$$m^2 = \frac{34,000}{480}$$

$$m = \sqrt[3]{\frac{34,000}{480}} = 4.14 \text{ mm}$$

$$\approx 4.5 \text{ mm (Nearest standard value)}$$

$$B = mY = 4.5 \times 10$$

$$= 45 \text{ mm.} \quad \textbf{Ans.}$$

Example 8.4. *A 4 speed (2 × 2) gear box is required to be designed for transmitting 8 H.P. with speed ranging from 300 R.P.M. with $\phi = 1.2$. Select on optimum ray diagram and hence calculate gear sizes module and width of gears. Calculate the shaft sizes and sketch the gear box. The gears made up of mild steel.*

Solution. The optimum ray diagram for the gear box is shown in Fig. 8.14.

Various speeds at the output shaft are as follows :

$N_1 = 300$ R.P.M.

$N_2 = 300 \times 1.2 = 360$ R.P.M.

$N_3 = 360 \times 1.2 = 432$ R.P.M.

$N_4 = 432 \times 1.2 = 520$ R.P.M.

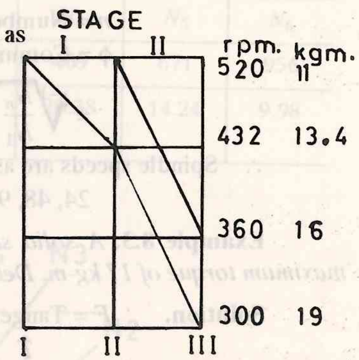


Fig. 8.14

$$\text{H.P.} = \frac{2\pi NT}{4500}$$

$T' =$ Torque at N'

$$= \frac{\text{H.P.} \times 4500}{2\pi N_1}$$

$$= \frac{8 \times 4500}{2\pi \times 300} = 19.0 \text{ kg-m}$$

$T' =$ Torque at N_2

$$= \frac{\text{H.P.} \times 4500}{2\pi \times N_2}$$

$$= \frac{8 \times 4500}{2\pi \times 360} = 16 \text{ kg-m}$$

$$T''' = \frac{\text{H.P.} \times 4500}{2\pi N_3}$$

$$= \frac{8 \times 4500}{2\pi \times 432} = 13.4 \text{ kg-m}$$

$$T''' = \frac{8 \times 4500}{2\pi \times 520} = 11 \text{ kg-m.}$$

Stage I $\quad r_1 =$ Transmission ratio

$= 1/1.2$

$$r_2 = \frac{1}{1.2^\circ} = \frac{1}{1}$$

The number of teeth are found as follows :

Transmission ratio (r)	*Transmission ratio rationalised and expressed in the form f/g*	*f + g*
$r_1 = \frac{1}{1.2}$	$\frac{1}{1.2} = \frac{5}{6}$ $(f = 5, g = 6)$	11
$r_2 = \frac{1}{1.2^\circ} = \frac{1}{1}$	$\frac{1}{1}$	2

Least common multiple (K) of $f + g$, *i.e.* 11 and 2 is 22

$$K = 22$$

$$r_{min} = \frac{5}{6} = \frac{f_{min}}{g}$$

$$\therefore \quad f_{min} = 5$$

$$\frac{f_{min}}{f_{min} + g} = \frac{5}{5+6} = \frac{5}{11}$$

If smallest number of teeth is to be greater than 17

$$EK \frac{f_{min}}{f_{min} + g} \geq 17$$

$$E \times 22 \times \frac{5}{11} = 17$$

$$E = \frac{17 \times 11}{22 \times 5} = 1.7 \approx 2 \text{ (say)}$$

E is the multiple taken such that it is an integer and greater than 1

$$EK = 2 \times 22 = 44$$

Teeth on gear 1 and 1′ are found as follows :

$T_1 =$ Number of teeth gear 1

$$= EK \frac{f_1}{f_1 + g_1} = 44 \times \frac{5}{11} = 20$$

$T_1' =$ Number of teeth on gear 1′

$$= EK \frac{g_1}{f_1 + g_1} = 44 \times \frac{6}{11} = 24$$

Teeth on gear 2 and 2′ are found as follows :

$$T_2 = EK \times \frac{f_2}{f_2 + g_2} = 44 \times \frac{1}{1+1} = 22$$

$T_2' = T_2 = 22$ as they are to have same speed.

d_1 = Diameter of shaft I

$$= \sqrt[3]{\frac{\text{Torque }(T^{iu})}{24}}$$

(as T^{iu} = 11 kg m = 1100 kg-cm is the torque transmitted by the shaft I).

