1. a.

1.5.1 Engine Lathe or Center Lathe

Figure 1.1 shows the parts of a Center lathe. Following is a brief description of the same.

1) Bed

It is a rigid structure which forms the base or foundation to support all the other parts such as headstock, tailstock, carriage, etc. It is usually made from *gray cast iron*. At the top of the bed are the guideways, which guides for accurate movement of carriage and tailstock.

2) Headstock (Live center)

The headstock mounted at the left end of the lathe bed serves as a housing for the spindle, driving gears or pulleys by means of which the workpiece can be rotated at different speeds. The headstock spindle is provided with a *live center* or *chuck* to support one end of the workpiece while it is being rotated.

3) Tailstock (Dead center)

The tailstock mounted at the right end of the lathe bed performs two functions:

- Provide support to the other end of the rotating work piece
- Hold a tool for performing operations like drilling, reaming, tapping, etc.

The tailstock can be made to slide along the bed, and can be clamped at any location so as to accommodate workpiece of different lengths. It can also be shifted laterally on the bed so as to make it offset for producing taper surfaces.

4) Carriage

The cutting tool is supported, moved and controlled with the help of carriage. The carriage consists of the following parts.

- **Saddle** – The saddle is a part of the carriage that can be made to slide along the bed-ways. It supports the cross-slide, compound rest and tool post.
- **Cross-slide** – The cross-slide is mounted on the saddle. It can be made to move in a direction prependicular to the saddle movement, or perpendicular to the lathe axis thereby providing the necessary depth of cut to the workpiece
- **Compound rest** – It is mounted on the cross-slide and supports the tool post. The compound rest has a circular base graduated in degrees. This helps the cutting tool to be swivelled at any angle to obtain taper surfaces.
- **Tool-post** – It is mounted on the compound rest, and is used to hold/support the cutting tool firmly in position during machining.
- **Apron** – It is fitted beneath the saddle facing the operator. It houses the gears, levers, hand-wheels and clutches to operate the carriage by hand or by automatic power feed.

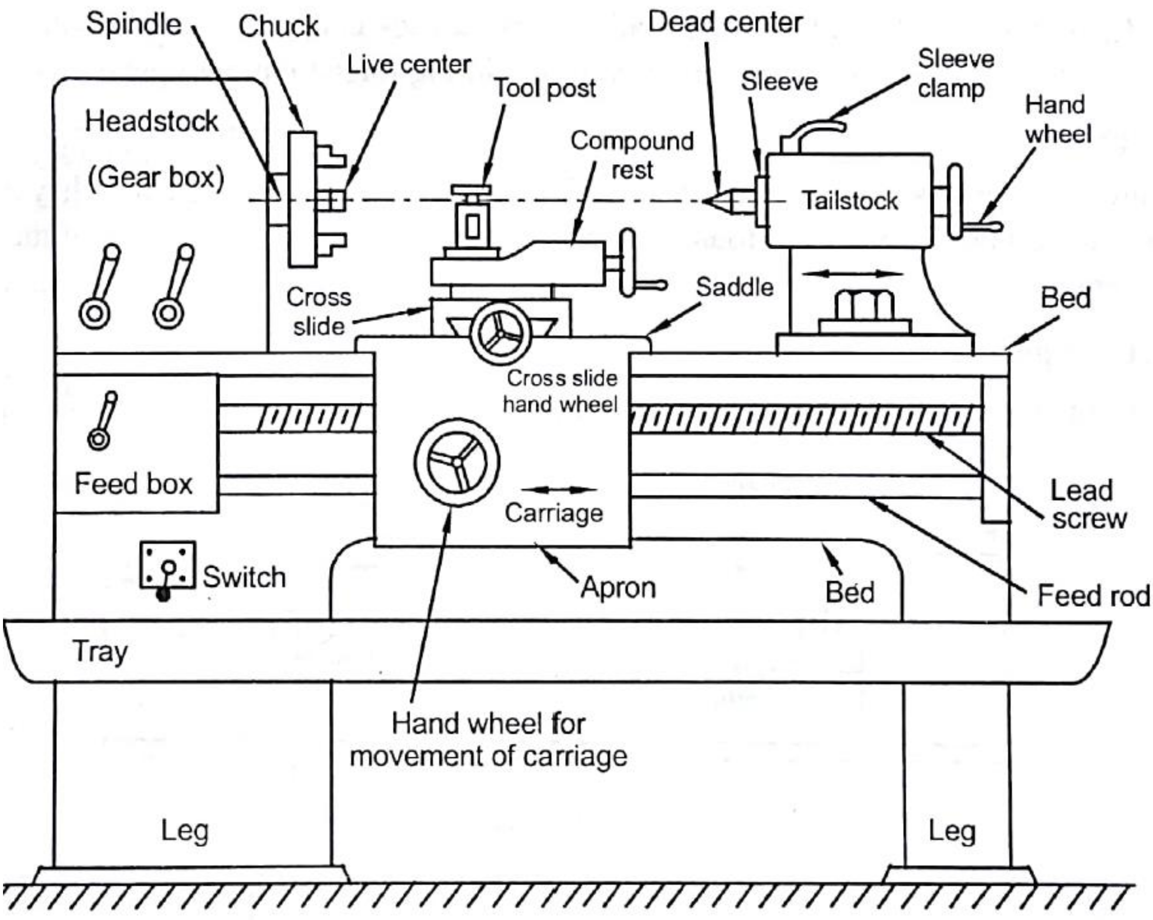


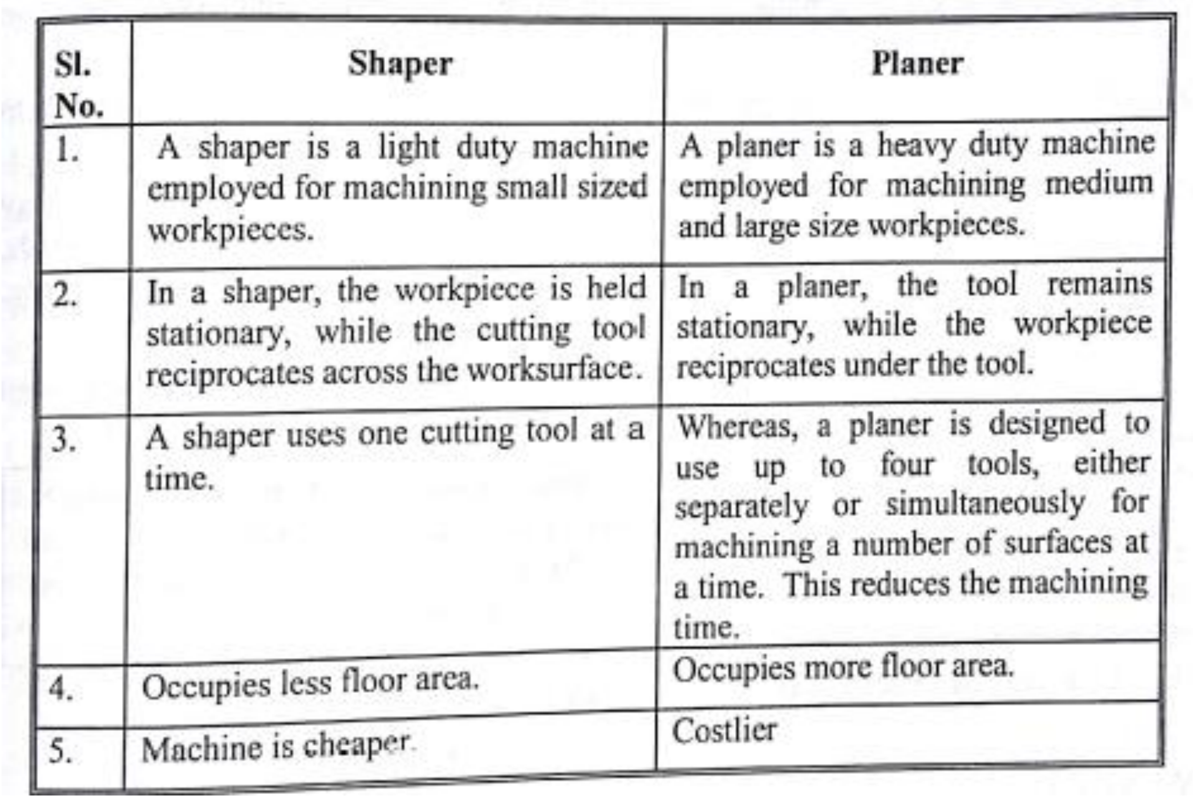
Figure 1.1 Parts of Center Lathe

- **Feed rod** – The feed rod is a long shaft that gives automatic feed to the carriage for various operations namely boring, turning etc., *except thread cutting.*
- **Lead screw** – It is a long shaft with square threads cut on it. The rotation of the lead screw facilitates the movement of carriage during thread cutting operations.

5) Legs

Legs are the supports which carry the entire load of the machine over them. They are firmly secured to the floor by means of foundation bolts in order to prevent vibrations of the machine during operation.

1. b.



Sl. No.	Shaper	Planer
1.	A shaper is a light duty machine employed for machining small sized workpieces.	A planer is a heavy duty machine employed for machining medium and large size workpieces.
2.	In a shaper, the workpiece is held stationary, while the cutting tool reciprocates across the worksurface.	In a planer, the tool remains stationary, while the workpiece reciprocates under the tool.
3.	A shaper uses one cutting tool at a time.	Whereas, a planer is designed to use up to four tools, either separately or simultaneously for machining a number of surfaces at a time. This reduces the machining time.
4.	Occupies less floor area.	Occupies more floor area.
5.	Machine is cheaper.	Costlier

2. a.

Vertical spindle milling machines are similar in construction to the horizontal milling machines, except that the spindle is held in a vertical position. Figure 1.13 shows the principal parts of the machine.

