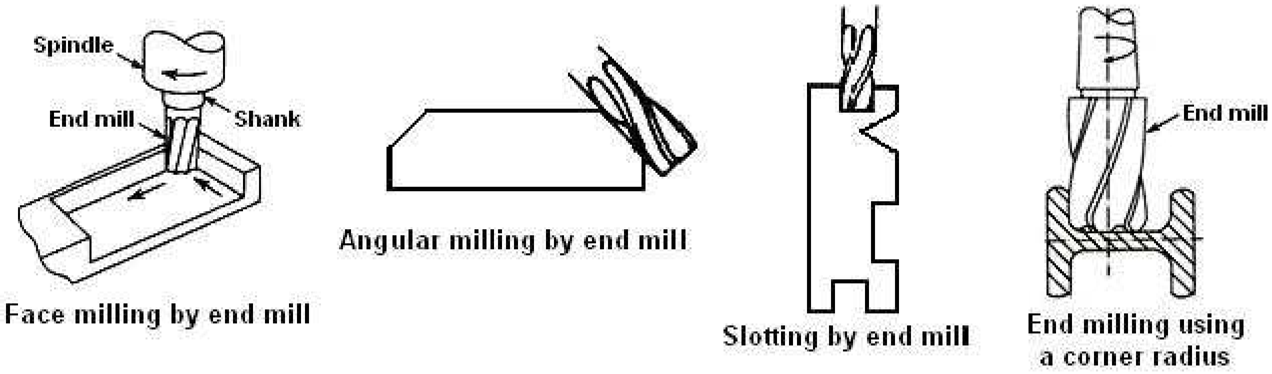


Fig Schematic views of the different end milling operations

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.

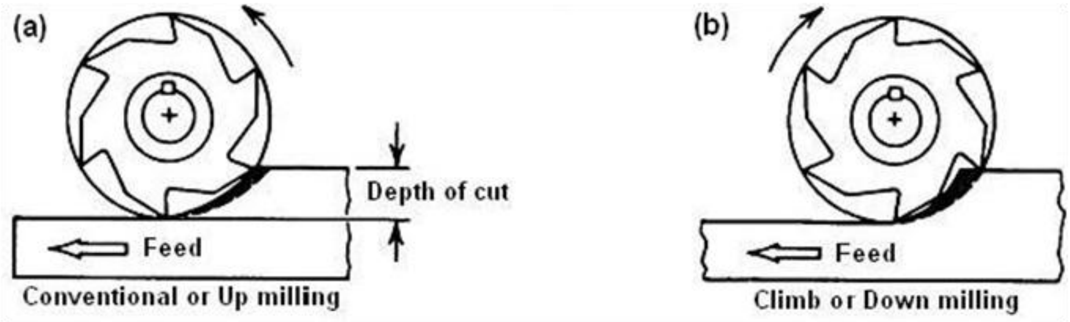


Fig. (a) schematically shows the up milling or conventional milling process.
Fig. Schematic views of (a) Up milling process and (b) Down milling process

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. (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.*

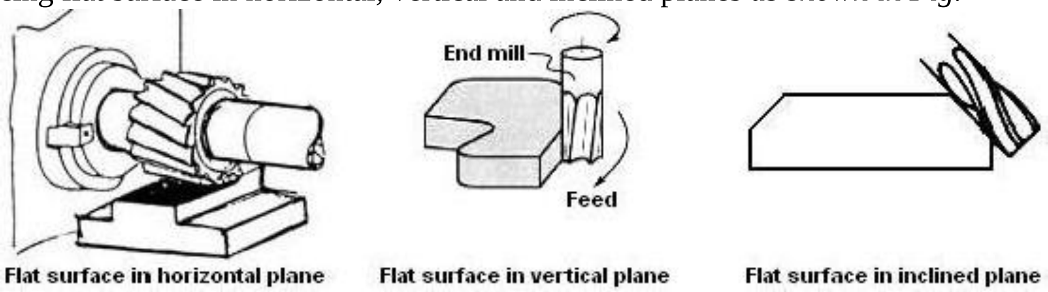


Fig. Producing flat surface in horizontal, vertical and inclined planes

Machining slots of various cross sections *as shown in Fig.*

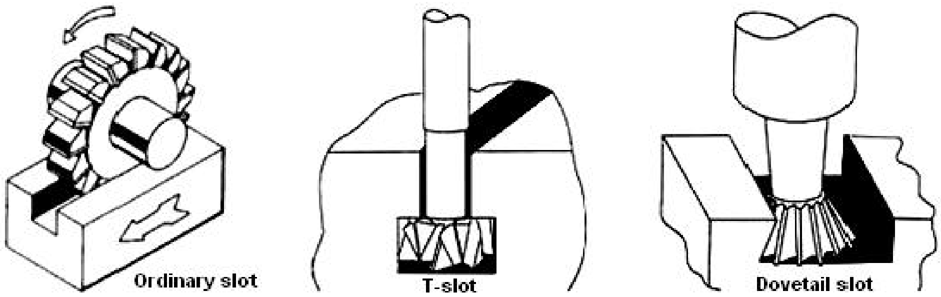


Fig. Machining slots of various cross sections Slitting or parting operation *as shown in Fig..*

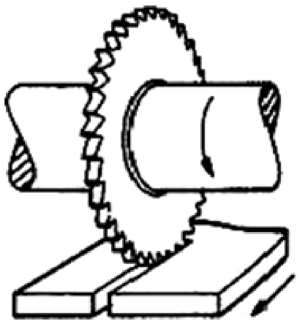


Fig. Parting by slitting saw

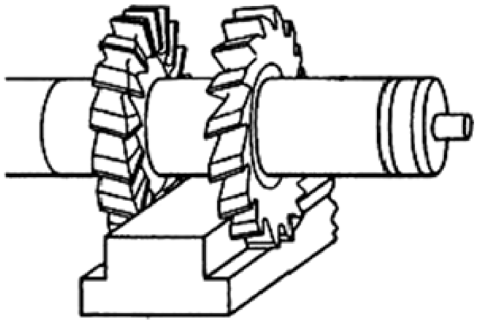


Fig. Straddle milling

Straddle milling or parallel facing operation by two single side milling cutters *as shown in Fig.*

Form milling operation by form cutters *as shown in Fig.*

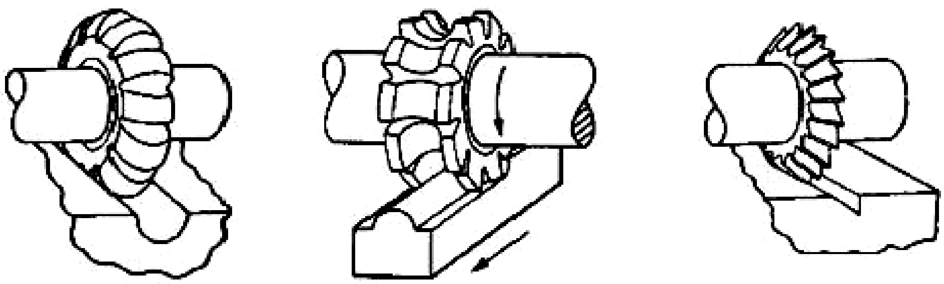
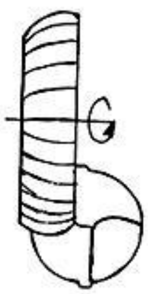


Fig. Form milling operations

Cutting helical grooves like flutes of the drills *as shown in Fig.*



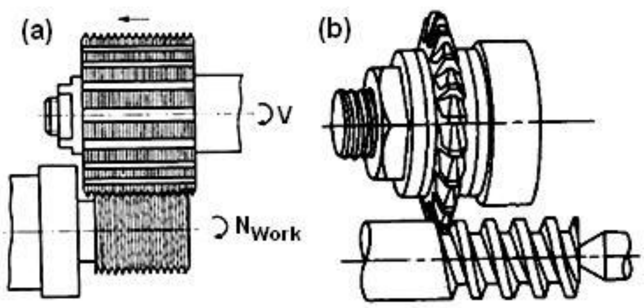


Fig. Cutting of drill flutes

Fig. (a) Short thread milling (b) Long thread milling Short thread milling for small size fastening screws, bolts etc. and long thread milling on large lead screws, power screws, worms etc. *These are illustrated in Fig. (a and b).*

Cutting teeth of spur gears, straight toothed bevel gears, worm wheels, sprockets in piece or batch production. *These are illustrated in Fig. (a, b and c).*

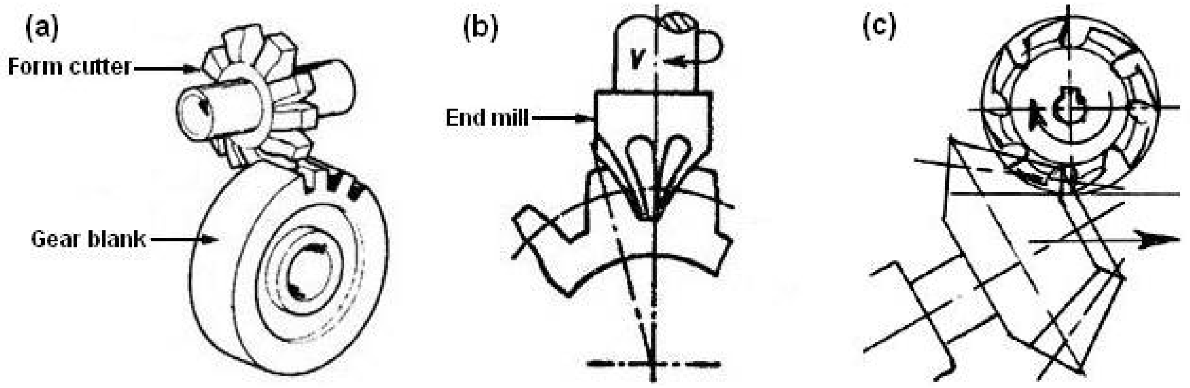


Fig. (a) Cutting teeth of spur gear by disc type cutter (b) Cutting teeth of spur gear by end mill
(c) Cutting teeth of straight toothed bevel gear by disc type cutter

Cutting the slots of external spline shafts *as shown in Fig.*

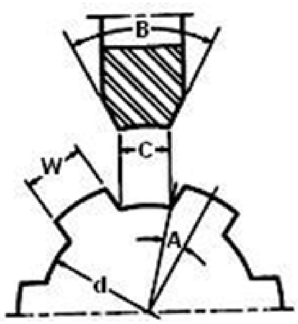


Fig. Cutting slots of external spline shaft

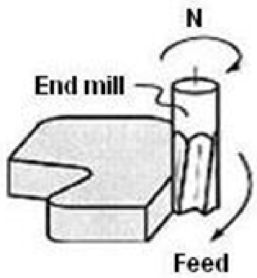
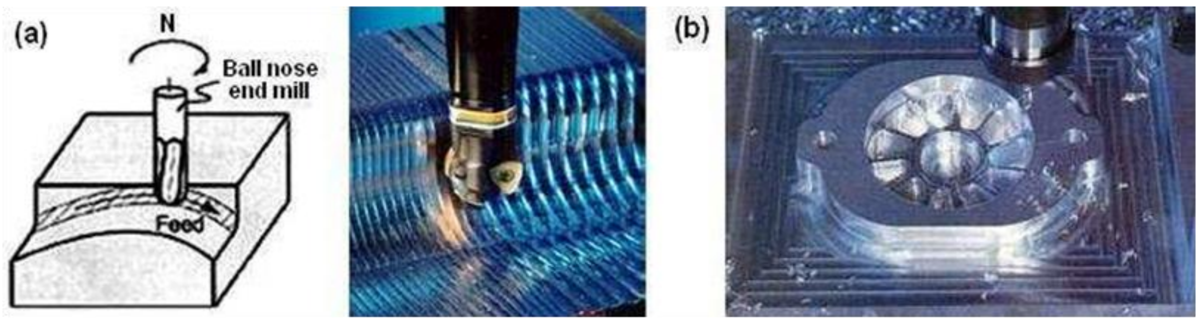


Fig. Profile milling of a cam

Profile milling like cam profiles *as shown in Fig.*



Surface contouring or 3-D contouring like die or mould cavities *as shown in Fig. (a and b).*
Fig. (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.*

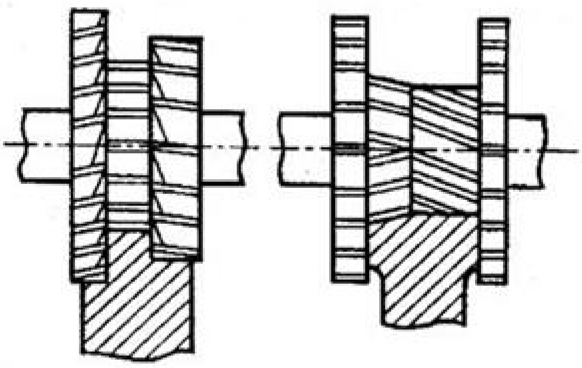


Fig. Gang milling

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. (a, b and c).*

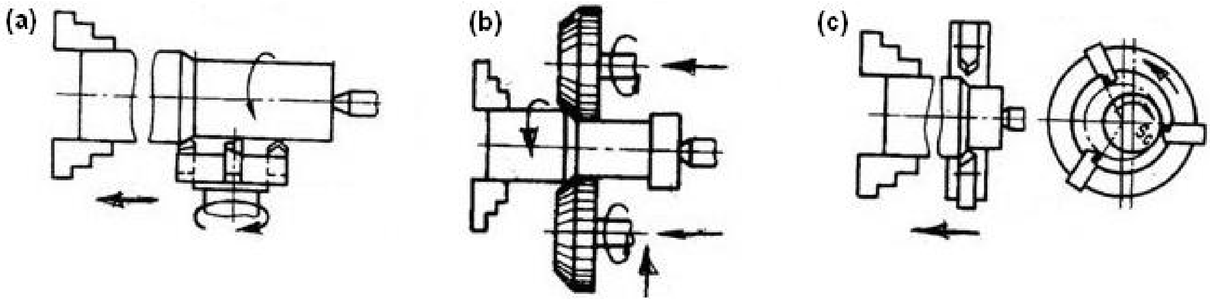


Fig. (a, b and c) Turning by rotary milling cutters

HOLE MAKING

Machining round holes in metal stock is one of the most common operations in the manufacturing industry. It is estimated that of all the machining operations carried out, there are about 20 % hole making operations. Literally no work piece leaves the machine shop without having a hole made in it. *The various types of holes are shown in Fig.*

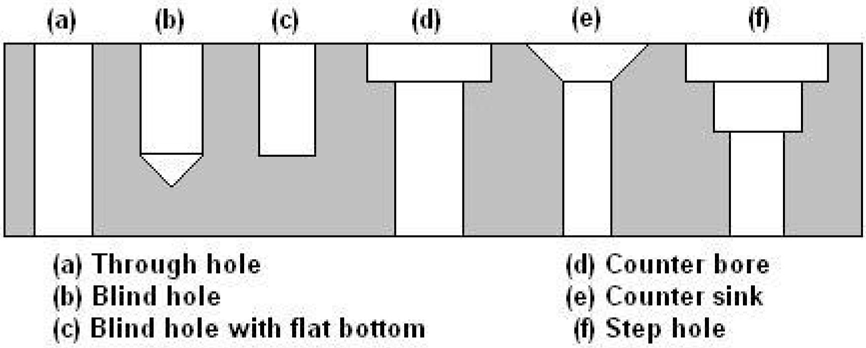


Fig. Various types of holes

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

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

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. illustrates a hand drilling machine.*

Fig Hand drilling machine

Fig. Table top sensitive 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. illustrates a table top sensitive drilling machine.*

Floor mounting sensitive drilling machine

The floor mounting sensitive drilling machine is a small machine designed for drilling small holes at high speed in light jobs. The base of the machine is mounted on the floor. It consists of a vertical column, a horizontal table, a head supporting the motor and driving mechanism, and a vertical spindle for driving and rotating the drill. There is no arrangement for any automatic feed of the drill spindle. The drill is fed into the work by purely hand control. High speed is necessary for drilling small holes. High speeds are necessary to attain required cutting speed by small diameter drill. Hand feed permits the operator to feel or sense the progress of the drill into the work, so that if the drill becomes worn out or jams on any account, the pressure on the drill may be released immediately to prevent it from breaking. As the operator senses the cutting action, at any instant, it is called sensitive drilling machine. Sensitive drilling machines are capable of rotating drills of diameter from 1.5 to 15.5 mm. Super sensitive drilling machines are designed to drill holes as small as 0.35 mm in diameter and the machine is rotated at a high speed of 20,000 r.p.m. or above. *Fig. illustrates a floor mounting sensitive drilling machine.*

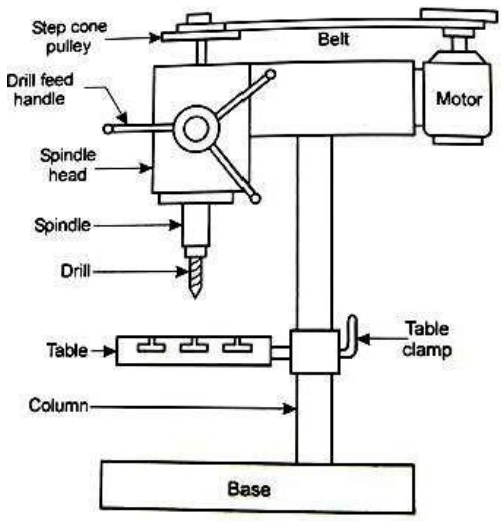


Fig. Floor mounting sensitive drilling machine machine

Fig. Pillar drilling

Pillar or Round column section upright drilling machine

Fig. illustrates a pillar or round column section upright drilling machine. This machine is usually called pillar drilling machine. It is quite similar to the table top drilling machine but of little larger size and higher capacity (0.55 ~ 1.1 kW) and are mounted on the floor. In this machine the drill feed and the work table movements are done manually. This low cost drilling machine has a base, a tall tubular column, an arm supporting the table and a drill head assembly. The arm may be moved up and down on the column and also be moved in an arc up to 180^0 around the column. The table may be rotated 360^0 about its own centre independent of the position of the arm. It is generally used for small jobs and light drilling. The maximum size of holes that can be drilled is not more than 50 mm.

Box column section upright drilling machine

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

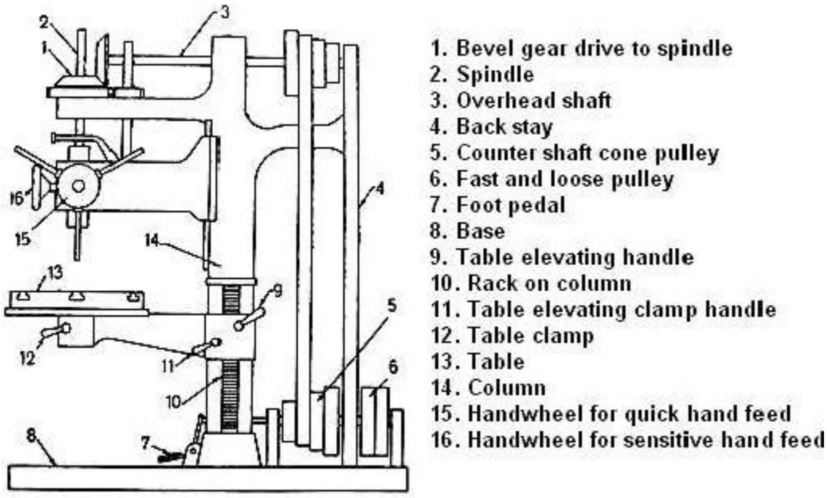


Fig. Box column section upright drilling machine

Base It is a part of the machine on which vertical column is mounted. The top of the base is accurately machined and has T-slots on it so that large work pieces and work holding devices may be set up and bolted to it.

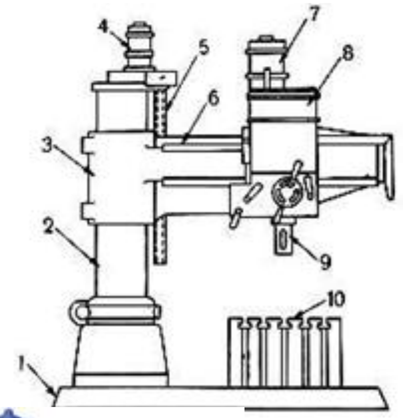
Column It is the vertical member of the machine which supports the table and the head containing all the driving mechanism. The column should be sufficiently rigid so that it can take up the entire cutting pressure of the drill. The column may be made of box section or of round section. Box column is a more rigid unit. In box column type, the front face of the column is accurately machined to form guide ways on which the table can slide up and down for vertical adjustment.

Table It is mounted on the column and is provided with T-slots for clamping the work directly on its face. The table may be round or rectangular in shape. The table may have three types of adjustments: vertical adjustment, radial adjustment about the column, and circular adjustment about its own axis. After the required adjustments have been made the table and the arm are clamped in position.

Drill head It is mounted on the top of the column and houses the driving and feeding mechanism for the spindle. In some of the machines the drill head may be adjusted up or down for accommodating different heights of work in addition to the table adjustment.

Spindle Holds the drill and transmits rotation and axial translation to the tool for providing cutting motion and feed motion - both to the drill.

Radial drilling machine



1. Base
2. Column
3. Radial arm
4. Motor for elevating the radial arm
5. Elevating screw
6. Guide ways for drill head
7. Motor for driving the drill spindle
8. Drill head
9. Drill spindle
10. Work table

Fig. illustrates a radial drilling machine. **The major parts are:**

Fig. Radial drilling machine

Base It is a large rectangular casting that is finished on its top to support a column on its one end and to hold the work table at the other end. In some machines T-slots are provided on the base for clamping work when it serves as a table.

Column The column is a cylindrical casting that is mounted vertically at one end of the base. It supports the radial arm which may slide up or down on its face. An electric motor is mounted on the top of the column which imparts vertical adjustment of the arm by rotating a screw passing through a nut attached to the arm.

Radial arm The radial arm that is mounted on the column extends horizontally over the base. It is a massive casting with its front vertical face accurately machined to provide guide ways on which the drill head may be made to slide. The arm may be swung round the column. In some machines this movement is controlled by a separate motor.

Drill head The drill head is mounted on the radial arm and drives the drill spindle. It encloses all the mechanism for driving the drill at multiple speeds and at different feed. All the mechanisms and controls are housed within a small drill head which may be made to slide on the guide ways of the arm for adjusting the position of drill spindle with respect to the work.

Spindle drive and feed mechanism

There are two common methods of driving the spindle. A constant speed motor is mounted at the extreme end of the radial arm. The motor drives a horizontal spindle which runs along the length of the arm and the motion is transmitted to the drill head through bevel gears. By the gear train within the drill head, the speed of the spindle may be varied. Through another gear train within the drill head, different feeds of the spindle are obtained. In some machines, a vertical motor is fitted directly on the drill head and through gear box multiple speed and the feed of the spindle can be obtained.

Working principle

The work is mounted on the table or when the work is very large it may be placed on the floor or in a pit. Then the position of the arm and the drill head is altered so that the drill may be pointed exactly on the location where the hole is to be drilled. When several holes are drilled on a large work piece, the drill head is moved from one position to the other after drilling the hole without altering the setting of the work. This versatility of the machine allows it to work on large work pieces. There are some more machines where the drill spindle can be additionally swiveled and / or tilted.

Gang drilling machine

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

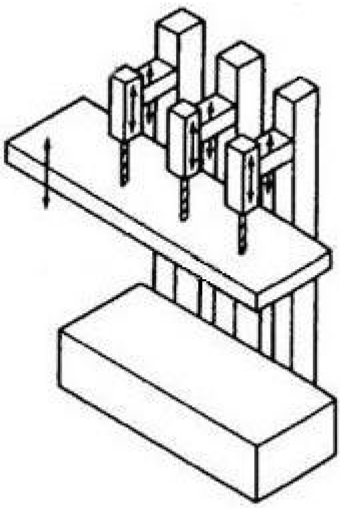


Fig. Gang drilling machine

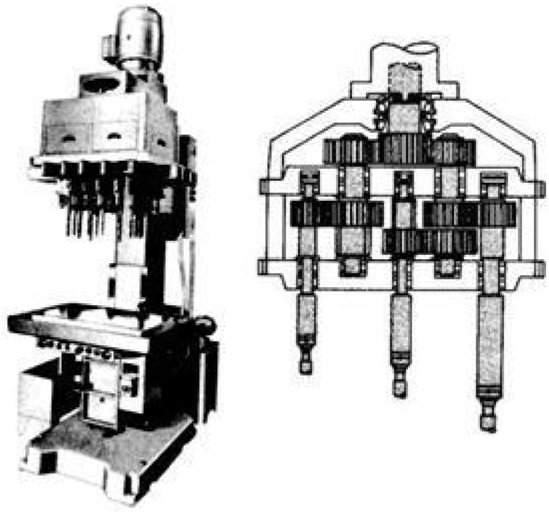


Fig. Multiple spindle drilling machine

Multiple spindle drilling machine

Fig. schematically shows a typical multiple spindle drilling machine. In this high production machine a large number of drills work concurrently on a blank through a jig specially made for the particular work. The entire drilling head works repeatedly using the same jig for batch or lot production. The rotations of the drills are derived from the main spindle and the central gear through a number of planetary gears in mesh with the central gear and the corresponding flexible shafts. The positions of those parallel shafts holding the drills are adjusted depending upon the locations of the holes to be made on the job. Each shaft possesses a telescopic part and two universal joints at its ends to allow its change in length and orientation respectively for adjustment of location of the drills of varying size and length. In some heavy duty multi spindle drilling machines, the work-table is raised to give feed motion instead of moving the heavy drilling head.

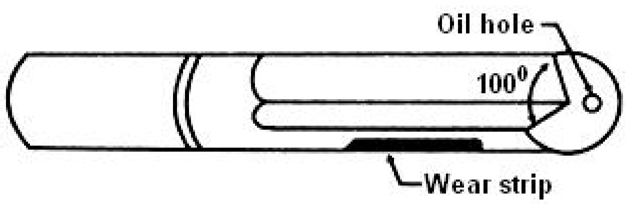
Deep hole drilling machine

Very deep holes of L/D ratio 6 to even 30, required for rifle barrels, long spindles, oil holes in shafts, bearings, connecting rods etc, are very difficult to make for slenderness of the drills and difficulties in cutting fluid application and chip removal. Such drilling cannot be done in ordinary drilling machines and by using ordinary drills. It needs machines like deep hole drilling machine such as gun drilling machines with horizontal axis or vertical axis.

These machines are provided with:

- High spindle speed.
- High rigidity.
- Tool guide.
- Pressurized cutting oil for effective cooling, chip removal and lubrication at the drill tip.

Fig. schematically shows a deep hole drill tool used in the deep hole drilling operation.



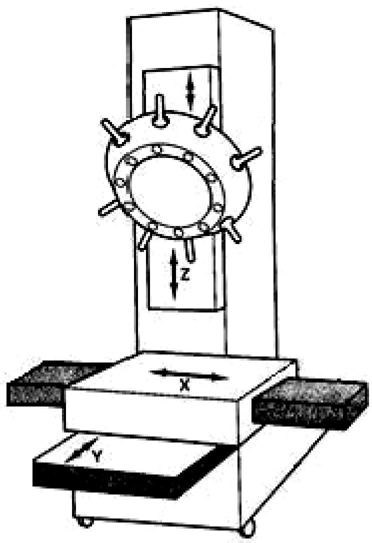


Fig. Deep hole drill machine

Fig. Turret type drilling

Turret type drilling machine

Fig. schematically shows a typical turret type drilling machine. Turret drilling machine is structurally rigid column type drilling machine but is more productive like gang drill machine by having a pentagon or hexagon turret. The turret holds a number of drills and similar tools, is indexed and moved up and down to perform quickly the desired series of operations progressively. These drilling machines are available with varying degree of automation both fixed and flexible type.

Spindle and drill head assembly

The spindle is a vertical shaft which holds the drill. It receives its motion from the top shaft though bevel gears. A long key-way is cut on the spindle and the bevel gear is connected to it by a sliding key. This construction is made to allow the spindle to be connected with the top shaft irrespective of its position when the spindle is raised or lowered for feeding the drill into the work piece. The spindle rotates within a non-rotating sleeve which is known as the quill. Rack teeth are cut on the outer surface of the sleeve. The sleeve may be moved up or down by rotating a pinion which meshes with the rack and this movement is imparted to the spindle to give the required feed.

The downward movement of the spindle is effected by rotating the pinion which causes the quill to move downward exerting pressure on the spindle through a thrust bearing and washer. The spindle is moved upward by the upward pressure exerted by the quill acting against a nut attached to the spindle through the thrust bearing. The lower end of the spindle is provided with Morse taper hole for accommodating taper shank drill. A slot is provided at the end of the taper hole for holding the tang of the drill to impart it a positive drive. *The drill spindle assembly is illustrated in Fig..*

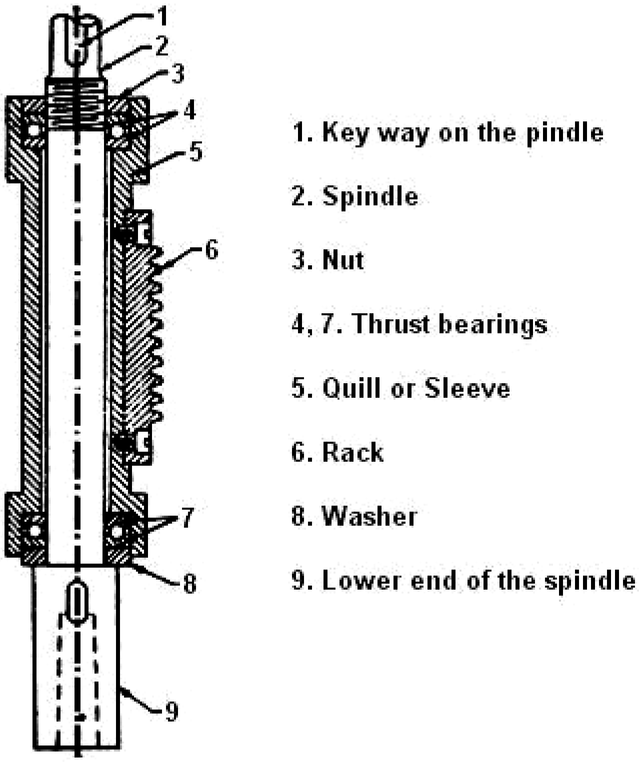


Fig. Drill spindle assembly

Spindle drive mechanism

The spindle drive mechanism of a drilling machine incorporates an arrangement for obtaining multiple speed of the spindle similar to a lathe to suit to various machining conditions.

Multiple speed of the spindle may be obtained as follows:

- By step cone pulley drive.
- By step cone pulley drive with one or more back gears.
- By gearing.

Step cone pulley drive *Fig. shows the schematic view of a spindle driving mechanism incorporating a step cone pulley.* The motion is transmitted from an overhead line shaft to the countershaft mounted on the base of the machine. The countershaft may be started or stopped by shifting the belt from loose pulley to fast pulley or vice versa by operating the foot-pedal 7. The step cone pulley mounted on the head of the machine receives power from the countershaft step cone pulley 5 through the belt. The drill spindle 2 receives power from the overhead shaft 3 through bevel gears 1 and the speed of the spindle may be varied by shifting the belt on different steps of the cone pulley 5. The number of spindle speeds available is dependent upon the number of steps on the cone pulley.

Step cone pulley drive with back gear In order to obtain larger number of spindle speeds back gears are incorporated in the machine in addition to the step cone pulley.

Spindle drive by gearing

Modern heavy duty drilling machines are driven by individual motor mounted on the frame of the machine. The multiple speeds may be obtained by sliding gear or sliding clutch mechanism or by the combination of the above two methods.

Feed mechanism

In a drilling machine, the feed is effect by the vertical movement of the drill into the work. The feed movement of the drill may be controlled by hand or power.

The hand feed may be applied by two methods:

- Quick traverse hand feed.
- Sensitive hand feed.

The quick traverse feed is used to bring the cutting tool rapidly to the hole location or for withdrawing the drill when the operation is completed. Quick hand feed is obtained by rotating the hand wheel pivoted to the pinion. One turn of the hand wheel will cause the pinion to rotate through one complete revolution giving quick hand feed movement of the spindle.

The sensitive hand feed is applied for trial cut and for drilling small holes. The sensitive feed hand wheel is attached to the rear end of the worm shaft. Rotation of the hand wheel will cause the worm and worm gear to rotate and a slow but sensitive feed is obtained.

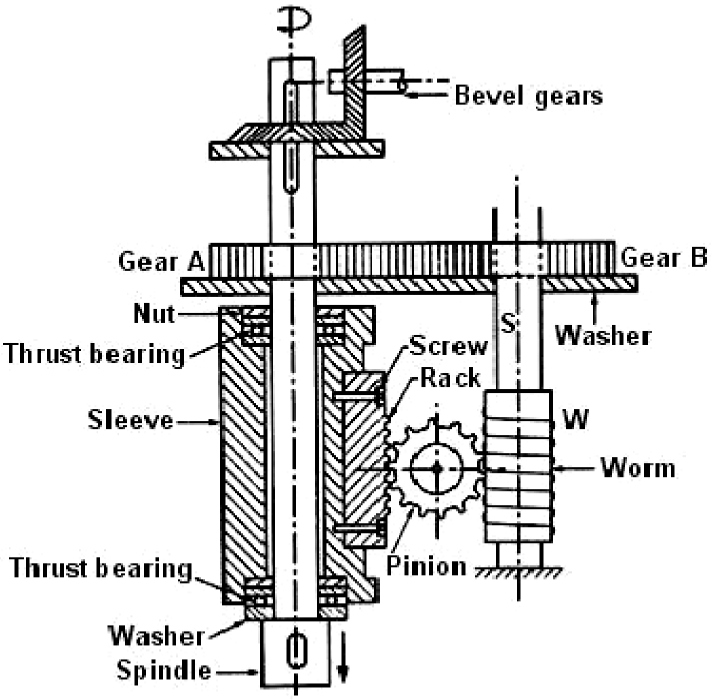


Fig. Automatic feed mechanism

The automatic feed is applied while drilling larger diameter holes as the cutting pressure required is sufficiently great. *Fig. illustrates the automatic feed mechanism.* The gear A rotates with the spindle as the spindle passes through it. Gear B is connected with gear A, so it also rotates. The shaft S rotates with the gear B as it connected to it. At a suitable distance under the shaft, there is a worm which drives a pinion. The pinion is connected with the rack on the non rotating sleeve (quill) fitted over the spindle. The rotation of the worm rotates the pinion. The rotation of the pinion moves the quill up and down through the rack cut on it. The quill moves the drill spindle up and down. Thus the automatic feed of the drill spindle is achieved. Different ranges of feed can be obtained by means of feed gearbox.

Work holding devices used in drilling machines

Before performing any operation in a drilling machine it is absolutely necessary to secure the work firmly on the drilling machine table. The work should never be held by hand, because the drill while revolving exerts so much of torque on the work piece that it starts revolving along with the tool and may cause injuries to the operator. The work holding devices commonly used for holding the work piece in a drilling machine table are: T-bolts and clamps, machine vises, step blocks, V-blocks, angle plate and drill jigs. When the work is heavy and / or of odd shape and size, it is directly clamped on the drilling machine table.

Drill jigs

These are used for holding the work in a mass production process. A drill jig can hold the work securely, locate the work and guide the tool at any desired position. The work may be clamped and unclamped quickly. Jigs are specially designed for each type of work where quantity production is desired. The work is clamped below the jig and the holes are located. The drill is guided by the drill bush. *Fig. schematically shows some types of drill jigs used in mass production.*

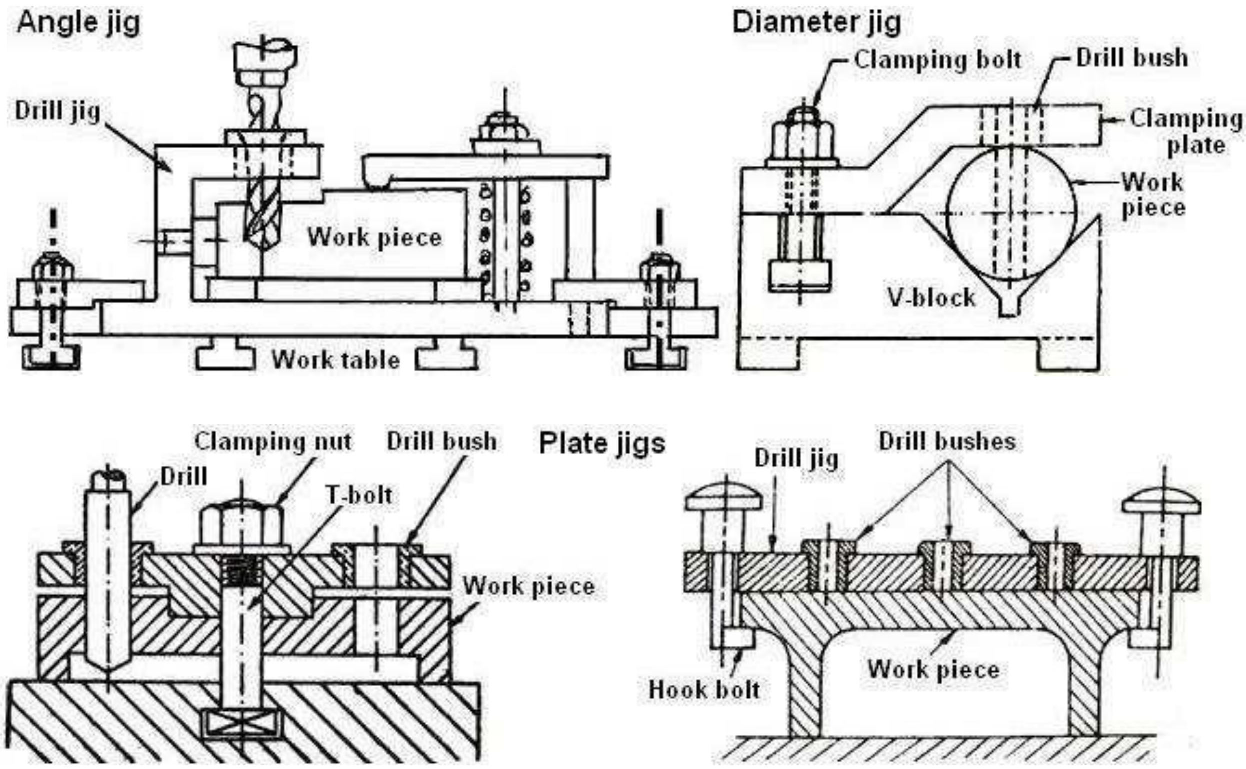


Fig. Some types of drill jigs

Tool holding devices used in drilling machines

In drilling machines mostly drills of various type and size are used for drilling holes. Often some other tools are also used for enlarging and finishing drilled holes, counter boring, countersinking, tapping etc. The different methods used for holding tools in a drill spindle are:

- By directly fitting in the spindle.
- By a sleeve.
- By a socket.
- By chucks.