$$d_1 = \sqrt[3]{\frac{1100}{24}} = 3.5 \text{ cm} = 35 \text{ mm}$$

d_2 = Diameter shaft II

$$= \sqrt[3]{\frac{T^{iu}}{24}} = \sqrt[3]{\frac{1340}{24}}$$

$$= 3.8 \text{ cm} = 38 \text{ mm}$$

(The max. torque transmitted by shaft II is 1340 kg-cm)

Stage II

Transmission ratio (r)	*Transmission ratio rationalised and expressed in the form f/g*	*f + g*
$r_3 = \frac{1}{\phi^2} = \frac{1}{(1.2)^2} = \frac{1}{1.44} \approx 1/1.5$	$\frac{1}{1.5} = \frac{2}{3}$	5
$r_4 = \frac{1}{\phi''} = \frac{1}{1.2^\circ} = 1/1$	1/1	2

K the least common multiple of $f + g$, *i.e.* 5 and 2 is 10

$$K = 10$$

$$r_{min} = \frac{2}{3} = \frac{f_{min}}{g}$$

$$\therefore \quad f_{min} = 2$$

$$\frac{f_{min}}{f_{min} + g} = \frac{2}{2+3} = \frac{2}{5}$$

If smallest number of teeth is to be 17

$$EK \times \frac{f_{min}}{f_{min} + g} = 17$$

$$E \times 10 \times \frac{2}{5} = 17$$

$$E = \frac{17 \times 5}{20} \approx 5$$

$$EK = 5 \times 10 = 50$$

T_3 = Number of teeth on gear 3

$$= EK \times \frac{f_3}{f_3 + g_3} = 50 \times \frac{2}{5} = 20.$$

T_3' = Number of teeth on gear 3′

$$= FK \times \frac{f_3}{f_3 + g_3} = 50 \times \frac{3}{5} = 30$$

T_4 = Number of teeth on gear 4

$$= FK \cdot \frac{f_4}{f_4 + g_4} = 50 \times \frac{1}{2} = 25$$

T_4' = Number of teeth on gear 4′

$$= T_4 = 25.$$

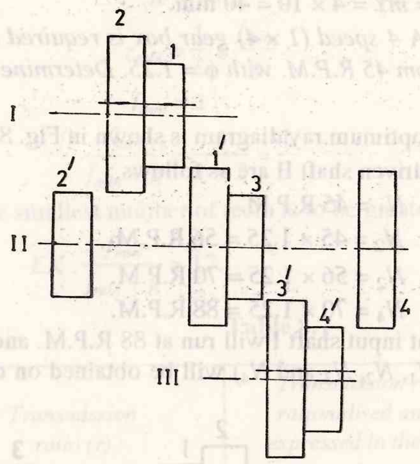


Fig. 8.15

The gear box is shown in Fig. 8.15.

d_3 = diameter of shaft

$$= \sqrt[3]{\frac{1900}{24}} = 4.4 \text{ cm}.$$

As the maximum torque transmitted by shaft III is 1900 kg cm.

To calculate Module (m)

Max. torque = 1900 kg-cm = 19,000 kg-mm.

Max. torque ray provides the value of the force acting at the gear teeth.

$$F = \frac{19{,}000}{m \times \frac{T_3}{2}} = \frac{19{,}000}{m \times \frac{30}{2}}$$

$$= \frac{38{,}000}{30\,m} = \frac{3800}{3\,m}$$

$$E = m^2.Y.C$$

$$\frac{3800}{3m} = m^2.Y.C = m^2 \times 10 \times 2$$

Assuming $Y = 10$ and $C = 2$ for mild steel gears

$$\frac{3800}{3m} = 20\text{ m}^2$$

$$m^3 = \frac{3800}{60}$$

$$m = \sqrt[3]{63.3} = 3.98\text{ mm}$$

Assume $m = 4$ mm (Nearest Standard Value)

B = Width of gear

$$\frac{B}{m} = Y$$

$$B = mY = 4 \times 10 = 40\text{ mm.}$$

Example 8.5. *A 4 speed (1 × 4) gear box is required to be designed with speed ranging from 45 R.P.M. with $\phi = 1.25$. Determine the number of teeth of gears.*

Solution. The optimum ray diagram is shown in Fig. 8.16.

The speeds of driven shaft II are as follows :

$$N_1 = 45\text{ R.P.M.}$$

$$N_2 = 45 \times 1.25 = 56\text{ R.P.M.}$$

$$N_2 = 56 \times 1.25 = 70\text{ R.P.M.}$$

$$N_4 = 70 \times 1.25 = 88\text{ R.P.M.}$$

This means that input shaft I will run at 88 R.P.M. and with the help of gears the speeds (N_1, N_2, N_3 and N_4) will be obtained on driven (output) shaft II.