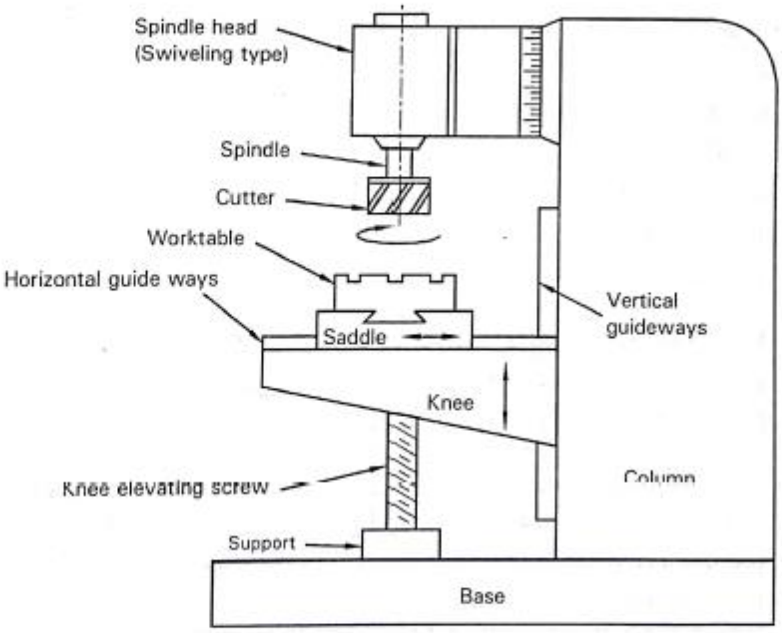


Figure 1.13 Vertical milling machine

Spindle

The spindle is located vertically, parallel to the face of the column, and perpendicular to the top of the worktable. The spindle is mounted in the spindle head and carries the cutter at its end. The spindle head houses the motor and feed controls, and can be either of *fixed type or swiveling type.*

In fixed type, the spindle head is fixed and can be adjusted up and down to perform certain operations. While, in swiveling type, the spindle head can be swiveled to any angle to the surface of the worktable. This permits working on angular surfaces of work pieces.

a) Base

The base is usually a strong and a hollow part, which forms the foundation of the machine and upon which all the other parts are mounted. The base also serves as a sump for the cutting fluid. A pump and filtration system is usually installed in the base. The hole provided in the center of the base, houses the support for the elevating screw that raises and lowers the knee.

b) Column

The column is a vertical hollow casting and is usually combined with the base to form a single casting. The column houses the spindle and bearings as well as the drive units like gears, clutches, shafts, and shifting mechanisms for transmitting power from the electric motor to the spindle at desired speeds. The front face of the vertical column is provided with a square or dovetail type guideway on which the knee slides up and down.

c) Spindle

The spindle is a hollow shaft supported by the column with suitable bearings that absorb both radial and thrust loads. The spindle is made hollow and tapered inside to accept standard *arbors*. The spindle obtains power from the motor and transmits it to the arbor. The arbor carrying the *cutter* rotates about a horizontal axis.

d) Overarm

An adjustable overarm mounted on the vertical column supports the yoke, which in turn supports the free end of the arbor.

e) Knee

The knee is a casting that slides up and down on the vertical guideways provided on the column by means of an elevating screw. The knee supports the saddle.

f) Saddle

The saddle mounted on the knee is provided with two slides (guideways) on its top and bottom surfaces. The slides are machined at right angles to each other. The lower slide fits the slide provided on top of the knee and facilitates horizontal movement of the saddle. The upper slide provided on the saddle accepts the slide provided on the bottom surface of the worktable.

g) Worktable

The worktable supported on the saddle can be moved longitudinally or at right angles to the movement of the saddle. The worktable is provided with T-slots all along its length for mounting a vice or other work holding devices. The worktable may be manually controlled or power fed.

2. b.

1) Surface grinding machine
    - Horizontal spindle type with reciprocating table
    - Vertical spindle type with reciprocating table.
    - Horizontal spindle with rotary table.
    - Vertical spindle with rotary table.
2) Cylindrical grinding machine
    - Center type
    - Centerless type
    - Chucking type
3) Internal grinding machine
    - Chuck type
    - Centerless type
4) Special purpose grinding machine
    - Tool and cutter grinding machine
    - Crankshaft grinding machine
    - Thread grinding machine
    - Cam grinding machine
    - CNC grinding machine, etc.

1.13.1 Horizontal Surface Grinding Machine

Horizontal spindle surface grinding machine with reciprocating table is the most common type of grinding machine and is widely used in industries for grinding flat surface or workparts. Figure 1.14 shows a horizontal spindle surface grinding machine with reciprocating table. The machine consists of the following parts:

a) Horizontal spindle

The machine consists of a horizontal spindle on which the grinding wheel is mounted and clamped rigidly. The spindle in turn is mounted within the wheel head that can be raised or lowered automatically or by means of an *infeed* or *downfeed hand wheel*. The wheel head slides up & down on the guideways provided on the front face of the column as shown in figure.

b) Worktable & Saddle

The machine has a rectangular worktable provided with T-slots for fastening magnetic chucks*, vices, fixtures, etc. The worktable is provided with a longitudinal feed movement, which controls the reciprocating *left* or *right* travel of the worktable. Transverse or cross-feed motion (motion perpendicular to longitudinal feed) is given by moving the saddle. Both longitudinal and transverse feed movements are accomplished either by a hand wheel or by hydraulic power.

Note The wheel head is given transverse motion at the *end* of each *table* motion.

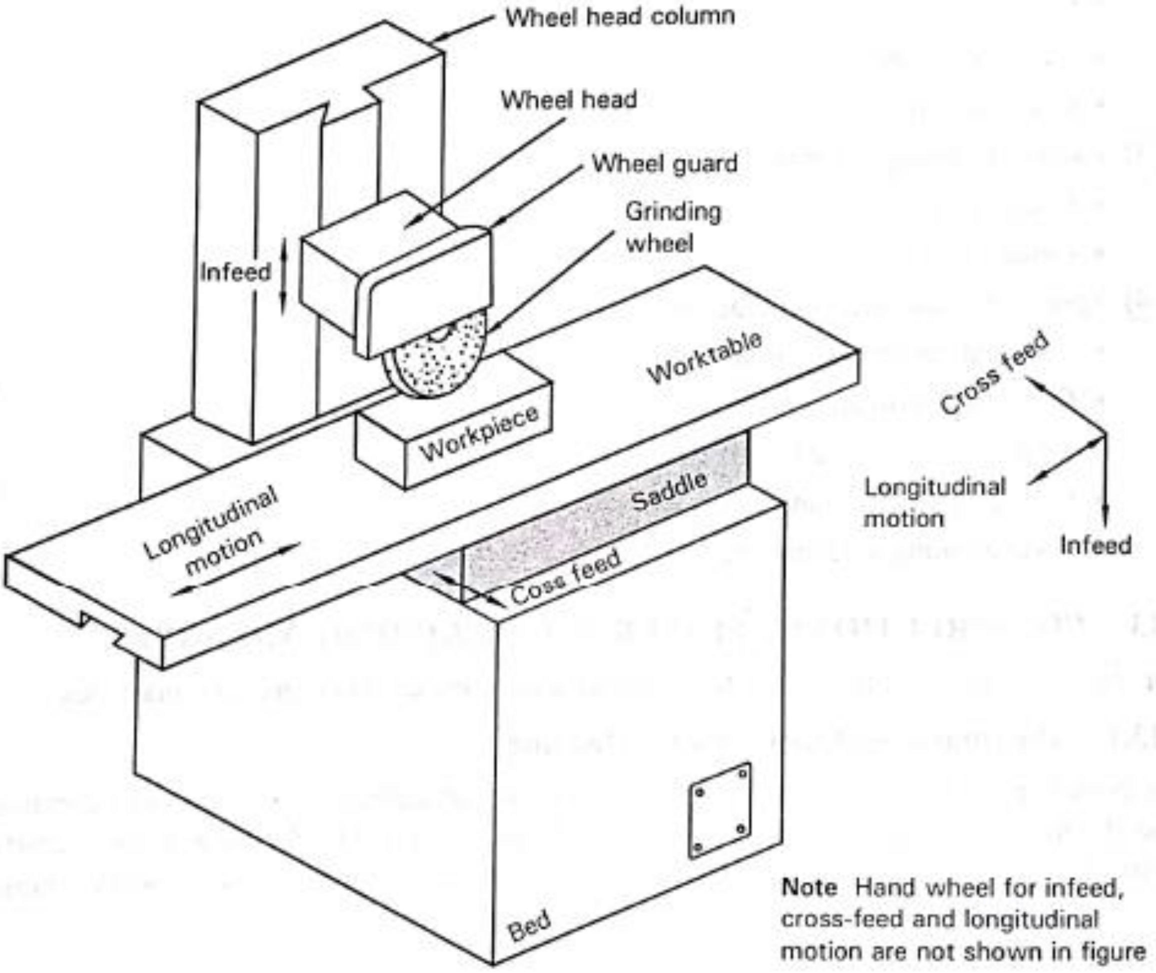


Figure 1.14 Horizontal surface grinding machine

c) Base

The base of the grinding machine has a column at the back for supporting the wheel head. The saddle which supports the worktable is mounted on the base on carefully machined guideways at the front of the machine. The base accommodates the electrical switches and an internal pump with piping arrangement for automatic application and re-circulation of coolant during the grinding process.

3. a.

5) Thread cutting

Thread cutting or threading is a machining process for cutting screw threads on metallic parts as shown in figure 2..5. In operation, a suitable tool which gives the required thread profile, say V-thread, square thread etc., is mounted on the tool post of the lathe. The workpiece is made to revolve at a very slow speed. The depth of cut is selected and the tool is made to move parallel to the lathe axis by means of automatic arrangement. Thread cutting is carried out in a number of passes. The final cut is a finishing cut with a very small depth of cut in order to obtain a good surface finish.

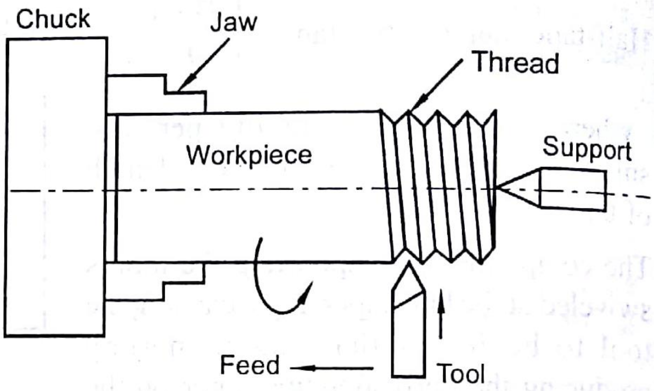


Figure 2.5 Thread cutting

In a Shaping machine, the cutting tool is reciprocated to and fro across the stationary workpiece. The workpiece is given an indexed feed (equal amount after each cut) in a direction perpendicular to the line of action of the cutting tool. The reciprocating motion of the tool is called the *primary motion,* while linear movement of the workpiece is called *feed motion.*

Horizontal cutting is the most common operation carried out on a shaper to obtain flat surfaces as shown in figure 2.30. The work is held rigidly on the worktable and an appropriate tool is held in the tool head mounted on the ram of the shaping machine. The length and position of the stroke of the ram is adjusted in such a way that the tool begins the forward stroke from a distance of around 15 *mm* from the beginning of the cut, and end the stroke at a distance of 5 *mm* after the end of the cut (from the end of worksurface). The cutting action takes place during the forward stroke only, and during the return stroke, the tool is lifted clear of the workpiece. Cross-feed to the table, before beginning the cut is given manually by hand, and once the cut starts, power feed can be employed. The depth of cut is given by the down feed screw of the tool head, or moving the table upwards.

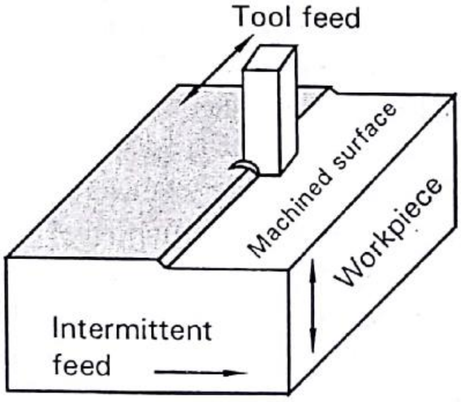


Figure 2.30 Horizontal shaping

3. b.

