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ME1252 – MANUFACTURING TECHNOLOGY – II

IV SEMESTER MECHANICAL ENGINEERING

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UNIT I
THEORY OF METAL CUTTING

Introduction – Material removal processes – Types of machine tools – Theory of metal cutting – Chipformation – Orthogonal cutting – Cutting tool materials – Tool wear – Tool life – Surface finish –Cutting fluids.

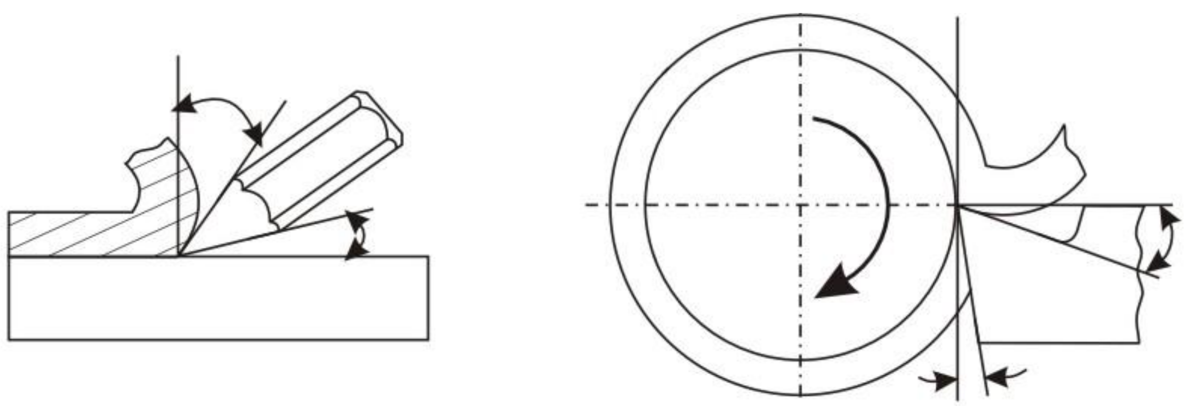
Geometry of single point turning tools

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

(i) 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



(i) Benefit of knowing and purpose of determining cutting forces.

The aspects of the cutting forces concerned:

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

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

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

(ii) Cutting force components and their significances

The single point cutting tools being used for turning, shaping, planing, slotting, boring etc. are characterised 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. 8.1 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

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. 5.5 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. 5.5.

Machining of brittle material produces discontinuous chips and mostly of irregular size and shape. The process of forming such chips is schematically

(i) 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.

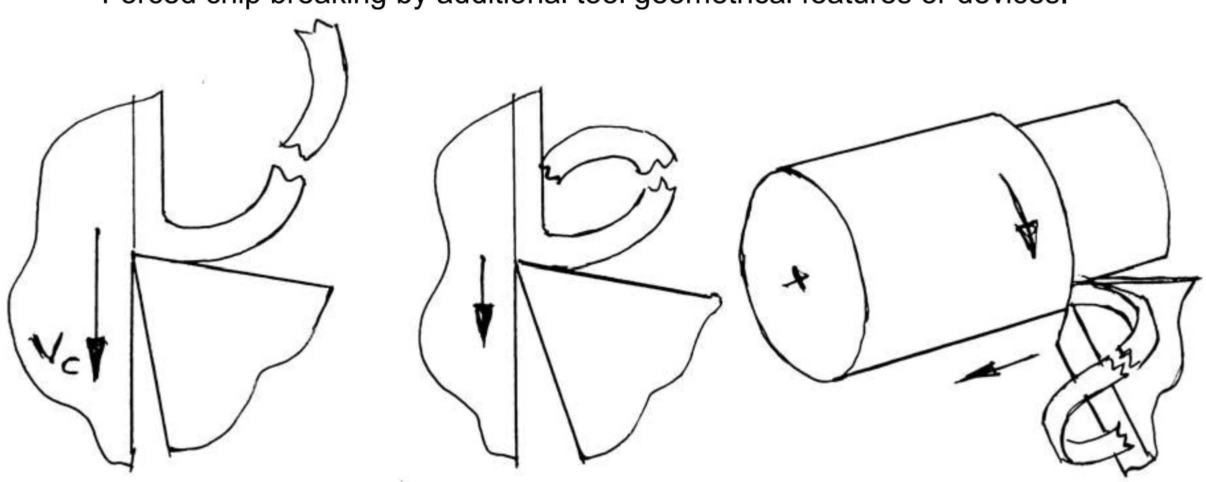
(ii) Principles of chip-breaking

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 :

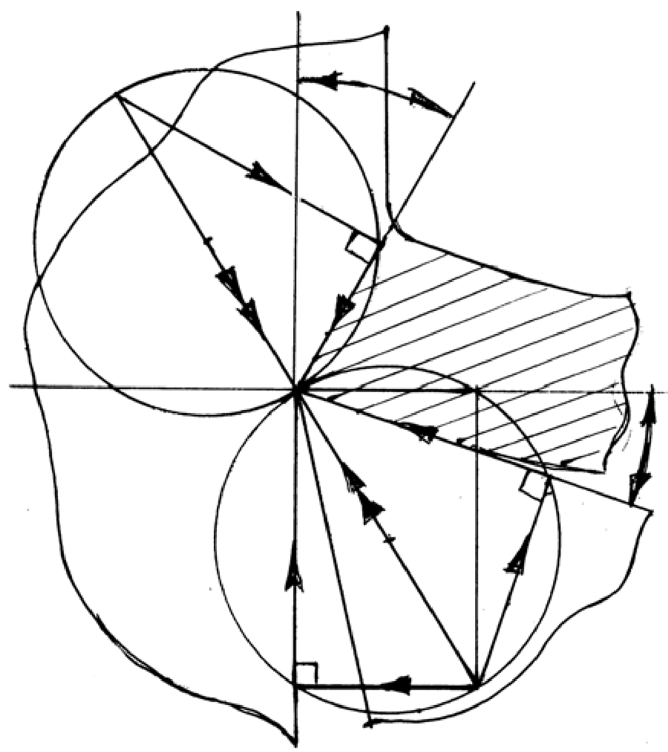
- Self breaking

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



(iii) Merchant's Circle Diagram and its use

In orthogonal cutting when the chip flows along the orthogonal plane, π_O, the cutting force (resultant) and its components P_Z and P_{XY} remain in the orthogonal plane. Fig. 8.5 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.



The circle(s) drawn taking R or R_1 as diameter 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.

Essential properties for 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:

i) high mechanical strength; compressive, tensile, and TRA

ii) fracture toughness – high or at least adequate

iii) high hardness for abrasion resistance

iv) high hot hardness to resist plastic deformation and reduce wear rate at elevated temperature

v) chemical stability or inertness against work material, atmospheric gases and cutting fluids

vi) resistance to adhesion and diffusion

vii) thermal conductivity – low at the surface to resist incoming of heat and high at the core to quickly dissipate the heat entered

viii) high heat resistance and stiffness

ix) manufacturability, availability and low cost.

iv)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.

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 that 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. 3.3.1 Version.

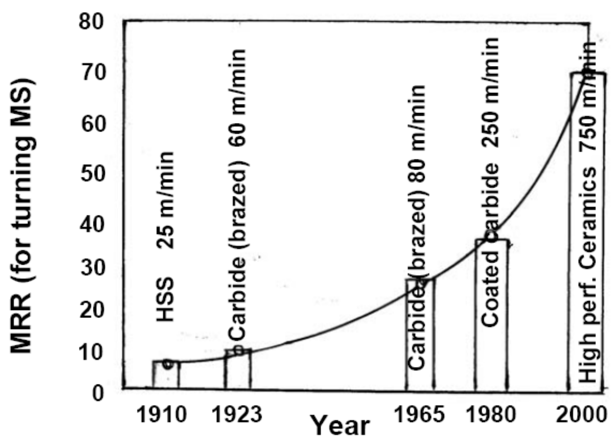


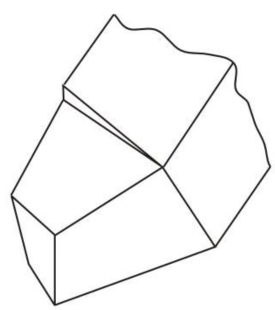
Fig. 3.3.1 *Productivity raised by cutting tool materials.*

Definition - •

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

clearance angle (α): Angle of inclination of clearance or flank surface
from the finished surface

Rake angle is provided for ease of chip flow and overall machining. Rake angle maybe positive, or negative or even zero



(i) Mechanism of chip formation in machining

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

- fulfill its basic functional requirements
- provide better or improved performance
- render long service life.

Machining is a process of gradual removal of excess material from the preformed blanks in the form of chips.

The form of the chips is an important index of machining because it directly or indirectly indicates:

- Nature and behaviour of the work material under machining condition

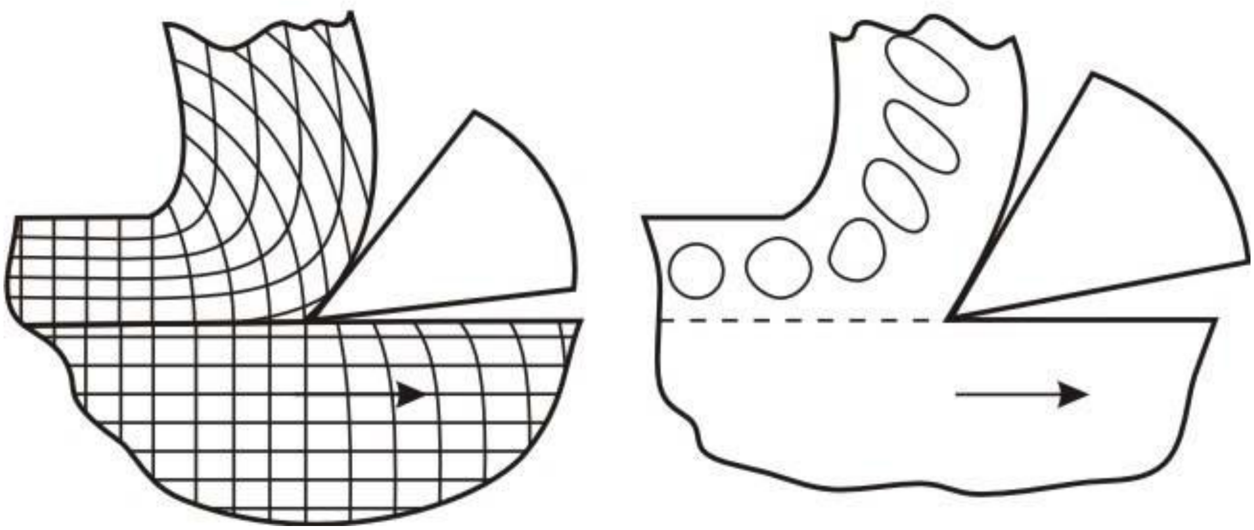
- Specific energy requirement (amount of energy required to remove unit volume of work material) in machining work
- Nature and degree of interaction at the chip-tool interfaces.

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.

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:

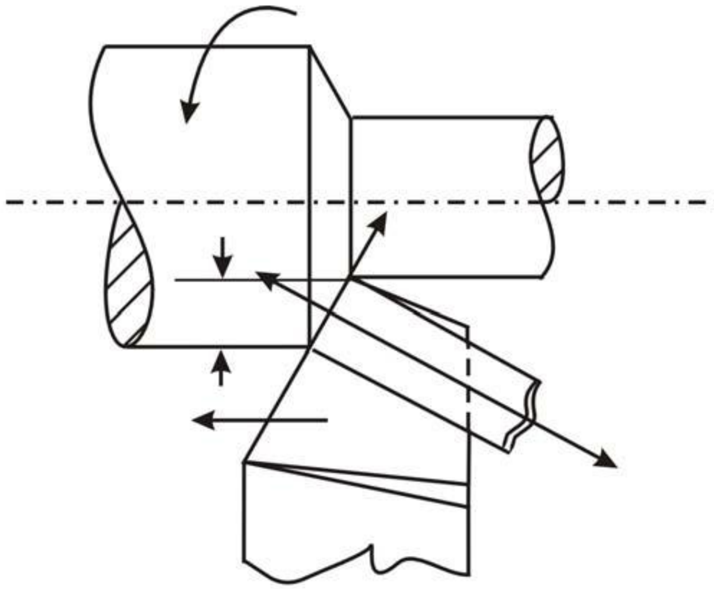
- Study of deformation of rectangular or circular grids marked on the side surface as shown in



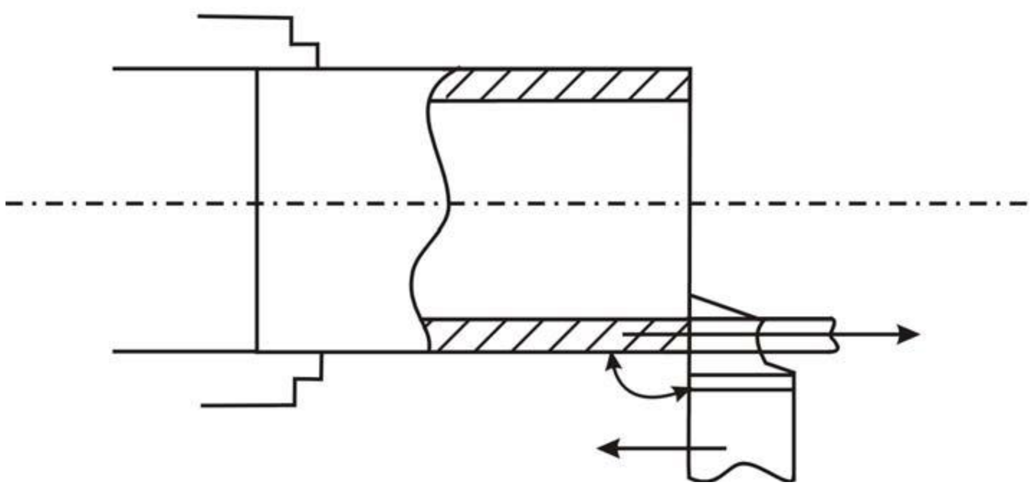
It has been established by several analytical and experimental methods including circular grid deformation that though the chips are initially compressed ahead of the tool tip, the final deformation is accomplished mostly by shear in machining ductile materials.
However, machining of ductile materials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

(i) Orthogonal and oblique cutting

It is appears from the diagram in Fig. 6.1 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.



Orthogonal cutting: when chip flows along orthogonal plane, π_o, i.e., $\rho_c = 0$
Oblique cutting: when chip flow deviates from orthogonal plane, i.e. $\rho_c \neq 0$
But practically ρ_c may be zero even if $\lambda = 0$ and ρ_c may not be exactly equal to λ even if $\lambda \neq 0$. Because there are some other (than λ) factors also which may cause chip flow deviation.



Characteristics and Applications of the Primary 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 upto 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)

(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 specially 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.

- **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.

- **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.

- **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 upto 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**

(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 3.3.4 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

PART A

1. What is an orthogonal cutting? Give two examples.

2. List out the difference between orthogonal cutting and oblique cutting.

3. What is the function of chip breakers?

4. Name any two conditions for continous chip formation while machining.

5. How can built up edge formed during machining be avoided?

6. What are desirable properties of cutting fluids?

7. Define tool wear and mention the types.

8. Define tool life.

9. What are the four important characteristics of materials used for cutting tools?

10. What is meant by tool signature?

11. What are the main functions of cutting fluids?

12. Name the factors that contribute to poor surface finish in cutting.

13. Define machinability of metal.

14. Write Taylor’s tool life equation.

15. What is shear plane angle?

16 Marks Questions (Part B Questions)

16. (i) Describe an expression for the determination of shear angle in an orthogonal metal cutting. (8)

(ii) The following cutting speed and cutting time observations have been noted in a machining process. Calculate (1)’n’ and C. (2) Recommend the cutting speed of a desired tool life of 60 minutes.

Cutting Speed (V): 25 m/min 35 m/min   Cutting Time (T): 90min 20min (8)

17. (i) What is a chip? What are the different types of chips? How are they formed? (8)

(ii) What is the measure of metal removing process machinability? What are the factors that affect it? (8)

18. (i) Explain the types of chip formed during machining process. (8)

(ii) List the various types of tool wear and discuss the factors affecting them. (8)

19. (i) Define the various tool parts of a single point cutting tool with a neat sketch. (8)

(ii) What are the standard angles of cutting tool? Explain in detail. (8)

20. (i) Explain the essential characteristics of a cutting fluid. (6)

(ii) The following equation for tool life is given for a turning operation;

V T 0.13 f 0.77 d 0.37 = C

A 60 minute tool life was obtained while cutting at V=30 m/min, f=0.3 mm/rev and d=2.5mm. Determine the change in tool life if the cutting speed, feed and depth of cut are increased by 20% individually and also taken together. (10)

21. What are the important properties required for cutting tool materials? (16)

22. What is meant by tool wear? Explain the parameters that influence tool wear. (16)

23. Draw the merchant’s circle diagram and derive the relationship between various cutting forces. (16)

24. Write a brief note on the type cutting fluids used for metal removal process. (16)

25. Explain the various factors affecting tool life. (16)

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 – Multispindle – Turret Indexing mechanism – Bar feed mechanism.

Classification Of Lathes

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

(a) According to configuration

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

(b) 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; example: centre lathes
- Single purpose
  - Only one (occasionally two) type of operation is done on limited ranges of size and material of jobs; example – 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; example:gear blank machining lathe etc.

(c) According to size or capacity

- Small (low duty)
  - In such light duty lathes (upto 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 upto 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; example : swiss type automatic lathe

(d) According to degree of automation

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

(e) According to type of automation

- Fixed automation
  - Conventional; example – single spindle automat, swiss type automatic lathe etc.
- Flexible automation
  - Modern; example CNC lathe, turning centre etc.

(f) 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
  - Only one (occasionally two) type of operation is done on limited ranges of size and material of jobs; example – 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; example: gear blank machining lathe etc.

(iii) Kinematic System And Working Principle Of Lathes

Amongst the various types of lathes, centre lathes are the most versatile and commonly used.Fig. 4.1.1 schematically shows the typical kinematic system of a 12 speed centre lathe.

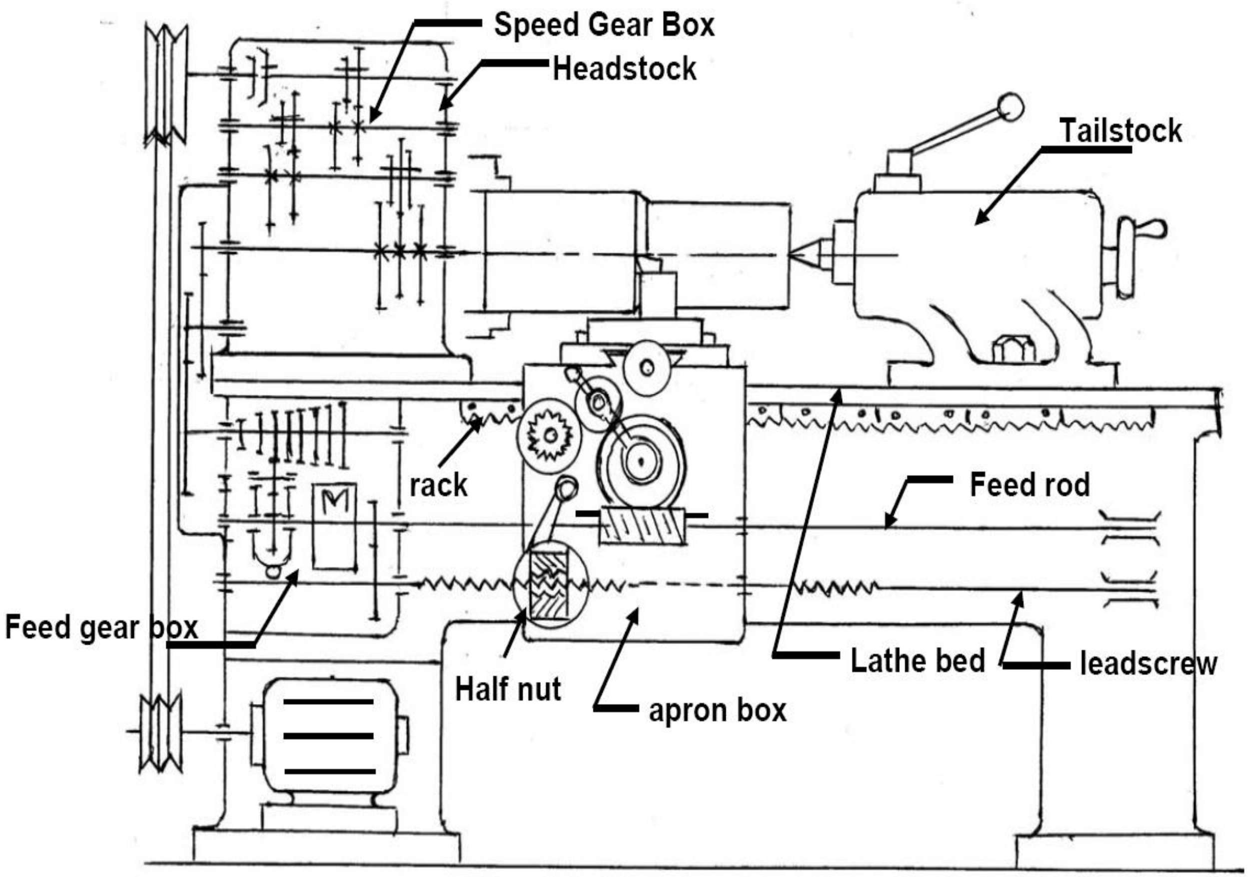


Fig. 4.1.1 Schematic diagram of a centre lathe.

The tool-work motions are:

- Formative motions: - cutting motion - feed motion
- Auxiliary motions: - indexing motion - relieving motion etc

In lathes

- Cutting motion is attained by rotating the job
- Feed motion by linear travel of the tool

  - either axially for longitudinal feed

  - or radially for cross feed

It is noted, in general, from Fig. 4.1.1

- 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 (FGR). 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 quil 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 attachments like
  - Taper turning attachment

  - Thread milling attachment and Copying attachment

(iv) Machining Operations Usually Done In Centre Lathes

The machining operations generally carried out in centre lathes are:

- Facing
- Centering
- Rough and finish turning
- Chamfering, shouldering, grooving, recessing etc
- Axial drilling and reaming by holding the cutting tool in the tailstock barrel
- Taper turning by
    - – offsetting the tailstock
    - – swivelling 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
- Forming; external and internal
- Cutting helical threads; external and internal
- Parting off
- Knurling

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, such as,

- Grinding, both external and internal by mounting a grinding attachment on the saddle
- Copying (profiles) by using hydraulic copying attachment
- Machining long and large threads for leadscrews, power-screws, worms etc. by using thread milling attachment.

Methods Of Mounting Job And Cutting Tool In General Purpose Machine Tools.