Drill directly fitted in the spindle

All drilling machines have the spindle bored out to a standard Morse taper (1:20) to receive the taper shank of the tool. While fitting the tool the shank is forced in the tapered hole and the tool is gripped by friction. The tool may be rotated with the spindle by friction between the tapered surface and the spindle; but to ensure a positive drive the tang or tongue of the tool fits into a slot at the end of the taper hole. The tool is removed by pressing a tapered wedge known as the drift or key into the slotted hole of the spindle. *Fig. (a) shows a drill directly fitted in the spindle. Fig. (b) shows a drift.*

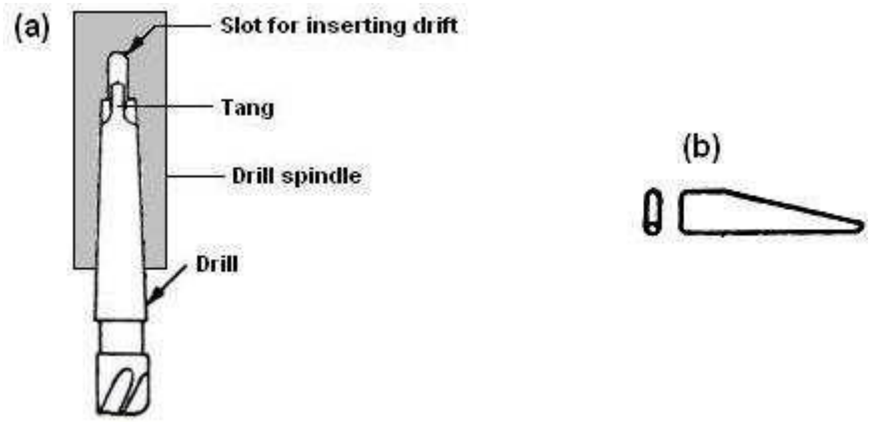


Fig. (a) Drill directly fitted in the spindle and (b) Drift or key

Drill sleeve

The drill spindle is suitable for holding only one size of shank. If the taper shank of the tool is smaller than the taper in the spindle hole, a taper sleeve is used. The outside taper of the sleeve conforms to the drill spindle taper and the inside the taper holds the shanks of smaller size tools or smaller sleeves. The sleeve fits into the taper hole of the spindle. The sleeve has a tang which fits into the slot of the spindle. The tang of the tool fits into a slot provided at the end of the taper hole of the sleeve. The sleeve with the tool may be removed by forcing a drift within the slot of the spindle and the tool may be separated from the sleeve by the similar process. Different size of the tool shanks may be held in the spindle by using different sizes of sleeves. *Fig. (a) shows a drill sleeve. Fig. (b) shows a drill sleeve holding a drill fitted in the drill spindle. Fig. (c) shows different sizes of drill sleeves.*

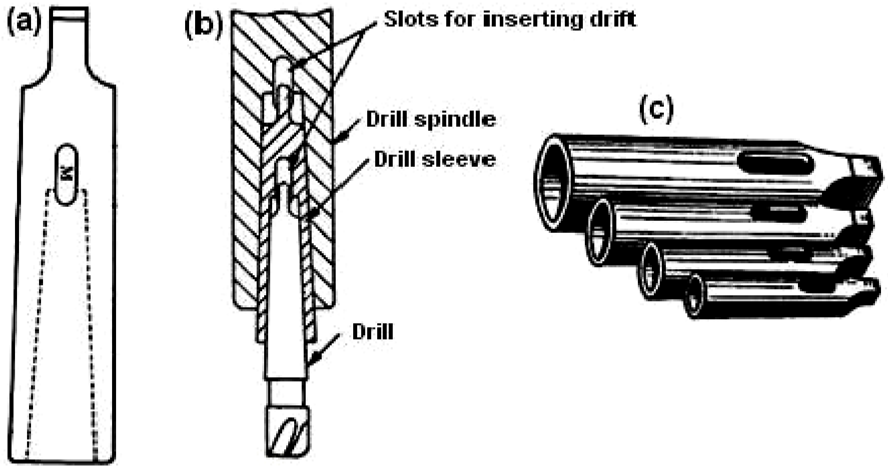


Fig. (a) Drill sleeve (b) Drill sleeve holding a drill fitted in the drill spindle and (c) Different sizes of drill sleeves.

Drill socket

When the tapered tool shank is larger than the spindle taper, drill sockets are used to hold the tool. Drill sockets are much longer in size than the drill sleeves. A socket consists of a solid shank attached to the end of a cylindrical body. The taper shank of the socket conforms to the taper of the drill spindle and fits into it. The body of the socket has a tapered hole larger than the drill spindle taper into which the taper shank of any tool may be fitted. The tang of the socket fits into the slot of the spindle and the tang of the tool fits into the slot of the socket. *Fig. shows a drill socket.*

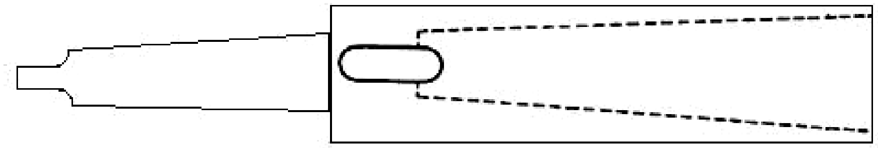


Fig. Drill socket

Drill chucks

The chucks are especially intended for holding smaller size drills are any other tools. A sleeve or socket can hold one size of tool shank only; but a drill chuck may be used to hold different sizes of tool shanks within a certain limit. Drill chucks have tapered shanks which are fitted into the drilling machine spindle. Different types of drill chucks are manufactured for different purposes. The most common type of drill chuck used is three jaw self centering drill chuck.

This type of chuck is particularly adapted for holding tools having straight shanks. Three slots are cut 120^0 apart in the chuck body which houses three jaws having threads cut at the back that meshes with a ring nut. The ring nut is attached to the sleeve. Bevel teeth are cut all round the sleeve body. The sleeve may be rotated by rotating a key having bevel teeth cut on its face which meshes with the bevel teeth on the sleeve. The rotation of the sleeve causes the ring nut to rotate in a fixed position and all the three jaws close or open by the same amount from the centre holding or releasing the shank of a tool. *Fig. shows a three jaw self centering drill chuck.*

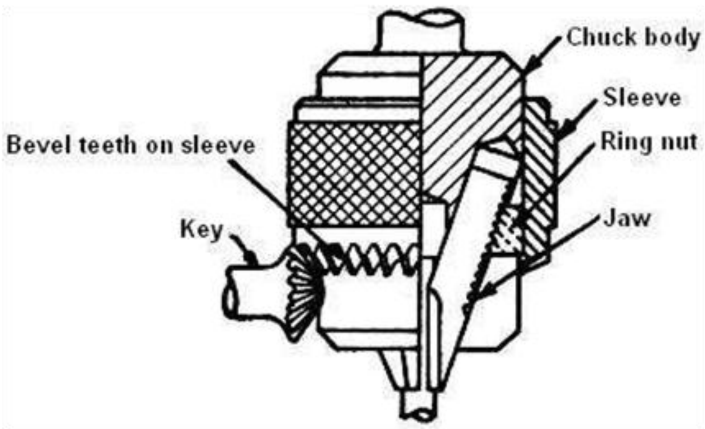


Fig. Three jaw self centering drill chuck

Drilling tools

Different types of drills are properly used for various applications depending upon work material, tool material, depth and diameter of the holes. General purpose drills may be classified as:

According to material:

- ➢ High speed steel - most common.
- ➢ Cemented carbides.
- ❖ Without or with coating.
- ❖ In the form of brazed, clamped or solid.

According to size:

- ➢ Large twist drills of diameter around 40 mm.
- ➢ Micro drills of diameter 25 µm to 500 µm.

- Medium range diameter ranges between 3 mm to 25 mm (most widely used).

According to number of flutes:

- Two fluted - most common.
- Single flute - e.g., gun drill (robust).
- Three or four flutes - called slot drill.

According to helix angle of the flutes:

- Usual: 20^0 to 35^0 - most common.
- Large helix: 45^0 to 60^0 - suitable for deep holes and softer work materials.
- Small helix: for harder / stronger materials.
- Zero helix: spade drills for high production drilling micro-drilling and hard work materials.

According to length to diameter ratio:

- Deep hole drill; e.g. crank shaft drill, gun drill etc.
- General type: L/φ ≅ 6 to 10.
- Small length: e.g. centre drill.

According to shank:

- Straight shank - small size drill being held in drill chuck.
- Taper shank - medium to large size drills being fitted into the spindle nose directly or through taper sockets and sleeves.

According to specific applications:

- Centre drill *[Fig. (a)]* for small axial holes with 60^0 taper ends to hold the lathe centre.
- Step drill and sub land drill *[Fig. (b and c)]* for small holes with 2 or 3 steps.
- Half round drill, gun drill and crank shaft drill *[Fig. (d, e and f)]* for making oil holes.
- Ejector drill for high speed drilling of large diameter holes.
- Taper drill for batch production.
- Trepanning tool *[Fig. (g)]* for large holes in soft materials.

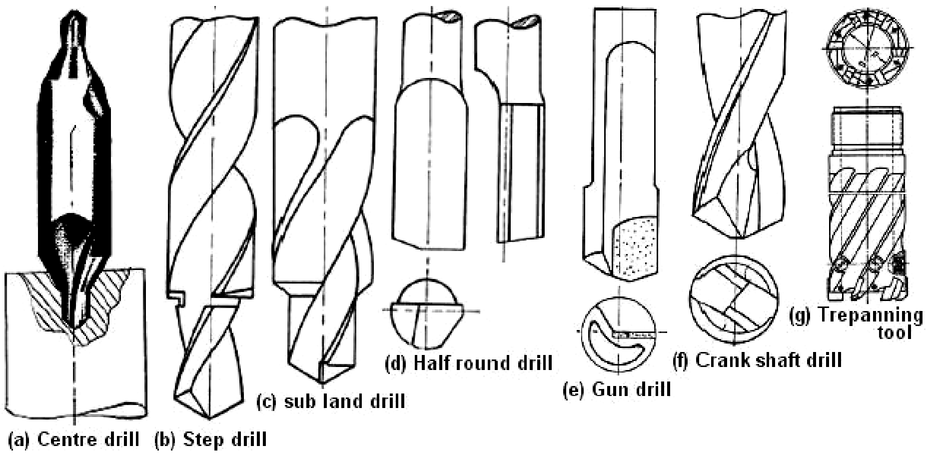


Fig. Different types of drills used in various applications

Twist drill nomenclature

The following are the nomenclature, definitions and functions of the different parts of a drill illustrated in Fig..

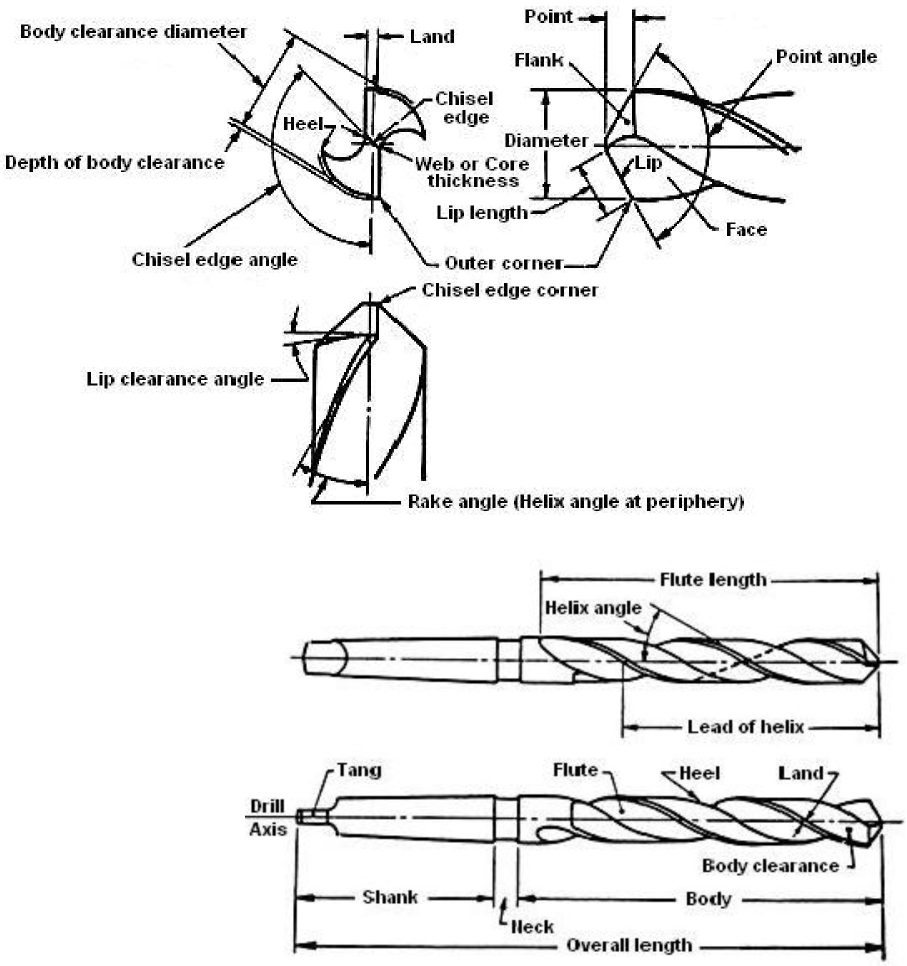


Fig. Twist drill nomenclature

Twist drill elements

Axis The longitudinal centre line of the drill.

Body That portion of the drill extending from its extreme point to the commencement of the neck, if present, otherwise extending to the commencement of the shank.

Body clearance That portion of the body surface which is reduced in diameter to provide diametral clearance.

Chisel edge The edge formed by the intersection of the flanks. The chisel edge is also sometimes called dead centre.

Chisel edge corner The corner formed by the intersection of a lip and the chisel edge.

Face The portion of the flute surface adjacent to the lip on which the chip impinges as it is cut from the work.

Flank That surface on a drill point which extends behind the lip to the following flute.

Flutes The groove in the body of the drill which provides lip.

The functions of the flutes are:

- To form the cutting edges.
- To allow the chips to escape.

- To cause the chips to curl.
- To permit the cutting fluid to reach the cutting edges.

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

Lands The cylindrically ground surface on the leading edges of the drill flutes. The width of the land is measured at right angles to the flute helix.

Lip (cutting edge) The edge formed by the intersections of the flank and face.

The requirements of the drill lip are:

- Both lips should be at the same angle of inclination (59^0) with the drill axis.
- Both lips should be of equal length.
- Both lips should be provided with the correct clearance.

Neck The diametrically undercut portion between the body and the shank of the drill.

Diameter and other particulars of the drill are engraved at the neck.

Outer corner The corner formed by the intersection of the flank and face.

Point The sharpened end of the drill, which is shaped to produce lips, faces, flanks and chisel edge.

Shank That part of the drill by which it is held and driven. The most common types of shank are the taper shank and the straight shank.

Tang The flattened end of the taper shank intended to fit into a drift slot in the spindle, socket or drill holder. The tang ensures positive drive of the drill from the spindle.

Web The central portion of the drill situated between the roots of the flutes and extending from the point toward the shank; the point end of the web or core forms the chisel edge.

Linear dimensions

Back taper (longitudinal clearance) It is the reduction in diameter of the drill from the point towards the shank. This permits all parts of the drill behind the point to clear and not rub against the sides of the hole being drilled. The taper varies from 1:4000 for small diameter drills to 1:700 for larger diameters.

Body clearance diameter The diameter over the surface of the drill body which is situated behind the lands.

Depth of body clearance The amount of radial reduction on each side to provide body clearance.

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

Flute length The axial length from the extreme end of the point to the termination of the flute at the shank end of the body.

Lead of helix The distance measured parallel to the drill axis between the corresponding points on the leading edge of the flute in one complete turn of the flute.

Lip length The minimum distance between the outer corner and the chisel edge corner of the lip.

Overall length The length over the extreme ends of the point and the shank of the drill.

Web (core) taper The increase in the web or core thickness from the point of the drill to the shank end of the flute. This increasing thickness gives additional rigidity to the drill and reduces the cutting pressure at the point end.

Web thickness The minimum dimension of the web or core measured at the point end of the drill.

Drill angles

Chisel edge angle The obtuse angle included between the chisel edge and the lip as viewed from the end of the drill.

Helix angle or rake angle This is the angle formed by the leading edge of the land with a plane having the axis of the drill.

Point angle This is the angle included between the two lips.

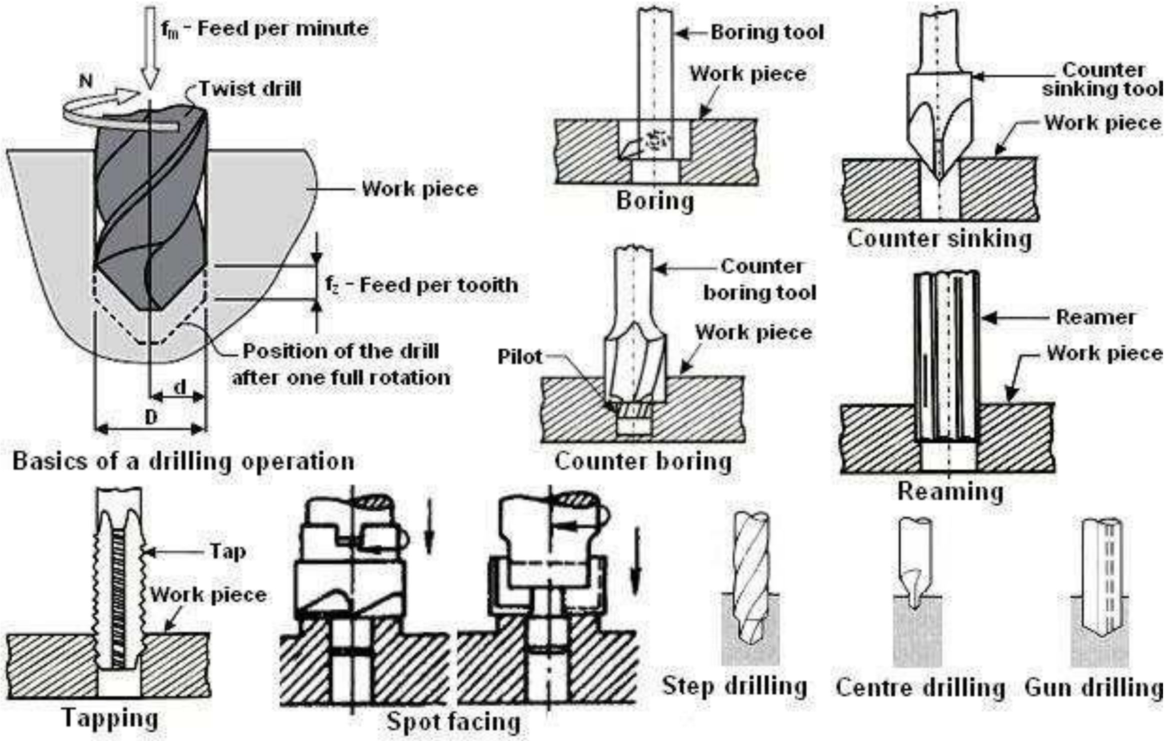
Lip clearance angle The angle formed by the flank and a plane at right angles to the drill axis.

Drilling operations

The wide range of applications of drilling machines includes:

- Drilling machines are generally or mainly used to originate through or blind straight cylindrical holes in solid rigid bodies and/or enlarge (coaxially) existing holes:
  - Of different diameters up to 40 mm.
  - Of varying length depending upon the requirement and the diameter of the drill.
  - In different materials excepting very hard or very soft materials like rubber, polythene etc.
- Originating stepped cylindrical holes of different diameter and depth.
- Making rectangular section slots by using slot drills having 3 or 4 flutes and 180^0 cone angle.
- Boring, after drilling, for accuracy and finish or prior to reaming
- Counter boring, countersinking, chamfering or combination using suitable tools.
- Spot facing by flat end tools.
- Trepanning for making large through holes and or getting cylindrical solid core.

- If necessary Reaming is done on drilled or bored holes for accuracy and good surface finish. Different types of reamers of standard sizes are available for different applications.
- Also used for cutting internal threads in parts like nuts using suitable attachment.



The different operations that can be performed in a drilling machine are shown in Fig.

Fig. Different operations performed in a drilling machine

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. illustrates the elements of a reamer. Fig. shows the different types of reamers of standard sizes.*

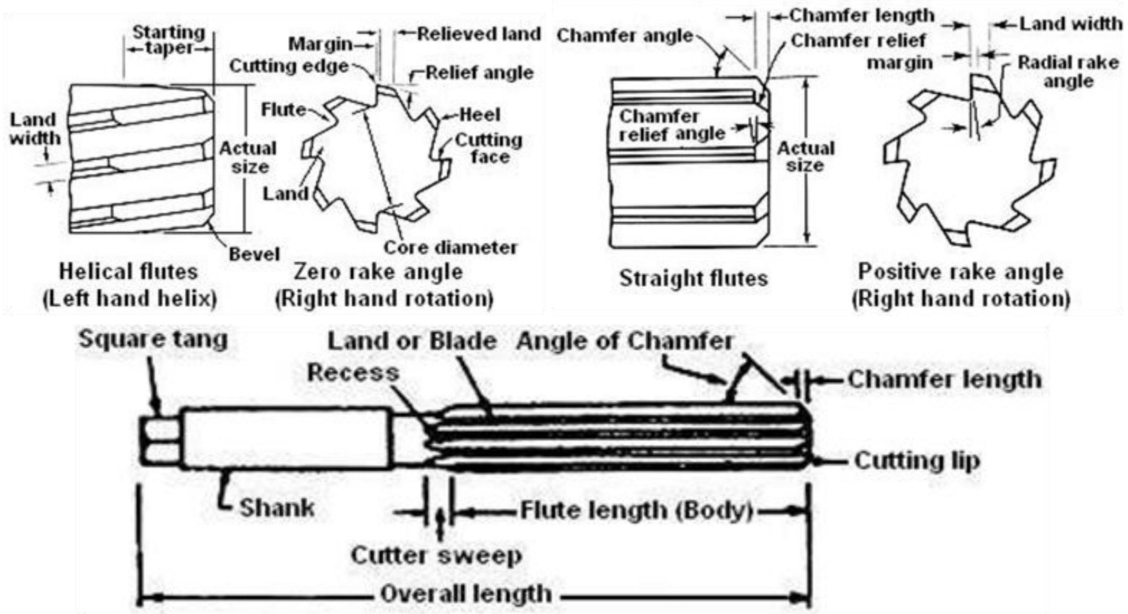
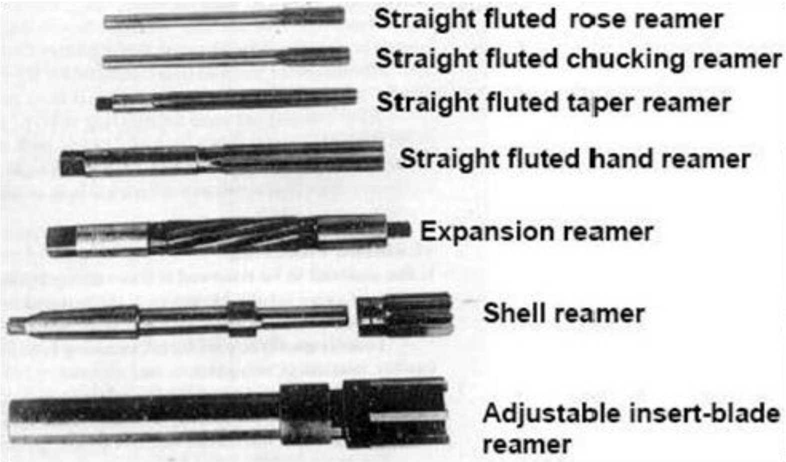


Fig. Elements of a reamer



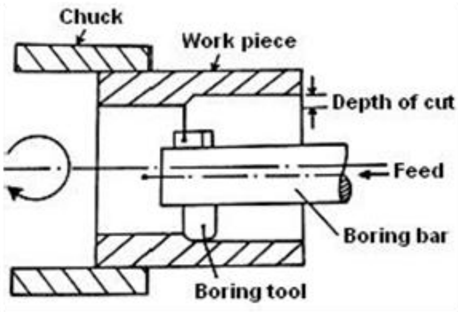


Fig. Different types of reamers

Fig. Principle of boring operation

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.*

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

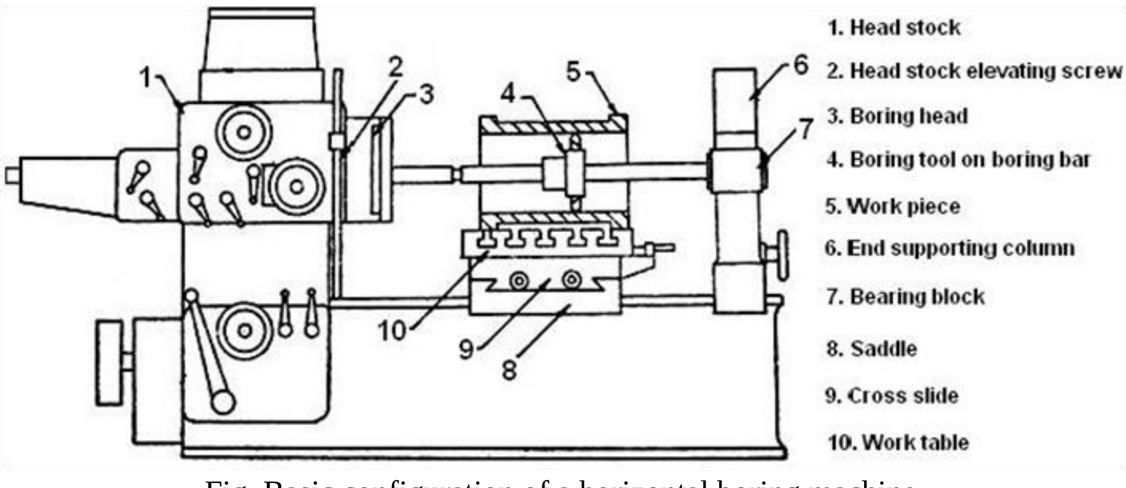


Fig. Basic configuration of a horizontal boring machine

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. shows the table type horizontal boring machine.*

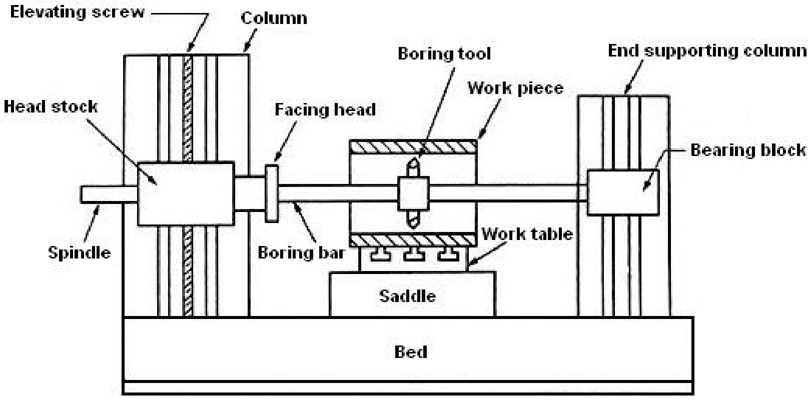


Fig. Table type horizontal boring machine

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. *Figshows the planer type horizontal boring machine.*

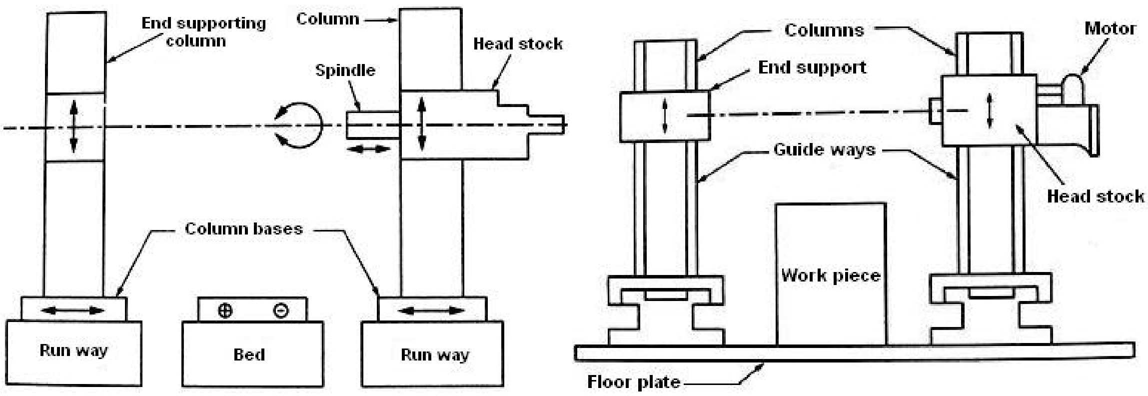


Fig. Planer type and Floor type horizontal boring machine

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. shows the 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. shows the multiple head type horizontal boring machine.*

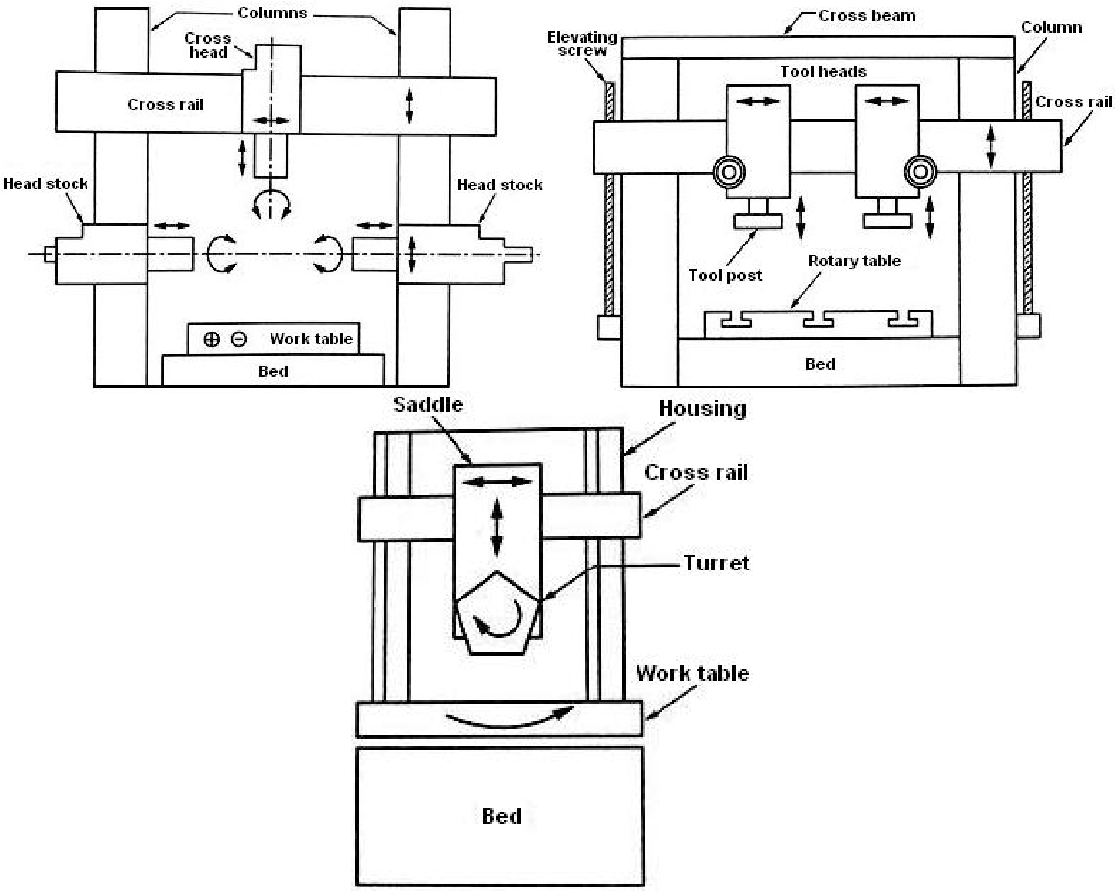


Fig. Multiple head type horizontal, Double column vertical and Turret boring machine

Vertical boring machines

For convenience, parts whose length or height is less than the diameter are machined on vertical boring machines. The typical works are: Large gear blanks, locomotive and rolling stock tires, fly wheels, large flanges, steam and water turbine castings etc. On a vertical boring machine, the work is fastened on a horizontal revolving table, and the cutting tool(s) which are stationary, advance vertically into it are as the table revolves.

There are two types of vertical boring machine: Single column vertical boring machine and double column vertical boring machine. The single column vertical boring machine looks like a drilling machine or a knee type vertical milling machine. Guide ways are employed on the column to support the spindle head in the vertical direction. *A double column vertical boring machine is shown in Fig.*. 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. shows the turret boring machine.*

Jig borers or jig boring machines

It is very precise vertical type boring machine. The spindle and spindle bearings are constructed with very high precision. The table can be moved precisely in two mutually perpendicular directions in a plane normal to the spindle axis. The coordinate method for locating holes is employed. Holes can be located to within tolerances of 0.0025 mm. Jig boring machines are relatively costlier. Hence, they are found only in the large machine shops, where a sufficient amount of accurate hole locating is done. Jig boring machines are basically designed for use in the making jigs, fixtures and other special tooling. *Fig. shows the block diagram of a jig boring machine.*

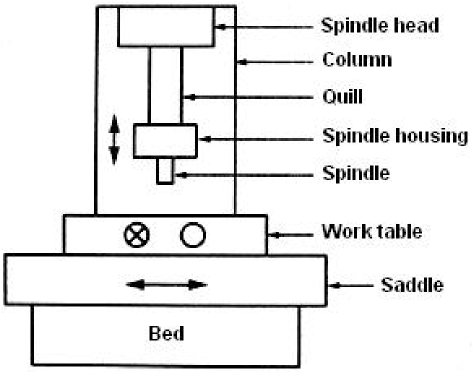


Fig. Block diagram of a jig boring machine

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. shows the different types of boring tools (bars).*

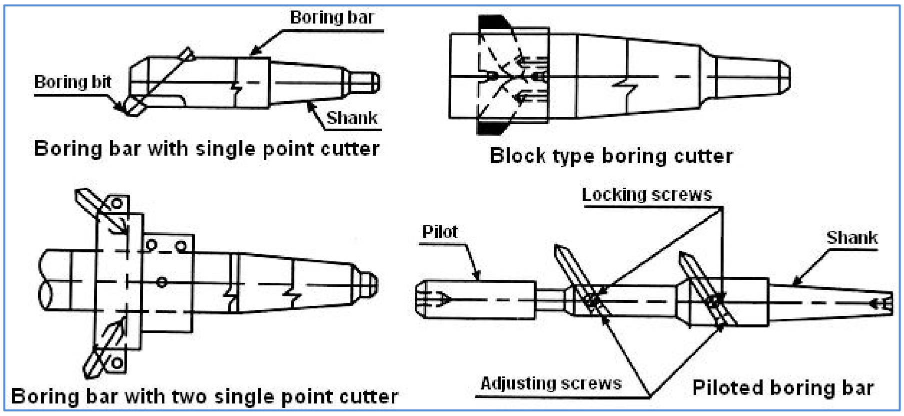
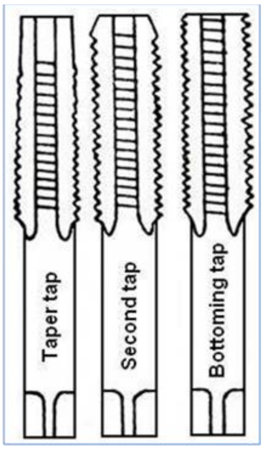


Fig. Different types of boring tools (bars)

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. shows the hand (solid) taps. Fig. shows the elements of a solid tap.*



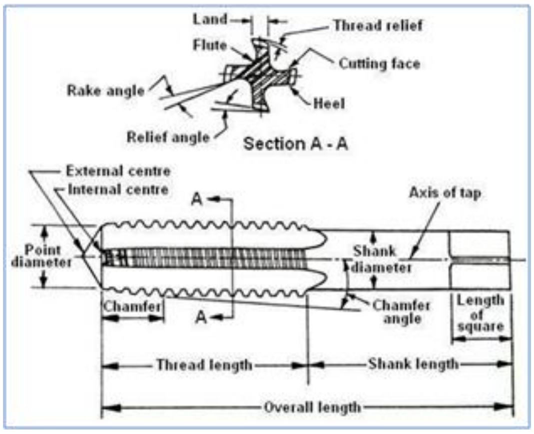


Fig. Hand (solid) taps   Fig. Elements of a solid tap

SAWING MACHINES

Sawing is one of the basic machining operations carried out in a narrow cutting zone though the successive removal of chips by the teeth on a saw blade. *The types of sawing machines used are:*

1. ***Hack saw*** (i) Manual hack saw (ii) Power hack saw
2. ***Band saw*** (i) Vertical band saw (ii) Horizontal band saw (iii) Contour band saw
3. ***Circular saw***

HACK SAW

A power hack saw [shown in Fig.] uses the hack saw blade. The blade is mounted in the hacksaw frame and reciprocated for the sawing operation. It is a very simple machine with a tool frame

for holding the saw and some work holding device similar to a vice. The reciprocating motion is inherently inefficient because no cutting takes place during the return stroke.