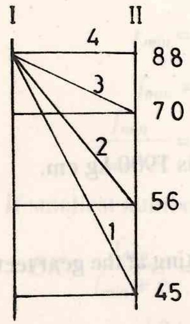


Fig. 8.16

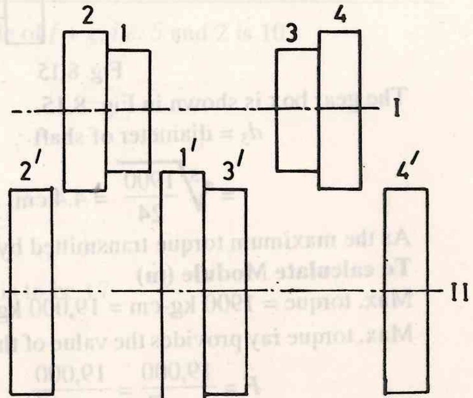


Fig 8.17

The transmission ratio (r) of ray 1 when speed is reduced from 88 R.P.M. to 45 is $\frac{1}{\phi^3}$ or $\frac{1}{(1.25)^3}$ and the transmission ratio of ray 2 when speed is reduced from 88 R.P.M. to 56 R.P.M. is $1/\phi^2$ or $\frac{1}{(1.25)^2}$. Similarly the transmission ratio of ray 3 when speed is reduced from 88 to 70 R.P.M. is $\frac{1}{\phi}$ or $\frac{1}{1.25}$ and transmission ratio of ray 4 when speed at input shaft and output shaft is same, *i.e.* 88 R.P.M. the transmission ratio is $\frac{1}{\phi^\circ}$ or $\frac{1}{1.25^\circ} = \frac{1}{1}$.

The number of teeth for the gears of gear box (Fig. 8.17) are calculated as follows :

The least common multiple (K) of $f + g$, *i.e.* 3, 5, 18 and 2 is 90. (See table 8.7)

$$K = 90$$

$$r_{min} = \frac{1}{2} = \frac{f_{min}}{g}$$

$$\therefore \quad f_{min} = 1$$

$$\frac{f_{min}}{f_{min} + g} = \frac{1}{1 + 2} = \frac{1}{3}$$

If the smallest number of teeth is to be greater than 17

$$EK \,.\, \frac{f_{min}}{f_{min} + g} \geq 17.$$

Table 8.7

Transmission ratio (r)	*Transmission ratio rationalised and expressed in the form f/g*	*f + g*
$r_1 = \frac{1}{(1.25)^3} \approx \frac{1}{2}$	$\frac{1}{2}$ ($f = 1, g = 2$)	3
$r_2 = \frac{1}{(1.25)^2} \approx \frac{1}{1.5}$	$\frac{1}{1.5} = \frac{2}{3}$	5
$r_3 = \frac{1}{1.25}$	$\frac{1}{1.25} = \frac{8}{10}$	18
$r_4 = \frac{1}{1.25^\circ} = \frac{1}{1}$	$\frac{1}{1}$	2

Where E is a multiple taken such that it is an integer and greater than 1

$$E \times 90 \times \frac{1}{3} = 17$$

$$E = \frac{17 \times 3}{90} \approx 1$$

$$EK = 1 \times 90 = 90$$

T_1 = Number of teeth on gear 1

$$= EK \cdot \frac{f_1}{f_1 + g_1} = 90 \times \frac{1}{1+2}$$

$$= \frac{90}{3} = 30$$

T_1' = Number of teeth on gear 2

$$= EK \cdot \frac{g_1}{f_1 + g_1} = 90 \times \frac{2}{3} = 60$$

T_2 = Number of teeth on gear 2

$$T_2 = EK \times \frac{f_2}{f_2 + g_2} = 90 \times \frac{2}{5} = 36$$

T_2' = Number of teeth on gear 2′

$$= EK \cdot \frac{g_2}{f_2 + g_2} = 90 \times \frac{3}{5} = 54$$

T_3 = Number of teeth on gear 3

$$= EK \cdot \frac{f_3}{f_3 + g_3} = 90 \times \frac{8}{18} = 40$$

T_3' = Number of teeth on gear 3′

$$= EK \times \frac{g_3}{f_3 + g_3} = 90 \times \frac{10}{18} = 50$$

T_4 = Number of teeth on gear 4

$$T_4 = EK \times \frac{f_4}{f_4 + g_4} = 90 \times \frac{1}{2} = 45 = T_4'.$$

8.17. Method of Obtaining Different Speeds of Spindle

A wide range of spindle speeds is required in order that a machine tool is adaptable for cutting different types of metals having different properties using varying grades of cutting tools on work-pieces of different diameters. The various methods used for obtaining different speeds of machine tool spindle are as follows :

(*i*) By fitting a cone pulley to the head stock.