(a) Job and tool mounting in lathes

- **In centre lathes**

 Mounting of jobs

The general systems of holding jobs in centre lathes;

Δ without additional support from tailstock;

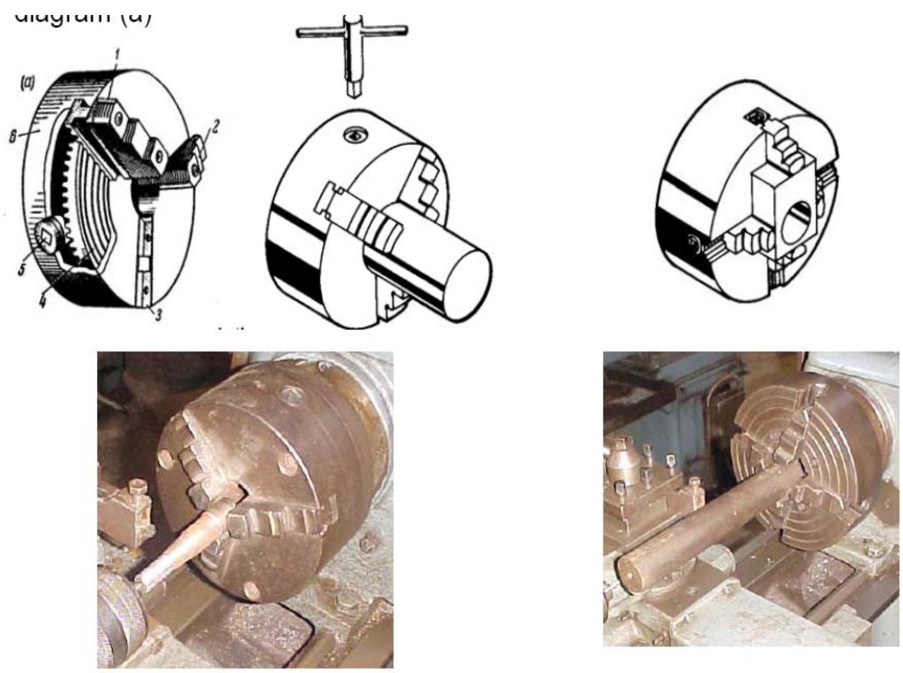
- Chucks – 3-jaw self centering chuck
- 4- independent jaw chuck
- Face plate
- Jigs and fixture

Fig. 4.5.1 visualises 3 – jaw and 4 – jaw chucks which are mounted at the spindle nose and firmly hold 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 (a)

(a) 3-Jaw chuck (b) 4-Jaw chuck

Fig. 4.5.1 *Holding jobs in centre lathes by 3-jaw and 4-jaw chucks.*

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 more odd sectional jobs in addition to cylindrical bars, both



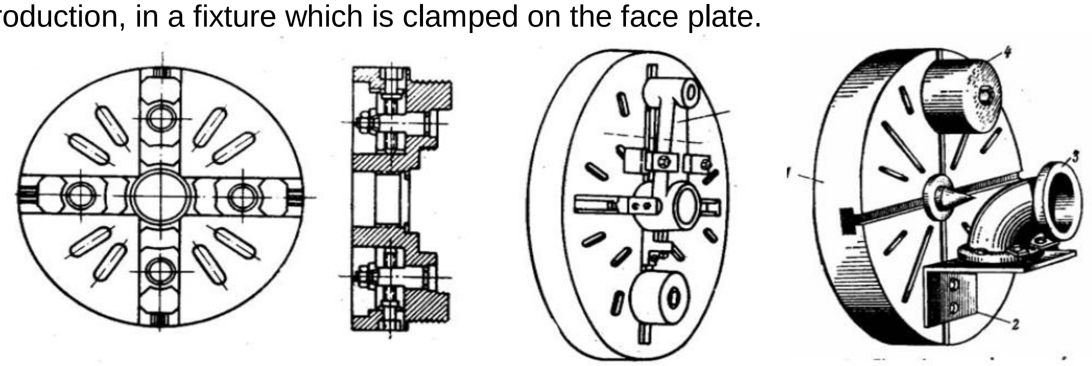
(a) 3-Jaw chuck (b) 4-Jaw chuck

Fig. 4.5.1 *Holding jobs in centre lathes by 3-jaw and 4-jaw chucks.*

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.

o For turning, facing, boring, threading and similar operations, jobs of odd shape and size are usually mounted on large face plate (instead of chuck) being fitted on the spindle nose as shown in Fig. 4.5.2.

o The job may be (b) directly clamped on the face plate or (c) in case of batch or small lot production, in a fixture which is clamped on the face plate.



(a) (b) (c)

Fig. 4.5.2 *Mounting of odd shaped jobs on face plate in centre lathe*

- Job mounting in centre lathe using support from the tailstock (centre)

  - o In-between centre
  - o In-between chuck and centre
  - o In-between headstock and tailstock with additional support of rest

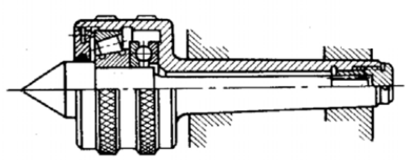
Fig. 4.5.3 schematically shows how long slender rods are held in between the live centre fitted into the spindle and the dead centre fitted in the quill of the tailstock. The torque and rotation are transmitted from the spindle to the job with the help of a lathe dog or catcher which is again driven 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. 4.5.4. 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. 4.5.3 *Mounting bar type job in between centres in centre lathe.*

(a) (b) (c)

dead centres



(d) revolving centre

Fig. 4.5.4 *Type of dead centres and revolving centre being fitted in the quill of the tailstock.*

forces) are essentially held strongly and rigidly in the chuck at headstock with support from the tailstock through a revolving centre as can be seen in Fig. 4.5.5.

(a) 3-jaw chuck

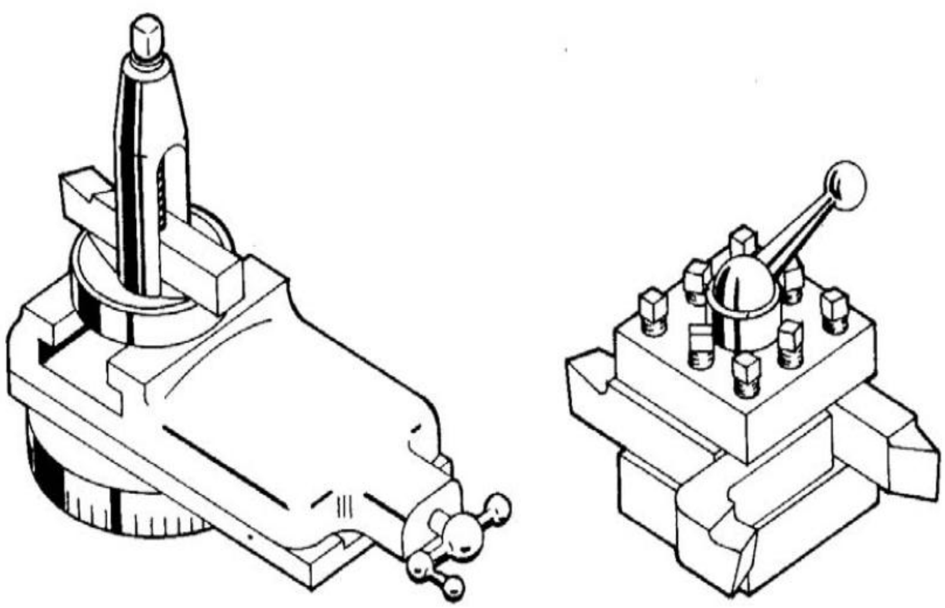
(b) 4-jaw chuck

Fig. 4.5.5 *Job mounted in between chuck and centre in centre lathe*

- **Mounting of tools in centre lathes**

  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. 4.5.7 is typically showing mounting of shank type HSS single point tools in rotatable (only one tool) and indexable (upto four tools) tool posts. Small tool bits are preferably fitted in a rectangular sectioned bar type tool holder which is mounted in the tool post as shown by the photograph in Fig. 4.5.5 (a).
- Fig. 4.5.8 typically shows how a circular form or thread chasing HSS tool is fitted in the tool holder which is mounted in the tool post.



(a) single tool (b) upto four tools

Fig. 4.5.7 *Mounting of shank type lathe tools in tool posts.*

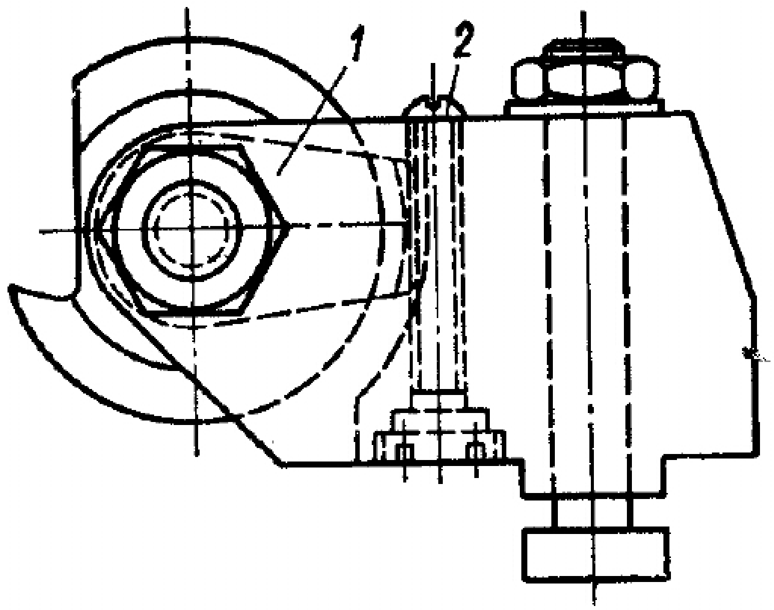
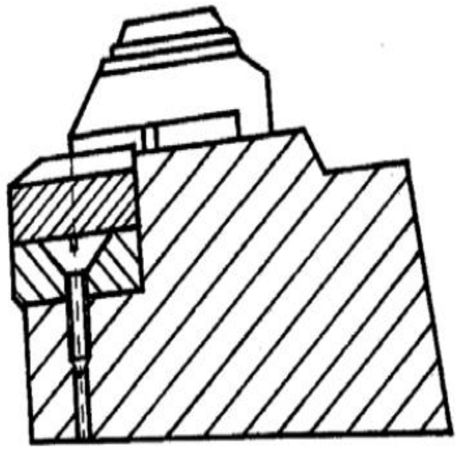
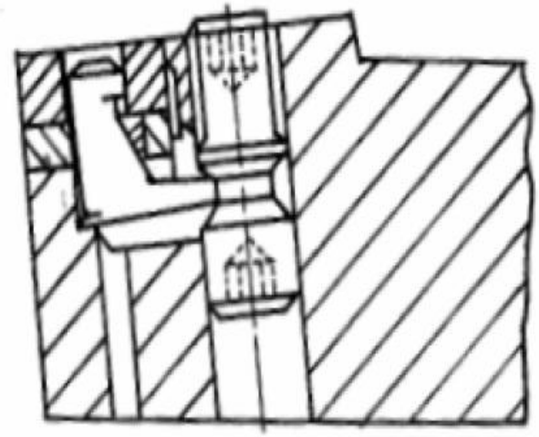


Fig. 4.5.8 *Mounting of form tool in tool post.*

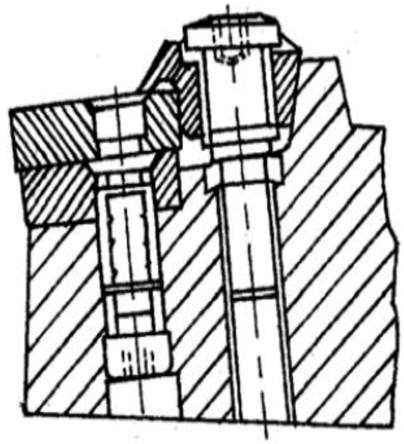
Carbide, ceramic and cermet inserts of various size and shape are mechanically clamped in the seat of rectangular sectioned steel bars which are mounted in the tool post. Fig. 4.5.9 shows the common methods of clamping of such inserts. After wearing out of the cutting point, the insert is indexed and after using all the corner-tips the insert is thrown away.



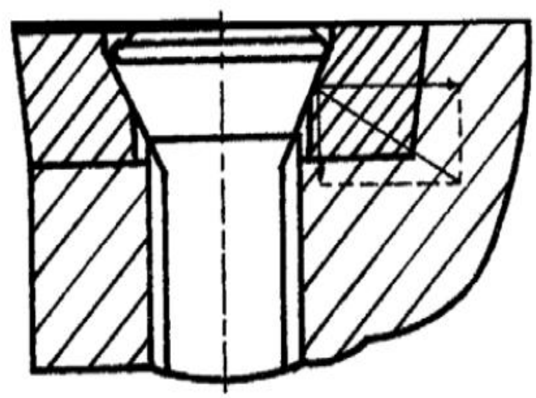
(a) clamp type



(b) lever type



(c) pin and clamp



(d) screw type

Fig. 4.5.9 *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. 4.5.10. 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.

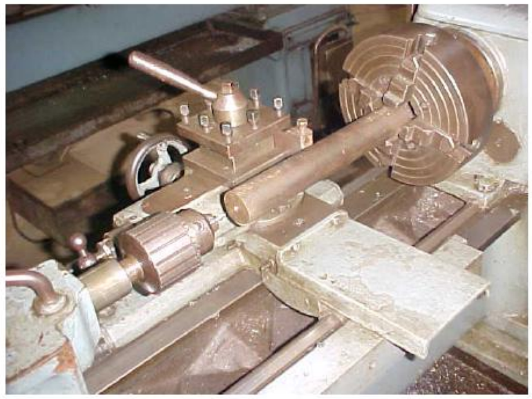


Fig. 4.5.10 *Holding drill chuck and drill in tailstock.*

- Often boring operation is done in centre lathes 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. 4.5.11 (a).

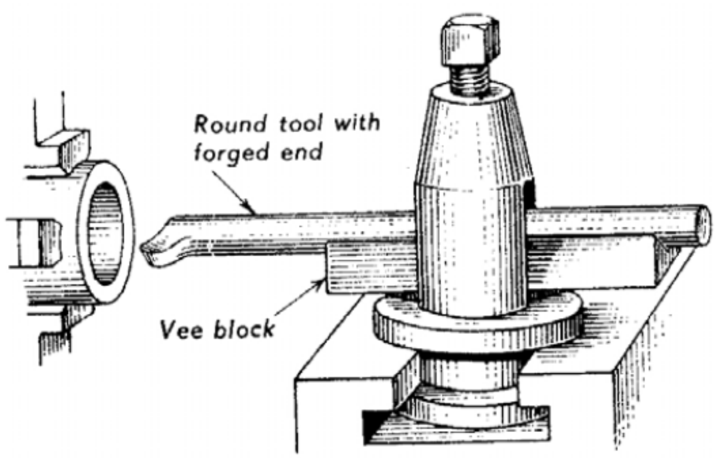


Fig. 4.5.11 *(a) Boring tool mounted in the tool post in centre lathe.*

- **In semiautomatic and 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 job or blank and the tool are also done much faster but properly.

- **Mounting of job in semiautomatic and automatic lathes.**

Semiautomatic lathes like capstan and turret lathes work on both chucking type (disc like) and bar type jobs. But automatic lathes like single spindle automat

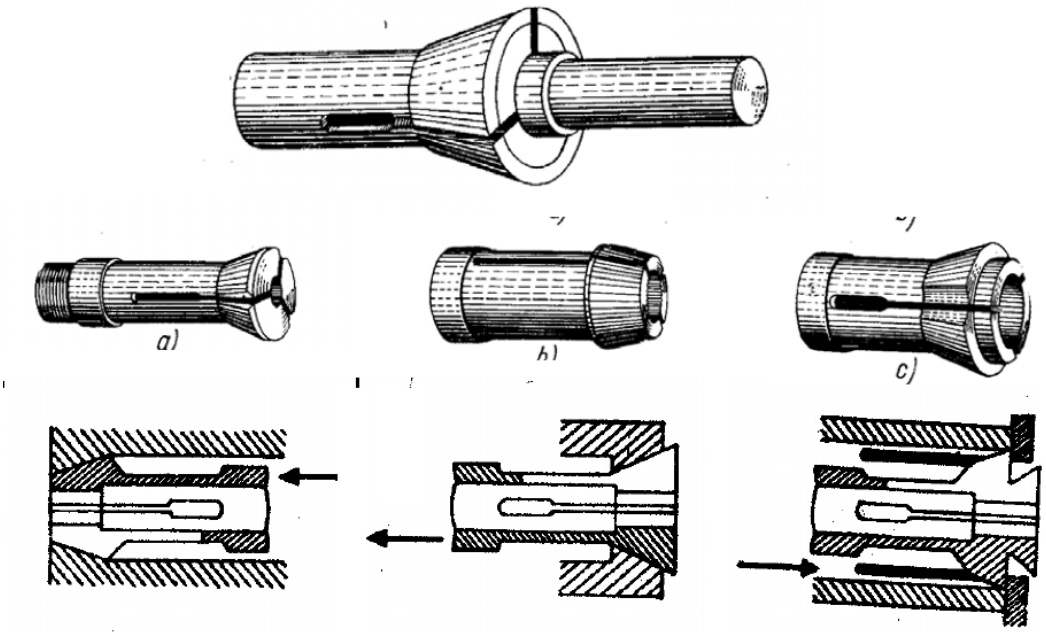
work on long bars of small (ϕ = 6 to 20 mm) circular or regular polygon section (square, hexagonal and octagonal). However, there is no scope of support from tailstock at all in any of such semiautomatic or automatic lathes. Only occasionally additional support is taken through a revolving centre during heavy transverse or radial cut in a turret lathe. In that case that centre is fitted into the turret head only. The devices or systems those are commonly used to hold the job or blank quickly, coaxially (with the spindle axis) strongly and rigidly in the aforesaid semiautomatic and automatic lathes are :

- Coventry concentric chuck – where the 3 jaws are actuated quickly and accurately by a ring cam
- Air operated chuck – where the jaws are moved more quickly and accurately by compressed air. Often hydraulically operated quick acting chucks are used in turret lathes for heavy jobs and cuts.
- Quick acting soft jaw chucks – preferably used where the gripping portion of the job need to be unaffected
- Collet chuck – used for holding long thin bars of regular section passing and fed through the hollow spindle.

Collet chucks inherently work at high speed with accurate location and strong grip. The collets are actuated

- Δ manually or semiautomatically in capstan and turret lathes
- Δ automatically in automatic lathes

Basically there are three types of spring collets as shown in Fig. 4.5.12. All of those collets are splitted at their gripping end to provide springiness and enable reduce the bore diameter to grip the bar by radial force.



(a) push type (b) pull type (c) stationary type

Fig. 4.5.12 *Collets used to hold bar stock in semiautomatic and automatic lathes.*

All the collet types; push, pull and stationary, have some relative advantages based on which those are selected appropriate for the application.

- **Mounting of cutting tools**
    - Δ **In semiautomatic lathes**

In semiautomatic lathes liken capstan lathe and turret lathe, the cutting tools are mounted in the

(a) **Radial slides –** moving transverse to the job axis

- ∗ Front slide – if fixed type, holds only one tool
  - if turret type, may hold upto 4 tools
- ∗ rear slide – for only one cutting tool

The cutting tools, mounted on the radial slides, are used for the external machining operations which need radial tool feed, e.g., facing, shouldering, grooving, recessing, forming, chamfering, parting etc.

(b) **Turret (mostly hexagonal)** – moving along the spindle axis

The cutting tools to be used for external or internal work requiring axial feed motions such as turning, drilling, boring, reaming, threading etc., are mounted on the faces of the turret. The turret holding upto six different tools, as shown in Fig. 4.5.13, for different machining operations moves slowly with one acting tool in front of it at desired feed rate, then after doing the particular machining operation returns at the end of which it gets indexed, i.e., rotated by 60° or multiple of it.

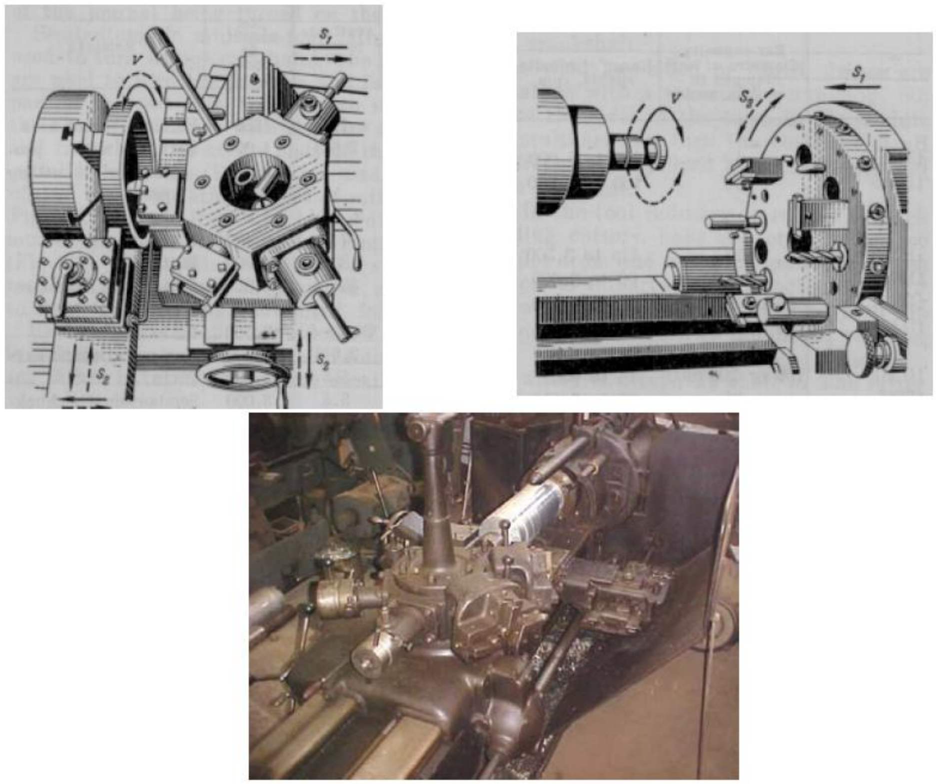


Fig. 4.5.13 *Mounting of cutting tools on the turret in semiautomatic lathe.*

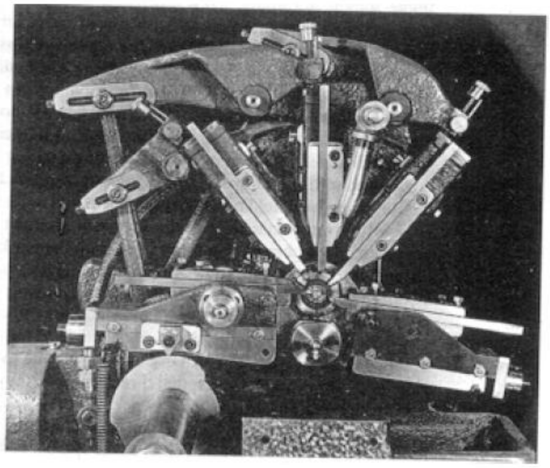
For faster production, a number of machining work, as far as feasible, are carried out simultaneously

- o by compounding the cutting tool enabling more than one work
- o by partially or fully overlapping the duration of action of radially moving tool with axially moving tool

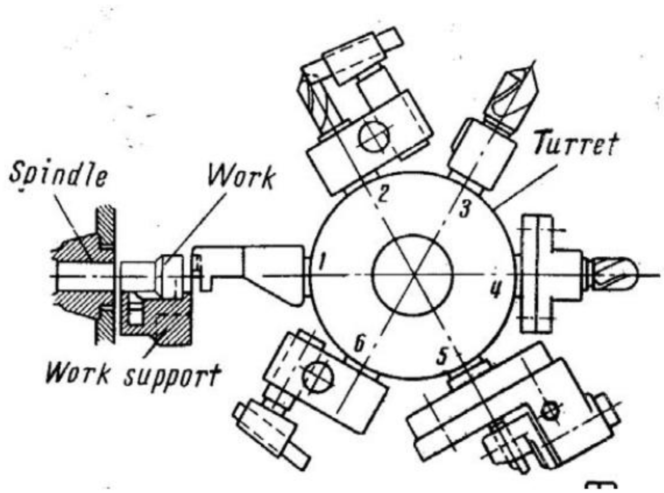
In addition to cutting tools, some other objects like stop-stock, revolving centre etc are also often need to be mounted in the turret.