1) Drilling

Drilling is a machining process carried out to produce a cylindrical hole in a solid workpiece by means of a revolving tool called *drill bit*. Refer figure 2.7. The tool is also called *twist drill*, since it has sharp twisted edges formed around a cylindrical body. The hole is generated by the sharp edges of the rotating drill bit that is forced to move against the rigidly clamped workpiece. The chips get curled and escapes through the helical grooves (flutes) provided in the drill bit.

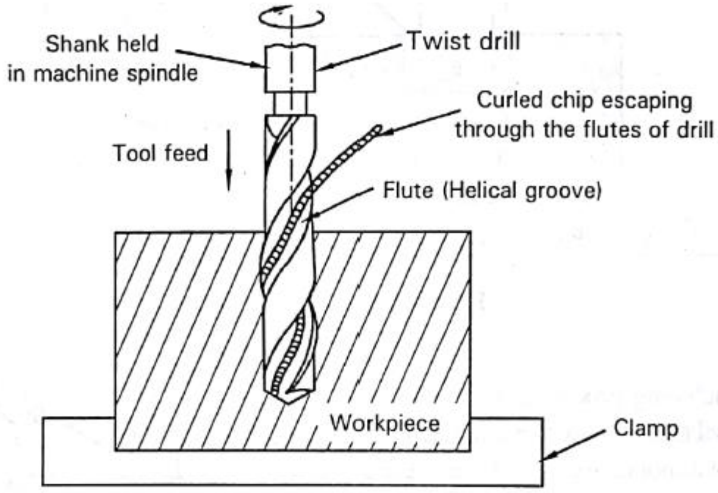


Figure 2.7 Drilling

3) Boring

Boring is a machining process carried out for enlarging a previously drilled hole by means of an adjustable cutting tool having only one cutting edge. Refer figure 2.9. Boring is usually performed when a drill bit of the required dimension† is not available. In such cases, a hole is first drilled to the nearest dimension and then a single point cutting tool is fastened and adjusted to a boring bar to enlarge the size of the existing hole to the required dimension. While boring, the tool is rotated at speeds slower than that of reaming.

In addition to enlarging a previously drilled hole, boring operation corrects the hole location and out-of- roundness, if any, as the tool can be adjusted to remove more metal from one side of the hole than the other.

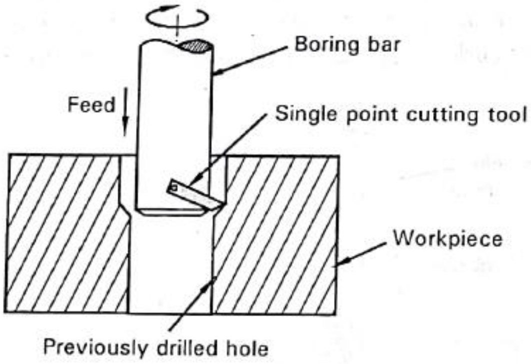


Figure 2.9 Boring

2) Reaming

Reaming is a machining process carried out for finishing a previously drilled hole so as to bring it to a more exact size and to improve the surface finish of the hole. Refer figure 2.8. The operation is carried out using a multi-tooth revolving tool called *reamer,* which consists of a set of parallel straight or helical cutting edges along the length of the cylindrical body. While reaming, the speed of the spindle is reduced to nearly half of that of the drilling. The material is removed in small amounts, and hence the surface of the drilled hole is finished with high accuracy.

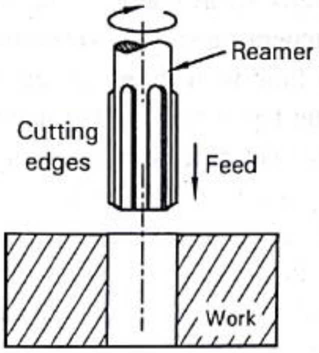


Figure 2.8 Reaming

1) Plain or Slab milling

Plain milling, also called *surface milling, peripheral milling* or *slab milling* is a machining process for producing a plain horizontal surface with a milling cutter whose axis is parallel to the surface of the workpiece being machined. Refer figure 2.16. The process is carried out on a horizontal milling machine with a cutter having straight or helical teeth* formed on the periphery of a cylindrical surface. The cutter is mounted on the arbor, rotating at a suitable speed, while the workpiece is fed against the cutter causing material to be removed from the workpiece. A plain smooth surface can be produced with this process.

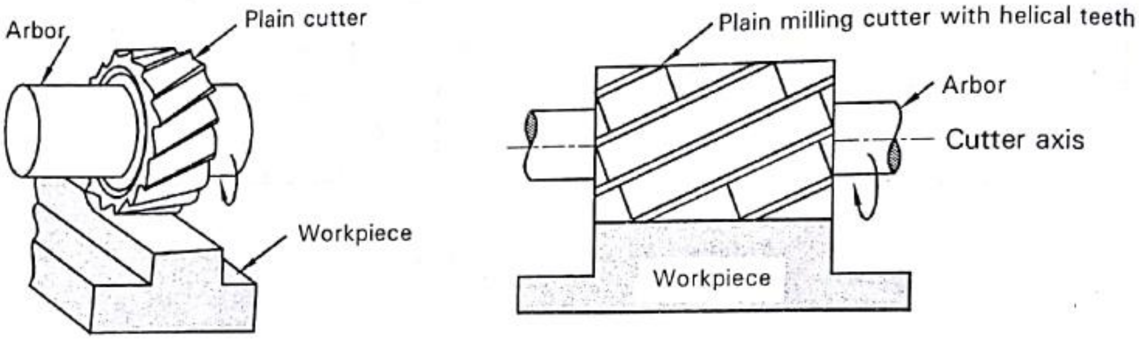


Figure 2.16 Plain/Slab milling

4. a.

2.3.6 Planing

In a Planing machine, the worktable carrying the workpiece is reciprocated to and fro across the cutting tool. The tool is given feed in the transverse direction (perpendicular to the direction of motion of the work piece) and also in the vertical direction for obtaining the required depth of cut. The reciprocating motion of the workpiece is called the *primary motion,* while linear movement of the cutting tool is called *feed motion.* Figure 2.31 shows the principle of operation of producing a flat surface on planing machine.

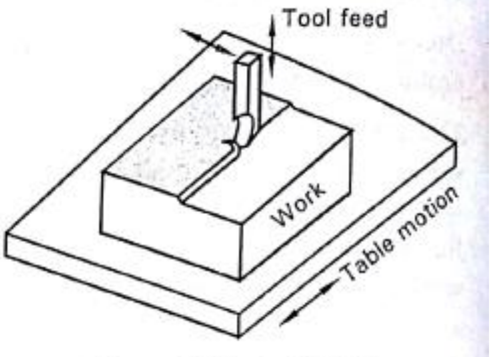
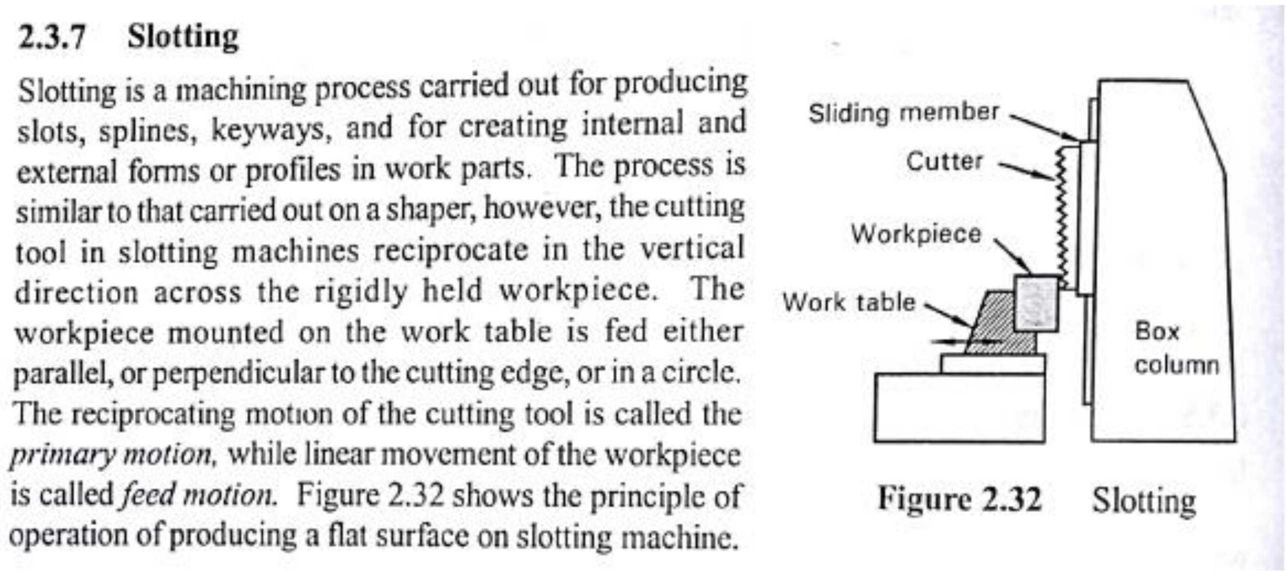


Figure 2.31 Planing

4. b.

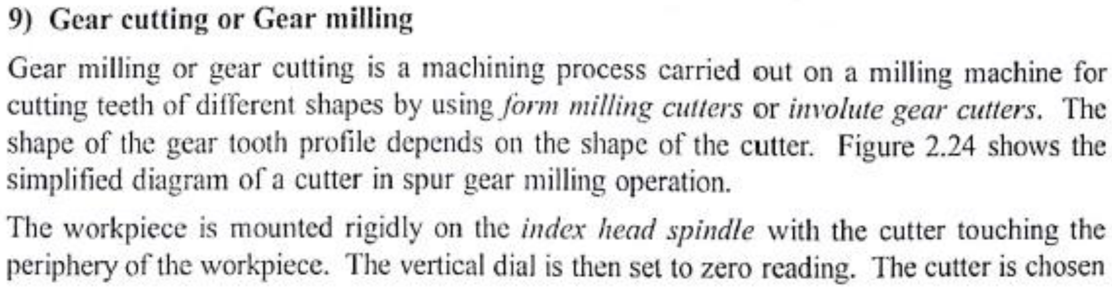


2.3.7 Slotting

Slotting is a machining process carried out for producing slots, splines, keyways, and for creating internal and external forms or profiles in work parts. The process is similar to that carried out on a shaper, however, the cutting tool in slotting machines reciprocate in the vertical direction across the rigidly held workpiece. The workpiece mounted on the work table is fed either parallel, or perpendicular to the cutting edge, or in a circle. The reciprocating motion of the cutting tool is called the *primary motion,* while linear movement of the workpiece is called *feed motion.* Figure 2.32 shows the principle of operation of producing a flat surface on slotting machine.