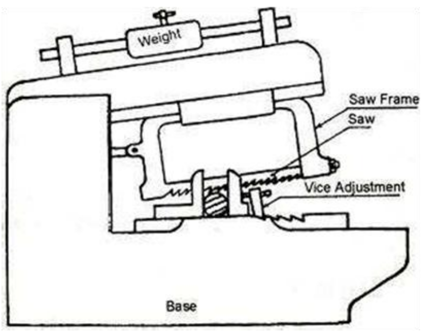


Fig. Power hack saw machine

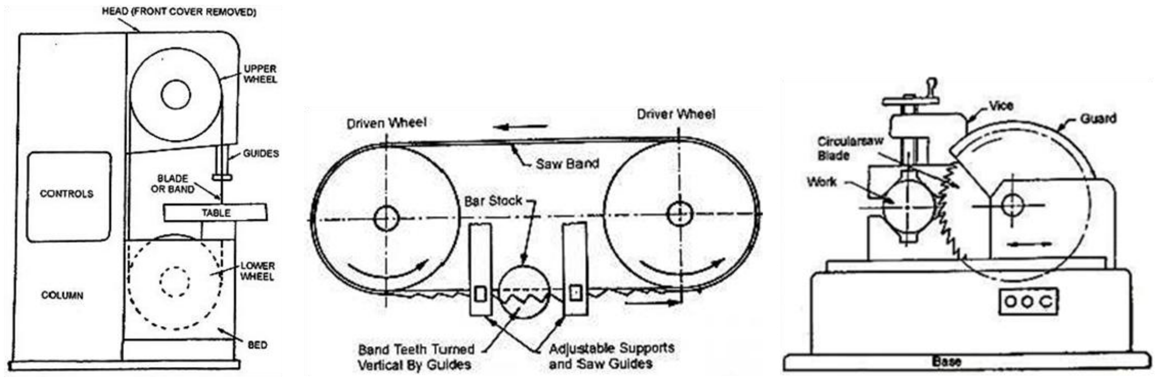


Fig. (a) Vertical, Horizantal and Circular saw machine

BAND SAW

A band saw basically has a continuous band of saw blade rotated between two disks such that the cutting action is continuous unlike the power hacksaw. Band saws are generally used for cutting off single stationary work pieces that can be held on to the table of the band saw. The saw blade can be tilted up to 45^0 to permit cutting at any angle. The band saw operates continuously such that the cutting force is always directed against the table.

It is relatively safer to use compared to the hack saw and it can cut work pieces without even clamping them to the table. Contour band saw machines are similar to band sawing machines and are used for sawing of any predefined contours in the work piece. Fig. (a and b) schematically shows the vertical and horizontal band saw machine.

CIRCULAR SAW

Circular saw [shown in Fig.] has the ability to run the saw at very high cutting speeds up to about 130 m/s and large feed rates. The stock can be cut very quickly and therefore care has to be takes in the selection of the parameters to maximize the productivity.

BROACHING

Basic principles of broaching

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

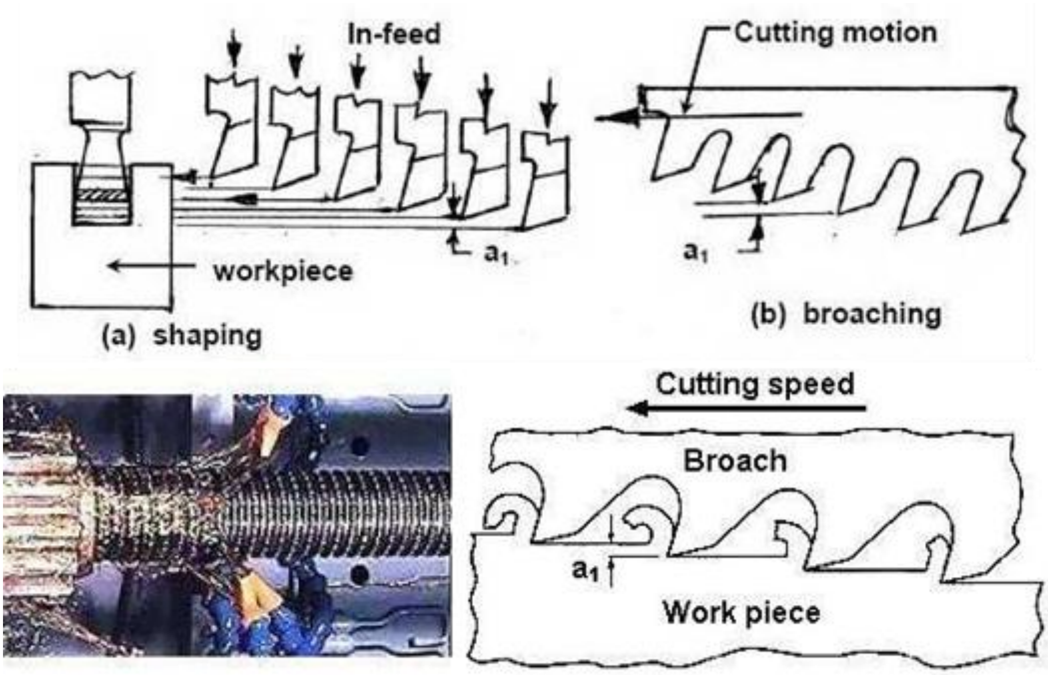


Fig. Basic principle of broaching

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

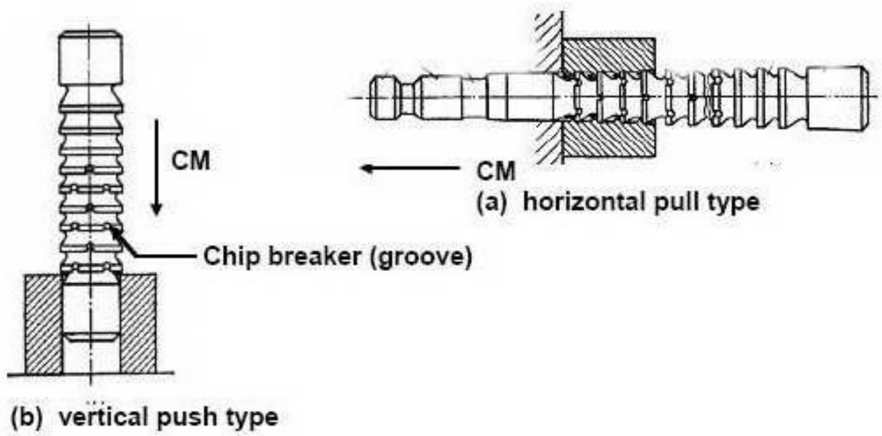


Fig. Schematic views of finishing hole by broaching

The cutting tool is called a broach, and the machine tool is called a broaching machine. The shape of the machined surface is determined by the contour of the cutting edges on the broach, particularly the shape of final cutting teeth. Broaching is a highly productive method of machining. Advantages include good surface finish, close tolerances, and the variety of possible machined surface shapes, some of them can be produced only by broaching. Owing to the complicated geometry of the broach, tooling is expensive. Broaching is a typical mass production operation.

Productivity improvement to ten times or even more be not uncommon, as the metal removal rate by broaching is vastly greater. Roughing, semi finishing and finishing of the component is done just in one pass by broaching, and this pass is generally accomplished in seconds.

Broaching can be used for machining of various integrate shapes which can not be otherwise machined with other operations. *Some of the typical examples of shapes produced by internal broaching are shown in Fig.*

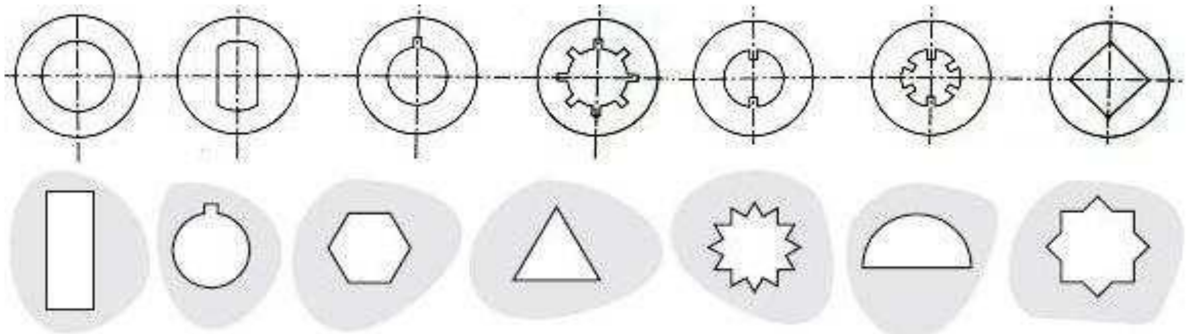


Fig. Typical examples of shapes produced by internal broaching

Different types of broaches and their applications

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

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

Internal broaching and broaches

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

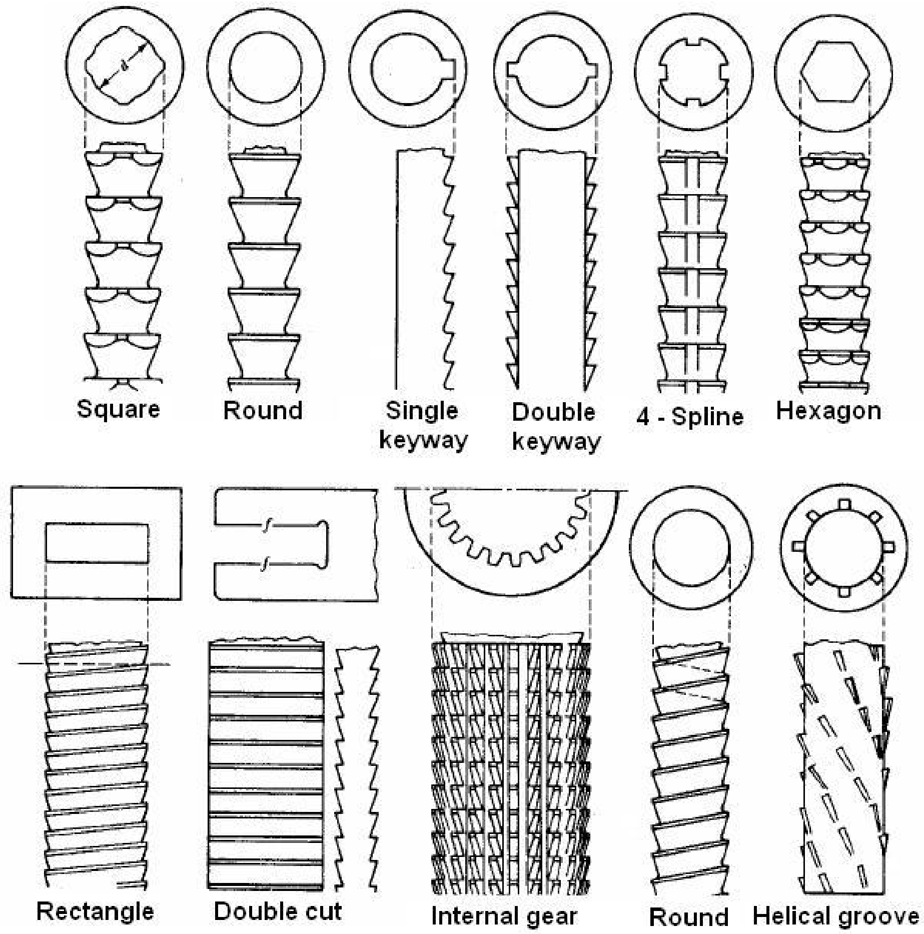
- Through holes of different form and dimensions.
- Non-circular holes and internal slots.
- Internal keyway and splines.
- Teeth of straight and helical fluted internal spur gears.

External broaching and broaches

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

- Un-obstructed outside surfacing; flat, peripheral and contour surfaces.
- Grooves, slots, keyways etc. on through outer surfaces of objects.
- External splines of different forms.
- Teeth of external spur gears or gear sectors as shown in Fig (b).

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



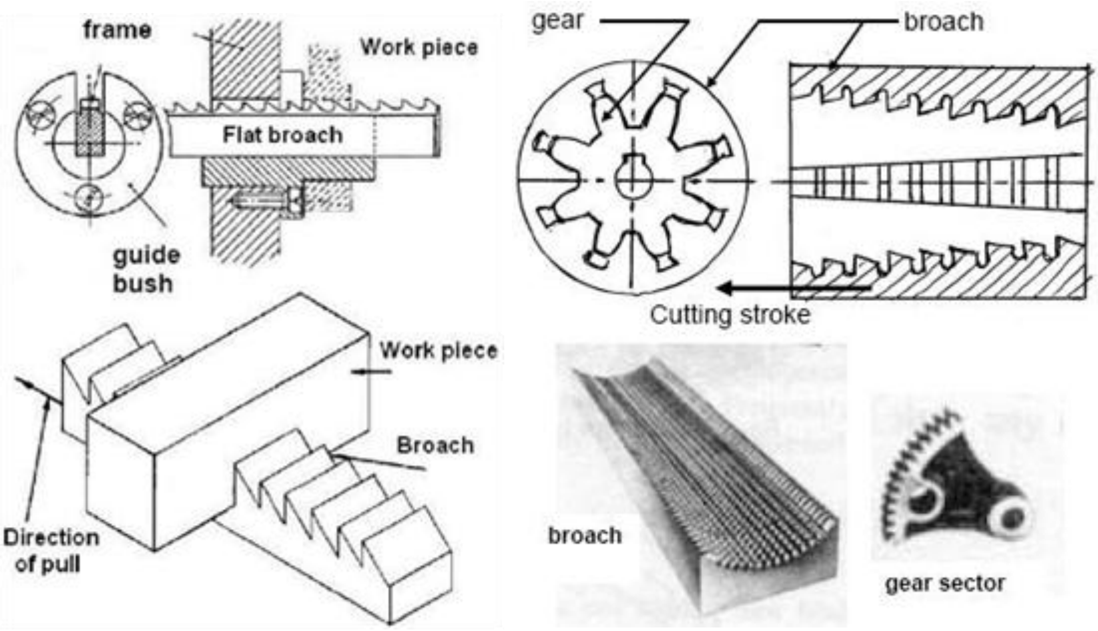


Fig. Internal broaching – tools and applications
Fig (a) External broaching – making slot Fig (b) Broaching of gears and gear sectors

Pull type and push type broaches

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

Ordinary cut or progressive type broach

Most of the broaches fall under the category of Ordinary – cut type where the teeth increase in height or protrusion gradually from tooth to tooth along the length of the broach. By such broaches, work material is removed in thin layers over the complete form. Whereas, Progressive cut type broaches have their teeth increasing in width instead of height. *Fig. 4.56 shows the working principle and configuration of such broach.*

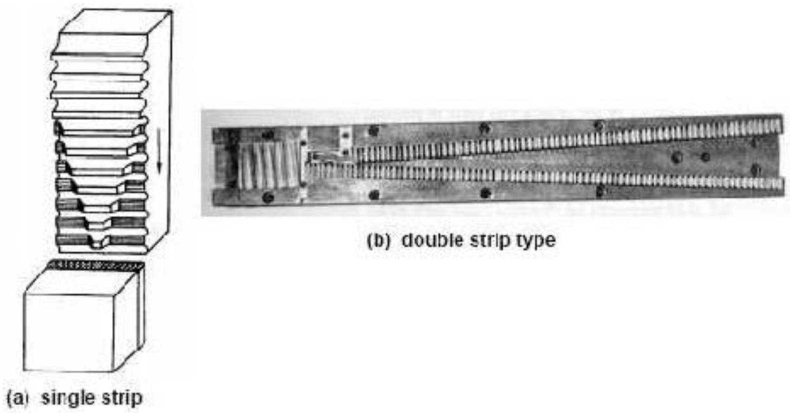


Fig. Progressive cut type broaches; (a) single bar and (b) double bar type

Solid, Sectional and module type broaches

Broaches are mostly made in single pieces especially those used for pull type internal broaching. But some broaches called sectional broaches, are made by assembling several sections or cutter-pieces in series for convenience in manufacturing and resharpening and also for having little flexibility required by production in batches having interbatch slight job variation. External broaches are often made by combining a number of modules or segments for ease of manufacturing and handling. *Fig. 4.57 typically shows solid, sectional and segmented (module) type broaches.*

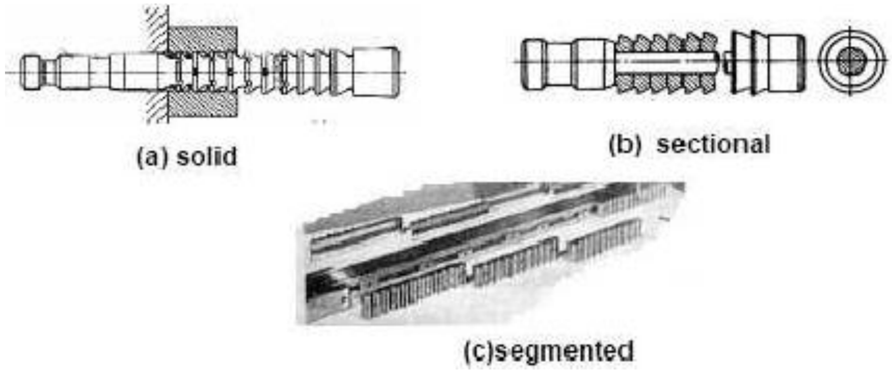


Fig. (a) Solid, (b) Sectional and (c) Segmented broaches

Profile sharpened and form relieved type broaches

Like milling cutters, broaches can also be classified as:

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

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

Advantages and limitations of broaching

Major advantages

- Very high production rate (much higher than milling, planing, boring etc.).
- High dimensional and form accuracy and surface finish of the product.
- Roughing and finishing in single stroke of the same cutter.
- Needs only one motion (cutting), so design, construction, operation and control are simpler.
- Extremely suitable and economic for mass production.
- Since all the machining parameters are built into the broach, very little skill is required from the operator.
- Any type of surface, internal or external can be generated with broaching.

Limitations

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

BROACH CONSTRUCTION

The broach is composed of a series of teeth, each tooth standing slightly higher than the previous one. This rise per tooth is the feed per tooth and determines the material removed by the tooth. There are basically three sets of teeth present in a broach. The roughing teeth that have the highest rise per tooth removes bulk of the material.

The semi-finishing tooth whose rise per tooth is smaller follows this. Hence they remove relatively smaller amounts of material compared to the roughing teeth. The last set of teeth is called the finishing or sizing teeth. Very little material is removed by these teeth. The necessary size is achieved by these teeth and hence all the teeth are of the same size as that required finally.

The pull end of the broach is attached to the pulling mechanism of the broaching machine with the front pilot aligning the broach properly with respect to the work piece axis before the actual cutting starts. The rear pilot helps to keep the broach to remain square with the work piece as it leaves the work piece after broaching. Broaching speeds are relatively low. However the production rate is high. Broaches are generally made to high speed steel in view of its high impact strength.

Configuration of broaching tool

Both pull and push type broaches are made in the form of slender rods or bars of varying section having along its length one or more rows of cutting teeth with increasing height (and width occasionally). Push type broaches are subjected to compressive load and hence are made shorter in length to avoid buckling. The general configuration of pull type broaches, which are widely used for enlarging and finishing preformed holes, is schematically shown in Fig.

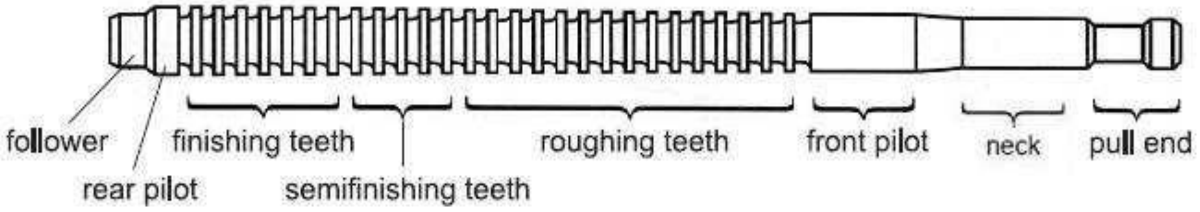


Fig. Configuration of a pull type broach used for internal broaching

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

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

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

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

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

$p = 1.25\sqrt{L}$ **to 1.5**$\sqrt{L}$ where, L = length of the hole or job.

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

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

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

Material of broach

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

Geometry of broaching teeth and their cutting edges

Fig. shows the general configuration of the broaching teeth and their geometry. The cutting teeth of HSS broaches are provided with positive radial or orthogonal rake (5^0 to 15^0) and sufficient primary and secondary clearance angles (2^0 to 5^0 and 5^0 to 20^0 respectively) as indicated in Fig. Small in-built chip breakers are alternately provided on the roughing teeth of the broach as can be seen in Figto break up the wide curling chips and thus preventing them from clogging the chip spaces and increasing forces and tool wear. More ductile materials need wider and frequent chip breakers.

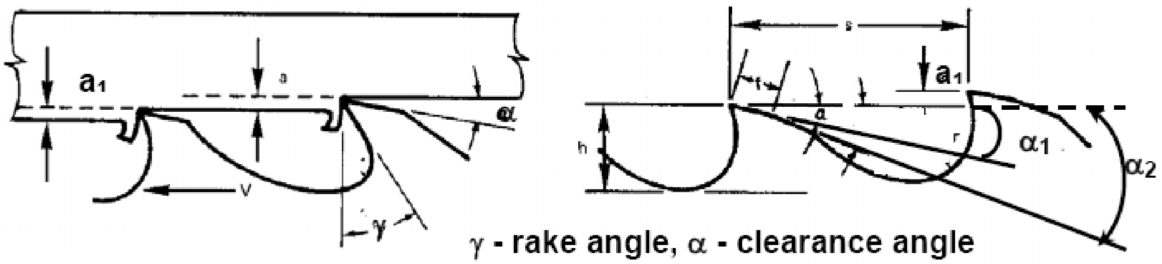


Fig. Geometry of teeth of broaching tools

BROACHING MACHINES

Broaching operation

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

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

Selection of broach and broaching machine

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

- Type of the job; size, shape and material.
- Geometry and volume of work material to be removed from the job.
- Desired length of stroke and the broach.
- Type of the broaching machines available or to be used.

Broaching machine has to be selected based on:

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

Function of broaching machines

The basic function of a broaching machine is to provide a precise linear motion of the tool past a stationary work position. There are two principal modifications of the broaching machines, horizontal, and vertical. The former are suitable for broaching of relatively long and small diameter holes, while the later are used for short lengths and large diameters.

The unique characteristics of broaching operation are:

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

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

Specification of broaching machines

Broaching machines are generally specified by:

- Type; horizontal, vertical etc.
- Maximum stroke length.
- Maximum working forces (pull or push).
- Maximum cutting velocity possible.
- Type of drive - Electro-Mechanical, Hydraulic etc.
- Power rating of electrical motor.
- Floor space required.

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

Classification of broaching machines

There are different types of broaching machines which are broadly classified as:

According to purpose of use

- General purpose.
- Single purpose.
- Special purpose.

According to nature of work

- Internal broaching.
- External (surface) broaching.

According to configuration

- Horizontal.
- Vertical.

According to number of slides or stations

- Single station type.
- Multiple station type.
- Indexing type.

According to tool / work motion

- Intermittent (one job at a time) type.
- Continuous type.

According to the type of drive

- Mechanical drive.
- Hydraulic drive.

PUSH BROACHING MACHINES

In these machines the broach movement is guided by a ram. These machines are simple, since the broach only needs to be pushed through the component for cutting and then retracted. The work piece is fixed into a boring fixture on the table. Even simple arbor presses can be used for push broaching.

Push down type vertical surface broaching machine

Fig. Push down type vertical surface broaching machine

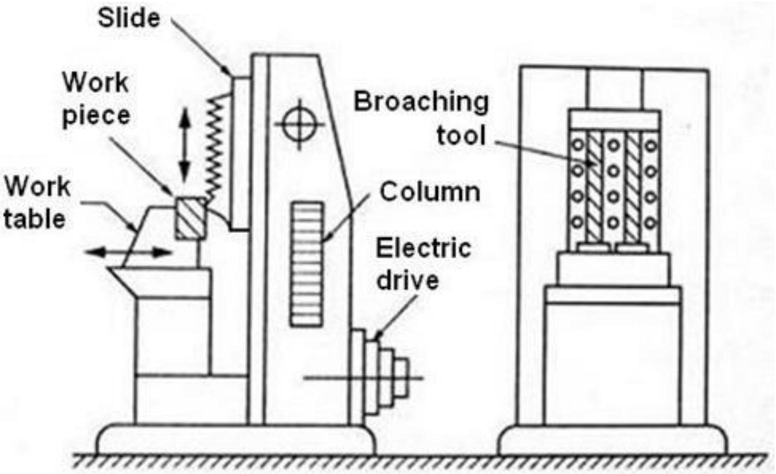


Fig. shows the push down type vertical surface broaching machine. It consists of a box shape column, slide and drive mechanism. Broach is mounted on the slide which is hydraulically operated and accurately guided on the column ways. Slide with the broach travels at various speeds. The slide is provided with quick return mechanism. The worktable is mounted on the base in front of the column. The fixture is clamped to the table. The work piece is held in the fixture.

After advancing the table to the broaching position, it is clamped and the slide with the broach travel downwards for machining the workpiece. Then the table recedes to load a new work piece and the slide returns to its upper position. The same cycle is then repeated.

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

PULL BROACHING MACHINES

These machines consist of a work holding mechanism, and a broach pulling mechanism along with a broach elevator to help in the removal and threading of the broach through the work piece. The work piece is mounted in the broaching fixture and the broach is inserted through the hole present in the work piece.

Then the broach is pulled through the work piece completely and the work piece is then removed from the table. Afterwards the broach is brought back to the starting point before a new work piece is located on the table. The same cycle is then repeated.

Pull type horizontal internal broaching machine

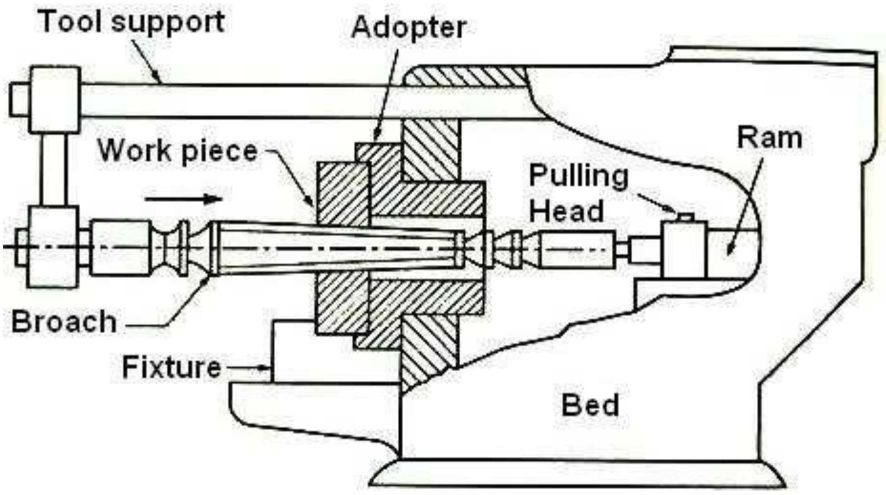


Fig. Pull type horizontal internal broaching machine

This machine has a box type bed. The length of bed is twice the length of stroke. Most of the modern horizontal broaching machines are provided with hydraulic or electric drive. It is housed in the bed. The job is located in the adopter. The adopter is fitted in the front vertical face of the machine. The small end of the broach is inserted through the hole of the job and connected to the pulling head.

The pulling head is mounted in the front end of the ram. The ram is connected to the hydraulic drive mechanism. The rear end of the broach is supported by a guide. The broach is moved along the guide ways. It is used for small and medium sized works. It is used for machining keyways, splines, serrations, internal gears, etc.

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

Pull down type vertical internal broaching machine

This machine has an elevator at the top. The pulling mechanism is enclosed in the base of the machine. The workpiece is mounted on the table by means of fixture. The tail end of the broach is gripped in the elevator. The broach is lowered through the work piece.

The broach is automatically engaged by the pulling mechanism and is pulled down through the job. After the operation is completed, the broach is raised and gripped by the elevator. The elevator returns to its initial position. *This is illustrated in Fig. (a).*

4.24.2 Pull up type vertical internal broaching machine

In this type, the ram slides on the vertical column of the machine. The ram carries the pulling head at its bottom. The pulling mechanism is above the worktable and the broach is in the base of the machine. The broach enters the job held against the underside of the table and is pulled upward. At the end of the operation, the work is free and falls down into a container. *This is illustrated in Fig. (b).*

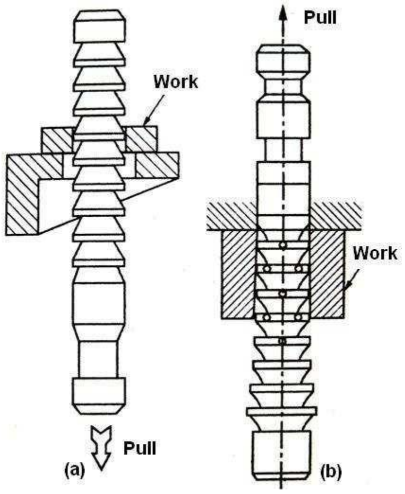


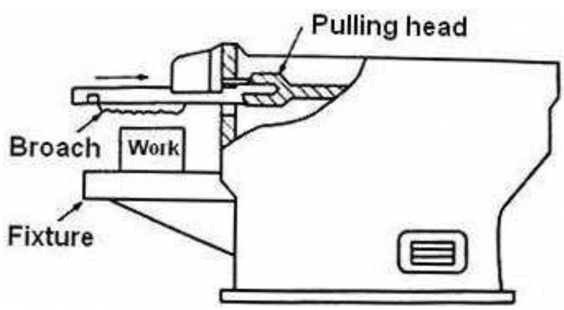
Fig. Vertical internal broaching operation (a) pull down type (b) pull up type

SURFACE BROACHING MACHINES

In horizontal surface broaching machines, the broach is pulled over the top surface of the work piece held in the fixture on the worktable as shown in Fig.. The cutting speed ranges from 3 to 12 *mpm* with a return speed up to 30 *mpm*. The construction and working principle of horizontal surface broaching machine is similar to that of pull type horizontal internal broaching machine.

In vertical surface broaching machines, the work piece is held in the fixture while the surface broach is reciprocated with the ram on the vertical guide ways on the column as shown in Fig. Surface broaching is relatively simple since the broach can be continuously held and then it will carry out only a reciprocating action.

Instead of using simple broach some times the progressive cut type broach with the teeth segments distributed into the three areas as shown in Fig. (b) is used in surface broaching. The progressive action reduces the maximum broaching force, but results in a longer broach.



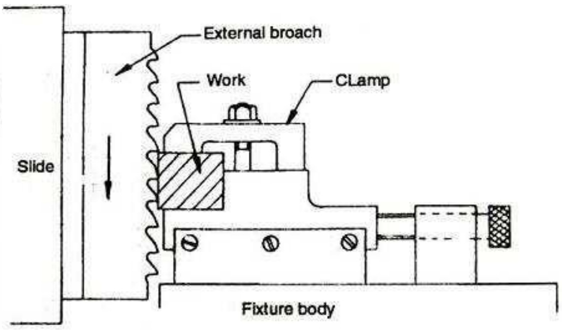


Fig. Horizontal surface broaching machine   Fig. Vertical surface broaching machine

CONTINUOUS BROACHING MACHINES

These broaching machines are also known as high production broaching machines. The reciprocation of the broach always involves an unproductive return stroke, which is eliminated in a continuous surface broaching machine. These machines are used for fast production of large number of pieces by surface broaching.

Horizontal continuous broaching machine

In this the small work pieces are mounted on the broaching fixtures which are in turn fixed to an endless chain continuously moving in between two sprockets. Broaches which are normally stationary are kept above the work pieces. The work pieces are pushed past the stationary broaches by means of the conveyor for cutting. The work pieces are loaded and unloaded onto the conveyor manually or automatically. *This is illustrated in Fig. (a).*

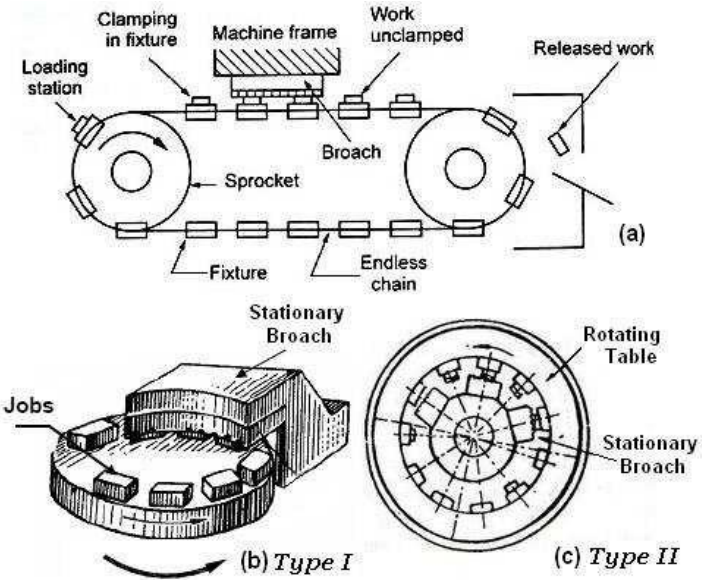


Fig. Continuous broaching machine (a) Horizontal type (b) and (c) Rotary type

Rotary continuous broaching machine

Type I: This machine has a rotary table and a vertical column. The vertical column has a guide way. An arm is fixed in the vertical column and it moves up and down in the guide way. Work pieces are clamped in the fixtures horizontally above the work table. The broach is fixed underside of the arm. Now the work table is rotated and the broaching operation is carried out. Depth of cut is given by moving the work table in upward direction. *This is illustrated in Fig. (b).*

Type II: This machine has a ring shaped rotating work table. Work pieces are clamped in the fixtures in the inner periphery of the work table. The stationary broaches are fixed in the outer periphery of the vertical column located inside the work table. Now the table is rotated and the broaching operation is carried out. *This is illustrated in Fig. (c).*

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

- Incorporating automation in tool – job mounting and releasing.
- Increasing number of workstations or slides for simultaneous multiple production.
- Quick changing the broach by turret indexing.
- Continuity of working

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UNIT - IV

MANUFACTURING TECHNOLOGY II – SPR1301

UNIT IV

ABRASIVE PROCESSES AND GEAR CUTTING

Abrasive processes: Grinding wheel – Specifications and selection – Types of grinding process –Cylindrical grinding – Surface grinding – Centre less grinding – Honing, lapping, super finishing, polishing and buffing – Abrasive jet machining – Gear cutting – Forming – Generation – Shaping – Hobbing.

Abrasive machining is a machining process where material is removed from a work piece using a multitude of small abrasive particles. Common examples include grinding, honing, and polishing.

4.1 Grinding

Grinding is the most common form of abrasive machining. It is a material cutting process which engages an abrasive tool whose cutting elements are grains of abrasive material known as grit. These grits are characterized by sharp cutting points, high hot hardness, chemical stability and wear resistance. The grits are held together by a suitable bonding material to give shape of an abrasive tool.

Major advantages and applications of grinding

Advantages

A grinding wheel requires two types of specification

- dimensional accuracy

- good surface finish

- good form and locational accuracy applicable to both hardened and unhardened material

4.1.1Grinding wheels

Grinding wheel consists of hard abrasive grains called grits, which perform the cutting or material removal, held in the weak bonding matrix. A grinding wheel commonly identified by the type of the abrasive material used. The conventional wheels include aluminium oxide and silicon carbide wheels while diamond and CBN (cubic boron nitride) wheels fall in the category of super abrasive wheel.

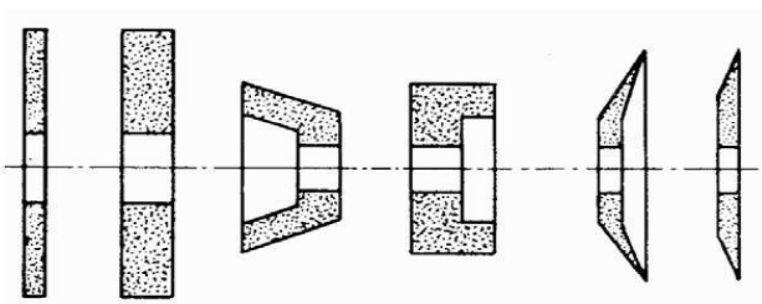
4.1.2 Specification of grinding wheel

A grinding wheel requires two types of specification

(a) Geometrical specification
(b) Compositional specification

Geometrical specification

This is decided by the type of grinding machine and the grinding operation to be performed in the work piece. This specification mainly includes wheel diameter, width and depth of rim and the bore diameter. The wheel diameter, for example can be as high as 400mm in high efficiency grinding or as small as less than 1mm in internal grinding. Similarly, width of the wheel may be less than an mm in dicing and slicing applications. Standard wheel configurations for conventional and super abrasive grinding wheels are shown in Fig.4.1 and 4.2.