Δ Mounting of tools in automatic lathes

In general purpose automatic lathes, i.e., single spindleautomats also, the tools requiring transverse feed motions are mounted in the radial slides and those requiring axial feeds are mounted in the hexagonal turret which rotates with the tools about a horizontal axis for indexing as shown in Fig. 4.5.14.



(a) radially moving tools



(b) axially moving tools in turret

***Fig. 4.5.14** Mounting of tools in single spindle automatic lathe.*

iii) Working Principles and Application of Various Attachments In Different Machine Tools.

(a) Attachments used in centre lathes

• **Taper turning attachment**

Taper cylindrical surface, which is a very common feature of several engineering components, is generally produced in lathes in a number of methods, depending upon length and angle of the tapered position of the job, such as offsetting tailstock, swivelling the compound slide using form tool and combined feed motions. But jobs with wide ranges of length and angle of taper are easily machined by using a simple attachment, called taper turning attachment. Fig. 4.6.1 schematically shows a taper turning attachment where the cross slide is delinked from the saddle and is moved crosswise by the guide block which moves along the guide bar preset at the desired taper angle. Thus, the cutting tool, which is fitted on the cross slide through the tool post and the compound slide, also moves along with the guide black in the same direction resulting the desired taper turning.

• **Copy turning attachment**

There are two common types of copy turning;

- mechanical type
- hydraulic type

- **Mechanical copying**

A simple mechanical type copy turning attachment has been schematically shown in Fig. 4.6.2. 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. 4.6.2

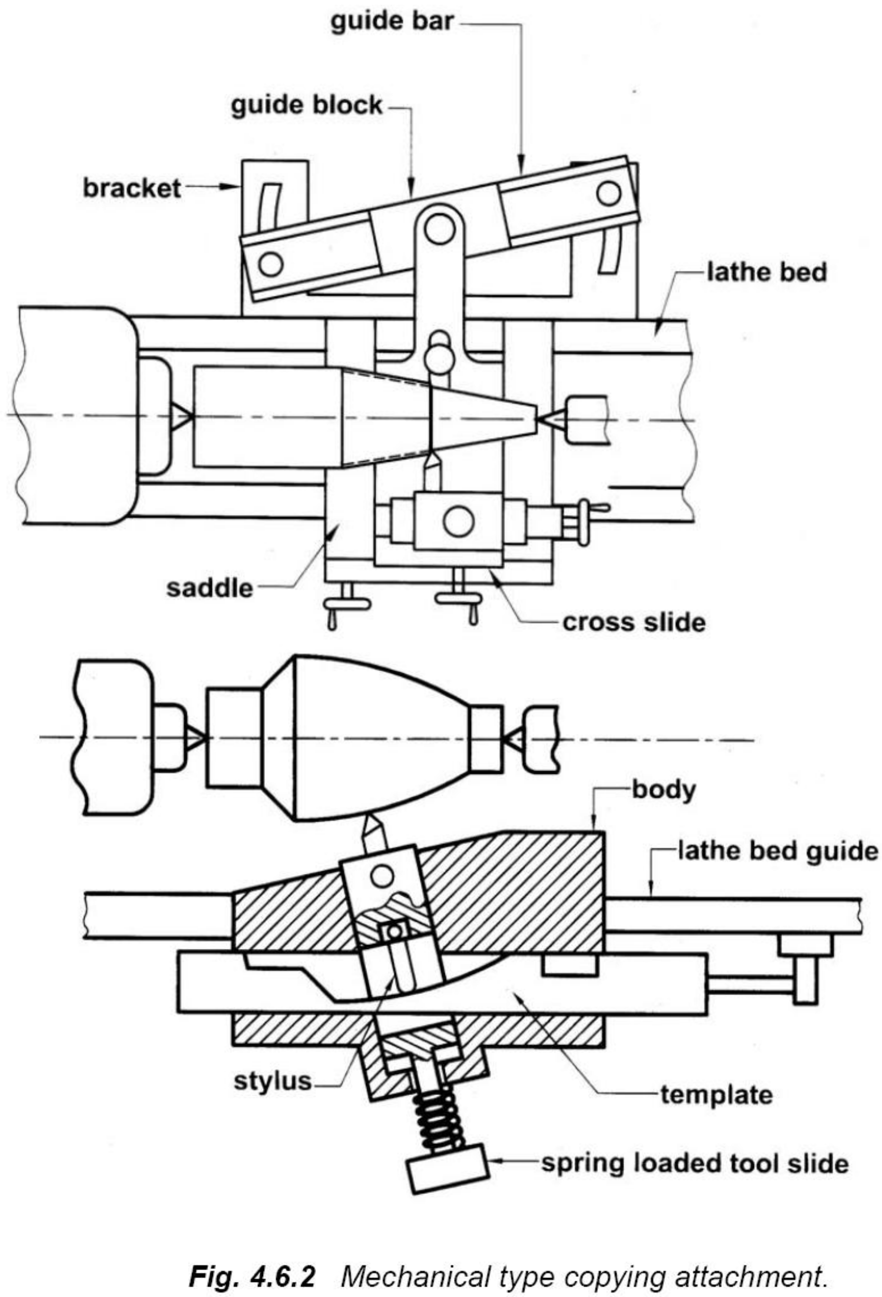


Fig. 4.6.2 *Mechanical type copying attachment.*

Hydraulic copying attachment

The mounting and working principle of hydraulic copying attachment for profile turning in centre lathe are schematically shown in Fig. 4.6.3. Here also, the stylus moves along the template profile to replicate it on the job. In mechanical system (Fig. 4.6.2) 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. 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.

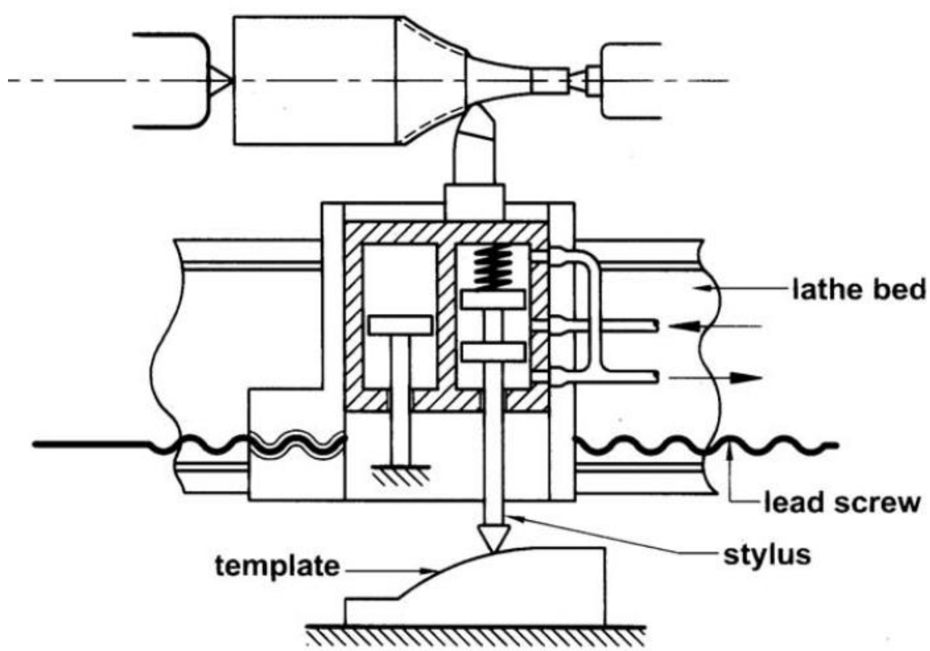


Fig. 4.6.3 Hydraulic copying attachment.

Milling attachment

This is 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. 4.6.4. Milling attachments are generally used for making flat surfaces, straight and helical grooves, splines, long and deep screw threads, worms etc. in centre lathes by using suitable milling cutters.

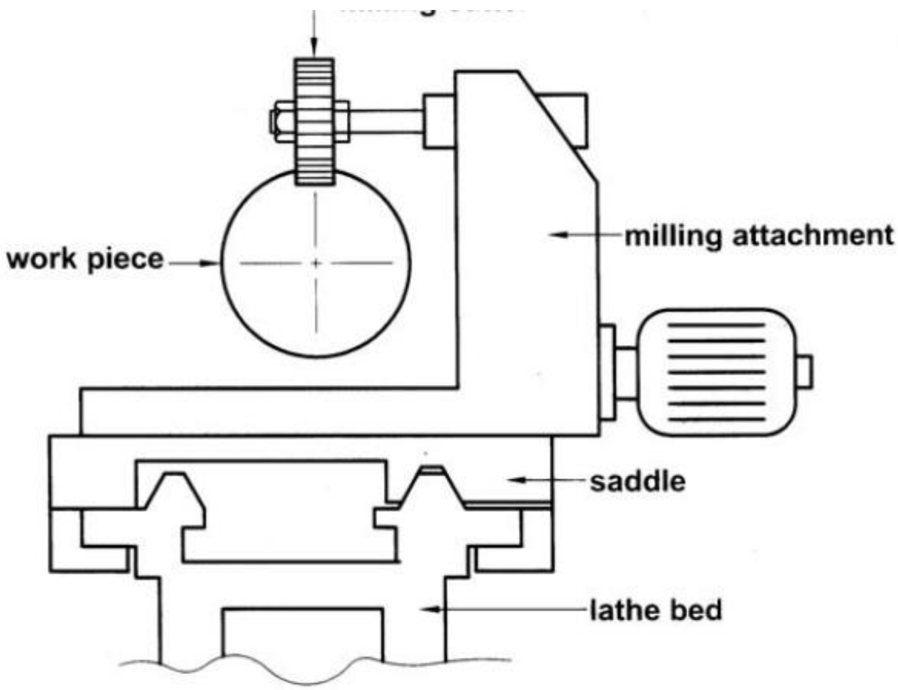


Fig. 4.6.4 Milling attachment used in lathe.

Grinding attachment

Grinding attachment is very similar to milling attachment. But in the former, there is no gear box and the spindle speed is much higher as needed for grinding operation. Such attachments are employed for external and internal cylindrical grinding, finishing grooves, splines etc. and also for finish grinding of screw threads in centre lathe. But unlike dedicated machines, attachments cannot provide high accuracy and finish.

• **Spherical turning attachments**

These simple attachments are used in centre lathes for machining spherical; both convex and concave surfaces and similar surfaces. Fig. 4.6.5 schematically visualises the usual setting and working principle of such attachments. In Fig. 4.6.5 (b), the distance R_i can be set according to the radius of curvature desired. In the type shown in Fig. 4.6.5 (a) 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 leadscrew. So when the cross slide is moved manually in transverse direction, the tool moves axially freely being guided by the template only.

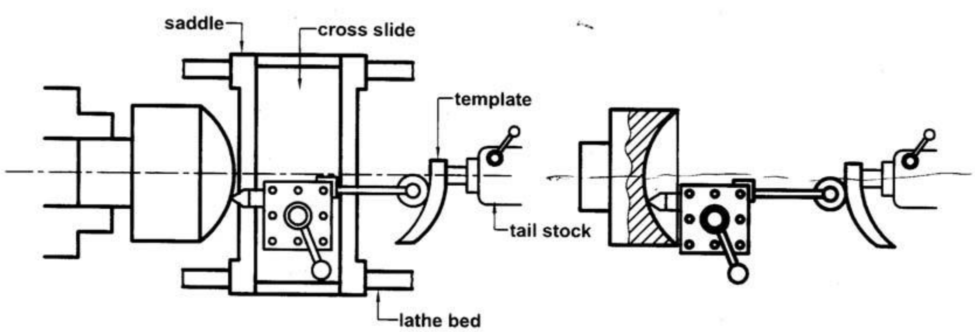


Fig. 4.6.5 *(a) Spherical turning using template.*

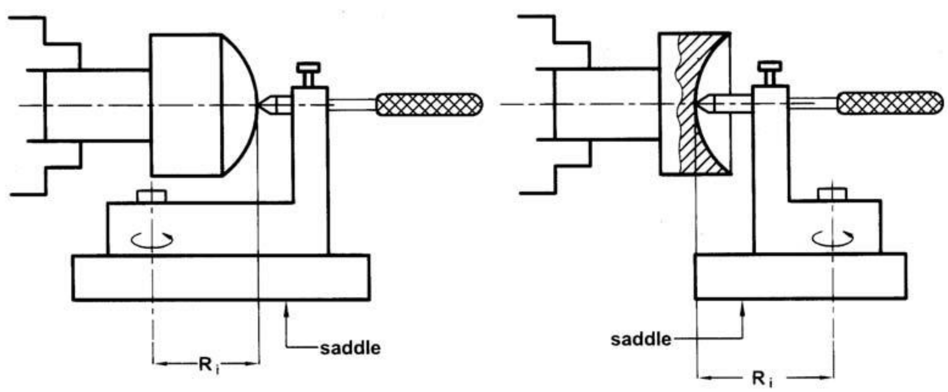


Fig. 4.6.5 *(b) Spherical turning without template.*

• **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 ± Δp) due to some kinematic error in the lathe.

Mathematically,

$p_s - p_a = \pm \Delta p$ (4.6.1)

Therefore for correct pitch, the error ± Δp need to be compensated and this may be done by a simple differential mechanism, namely correcting bar attachment as schematically indicated in Fig. 4.6.7.

In equation 4.6.1,

$p_a = 1 \times U_C \times L$

$\pm \Delta p = p_s \tan(\pm\alpha).L/(\pi mZ)$ (4.6.2)

where, U_C = transmission ratio

L = lead of the leadscrew

m, Z = module and 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.

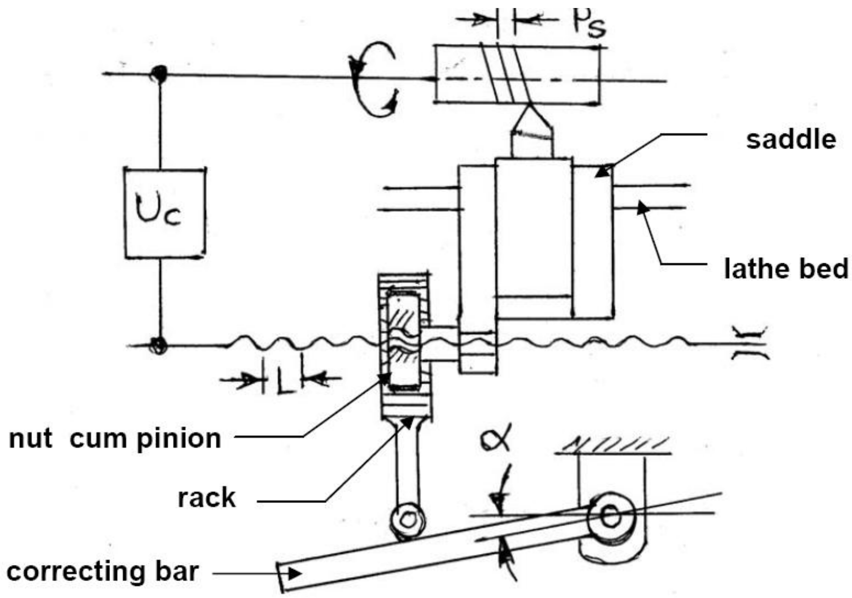


Fig. 4.6.7 *Thread pitch correcting attachment.*

Constructional Features and Uses of General Purpose Semiautomatic and Automatic Lathes.

Automation is incorporated in a machine tool or machining system as a whole for higher productivity with consistent quality aiming meeting the large requirements and overall economy. Such automation enables quick and accurate auxiliary motions, i.e., handling operations like tool – work mounting, bar feeding, tool indexing etc. repeatably with minimum human intervention but with the help of special or additional mechanism and control systems. These systems may be of mechanical, electro-mechanical, hydraulic or electronic type or their combination.
It is already mentioned that according to degree of automation machine tools are classified as,

- Non automatic where most of the handling operations irrespective of processing operations, are done manually, like centre lathes etc.
- Semiautomatic
- Automatic where all the handling or auxilliary operations as well as the processing operations are carried out automatically.

General purpose machine tools may have both fixed automation or flexible automation where the latter one is characterised by computer Numerical Control (CNC).

Amongst the machine tools, lathes are most versatile and widely used. Here automation of lathes only have been discussed.
The conventional general purpose automated lathes can be classified as,

(a) Semiautomatic:
- capstan lathe (ram type turret lathe)
- turret lathe
- multiple spindle turret lathe
- copying (hydraulic) lathe

(b) Automatic:
- Automatic cutting off lathe
- Single spindle automatic lathe
- Swiss type automatic lathe
- multiple spindle automatic lathes

The other categories of semiautomatic and automatic lathes are :

- Vertical turret lathe
- Special purpose lathes
- Non conventional type, i.e., flexibly automatic CNC lathes, turning centre etc.

(a) Semiautomatic lathes

The characteristic features of such 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.

Capstan and Turret lathes

The semiautomatic lathes, capstan lathe and turret lathe are very similar in construction, operation and application. Fig. 4.7.1 schematically shows the basic configuration of capstan lathe and Fig. 4.7.2 shows that of turret lathe.

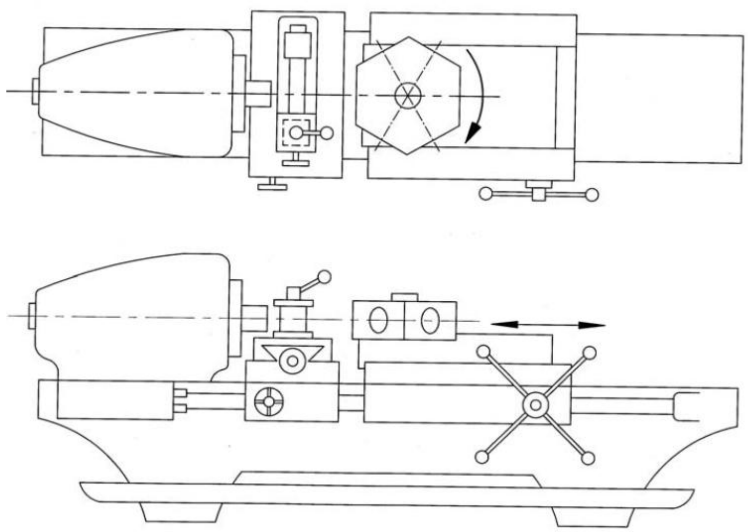


Fig. 4.7.1 *Schematic configuration of capstan lathe.*

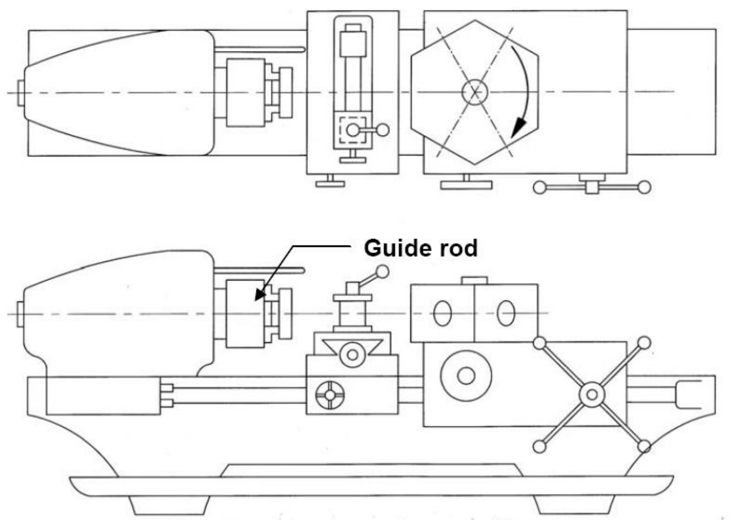


Fig. 4.7.2 *Schematic configuration of turret lathe.*

In contrast to centre lathes, capstan and turret lathes

- are semiautomatic
- possess an axially movable indexable turret (mostly hexagonal) in place of tailstock
- holds large number of cutting tools; upto four in indexable tool post on the front slide, one in the rear slide and upto 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 relatively costlier

- are suitable and economically viable for batch production or small lot production.

- heavy turret being mounted on the saddle which directly slides with larger stroke length on the main bed as indicated in Fig. 4.7.2

- One additional guide rod or pilot bar is provided on the headstock of the turret lathes as shown in Fig. 4.7.2, to ensure rigid axial travel of the turret head

- External screw threads are cut in capstan lathe, if required, using a self opening die being mounted in one face of the turret, whereas in turret lathes external threads are generally cut, if required, by a single point or multipoint chasing tool being mounted on the front slide and moved by a short leadscrew and a swing type half nut.

Fig. 4.7.3 and Fig. 4.7.4 are showing the pictorial views of a typical capstan lathe and a horizontal turret lathe respectively.
Ram type turret lathes, i.e., capstan lathes are usually single spindle and horizontal axis type. Turret lathes are also mostly single spindle and horizontal type but it may be also

- Vertical type and

- Multispindle type

Some more productive turret lathes are provided with preoptive drive which enables on-line presetting and engaging the next work-speed and thus help in reducing the cycle time.
Version 2

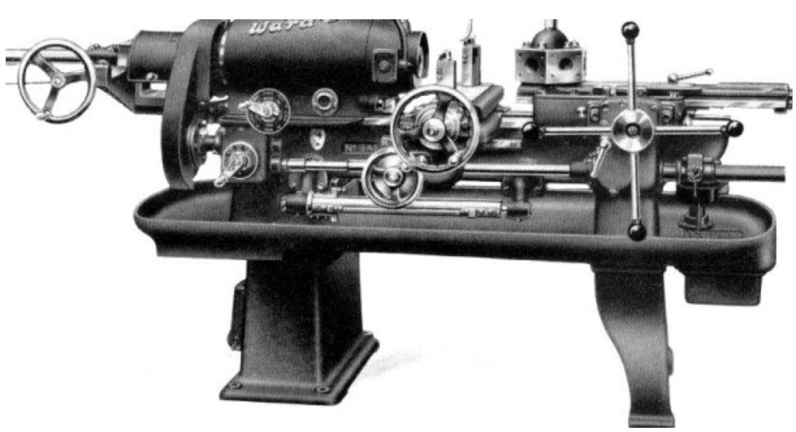


Fig. 4.7.3 *Pictorial view of a capstan lathe*

Ram type turret lathes, i.e., capstan lathes are usually single spindle and horizontal axis type. Turret lathes are also mostly single spindle and horizontal type but it may be also

• Vertical type and

• Multispindle type

Some more productive turret lathes are provided with preoptive drive which enables on-line presetting and engaging the next work-speed and thus help in reducing the cycle time.

Multiple spindle Vertical Turret lathe

Turret lathes are mostly horizontal axis single spindle type. The multiple spindle vertical turret lathes are characterised by:

• Suitably used for large lot or mass production of jobs of generally;

Δ chucking type

Δ relatively large size

Δ requiring limited number of machining operations

• Machine axis – vertical for

Δ lesser floor space occupied

Δ easy loading and unloading of blanks and finished jobs

Δ relieving the spindles of bending loads due to job – weight.

• Number of spindle – four to eight.
Such vertical turret lathes are of three categories:

∗ **Parallel processing type:**
The spindle carrier remains stationary. Only the tool slides move with cutting tools radially and axially. Identical jobs (say six) are simultaneously mounted and machined in the chucks parallely at all stations each one having same set of axially and / or radially moving cutting tools.