Figure 2.32 Slotting

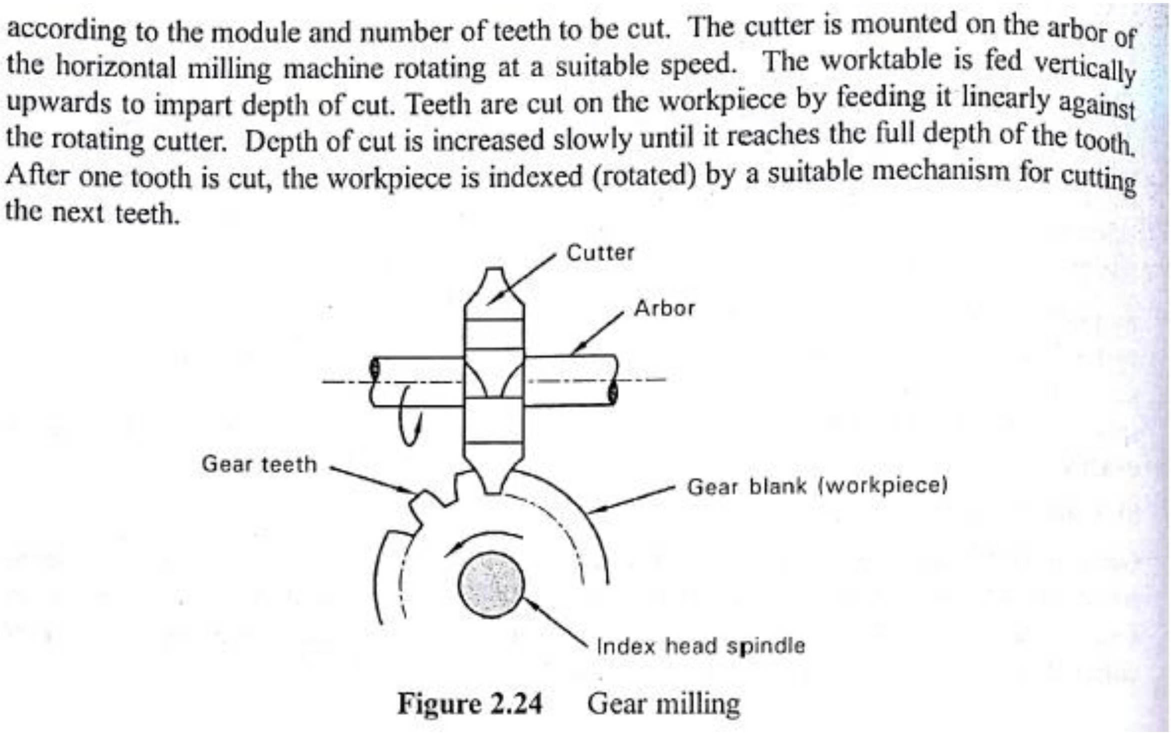
4. c.



9) Gear cutting or Gear milling

Gear milling or gear cutting is a machining process carried out on a milling machine for cutting teeth of different shapes by using *form milling cutters* or *involute gear cutters.* The shape of the gear tooth profile depends on the shape of the cutter. Figure 2.24 shows the simplified diagram of a cutter in spur gear milling operation.

The workpiece is mounted rigidly on the *index head spindle* with the cutter touching the periphery of the workpiece. The vertical dial is then set to zero reading. The cutter is chosen



according to the module and number of teeth to be cut. The cutter is mounted on the arbor of the horizontal milling machine rotating at a suitable speed. The worktable is fed vertically upwards to impart depth of cut. Teeth are cut on the workpiece by feeding it linearly against the rotating cutter. Depth of cut is increased slowly until it reaches the full depth of the tooth. After one tooth is cut, the workpiece is indexed (rotated) by a suitable mechanism for cutting the next teeth.

Figure 2.24 Gear milling

4. d.

1) Surface grinding

Surface grinding is a machining process primarily carried out for producing a flat surface of the desired finish as shown in figure 2.26. However, with the use of special fixtures and form dressing devices, angular and formed (curved) surfaces can also be finished.

In operation, the work piece is secured firmly on the worktable by means of a magnetic chuck, vice, etc., and the grinding wheel is brought in contact with the surface of the workpiece. The abrasive action of the grinding wheel on the surface of the workpiece causes material to be removed from it in the form of fine chips. Longitudinal feed to the work piece is given by reciprocating the worktable, and after each longitudinal feed, cross-feed is given so as to finish the workpiece all along its width. Vertical downward movement of the wheel, or in some machines, upward movement of the workpiece gives the required depth of cut.

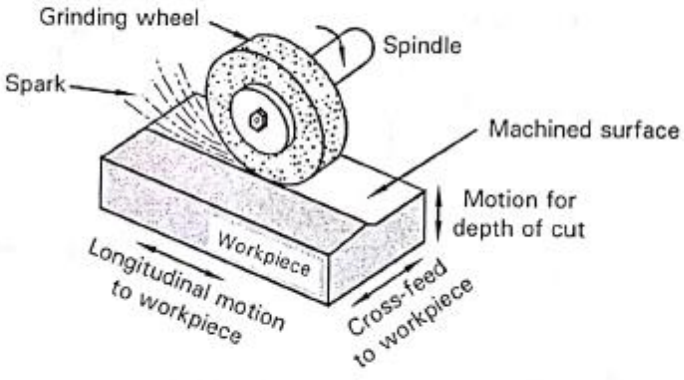


Figure 2.26 Surface grinding

4. e.

1) Cylindrical Turning

Cylindrical turning, also called plain turning or straight turning is a machining process for producing a cylindrical surface on the workpiece as shown in figure 2.1. One end of the workpiece is held rigidly in a chuck, while the other end is supported by the dead center of the machine. The cutting tool is fed against the revolving workpiece, in a direction *parallel* to the lathe axis so as to produce a cylindrical surface.

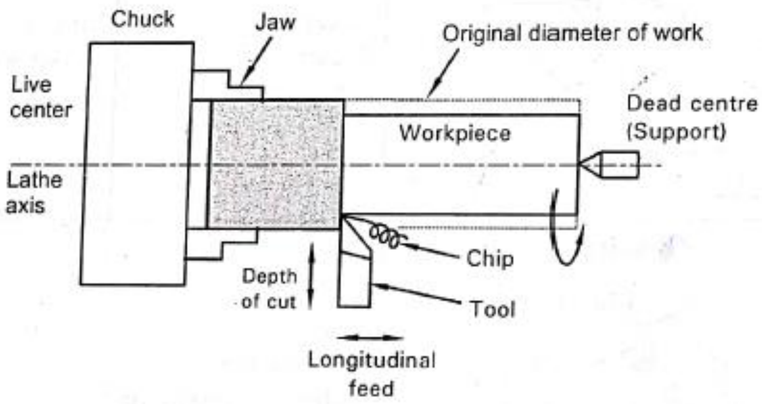
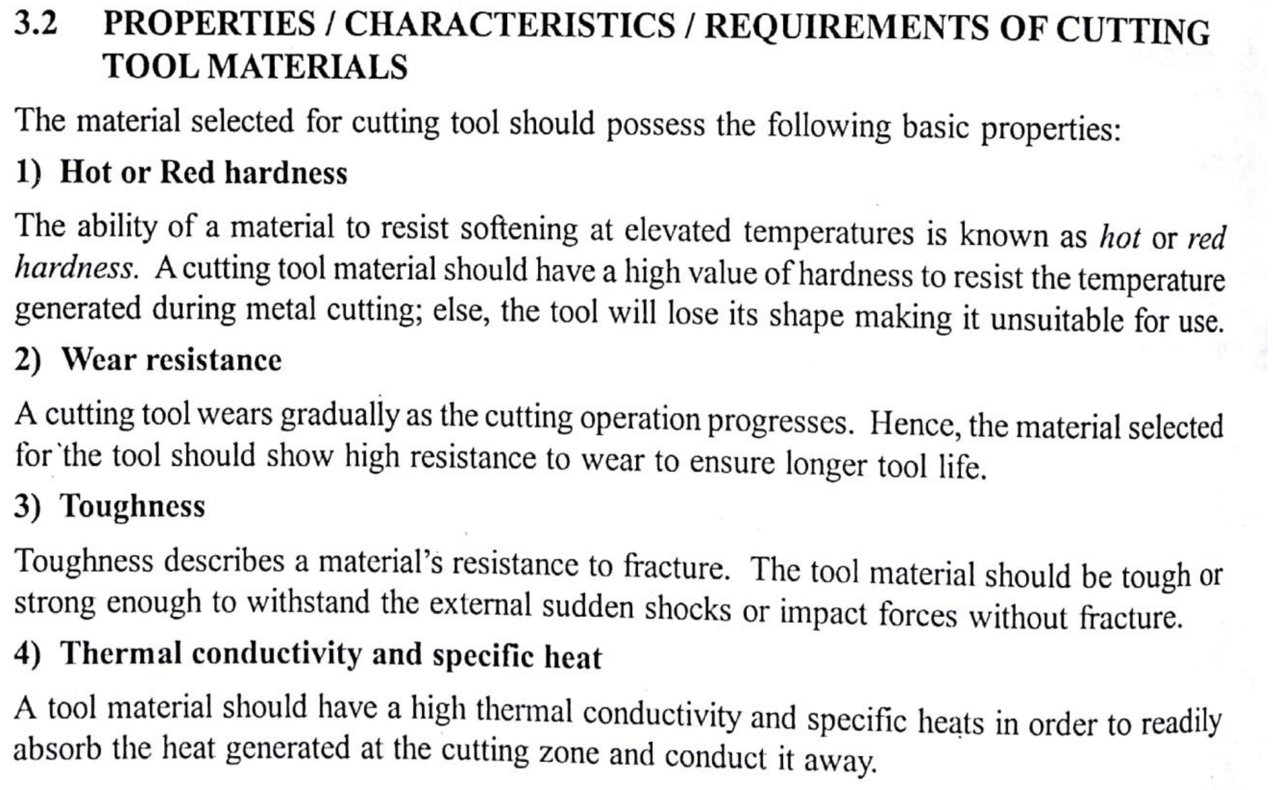


Figure 2.1 Cylindrical turning

5.a.



3.2 PROPERTIES / CHARACTERISTICS / REQUIREMENTS OF CUTTING TOOL MATERIALS

The material selected for cutting tool should possess the following basic properties:

1) Hot or Red hardness

The ability of a material to resist softening at elevated temperatures is known as *hot* or *red hardness*. A cutting tool material should have a high value of hardness to resist the temperature generated during metal cutting; else, the tool will lose its shape making it unsuitable for use.

2) Wear resistance

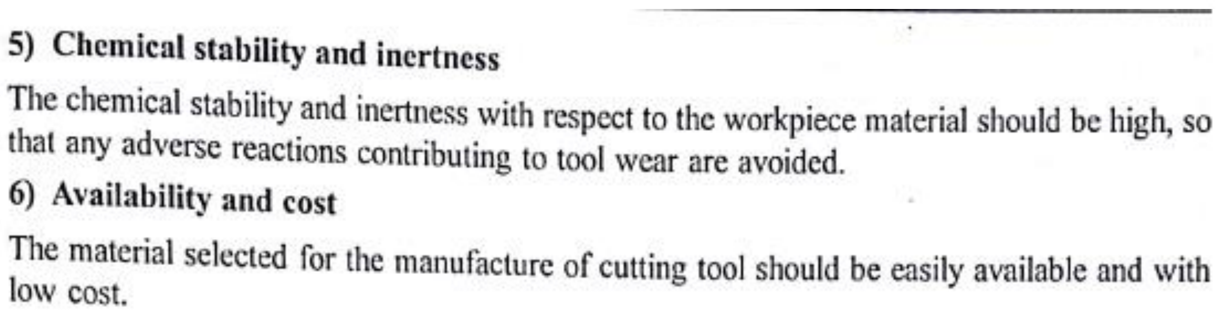
A cutting tool wears gradually as the cutting operation progresses. Hence, the material selected for the tool should show high resistance to wear to ensure longer tool life.