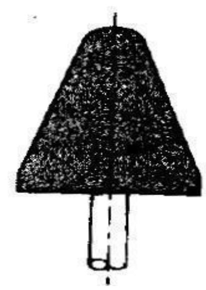


FIG.4.1 : Standard wheel configuration for conventional grinding wheels, FIG.4.2

Compositional specifications

Specification of a grinding wheel ordinarily means compositional specification. Conventional abrasive grinding wheels are specified encompassing the following parameters.

1) the type of grit material
2) the grit size
3) the bond strength of the wheel, commonly known as wheel hardness
4) the structure of the wheel denoting the porosity i.e. the amount of inter grit spacing
5) the type of bond material
6) other than these parameters, the wheel manufacturer may add their own identification code prefixing or suffixing (or both) the standard code.

Marking system for conventional grinding wheel

The standard marking system for conventional abrasive wheel can be as follows: 51 A 60 K 5 V 05, where

- The number "51" is manufacturer"s identification number indicating exact kind of abrasive used.
- The letter "A" denotes that the type of abrasive is aluminium oxide. In case of silicon carbide the letter "C" is used.
- The number "60" specifies the average grit size in inch mesh. For a very large size grit this number may be as small as 6 where as for a very fine grit the designated number may be as high as 600.
- The letter "K" denotes the hardness of the wheel, which means the amount of force required to pull out a single bonded abrasive grit by bond fracture. The letter symbol can range between "A" and "Z", "A" denoting the softest grade and "Z" denoting the hardest one.
- The number "5" denotes the structure or porosity of the wheel. This number can assume any value between 1 to 20, "11" indicating high porosity and "20" indicating low porosity.
- The letter code „V" means that the bond material used is vitrified. The codes for other bond materials used in conventional abrasive wheels are B (resinoid), BF (resinoid reinforced), E(shellac), O(oxychloride), R(rubber), RF (rubber reinforced), S(silicate)
- The number "05" is a wheel manufacturer"s identifier.

Marking system for super abrasive grinding wheel

Marking system for super abrasive grinding wheel is somewhat different as illustrated below R D 120 N 100 M 4, where

- The letter "R" is manufacture"s code indicating the exact type of super abrasive used.
- The letter "D" denotes that the type of abrasive is diamond. In case of CBN the letter "B" is used.
- The number "120" specifies the average grain size in inch mesh. However, a two number designation (e.g. 120/140) is utilized for controlling the size of super abrasive grit. The two number designation of grit size along with corresponding designation in micron is given in table 28.1.
- Like conventional abrasive wheel, the letter "N" denotes the hardness of the wheel. However, resin and metal bonded wheels are produced with almost no porosity and effective grade of the wheel is obtained by modifying the bond formulation.

- The number "100" is known as concentration number indicating the amount of abrasive contained in the wheel. The number "100" corresponds to an abrasive content carats/cm .

For diamond grit, “100“ concentration is 25% by volume. For CBN the corresponding volumetric concentration is 24%.

- The letter “M“ denotes that the type of bond is metallic. The other types of bonds used in super abrasive wheels are resin, vitrified or metal bond, which make a composite structure with the grit material. However, another type of super abrasive wheel with both diamond and CBN is also manufactured where a single layer of super abrasive grits are bonded on a metal perform by a galvanic metal layer or a brazed metal layer

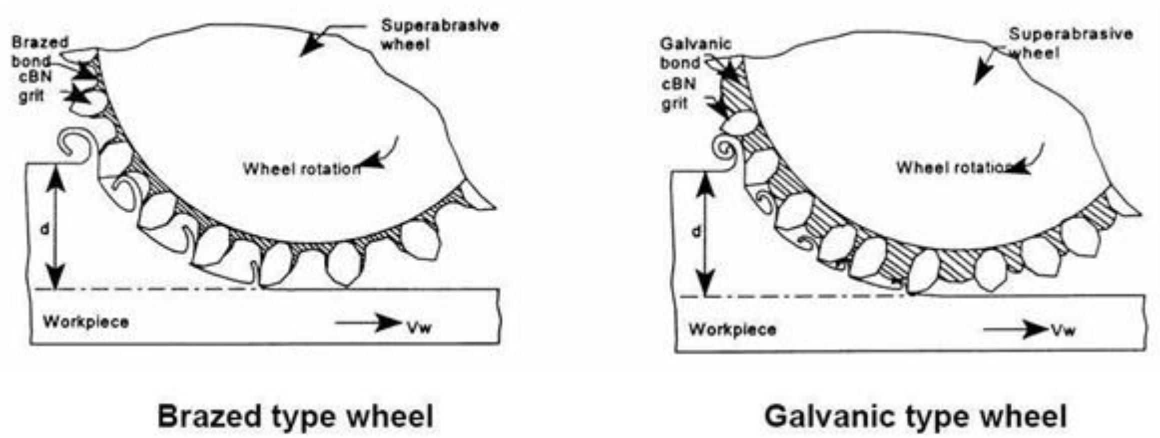


FIG. 4.3

4.2 Selection of grinding wheels

Selection of grinding wheel means selection of composition of the grinding wheel and this depends upon the following factors:

1) Physical and chemical characteristics of the work material
2) Grinding conditions
3) Type of grinding (stock removal grinding or form finish grinding)

4.2.1 Type of abrasives

Aluminium oxide Aluminium oxide may have variation in properties arising out of differences in chemical composition and structure associated with the manufacturing process.
Pure Al2O3 grit with defect structure like voids leads to unusually sharp free cutting action with low strength and is advantageous in fine tool grinding operation, and heat sensitive operations on hard, ferrous materials.
Regular or brown aluminium oxide (doped with TiO2) possesses lower hardness and higher toughness than the white Al2O3 and is recommended heavy duty grinding to semi finishing. Al2O3 alloyed with chromium oxide (<3%) is pink in colour.
Monocrystalline Al2O3 grits make a balance between hardness and toughness and are efficient in medium pressure heat sensitive operation on ferrous materials.
Microcrystalline Al2O3 grits of enhanced toughness are practically suitable for stock removal grinding. Al2O3 alloyed with zirconia also makes extremely tough grit mostly suitably for high pressure, high material removal grinding on ferrous material and are not recommended for

precision grinding. Microcrystalline sintered Al2O3 grit is the latest development particularly known for its toughness and self sharpening characteristics.

Silicon carbide

Silicon carbide is harder than alumina but less tough. Silicon carbide is also inferior to Al2O3 because of its chemical reactivity with iron and steel.

Black carbide containing at least 95% SiC is less hard but tougher than green SiC and is efficient for grinding soft nonferrous materials.

Green silicon carbide contains at least 97% SiC. It is harder than black variety and is used for grinding cemented carbide.

Diamond

Diamond grit is best suited for grinding cemented carbides, glass, sapphire, stone, granite, marble, concrete, oxide, non-oxide ceramic, fiber reinforced plastics, ferrite, graphite. Natural diamond grit is characterized by its random shape, very sharp cutting edge and free cutting action and is exclusively used in metallic, electroplated and brazed bond. Monocrystalline diamond grits are known for their strength and designed for particularly demanding application. These are also used in metallic, galvanic and brazed bond. Polycrystalline diamond grits are more friable than monocrystalline one and found to be most suitable for grinding of cemented carbide with low pressure. These grits are used in resin bond.

CBN (cubic boron nitride)

Diamond though hardest is not suitable for grinding ferrous materials because of its reactivity. In contrast, CBN the second hardest material, because of its chemical stability is the abrasive material of choice for efficient grinding of HSS, alloy steels, HSTR alloys.

Presently CBN grits are available as monocrystalline type with medium strength and blocky monocrystals with much higher strength. Medium strength crystals are more friable and used in resin bond for those applications where grinding force is not so high. High strength crystals are used with vitrified, electroplated or brazed bond where large grinding force is expected

Microcrystalline CBN is known for its highest toughness and auto sharpening character and found to be best candidate for HEDG and abrasive milling. It can be used in all types of bond.

4.2.2 Grit size

The grain size affects material removal rate and the surface quality of work piece in grinding. Large grit- big grinding capacity, rough work piece surface

Fine grit- small grinding capacity, smooth work piece surface

4.2.3 Grade

The worn out grit must pull out from the bond and make room for fresh sharp grit in order to avoid excessive rise of grinding force and temperature. Therefore, a soft grade should be chosen for grinding hard material. On the other hand, during grinding of low strength soft material grit does not wear out so quickly. Therefore, the grit can be held with strong bond so that premature grit dislodgement can be avoided.

4.2.4 Structure / concentration

The structure should be open for grinding wheels engaged in high material removal to provide chip accommodation space. The space between the grits also serves as pocket for holding grinding fluid. On the other hand dense structured wheels are used for longer wheel life, for holding precision forms and profiles.

4.2.5 Bond

vitrified bond

Vitrified bond is suitable for high stock removal even at dry condition. It can also be safely used in wet grinding. It can not be used where mechanical impact or thermal variations are like to occur. This bond is also not recommended for very high speed grinding because of possible breakage of the bond under centrifugal force.

Resin bond

Conventional abrasive resin bonded wheels are widely used for heavy duty grinding because of their ability to withstand shock load. This bond is also known for its vibration absorbing characteristics and finds its use with diamond and CBN in grinding of cemented carbide and steel respectively. Resin bond is not recommended with alkaline grinding fluid for a possible chemical attack leading to bond weakening. Fiberglass reinforced resin bond is used with cut off wheels which requires added strength under high speed operation.

Shellac bond

At one time this bond was used for flexible cut off wheels. At present use of shellac bond is limited to grinding wheels engaged in fine finish of rolls.

Rubber bond

Its principal use is in thin wheels for wet cut-off operation. Rubber bond was once popular for finish grinding on bearings and cutting tools.

Metal bond

Metal bond is extensively used with super abrasive wheels. Extremely high toughness of metal bonded wheels makes these very effective in those applications where form accuracy as well as large stock removal is desired.

Electroplated bond

This bond allows large (30-40%) crystal exposure above the bond without need of any truing or dressing. This bond is specially used for making small diameter wheel, form wheel and thin super abrasive wheels. Presently it is the only bond for making wheels for abrasive milling and ultra high speed grinding.

Brazed bond

This is relatively a recent development, allows crystal exposure as high 60-80%. In addition grit spacing can be precisely controlled. This bond is particularly suitable for very high material removal either with diamond or CBN wheel. The bond strength is much greater than provided by electroplated bond. This bond is expected to replace electroplated bond in many applications.

4.3 Truing and dressing of grinding wheel

4.3.1 Truing

Truing is the act of regenerating the required geometry on the grinding wheel, whether the geometry is a special form or flat profile. Therefore, truing produces the macro-geometry of the grinding wheel.

Truing is also required on a new conventional wheel to ensure concentricity with specific mounting system. In practice the effective macro-geometry of a grinding wheel is of vital importance and accuracy of the finished work piece is directly related to effective wheel geometry.

4.3.2 Truing tools

There are four major types of truing tools:

Steel cutter:
These are used to roughly true coarse grit conventional abrasive wheel to ensure freeness of cut.

Vitrified abrasive stick and wheel:
It is used for off hand truing of conventional abrasive wheel. These are used for truing resin bonded super abrasive wheel.

Steel or carbide crash roll
It is used to crush-true the profile on vitrified bond grinding wheel.

Diamond truing tool:
Single point diamond truing tools

The single point diamond truing tools for straight face truing are made by setting a high quality single crystal into a usually cylindrical shank of a specific diameter and length by brazing or casting around the diamond. During solidification contraction of the bonding metal is more than diamond and latter is held mechanically as result of contraction of metal around it. Some application of single point diamond truing tool is illustrated in Fig.4.4

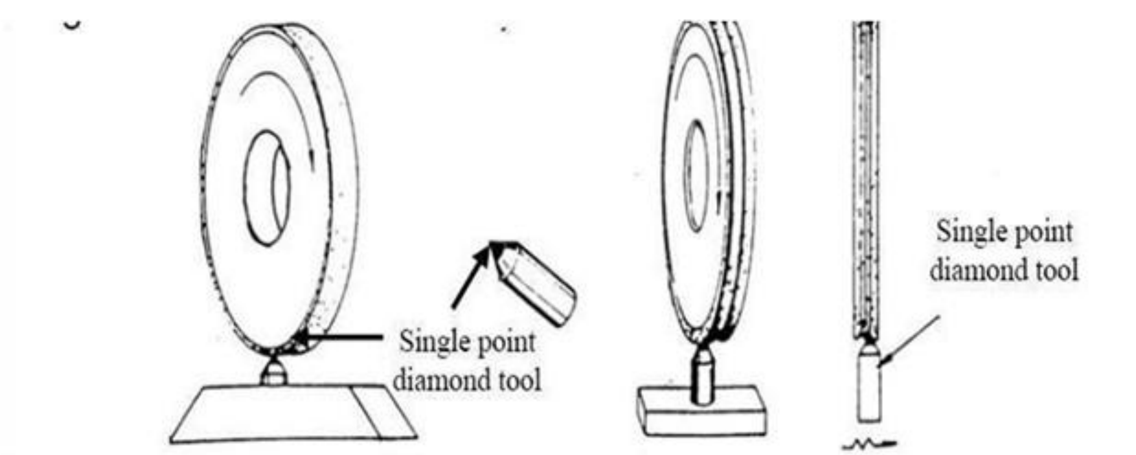
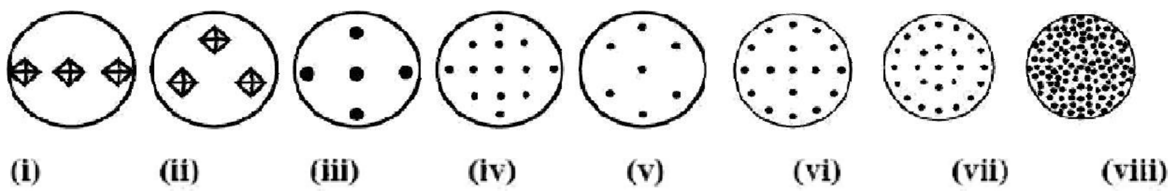


FIG.4.4 Application of single point diamond truing tool

Multi stone diamond truing tool

In this case the truing tool consists of a number of small but whole diamonds, some or all of which contact the abrasive wheel at the same time. The diamond particles are surface set with a metal binder and it is possible to make such tool with one layer or multilayer configuration. Normal range of diamond used in this tool is from as small as about 0.02 carat to as large as of 0.5 carat. These tools are suitable for heavy and rough truing operation. Distribution pattern of diamond in this tool shown in Fig.4.5



Distribution of diamond	Diamond weight	Distribution of diamond`	Diamond weight
(i) 1 layer-3stone	10	(v) 5 layer-17 stone	50
(ii) 2 layer-3 stone	10	(vi) 5 layer-7 stone	10
(iii) 3 layer-5 stone	10	(vii) 5 layer-25 stone	250
(iv) 5 layer-13 stone	25	(viii) throughout	50

FIG.4.5 Diamond distribution pattern of diamond particles in a multi-stone diamond

This wheel truing tool consists of crushed and graded diamond powder mixed with metal powder and sintered. The diamond particles are not individually set in a pattern but are distributed evenly throughout the matrix in the same way that an abrasive wheel consists of abrasive grains and bonding agent. The size of diamond particles may vary from 80-600 microns. By using considerably smaller diamond grit and smaller diamond section it is possible to true sharp edge and fine grit grinding wheel. The use of crushed diamond product ensures that there are always many sharp points in use at the same time and these tools are mainly used in fine grinding, profile grinding, thread grinding, cylindrical grinding and tool grinding. Truing action of an impregnated diamond tool is shown schematically in Fig4.6.

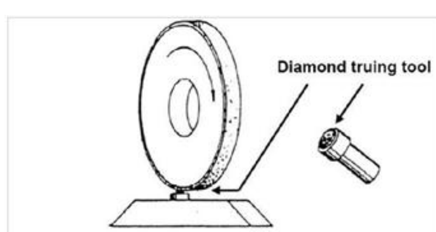


FIG. 4.6 Impregnated diamond truing tools

Rotary powered diamond truing wheels

Rotary powered truing devices (Fig.4.7) are the most widely recommended truing tool in long run mass production and are not ideally suited for those wheels with large diameters (greater than 200 mm). They can be pneumatic, hydraulic or electrically powered. Rotary powered truing device can be used in cross axis and parallel axis mode. Basically there are three types of truing wheels.

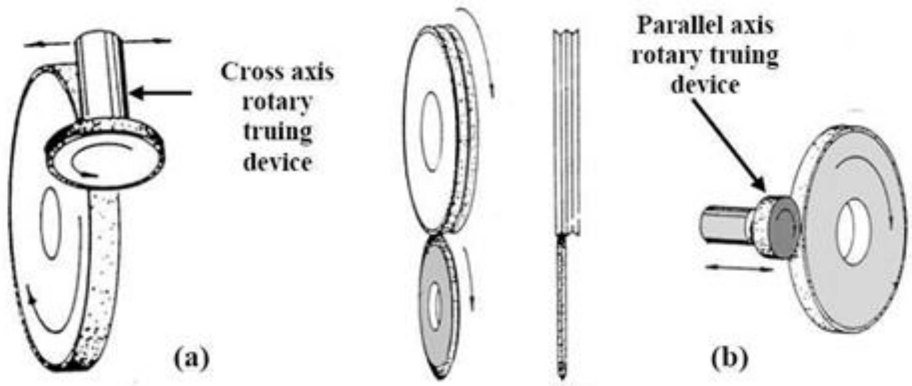


FIG. 4.7 Rotary power truing wheel being used in (a) cross-axis (b) parallel-axis

Surface set truing wheels
Here the diamond particles are set by hand in predetermined pattern. A sintered metal bond is used in this case. These truing wheels are designed for high production automated operations.

Impregnated truing wheels
In this case impregnated diamond particles are distributed in a random pattern to various depths in a metal matrix. This type of roll finds its best applications (i.e. groove grinding) where excess wheel surfaces must be dressed of.

Electroplated truing tool
In this truing wheel diamond particles are bonded to the wheel surface with galvanically deposited metal layer. Main advantage of this technique is that no mould is necessary to fabricate the diamond truing wheel unlike that of surface set or impregnated truing wheels.

Diamond form truing blocks
`Diamond form truing block can be either diamond impregnated metal bond or electroplated, as shown in Fig.4.8. Brazed type diamond truing block has also come as an alternative to electroplated one. They can be as simple as flat piece of metal plated with diamond to true a straight faced wheel or contain an intricate form to shape the grinding wheel to design profile. Truing block can eliminate the use of self propelled truing wheels and are used almost exclusively for horizontal spindle surface grinder to generate specific form.

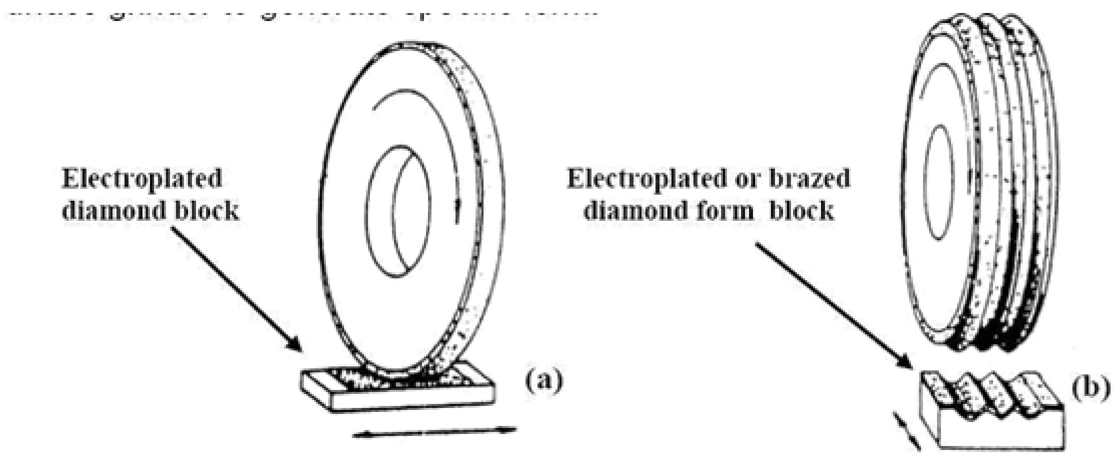


FIG. 4.8 Diamond from truing block to true (a)A straight head (b) a form wheel

Dressing

Dressing is the conditioning of the wheel surface which ensures that grit cutting edges are exposed from the bond and thus able to penetrate into the work piece material. Also, in dressing attempts are made to splinter the abrasive grains to make them sharp and free cutting and also to remove any residue left by material being ground. Dressing therefore produces micro-geometry. The structure of micro-geometry of grinding wheel determine its cutting ability with a wheel of given composition. Dressing can substantially influence the condition of the grinding tool.

Truing and dressing are commonly combined into one operation for conventional abrasive grinding wheels, but are usually two distinctly separate operation for super abrasive wheel.

<u>Dressing of super abrasive wheel</u>

Dressing of the super abrasive wheel is commonly done with soft conventional abrasive vitrified stick, which relieves the bond without affecting the super abrasive grits.
However, modern technique like electrochemical dressing has been successfully used in metal bonded super abrasive wheel. The wheel acts like an anode while a cathode plate is placed in front of the wheel working surface to allow electrochemical dissolution.

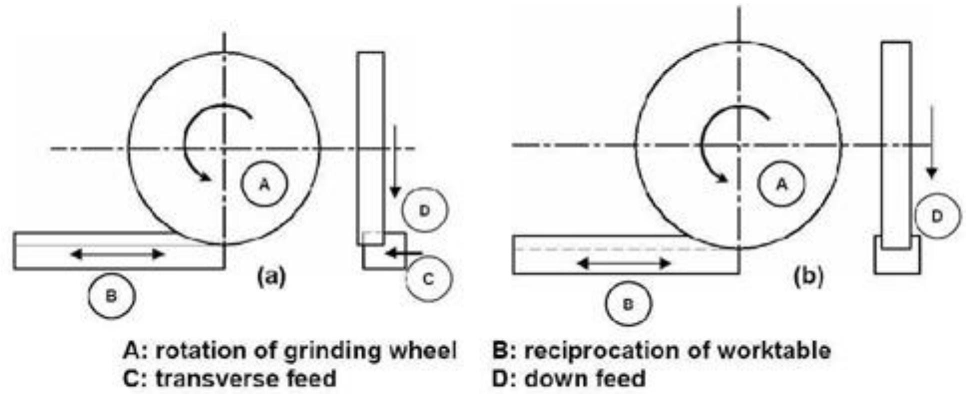


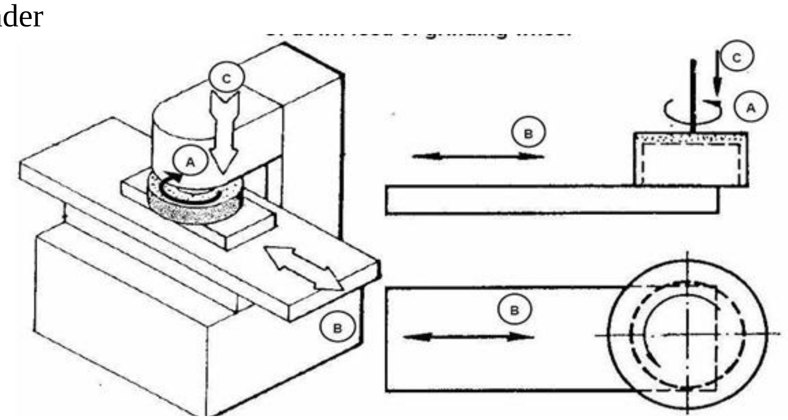
FIG. 4.9 Surface grinding (a) transverse grinding (b) plunge grinding

Vertical spindle reciprocating table grinder

This grinding machine with all working motions is shown in Fig. 4.10. The grinding operation is similar to that of face milling on a vertical milling machine. In this machine a cup shaped wheel grinds the work piece over its full width using end face of the wheel as shown in Fig. 4.11. This brings more grits in action at the same time and consequently a higher material removal rate may be attained than for grinding with a peripheral wheel.

FIG. 4.10 vertical spindle reciprocating in Table surface grinder

FIG. 4.11 Surface grinding



Horizontal spindle rotary table grinder

Surface grinding in this machine is shown in Fig.4.12. In principle the operation is same as that for facing on the lathe. This machine has a limitation in accommodation of work piece and therefore does not have wide spread use. However, by swivelling the worktable, concave or convex or tapered surface can be produced on individual part as illustrated in Fig. 4.13

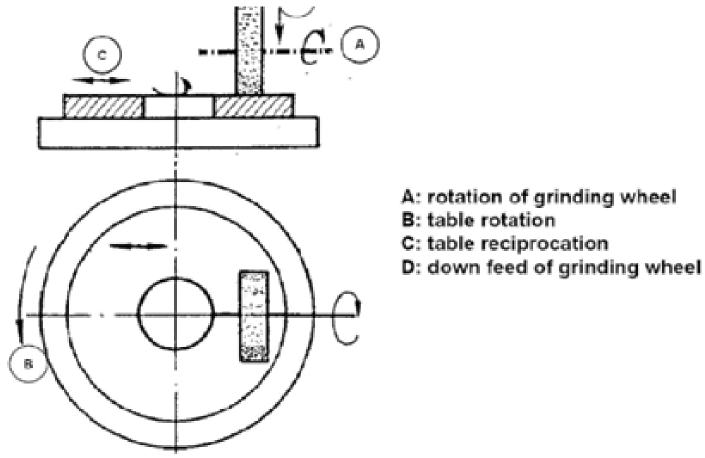


FIG.4.12 *Surface grinding in Horizontal spindle rotary table surface grinder*

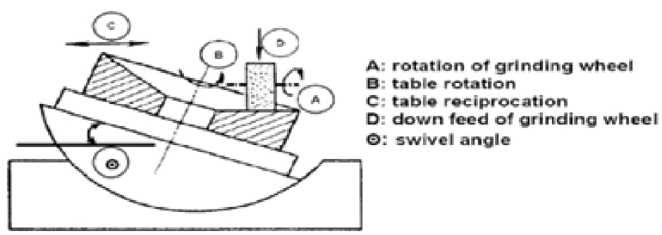


FIG. 4.13 *Grinding of a tapered surface in horizontal spindle rotary table surface grinder*

Vertical spindle rotary table grinder

The principle of grinding in this machine is shown in Fig. 4.14. The machine is mostly suitable for small work pieces in large quantities. This primarily production type machine often uses two or more grinding heads thus enabling both roughing and finishing in one rotation of the work table. **A:**

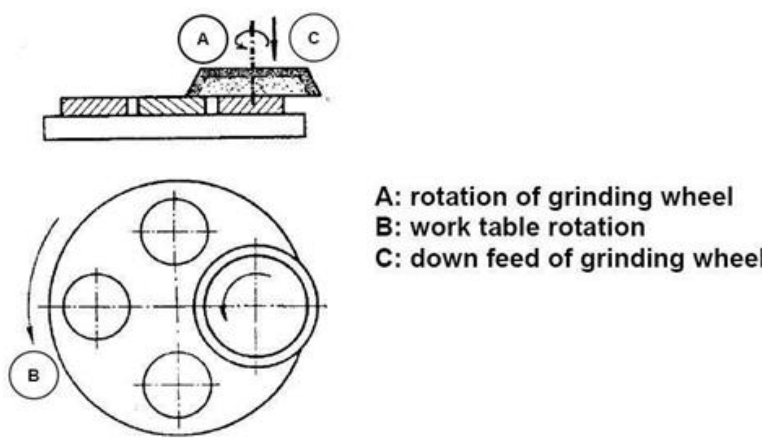


FIG. 4.14 Surface grinding in vertical spindle rotary table surface grinder

Creep feed grinding machine:

This machine enables single pass grinding of a surface with a larger downfeed but slower table speed than that adopted for multi-pass conventional surface grinding. This machine is characterised by high stiffness, high spindle power, recirculating ball screw drive for table movement and adequate supply of grinding fluid. A further development in this field is the creep feed grinding centre which carries more than one wheel with provision of automatic wheel changing. A number of operations can be performed on the work piece. It is implied that such machines, in the view of their size and complexity, are automated through CNC.

High efficiency deep grinding machine:
The concept of single pass deep grinding at a table speed much higher than what is possible in a creep feed grinder has been technically realized in this machine. This has been made possible mainly through significant increase of wheel speed in this new generation grinding machine.

4.3 Cylindrical grinding machine
This machine is used to produce external cylindrical surface. The surfaces may be straight, tapered, steps or profiled. Broadly there are three different types of cylindrical grinding machine as follows:

1. Plain centre type cylindrical grinder
2. Universal cylindrical surface grinder

3. Centre less cylindrical surface grinder

4.3.1 Plain centre type cylindrical grinder

Figure 4.15 illustrates schematically this machine and various motions required for grinding action. The machine is similar to a centre lathe in many respects. The work piece is held between head stock and tailstock centres. A disc type grinding wheel performs the grinding action with its peripheral surface. Both traverse and plunge grinding can be carried out in this machine as shown in Fig.4.15

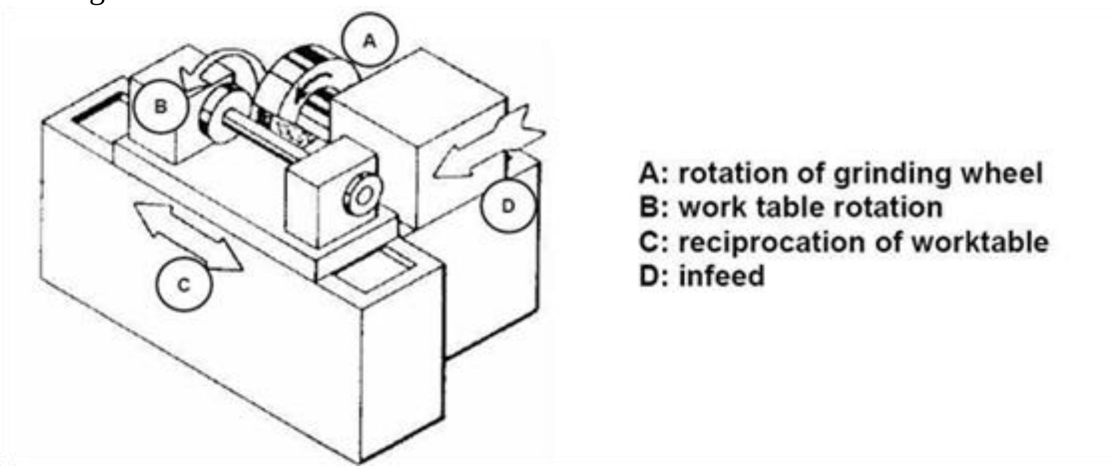


FIG. 4.15 Plain centre type cylindrical grinder

Universal cylindrical surface grinder

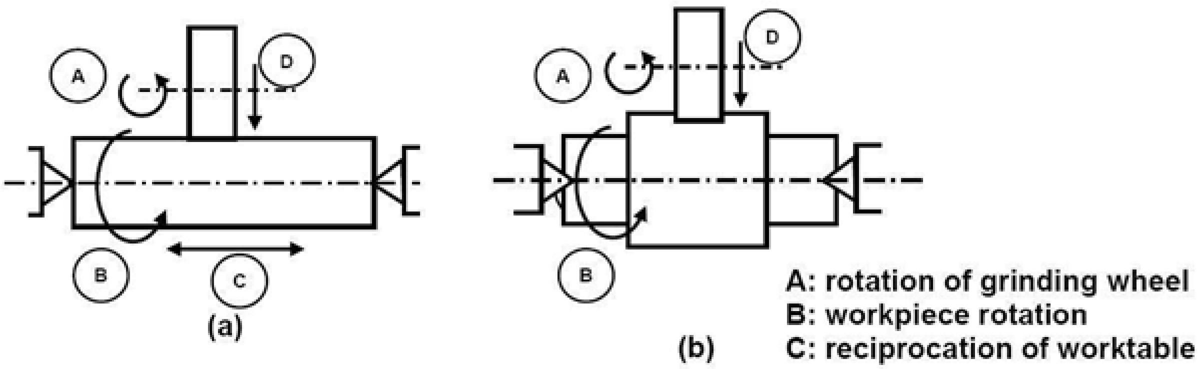
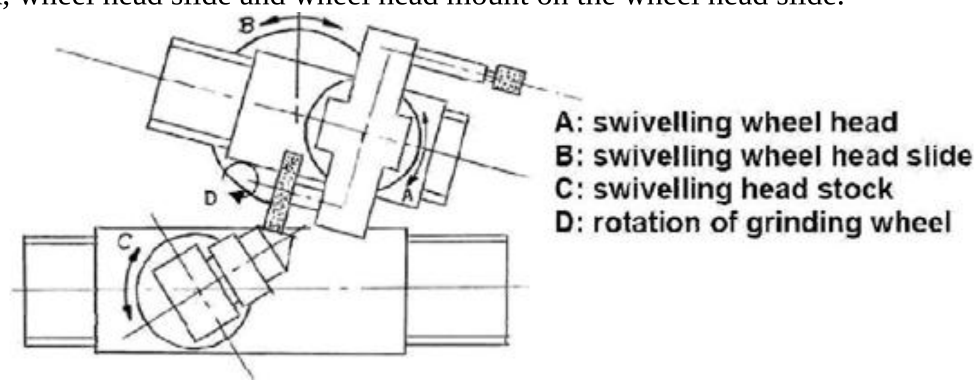


FIG. 4.16 cylindrical (a) transverse grinding (b) plunge grinding **D: infeed**

Universal cylindrical grinder is similar to a plain cylindrical one except that it is more versatile. In addition to small worktable swivel, this machine provides large swivel of head stock, wheel head slide and wheel head mount on the wheel head slide.



Special application of cylindrical grinder

Principle of cylindrical grinding is being used for thread grinding with specially formed wheel that matches the thread profile. A single ribbed wheel or a multi ribbed wheel can be used as shown in Fig. 4.17.

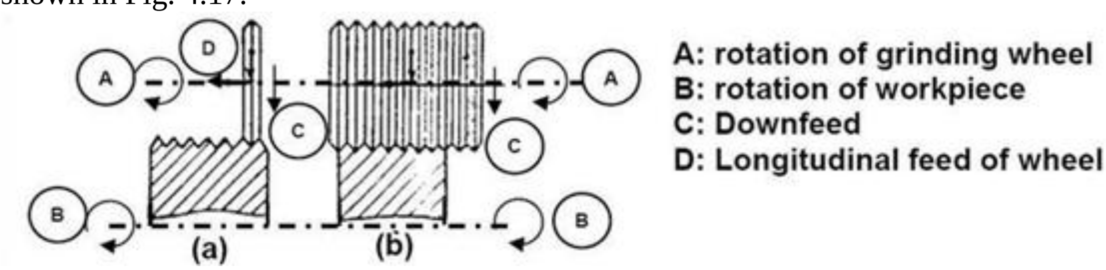
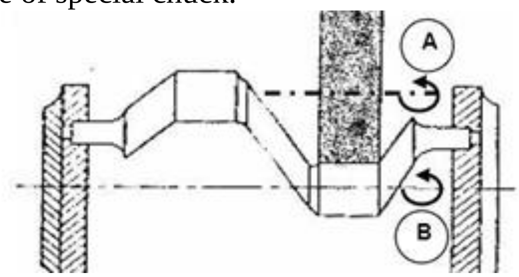


FIG. 4.17 Thread grinding with (a) single rib (b)multi-ribbed wheel

Roll grinding is a specific case of cylindrical grinding wherein large work pieces such as shafts, spindles and rolls are ground.

Crankshaft or crank pin grinders also resemble cylindrical grinder but are engaged to grind crank pins which are eccentric from the centre line of the shaft as shown in Fig. 14.18. The eccentricity is obtained by the use of special chuck.



A: Rotation of wheel roration of crank pin
FIG.4.18 Grinding of crank pin

Cam and camshaft grinders are essentially subsets of cylindrical grinding machine dedicated to finish various profiles on disc cams and cam shafts. The desired contour on the work piece is generated by varying the distance between wheel and work piece axes. The cradle carrying the head stock and tail stock is provided with rocking motion derived from the rotation of a master cam that rotates in synchronisation with the work piece. Newer machines however, use CNC in place of master cam to generate cam on the work piece.

4.3.2 External centre less grinder

This grinding machine is a production machine in which outside diameter of the work piece is ground. The work piece is not held between centres but by a work support blade. It is rotated by means of a regulating wheel and ground by the grinding wheel.
In through-feed centre less grinding, the regulating wheel revolving at a much lower surface speed than grinding wheel controls the rotation and longitudinal motion of the work piece. The regulating wheel is kept slightly inclined to the axis of the grinding wheel and the work piece is fed longitudinally as shown in Fig. 4.19.

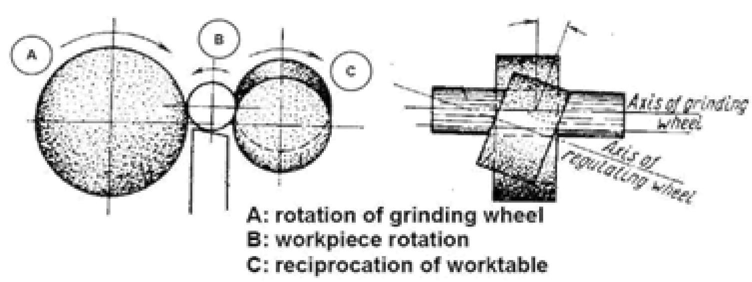


FIG : 4.19 Centre less through feed grinding
Parts with variable diameter can be ground by Centre less infeed grinding as shown in Fig. 4.20(a). The operation is similar to plunge grinding with cylindrical grinder.
End feed grinding shown in Fig. 4.20 (b) is used for work piece with tapered surface.