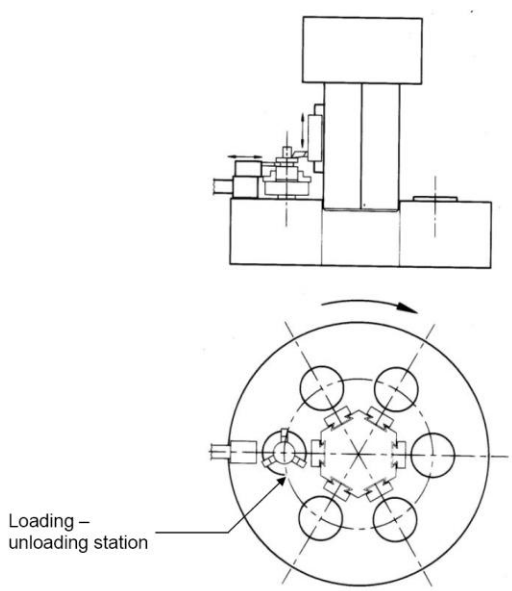


Fig. 4.7.5 *Basic configuration of multispindle automatic vertical lathe*

Progressively processing type:
The spindle carrier with the blanks fitted in the chucks on the rotating spindle is indexed at regular interval by a Geneva mechanism. At each station the job undergoes a few preset machining work by the axially and / or radially fed cutting tools. The blank getting all the different machining operations progressively at the different work stations is unloaded at a particular station where the finished job is replaced by another fresh blank. This type of lathes are suitable for jobs requiring large number of operations.

- Automatic (screw cutting) lathe
- Swiss type automatic lathe
- Multispindle automatic lathe
-

Continuously working type:
Like in parallel processing type, here also each job is finished in the respective station where it was loaded. The set of cutting tools, mostly fed only axially along a face of the ram continuously work on the same blank throughout its one cycle of rotation along with the spindle carrier. The tool ram having same tool sets on its faces also rotate simultaneously along with the spindle carrier which after each rotation halts for a while for unloading the

finished job and loading a fresh blank at a particular location. Such system is also suitable for jobs requiring very few and simple machining operations.

Hydraulic copying (tracer controlled) lathes
Jobs having steps, tapers and / or curved profiles, as typically shown in Fig. 4.7.6, are conveniently and economically produced in batch or lot in semiautomatically operated tracer controlled hydraulic copying lathe. The movement of the stylus along the template provided with the same desired job-profile) is hydraulically transmitted to the cutting tool tip which replicates the template profile.

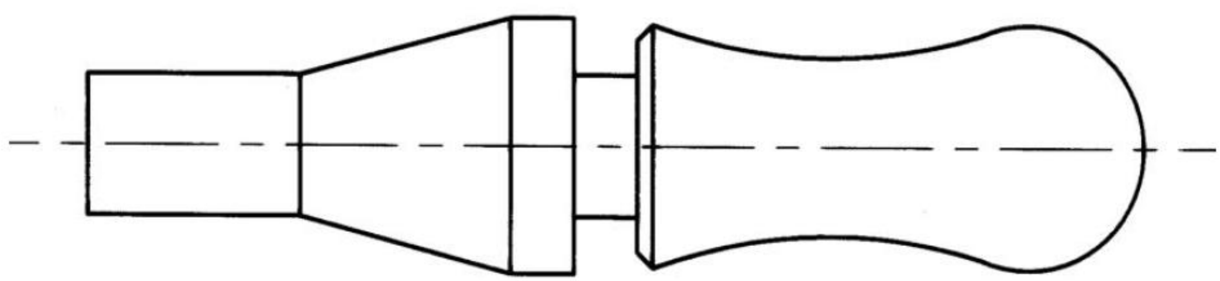


Fig. 4.7.6 A typical job suitable for copy turning.

(b) General Purpose Automatic lathes
Automatic lathes are essentially used for large lot or mass production of small rod type of jobs. Automatic lathes are also classified into some distinguished categories based on constructional features, operational characteristics, number of spindles and applications as follows

- Single spindle
- Automatic cutting off lathes

Automatic cutting off lathe
These simple but automatic lathes are used for producing short work pieces of simple form by using few cross feeding tools. In addition to parting some simple operations like short turning, facing, chamfering etc. are also done.
Single spindle automatic lathe
The general purpose single spindle automatic lathes are widely used for quantity or mass production (by machining) of high quality fasteners; bolts, screws, studs etc., bushings, pins, shafts, rollers, handles and similar small metallic parts from long bars or tubes of regular section and also often from separate small blanks. Fig. 4.7.7 shows a typical single spindle automatic lathe. Unlike the semiautomatic lathes, single spindle automats are:

- preferably and essentially used for larger volume of production i.e., large lot production and mass production

- used always for producing jobs of rod, tubular or ring type and of relatively smaller size.

- run fully automatically, including bar feeding and tool indexing, and continuously over a long duration repeating the same machining cycle for each product

- provided with upto five radial tool slides which are moved by cams mounted on a cam shaft

- of relatively smaller size and power but have higher spindle speeds

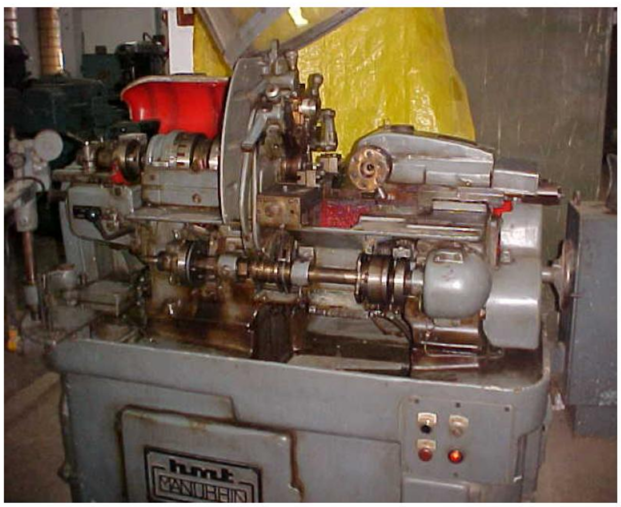


Fig. 4.7.7 *A typical single spindle automatic lathe.*

Swiss type automatic lathe

The characteristics and applications of these single spindle automatic lathes are :

• In respect of application:

Used for lot or mass production of thin slender rod or tubular jobs, like components of small clocks and wrist watches, by precision machining;

- Job size (approximately)

  – Diameter range – 2 to 12 mm

  – Length range – 3 to 30 mm

Dimensional accuracy and surface finish – almost as good as provided by grinding

• In respect of configuration and operation

  o The headstock travels enabling axial feed of the bar stock against the cutting tools as indicated in Fig. 4.7.8

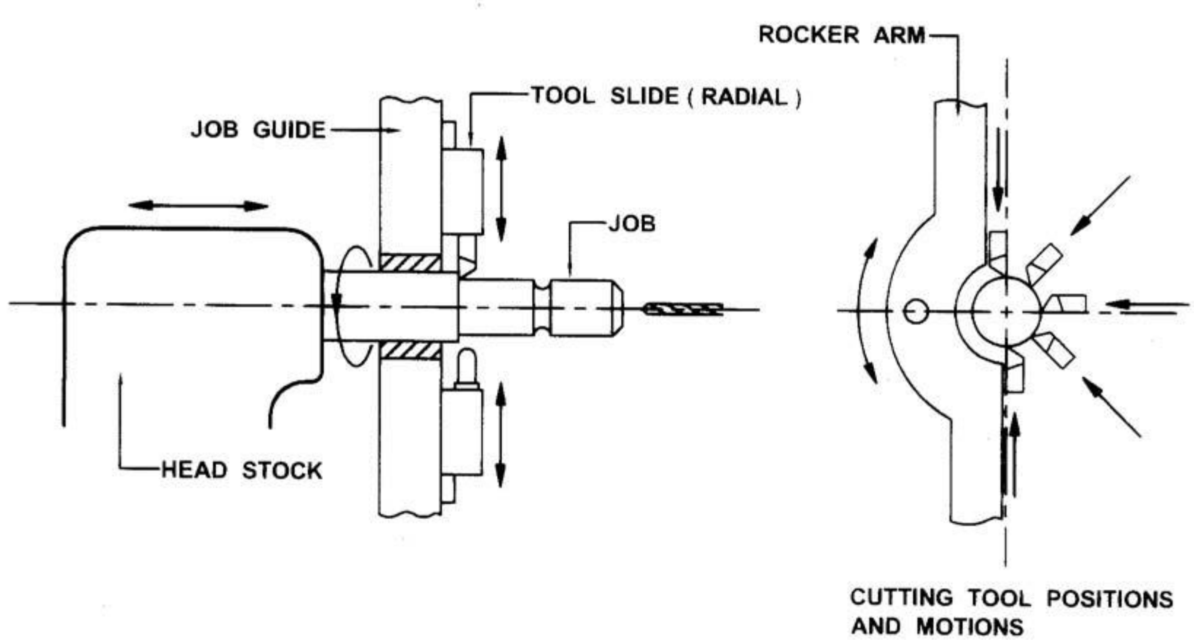
  o There is no tailstock or turret

  o High spindle speed (2000 – 10,000 rpm) for small job diameter

  o The cutting tools (upto five in number including two on the rocker arm) are fed radially

  o Drilling and threading tools, if required, are moved axially using swivelling device(s)

  o The cylindrical blanks are prefinished by grinding and are moved through a carbide guide bush as shown.



Multispindle automatic lathes

For further increase in rate of production of jobs usually of smaller size and simpler geometry.Multispindle automatic lathes having four to eight parallel spindles are preferably used. Unlike multispindle turret lathes, multispindle automatic lathes;

  o are horizontal (for working on long bar stocks)

  o work mostly on long bar type or tubular blanks

Multiple spindle automats also may be parallel action or progressively working type. Machining of the inner and outer races in mass production of ball bearings are, for instance, machined in multispindle automatic lathes.

(ii) Kinematic Systems and Working Principles of Semi Automatic and Automatic Lathes

The kinematic systems and basic principles of working of the following general purpose semi-automatic and automatic lathes of common use have been visualised and briefly discussed here:

(a) Semi-automatic lathes:

- Capstan and single spindle turret lathe
- Hydraulic copying lathe

(b) Automatic lathes

- Single spindle automatic (screw cutting) lathe
- Swiss type automatic lathe

Kinematic system and working principle of capstan lathe
Like general configurations and applications, the basic kinematic systems are also very similar in capstan lathes and turret lathes (particularly single spindle bar and horizontal types) in respect of their major functions, i.e.,

o bar feeding mechanism

o turret moving and indexing

o speed and feed drives

Turret indexing mechanism in capstan and turret lathes
Turret indexing mechanism of capstan and single spindle turret lathe is typically shown schematically in Fig. 4.7.10.
The turret (generally hexagonal) holding the axially moving cutting tools have the following motions to be controlled mechanically and manually;

o forward axial traverse comprising;

Δ quick approach – manually done by rotating the pinion as shown

Δ slow working feed – automatically by engaging the clutch

Δ stop at preset position depending upon the desired length of travel of the individual tools

o quick return – manually done by disengaging the clutch and moving the turret back

o indexing of the turret by 60^{o} (or multiple of it) – done manually by further moving the turret slide back.

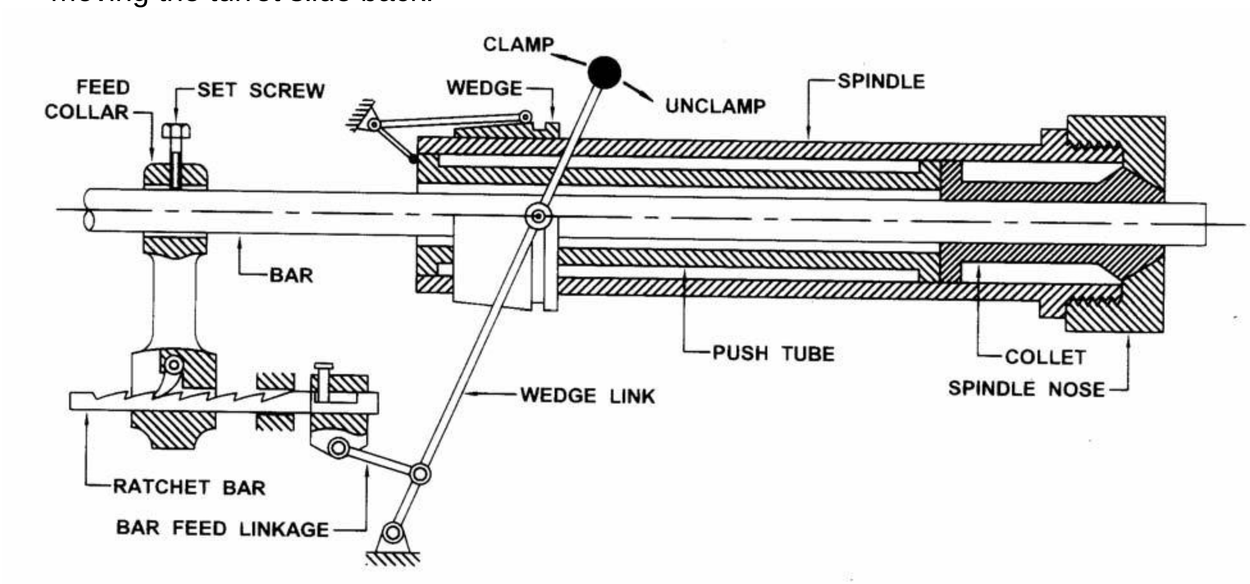
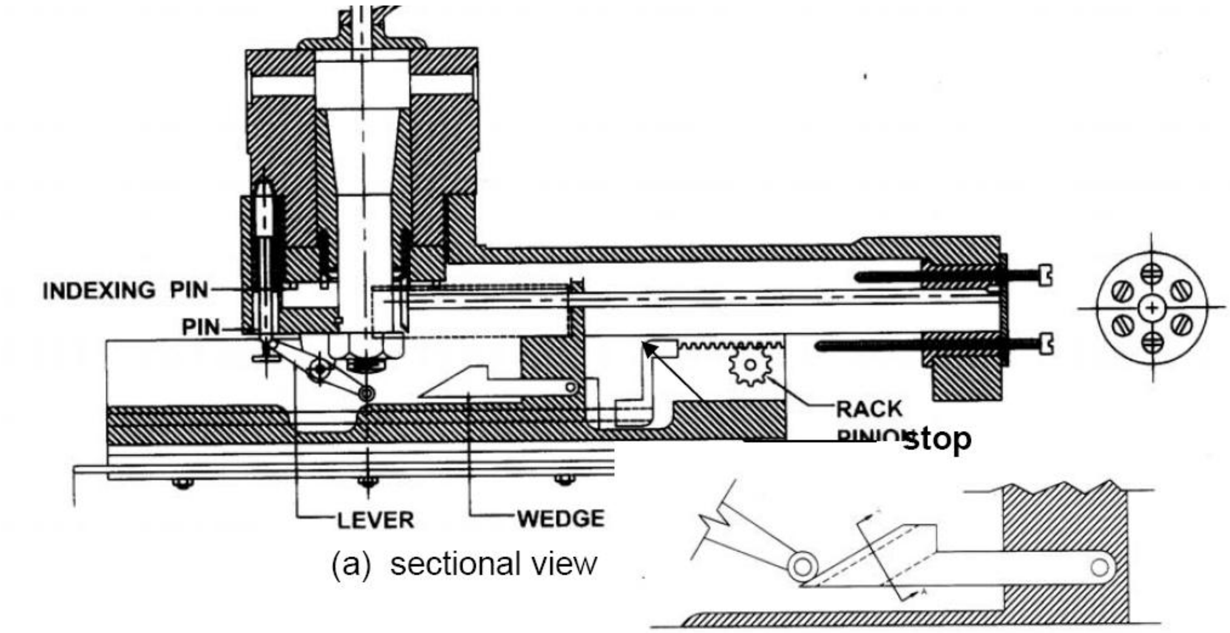


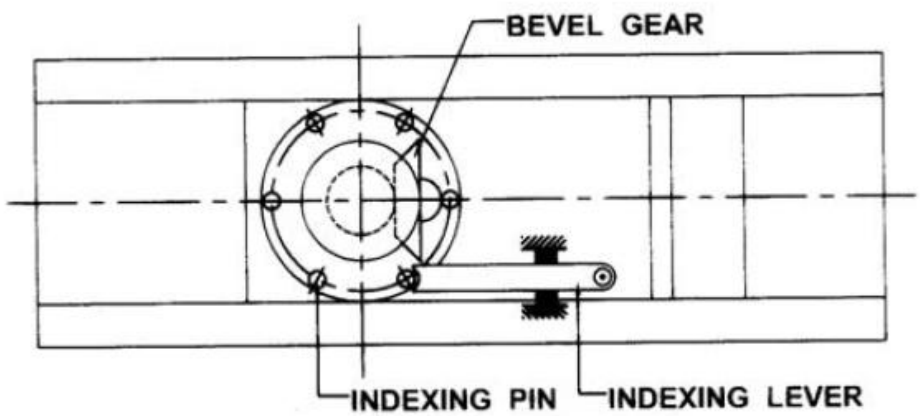
Fig. 4.7.9 *Typical bar feeding mechanism in capstan lathe.*

Just before indexing at the end of the return stroke, the locking pin is withdrawn by the lever which is lifted at its other end by gradually riding against the hinged wedge as indicated in Fig. 4.7.10 (a). Further backward travel of the turret slide causes rotation of the free head by the indexing pin and lever as indicated in Fig. 4.7.10 (b). Rotation of the turret head by exact angle is accomplished by insertion of the locking pin in the next hole of the six equispaced holes. After indexing and locking, the turret head is moved forward with the next cutting tool at its front face when the roller of the lever returns through the wider slot of the wedge without disturbing the locking pin as indicated in the figure. The forward motion of the turret head is automatically stopped when the set-screw corresponding to the working tool is arrested by the mechanical stop. The end position and hence length of travel of the tool is governed by presetting the screw. There are six such screws, each one corresponds with particular face or tool of the turret. The drum holding those equispaced six screw with different projection length is rotated along with the indexing (rotation) of the turret head by a pair of bevel gears (1:1) as indicated in Fig. 4.7.10 (a). The bottom most screw, which corresponds with the tool on the front face of the turret, when hits or touches the stop, the turret movement is stopped either manually by feeling or automatically by disengaging the clutch between the feed rod and the turret slide.



(a) sectional view

(a) sectional view



(b) top (inner) view

Common use.
This general purpose and widely use spindle automatic screw cutting lathe (SSASCL) because such lathes were introduced aiming mainly mass production of fasteners having screw threads. Fig. 4.7.13 schematically shows the typical kinematic system of single spindle automat. The major characteristic functions that are automatically accomplished in sequence and proper synchrony in such lathes are : Δ spindle speed change – magnitude and direction of rotation bar feeding

Δ transverse too

Δ turret indexing and travelling

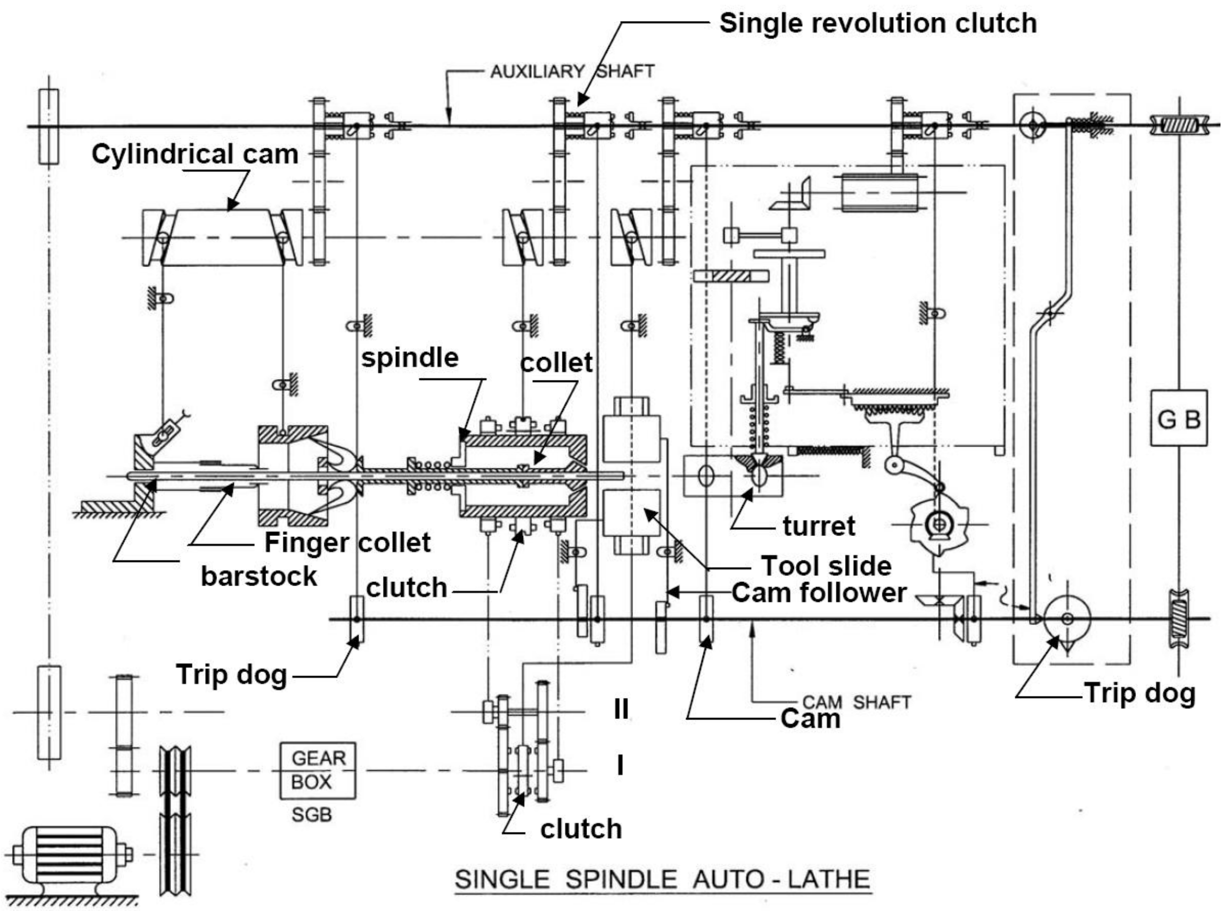


Fig. 4.7.13 *Typical kinematic system of single spindle automatic lathe.*

∆ Change of spindle speed

Repetitive production in large volume and limted ranges of job – tool materials and job – diameter necessitate a small number of spindle speeds in automatic lathes unlike centre lathes. However, at least two speeds, high and low (for threading etc.) and provision of reversal of those speeds need to be provided in automatic lathes. Power and speed are transmitted from the motor to shaft – I through belt-pulley and a speed gear box (SGB) if required as can be seen in Fig. 4.7.13. The two gear loosely mounted on shaft I are in mesh with two gears fixed on shaft II. Rotations are transmitted from shaft II to the spindle by two pairs of chain and sprockets as indicated in the kinematic diagram (Fig. 4.7.13). The two sprockets are loosely mounted on the spindle and simultaneously rotate at the same speed, low or high, but in opposite directions. The spindle is made to rotate at high or low speed and clockwise or anticlockwise by engaging the clutches on shaft I and the spindle respectively. The clutch is shifted by a lever and cylindrical cam which is rotated at the desired moment by one revolution only with the help of a single revolution clutch which is again triggered by a trip dog controlled by the camshaft as shown in the figure.