3) Toughness

Toughness describes a material's resistance to fracture. The tool material should be tough or strong enough to withstand the external sudden shocks or impact forces without fracture.

4) Thermal conductivity and specific heat

A tool material should have a high thermal conductivity and specific heats in order to readily absorb the heat generated at the cutting zone and conduct it away.



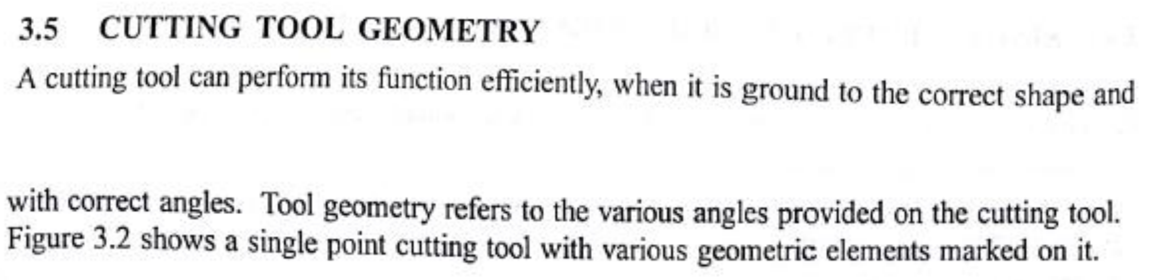
5) Chemical stability and inertness

The chemical stability and inertness with respect to the workpiece material should be high, so that any adverse reactions contributing to tool wear are avoided.

6) Availability and cost

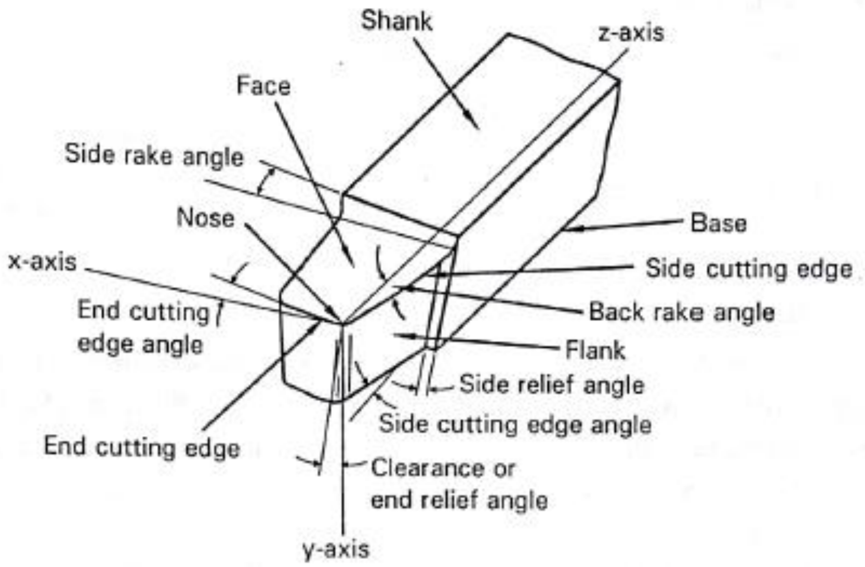
The material selected for the manufacture of cutting tool should be easily available and with low cost.

5. b.

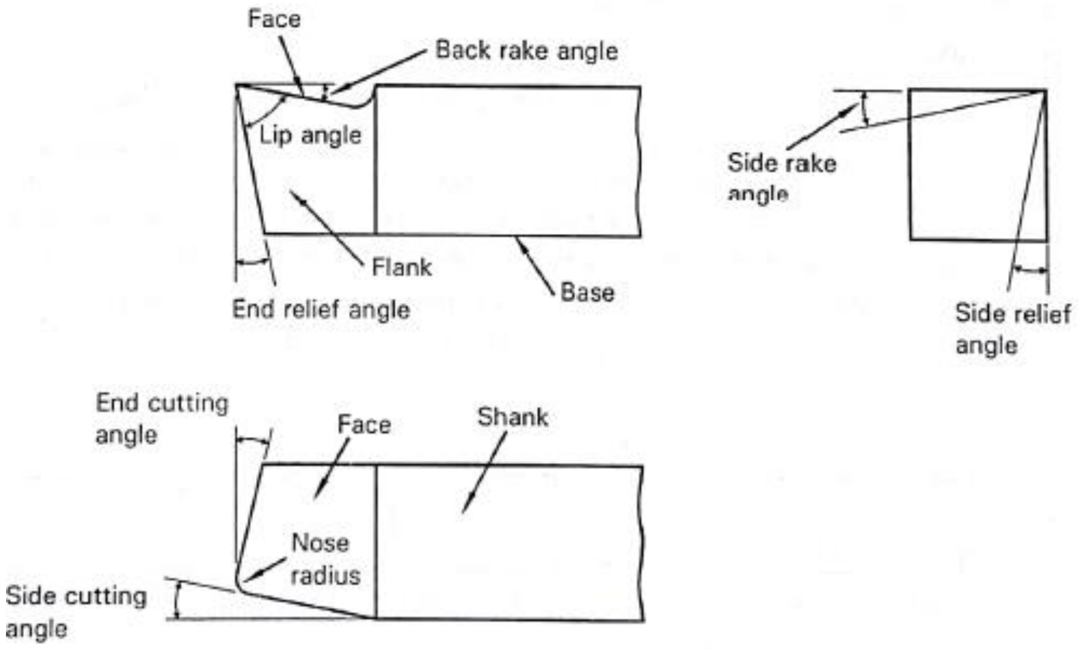


3.5 CUTTING TOOL GEOMETRY

A cutting tool can perform its function efficiently, when it is ground to the correct shape and with correct angles. Tool geometry refers to the various angles provided on the cutting tool. Figure 3.2 shows a single point cutting tool with various geometric elements marked on it.



(a) Pictorial view of a single point cutting tool



(b) Principal views of single point cutting tool

Figure 3.2 Geometry of single point cutting tool

a) Rake angle

Rake angle is the inclination of the face (top surface) of the tool with respect to the horizontal reference surface. Rake angle facilitate wedge action in cutting and help the *chips* to flow away from the cutting edge thereby reducing the pressure of the chip on the tool face. Rake angle can be zero (neutral), positive or negative as shown in figure 3.3.

- **Zero (neutral) rake angle**

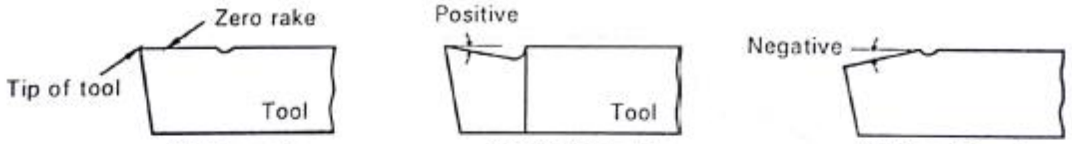
When the face of the cutting tool is flat or horizontal as shown in figure 3.3(a), the tool is said to contain a zero rake. Zero rake increases the strength of the tool and prevents the cutting edge from digging into the workpiece. However, tools with zero rake have a larger crater wear due to the chip sliding over the rake face. Zero rake angle is not used in metal cutting operations, but metal forming tools are provided with zero rake, as they are mainly used for finishing formed surfaces where little amount of pressure is required to remove small amounts of material.

- **Positive rake angle**

When the face of the tool is so ground that it slopes downwards from the tip of the tool as shown in figure 3.3(b), the tool is said to contain a positive rake. Positive rake angle helps in the formation of continuous chip in ductile materials and contributes in avoiding the formation of built-up-edge chip. Tools with positive rake angle are used for cutting non-ferrous and low-tensile strength materials, and also for materials which work harden while being machined. However, excessive positive rake makes the tool sharp and pointed thereby reducing the strength of the cutting edge. Hence for machining hard metals, tools are given smaller rake angles, while for machining soft metals, larger rake angles are used.

- **Negative rake angle**

When the face of the cutting tool slopes upwards from the tip of the tool as shown in figure 3.3(c), it is said to contain a negative rake. Cutting tools with negative rake angle are stronger, making them suitable for machining high strength materials; for taking interrupted cuts, and machining with high feeds. Negative rake angles are generally employed on carbide tipped tools for machining extra-hard surfaces, hardened steel parts, cast steels etc. However, increased negative rake angle leads to increased cutting force during machining, which in turn causes vibrations, and increased power consumption. Hence, tools with negative rake should be used only when absolutely necessary.



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

Figure 3.3 Types of rake angle

Rake angle is a combination of *back rake angle* and *side rake angle* as discussed below:

- **Back rake angle** measures the downward slope of the top surface of the tool from the tip of the tool (nose) to the rear along the longitudinal axis (z-axis). Back rake angle can be positive or negative type. It allows the chip to flow smoothly when the material is cut by primary cutting edge.

- **Side rake angle** measures the slope of the top surface of the tool to the side in a direction perpendicular to the longitudinal axis (z-axis). Side rake angle can be positive or negative type. It allows the chip to flow smoothly when the material is cut by side cutting edge.

b) Side cutting edge angle

It is the angle between the side cutting edge and the longitudinal axis (z-axis) of the tool. It avoids formation of built-up-edge, controls the direction of chip flow, and distributes the cutting force and heat produced over a larger cutting edge.

c) Side relief angle

It is the angle made by the flank of the tool and a plane perpendicular to the base just under the side cutting edge. Side relief angle permits the tool to be fed side-ways into the job (workpiece), so that it can cut without rubbing against the job.

d) End cutting edge angle

It is the angle between the end cutting edge and a line perpendicular to the tool shank. It acts as a relief angle by allowing only a small section of the end cutting edge to participate in the cutting action thereby preventing chatter and vibration.

e) End relief angle

It is the angle between a plane perpendicular to the base and the end flank of the tool. End relief angle prevents the end of the cutting tool from rubbing against the job during machining.

f) Lip angle

It is the angle between the tool face and the ground end surface of the flank. Lip angle is maximum when clearance and rake angle are minimum. The larger the lip angle, the stronger will be the cutting edge. Hence for cutting hard metals, the rake angle is reduced and lip angle is increased, however the cutting speeds must be kept low.

5. c.

3.8 PROPERTIES OF CUTTING FLUIDS

A cutting fluid should possess the following properties for efficient machining of work parts:.