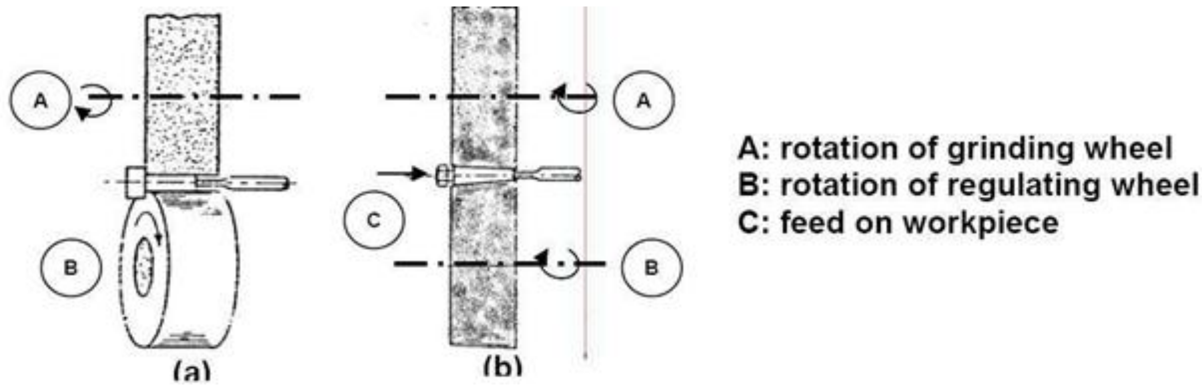


FIG. 4.20 Centre less (a) infeed (b) end feed grinding

The grinding wheel or the regulating wheel or both require to be correctly profiled to get the required taper on the work piece.

4.3.3 Tool post grinder

A self powered grinding wheel is mounted on the tool post or compound rest to provide the grinding action in a lathe. Rotation to the work piece is provided by the lathe spindle. The lathe carriage is used to reciprocate the wheel head.

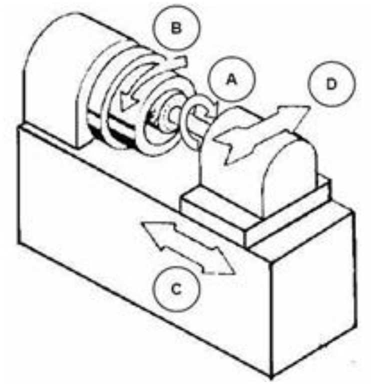
4.4 Internal grinding machine

This machine is used to produce internal cylindrical surface. The surface may be straight, tapered, grooved or profiled.
Broadly there are three different types of internal grinding machine as follows:

1. Chucking type internal grinder
2. Planetary internal grinder
3. Centre less internal grinder

4.4.1 Chucking type internal grinder

Figure 4.21 illustrates schematically this machine and various motions required for grinding action. The work piece is usually mounted in a chuck. A magnetic face plate can also be used. A small grinding wheel performs the necessary grinding with its peripheral surface. Both transverse and plunge grinding can be carried out in this machine as shown in Fig. 4.22



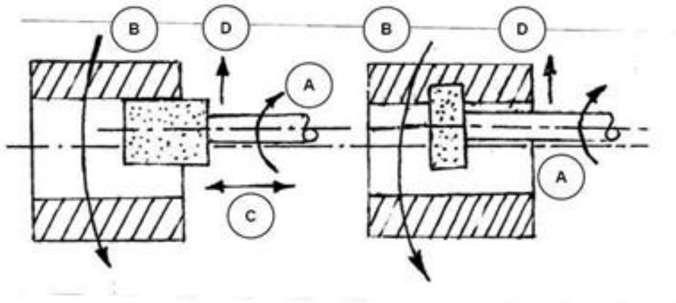


FIG. 4.21 Internal centre less grinder FIG 4.22 internal (a) transverse grinding end (b) plunge grinding

4.4.2 Planetary internal grinder

Planetary internal grinder is used where the work piece is of irregular shape and can not be rotated conveniently as shown in Fig. 4.23. In this machine the work piece

does not rotate. Instead, the grinding wheel orbits the axis of the hole in the work piece.

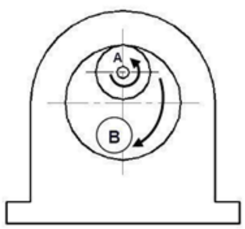


FIG 4.23 internal grinding in planetary grinder

A: Rotation of grinding wheel
B: Orbiting motion of grinding
C:

4.4.3 Centre less internal grinder

This machine is used for grinding cylindrical and tapered holes in cylindrical parts (e.g. cylindrical liners, various bushings etc). The work piece is rotated between supporting roll, pressure roll and regulating wheel and is ground by the grinding wheel as illustrated in Fig. 4.24

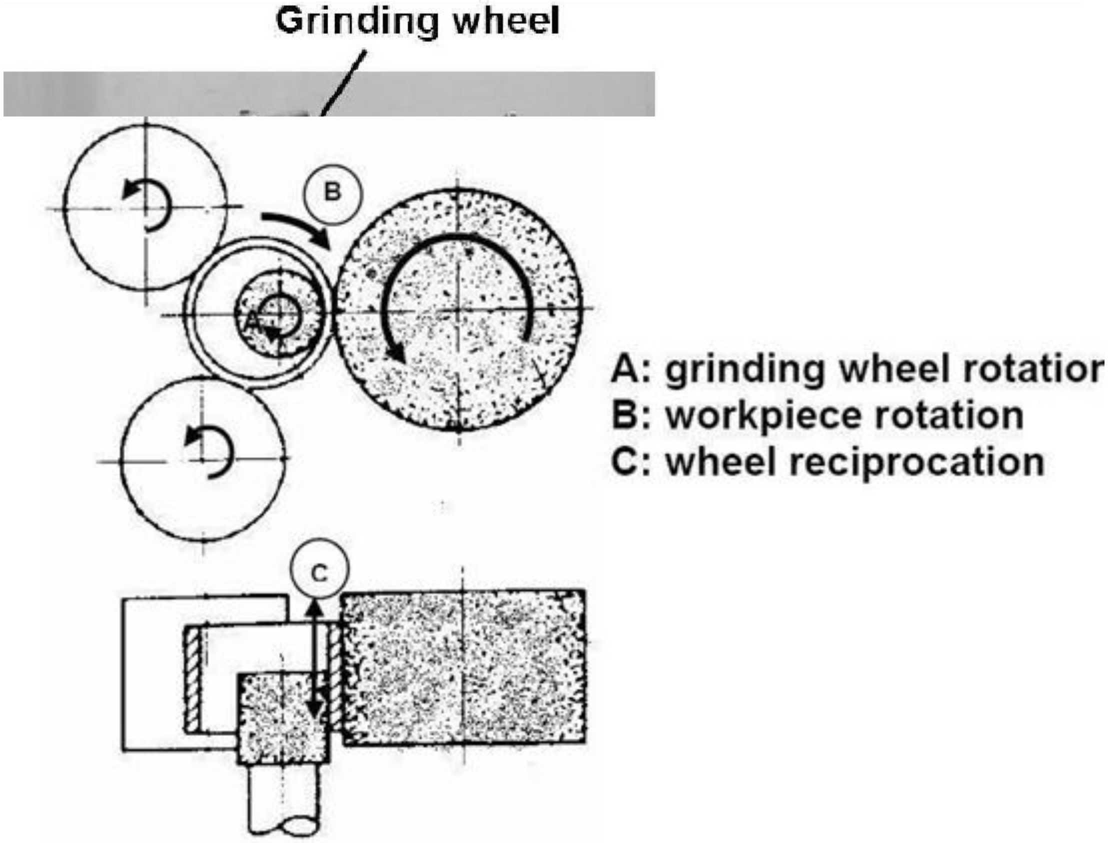


FIG. 4.24 internal centre less grinding

4.5 Tool and cutter grinder machine

Tool grinding may be divided into two subgroups: tool manufacturing and tool resharpening. There are many types of tool and cutter grinding machine to meet these requirements. Simple single point tools are occasionally sharpened by hand on bench or pedestal grinder. However, tools and cutters with complex geometry like milling cutter, drills, reamers and hobs require sophisticated grinding machine commonly known as universal tool and cutter grinder. Present trend is to use tool and cutter grinder equipped with CNC to grind tool angles, concentricity, cutting edges and dimensional size with high precision. FIG. 4.25 pictorial view of a tool and cutting grinder

Lapping

Lapping is regarded as the oldest method of obtaining a fine finish. Lapping is basically an abrasive process in which loose abrasives function as cutting points finding momentary support from the laps. Figure 4.26 schematically represents the lapping process. Material removal in lapping usually ranges from .003 to .03 mm but many reach 0.08 to 0.1mm in certain cases.

Characteristics of lapping process:

Use of loose abrasive between lap and the work piece

Usually lap and work piece are not positively driven but are guided in contact ith each other

Relative motion between the lap and the work should change continuously so that path of the abrasive grains of the lap is not repeated on the work piece.

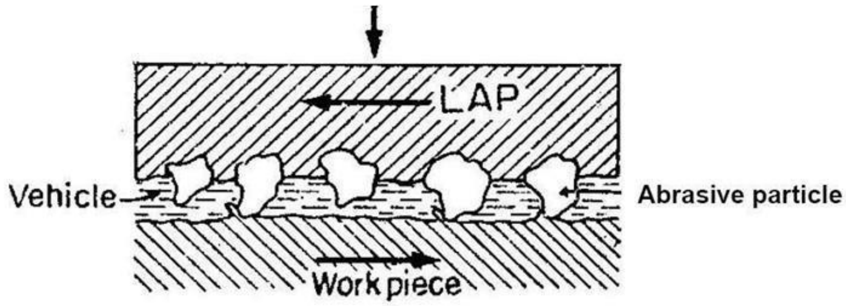


FIG. 4.26 scheme of lapping process

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

Abrasives of lapping:

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

Vehicle materials for lapping

- Machine oil
- Rape oil
- grease

Technical parameters affecting lapping processes are:

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

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

4.5.1 Hand lapping

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

Laps in the form of ring made of closed grain cast iron are used for manual lapping of external cylindrical surface. The bore of the ring is very close to size of the work piece however, precision adjustment in size is possible with the use of a set screw as illustrated in Fig.4.27(a). To increase range of working, a single holder with interchangeable ring laps can also be used. Ring lapping is recommended for finishing plug gauges and machine spindles requiring high precision. External threads can be also lapped following this technique. In this case the lap is in the form of a bush having internal thread.

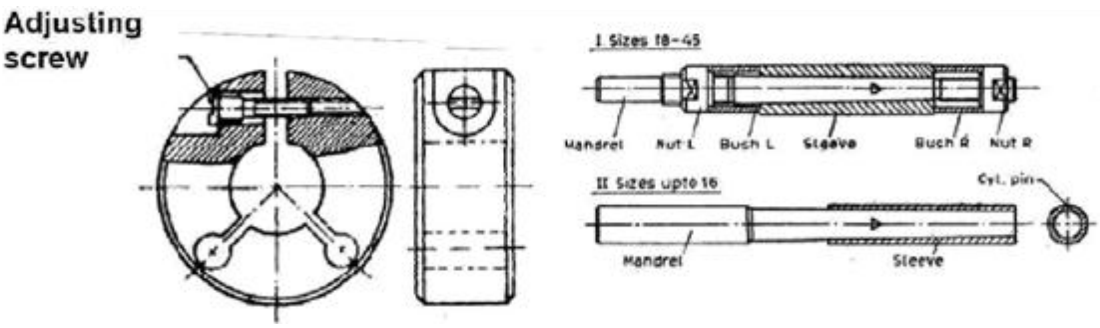


FIG. 4.27 (a)Manual Ring laping of external cylindrical surfaces (b) manual lapping of internal cylindrical surfaces

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

4.5.2 Lapping Machine

Machine lapping is meant for economic lapping of batch qualities. In machine lapping, where high accuracy is demanded, metal laps and abrasive powder held in suitable vehicles are used. Bonded abrasives in the form wheel are chosen for commercial lapping. Machine lapping can also employ abrasive paper or abrasive cloth as the lapping medium. Production lapping of both flat and cylindrical surfaces are illustrated in Fig. 4.28 (a) and (b). In this case cast iron plate with loose abrasive carried in a vehicle can be used. Alternatively, bonded abrasive plates may also be used. Centre less roll lapping uses two cast iron rolls, one of which serves as the lapping roller twice in diameter than the other one known as the regulating roller. During lapping the abrasive compound is applied to the rolls rotating in the same direction while the work piece is fed across the rolls. This process is suitable for lapping a single piece at a time and mostly used for lapping plug gauges, measuring wires and similar straight or tapered cylindrical parts.

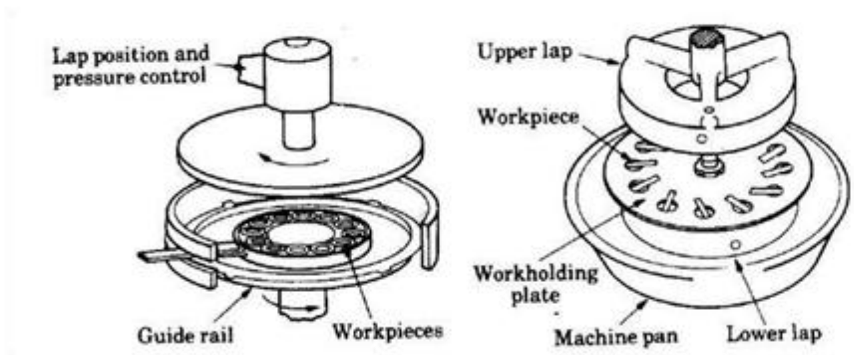


FIG. 4.28 production lapping (a) flat surface (b) cylindrical surfaces

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

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

4.6 Honing

Honing is a finishing process, in which a tool called hone carries out a combined rotary and reciprocating motion while the work piece does not perform any working motion. Most honing is done on internal cylindrical surface, such as automobile cylindrical walls. The honing stones are held against the work piece with controlled light pressure. The honing head is not guided externally but, instead, floats in the hole, being guided by the work surface (Fig.4.29). It is desired that

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

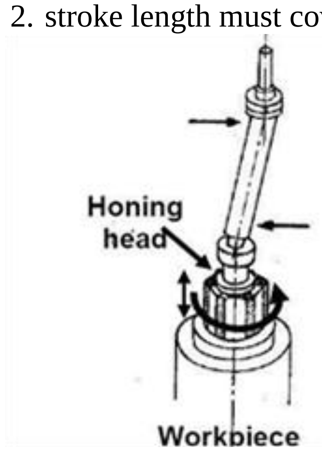


FIG. 4.29 Honing tool

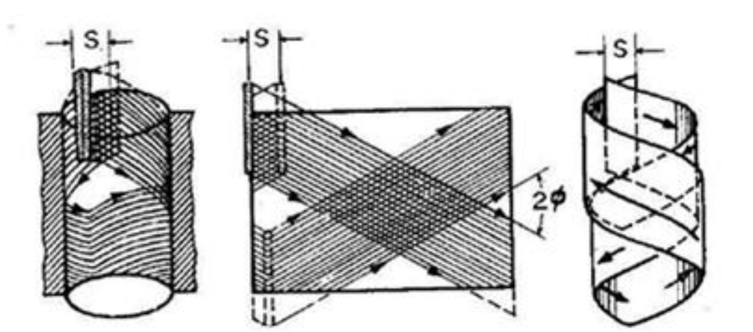


FIG. 4.30 lay pattern produced by combination of rotary and oscillatory motion

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

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

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

Super abrasive honing stick with monolayer configuration (Fig. 4.31), where a layer of CBN grits are attached to stick by a galvanically deposited metal layer, is typically found in single stroke honing application.

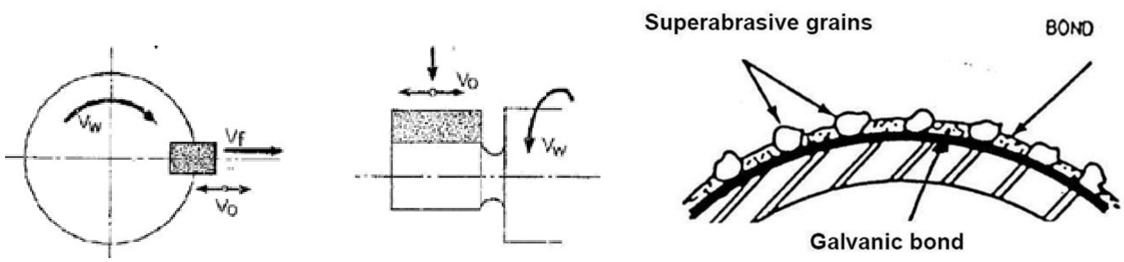


FIG. 4.31 Super abrasive honing stick with single layer configuration

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

4.7 Superfinishing

Figure 4.32 illustrates superfinishing end-face of a cylindrical work piece. In this both feeding and oscillation of the superfinishing stone is given in the radial direction.

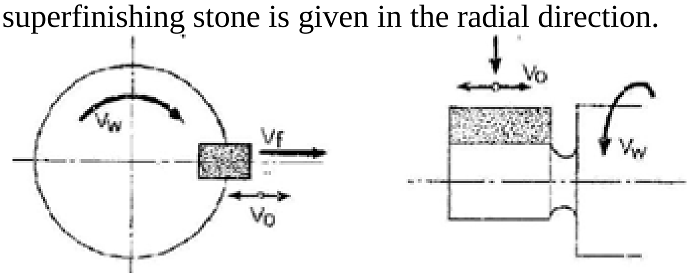
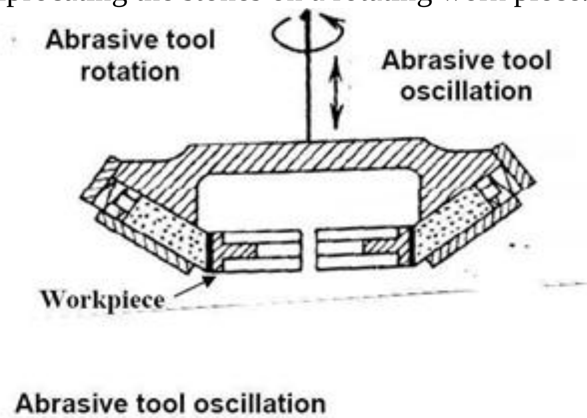


FIG. 4.32 super finishing of end face of a cylindrical work piece in radial mode FIG. 4.33 super finishing operation in plunge mode

Figure 4.33 shows the superfinishing operation in plunge mode. In this case the abrasive stone covers the section of the work piece requiring superfinish. The abrasive stone is slowly fed in radial direction while its oscillation is imparted in the axial direction.

Superfinishing can be effectively done on a stationary work piece as shown in Fig. 4.34. In this the abrasive stones are held in a disc which oscillates and rotates about the axis of the work piece.

Fig. 4.35 shows that internal cylindrical surfaces can also be superfinished by axially oscillating and reciprocating the stones on a rotating work piece.



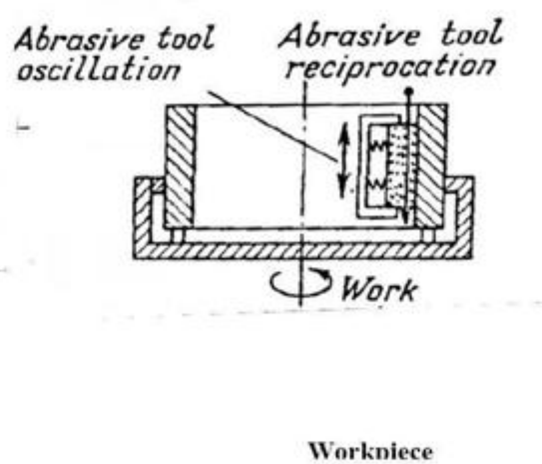
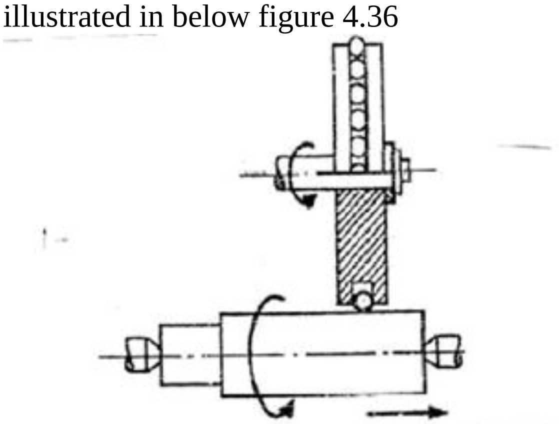


FIG. 4.34 Abrasive tool rotating and oscillating about a stationary work piece FIG. 4.35 super finishing of internal surface

Burnishing

The burnishing process consists of pressing hardened steel rolls or balls into the surface of the work piece and imparting a feed motion to the same. Ball burnishing of a cylindrical surface is illustrated in below figure 4.36



G. 4.36 Scheme of ball burnishing

Magnetic float polishing

Magnetic float polishing (Fig.4.37) finds use in precision polishing of ceramic balls. A magnetic fluid is used for this purpose. The fluid is composed of water or kerosene carrying fine ferro-magnetic particles along with the abrasive grains. Ceramic balls are confined between a rotating shaft and a floating platform. Abrasive grains ceramic ball and the floating platform can remain in suspension under the action of magnetic force. The balls are pressed against the rotating shaft by the float and are polished by their abrasive action. Fine polishing action can be made possible through precise control of the force exerted by the abrasive particles on the ceramic ball.

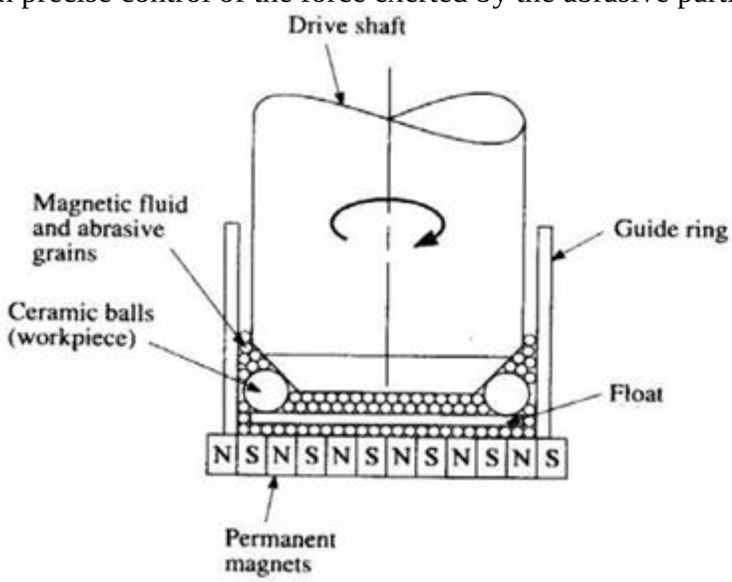


FIG. 4.37 Scheme of magnetic float polishing

Magnetic field assisted polishing

Magnetic field assisted polishing is particularly suitable for polishing of steel or ceramic roller. The process is illustrated schematically in Fig.4.38. A ceramic or a steel roller is mounted on a rotating spindle. Magnetic poles are subjected to oscillation, thereby, introducing a vibratory motion to the magnetic fluid containing this magnetic and abrasive particles. This action causes polishing of the cylindrical roller surface. In this technique, the material removal rate increases with the field strength, rotational speed of the shaft and mesh number of the abrasive. But the surface finish decreases with the increase of material removal rate.

FIG. 4.38 Scheme of magnetic field assisted polishing

Electropolishing

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

4.8 Abrasive Jet Machining

In Abrasive Jet Machining (AJM), abrasive particles are made to impinge on the work material at a high velocity. The jet of abrasive particles is carried by carrier gas or air. The high velocity stream of abrasive is generated by converting the pressure energy of the carrier gas or air to its kinetic energy and hence high velocity jet. The nozzle directs the abrasive jet in a controlled manner onto the work material, so that the distance between the nozzle and the work piece and the impingement angle can be set desirably. The high velocity abrasive particles remove the material by micro-cutting action as well as brittle fracture of the work material. Fig. 4.39 schematically shows the material removal process.

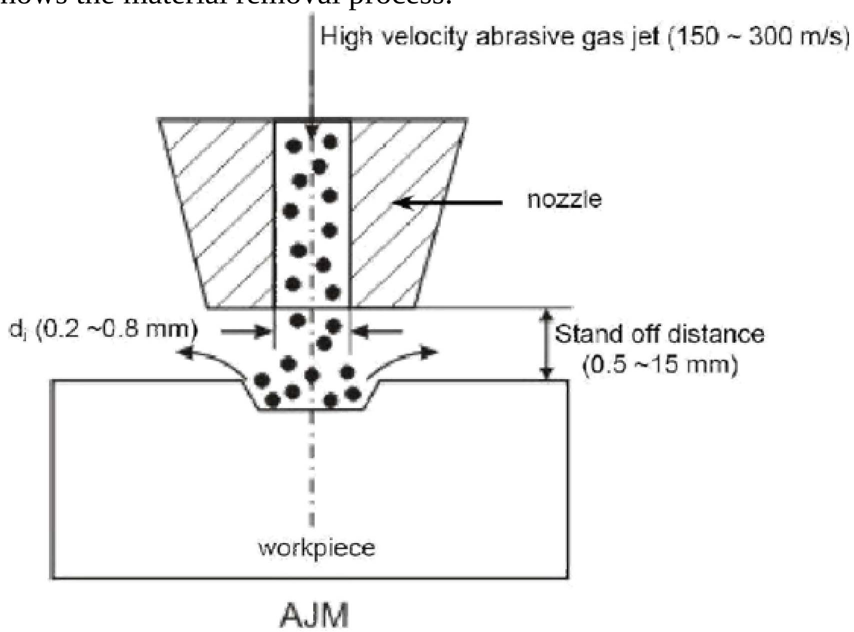


FIG. 4.39 Schematic representation of AJM

AJM is different from standard shot or sand blasting, as in AJM, finer abrasive grits are used and the parameters can be controlled more effectively providing better control over product quality.In AJM, generally, the abrasive particles of around 50 µm grit size would impinge on the work material at velocity of 200 m/s from a nozzle of I.D. of 0.5 mm with a stand off distance of around 2 mm. The kinetic energy of the abrasive particles would be sufficient to provide material removal due to brittle fracture of the work piece or even micro cutting by the abrasives.

Equipment

In AJM, air is compressed in an air compressor and compressed air at a pressure of around 5 bar is used as the carrier gas as shown in Fig 4.40 .it also shows the other major parts of the

AJM system. Gases like CO_2, N_2 can also be used as carrier gas which may directly be issued from a gas cylinder. Generally oxygen is not used as a carrier gas. The carrier gas is

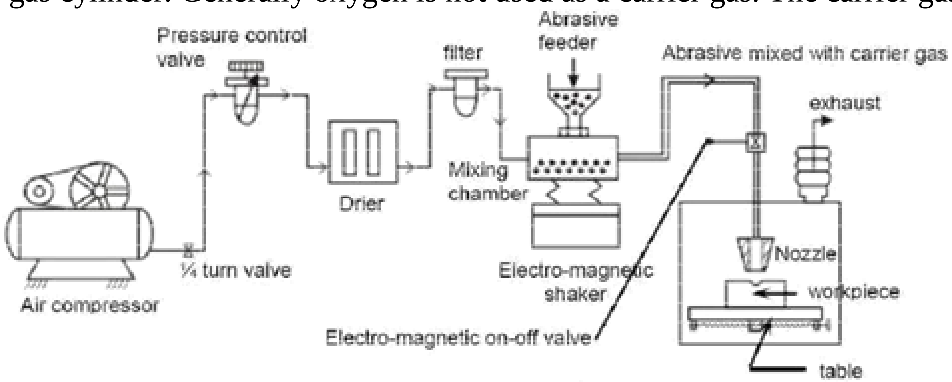


FIG 4.40

first passed through a pressure regulator to obtain the desired working pressure. The gas is then passed through an air dryer to remove any residual water vapour. To remove any oil vapour or particulate contaminant the same is passed through a series of filters. Then the carrier gas enters a closed chamber known as the mixing chamber. The abrasive particles enter the chamber from a hopper through a metallic sieve. The sieve is constantly vibrated by an electromagnetic shaker. The mass flow rate of abrasive (15 gm/min) entering the chamber depends on the amplitude of vibration of the sieve and its frequency. The abrasive particles are then carried by the carrier gas to the machining chamber via an electro-magnetic on-off valve. The machining enclosure is essential to contain the abrasive and machined particles in a safe and eco-friendly manner. The machining is carried out as high velocity (200 m/s) abrasive particles are issued from the nozzle onto a work piece traversing under the jet.

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

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

With conventional abrasive honing stick, several strokes are necessary to obtain the desired finish on the work piece. However, with introduction of high performance diamond and CBN grits it is now possible to perform the honing operation in just one complete stroke. Advent of precisely engineered microcrystalline CBN grit has enhanced the capability further. Honing stick with microcrystalline CBN grit can maintain sharp cutting condition with consistent results over long duration. Super abrasive honing stick with monolayer configuration, where a layer of CBN grits are attached to stick by a galvanically deposited metal layer, is typically found in single stroke honing application.

GEAR CUTTING

Gears are important machine elements and widely totransmit power and motion positively (without andnon-intersecting non parallel shafts:

- used in various mechanisms and devices slip) between parallel, intersecting (axis)
- Without change in the direction of rotation
- With change in the direction of rotation
- Without change of speed (of rotation)
- With change in speed at any desired ratio

Often some gearing system (rack – and – pinion) is also used to transform rotary motion into linearmotion and vice-versa. There are large varieties of gears used in industrial equipment's as well as avariety of other applications.

Special attention is paid to gear manufacturing because of the specific requirements to the gears. The gear tooth flanks have a complex and precise shape with high requirements to the surface finish.Gears can be manufactured by most of manufacturing processes. (casting, forging, extrusion,powder metallurgy, blanking, etc.)

But machining is applied to achieve the final dimensions, shape and surface finish in the gear.The initial operations that produce a semi finishing part ready for gear machining as referred to asblanking operations; the starting product in gear machining is called a gear blank.

Two principal methods of gear manufacturing include:

- **Gear forming** - where the profile of the teeth is obtained as the replica of the form of the cutting tool (edge); e.g., milling, broaching etc.

- **Gear generation** - where the complicated tooth profile is provided by much simpler form cutting tool (edges) through rolling type, tool – workmotions, e.g., hobbing, gear shaping etc.

Manufacture of gears needs several processing operations in sequential stages depending upon the material and type of the gears and quality desired. *Those stages generally are:*

- Preforming the blank without or with teeth.
- Annealing of the blank, if required, as in case of forged or cast steels.
- Preparation of the gear blank to the required dimensions by machining.
- Producing teeth or finishing the preformed teeth by machining.
- Full or surface hardening of the machined gear (teeth), if required.
- Finishing teeth, if required, by shaving, grinding etc.
- Inspection of the finished gears.

GEAR FORMING

Production of gears by gear forming method uses a single point cutting tool or a milling cutter having the same form of cutting edge as the space between the gear teeth being cut. This method usessimple and cheap tools in conventional machines and the setup required is also simple. The principle ofgear forming is shown in Fig.

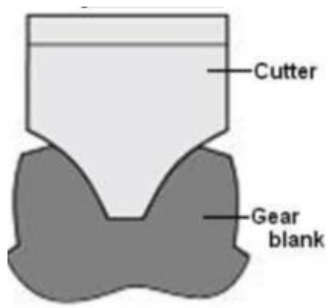


Fig. Principle of gear forming

Shaping, planing and slotting

Figschematically shows how teeth of straight toothed spur gear can be produced inshaping machine.

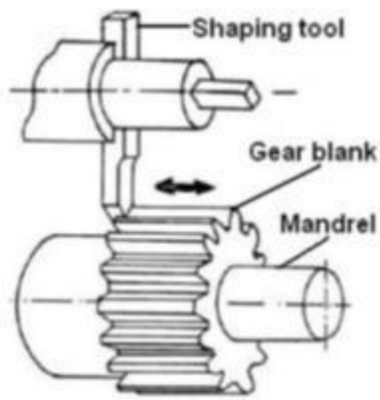


Fig. Gear teeth cutting in ordinary shaping machine

Both productivity and product quality are very low in this process. So this process is used only for making one or few teeth on one or two pieces of gears as and when required for repair and maintenance purpose. The planning and slotting machines work on the same principle. Planing machine is used for making teeth of large gears whereas slotting, generally, for internal gears.

Milling

Gear teeth can be produced by both disc type and end mill type form milling cutters in a milling machine. Fig. illustrates the production of external spur gear teeth by using disc type and end mill type cutters. Fig. Fig. shows the form cutters used for finishing cuts and for rough cuts. Fig. illustrates the production of external helical gear teeth by using form milling cutter. Fig. shows the dividing head and foot stock used to index the gear blank in form milling.

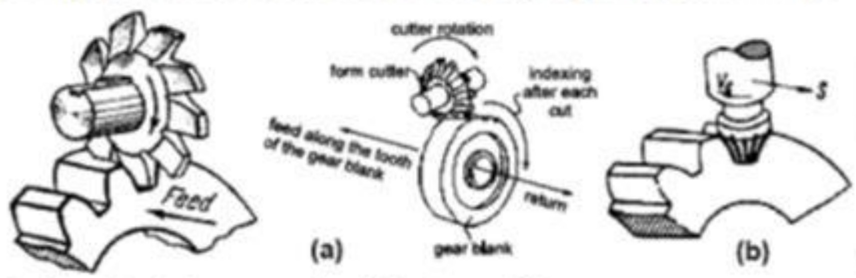


Fig. Producing external teeth by form milling cutters (a) disc type and (b) end mill type

Fig. Form milling cutters

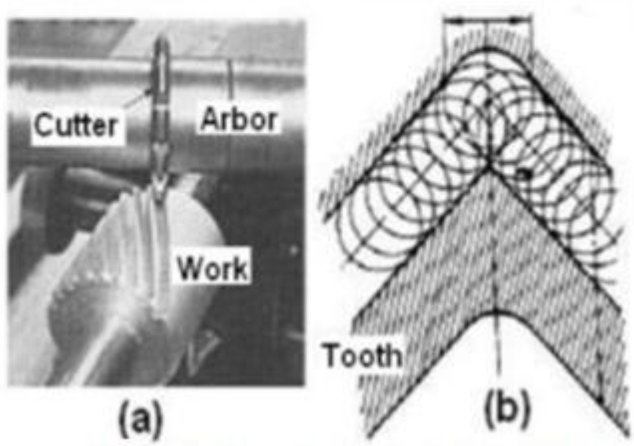


Fig. Producing external teeth by form milling cutters (a) single helical and (b) double helical teeth

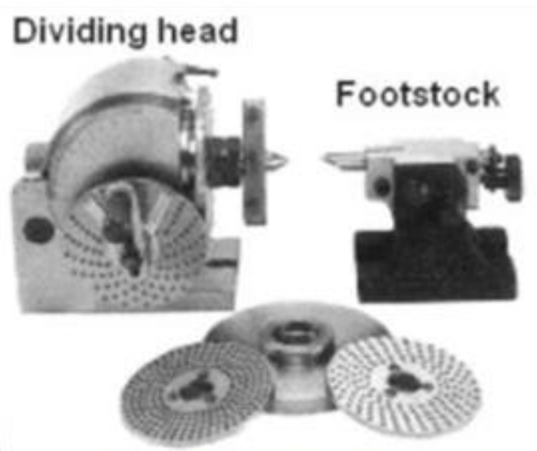
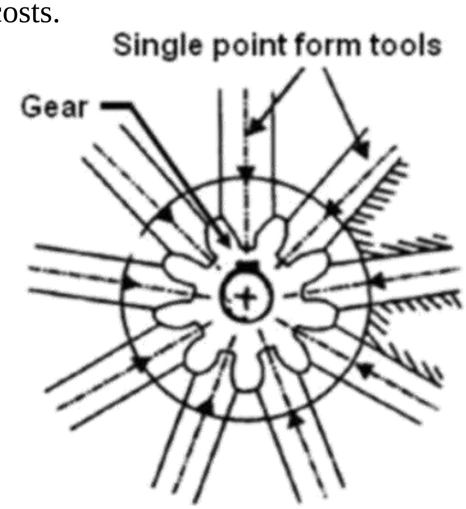


Fig. Dividing head and footstock used to index the gear blank in form milling

The form milling cutter called DP (Diametral Pitch, used in inch systems which is equivalent to the inverse of a module) cutter have the shape of the teeth similar to the tooth space with the involute form of the corresponding size gear. These can be used on either horizontal axis or vertical axis milling machines, through horizontal axis is more common.

Fast production of teeth of spur gears by parallel multiple teeth shaping

In principle, it is similar to ordinary shaping but all the tooth gaps are made simultaneously,without requiring indexing, by a set of radially infeeding single point form tools as indicated inFig. This old process was highly productive but became almost obsolete for very high initial andrunning costs.

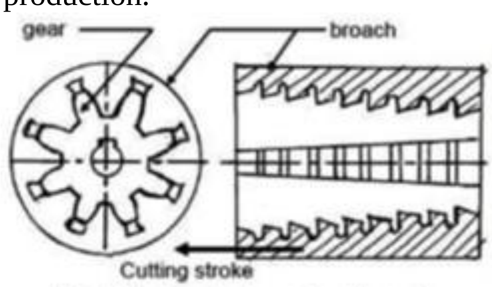


High production of straight teeth of external spur gears by parallel shaping

Fig. High production of straight teeth of external spur gears by parallel shaping

Fast production of teeth of spur gears by Broaching

Teeth of small internal and external spur gears; straight or single helical, of relatively softermaterials are produced in large quantity by this process. Fig. (a and b) schematically shows howexternal teeth are produced by a broaching in one pass. The process is rapid and produces fine surfacefinish with high dimensional accuracy. However, because broaches are expensive and a separate broachis required for each size of gear, this method is suitable mainly for high-quantity production.