∆ **Bar feeding mechanism**

For feeding the barstock to a desired projection length after completing machining and parting a job, first the collet is opened by withdrawing the push force by moving the taper ring outward by a lever automatically with the help of the cylindrical cam. Then the cam at the other end of the cylinder pushes the rod forward using the lever, a slide and finger collet. Next half of the rotation of that cylindrical cam accomplishes clamping collet and return of the finger collet by moving the levers in opposite direction.

Here again, the cylindrical cam is rotated by only one revolution by actuating another single revolution clutch at the proper moment by a trip dog as indicated in the figure.

∆ **Transverse tool feeds**

The radially moving cutting tools (upto five) are fed sequentially at preset timings and desired length and rate of travel by individual cams mounted on the cam shaft which rotates slowly with one rotation for one machining cycle i.e., one product.

All the single revolution clutches are mounted on the auxiliary shaft which positively roates at a constant speed of 120 rpm. Rotation is transmitted from that to the cam shaft through speed reduction and a feed gear box (FGB) to vary the cam-shaft speed depending upon the cycle time for each job.

∆ **Feed motions of the axially fed cutting tools mounted on the turret**

The end points, length and rate of travel of the six tools on the turret are governed by a single plate cam having six lobes corresponding to the tools in the turret as shown in the figure. The rotational speed of that cam is kept same as that of the cam shaft.

∆ **Turret indexing mechanism**

The hexagonal turret is rotated (for indexing) by a Geneva mechanism where a Geneva disc having six radial slots is driven by a revolving pin. Before starting rotation, the locking pin is withdrawn by a cam lever mechanism shown in the diagram. The single rotation of the disc holding the indexing pin is derived from the auxiliary shaft with the help of another single revolution clutch as indicated

- **Kinematic system and operating principle of Swiss type automatic lathe**

The kinematic diagram of typical Swiss type automatic lathe is schematically shown in Fig. 4.7.14.

Both the high speed of the spindle and the low speed of the cam shaft are derived from the motor as indicated in the diagram. All the cutting tools mounted on the transverse slides are travelled to desired depth and at desired feed rate by a set of plate cams mounted on the cam shaft. The headstock with the spindle having the barstock clamped in it is moved forward and returned at desired feed rate by a set of plate cams mounted on the camshaft as shown.

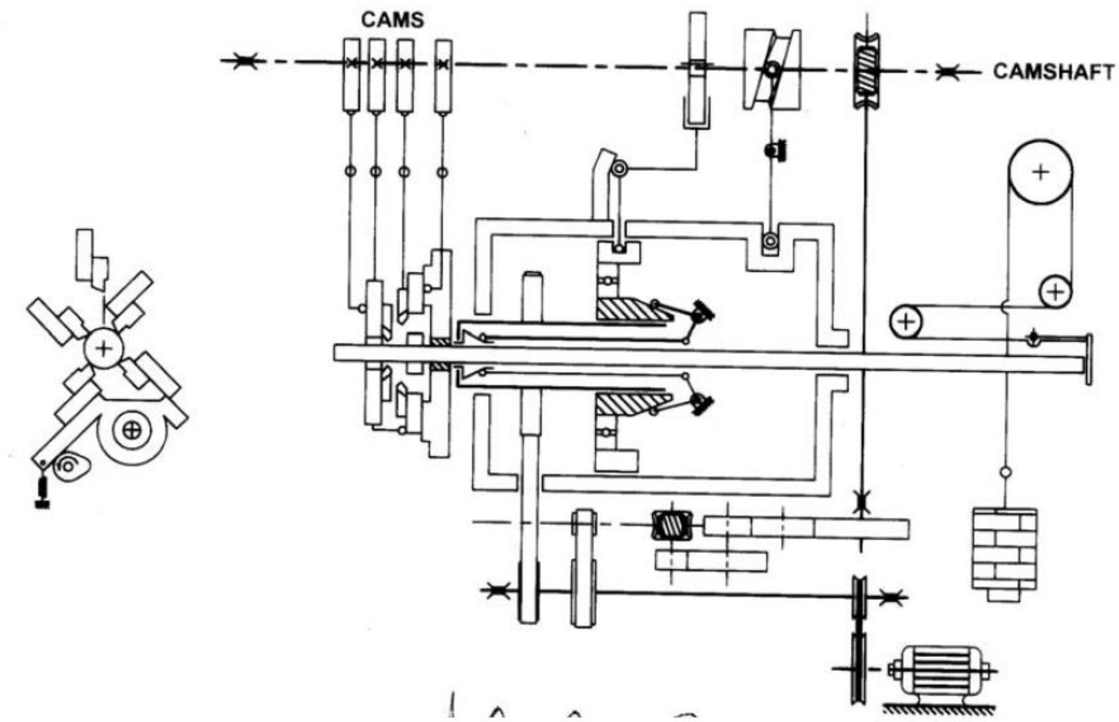


Fig. 4.7.14 *Kinematic system of Swiss type automatic lathe.*

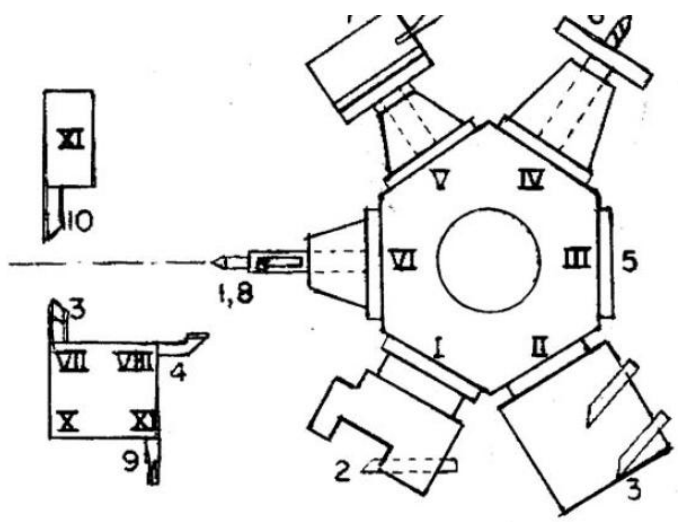


Fig. 4.7.15 *Tool layout for a typical job in single automatic lathe.*

Feeding of the bar, after completion and parting of a job is done sequentially by

- Opening the collet by shifting the taper ring by a cam as shown
- Pushing the bar, against the last working tool, by a gravitational force
- Collet clamping by return of the ring

(iii) Process Planning And Tool Layout For Machining A Product In Semi-Automatic And Automatic Lathes.

The procedural steps to be followed in sequence for batch or lot production of a job by machining in semi-automatic and automatic general purpose machine tools are :

(a) Thorough study of the job to be produced: in respect of :

- volume of production, i.e., number of pieces of the specific job to be produced
- material and its properties
- size and shape
- surfaces to be machined
- required dimensions with tolerances and surface finish
- end use of the product

(b) Selection of machine tool (after studying the job): in respect of ;
  - type
  - size
  - precision
  - kind and degree of automation

(c) Selection of blank (based on job and machine selected): in respect of;
  - bar chucking or housing type
  - preformed by; casting, forging, rolling etc.
  - if bar type; cross section (circular, tubular, square, hexagon etc.)
  - nominal size based on largest dimensions and availability
  - preformed by hot working or cold working

(d) Identification and listing of the elementary machining operations required, depending upon the product configuration

(e) Combine elementary machining operations as much as possible for saving time

(f) Sequence the operations (after combining)

(g) Select cutting tools: in respect of;
  - type
  - material
  - size
  - geometry
  - availability

  depending upon the machining operations (after combining) and work material

(h) work scheduling or preparation of the instruction sheet or operation chart giving column-wise :
  - description of the machining work to be done in sequence
  - cutting tools : type and location
  - speed and feed for each operation
  - length of travel of the tools
  - cutting fluid application;
    - yes or not required
    - type of cutting fluid

(i) Tool layout : schematically showing the type and configuration of the cutting tools and their location and mounting.

A typical tool layout for a particular job being machined in a single spindle automatic lathe is schematically shown in Fig. 4.7.15.

PART A

1. Name any four types of cutting tool used in a lathe.

2. How lathes are specified?

3. What are the requirements for tool material?

4. Give the expression to estimate the power required in machining.

5. Differentiate capstan and turret lathe.

6. What are the functions of feed rod and lead screw?

7. Why were power chucks developed?

8. What are the advantages of automatic lathes?

9. Calculate the power required for a steel rod of diameter at 200 rpm. Assume cutting force of 160 kg.

10. How is the size of a turret lathe specified?

11. Why is hollow spindle used in lathe?

12. What is meant by semi automatic lathe?

13. A shaft of 25 mm diameter is turned at a cutting speed of 50 m/min.Find the rpm of the shaft.

14. What are the applications of offset cutter holder?

15. What is meant by tool signature?

16. State the need for tumbler gear mechanism.

16 Marks Questions (Part B Questions)

17. Explain the operation and working principle of a centre lathe with neat sketch. (16)

18. Explain the mechanisms used for driving the headstock in a lathe. (16)

19. (i) What is a lathe carriage? Explain the various parts of a lathe carriage with a neat sketch (8)

(ii) Explain the various attachments used on a centre lathe. (8)

20. With a suitable sketch, explain any two taper turning methods. (16)

21. With a neat sketch, explain the thread cutting mechanism of a lathe. (16)

22. (i) How do you specify a lathe? Explain with suitable diagram. (6)

(ii) Explain the working principle of apron mechanism with neat sketch. (10)

23. (i) Differentiate between capstan and turret lathe. (6)

(ii) Explain the turret indexing mechanism with neat sketch. (10)

24. Explain the construction and working principle of a multi spindle automatic lathe with neat sketch. (16)

25. Explain the various lathe operations with neat sketch. (16)

26. Explain the bar feeding mechanism and turret indexing mechanism of a semi automatic lathe with neat sketch. (16)

27. (i) Briefly explain the principle of working of the sliding head type single spindle automatic machine. (8)

(ii) Describe with a neat sketch a turret automatic screw machine. (8)

28. What is a Swiss type automatic screw machine? How it functions and what are its main applications? (16)

29. Explain the working principle of capstan and turret lathe with neat sketch. (16)

30. Explain various tool-holding devises of semi automatic lathe with neat sketch. (16)

31. (i) Explain the types of possible machining operation on a turret lathe. (8)

(ii) Describe the single spindle automatic cutting off machine with neat sketch. (8)

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UNIT III
OTHER MACHINE TOOLS

Reciprocating machine tools: shaper, planer and 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

Configurations and basic functions of

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

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

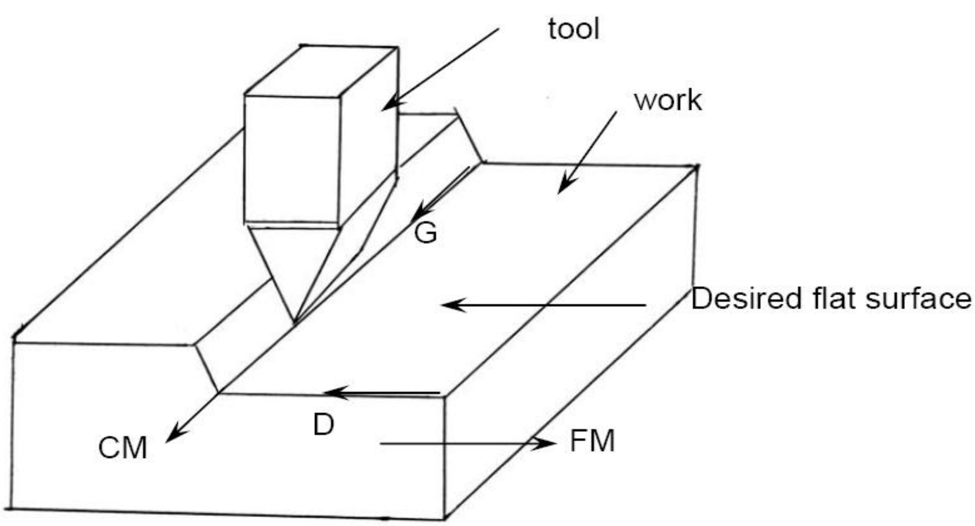


Fig. 4.4.2 *Principle of producing flat surface in shaping machine*

Planing machine

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

- o Though in principle both shaping and planing machines produce flat surface in the same way by the combined actions of the Generatrix and Directrix but in planing machine, instead of the tool, the workpiece reciprocates giving the fast cutting motion and instead of the job, the tool(s) is given the slow feed motion(s).

- o Compared to shaping machines, planing machines are much larger and more rugged and generally used for large jobs with longer stroke length and heavy cuts. In planing machine, the workpiece is mounted on the reciprocating table and the tool is mounted on the horizontal rail which, again, can move vertically up and down along the vertical rails.

- o Planing machines are more productive (than shaping machines) for longer and faster stroke, heavy cuts (high feed and depth of cut) possible and simultaneous use of a number of tools.

As in shaping machines, in planing machines also;

- Δ The length and position of stroke can be adjusted

- Δ Only single point tools are used

- Δ The quick return persists

- Δ Form tools are often used for machining grooves of curved section

- Δ Both shaping and planing machines can also produce large curved surfaces by using suitable attachments.

Slotting machine

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

Fig. 4.4.4 *Photographic view of a slotting machine*

Kinematic system and working principles of

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

• **Shaping machine**

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

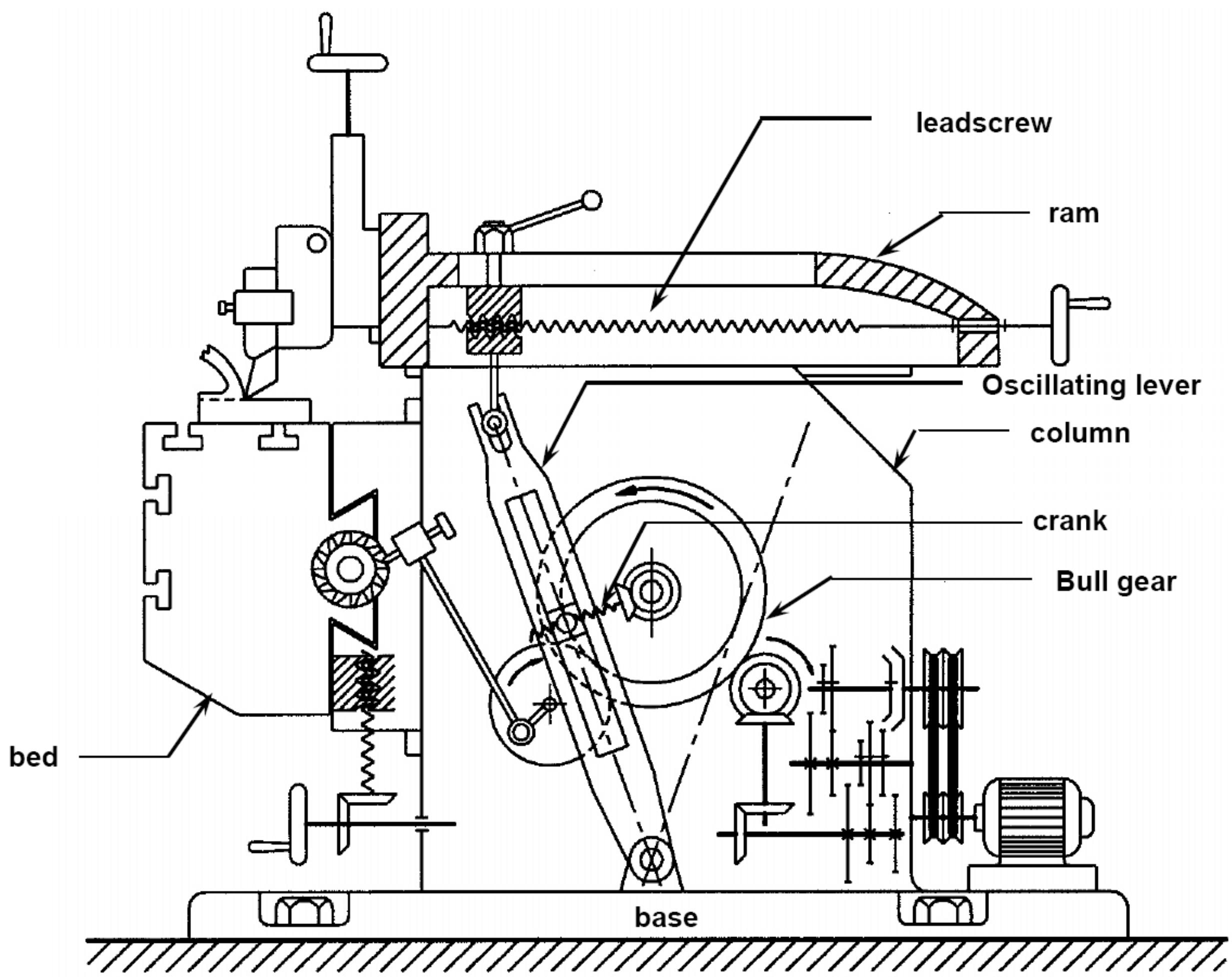


Fig. 4.4.5 *Kinematic diagram of a shaping machine.*

The central large bull gear receives its rotation from the motor through the belt-pulley, clutch, speed gear box and then the pinion. The rotation of the crank causes oscillation of the link and thereby reciprocation of the ram and hence the tool in straight path.
(Version 2 ME, IIT Kharagpur) Cutting velocity which needs to be varied depending upon the tool-work materials, depends upon

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

As, 111000*sCsxNVQRR*⎛ ⎞=+⎜ ⎟⎝ ⎠ (4.5.1)
To reduce idle time, return stroke is made faster and hence QRR > 1.0 (4.5.2)
Since 22*LsQRRLs*+=− (4.5.3)

where, L = length (fixed) of the oscillating lever
and s = stroke length
The benefit of quick return decreases when S becomes less.
The changes in length of stroke and position of the stroke required for different machining are accomplished respectively by

Δ Adjusting the crank length by rotating the bevel gear mounted coaxially with the bull gear

Δ Shifting the nut by rotating the leadscrew as shown in Fig. 4.4.5.

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

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

• **Planing machine**

The simple kinematic system of the planing machine enables transmission and transformation of rotation of the main motor into reciprocating motion of the large work table and the slow transverse feed motions (horizontal and vertical) of the tools. The reciprocation of the table, which imparts cutting motion to the job, is attained by rack-pinion mechanism. The rack is fitted with the table at its bottom surface and the pinion is fitted on the output shaft of the speed gear box which not only enables change in the number of stroke per minute but also quick return of the table.
The blocks holding the cutting tools are moved horizontally along the rail by screw-nut system and the rail is again moved up and down by another screw-nut pair as indicated in Fig. 4.4.3.

• **Slotting machine**

The schematic view of slotting machine is typically shown in Fig. 4.4.6
The vertical slide holding the cutting tool is reciprocated by a crank and connecting rod mechanism, so here quick return effect is absent. The job, to be machined, is mounted directly or in a vice on the work table. Like shaping machine, in slotting machine also the fast cutting motion is imparted to the tool and the feed motions to the job. In slotting machine, in addition to the
longitudinal and cross feeds, a rotary feed motion is also provided in the work table.
The intermittent rotation of the feed rod is derived from the driving shaft with the help of a four bar linkage as shown in the kinematic diagram.
It is also indicated in Fig. 4.4.6 how the intermittent rotation of the feed rod is transmitted to the leadsrews for the two linear feeds and to the worm – worm wheel for rotating the work table. The working speed, i.e., number of strokes per minute, N_s may be changed, if necessary by changing the belt-pulley ratio or using an additional “speed gear box”, whereas, the feed values are changed mainly by changing the amount of angular rotation of the feed rod per stroke of the tool. This is done by adjusting the amount of angle of oscillation of the paul as shown in Fig. 4.4.6. The directions of the

feeds are reversed simply by rotating the tapered paul by 180^{o} as done in shaping machines.

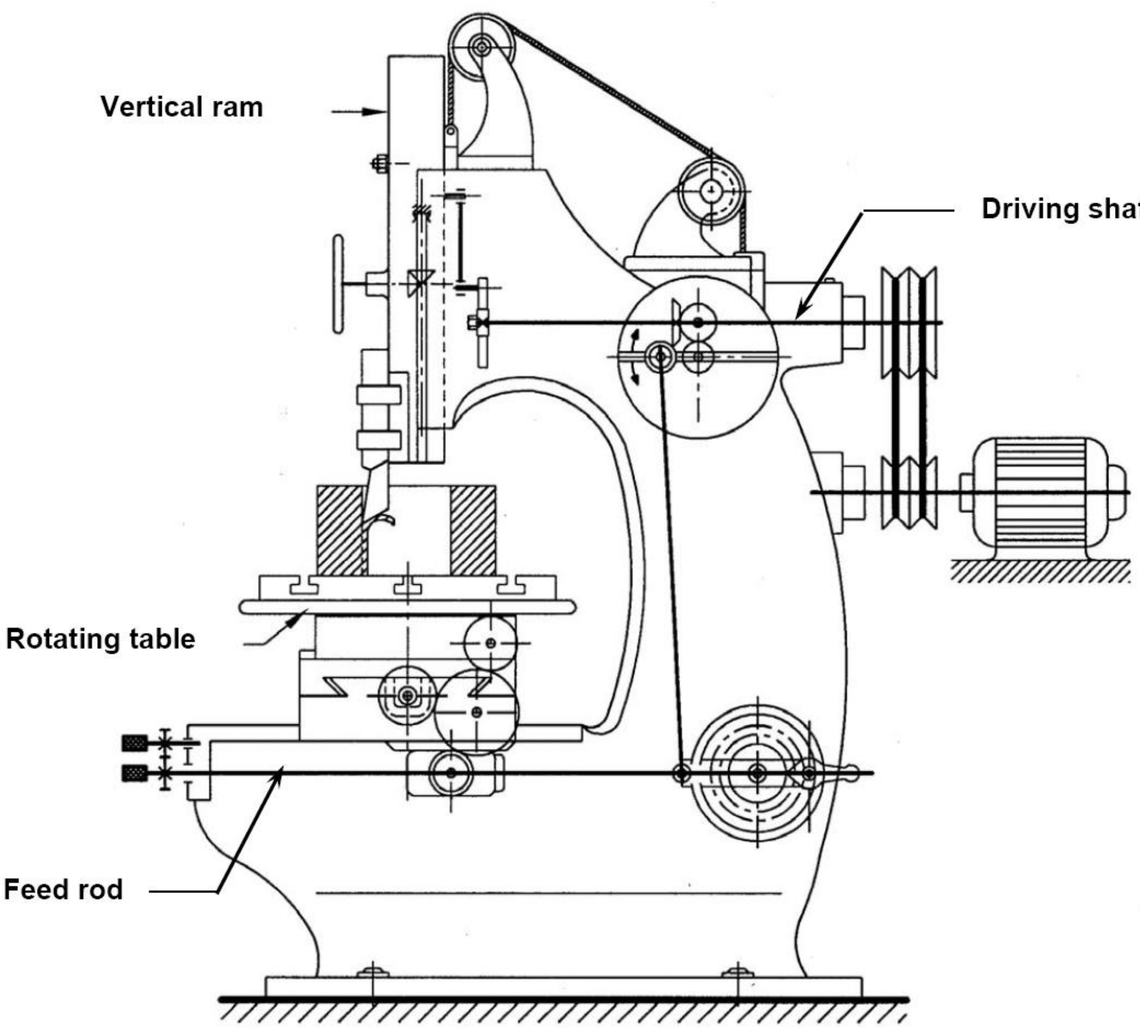


Fig. 4.4.6 *Kinematic system of a slotting machine.*
Various applications of

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

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

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

(a) horizontal surface (b) vertical surface

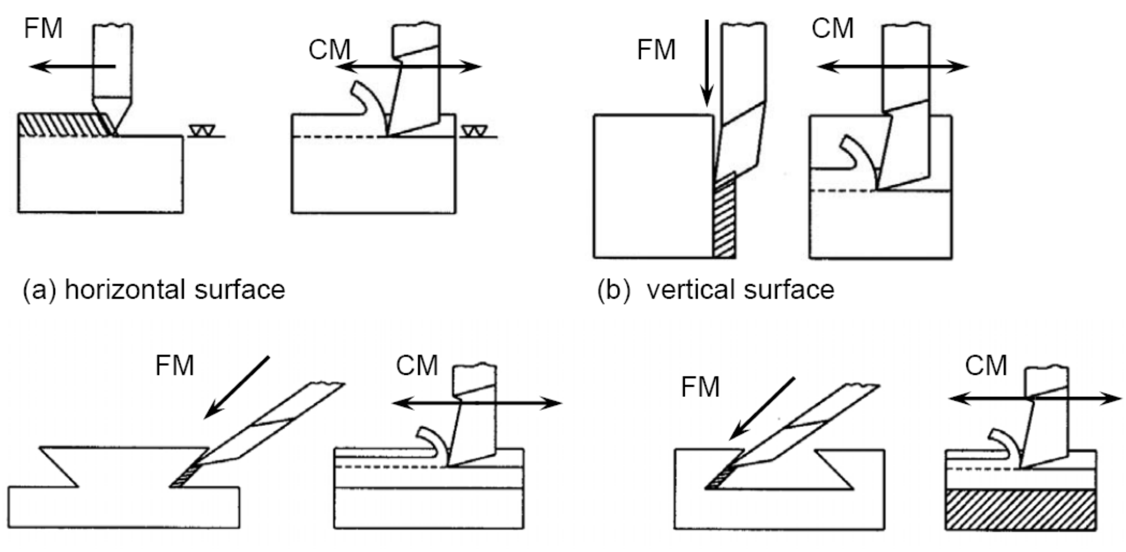
(c) inclined surfaces (dovetail slides and guides)