1) *High specific heat* & *High thermal conductivity*, so that maximum heat will be absorbed and removed per unit of fluid volume circulated.
2) *Good lubricating property*, so that a strong protective film between the tool face and the workpiece metal can exist. Such a film assists the chip in sliding easily over the tool face. Besides reducing heat, a good lubricating fluid lowers power requirements and reduces the rate of tool wear, particularly in machining tough and ductile metals.
3) *Non-corrosive,* in order to avoid damage to the workpiece and the machine parts.
4) *Non-toxic* and *odourless*, in order to provide better working conditions to human operators.
5) A cutting fluid should have a high flash point* to avoid problems associated with heat damage, production of smoke, or fluid ignition.
6) *Low viscosity*, for easy circulation. Low viscosity fluids also allow grit and dirt to settle out of suspension and helps for easy re-circulation through the machining system.
7) *Highly stable*, in order to resist its decomposition during its storage and use.
8) In some operations, *fluid transparency* may be a desired characteristic for a cutting fluid. Transparent fluids allow operators to see the work area more clearly during machining operations.

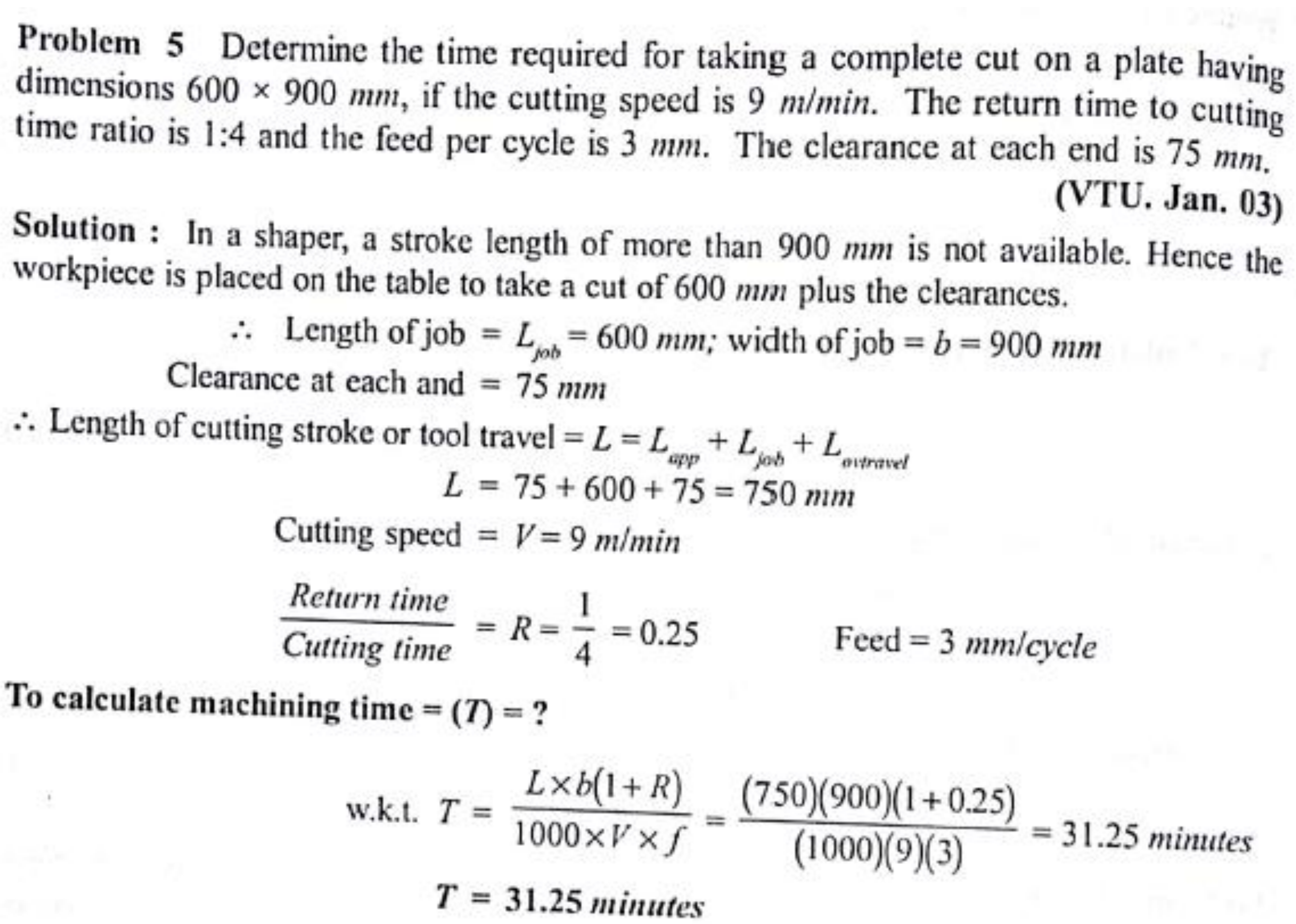
6. a.

Speed :- It is defined as the distance travelled by the tool in unit time.

Feed :- It is the movement given to the tool to remove material across the entire machining area.

Depth of cut :- It is the depth upto which the tool removes material in one pass.

6. c.



Problem 5 Determine the time required for taking a complete cut on a plate having dimensions 600 × 900 *mm*, if the cutting speed is 9 *m/min*. The return time to cutting time ratio is 1:4 and the feed per cycle is 3 *mm*. The clearance at each end is 75 *mm*.

(VTU. Jan. 03)

Solution : In a shaper, a stroke length of more than 900 *mm* is not available. Hence the workpiece is placed on the table to take a cut of 600 *mm* plus the clearances.

$\therefore$ Length of job $= L_{job} = 600\ mm$; width of job $= b = 900\ mm$

Clearance at each and $= 75\ mm$

$\therefore$ Length of cutting stroke or tool travel $= L = L_{app} + L_{job} + L_{ovtravel}$

$$L = 75 + 600 + 75 = 750\ mm$$

Cutting speed $= V = 9\ m/min$

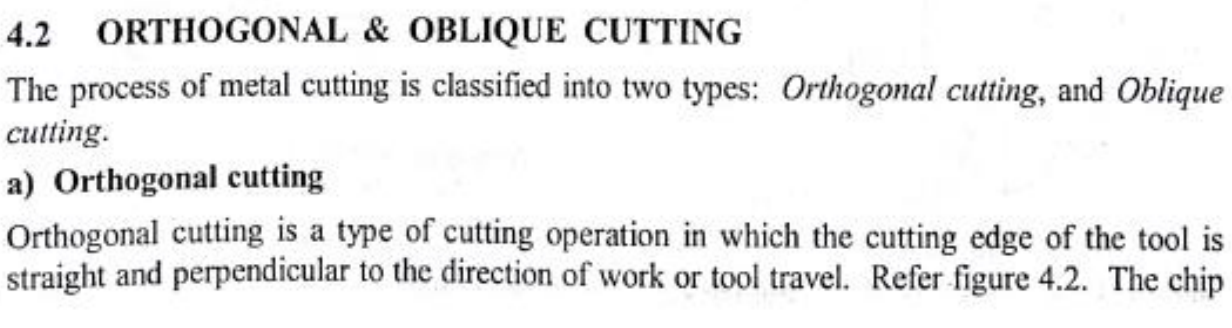
$$\frac{Return\ time}{Cutting\ time} = R = \frac{1}{4} = 0.25 \qquad \text{Feed} = 3\ mm/cycle$$

To calculate machining time = (*T*) = ?

$$\text{w.k.t. } T = \frac{L \times b(1+R)}{1000 \times V \times f} = \frac{(750)(900)(1+0.25)}{(1000)(9)(3)} = 31.25\ minutes$$

$$T = 31.25\ minutes$$

7. a.



4.2 ORTHOGONAL & OBLIQUE CUTTING

The process of metal cutting is classified into two types: *Orthogonal cutting*, and *Oblique cutting*.

a) Orthogonal cutting

Orthogonal cutting is a type of cutting operation in which the cutting edge of the tool is straight and perpendicular to the direction of work or tool travel. Refer figure 4.2. The chip flows over the tool face, and the direction of chip flow velocity is normal to the cutting edge. Only two components of the cutting force acts on the tool, and both of them are perpendicular to each other and can be represented in a 2-D (two-dimensional) plane. Hence, orthogonal cutting is also referred to as 2-D cutting operation. The drawback of this type of cutting is shorter tool life. This is because, for the same feed and depth of cut, the force which shears the metal acts on a smaller area thereby reducing the life of cutting tool. Orthogonal cutting is used for parting off operation on lathe, broaching and slotting operations.

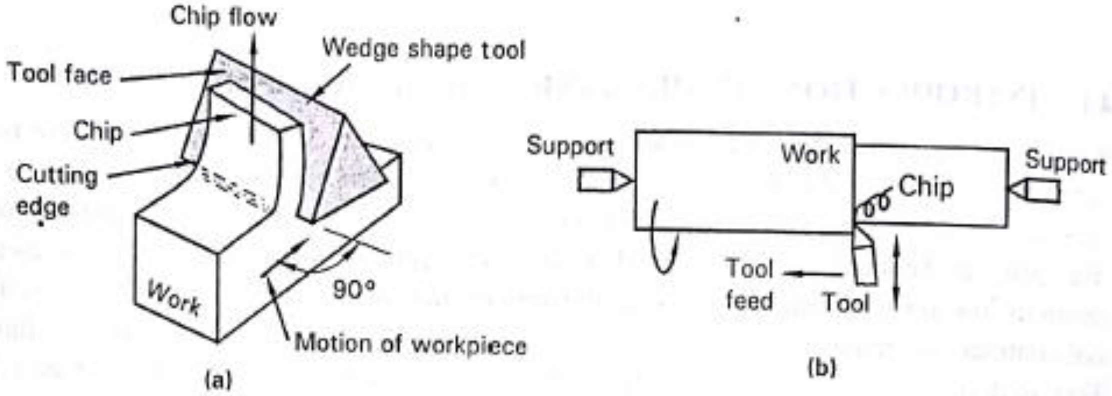


Figure 4.2 Orthogonal cutting

b) Oblique cutting

Oblique cutting is a type of cutting operation in which the cutting edge of the tool is straight and inclined to the direction of work or tool travel. Refer figure 4.3. This inclination causes change in the direction of the chip to flow across the tool face with a side-ways movement producing a helical form of chip. Three components of the cutting force acts at the cutting edge and they are mutually perpendicular to each other, and can be represented in a 3-D (three-dimensional) plane. Hence, oblique cutting is also referred to as 3-D cutting operation. The advantage of this type of cutting is that, the cutting force acts comparatively on a larger area enhancing tool life. In general, all metal cutting operations are carried out through oblique cutting method.