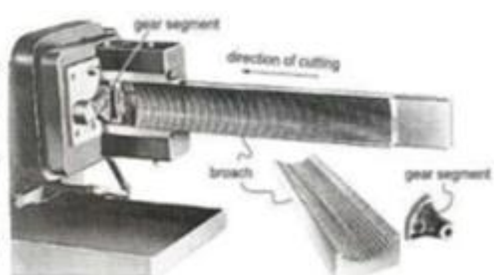


Fig a) High production of straight teeth of external spur gears by broaching

Fig (b) Broaching the teeth of a gear segment by horizontal external broaching in one pass

GEAR GENERATION

To obtain more accurate gears, the gear is generally generated using a cutter, which is similar to the gear with which it meshes by following the general gear theory. The gears produced by generationare more accurate and the manufacturing process is also fast.

Generation method is characterized by automatic indexing and ability of a single cutter to coverthe entire range of number of teeth for a given combination of module and pressure angle andhenceprovides high productivity and economy. These are used for large volume production.

In gear generating, the tooth flanks are obtained (generated) as an outline of the subsequentpositions of the cutter, which resembles in shape the mating gear in the gear pair. In

gear generating, twomachining processes are employed, shaping and milling. There are several modifications of theseprocesses for different cutting tool used:

- Milling with a hob (gear hobbing).
- Gear shaping with a pinion-shaped cutter.
- Gear shaping with a rack-shaped cutter.

Cutters and blanks rotate in a timed relationship: a proportional feed rate between them is maintained.Gear generating is used for high production runs and for finishing cuts.

Sunderland method using rack type cutter

Fig. schematically shows the principle of this generation process where the rack type HSS cutter (having rake and clearance angles) reciprocates to accomplish the machining (cutting) action while rolling type interaction with the gear blank like a pair of rack and pinion.

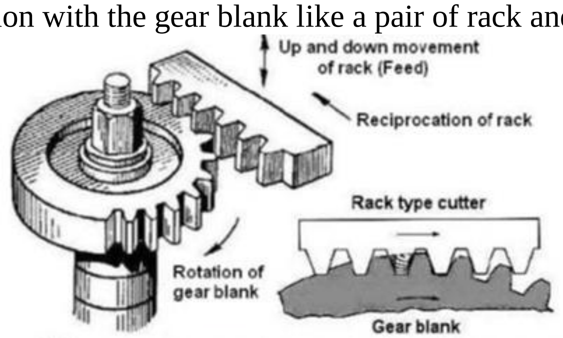


Fig. External gear teeth generation by rack type cutter

The favourable and essential applications of this method (and machine) include:

- Moderate size straight and helical toothed external spur gears with high accuracy and finish.

- Cutting the teeth of double helical or herringbone gears with a central recess (groove).

- Cutting teeth of straight or helical fluted cluster gears.

However this method needs, though automatic, few indexing operations. Advantages of this method involve a very high dimensional accuracy and cheap cutting tool (the rack type cutter's teeth blanks are straight, which makes sharpening of the tool easy). The process can be used for low-quantity as well as high-quantity production of spur and helical external gears.

Gear shaping

In principle, gear shaping is similar to the rack type cutting process, except that, the linear type rack cutter is replaced by a circular cutter as indicated in Fig. where both the cutter and the blankrotate as a pair of spur gears in addition to the reciprocation of the cutter. Fig. schematically showsthe generating action of a gear-shaper cutter.

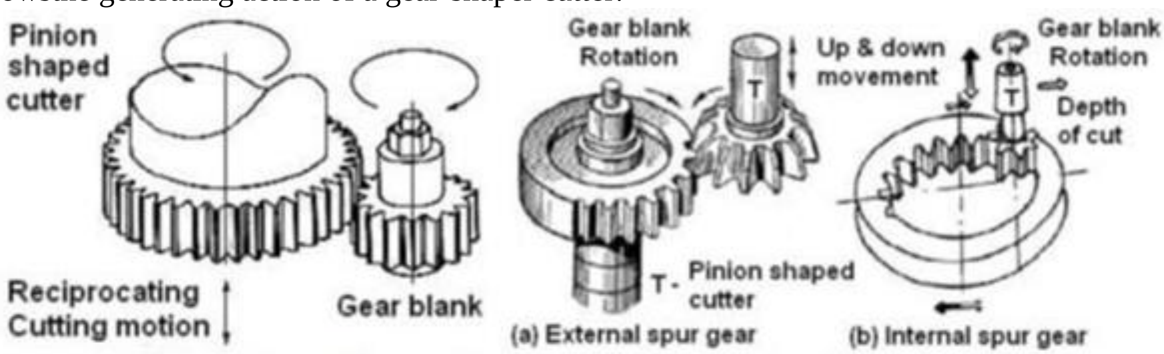


Fig : Setup of gear teeth generation by gear shaping operation with a pinion-shaped cutter

Fig. Setup of gear teeth generation by gear shaping operation with a pinion-shaped cutter

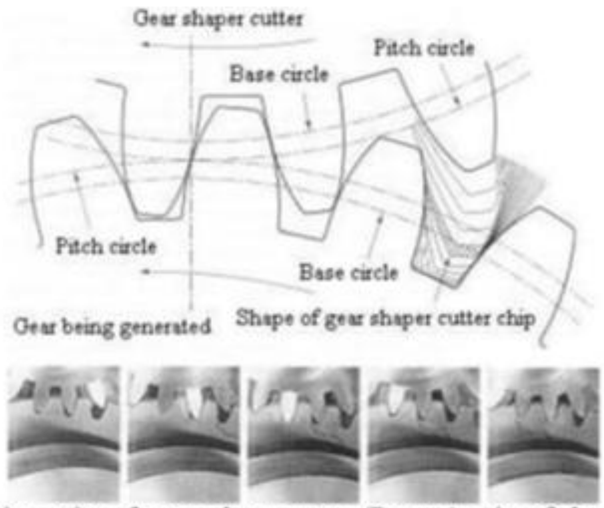


Fig. Generating action of a gear-shaper cutter; (Bottom) series of photographs showing

Fig. Generating action of a gear-shaper cutter; (Bottom) series of photographs showingvarious stages in generating one tooth in a gear by means of a gear-shaper cutter,action taking place from right to left. One tooth of the cutter was painted white.

The gear shaper cutter is mounted on a vertical ram and is rotated about its axis as it performs the reciprocating action. The work piece is also mounted on a vertical spindle and rotates in mesh with the shaping cutter during the cutting operation. The relative rotary motions of the shaping cutter and the gear blank are calculated as per the requirement and incorporated with the change gears.
The cutter slowly moves into the gear blank surface with incremental depths of cut, till it reaches the full depth. The cutter and gear blank are separated during the return (up) stroke and come to the correct position during the cutting (down) stroke. Gear shaping can cut internal gears, splines and continuous herringbone gears that cannot be cut by other processes. The gear type cutter is made of HSS and possesses proper rake and clearance angles.

The additional advantages of gear shaping over rack type cutting are:

- Separate indexing is not required at all.
- Straight or helical teeth of both external and internal spur gears can be produced withhighaccuracy and finish.
- Productivity is also higher.

Gear hobbing

Gear hobbing is a machining process in which gear teeth are progressively generated by a series of cuts with a helical cutting tool (hob). The gear hob is a formed tooth milling cutter with helical teetharranged like the thread on a screw. These teeth are fluted to produce the required cutting edges. Allmotions in hobbing are rotary, and the hob and gear blank rotate continuously as in two gears meshinguntil all teeth are cut. This process eliminates the unproductive return motion of the gear shapingoperation. The work piece is mounted on a vertical axis and rotates about its axis.The hob is mounted on an inclined axis whose inclination is equal to the helix angle of the hob.The hob is rotated in synchronization with the rotation of the blank and is slowly moved into the gearblank till the required tooth depth is reached in a plane above the gear blank.

The tool-work configuration and motions in hobbing are shown in Fig., where the HSS orcarbide cutter having teeth like gear milling cutter and the gear blank apparently interact like a pair ofworm and worm wheel. The hob (cutter) looks and behaves like a single or multiple start worms. Havinglesser number (only three) of tool – work motions, hobbing machines are much more rigid, strong andproductive than gear shaping machine. But hobbing provides lesser accuracy and finish and is used onlyfor cutting straight or helical teeth (single) of external spur gears and worm wheels.

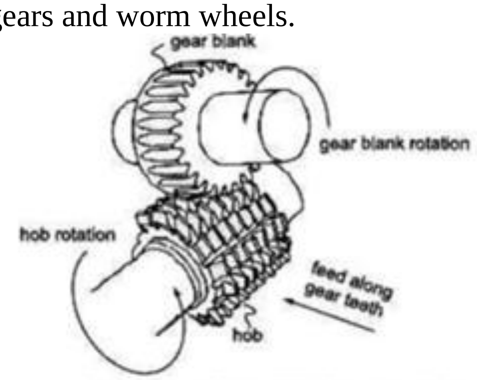


Fig. Setup of gear hobbing operation

Fig. Setup of gear hobbing operation

Fig. shows the generation of different types of gears by gear hobbing. When bobbing a spurgear, the angle between the hob and gear blank axes is 90° minus the lead angle at the hob threads. Forhelical gears, the hob is set so that the helix angle of the hob is parallel with the tooth direction of thegear being cut. Additional movement along the tooth length is necessary in order to cut the whole toothlength. Machines for cutting precise gears are generally CNC type and often are housed in temperaturecontrolled rooms to avoid dimensional deformations.

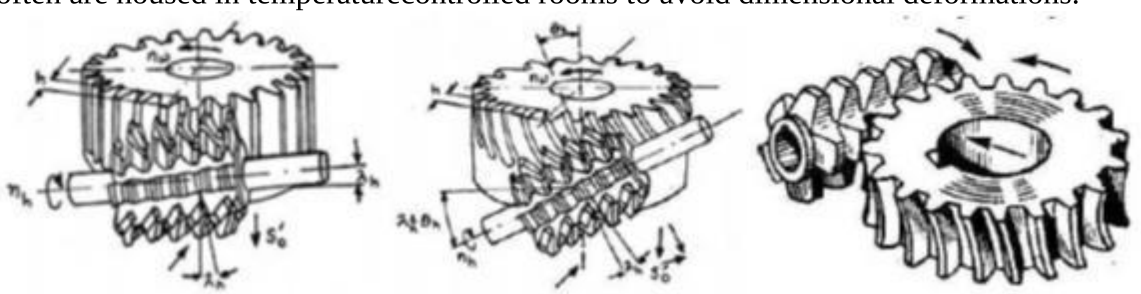


Fig. Generation of external gear teeth by hobbing (a) spur gear (b) helical gear and (c) worm wheel

Fig Generation of external gear teeth by hobbing (a) spur gear (b) helical gear and (c) worm wheel.

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SCHOOL OF MECHANICAL ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING

UNIT - V

MANUFACTURING TECHNOLOGY II – SPR1301

UNIT - V

CNC MACHINE TOOLS AND FUNDAMENTALS OF CAD/CAM

Numerical control: Brief principles and description of numerical control application to M/c tools. DNC, CNC and adaptive control. Programming of CNC M/C tools, CNC programming based on CAD. Fundamentals of CAD/CAM, Computer integrated manufacturing, Compute Aided Process Planning, Computer Integrated Production Planning system.

Numerical Control Definition and applications

Introduction

The subject of this lecture is the interface between CAD and the manufacturing processes actually used to make the parts, and how to extract the data from the CAD model for the purpose of controlling a manufacturing process. Getting geometric information from the CAD model is of particular relevance to the manufacture of parts directly by machining (i.e. by material removal), and to the manufacture of tooling for forming and molding processes by machining. The use of numerical information for the control of such machining processes is predominantly through the numerical control NC of machines.

Fundamentals of numerical control

Today numerically controlled devices are used in all manner of industries. Milling machines manufacture the molds and dies for polymer products. Flame cutting and plasma arc machines cut shapes from large steel plates. Lasers are manipulated to cut tiny cooling holes in gas turbine parts. Electronic components are inserted into printed circuit boards by NC insertion machines.

Numerical Control NC is a form of programmable automation in which the mechanical actions of a machine tool or other equipment are controlled by a program containing coded alphanumerical data. Numerical control NC is any machining process in which the operations are executed automatically in sequences as specified by the program that contains the information for the tool movements. The alphanumerical data represent relative positions between a workhead and a workpart as well as other instructions needed to operate the machine. The workhead is a cutting tool or other processing apparatus, and the workpart is the object being processed.

Applications of Numerical Control

1. Machine tool applications, such as drilling, milling, turning, and other metal working

2. Nonmachine tool applications, such as assembly, drafting, and inspection.

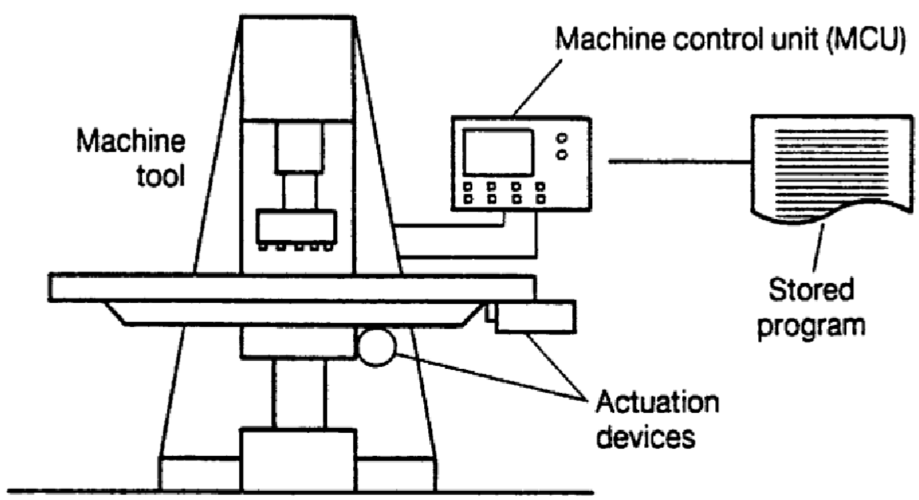
The common operating feature of NC in all of these applications is control of the workhead movement relative to the workpart.

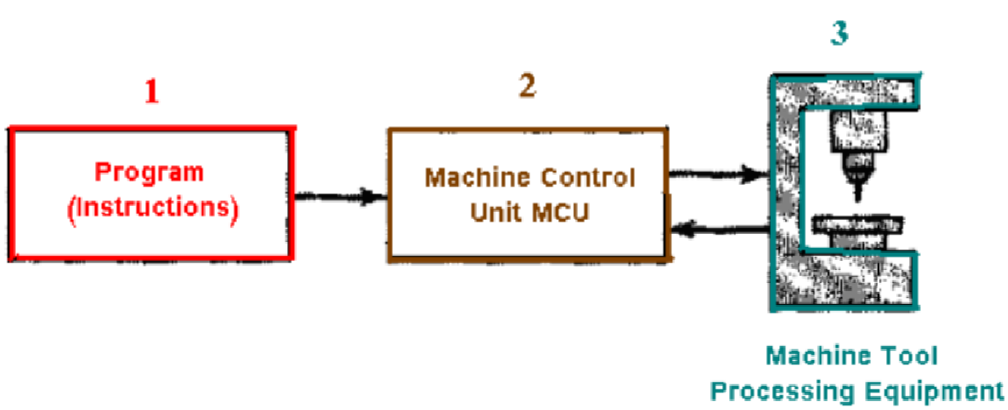
Basic Components of an NC System

The essential features of numerically controlled machines have been established for many years. They comprise a controller, known as the machine control unit MCU, capable of reading and

interpreting a stored program and using the instructions in this to control a machine via actuation devices. This arrangement is shown in the following Figure.

Basic Components of an NC System





An NC system consists of three basic components:

(1) Program of instructions:

The detailed step-by-step commands that direct the actions of the processing equipment. In machine tool applications, the program of instructions is called a part program, and the person who prepares the program is called a part programmer. In these applications, the individual commands refer to positions of a cutting tool relative to the worktable on which the workpart is fixtured. Additional instructions are usually included, such as spindle speed, feed rate, cutting tool selection, and other functions. The program is coded on a suitable medium for submission to the machine control unit.

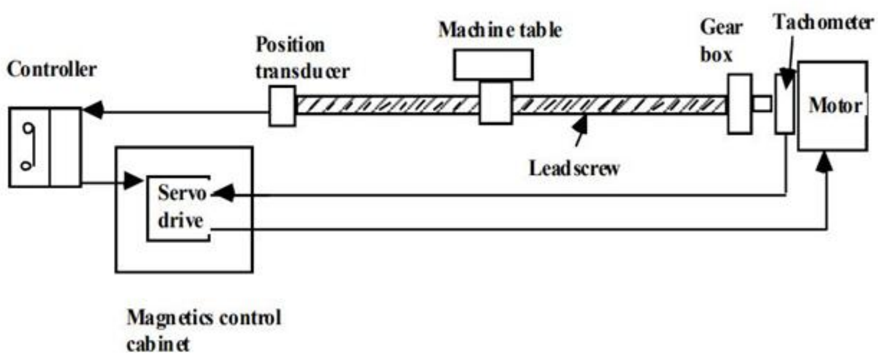
(2) Machine control unit MCU:

Consists of a microcomputer and related control hardware that stores the program of instructions and executes it by converting each command into mechanical actions of the processing equipment, one command at a time. The related hardware of the MCU includes components to interface with processing equipment and feedback control elements. The MCU also includes one or more reading devices for entering part programs into memory. The MCU also includes control system software, calculation algorithms, and translation software to convert the NC part program into a usable format for the MCU. NC and CNC: Because the MCU is a computer, the term computer numerical control CNC is used to distinguish this type of NC from its technological predecessors that were based entirely on a hard-wired electronics. Today, virtually all new MCUs are based on computer technology; hence, when we refer to NC we mean CNC.

(3) Processing equipment:

Performs useful work and accomplishes the processing steps to transform the starting workpiece into a completed part. Its operation is directed by the MCU, which in turn is driven by instructions contained in the part program. In the most common example of NC, machining, the processing equipment consists of the worktable and spindle as well as the motors and controls to drive them.

MAJOR COMPONENTS OF AN NC MACHINE TOOL



NC Coordinate Systems

In machine tools the cutter may typically move in multiple directions with respect to the workpiece, or vice versa, and therefore the controller normally drives more than one machine axis. Examples of machine applications and numbers of axes are as follows:

1. 2-axis motion, generally in two orthogonal directions in a plane, which applies to most lathes as well as punch presses, flame and plasma-arc and cloth cutting machines, electronic component insertion and some drilling machines.

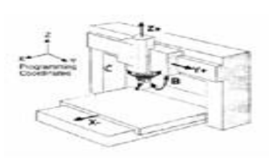
2. 3-axis motion, which is generally along the three principal directions (x, y and z) of the Cartesian coordinate system, and applies to milling, boring, drilling and coordinate measuring machines.

3. 4-axis motion typically involves three linear and one rotary axis, or perhaps two x-y motions, as for example for some lathes fitted with supplementary milling heads.

4. 5-axis machines normally involve three linear (x, y and z) axes, with rotation about two of these, normally x and y, and are generally milling machines.

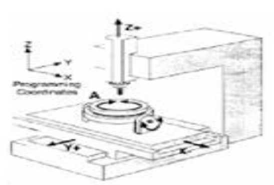
A 3-AXIS MACHINING CENTER

5-AXIS MACHINE CONFIGURATIONS



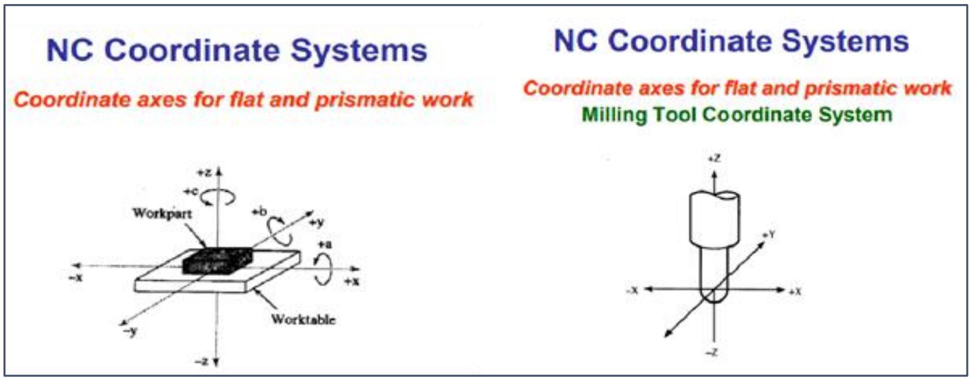
Rotational axes on the spindle

Rotational axes on spindle and the table



Rotational axes on the table

To program the NC processing equipment, a standard axis system must be defined by which the position of the workhead relative to the workpart can be specified. There are two axis systems used in NC, one for flat and prismatic workparts and the other for rotational parts. Both axis systems are based on the Cartesian coordinate system.



• Coordinate axes for flat and prismatic work The axis system for flat and prismatic parts consists of three linear axes (x, y, z) in the Cartesian coordinate system, plus three rotational axes (a, b, c). In most machine tool applications, the x-and y-axes are used to move and position the worktable to which the part is attached, and the z-axis is used to control the vertical position of the cutting tool. The a-, b-, and c-rotational axes specify angular positions about the x-, y-, and z-axes, respectively. The rotational axes can be used for: (1) Orientation of the workpart to present different surfaces for machining or (2) Orientation of the tool or workhead at some angle relative to the part.

NC Coordinate Systems

Coordinate axes for rotational work

The coordinate axes for a rotational NC system are associated with NC lathes and turning centers. Although the work rotates, this is not one of the controlled axes on most of these turning machines. Consequently, the y-axis is not used. The path of the cutting tool relative to the rotating workpiece is defined in the x-z plane, where the x-axis is the radial location of the tool, and the z-axis is parallel to the axis of rotation of the part.

Information Needed by a CNC

1. Preparatory Information: units, incremental or absolute positioning
2. Coordinates: X,Y,Z, RX,RY,RZ
3. Machining Parameters: Feed rate and spindle speed
4. Coolant Control: On/Off, Flood, Mist
5. Tool Control: Tool and tool parameters
6. Cycle Functions: Type of action required
7. Miscellaneous Control: Spindle on/off, direction of rotation, stops for part movement

This information is conveyed to the machine through a set of instructions arranged in a desired sequence – Program.

Zero point and Target point

The part programmer must decide where the origin of the coordinate axis system should be located. This decision is usually based on programming convenience. For example, the origin might be located at one of the corners of the part. If the workpart is symmetrical, the zero point might be most conveniently defined at the center of symmetry. Wherever the location, this zero point is communicated to the machine tool operator. At the beginning of the job, the operator must move the cutting tool under manual control to some target point on the worktable, where the tool can be easily and accurately positioned. The target point has been previously referenced to the origin of the coordinate axis system by the part programmer. When the tool has been accurately positioned at the target point, the operator indicates to the MCU where the origin is located for subsequent tool movements.

Open-loop and Closed-loop Control Systems

• A numerical control systems require Motors to control both position and velocity of the machine tool.
• Each axis must be separately driven
• The control system can be implemented in two ways – open loop system – close loop system

Open Loop System

• Instructions are feed to the controller
• Converted to electrical pulses or signals
• Sent to the Stepper motors
• The number of electronic pulses determines the distance
• A frequency of the pulses determines the speed
• Used mainly in point-to-point applications.

Open loop control system is usually appropriate when the following conditions apply:

• The actions performed by the control system are simple.
• The actuating function is very reliable
• Reaction forces opposing the actuator are small enough to have no effect on the actuation.

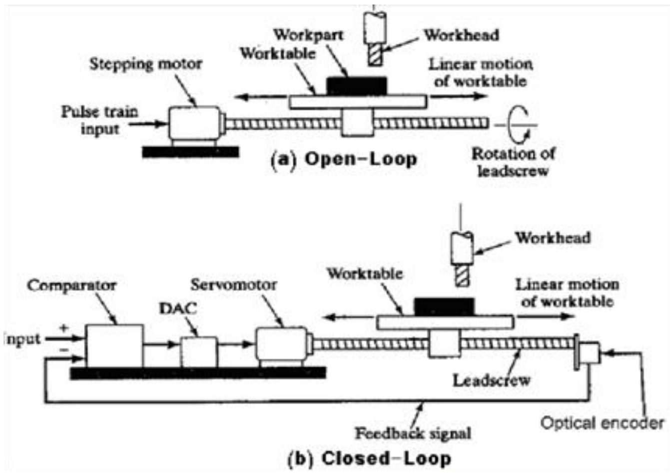
Open Loops Systems

Advantages

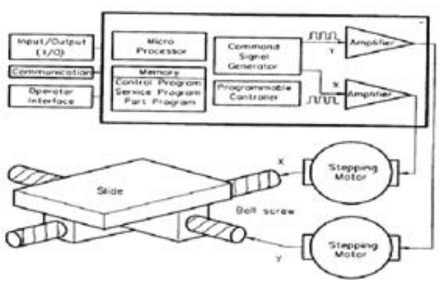
– Less expensive
– Less complicated

Disadvantages

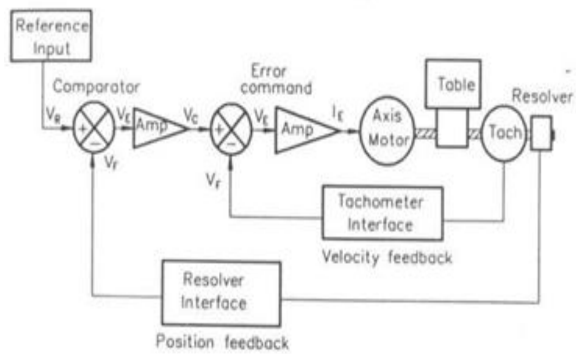
– Accuracy
– Repeatability
– Setup



A Diagram of the Open Loop System



Feed Back System



Closed Loop Systems

Main difference from an open loop system is the inclusion of a feedback system in the controller.

– Feedback may be analog or digital

– The feedback mechanism allows the machine to “know” where the tool is in regards to previous movements

Types of Feedback:

• Analog feedback – Measures the variation of position and velocity in terms of voltage levels.

• Digital feedback – Monitor output variations in the form of electrical pulses.

Features of Motion Control Systems

Point-to-Point versus Continuous Path Control:

Motion control systems for NC can be divided into two types:

(1) point-to-point

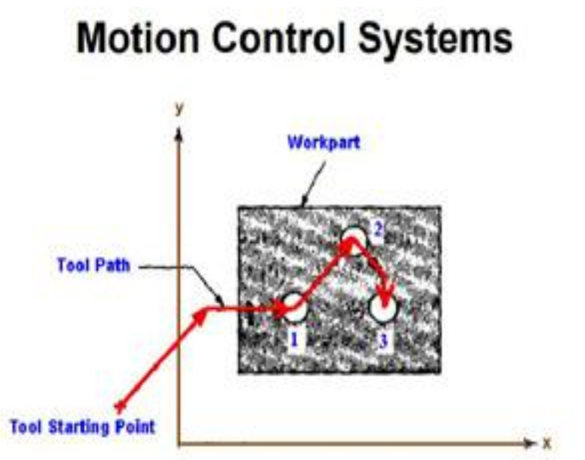
(2) continuous path

Point-to-point systems:

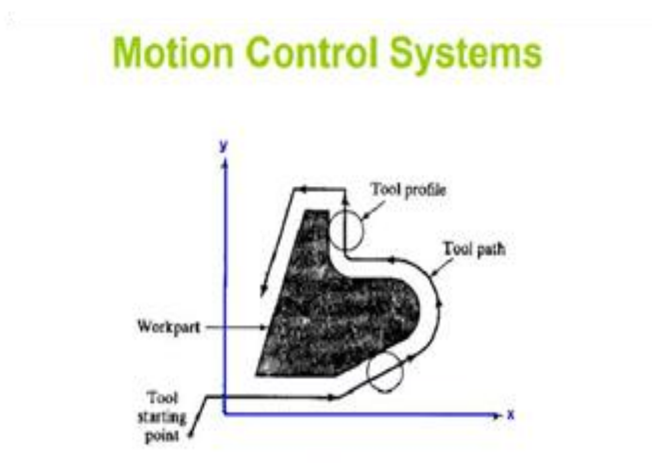
Also called positioning systems, move the worktable to a programmed location without regard for the path taken to get to that location (the path is not defined by the programmer). Once the move has been completed, some processing action is accomplished by the workhead at the location, such as drilling or punching a hole. Thus, the program consists of a series of point locations at which operations are performed, as depicted in the following Figure. Because this movement from one point to the next is nanomachining, it is made as rapid as possible.

Continuous path (Contouring) systems:

Generally refer to systems that are capable of continuous simultaneous control of two or more axes. This provides control of the tool trajectory relative to the workpart. In this case, the tool performs the process while the worktable is moving, thus enabling the system to generate angular surfaces, two-dimensional curves, or three-dimensional contours in the workpart. This control mode is required in many milling and turning operations. A simple two-dimensional profile operation is shown in the following figure to illustrate continuous path control.



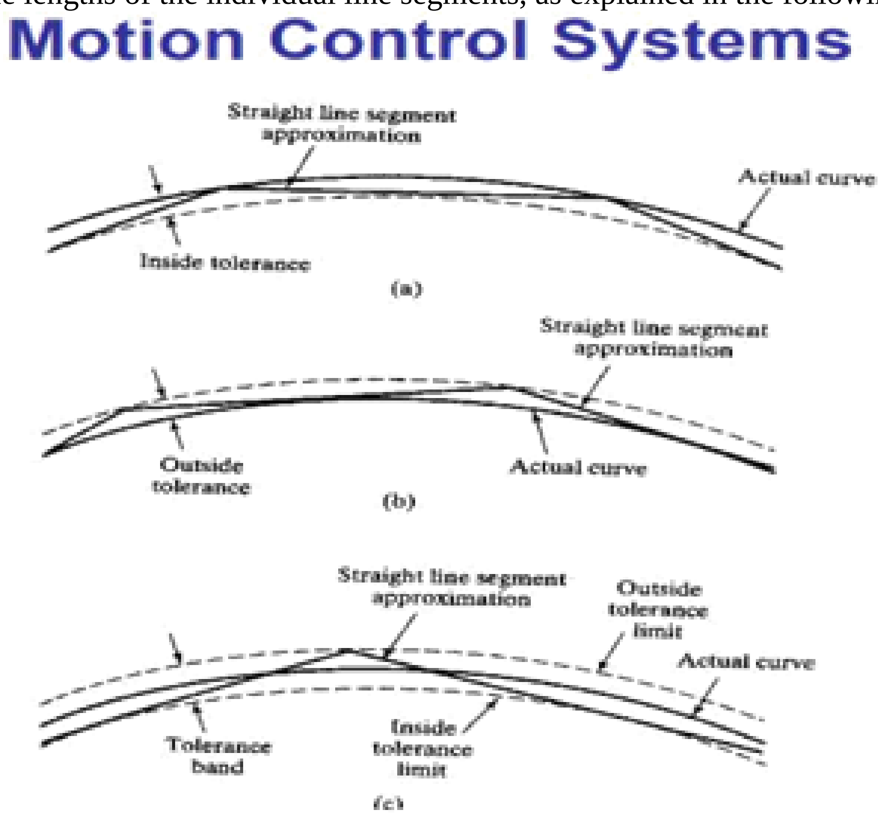
Point-to-point (positioning) control in NC. At each x-y position, table movement stops to perform the hole-drilling operation.



Continuous path (contouring) control in NC (x-y plane only). Note that cutting tool path must be offset from the part outline by a distance equal to its radius.

Interpolation Methods

One of the important aspects of contouring is interpolation. The paths that a contouring-type NC system is required to generate often consist of circular arcs and other smooth nonlinear shapes. Some of these shapes can be defined mathematically by relatively simple geometric formulas, whereas others cannot be mathematically defined except by approximation. In any case, a fundamental problem in generating these shapes using NC equipment is that they are continuous, whereas NC is digital. To cut along a circular path, the circle must be divided into a series of straight line segments that approximate the curve. The tool is commanded to machine each line segment in succession so that the machined surface closely matches the desired shape. The maximum error between the nominal (desired) surface and the actual (machined) surface can be controlled by the lengths of the individual line segments, as explained in the following figure.



Approximation of a curved path in NC by a series of straight line segments. The accuracy of the approximation is controlled by the maximum deviation (called the tolerance) between the nominal (desired) curve and the straight line segments that are machined by the NC system. In

(a) the tolerance is defined on only the inside of the nominal curve.
(b) In (b) the tolerance is defined on only the outside of the desired curve.
(c) In (c) the tolerance is defined on both the inside and outside of the desired curve.

A number of interpolation methods are available to deal with the various problems encountered in generating a smooth continuous path in contouring.
They include:
(1) linear interpolation,
(2) circular interpolation,
(3) helical interpolation,
(4) parabolic interpolation, and
(5) cubic interpolation.

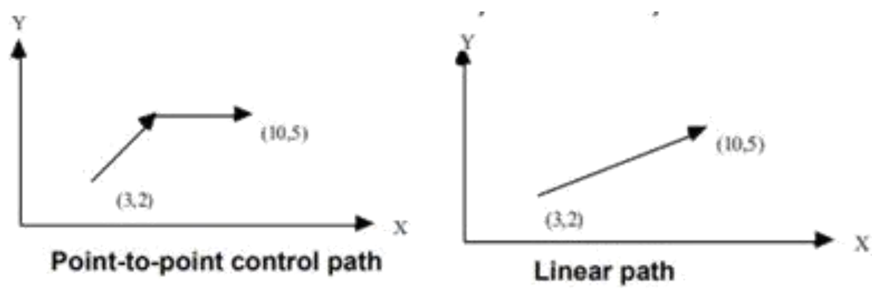
• The interpolation module in the MCU performs the calculations and directs the tool along the path. In CNC systems, the interpolator is generally accomplished by software. Linear and circular interpolators are almost always included in modern CNC systems.
CNC Interpolation
• Interpolation is performed either using software or electronically
• Interpolation performs two functions
- ➢ It computes individual drive axes to move the tool along a given path at a specified feed rate
- ➢ It generates intermediate coordinates points along a program path.

$$V_x = \frac{\Delta x}{(\Delta x^2 + \Delta y^2)^{1/2}} V_f$$

$$V_y = \frac{\Delta y}{(\Delta x^2 + \Delta y^2)^{1/2}} V_f$$

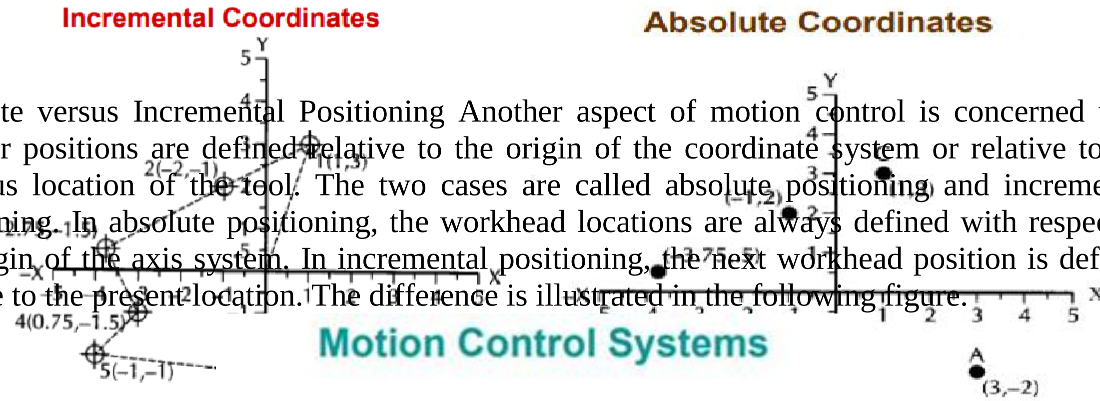
INTERPOLATION

Control multiple axes simultaneously to move on a line, a circle, or a curve.

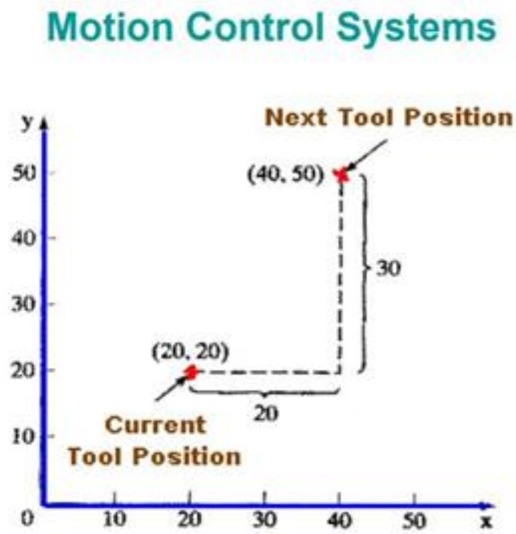


$$V_x = 6\frac{(10-3)}{\sqrt{(10-3)^2+(5-2)^2}} = 6\,\frac{7}{\sqrt{49+9}} = 5.5149$$

$$V_y = 6\frac{(5-2)}{\sqrt{(10-3)^2+(5-2)^2}} = 6\,\frac{3}{\sqrt{49+9}} = 2.3635$$



Absolute versus Incremental Positioning Another aspect of motion control is concerned with whether positions are defined relative to the origin of the coordinate system or relative to the previous location of the tool. The two cases are called absolute positioning and incremental positioning. In absolute positioning, the workhead locations are always defined with respect to the origin of the axis system. In incremental positioning, the next workhead position is defined relative to the present location. The difference is illustrated in the following figure.



Absolute versus incremental positioning The workhead is presently at point (20, 20) and is to be moved to point (40, 50). In absolute positioning, the move is specified by x=40, y=50; whereas in incremental positioning, the move is specified by x=20, y=30

Computer Numerical Control

Today, NC means computer numerical control. Computer numerical control CNC is defined as an NC system whose MCU is based on a dedicated microcomputer rather than on a hard-wired controller.