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

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

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

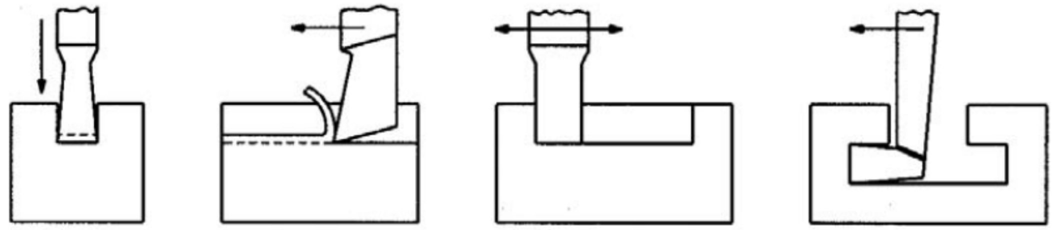
Δ Some other machining applications of shaping machines are cutting external keyway and splines, smooth slitting or parting, cutting teeth



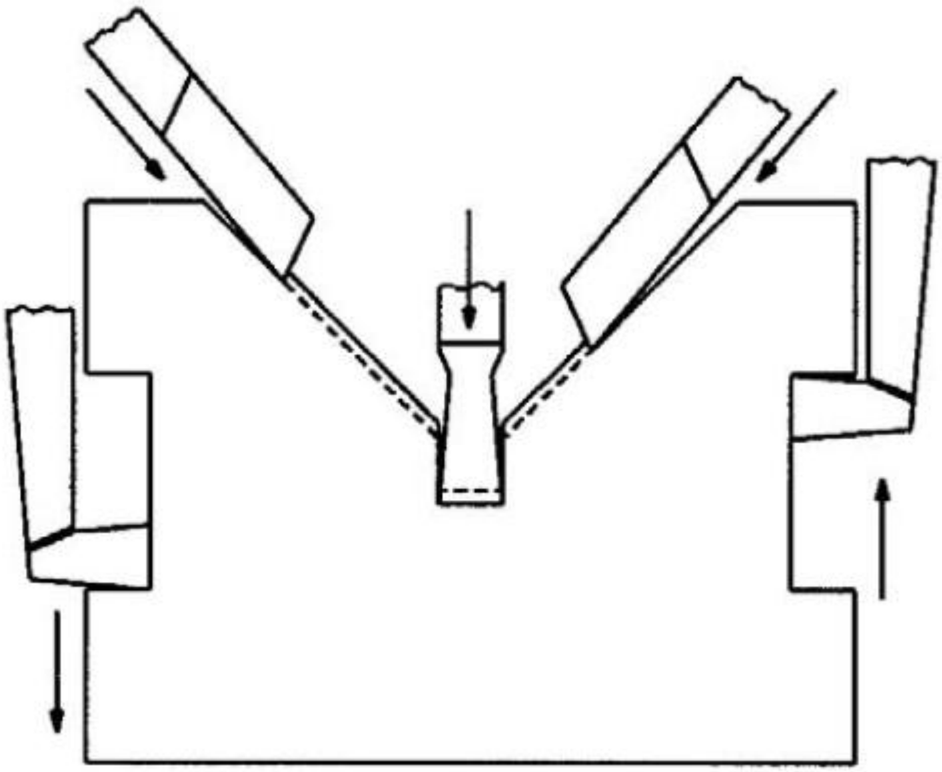
(c) inclined surfaces (dovetail slides and guides)

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

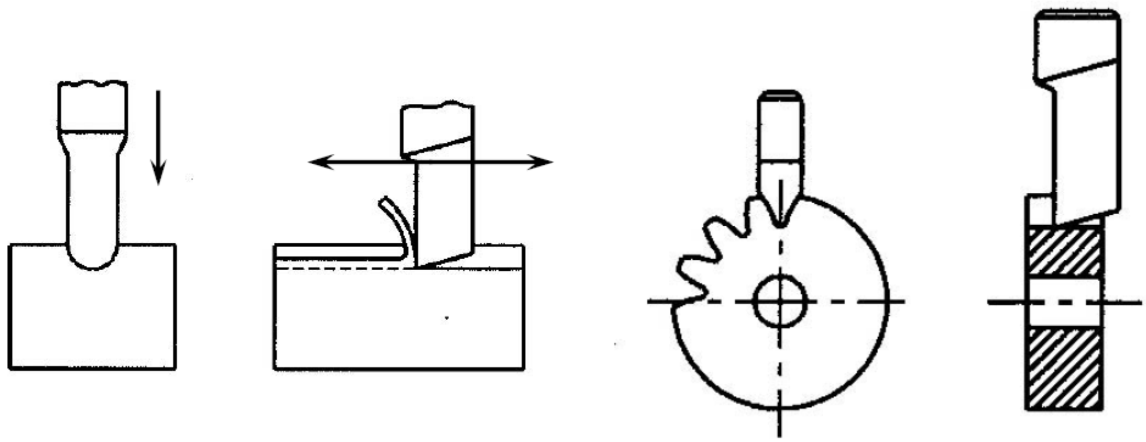
of rack for repair etc. using simple or form type single point cutting tools. Some unusual work can also be done, if needed, by developing and using special attachments.



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



(d) Vee-block



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

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

• **Planing machines**

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

Δ The common machining work shown in Fig. 4.4.7, Fig. 4.4.8 and Fig. 4.4.9 which are also done in shaping machines

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

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

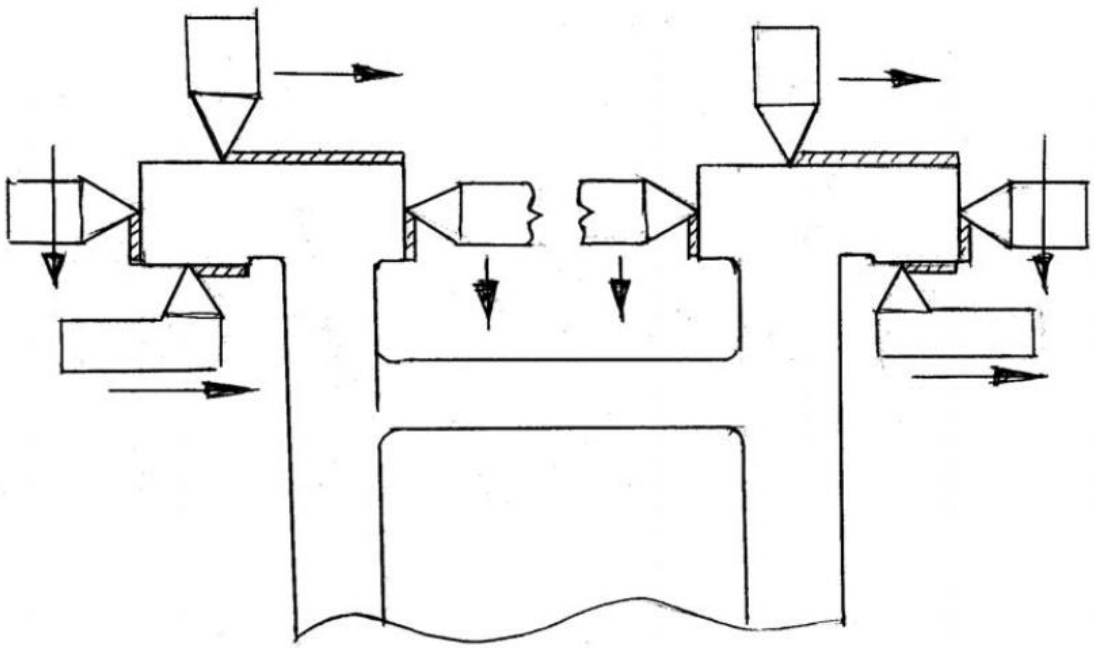


Fig. 4.4.10 *Machining of a machine bed in planing machine*

• **Slotting machine**

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

Δ Vertical tool reciprocation with down stroke acting

Δ Longer stroke length

Δ Less strong and rigid

Δ An additional rotary feed motion of the work table

Δ Used mostly for machining internal surfaces.

The usual and possible machining applications of slotting machines are :

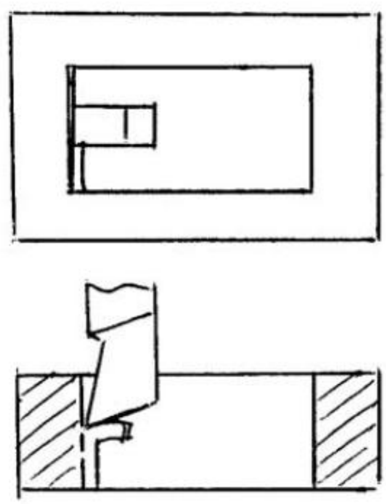
o Internal flat surfaces

o Enlargement and / or finishing non-circular holes bounded by a number of flat surfaces as shown in Fig. 4.4.11 (a)

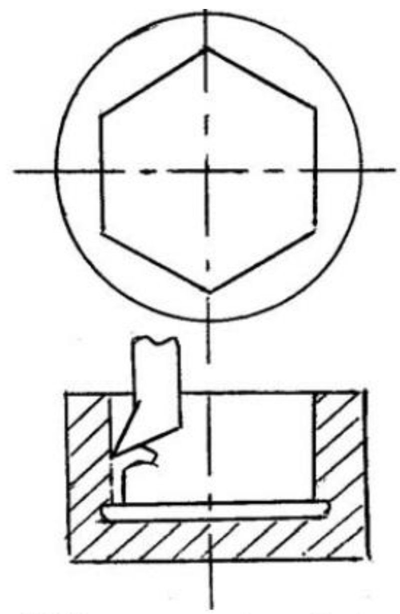
o Blind geometrical holes like hexagonal socket as shown in Fig. 4.4.11 (b)

o Internal grooves and slots of rectangular and curved sections.

o Internal keyways and splines, straight tooth of internal spur gears, internal curved surface of circular section, internal oil grooves etc. which are not possible in shaping machines.



(a) through rectangular hole



(b) hexagonal socket

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

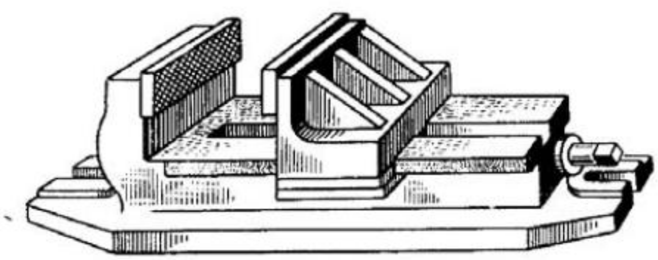
(ii) (b) Mounting of jobs and tools in drilling machines

Mounting of job and tool in drilling machine are typically shown in Fig. 4.5.15 (a).

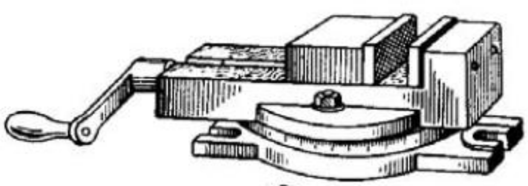
- **Mounting of job or blank**

In general purpose drilling machines like column and radial arm type, the workpiece or blank is generally mounted

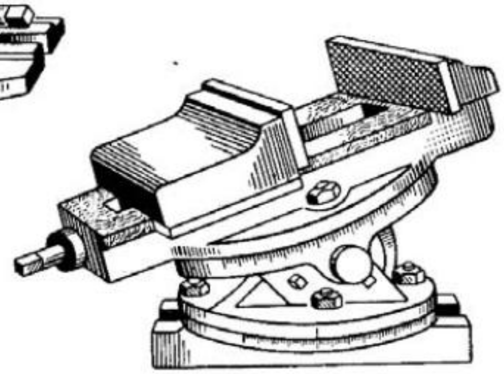
- ∆ by directly clamping on the drilling machine bed particularly when the job is heavy and / or of odd shape and size
- ∆ in a vice which is clamped on the bed as shown in Fig. 4.5.15 (a)
- ∆ in a suitable jig clamped on the bed.



(a)



(b)



(c)

Fig. 4.5.15 *(b) Vices to hold jobs in drilling machines*

Direct clamping of job or clamping of the vice and jig on the drilling bed are done with the help of clamp plates, T-bolts etc., as indicated in Fig. 4.5.16. Fig. 4.5.15 (b) shows the type of vices; plain, swivelling and universal type being used for holding small jobs in drilling machines. Fig. 4.5.16 also typically shows how a job is fitted in a jig for drilling in batch production

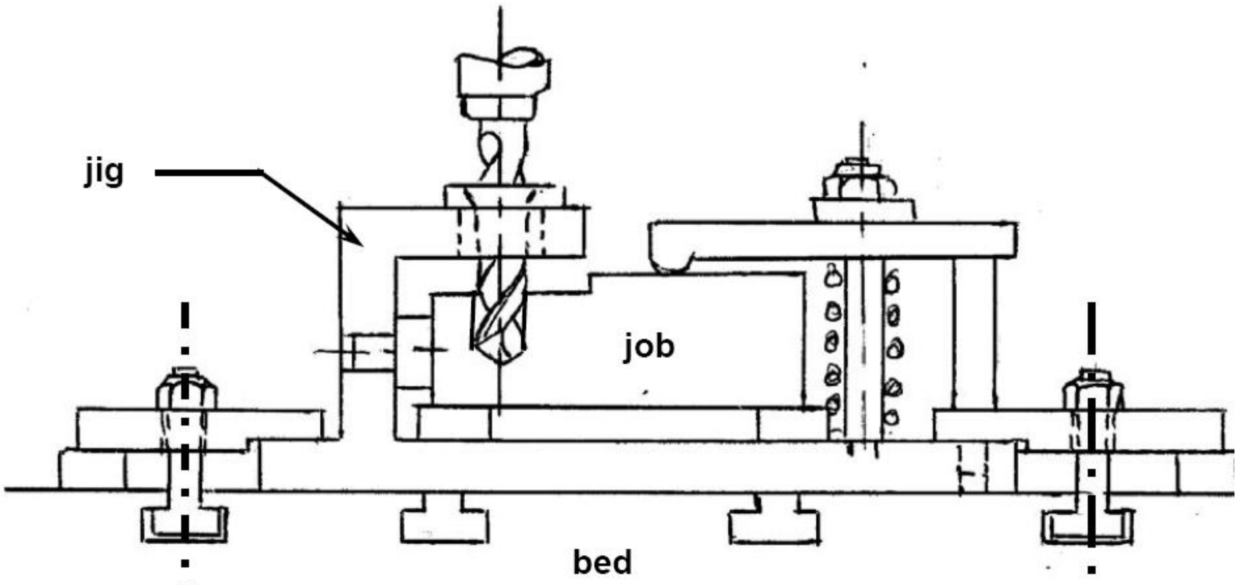


Fig. 4.5.16 *Mounting of job in a jig which is clamped on the drill - be*

- **Mounting of tools 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, counterboring, countersinking, tapping etc.
The basic methods of mounting drill bits in the spindle are simple as already has been typically shown in Fig. 4.5.15 (a).
Small straight shank type solid HSS and carbide drills are held in a drill chuck which is fitted in the drill spindle at its taper bore.
Larger taper shank drills are put straight in the spindle without drill chuck. However, for fitting the taper shank of the drill chuck and the taper shank drills in the spindle having larger taper bore, some sockets are put in between.
The sockets of varying size as shown in Fig. 4.5.17 are tapered inside to accommodate the taper shank of the drill chuck, drills and smaller sockets and tapered outside for fitting in the taper bore of the spindle :

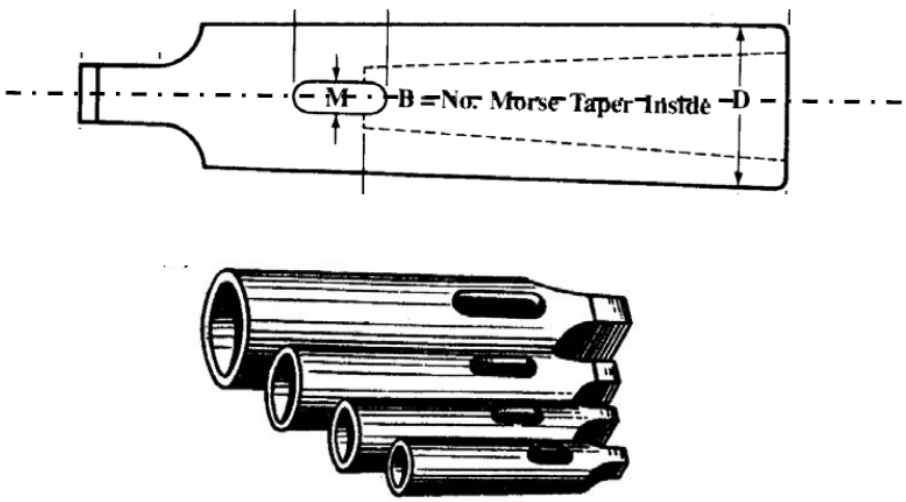


Fig. 4.5.17 *Drill socket for mounting drill chuck and taper shank drills in spindle*

(c) Mounting of jobs and cutting tools in

- Shaping machines
- Planning machines
- Slotting machines

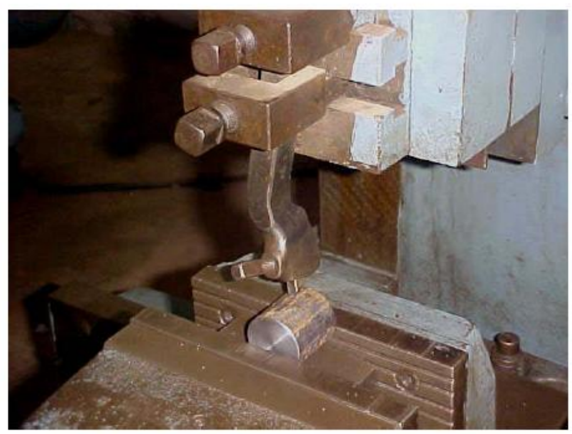
Job – tool mounting in shaping machines

Shaping machines with their limited stroke length and rigidity are used for machining small or medium size jobs.

- Job is mounted on the bed of shaping machine in the following ways :
  - Relatively large and odd shaped blanks are generally directly clamped on the bed with the help of clamps, supports, and T-bolts being fitted in the T-slots in the bed. Some odd shaped jobs are often clamped on the side surfaces of the bed.
  - Blanks of small size and geometric shape are gripped in a vice which is firmly clamped on the bed as shown in Fig. 4..5.19. For locating and supporting the blank in the vice parallel blocks and Vee-blocks are used.
  - In case of batch or small lot production, the blank is mounted in the fixture designed and used for that purpose. The fixture remains rigidly clamped on the bed.

Machining is done in shaping machines only by single point tools, even if it is a form tool. And only one tool is used at a time. That shank type tool is mounted, as can be seen in Fig. 4.5.19,

- Δ either directly in the clapper box
- Δ or in a tool holder which is fitted in the clapper box.



- **Job-tool mounting in planing machine**

Planing machines are used for machining large and heavy jobs requiring large work table, large stroke length and reasonable productivity.

- **Mounting of job in Planing machine**

  - For conventional machining the large and heavy job is directly mounted on the work table and rigidly clamped with the help of number of clamps, angle plates, and T-bolts.
  - Occasionally, some rod like jobs are mounted in between centres for some special work requiring rotation of the rod.

- **Mounting of tools in planing machines**

In planning machines also, only single point cutting tools are used but usually more than one tool is used simultaneously from different planes and angles. Fig. 4.5.20 typically shows the method of tool mounting in planning machine.

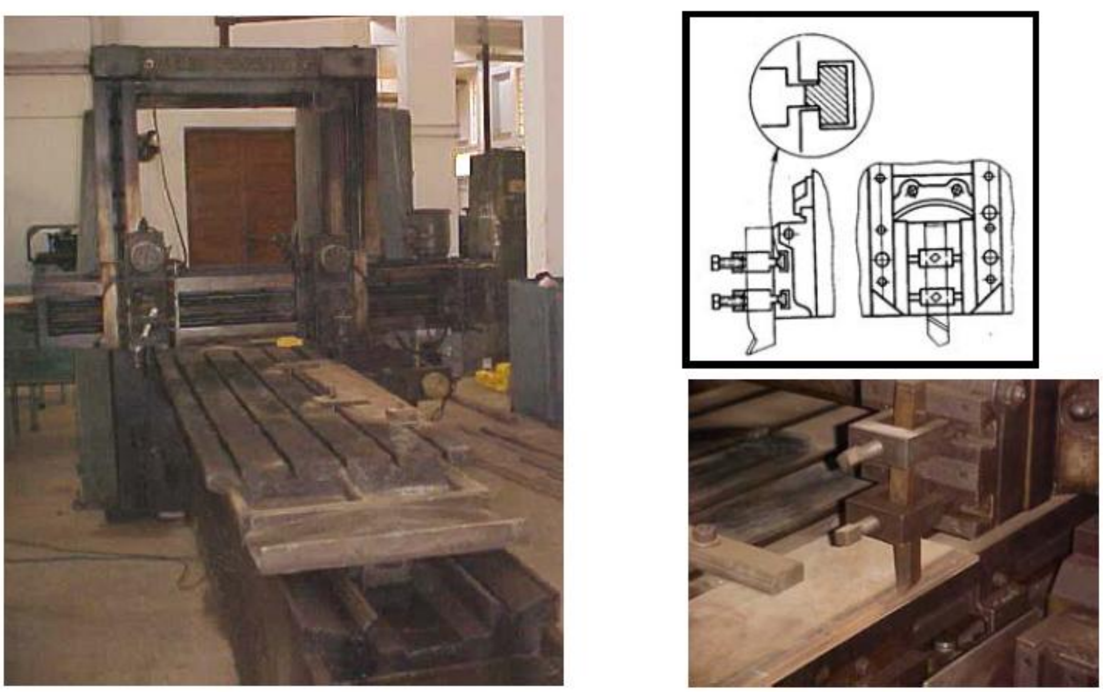


Fig. 4.5.20 *Mounting of cutting tools in planning machine*

- **Job-tool mounting in slotting machine**

Vertical shaper like but less rigid slotting machines are used for less volume of machining work with light cuts and lower MRR using only one single point tool at a time.