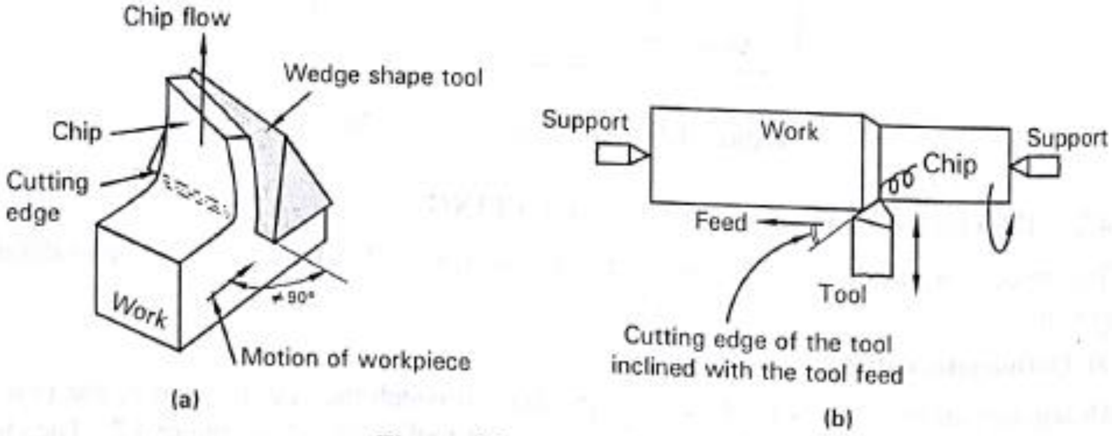


Figure 4.3 Oblique cutting

7. b.

4.5 MERCHANT's MODEL FOR ORTHOGONAL CUTTING

During metal cutting process, various forces act on the cutting tool and flowing chip. Refer figure 4.6. It is desirable to know the value of these forces, since it helps to calculate the power required for operating the machine tool; design and stiffness, etc.; for machine tolerances; whether the workpiece is capable of withstanding the cutting pressure, and other relevant information. The relationship among the various forces was established by *Merchant* with the following assumptions:

1) The tool is perfectly sharp and there is no contact between the workpiece and tool flank.
2) The width of the cutting tool is greater than that of the workpiece.
3) Only continuous type of chip is produced
4) There is no sideways flow of chip
5) Cutting velocity remains constant
6) Depth of cut is constant
7) Inertial forces of the chip are neglected

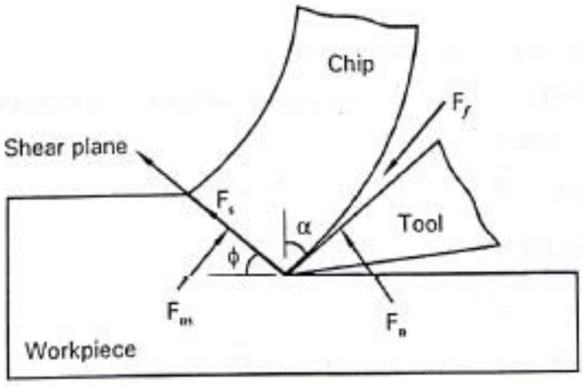


Figure 4.6 Forces acting on chip during metal cutting

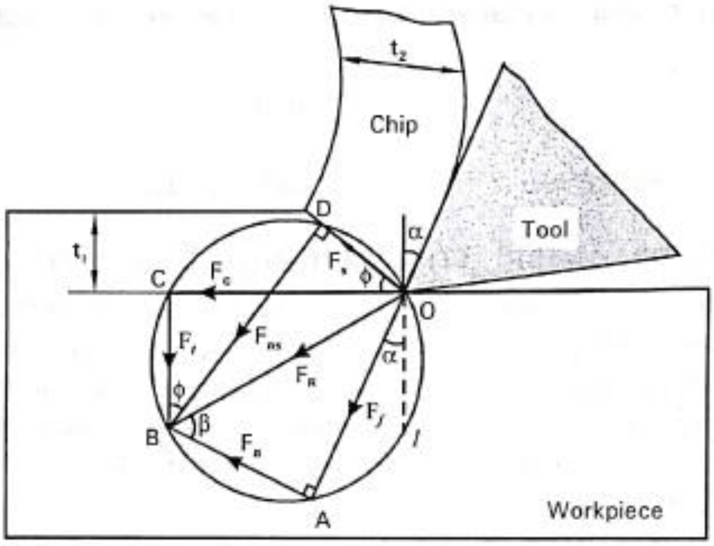


Figure 4.7 Merchants circle diagram

$$F_c = F_R \cos(\beta - \alpha)$$

$$F_t = F_R \sin(\beta - \alpha)$$

$$F_s = F_R \cos(\phi + \beta - \alpha)$$

$$\text{or} \quad F_s = F_C \cos\phi - F_t \sin\phi$$

$$F_{ns} = F_R \sin(\phi + \beta - \alpha)$$

$$F_f = F_c \sin\alpha + F_t \cos\alpha$$

$$F_n = F_c \cos\alpha - F_t \sin\alpha$$

$$\mu = \frac{F_f}{F_n} = \frac{F_c \sin\alpha + F_t \cos\alpha}{F_c \cos\alpha - F_t \sin\alpha}$$

8. a.

Solution : Chip length $= L_2 = 96mm$, Uncut chip length $= L_1 = 240mm$; $\alpha = 20°$ depth of cut $= d = 0.6mm$, Horizontal component $F_H = F_C = 2400\ N$

Vertical component $F_v = F_t = 240\ N$

(a) Shear plane angle (ϕ)

$$\text{w.k.t. } \tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha} \qquad \therefore\ \phi = \tan^{-1}\left(\frac{r\cos\alpha}{1 - r\sin\alpha}\right) \qquad \text{----[1]}$$

$$\text{where } r = \frac{t_1}{t_2} = \frac{L_2}{L_1}\frac{(chip\,length)}{(uncut\,chip\,length)} = \frac{96}{240} = 0.4$$

$$\therefore \text{ Equation (1) becomes } \phi = \tan^{-1}\left(\frac{0.4\cos 20}{1 - (0.4)\sin 20}\right) = 23.5°$$

Shear plane angle $\phi = 23.5°$

(b) Chip thickness (t_2)

$$\text{w.k.t. chip thickness ratio} = r = \frac{t_1}{t_2} \qquad \text{----[2]}$$

t_1 = feed (in present problem depth of cut is given)

$\therefore$ Equation (2) becomes $0.4 = \frac{0.6}{t_2}$

Chip thickness = t_2 = 1.5*mm*

(c) Friction angle (β)

$$\text{w.k.t. } \mu = \tan\beta$$

$$\text{or } \beta = \tan^{-1}(\mu) \qquad \text{----[3]}$$

$$\text{where } \mu = \text{co-efficient of friction} = \frac{F_C\sin\alpha + F_t\cos\alpha}{F_C\cos\alpha - F_t\sin\alpha}$$

$$\mu = \frac{2400\sin 20 + 240\cos 20}{2400\cos 20 - 240\sin 20} = \frac{1046.37}{2173.17} = 0.48$$

$\therefore$ Equation (3) becomes, $\beta = \tan^{-1}(0.48) = 25.6°$

$\therefore$ **Friction angle β = 25.6°**

(d) Resultant cutting force (*R*)

$$\text{w.k.t. } R = \sqrt{F_C^2 + F_t^2} = \sqrt{2400^2 + 240^2} = 2412\ N$$

$\therefore$ **R = 2412 *N***

8.b.

Solution : feed $t_1 = 0.25$ *mm/rev*, chip thickness $t_2 = 0.45$ *mm*, width of cut $b_1 = 2.5$ *mm*, cutting force $F_c = 113$ *kg* = 1108.53 *N*, Thrust force $F_t = 29.5$ *kg* = 289.39 *N*, cutting speed $V_c = 150$ *m/min* & rake angle $\alpha = +10°$

(a) Chip thickness ratio (*r*)

$$\text{w.k.t. } r = \frac{t_1}{t_2} = \frac{0.25}{0.45} = 0.555 \qquad \boldsymbol{r = 0.555}$$

(b) Chip reduction co-efficient (k)

$$\text{w.k.t } k = \frac{1}{r} = \frac{1}{0.555} = 1.8 \qquad \boldsymbol{k = 1.8}$$

(c) Shear angle (ϕ)

$$\text{w.k.t. } \tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha}$$

$$\therefore \quad \phi = \tan^{-1}\left[\frac{0.555\cos(10°)}{1 - 0.555\sin(10°)}\right] = \tan^{-1}(0.604)$$

$$\boldsymbol{\phi = 31.16°}$$

(d) Velocity of chip along tool face (V_f)

$$\text{w.k.t.}\quad V_f = \frac{V_C \sin\phi}{\cos(\phi-\alpha)} \qquad \text{(Equation } V_f = r \times V_c \text{ can also be used)}$$

$$V_f = \frac{150\sin(31.16)}{\cos(31.16-10°)}$$

$$V_f = \mathbf{83.22}\ m/min$$

(e) Frictional force (F_f)

$$\text{w.k.t}\quad F_f = F_C \sin\alpha + F_t \cos\alpha$$

$$F_f = 1108.5 \sin 10° + 289.39 \cos 10°$$

$$F_f = \mathbf{477.48}\ N$$

(f) Shear stress (or) ultimate shear stress (τ_s) (or) maximum shear stress (τ_m)

$$\text{w.k.t shear stress} = \frac{shear\ force(F_s)}{shear\ area}$$

$$\text{Shear force} = F_s = F_c \cos\phi - F_t \sin\phi$$

$$\text{Shear Area} = A_s = \frac{b_1 t_1}{\sin\phi}, \left(\because A_s = \frac{A_o}{Sin\phi}, A_o = b_1 t_1\right)$$

$$\therefore F_s = 1108.5 \cos 31.16° - 289.39 \sin 31.16$$

$$F_s = 798.8\ N$$

$$\text{Shear area} = \frac{b_1 t_1}{\sin\phi} = \frac{(2.5)(0.25)}{\sin 31.16°}$$

$$\text{Shear area} = A_s = 1.207\ mm^2$$

$$\therefore\ \text{Shear stress} = \frac{F_s}{A_s} = \frac{798.8}{1.207}$$

$$\textbf{Shear stress} = \mathbf{661.8}\ N/mm^2$$

(g) Power required for cutting

$$\text{w.k.t. Power} = \frac{F_c \times V_c}{60000}\ kW$$

$$\therefore\ \text{Power} = \frac{(1108.5)(150)}{60000} = 2.77\ kW$$

$$\textbf{Power} = \mathbf{2.77}\ kW$$

9. a.

5.7 TAYLOR'S TOOL LIFE EQUATION

Of all the variables like feed, speed, depth of cut, type of workpiece material, coolant etc., that affect the tool life, the *cutting speed* forms the most significant parameter. F.W. Taylor, an American engineer developed a standardized test to determine the relationship between the cutting speed and the time the tool remains useful.

The test was carried out for different combinations of tool and workpiece material; and the flank wear of the tool under test was measured. It was found that a practical amount of wear to measure before breakage was 0.75 *mm* (V_B) for solid and brazed tips, and 1.25 *mm* (V_B) for ceramic tools. Tests were carried out to determine the time taken to reach this amount of wear at different cutting speeds. The results were plotted on a graph showing that a logarithmic relationship existed between the cutting speed and the tool life (cutting time). Refer figure 5.4

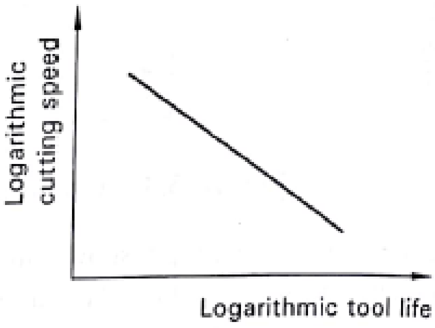


Figure 5.4

An empirical relation of tool life with cutting speed was given by Taylor and is known as Taylor's tool life equation. $VT^n = C$

where V = cutting speed in *m/min*

T = tool life in *minutes*.