Features of CNC

1. Storage of more than one-part program
2. Various forms of program input
3. Program editing at the machine tool
4. Using programming subroutines and macros.
5. Interpolation.
6. Positioning features for setup
7. Cutter length and size compensation
8. Acceleration and deceleration calculations
9. Communication interface
10. Diagnostics

The Machine Control Unit for CNC

The MCU is the hardware that distinguishes CNC from conventional NC. The general configuration of CNC MCU

The Machine Control Unit for CNC

MCU consists of the following components and subsystems:

(1) Central processing unit
(2) Memory
(3) I/O interface
(4) Controls for machine tool axes and spindle speed
(5) Sequence controls for other machine tool functions

These subsystems are interconnected by means of a system bus.

Central Processing Unit

Manages the other components in the MCU based on software contained in memory. The CPU can be divided into three sections:

(1) Control section
(2) Arithmetic-logic unit
(3) Immediate access memory

Memory

Consists of

1. Main memory and
2. Secondary memory.

Main memory (Primary storage) consists of ROM (read-only memory) and RAM (Random access memory) devices. Operating system software and machine interface programs are generally stored in ROM. Numerical control part programs are stored in RAM devices. Current programs in RAM can be erased and replaced by new programs as jobs are changed. High-capacity secondary memory (also called auxiliary storage or secondary storage) devices are used to store large programs and data files, which are transferred to main memory as needed.

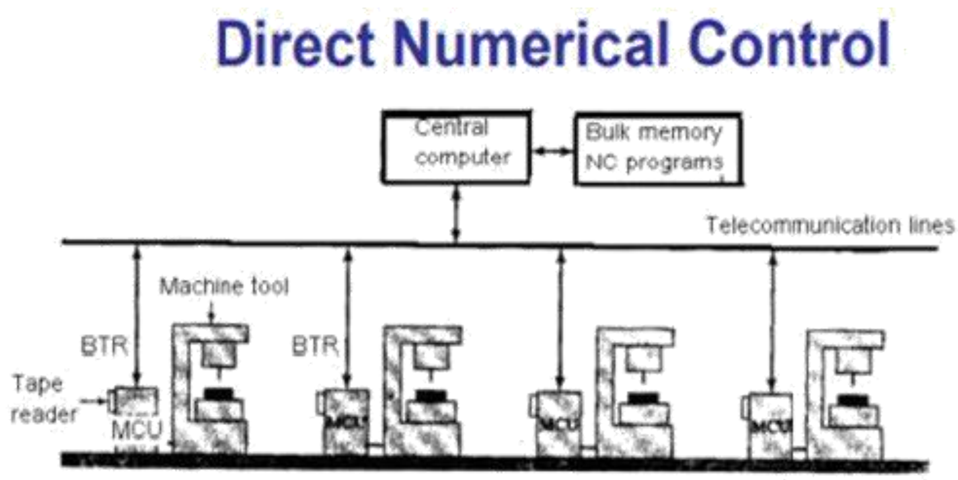
Input/Output Interface

Provides communication between the various components of the CNC system, other computer systems, and the machine operator.

Controls for Machine Tool Axes and Spindle Speed

These are hardware components that control the position and velocity (feed rate) of each machine axis as well as the rotational speed of the machine tool spindle

Sequence Controls for other Machine Tool Functions
In addition to control of table position, feed rate, and spindle speed, several additional functions are accomplished under part program control. These auxiliary functions are generally ON/OFF (binary) actuations and interlocks.



General configuration of a DNC system. Connection to MCU is behind the tape reader.
Key: BTR=behind the tape reader, MCU=machine control unit.

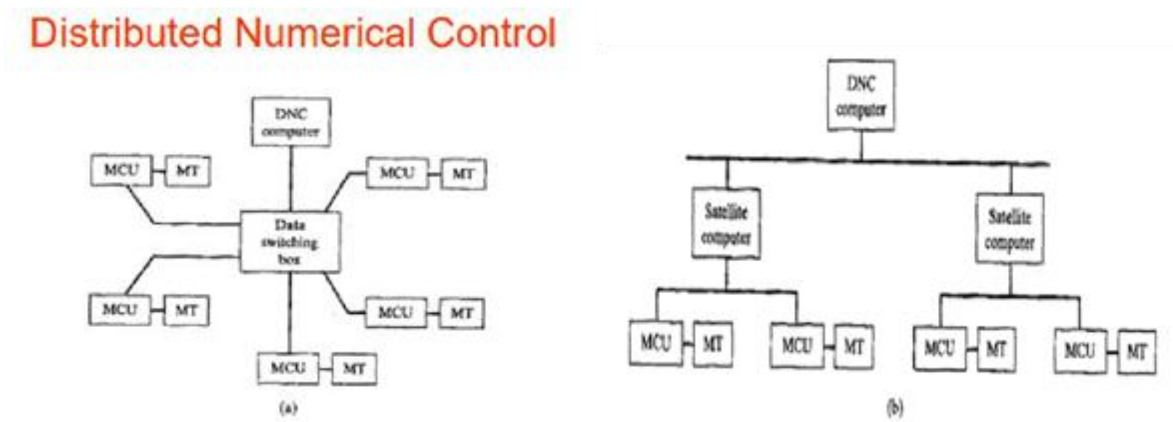
Direct Numerical Control

DNC involved the control of a number of machine tools by a single (mainframe) computer through direct connection and in real time. Instead of using a punched tape reader to enter the part program into the MCU, the program was transmitted to the MCU directly from the computer, one block of instructions at a time. This mode of operation was referred to by the name behind the tape reader BTR. The DNC computer provided instruction blocks to the machine tool on demand; when a machine needed control commands, they were communicated to it immediately. As each block was executed by the machine, the next block was transmitted. In addition to transmitting data to the machines, the central computer also received data back from the machines to indicate operating performance in the shop. Thus, a central objective of DNC was to achieve two-way communication between the machines and the central computer.

Distributed Numerical Control

Distributed Numerical Control

Distributed NC systems can take on a variety of physical configurations, depending on the number of machine tools included, job complexity, security requirements, and equipment availability and preferences. DNC permits complete part programs to be sent to the machine tools, rather than one block at a time. The switching network is the simplest DNC system to configure. It uses a data switching box to make a connection from the central computer to a given CNC machine for downloading part programs or uploading data. Local area networks have been used for DNC since the early 1980s. Various network structures are used in DNC systems, among which is the centralized structure illustrated in Figure (b). In this arrangement, the computer system is organized as hierarchy, with the central (host) computer coordinating several satellite computers that are each responsible for a number of CNC machines.



Two configurations of DNC: (a) switching network and (b) LAN.

Key: MCU=machine control unit, MT=machine tool.

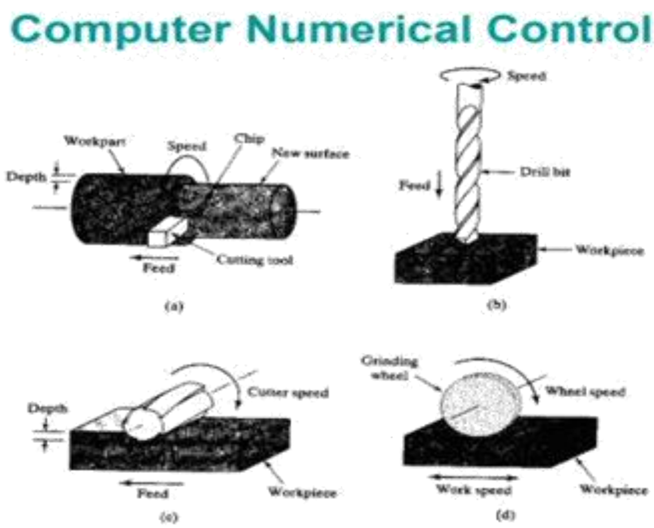
Applications of NC

Two categories: (1) machine tool applications, and (2) non-machine tool applications.

Machine tool applications are those usually associated with the metalworking industry. Non-machine tool applications comprise a diverse group of operations in other industries. Machine Tool Applications The most common applications of NC are in machine tool control. Machining was the first application of NC, and it is still one of the most important commercially.

Machining Operations and NC Machine Tools

Machining is a manufacturing process in which the geometry of the work is produced by removing excess material. By controlling the relative motion between a cutting tool and the workpiece, the desired geometry is created. There are four common types of machining operations: (a) turning, (b) drilling, (c) milling, and (d) grinding. Each of the machining operations is carried out at a certain combination of speed, feed, and depth of cut, collectively called the cutting conditions for the operation.



The four common machining operations: (a) turning, (b) drilling, (c) peripheral milling, and (c) surface grinding.

Advantages of CNC machines

CNC machines have many advantages over conventional machines. Some of them are:

1. There is a possibility of performing multiple operations on the same machine in one setup.
2. More complex part geometries are possible.
3. The scrap rate is significantly reduced because of the precision of the CNC machine and lesser operator impact.
4. It is easier to perform quality assurance by a spotcheck instead of checking all parts.
5. Production is significantly increased.
6. Shorter manufacturing lead time.

Disadvantages of CNC machines

1. They are quite expensive.
2. They have to be programmed, set up, operated, and maintained by highly skilled personnel.

Applications of NC/CNC machine tools

CNC was initially applied to metal working machinery: Mills, Drills, boring machines, punch presses etc and now expanded to robotics, grinders, welding machinery, EDM's,flame cutters and also for inspection equipment etc.

The machines controlled by CNC can be classified into the following categories:

CNC mills and machining centres.

- ✓ CNC lathes and turning centers
- ✓ CNC EDM
- ✓ CNC grinding machines
- ✓ CNC cutting machines (laser, plasma, electron, or flame)
- ✓ CNC fabrication machines (sheet metal punch press, bending machine, or press brake)
- ✓ CNC welding machines

CNC coordinate measuring machines:

A coordinate measuring machine is a dimensional measuring device, designed to move the measuring probe to determine the coordinates along the surface of the work piece. Apart from dimensional measurement, these machines are also used for profile measurement, angularity. A CMM consists of four main components: the machine, measuring probe, control system and the measuring software. The control system in a CMM performs the function of a live interaction between various machine drives, displacement transducers, probing systems and the peripheral devices. Control systems can be classified according to the following groups of CMM

Reference Points

Part programming requires establishment of some reference points. Three reference points are either set by manufacturer or user.

a) Machine Origin

The machine origin is a fixed point set by the machine tool builder. Usually it cannot be changed. Any tool movement is measured from this point. The controller always remembers tool distance from the machine origin.

b) Program Origin

It is also called home position of the tool. Program origin is point from where the tool starts for its motion while executing a program and returns back at the end of the cycle. This can be any point within the workspace of the tool which is sufficiently away from the part. In case of CNC lathe it is a point where tool change is carried out.

c) Part Origin

The part origin can be set at any point inside the machine's electronic grid system. Establishing the part origin is also known as zero shift, work shift, floating zero or datum. Usually part origin needs to be defined for each new setup. Zero shifting allow the relocation of the part. Sometimes the part accuracy is affected by the location of the part origin. the reference points on a lathe and milling machine.

Axis Designation

An object in space can have six degrees of freedom with respect to an imaginary Cartesian coordinate system. Three of them are liner movements and other three are rotary movements. Machining of simple part does not require all degrees of freedom. With the increase in degrees of freedom, complexity of hardware and programming increases.

Number of degree of freedom defines axis of machine. Axes interpolation means simultaneous movement of two or more different axes to generate required contour. For typical lathe machine degree of freedom is 2 and so it called 2 axis machines. For typical milling machine degree of freedom is, which means that two axes can be interpolated at a time and third remains independent. Typical direction for the lathe and milling machine is as shown in figure 12 and figure 13**)**

Setting up of Origin

In case of CNC machine tool rotation of the reference axis is not possible. Origin can set by selecting three reference planes X, Y and Z. Planes can be set by touching tool on the surfaces of the workpiece and setting that surfaces as X=x, Y=y and Z=z.

Coding Systems

The programmer and the operator must use a coding system to represent information, which the controller can interpret and execute. A frequently used coding system is the Binary-Coded Decimal or BCD system. This system is also known as the EIA Code set because it was developed by Electronics Industries Association. The newer coding system is ASCII and it has become the ISO code set because of its wide acceptance.

CNC Code Syntax

The CNC machine uses a set of rules to enter, edit, receive and output data. These rules are known as CNC Syntax, Programming format, or tape format. The format specifies the order and arrangement of information entered. This is an area where controls differ widely. There are rules for the maximum and minimum numerical values and word lengths and can be entered, and the arrangement of the characters and word is important. The most common CNC format is the word address format and the other two formats are fixed sequential block address format and tab sequential format, which are obsolete. The instruction block consists of one or more words. A word consists of an address followed by numerals. For the address, one of the letters from A to Z is used.

The address defines the meaning of the number that follows. In other words, the address determines what the number stands for. For example, it may be an instruction to move the tool along the X axis, or to select a particular tool. Most controllers allow suppressing the leading zeros when entering data. This is known as leading zero suppression. When this method is used, the machine control reads the numbers from right to left, allowing the zeros to the left of the significant digit to be omitted. Some controls allow entering data without using the trailing zeros.

Types of CNC codes

Preparatory codes

The term "preparatory" in NC means that it "prepares" the control system to be ready for implementing the information that follows in the next block of instructions. A **preparatory function** is designated in a program by the word address G followed by two digits. Preparatory functions are also called **G-codes** and they specify the control mode of the operation.

Miscellaneous codes

Miscellaneous functions use the address letter M followed by two digits. They perform a group of instructions such as coolant on/off, spindle on/off, tool change, program stop, or program end. They are often referred to as machine functions or **M-functions**.

In principle, all codes are either modal or non-modal. **Modal code** stays in effect until cancelled by another code in the same group. The control remembers modal codes. This gives the programmer an opportunity to save programming time.

Nonmodal code stays in effect only for the block in which it is programmed. Afterwards, its function is turned off automatically. For instance G04 is a non-modal code to program a dwell. After one second, which is say, the programmed dwell time in one particular case, this function is cancelled. To perform dwell in the next blocks, this code has to be reprogrammed. The control does not memorize the nonmodal code, so it is called as one shot codes. One-shot commands are **nonmodal**.

Commands known as "canned cycles" (a controller's internal set of preprogrammed subroutines for generating commonly machined features such as internal pockets and drilled holes) are non-modal and only function during the call.

On some older controllers, cutter positioning (axis) commands (e.g., G00, G01,G02, G03, & G04) are non-modal requiring a new positioning command to be entered each time the cutter (or axis) is moved to another location.

G –codes:

G00 - Rapid move (not cutting)
G01 - Linear move
G02 - Clockwise circular motion
G03 - Counterclockwise circular motion
G04 - Dwell
G05 - Pause (for operator intervention)
G08 - Acceleration
G09 - Deceleration
G17 - x-y plane for circular interpolation
G18 - z-x plane for circular interpolation
G19 - y-z plane for circular interpolation
G20 - turning cycle or inch data specification
G21 - thread cutting cycle or metric data specification
G24 - face turning cycle
G25 - wait for input to go low
G26 - wait for input to go high
G28 - return to reference point
G29 - return from reference point
G31 - Stop on input
G33-35 - thread cutting functions
G35 - wait for input to go low
G36 - wait for input to go high
G40 - cutter compensation cancel
G41 - cutter compensation to the left
G42 - cutter compensation to the right
G43 - tool length compensation, positive
G44 - tool length compensation, negative
G50 - Preset position
G70 - set inch based units or finishing cycle
G71 - set metric units or stock removal
G72 - indicate finishing cycle
G72 - 3D circular interpolation clockwise
G73 - turning cycle contour
G73 - 3D circular interpolation counter clockwise
G74 - facing cycle contour
G74.1 - disable 360 deg arcs
G75 - pattern repeating
G75.1 - enable 360 degree arcs
G76 - deep hole drilling, cut cycle in z-axis G77 - cut-in cycle in x-axis
G 78 - multiple threading cycle G80 - fixed cycle cancel
G81-89 - fixed cycles specified by machine tool manufacturers G81 - drilling cycle
G82 - straight drilling cycle with dwell

G83 - drilling cycle
G83 - peck drilling cycle
G84 - taping cycle
G85 - reaming cycle
G85 - boring cycle
G86 - boring with spindle off and dwell cycle
G89 - boring cycle with dwell
G90 - absolute dimension program
G91 - incremental dimensions
G92 - Spindle speed limit
G93 - Coordinate system setting
G94 - Feed rate in ipm
G95 - Feed rate in ipr
G96 - Surface cutting speed
G97 - Rotational speed rpm
G98 - withdraw the tool to the starting point or feed per minute
G99 - withdraw the tool to a safe plane or feed per revolution
G101 - Spline interpolation

M-Codes control machine functions.

M00 - program stop
M01 - optional stop using stop button
M02 - end of program
M03 - spindle on CW
M04 - spindle on CCW
M05 - spindle off
M06 - tool change
M07 - flood with coolant
M08 - mist with coolant
M08 - turn on accessory (e.g. AC power outlet)
M09 - coolant off
M09 - turn off accessory
M10 - turn on accessory
M11 - turn off accessory or tool change
M17 - subroutine end
M20 - tailstock back
M20 - Chain to next program
M21 - tailstock forward
M22 - Write current position to data file
M25 - open chuck
M25 - set output #1 off

Part Programming:

As mention earlier, a part program is a set of instructions often referred to as blocks, each of which refers to a segment of the machining operation performed by the machine tool. Each block may contain several code words in sequence.

These provide:

1. Coordinate values (X, Y, Z, etc.) to specify the desired motion of a tool relative to a work piece. The coordinate values are specified within motion codeword and related interpolation parameters to indicate the type of motion required (e.g.point-to-point, or continuous straight or continuous circular) between the start and end coordinates. The CNC system computes the instantaneous motion command signals from these code words and applies them to drive units of the machine.

2. Machining parameters such as, feed rate, spindle speed, tool number, tool offset compensation parameters etc.

3. Codes for initiating machine tool functions like starting and stopping of the spindle, on/off control of coolant flow and optional stop. In addition to these coded functions, spindle speeds, feeds and the required tool numbers to perform machining in a desired sequence are also given.

4. Program execution control codes, such as block skip or end of block codes, block number etc.

5. Statements for configuring the subsystems on the machine tool such as programming the axes, configuring the data acquisition system etc.

A typical block of a Part program is shown below in Fig. 23.7. Note that the block contains a variety of code words such G codes, M codes etc. Each of these code words configure a particular aspect of the machine, to be used during the machining of the particular segment that the block programmes.

MANUAL PART PROGRAMMING

To prepare a part program using the manual method, the programmer writes the machining instructions on a special form called a part programming manuscript. The instructions must be prepared in a very precise manner because-the typist prepares the NC tape directly from the manuscript. Manuscripts come in various forms, depending on the machine too land tape format to be used. For example, the manuscript form for a two-axis point-to-point drilling machine would be different than one for a three-axis contouring machine. The manuscript is a listing of the relative tool and workpiece locations. It also includes other data, such as preparatory commands, miscellaneous instructions, and speed/ feed specifications, all of which are needed to operate the machine under tape control. Manual programming jobs can be divided into two categories: point-to-point jobs and contouring jobs. Except for complex work parts with many holes to be drilled, manual programming is ideally suited for point-to-point applications. On the other hand, except for the simplest milling and turning jobs, manual programming can become quite time consuming for applications requiring continuous-path control of the tool. Accordingly, we shall be concerned only with manual part programming for point-to-point operations. Contouring is much more appropriate for computer- assisted part programming. The basic method of manual part programming for a point-to-point application is best demonstrated by means of an example.

COMPUTER-ASSISTED PART PROGRAMMING

The work part of Example was relatively simple. It was a suitable application for manual programming. Most parts machined on NC systems are considerably more complex. In the more complicated point-to-point jobs and in contouring applications, manual part programming becomes an extremely tedious task and subject to errors. In these instances it is much more appropriate to employ the high-speed digital computer to assist in the part programming process. Many part programming language systems have been developed to perform automatically cost of the calculations which the programmer would otherwise be forced to do. This saves time and results in a more accurate and more efficient part program.

The part programmer's job

Computer-assisted part programming, the NC procedure for preparing the tape from the engineering drawing is followed as. The machining instructions are written in English-like statements of the NC programming language, which are then processed by the computer to prepare the tape. The comter automatically punches the tape in the proper tape format for the particular C machine.

The part programmer's responsibility in computer-assisted part programming consists of two basic steps:

l. Defining the workpart geometry
2. Specifying the operation sequence and tool path

No matter how complicated the workpart may appear, it is composed of sic geometric elements. Using a relatively simple workpart to illustrate, consider e component shown in Figure. Although somewhat irregular in overall appearance, the outline, of the part consists of intersecting straight lines and a partial circle. The holes in the part can be expressed in terms of the center location and radius of the hole. Nearly any component that can be conceived by a designer can be described by points, straight lines, planes, circles, cylinders, and other mathematically defined surfaces. It is the part programmer's task to enumerate the ements out of which the part is composed. Each geometric element must be identified and the dimensions and location of the element explicitly defined.
After defining the workpart geometry, the programmer must next construct e path that the cutter will follow to machine the part. This tool path specification involves a detailed step-by-step sequence of cutter moves. The moves are made among the geometry elements, which have

previously been defined. The part programmer can use the various motion commands to direct the tool to machine along the workpart surfaces, to go to point locations, to drill holes at these locations, and so on. In addition to part geometry and tool motion statements, the programmer must also provide other instructions to operate the machine tool properly. Sample workpart, like other parts, can be defined in terms of basic geometric elements, such as points, lines, and circles.

The computer's job

The computer's job in computer-assisted part programming consists of the following steps:

l. Input translation
2. Arithmetic calculations
3. Cutter offset computation
4. Postprocessor

The sequence of these steps and their relationships to the part programmer and the machine tool are illustrated in Figure. The part programmer enters the program written in the APT or other language. The input translation component converts the coded instructions contained in the program into computer-usable form, preparatory to further processing.
The arithmetic calculations unit of the system consists of a comprehensive set of subroutines for solving the mathematics required to generate the part surface. These subroutines are called by the various part programming language statements. The arithmetic unit is really the fundamental element in the part programming package. This unit frees the programmer from the time-consuming geometry and Trigonometry calculations, to concentrate on the work part processing.

Steps in computer-assisted part programming

Cutter offset problem in part programming for contouring.
The second task of the part programmer is that of constructing the tool path. However, the actual tool path is different from the part outline because the tool is defined as the path taken by the center of the cutter. It is at the periphery of e cutter that machining takes place. The purpose of the cutter offset computations is to offset the tool path from the desired part surface by the radius of the tter. This means that The part programmer can define the exact part outline in the ometry statements. Thanks to the cutter offset calculation provided by the programming system, the programmer need not be concerned with this task. The tter offset problem is illustrated in Figure.
As noted previously, NC machine tool systems are different. They have different features and capabilities. They use different NC tape formats. Nearly all of part programming languages, including APT, are designed to be general purpose languages, not limited to one or two machine tool types. Therefore, the al task of the computer in computer-assisted part programming is to take the general instructions and make them specific to a particular machine tool system. The unit that performs this task is called a postprocessor. The postprocessor is a separate computer program that has been written to prepare the punched tape for a specific machine tool. The input to the postprocessor is output from the other three components: a series of cutter locations and

other ructions. The output of the postprocessor is the NC tape written in the correct format for the machine on which it is to be used.

Part programming languages

NC part programming language consists of a software package (computer pro) plus the special rules, conventions, and vocabulary words for using that ware. Its purpose is to make it convenient for a part programmer to communicate- the necessary part geometry and tool motion information to the computer so the desired part program can be prepared. The vocabulary words are typically English-like, to make the NC language easy to use. There have probably been over l00 NC part programming languages loped since the initial MIT research on NC programming in the mid-l95Os. of the languages were developed to meet particular needs and have not survived the test of time. Today, there are several dozen NC languages still in use. Refinements and enhancements to existing languages are continually being made. The following list provides a description of some of the important NC languages in current use.

APT (Automatically Programmed Tools). The APT language was the product of the MIT developmental work on NC programming systems. Its development began in June, l956, and it was first used in production around l959. Today it is the most widely used language in the United States. Although first intended as a contouring language, modem versions of APT can be used for both positioning and continuous-path programming in up to five axes. Versions of APT for particular processes include APTURN (for lathe operations), APTMIL (for milling and drilling operations), and APTPOINT (for point-to-point operations).

ADAPT (Adaptation of APT). Several part programming languages are based directly on the APT program. One of these is ADAPT, which was developed by IBM under Air Force contract. It was intended to provide many of the features of APT but to utilize a smaller computer. The full APT program requires a computing system that would have been considered large by the standards of the l96Os. This precluded its use by many small and medium-sized firms that did not have access to a large computer. ADAPT is not as powerful as APT, but it can be used to program for both positioning and contouring jobs.

EXAPT (Extended subset of APT). This was developed in Germany starting around l964 and is based on the APT language. There are three versions:

EXAPT I-designed for positioning (drilling and also straight-cut milling), EXAPT II- designed for turning, and EXAPT III-designed for limited contouring operations. One of the important features of EXAPT is that it attempts to compute optimum feeds and speeds automatically.

UNIAPT. The UNIAPT package represents another attempt to adapt the APT language to use on smaller computers. The name derives from the developer, the United Computing Corp. of Carson, California. Their efforts have provided a limited version of APT to be implemented on minicomputers, thus allowing many smaller shops to possess computer-assisted programming capacity.

SPLIT (Sundstrand Processing Language Internally Translated). This is a proprietary system intended for Sundstrand's machine tools. It can handle up to five- axis positioning and possesses contouring capability as well. One of the unusual features of SPLIT is that the postprocessor is built into the program. Each machine tool uses its own SPLIT package, thus obviating the need for a special postprocessor.

COMPACT II. This is a package available from Manufacturing Data Systems, Inc. (MDSI), a firm based in Ann Arbor, Michigan. The NC language is similar to SPLIT in many of its features. MDSI leases the COMPACT II system to its users on a time-sharing basis. The part programmer uses a remote terminal to feed the program into one of the MDSI computers, which in turn produces the NC tape. The COMPACT II language is one of the most widely used programming languages. MDSI has roughly 3OOO client companies which use this system.

PROMPT. This is an interactive part programming language offered by Weber N/C System, Inc., of Milwaukee, Wisconsin. It is designed for use with a variety of machine tools, including lathes, machining centers, flame cutters, and punch presses.

CINTURN II. This is a high-level language developed by Cincinnati Milacron to facilitate programming of turning operations. The most widely used NC part programming language is APT, including its derivatives (ADAPT, EXAPT, UNIAPT, etc.).

PART PROGRAMMING USING CAD/CAM

A CAD/CAM system is a computer interactive graphics system equipped with software to accomplish certain tasks in design and manufacturing functions. One of the important tasks performed on a CAD/CAM system is NC part programming. In this method of part programming, portions of the procedure usually done by the part programmer are instead done by the computer.

The two main tasks of a part programmer in a computer assisted programming are

(a) defining the part geometry and
(b) specifying the tool path.

The proposed methodology is used to automate both of these tasks. Part geometry definition: The fundamental objective of CAD/CAM system is to integrate the design engineering and manufacturing engineering functions. Certainly one of the important design functions is to design the individual components of the product. If a CAD/CAM system is used, a computer graphics model of each part is developed by the designer and stored in the CAD/CAM database. That model contains all of the geometric, dimensional and material specifications for the part. When the same CAD/CAM system, or a CAM system that has access to the same CAD database in which the part model resides, is used to perform NC part programming it makes little sense to recreate the geometry of the part during the programming procedure. Instead, the programmer has the capability to retrieve the part geometry model from the storage and to use that model to construct the appropriate cutter path. The significant advantage of using CAD/CAM in this way is that it eliminates one of the time-consuming steps in computer-assisted part programming geometry definition. After the part geometry has been retrieved, the usual procedure is to label the geometric elements that will be used during part programming. These labels are the variable names (symbols) given to the lines circles and surfaces that comprise the part. Most systems have the capacity to automatically label the geometry elements of the part and to display the labels. If the NC programmer does not have access to the data base, then the NC Programming must be defined. This is done by using similar interactive graphics techniques that the product designer would use to design the part. Points are defined in a coordinate system using the computer graphics system, lines and circles are defined from the points, surfaces are defined, and so forth, to construct a geometric model of the part. The advantage of using the interactive graphics system over conventional computer-assisted part programming is that the programmer receives immediate visual verification of the definitions being created. This tends to improve the speed and accuracy of the geometry definition process.

Tool path generation using CAD/CAM:

The second task of the NC programmer in computer-assisted part programming is tool path specification. The first step in specifying the tool path is to select the cutting tool for the operation. Most CAD/CAM systems have tool libraries that can be called by the programmer to identify what tools are available in the tool crib. The programmer must decide which of the available tools is most appropriate for the operation under consideration and specify it for the tool path. This permits the tool diameter and other dimensions to be entered automatically for tool offset calculations. If the desired cutting tool is not available in the library, an appropriate tool can be specified by the programmer. It then becomes part of the library for future use. The next step is tool path definition. There are differences in capabilities of the various CAD/CAM systems, which result in different approaches for generating the tool path. The most basic approach involves the use of the interactive graphics system to enter the motion commands one-by-one, similar to computer-assisted part programming. Individual statements in APT or other part programming language are entered and the CAD/CAM system provides an immediate graphic display of the action resulting from the command, thereby validating the statement. A more-advanced approach for generating tool path commands is to use one of the automatic software modules available on the CAD/CAM system. These modules have been developed to accomplish a number of common machining cycles for milling, drilling and turning. They are subroutines in the NC programming package that can be called and the required parameters given to execute the machining cycle. Computer-Automated part programming: In the CAD/CAM approach to NC part programming, several aspects of the procedure are automated. In the future, it should be possible to automate the complete NC part programming procedure. The proposed system is an automated system where the input is a geometric model of a part that has been defined during product design and the output is a NC part program. The system possesses sufficient logic and decision-making capability to accomplish NC part programming for the entire part without human assistance. This can most readily be done for certain NC processes that involve well-defined, relatively medium complex part geometries. Special algorithms have been developed to process the design data and generate the NC program.

INTRODUCTION

The proposed CNC module is based on the process sequence made in the previous module and on the parameters of the features as derived from the feature recognition module. The CNC code contains the geometry of the tool path and the motion of the tool specified in a definite syntax as demanded by the type of controller. The overall tool path generated for the part is a union of the individual tool paths for each feature/ operation and combined in a logical sequence. To avoid any collisions, a suitable tool retraction plane is used. Each type of operation or feature is associated with a particular type of path and motion patterns and these are stored in parametric form and are instanced whenever necessary. Once the tool path is defined it is only a matter of issuing the motion statements to describe the motion. These are also standard per feature/operation type and are stored with the parametric tool path data. The user is also provided with a choice of selecting process parameters. Tool changing statements are issued automatically but the user is advised to confirm that the suitable tool is placed in the Automatic Tool Changer (ATC) or turret. And other auxiliary statements (coolant on/off, etc) complete the program. A program in C is used to generate the NC part program. And the output of this module is stored in separate text file. This output file can be opened as an input file for the CNC machine. The simulation run is made to check for any tool hits or other difficulties. If required the user may make necessary changes in the program so as to suite his requirements. And finally the component is produced. The NC code generated in this module is suitable for the FANUC controllers. Simulation runs are carried out on the CNC machine, for the sequence of operations, for collision free tool paths and few components are also produced, to validate the proposed system. The results were found to be satisfactory.

FUNDAMENTALS OF PROGRAMMING

The CNC machine tool receives the directions for operation through a CNC program. The program is generated as per the program manuscript written for the job/operations to be carried out on the CNC machine. The program is prepared by listing the coordinate values(x, y and z) of the entire tool paths as suited to machine the complete component. The coordinate values are prefixed with preparatory codes to indicate the type of movement required like point-to-point, straight, and circular, along with coordinate values for tool path generation. Also, the co-ordinates are suffixed with miscellaneous codes for initiating spontaneous machine tool functions like start/stop, spindle/coolant, program/optional stops. In addition to these coded functions the coordinate values are supplemented with feed rate figures, spindle speed codes and tool codes, for proper selection of speeds, feeds and required cutting tools, during a particular operation. All these elements in a line of information form one meaningful command for the system/machine to execute, and is called a block of information. A number of such blocks sequentially written form a program for the particular component. Part Program: A part program contains all the information for machining a component which is given as a input to the control unit. The control unit provides the control signals at the correct time and in the correct sequence to the various drive units of the machine.

The input information required is a series of blocks; one operation requires one block. Within each block there may be different types of data.

Fundamentals of CAD/CAM

CAD/CAM is a term which means computer-aided design and computer- aided manufacturing. It is the technology concerned with the use of digital computers to perform certain functions in design and production. This technology is moving in the direction of greater integration of design and manufacturing, two activities which have traditionally been treated as distinct and separate functions in a production firm. Ultimately, CAD/CAM will provide the technology base for the computer integrated factory of the future.
Computer-aided design (CAD) can be defined as the use of computer systems to assist in the creation, modification, analysis, or optimization of a design.
The computer systems consist of the hardware and software to perform the specialized design functions required by the particular user firm. The CAD hardware typically includes the computer, one or more graphics display terminals, keyboards, and other peripheral equipment. The CAD software consists of the computer programs to implement computer graphics on the system plus application programs to facilitate the engineering functions of the user company. Examples of these application programs include stress-strain analysis of components, dynamic response of mechanisms, heat-transfer calculations, and numerical control part programming. The collection of application programs will vary from one user firm to the next because their product lines, manufacturing processes, and customer markets are different. These factors give rise to differences in CAD system requirements. Computer-aided manufacturing (CAM) can be defined as the use of computer systems to plan, manage, and control the operations of a manufacturing plant through either direct or indirect computer interface with the plant's production resources.

As indicated by the definition, the applications of computer-aided manufacturing fall into two broad categories:

1. Computer monitoring and control. These are the direct applications in which the computer is connected directly to the manufacturing process for the purpose of monitoring or controlling the process.
2. Manufacturing support applications. These are the indirect applications in which the computer is used in support of the production operations in the plant, but there is no direct interface between the computer and the manufacturing process.

The distinction between the two categories is fundamental to an understanding of computer-aided manufacturing. It seems appropriate to elaborate on our brief definitions of the two types.
Computer monitoring and control can be separated into monitoring applications and control applications. Computer process monitoring involves a direct computer interface with the manufacturing process for the purpose of observing the process and associated equipment and collecting data from the process. The computer is not used to control the operation directly. The control of the process remains in the hands of human operators, who may be guided by the information compiled by the computer. Computer process control goes one step further than monitoring by not only observing the process but also controlling it based on the observations. The distinction between monitoring and control is displayed in Figure. With computer

monitoring the flow of data between the process and the computer is in one direction only, from the process to the computer. In control, the computer interface allows for a two-way flow of data. Signals are transmitted from the process to the computer, just as in the case of computer monitoring. In addition, the computer issues command signals directly to the manufacturing process based on control algorithms contained in its software. In addition to the applications involving a direct computer-process interface for the purpose of process monitoring and control, computer-aided manufacturing also includes indirect applications in which the computer serves a support role in the manufacturing operations of the plant. In these applications, the computer is not linked directly to the manufacturing process.

Computer monitoring versus computer control:

(a) computer monitoring, (b) computer control.

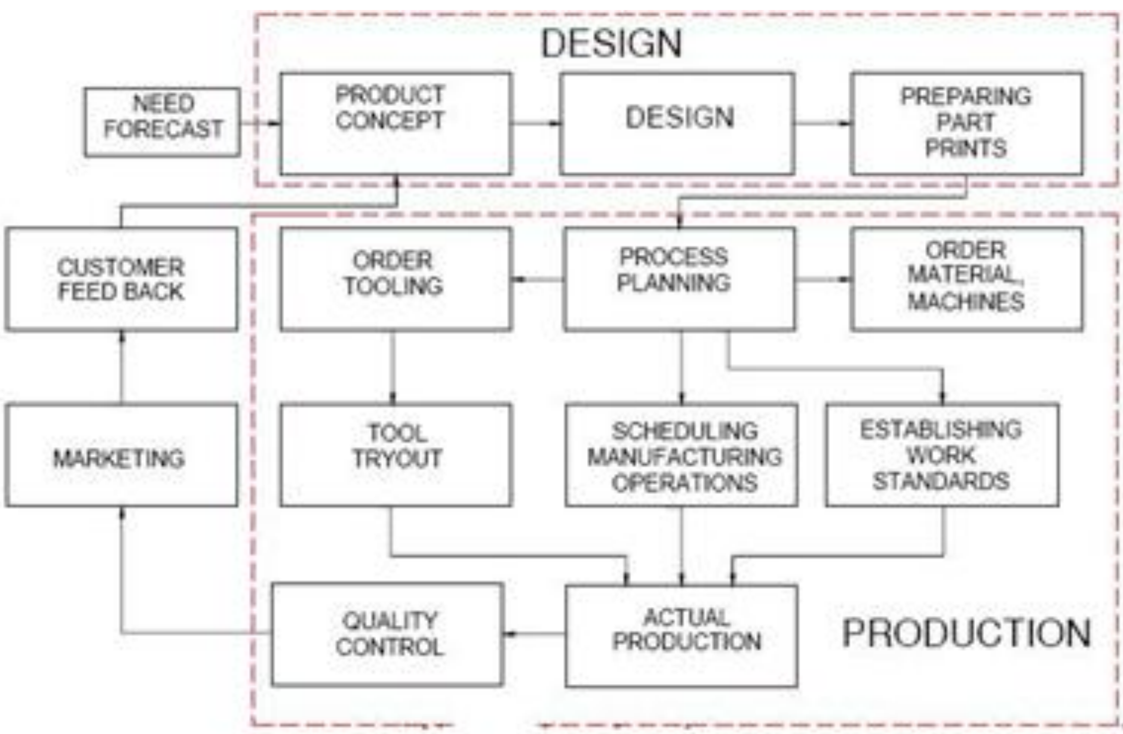
Instead, the computer is used "off-line" to provide plans, schedules, forecasts, instructions, and information by which the firm's production resources can be managed more effectively. The form of the relationship between the computer and the process is represented symbolically in Figure. Dashed lines are used to indicate that the communication and control link is an off-line connection, with human beings often required to consummate the interface.