- **Job mounting on slotting machine**

It is already known that in slotting machine the flat work table can linearly slide along X and Y directions over the guides. In addition to that there is a rotary table fitted on the top of the sliding bed. On the rotary table chuck, face plate and even small fixtures can be mounted.

Depending on the types of the job and machining work required, the blank is mounted

- Δ directly on the top of the sliding bed with the help of clamps etc.
- Δ on the rotary table or in the chuck as shown in Fig. 4.5.21.
- Δ occasionally in the fixture which is clamped on the flat bed or face plate.

- **Tool mounting in slotting machine**

The method of mounting the single point cutting tool is also typically shown in Fig. 4.5.21.

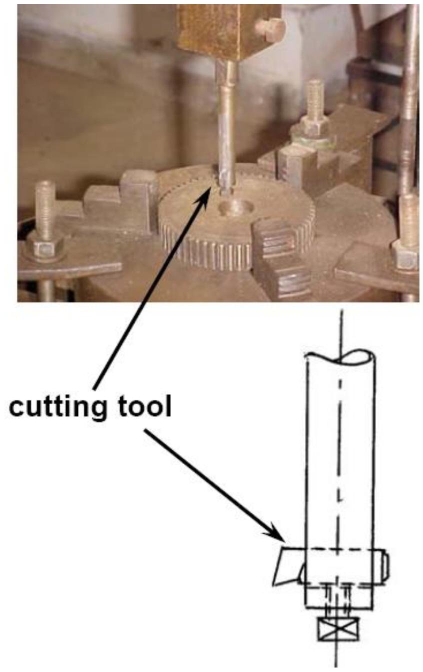


Fig. 4.5.21 *Mounting of job and tool in slotting machine*

(ii) (d) Mounting of Job and Tool in milling machines

- **Mounting of job or blank**

Job or blank is mounted in general purpose milling machines as follows :

- relatively large and irregular shaped jobs for piece or job order production are directly mounted and clamped on the table with the help of clamps, supports, Vee-blocks, T-bolts etc.
- small components of geometrical shape are gripped in the vice which is rigidly clamped on the table
- jobs requiring indexing motion, e.g., prisms, bolt-heads, gears, splines etc. are mounted directly or indirectly (using a mandril) in a dividing or indexing head as shown in Fig. 4.5.22
- small jobs, for its repetitive or batch production, are preferably mounted (located, supported and clamped) in the fixture (designed for the purpose) which is firmly clamped on the table.

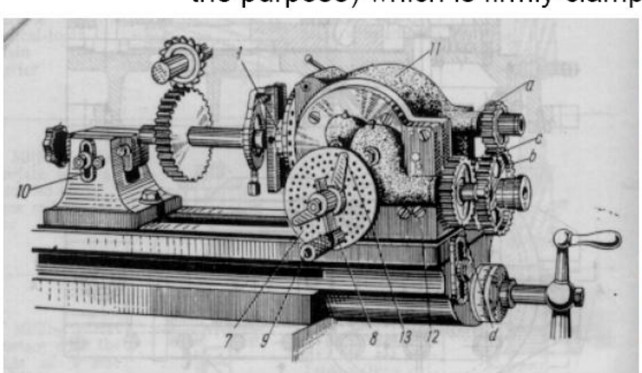


Fig. 4.5.22 *Mounting of job on the dividing head in milling machine.*

Mounting of cutting tools in milling machines

Milling cutters are rotary tools of various sizes, configurations and materials. The general methods of mounting cutting tools in general purpose milling machines are :

- Plain or slab milling cutters and disc type profile sharpened or form relieved cutters (having central bore) are mounted on horizontal milling arbour as shown in Fig. 4.5.23.
- End milling cutters with straight shank are mounted coaxially in the spindle – bore with the help of collet - chuck as shown in Fig. 4.5.24
- Shell milling cutters and heavy face milling cutters are mounted in the hollow spindle with the help of a short but rugged arbour, a fastening screw and a draw bar as shown in Fig. 4.5.25
- In case of carbide tipped milling cutters, the uncoated or coated carbide inserts of desired size, shape and number are mechanically clamped at the periphery of the plain and disc type milling cutters, large end milling cutters and face milling cutters as typically shown in Fig. 4.5.26. End mills of very small diameter are provided with one or two carbide inserts clamped at the tool – end.

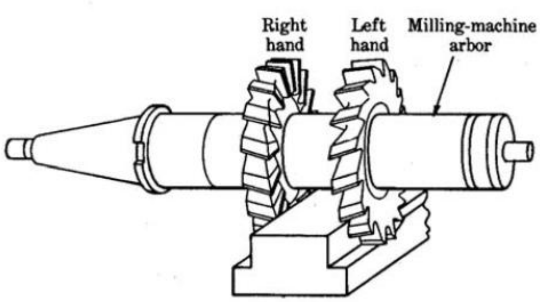
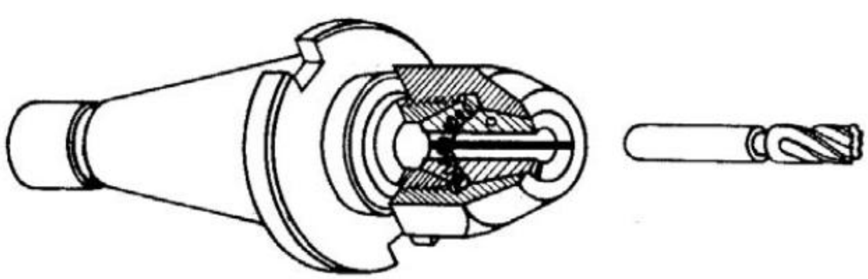


Fig. 4.5.23 *Mounting of cutting tools on milling arbours.*



4.5.24 *Mounting of straight shank end milling cutters in spindle by collet.*

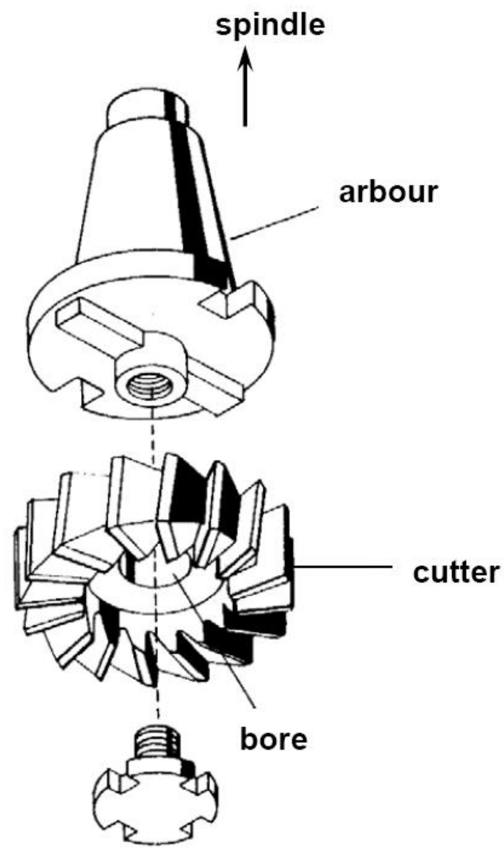


Fig. 4.5.25 *Mounting shell and face milling cutters in milling machine spindle.*

BASIC PRINCIPLES OF BROACHINING

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

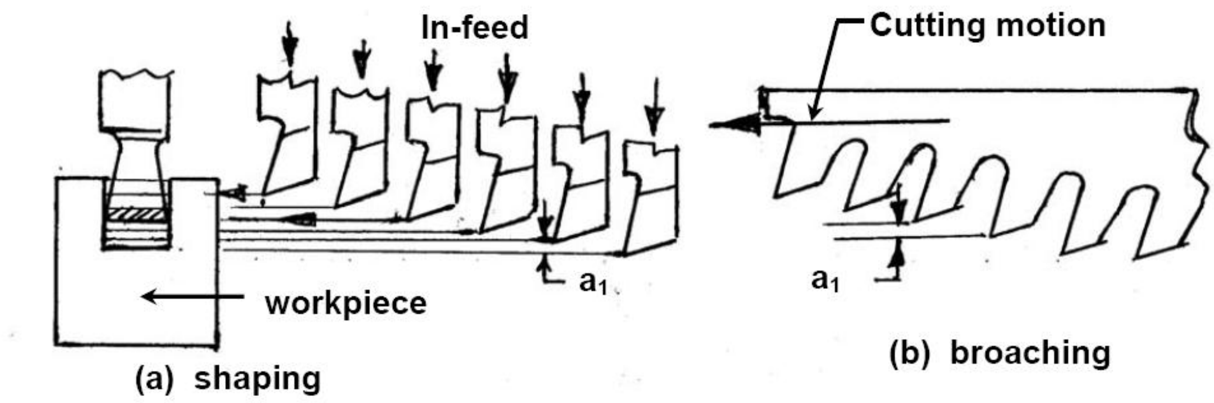


Fig. 4.10.1 Basic principle of broaching.

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

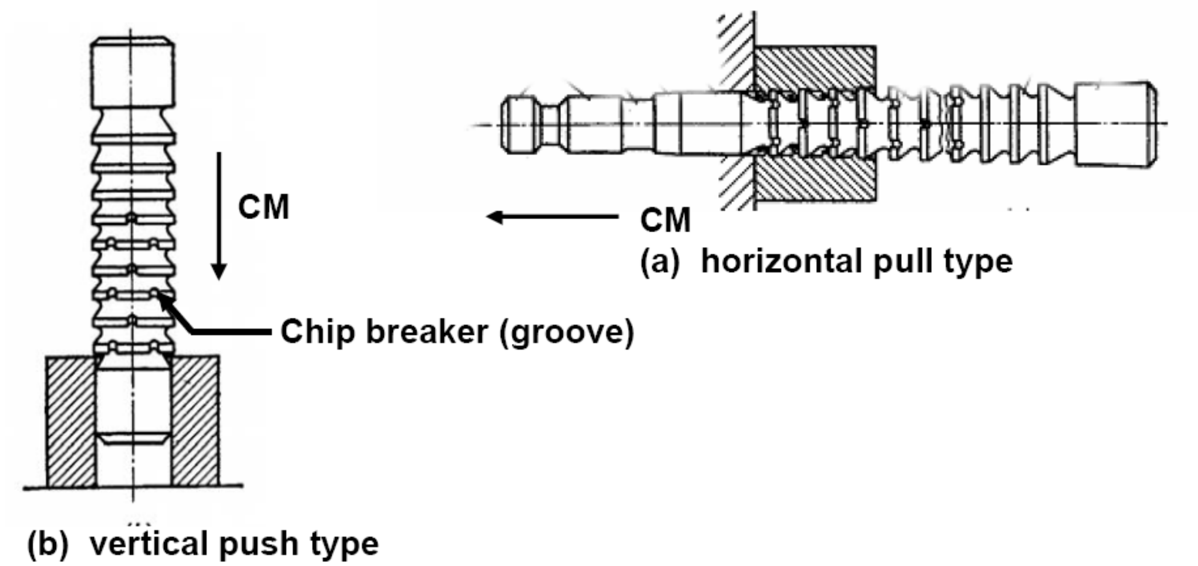


Fig. 4.10.2 Schematic views of finishing hole by broaching.

Construction And Operation Of Broaching

 Construction of broaching tools

Construction of any cutting tool is characterised mainly by

- Configuration
- Material and
- Cutting edge geometry

• **Configuration of broaching tool**

Both pull and push type broaches are made in the form of slender rods or bars of varying section having along its length one or more rows of cutting teeth with increasing height (and width occasionally). Push type broaches are subjected to compressive load and hence are made shorter in length to avoid buckling.
The general configuration of pull type broaches, which are widely used for enlarging and finishing preformed holes, is schematically shown in Fig. 4.10.3.

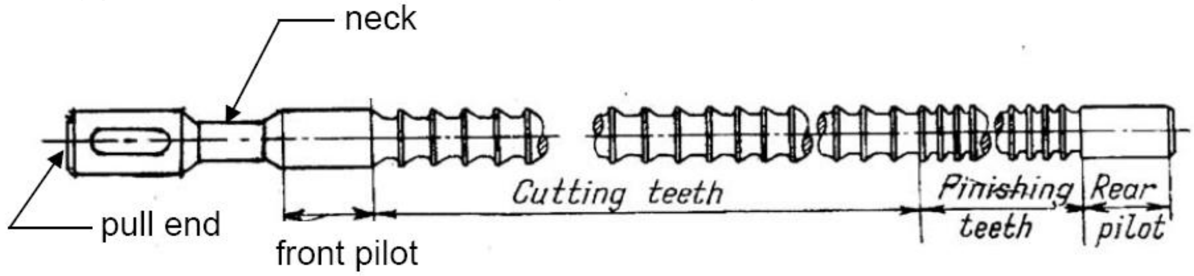


Fig. 4.10.3 *Configuration of a pull type broach used for finishing holes.*

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

- Pull end for engaging the broach in the machine.
- Neck of shorter diameter and length, where the broach is allowed to fail, if at all, under overloading
- Front pilot for initial locating the broach in the hole
- Roughing and finishing teeth for metal removal
- Finishing and burnishing teeth

- Rear pilot and follower rest or retriever

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

- o Type of the broach; pull or push type
- o Number of cutting edges and their pitch depending upon the work material and maximum thickness of the material layer to be removed
- o 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
1.25***pL***= to 1.5***L***
where, L = length of the hole or job.
The total number of cutting teeth for a broach is estimated from,
$T_n \geq$ (total depth of material) / tooth rise, a_1 (which is decided based on the tool – work materials and geometry).

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

• **Material of broach**

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

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

Fig. 4.10.4 shows the general configuration of the broaching teeth and their geometry. The cutting teeth of HSS broaches are provided with positive radial or orthogonal rake (5^o to 15^o) and sufficient primary and secondary clearance angles (2^o to 5^o and 5^o to 20^o respectively) as indicated in Fig. 4.10.4.
Small in-built chip breakers are alternately provided on the roughing teeth of the broach as can be seen in Fig. 4.10.2 to break up the wide curling chips

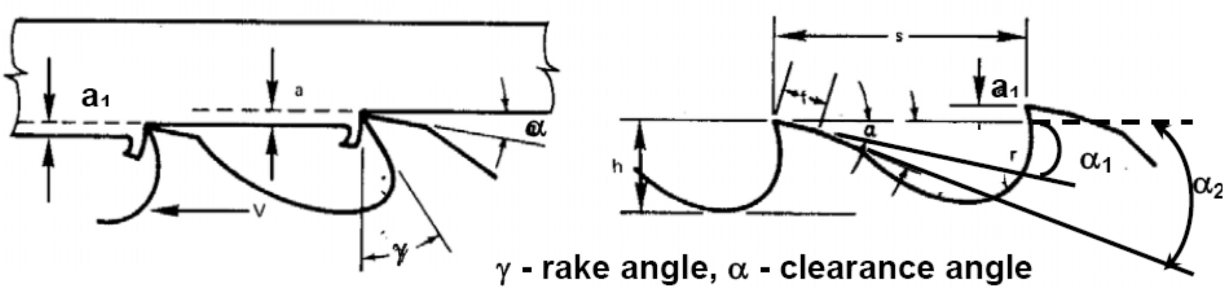


Fig. 4.10.4 *Geometry of teeth of broaching tools.*

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

 Broaching operation

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

• Selection of broach and broaching machine

• Mounting and clamping the broach in the broaching machine

• Fixing workpiece in the machine

- Planning tool - work motions
- Selection of the levels of the process parameters and their setting
- Conducting machining by the broach.

• **Selection of broach and broaching machine**

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

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

Broaching machine has to be selected based on

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

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

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

Fig. 4.10.5 typically shows a broach pull head commonly used for holding, clamping and pulling pull type broach. Just before fitting in or removing the broach from the broach pull head (Fig. 4.10.5 (a)), the sliding outer socket is
Fig. 4.10.5 *Mounting and clamping pull type broach.*
pushed back against the compression spring. After full entry of the pull end of the broach in the head the socket is brought forward which causes locking of the broach by the radially moving strips as shown in Fig. 4.10.5 (b).
Pull type broaches are also often simply and slight flexibly fitted by a suitable adapter and pin as can be seen in Fig. 4.10.6.
Fig. 4.10.6 *Fitting pull type broach by an adapter and a pin.*

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

Broaching is used for mass production and at fast rate. The blanks are repeatedly mounted one after another in an appropriate fixture where the blanks can be easily, quickly and accurately located, supported and clamped. **(a) (b) unclamp / fitting inclamp comp. spring broach pin**
Fig. 4.10.5 typically shows a broach pull head commonly used for holding, clamping and pulling pull type broach. Just before fitting in or removing the broach from the broach pull head (Fig. 4.10.5 (a)), the sliding outer socket is

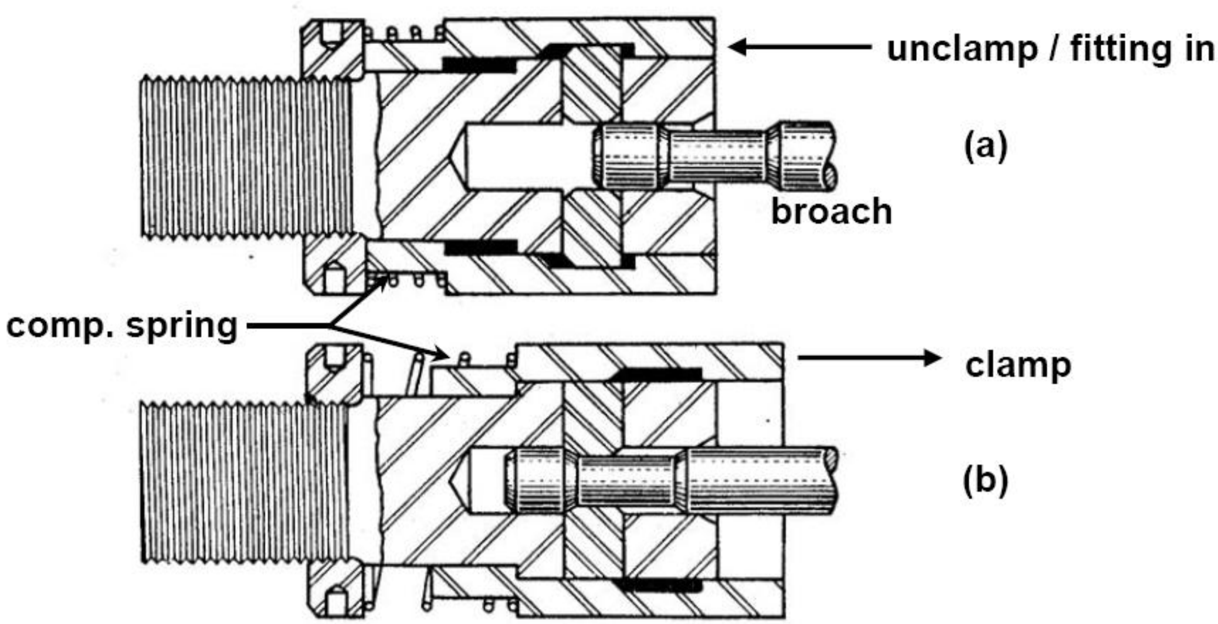


Fig. 4.10.5 *Mounting and clamping pull type broach.*
pushed back against the compression spring. After full entry of the pull end of the broach in the head the socket is brought forward which causes locking of the broach by the radially moving strips as shown in Fig. 4.10.5 (b).
Pull type broaches are also often simply and slight flexibly fitted by a suitable adapter and pin as can be seen in Fig. 4.10.6.
Fig. 4.10.6 *Fitting pull type broach by an adapter and a pin.*

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

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

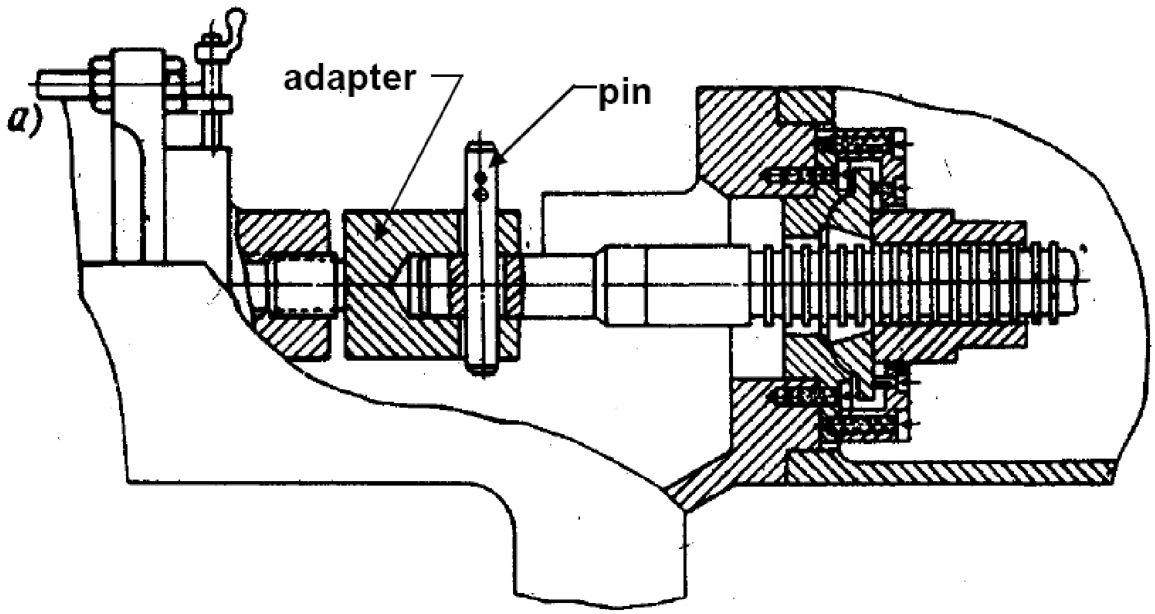


Fig. 4.10.6 *Fitting pull type broach by an adapter and a pin.*

Mounting of workpiece or blank in broaching machine

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

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

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

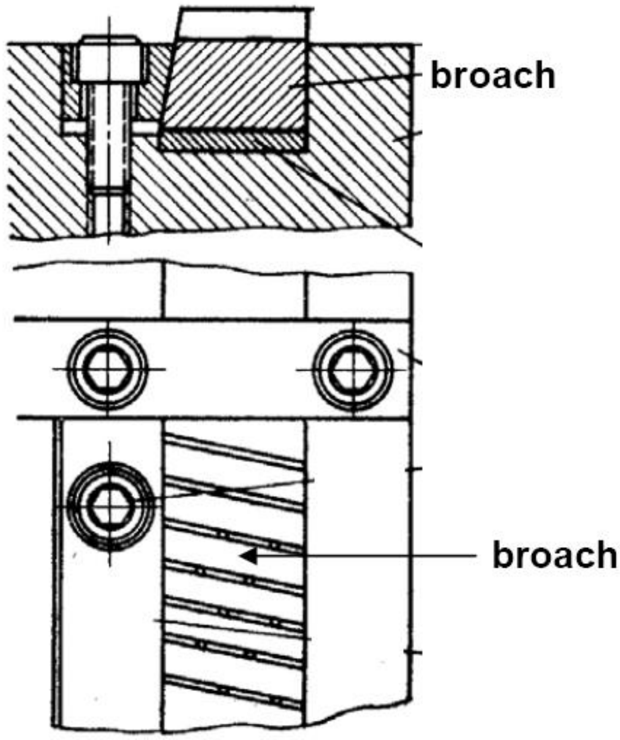


Fig. 4.10.7 *Mounting external broach for surfacing and slotting.*

Tool – work motions and process variables

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

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

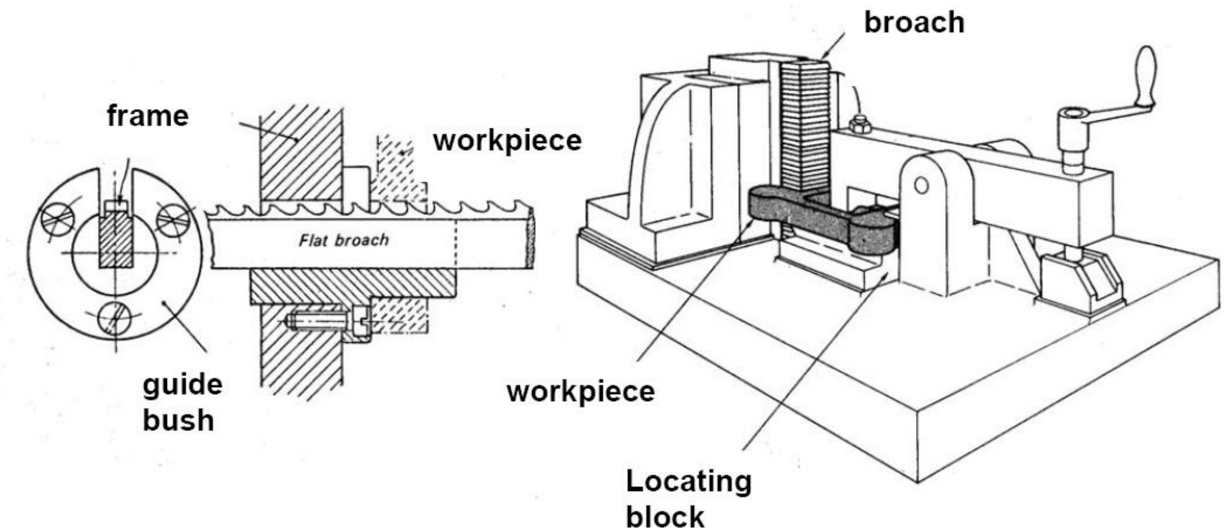


Fig. 4.10.8 *Mounting blank in broaching machine.*

Different Types Of Broaches And Their Applications

Broaching is getting more and more widely used, wherever feasible, for high productivity as well as product quality. Various types of broaches have been developed and are used for wide range of applications.