C = A constant called *Machining constant*, which is numerically equal to the cutting speed in *m/min* that would give a tool life of 1 *min*.

n = an exponential index for a particular combination of tool & workpiece material.

9. b.

Solution : Let Cutting speed $V_1 = 30$ *m/min* $V_2 = 25$ *m/min*

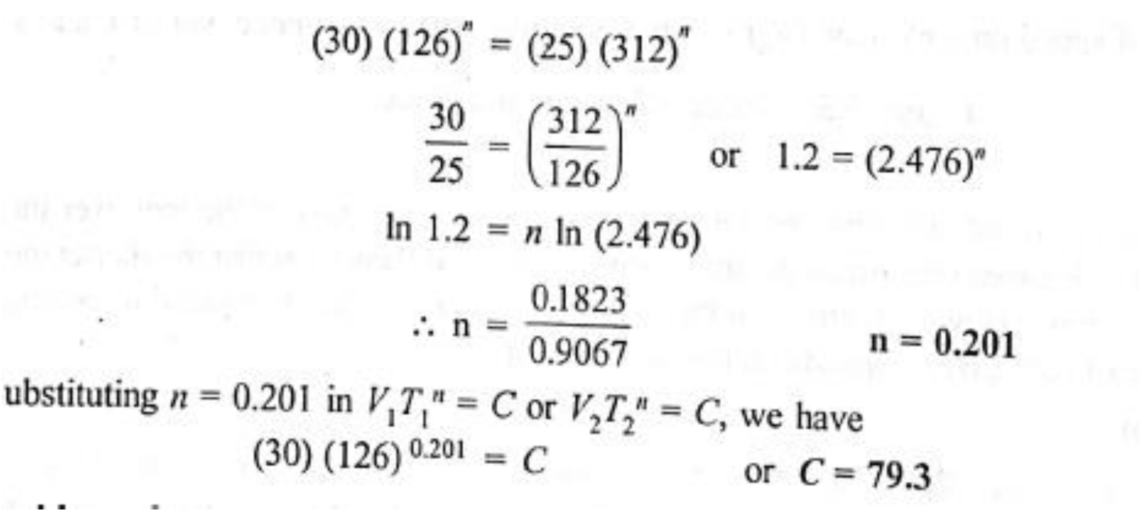
Tool life $T_1 = 2.1$ *hours* $T_2 = 5.2$ *hours*

$T_1 = 126$ *min* $T_2 = 312$ *min*

w.k.t $VT^n = C$ Taylors tool life equation.

For the given two cutting conditions, equation is written as $V_1T_1^n = C$ and $V_2T_2^n = C$

∴ Equating both the equations $V_1T_1^n = V_2\ T_2^n$



$$(30)\,(126)^n = (25)\,(312)^n$$

$$\frac{30}{25} = \left(\frac{312}{126}\right)^n \qquad \text{or} \quad 1.2 = (2.476)^n$$

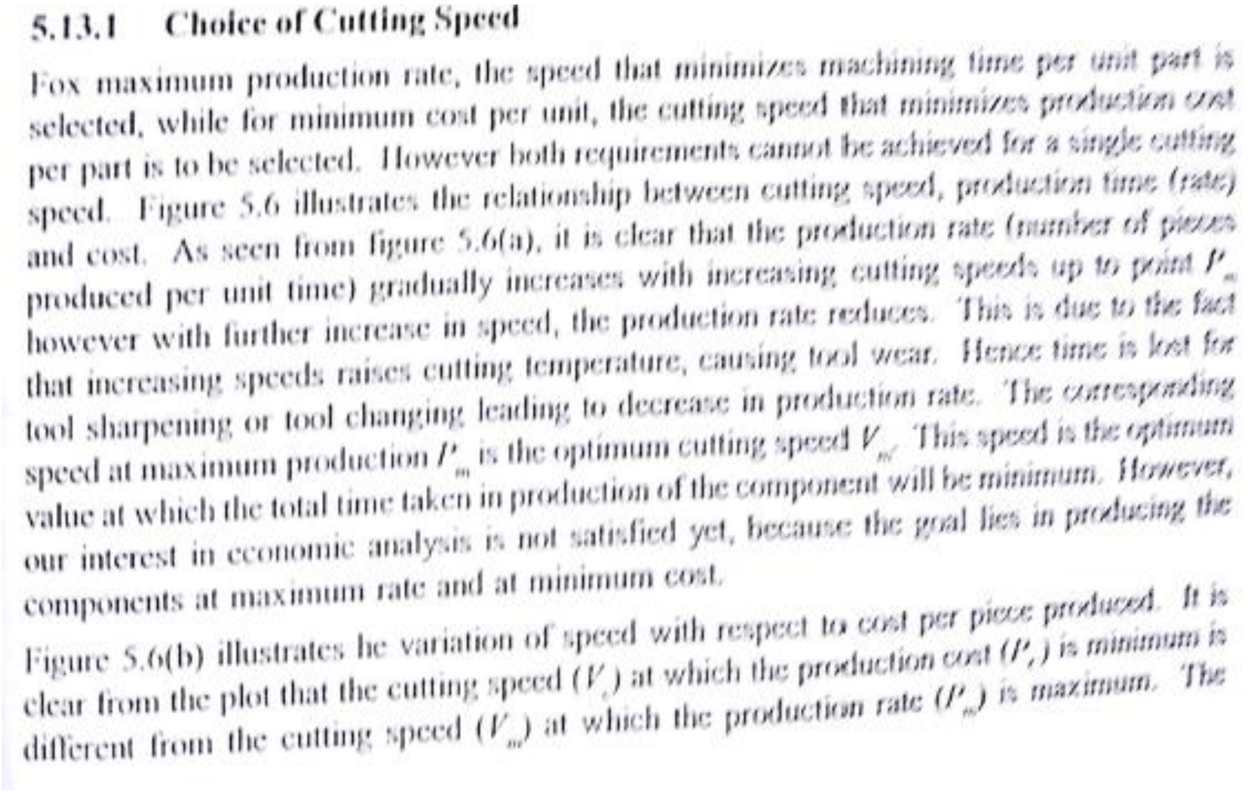
$$\ln 1.2 = n \ln (2.476)$$

$$\therefore \text{n} = \frac{0.1823}{0.9067} \qquad \textbf{n = 0.201}$$

ubstituting $n = 0.201$ in $V_1T_1^{\,n} = C$ or $V_2T_2^{\,n} = C$, we have

$$(30)\,(126)^{0.201} = C \qquad \text{or} \quad C = 79.3$$

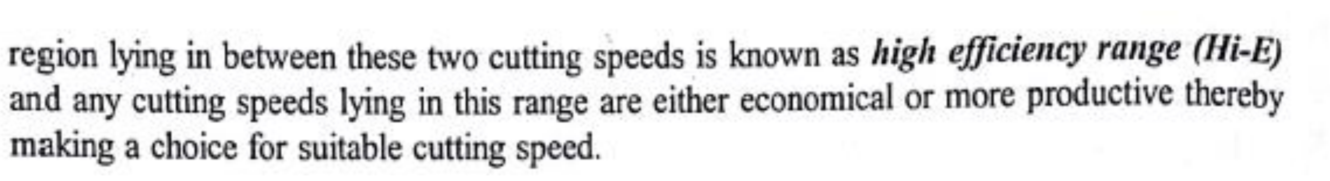
10. a.



5.13.1 Choice of Cutting Speed

Fox maximum production rate, the speed that *minimizes machining time per unit part* is selected, while for minimum cost per unit, the cutting speed *that minimizes production cost* per part is to be selected. However both requirements cannot be achieved for a single cutting speed. Figure 5.6 illustrates the relationship between cutting speed, production time (rate) and cost. As seen from figure 5.6(a), it is clear that the production rate (number of pieces produced per unit time) gradually increases with increasing cutting speeds up to point P'_m however with further increase in speed, the production rate reduces. This is due to the fact that increasing speeds raises cutting temperature, causing tool wear. Hence time is lost for tool sharpening or tool changing leading to decrease in production rate. The corresponding speed at maximum production P'_m is the optimum cutting speed V_m. This speed is the optimum value at which the total time taken in production of the component will be minimum. However, our interest in economic analysis is not satisfied yet, because the goal lies in producing the components at maximum rate and at minimum cost.

Figure 5.6(b) illustrates he variation of speed with respect to cost per piece produced. It is clear from the plot that the cutting speed (V_c) at which the production cost (P'_c) is *minimum* is different from the cutting speed (V_m) at which the production rate (P'_m) is *maximum*. The



region lying in between these two cutting speeds is known as ***high efficiency range (Hi-E)*** and any cutting speeds lying in this range are either economical or more productive thereby making a choice for suitable cutting speed.

10. b.

5.14 TOOL LIFE FOR MINIMUM COST (T_{min})

For minimum production cost, the life of the cutting tool must extend for longer periods. This can be achieved with minimum cutting speed, because, as the cutting speed increases, tool wear also increases. The tool life that corresponds to minimum cutting speed for minimum cost can be calculated using Taylor's tool life equation: $VT^n = C$

where $V = V_C$ = Cutting speed for minimum cost

T = Tool life,

C and n or Taylor's constants.

5.15 TOOL LIFE for MINIMUM PRODUCTION TIME or MAXIMUM PRODUCTION RATE (T_{max})

The tool life for minimum production time or maximum production rate is a function of the index n as described in Taylor's tool life equation. The equation is of the form as given below:

$$T_{max} = \left(\frac{1}{n} - 1\right) T_c \qquad T_c = \text{tool changing time}$$

or T_{max} can be calculated using Taylor's equation: $VT^n = C$

where $V = V_m$ = Cutting speed for maximum production

5.16 TOOL LIFE FOR MAXIMUM EFFICIENCY (MAXIMUM PROFIT RATE)

The equations discussed with respect to cutting speed and tool life for minimum cost and maximum production do not throw any light with respect to maximizing the profit rate. The maximize profit rate depends on the rate of production and on the margin between the selling price and cost or production. For example, to achieve minimum cost, the cutting speed has to be minimum, however the production rate may be too low to maximize the profit rate. Thus the cutting speed for maximum efficiency (V_{mp}) would be different from that for minimum cost and maximum production rate.

$$\text{Tool life for maximum efficiency} = T_{mp} = \left[\frac{C}{V_{mp}}\right]^{1/n}$$

$$\text{where } V_{mp} = \frac{BC_t}{n(S_p - C_m)\left[\left(\frac{C}{V_{mp}}\right)^{1/n} - (1-n)\left[C_t T_h + (S_p - C_m) T_c\right]\right]}$$

where S_p = sale price or revenue per piece

C_m = cost of material used per piece, and T_h = time for loading and unloading job