Some examples of CAM for manufacturing support that are discussed in subsequent chapters of this book include: Numerical control part programming by computers Control programs are prepared for automated machine tools. Computer-automated process planning the computer prepares a listing of the operation sequence required to process a particular product or component. Computer-generate work standards the computer determines the time standard for a particular production operation. Production scheduling The computer determines an appropriate schedule for meeting production requirements. Material requirements planning The computer is used to determine when to order raw materials and purchased components and how many should be ordered to achieve the production schedule. Shop floor control In this CAM application, data are collected from the factory to determine progress of the various production shop orders. In all of these examples, human beings are presently required in the application either to provide input to the computer programs or to interpret the computer output and implement the required action. CAM for manufacturing support.

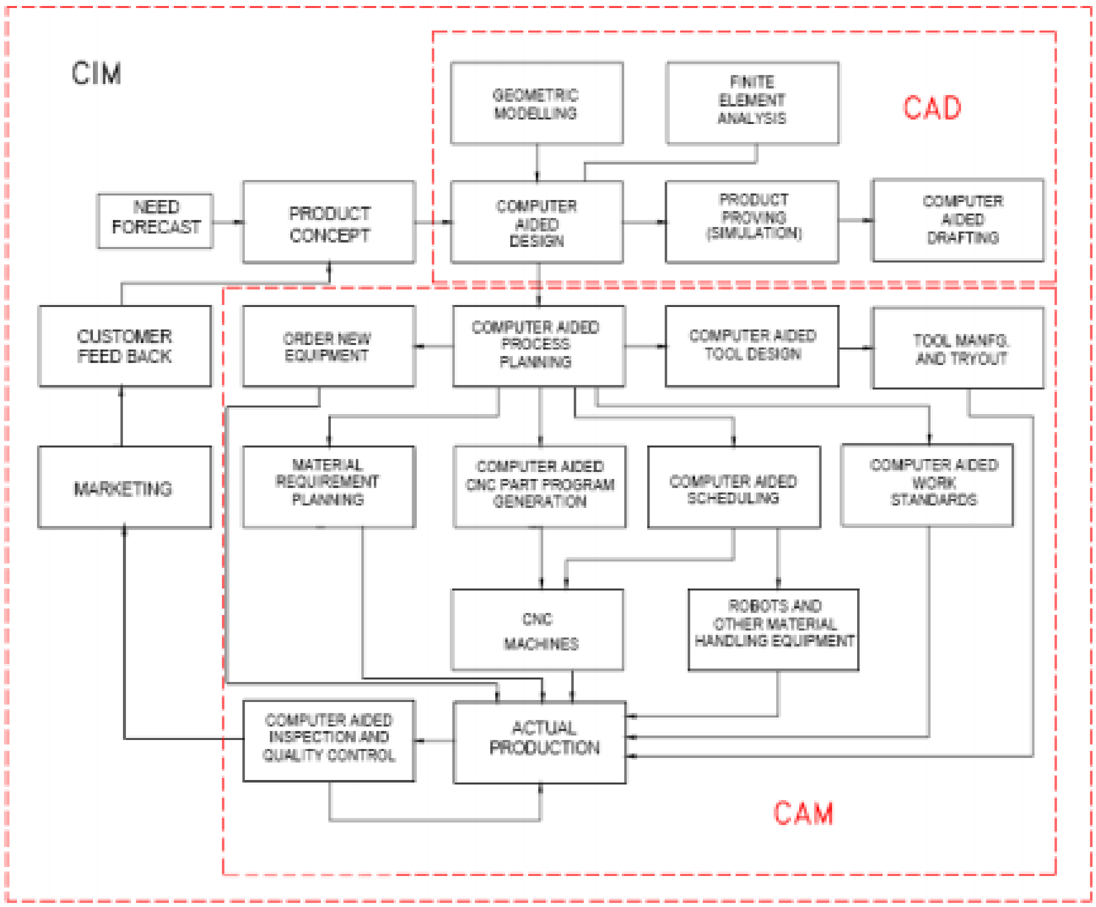
THE PRODUCT CYCLE AND CAD/CAM

A diagram showing the various steps in the product cycle is presented in Figure. The cycle is driven by customers and markets which demand the product. It is realistic to think of these as a large collection of diverse industrial and consumer markets rather than one monolithic market. Depending on the particular customer group, there will be differences in the way the product cycle is activated. In some cases, the design functions are performed by the customer and the product is manufactured by a different firm. In other cases, design and manufacturing is accomplished by the same firm. Whatever the case, the product cycle begins with a concept, an idea for a product. This concept is cultivated, refined, analyzed, improved, and translated into a plan for the product through the design engineering process. The plan is documented by drafting Ii set of engineering drawings showing how the product is made and providing a set of specifications indicating how the product should perform. Except for engineering changes which typically follow the product throughout its life cycle, this completes the design activities in Figure. The next activities involve the manufacture of the product. A process plan is formulated which specifies the sequence of production operations required to make the product. New equipment and tools must sometimes be acquired to produce the new product. Scheduling provides a plan that commits the company to the manufacture of certain quantities of the product by certain dates. Once all of these plans are formulated, the product goes into production, followed by quality testing, and delivery to the customer. A diagram showing the various steps in the product cycle is presented in Figure. The cycle is driven by customers and markets which demand the product. It is realistic to think of these as a large collection of diverse industrial and consumer markets rather than one monolithic market. Depending on the particular customer group, there will be differences in the way the product cycle is activated. In some cases, the design functions are performed by the customer and the product is manufactured by a different firm. In other cases, design and manufacturing is accomplished by the same firm. Whatever the case, the product cycle begins with a concept, an idea for a product. This concept is cultivated, refined, analyzed, improved, and translated into a plan for the product through the design engineering process. The plan is documented by drafting Ii set of engineering drawings showing how the product is made and providing a set of specifications indicating how the product should perform.

PRODUCT CYCLE IN CONVENTIONAL ENVIRONMENT



PRODUCT CYCLE IN AN COMPUTERISED ENVIRONMENT



Product cycle (design and manufacturing)

The impact of CAD/CAM is manifest in all of the different activities in the product cycle, as indicated in Figure. Computer-aided design and automated drafting are utilized in the conceptualization, design, and documentation of the product. Computers are used in process planning and scheduling to perform these functions more efficiently. Computers are used in production to monitor and control the manufacturing operations. In quality control, computers are used to perform inspections and performance tests on the product and its components.

As illustrated in Figure, CAD/CAM is overlaid on virtually all of the activities and functions of the product cycle. In the design and production operations of a modem manufacturing firm, the computer has become a pervasive, useful, and indispensable tool. It is strategically important and competitively imperative that manufacturing firms and the people who are employed by them understand CAD/CAM.

AUTOMATION AND CAD/CAM

Automation is defined as the technology concerned with the application of complex mechanical, electronic, and computer-based systems in the operation and control of production. It is the purpose of this section to establish the relationship between CAD/CAM and automation. As indicated in previous Section, there are differences in the way the product cycle is implemented for different firms involved in production.

Production activity can be divided into four main categories:

l. Continuous-flow processes

2. Mass production of discrete products

3. Batch production

4. Job shop production

The definitions of the four types are given in Table. The relationships among the four types in terms of product variety and production quantities can be conceptualized as shown in Figure.

There is some overlapping of the categories as the figure indicates. Table provides a list of some of the notable achievements in automation technology for each of the four production types. One fact that stands out from Table is the importance of computer technology in automation. Most of the automated production systems implemented today makes use of computers. This connection between the digital computer and manufacturing automation may seem perfectly logical to the reader. However, this logical connection has not always existed.

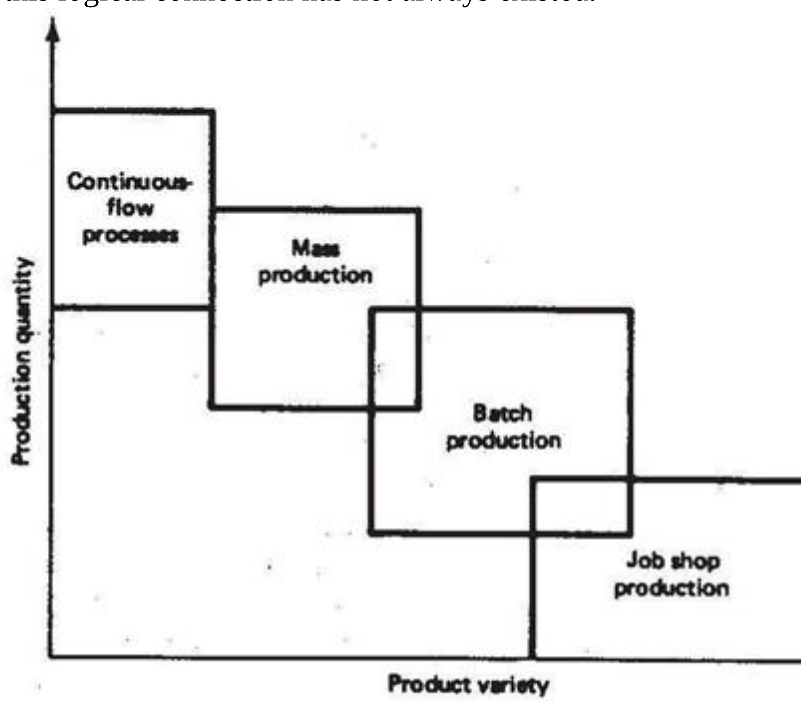


TABLE Automation Achievements for the Four Types of Production

Category	Automation achievements
l. Continuous-flow processes	Flow process from beginning to end Sensor technology available to measure important process variables Use of sophisticated control and optimization strategies Fully computer-automated plants
2. Mass production of discrete products	Automated transfer machines Dial indexing machines Partially and fully automated assembly lines Industrial robots for spot welding, parts handling, machine loading, spray painting, etc.
Automated materials handling systems Computer production monitoring	
3. Batch production 4. Job shop production	Numerical control (NC), direct numerical control (DNC), computer numerical control (CNC) Adaptive welding, parts handling, etc. Computer-integrated manufacturing systems Numerical control, computer numerical control

FUNDAMENTALS OF CAD

INTRODUCTION

The computer has grown to become essential in the operations of business, government, the military, engineering, and research. It has also demonstrated itself, especially in recent years, to be a very powerful tool in design and manufacturing. In this and the following two chapters, we consider the application of computer technology to the design of a product. This section provides an overview of computer-aided design. The CAD system defined as defined in previous section, computer-aided design involves any type of design activity which makes use of the computer to develop, analyze, or modify an engineering design. Modem CAD systems (also often called CAD/CAM systems) are based on interactive computer graphics (ICG). Interactive computer graphics denotes a user-oriented system in which the computer is employed to create, transform, and display data in the form of pictures or symbols. The user in the computer graphics design system is the designer, who communicates data and commands to the computer through any of several input devices. The computer communicates with the user via a cathode ray tube (CRT). The designer creates an image on the CRT screen by entering commands to call the desired software sub-routines stored in the computer. In most systems, the image is constructed out of basic geometric elements- points, lines, circles, and so on. It can be modified according to the commands of the designer- enlarged, reduced in size, moved to another location on the screen, rotated, and other transformations. Through these various manipulations, the required details of the image are formulated.

The typical ICG system is a combination of hardware and software. The hardware includes a central processing unit, one or more workstations (including the graphics display terminals), and peripheral devices such as printers. Plotters, and drafting equipment. Some of this hardware is shown in Figure. The software consists of the computer programs needed to implement graphics processing on the system. The software would also typically include additional specialized application programs to accomplish the particular engineering functions required by the user company. It is important to note the fact that the ICG system is one component of a computer-aided design system. As illustrated in Figure, the other major component is the human designer. Interactive computer graphics is a tool used by the designer to solve a design problem. In effect, the ICG system magnifies the powers of the designer. This has been referred to as the synergistic effect. The designer performs the portion of the design process that is most suitable to human intellectual skills (conceptualization, independent thinking); the computer performs the task: best suited to its capabilities (speed of calculations, visual display, storage of large 8IWWIts of data), and the resulting system exceeds the sum of its components.

There are several fundamental reasons for implementing a computer-aided design system.

l. To increase the productivity of the designer. This is accomplished by helping the designer to the product and its component subassemblies and parts; and by reducing the time required in synthesizing, analyzing, and documenting the design. This productivity improvement translates not only into lower design cost but also into shorter project completion times.

2. To improve the quality of design. A CAD system permits a more thorough engineering analysis and a larger number of design alternatives can be investigated. Design errors are also reduced through the greater accuracy provided by the system. These factors lead to a better design.

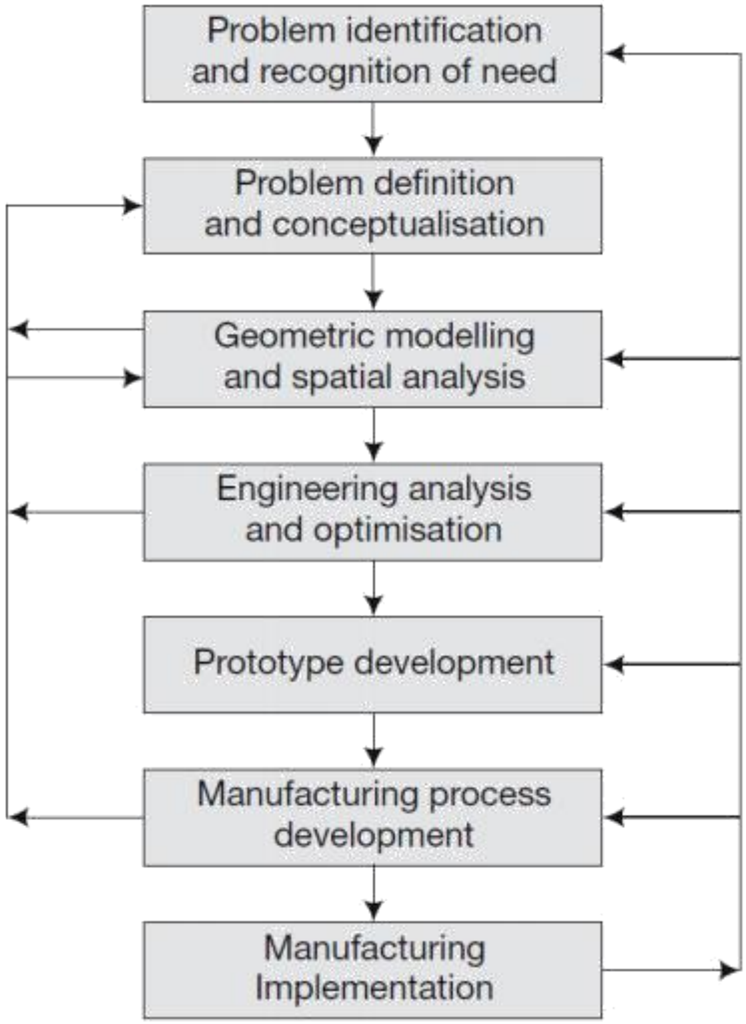
3. To improve communications. Use of a CAD system provides better engineering drawings, more standardization in the drawings, better documentation of the design, fewer drawing errors and greater legibility.

4. To create a database for manufacturing. In the process of creating the documentation for the product design (geometries and dimensions of the product and its components, material specifications for components, bill of materials, etc.), much of the required database to manufacture the product is also created.

THE DESIGN PROCESS

Before examining the several facets of computer-aided design, let us first consider the general design process. The process of designing something is characterized by Shigley as an iterative procedure, which consists of six identifiable steps or phases:-

l. Recognition of need 2. Definition of problem 3. Synthesis 4. Analysis and optimization 12 5. Evaluation 6. Presentation



Recognition of need involves the realization by someone that a problem exists for which some corrective action should be taken. This might be the identification of some defect in a current machine design by an engineer or the perception of a new product marketing opportunity by a salesperson. Definition of the problem involves a thorough specification of the item to be designed. This specification includes physical and functional characteristics, cost, quality, and operating performance. Synthesis and analysis are closely related and highly interactive in the design process. A certain component or subsystem of the overall system is conceptualized by the designer, subjected to analysis, improved through this analysis procedure, and redesigned. The process is repeated until the design has been optimized within the constraints imposed on the designer.

The components and subsystems are synthesized into the final overall system in a similar interactive manner. Evaluation is concerned with measuring the design against the specifications established in the problem definition phase. This evaluation often requires the fabrication and testing of a prototype model to assess operating performance, quality, reliability, and other criteria. The final phase in the design process is the presentation of the design. This includes documentation of the design by means of drawings, material specifications, assembly lists, and so on. Essentially, the documentation requires that a design database be created. Figure illustrates the basic steps in the design process, indicating its iterative nature.

Engineering design has traditionally been accomplished on drawing boards, with the design being documented in the form of a detailed engineering drawing. Mechanical design includes the drawing of the complete product as well as its components and subassemblies, and the tools and fixtures required to manufacture the product. Electrical design is concerned with the preparation of circuit diagrams, specification of electronic components, and so on. Similar manual documentation is required in other engineering design fields (structural design, aircraft design, chemical engineering design, etc.).

In each engineering discipline, the approach has traditionally been to synthesize a preliminary design manually and then to subject that design to some form of analysis. The analysis may involve sophisticated engineering calculations or it may involve a very subjective judgment of the aesthete appeal possessed by the design. The analysis procedure identifies certain improvements that can he made in the design. As stated previously, the process is iterative. Each iteration yields an improvement in the design. The trouble with this iterative process is that it is time consuming. Many engineering labor hours are required to complete the design project.

THE APPLICATION OF COMPUTERS FOR DESIGN

The various design-related tasks which are performed by a modem computer-aided design-system can be grouped into four functional areas:

l. Geometric modeling
2. Engineering analysis
3. Design review and evaluation
4. Automated drafting

BENERTS OF COMPUTER-AIDED DESIGN

There are many benefits of computer-aided design, only some of which can be easily measured. Some of the benefits are intangible, reflected in improved work quality, more pertinent and usable information, and improved control, all of which are difficult to quantify. Other benefits are tangible, but the savings from them show up for downstream in the production process, so that it is difficult to assign a dollar figure to them in the design phase. Some of the benefits that derive from implementing CAD/CAM can be directly measured.

Introduction to Computer Integrated Manufacturing (CIM)

Computer-integrated manufacturing (CIM) is the manufacturing approach of using computers to control the entire production process. This integration allows individual processes to exchange information with each other and initiate actions. Through the integration of computers, manufacturing can be faster and less error-prone, although the main advantage is the ability to create automated manufacturing processes.

Role of Computer in Manufacturing

The computer has had a substantial impact on almost all activities of a factory. The operation of a **CIM system gives the user substantial benefits:**

- Reduction of design costs by 15-30%;
- Reduction of the in-shop time of a part by 30-60%;
- Increase of productivity by 40-70%;
- Better product quality, reduction of scrap 20-50%.

Manufacturing Method

As a method of manufacturing, three components distinguish CIM from other manufacturing methodologies:

- Means for data storage, retrieval, manipulation and presentation;
- Mechanisms for sensing state and modifying processes;
- Algorithms for uniting the data processing component with the sensor/modification component.

CIM is an example of the implementation of Information and Communication Technologies(ICTs)in manufacturing.

CIM is a manufacturing approach that provides a complete automation of a manufacturing facility. All the operations are controlled by computers and have a common storage and distribution. The various processes involved in a CIM are listed as follows:

- Computer-aided design
- Prototype manufacture
- Determining the efficient method for manufacturing by calculating the costs and considering the production methods, volume of products, storage and distribution

- Ordering of the necessary materials needed for the manufacturing process
- Computer-aided manufacturing of the products with the help of computer numerical controllers
- Quality controls at each phase of the development.
- Product assembly with the help of robots
- Quality check and automated storage
- Automatic distribution of products from the storage areas to awaiting lorries/trucks
- Automatic updating of logs, financial data and bills in the computer system

CIM is a combination of different applications and technologies like CAD, CAM, computer-aided engineering, robotics, manufacturing resource planning and enterprise management solutions. It can also be considered as an integration of all enterprise operations that work with a common data repository.

The major components of CIM are as follows:

- Data storage, retrieval, manipulation and presentation mechanisms
- Real-time sensors for sensing the current state and for modifying processes
- Data processing algorithms

The Computer Integrated Manufacturing Open System Architecture (CIMOSA) was proposed in 1990 by the AMCIE consortium to provide an open systems architecture that specifies both enterprise modeling and enterprise integration required by CIM environments.

The CIM approach has found a wide range of applications in industrial and production engineering, mechanical engineering and electronic design automation. CIM increases the manufacturing productivity and lowers the total cost of manufacturing. It also offers great flexibility, quality and responsiveness.

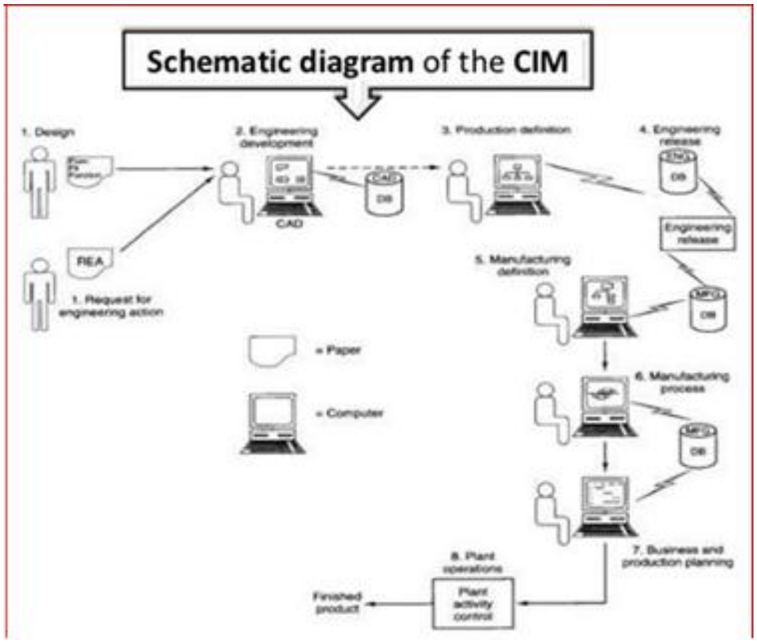
Devices and Equipment used in CIM
CNC, DNC, PNC
Other Devices
1. Robotics
2. Computers
3. Software
4. Controllers
5. Networks & Interfacing

Technologies in CIM

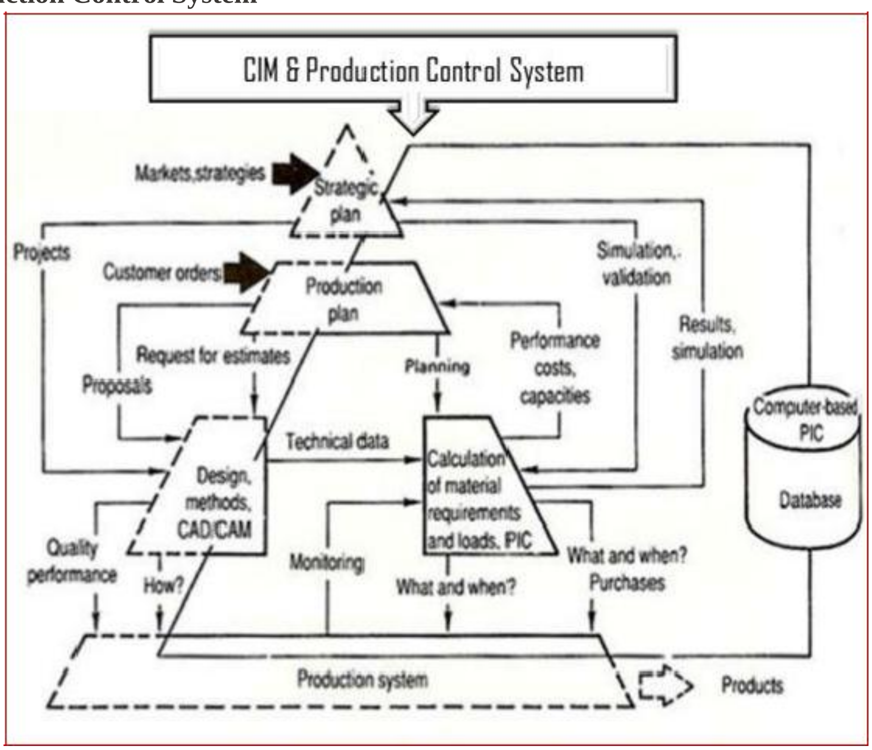
1. FMS (Flexible Manufacturing System)
2. ASRS (Automated Storage and Retrieval System)
3. AGV (Automated Guided Vehicle)
4. Automated conveyance systems & Robotics

5. Variable Mission Mfg. (VMM)
6. Computerized Mfg. System (CMS)

Schematic diagram of the CIM



CIM & Production Control System



Key challenges

There are three major challenges for the development of a smoothly operating computer-integrated manufacturing system:

Integration of components from different suppliers: When different machines, such as CNC, conveyors and robots, are using different communications protocols. In the case of AGVs (automated guided vehicles), even differing lengths of time for charging the batteries may cause problems.

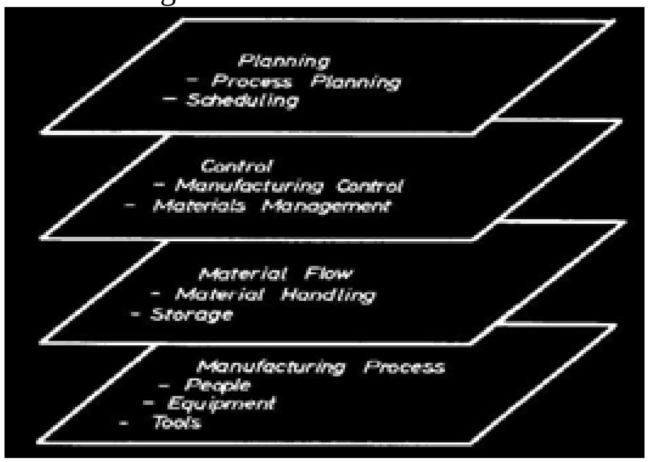
Data integrity: The higher the degree of automation, the more critical is the integrity of the data used to control the machines. While the CIM system saves on labor of operating the machines, it requires extra human labor in ensuring that there are proper safeguards for the data signals that are used to control the machines.

Process control: Computers may be used to assist the human operators of the manufacturing facility, but there must always be a competent engineer on hand to handle circumstances which could not be foreseen by the designers of the control software.

Subsystems in computer-integrated manufacturing

- CAD (Computer-Aided Design) involves the use of computers to create design drawings and product models.
- CAE (Computer-Aided Engineering) is the broad usage of computer software to aid in engineering tasks.
- CAM (Computer-Aided Manufacturing) is the use of computer software to control machine tools and related machinery in the manufacturing of work pieces.
- CAPP (Computer-Aided Process Planning) is the use of computer technology to aid in the process planning of apart or product, in manufacturing.
- CAQ (Computer-Aided Quality Assurance) is the engineering application of computers and computer controlled machines for the inspection of the quality of products.
- PPC (Production Planning and Control) A production (or manufacturing) planning and control (MPC) system is concerned with planning and controlling all aspects of manufacturing, including materials, scheduling machines and people, and coordinating suppliers and customers.
- ERP (Enterprise Resource Planning) systems integrate internal and external management information across an entire organization, embracing finance/accounting, manufacturing, and sales and services.

Four-Plan Concept of Manufacturing



CIM System discussed:

• Computer Numerical Control (CNC)
• Direct Numerical Control (DNC)
• Computer Process Control
• Computer Integrated Production Management
• Automated Inspection Methods
• Industrial Robots etc.

A CIM System consists of the following basic components:

I Machine tools and related equipment
II. Material Handling System (MHS)
III. Computer Control System
IV. Human factor/labor

CIMS Benefits:

1. Increased machine utilization
2. Reduced direct and indirect labor
3. Reduce mfg. lead time
4. Lower in process inventory
5. Scheduling flexibility, etc.

CIM refers to a production system that consists of:

1. A group of NC machines connected together by

2. An automated materials handling system

3. And operating under computer control

4.

Advantages	Disadvantages
➢ Responsiveness to shorter product life cycles	➢ Unfamiliar technologies used.
➢ Better process control emphasizes product quality and uniformity.	➢ Requires major change in corporate culture.
➢ Supports and co-ordinates exchange of information	➢ Reduction in short term profit.
➢ Designs components for machines.	➢ Perceived risk is high.
➢ Decreases the cost of production and maintenance	➢ High maintenance cost and expensive implementation.

COMPUTER-AIDED PROCESS PLANNING

THE PLANNING FUNCTION

Process planning is concerned with determining the sequence of individual manufacturing operations needed to produce a given part or product. The resulting operation sequence is documented on a form typically referred to as a route sheet. The route sheet is a listing of the production operations and associated machine tools for a workpart or assembly. Closely related to process planning are the functions of determining appropriate cutting conditions for the machining operations and setting the time standards for the operations. All three functions-planning the process, determining the cutting conditions, and setting the time standards-have traditionally been carried out as tasks with a very high manual and clerical content. They are also typically routine tasks in which similar or even identical decisions are repeated over and over. Today, these kinds of decisions are being made with the aid of computers. In the first four sections of this chapter we consider the process planning function and how computers can be used to perform this function.

Traditional process planning

There are variations in the level of detail found in route sheets among different companies and industries. In the one extreme, process planning is accomplished by releasing the part print to the production shop with the instructions make to drawing. Most firms provide a more detailed list of steps describing each operation and identifying each work center. In any case, it is traditionally the task of the manufacturing engineers or industrial engineers in an organization to write these process plans for new part designs to be produced by the shop.

The process planning procedure is very much dependent on the experience and judgment of the planner. It is the manufacturing engineer's responsibility to determine an optimal routing for each new part design. However, individual engineers each have their own opinions about what constitutes the best routing. Accordingly, there are differences among the operation sequences developed by various planners. We can illustrate rather dramatically these differences by means of an example. In one case cited, a total of 42 different routings were developed for various sizes of a relatively simple part called an "expander sleeve." There were a total of 64 different sizes and styles, each with its own part number. The 42 routings included 2O different machine tools in the shop.

The reason for this absence of process standardization was that many different individuals had worked on the parts: 8 or 9 manufacturing engineers, 2 planners, and 25 NC part programmers. Upon analysis, it was determined that only two different routings through four machines were needed to process the 64 part numbers. It is clear that there are potentially great differences in the perceptions among process planners as to what constitutes the "optimal" method of production. In addition to this problem of variability among planners, there are often difficulties in the conventional process planning procedure. New machine tools in the factory render old routings less than optimal. Machine breakdowns force shop personnel to use temporary routings, and these become the documented routings even after the machine is repaired. For these reasons and others, a significant proportion of the total number of process plans used in manufacturing are not optimal.

Automated process planning

Because of the problems encountered with manual process planning, attempts have been made in recent years to capture the logic, judgment, and experience required for this important function and incorporate them into computer programs. Based on the characteristics of a given part, the program automatically generates the manufacturing operation sequence. A computer-aided process planning (CAPP) system offers the potential for reducing the routine clerical work of manufacturing engineers. At the same time, it provides the opportunity to generate production routings which are rational, consistent, and perhaps even optimal. Two alternative approaches to computer-aided process planning have been developed. These are:

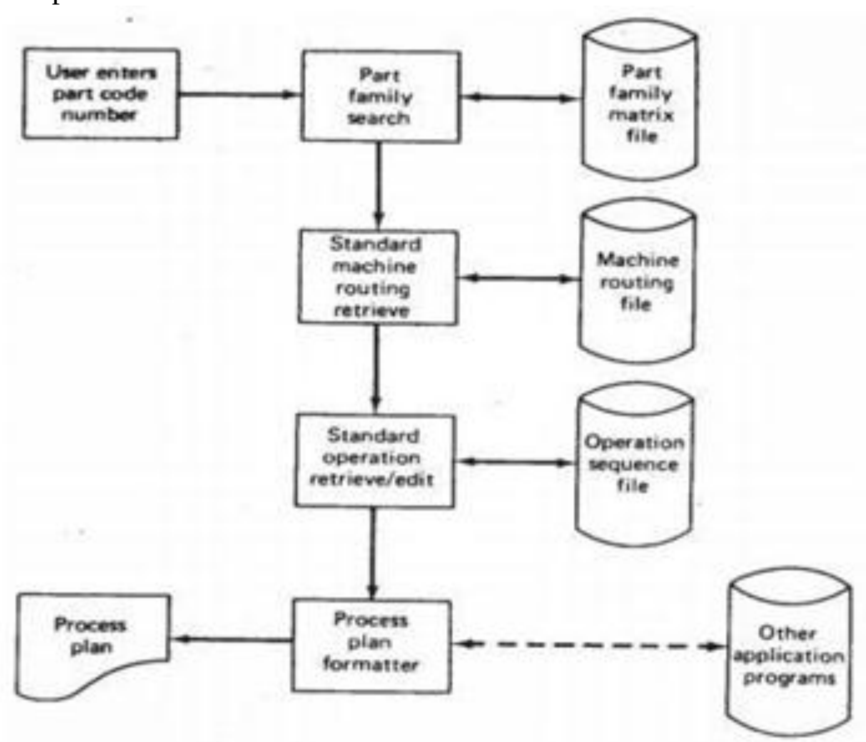
l. Retrieval-type CAPP systems (also called variant systems)

2. Generative CAPP systems The two types are described in the following two sections.

RETRIEVAL - TYPE PROCESS PLANNING SYSTEMS

Retrieval-type CAPP systems use parts classification and coding and group technology as a foundation. In this approach, the parts produced in the plant are grouped into part families, distinguished according to their manufacturing characteristics. For each part family, a standard process plan is established. The standard process plan is stored in computer files and then retrieved for new workparts which belong to that family. Some form of parts classification and coding system is required to organize the computer files and to permit efficient retrieval of the appropriate process plan for a new workpart. For some new parts, editing of the existing process plan may be required. This is done when the manufacturing requirements of the new part are slightly different from the standard. The machine routing may be the same for the new part, but the specific operations required at each machine may be different.

The complete process plan must document the operations as well as the sequence of machines through which the part must be routed. Because of the alterations that are made in the retrieved process plan, these CAPP systems are sometimes also called by the name' 'variant system." Figure will help to explain the procedure used in a retrieval process planning system. The user would initiate the procedure by entering the part code number at a computer terminal. The CAPP program then searches the part family matrix file to determine if a match exists. If the file contains an identical code number, the standard machine routing and operation sequence are retrieved from the respective computer files for display to the user. The standard process plan is examined by the user to permit any necessary editing of the plan to make it compatible with the new part design. After editing, the process plan formatter prepares the paper document in the proper form. If an exact match cannot be found between the code numbers in the computer file and the code number for the new part, the user may search the machine routing file and the operation sequence file for similar parts that could be used to develop the plan for the new part. Once the process plan for a new part code number has been entered, it becomes the standard process for future parts of the same classification.



Information flow in a retrieval-type computer-aided process planning

In Figure the machine routing file is distinguished from the operation sequence file to emphasize that the machine routing may apply to a range of different part families and code numbers. It would be easier to find a match in the machine routing file than in the operation sequence file. Some CAPP retrieval sys terns would use only one such file which would be a combination of operation sequence file and machine routing file. The process plan formatter may use other application programs. These could include programs to compute machining conditions, work standards, and standard costs. Standard cost programs can be used to determine total product costs for pricing purposes. A number of retrieval-type computer-aided process planning systems have been developed. These include MIPLAN, one of the MICLASS modules [6,2O] the CAPP system developed by Computer-Aided Manufacturing-International [l], COMCAPP V by MDSI, and systems by individual companies [lO]. We will use MIPLAN as an example to illustrate these industrial systems.

GENERATIVE PROCESS PLANNING SYSTEMS

Generative process planning involves the use of the computer to create an individual process plan from scratch, automatically and without human assistance. The computer would employ a set of algorithms to progress through the various technical and logical decisions toward a final plan for manufacturing. Inputs to the ~ tern would include a comprehensive description of the workpart. This may involve the use of some form of part code number to summarize the workpart data, but does not involve the retrieval of existing standard plans. Instead, the general CAPP system synthesizes the design of the optimum process sequence, based an analysis of part geometry, material, and other factors which would influence manufacturing decisions. In the ideal generative process planning package, any part design could have presented to the system for creation of the optimal plan. In practice, cu generative- type systems are far from universal in their applicability. They term fall short of a truly generative capability, and they are developed for some limited range of manufacturing processes. We will illustrate the generative process planning approach by means system called GENPLAN developed at Lockheed-Georgia Company BENEFITS OF CAPP Whether it is a retrieval system or a generative system, computer-aided process planning offers a number of potential advantages over manually oriented process planning.

l. Process rationalization. Computer-automated preparation of operation routings is more likely to be consistent, logical, and optimal than its manual counterpart. The process plans will be consistent because the same computer software is being used by all planners. We avoid the tendency for drastically different process plans from different planners. The process plans tend to be more logical and optimal because the company has presumably incorporated the experience and judgment of its best manufacturing people into the process planning computer software.

2. Increased productivity of process planners. With computer-aided process planning, there is reduced clerical effort, fewer errors are made, and the planners have immediate access to the process planning data base. These benefits translate into higher productivity of 131 the process planners. One system was reported to increase productivity by 6OO% in the process planning function [lO].

3. Reduced turnaround time. Working with the CAPP system, the process planner is able to prepare a route sheet for a new part in less time compared to manual preparation. "Ibis leads to an overall reduction in manufacturing lead time.

4. Improved legibility. The computer-prepared document is neater and easier to read than manually written route sheets. CAPP systems employ standard text, which facilitates interpretation of the process plan in the factory.

5. Incorporation of other application programs. The process planning system can be designed to operate in conjunction with other software packages to automate many of the time-consuming manufacturing support functions.

Diagram of Generative process Plan