Broaches can be broadly classified in several aspects such as,

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

 Internal and external broaching (tool)

o **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;

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

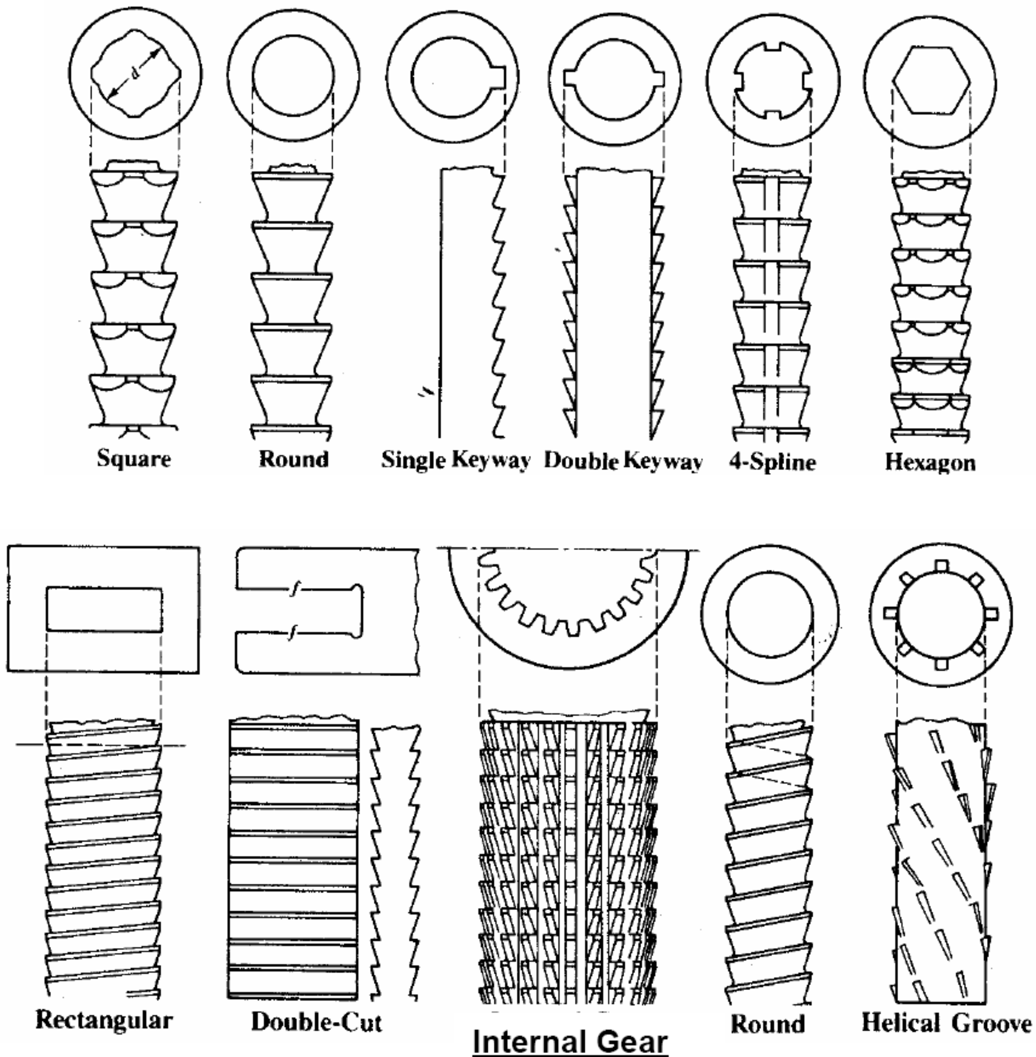


Fig. 4.10.9 *Internal broaching – tools and applications.*

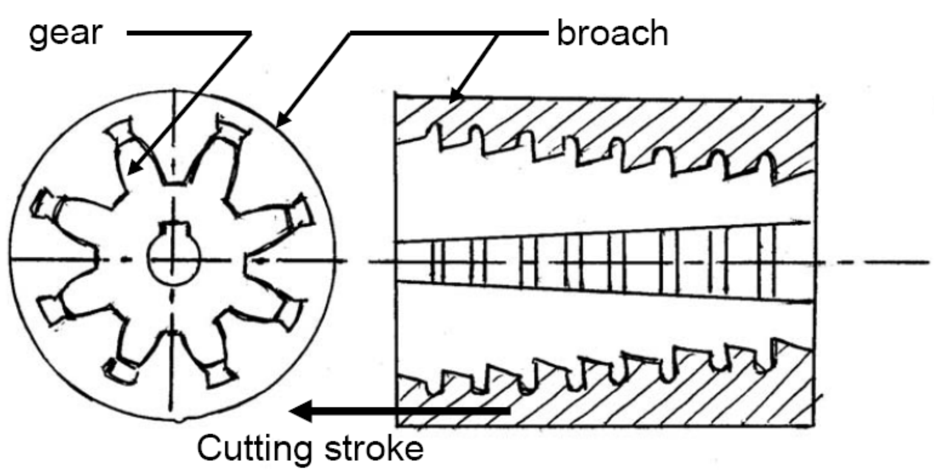


Fig. 4.10.10 *Machining external gear teeth by broaching.*

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

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

External broaching tools are often made in segments which are clamped in fixtures for operation.
Fig. 4.10.11 *Typical external broaching (a) making slot*
(b) teeth of gear sector

- **Pull type and push type broaches**

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

- **Ordinary – cut and Progressive type broach**

Most of the broaches fall under the category of Ordinary – cut type where the teeth increase in height or protrusion gradually from tooth to tooth along the length of the broach. By such broaches, work material is removed in thin **(a) (b) gear sector broach**

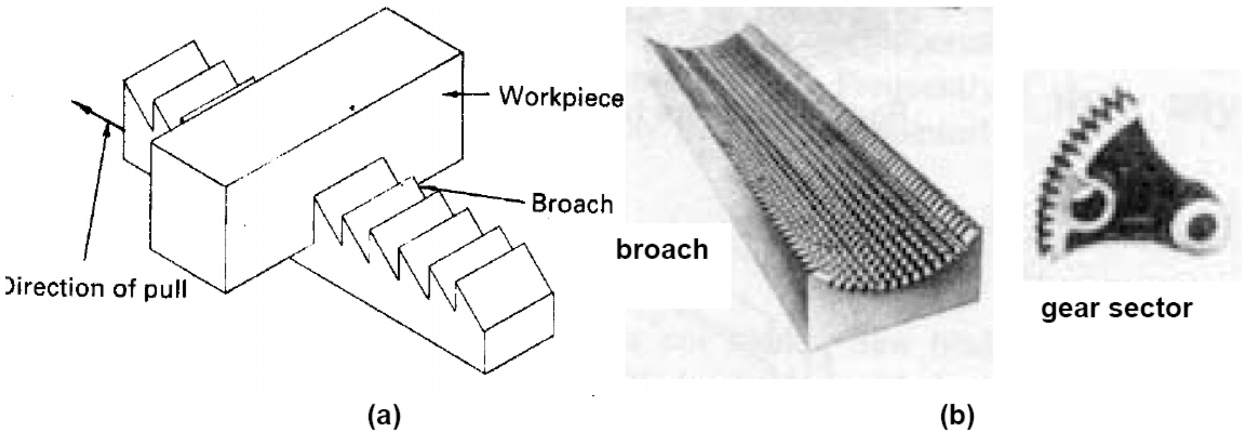


Fig. 4.10.11 *Typical external broaching (a) making slot (b) teeth of gear sector*

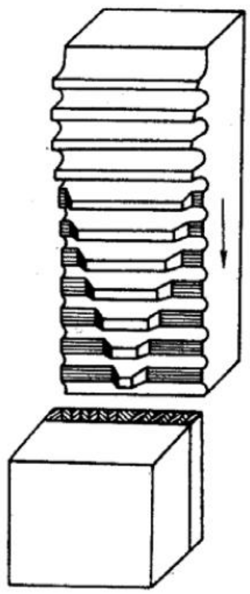
Pull type and push type broaches

During operation a pull type broach is subjected to tensile force, which helps in maintaining alignment and prevents buckling.

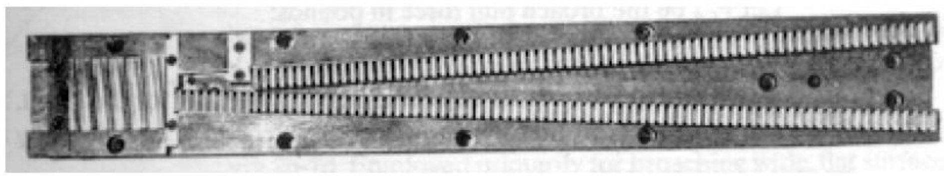
Pull type broaches are generally made as a long single piece and are more widely used, for internal broaching in particular. Push type broaches are essentially shorter in length (to avoid buckling) and may be made in segments. Push type broaches are generally used for external broaching, preferably, requiring light cuts and small depth of material removal.

Ordinary – cut and Progressive type broach

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



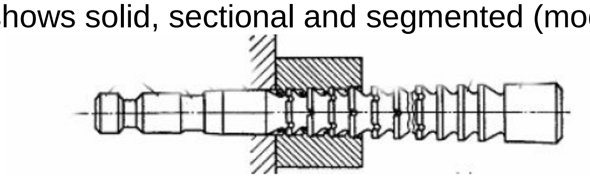
a) single strip



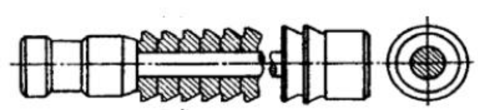
(b) double strip type

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

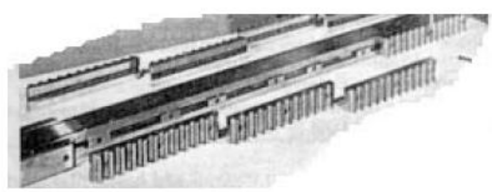
Solid, Sectional and module type broaches
Broaches are mostly made in single pieces specially those used for pull type internal broaching. But some broaches called sectional broaches, are made by assemblying several sections or cutter-pieces in series for convenience in manufacturing and resharpening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



(a) solid



(b) sectional



(c)segmented

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

Broaching Machines
The unique characteristics of broaching operation are

- For producing any surface, the form of the tool (broach) always provides the Generatrix and the cutting motion (of the broach relative to the job surface) provides the Directrix.

- So far as tool – work motions, broaching needs only one motion and that is the cutting motion (velocity) preferably being imparted to the broach.

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

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

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

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

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

- According to configuration

    Δ horizontal

    Δ vertical

- According to number of slides or stations

    Δ single station type

    Δ multiple station type

    Δ indexing type

- According to tool / work motion

    Δ intermittent (one job at a time) type

    Δ continuous type

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

o **Horizontal broaching machine**

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

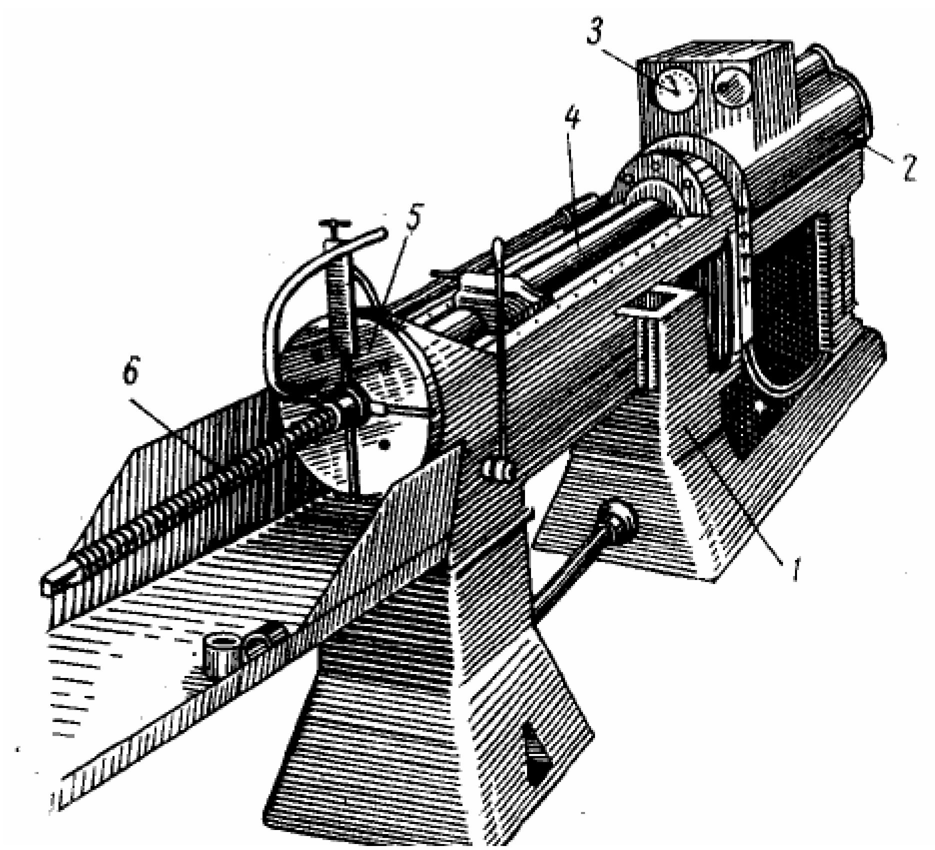


Fig. 4.10.14 *Horizontal broaching machine.*

Vertical broaching machine
Vertical broaching machines, typically shown in Fig. 4.10.15,

Δ occupies less floor space

Δ are more rigid as the ram is supported by base

Δ mostly used for external or surface broaching though internal broaching is also possible and occasionally done.

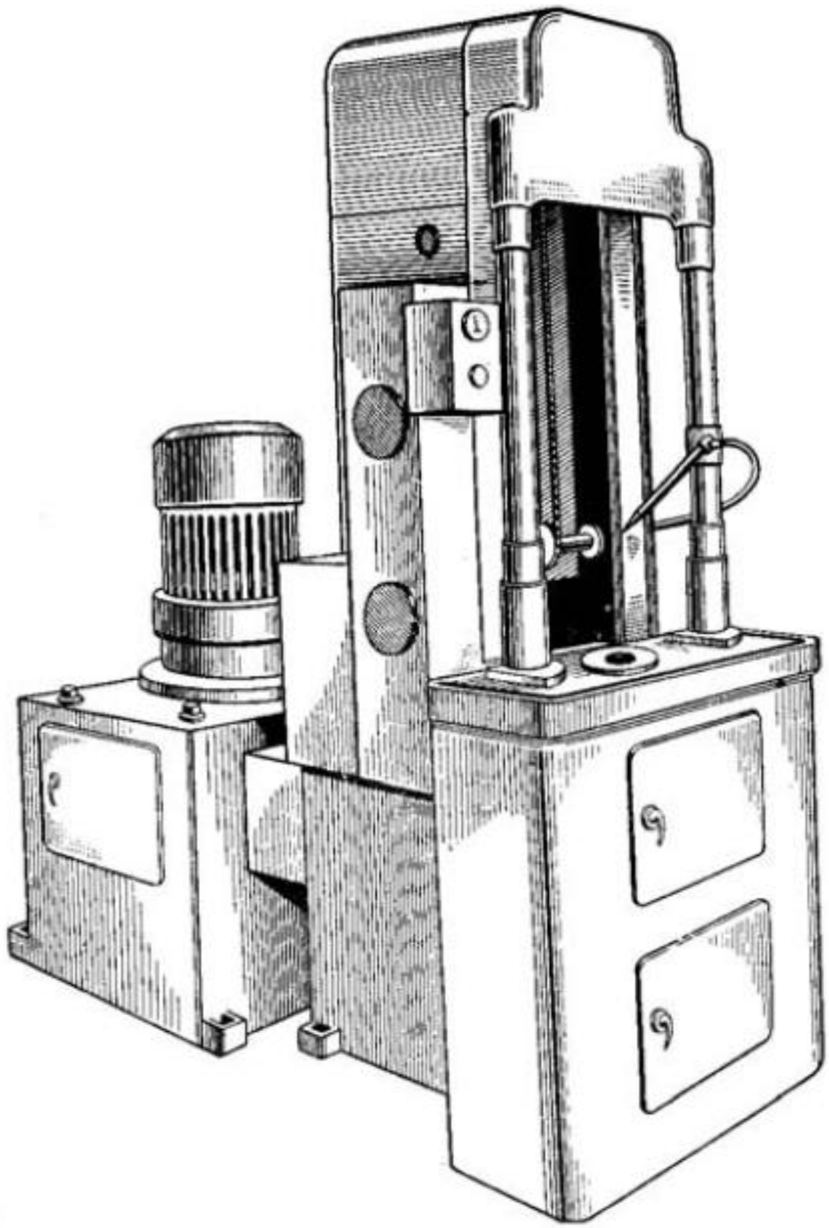


Fig. 4.10.15 Vertical broaching machine.

High production broaching machines

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

- Δ incorporating automation in tool – job mounting and releasing

Δ increasing number of workstations or slides for simultaneous multiple production

Δ quick changing the broach by turret indexing

Δ continuity of working

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

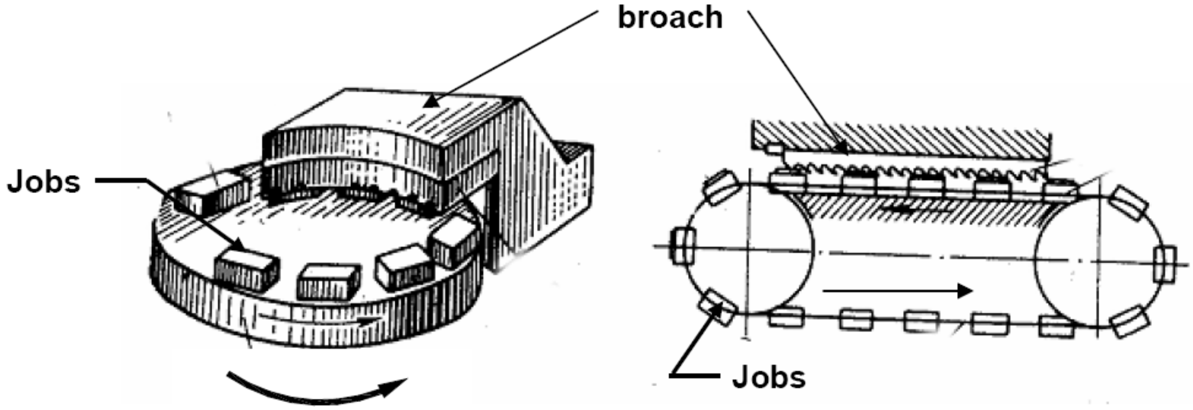


Fig. 4.10.16 *Continuous broaching.*

ADVANTAGES AND LIMITATIONS OF BROACHING

□ **Major advantages**

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

□ **Limitations**

- Only through holes and surfaces can be machined
- Usable only for light cuts, i.e. low chip load and unhard materials

- Cutting speed cannot be high

- Defects or damages in the broach (cutting edges) severely affect product quality

- Design, manufacture and restoration of the broaches are difficult and expensive

- Separate broach has to be procured and used whenever size, shape and geometry of the job changes

- Economic only when the production volume is large.

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.

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

28.1Grinding 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 superabrasive wheel.

28.1.2 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 workpiece. 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 superabrasive grinding wheels are shown in Fig.28.1 and 28.2.

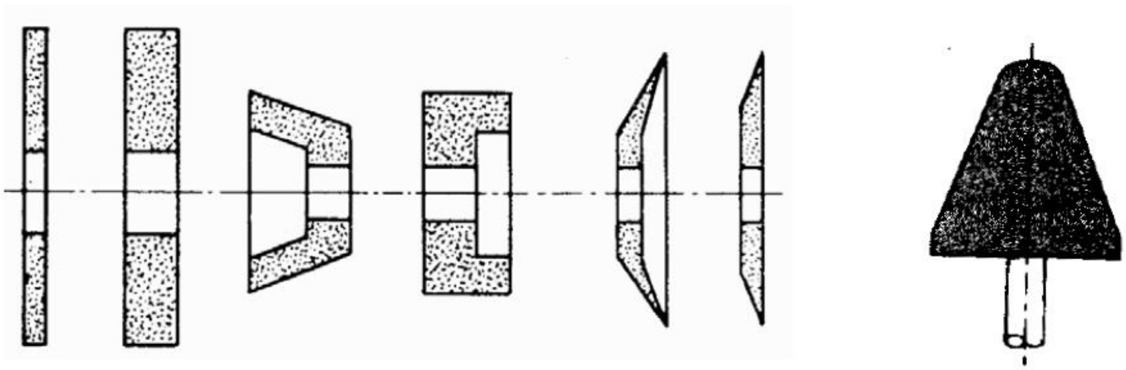


Fig.28.1*: Standard wheel configuration for conventional grinding wheels*

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.