(*ii*) By geared mechanism.

(*iii*) By using a variable speed electric motor.

(*iv*) By hydraulic operation.

Any of these methods can be combined to simplify the transmission without reducing the number of speeds available.

8.18. Cone Pulley Arrangement

In this arrangement a cone pulley fitted to the head stock is driven through a counter shaft by an electric motor (Fig. 8.18). The number of speeds obtained depends upon the number of steps on the cone pulley. The various direct speed are obtained by changing the driving belt to the different steps on the cone pulley. A cone pulley with three steps produces three direct speeds of the spindle.

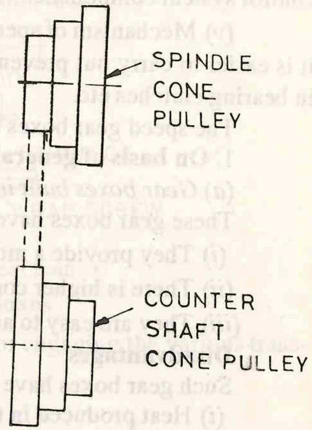


Fig. 8.18

8.19. Cone Pulley Drive by Back Gears

In order to obtain larger number of speeds the head stock is equipped with a cone pulley and back gears. Spindle carries a sleeve over it which is a loose fit (Fig. 8.19). The cone pulley is firmly secured to the sleeve. A pinion P_1 revolves with the cone pulley. A lock pin L engages the gear G_1 with the cone pulley. Back gears G_2 and P_2 are fastened to the quill which revolves on the shaft S at the ends of which the bearings are eccentric with the remaining part of the shaft on which the quill revolves. When speed change is desired the back gears are pulled in by means of back gear handle H. When the back gears are in the lock pin is out the power is transmitted from a pinion P_1 to back gear G_2 and then to pinion P_2 and finally to the spindle. A lathe with three steps on cone pulley and with back gears would have six spindle speeds three direct speeds and three indirect speeds through back gears.

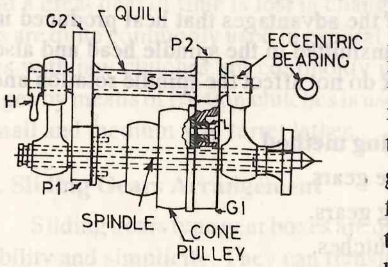


Fig. 8.19

8.20. Speed Gear Boxes

The construction of a speed gear box is intimately linked with the whole structure of the spindle drive. A speed gear box should possess the following requirements :

(*i*) It should provide the designed series of spindle speeds.

(*ii*) It should transmit power of an amount dictated by the purpose of the machine tool.

(*iii*) It should provide smooth silent operation of the transmission and accurate vibrationless rotation of the spindle.

(*iv*) It should have simple construction. This is characterised to a considerable extent by the total number of shaft gears, clutches bearing and control system components.

(*v*) Mechanism of speed gear boxes should be easily accessible so that it is easier to carry out preventive maintenance and to make the adjustments in bearing clutches etc.

The speed gear boxes can be built in two ways :

1. **On basis of general layout**

(*a*) *Gear boxes built into the spindle head (or head stock).*

These gear boxes have the following advantages :

(*i*) They provide a more compact spindle drive.

(*ii*) There is higher concentration of controls.

(*iii*) They are easy to assemble.

Disadvantages

Such gear boxes have the following disadvantages :

(*i*) Heat produced in the gear-box may heat that spindle head.

(*ii*) Vibration from the gear box may be transmitted to the spindle.

These gear boxes are commonly used in medium and heavy machine tools.

(*b*) **Gear boxes with a divided drive.** In such gear boxes the gear box and spindle head or head stock are designed as separate units and the gear box is linked to the spindle head through some type of transmission such as belt transmission. Such gear boxes have the advantages that heat produced in the gear box by friction losses is not transmitted to the spindle head and also the vibrations developed in the gear box do not affect the spindle rotation and the spindle runs smoothly.

2. **On basis of speed changing method**

(*i*) Speed boxes with change gears.

(*ii*) Speed boxes with sliding gears.

(*iii*) Speed boxes with jaw clutches.

(*iv*) Speed boxes with frictional clutches.

8.21. Gear Box Layout

Gear box layout depends upon the general layout of the machine tool, *i.e.* the spatial and dimensional relation between the various units and the spatial relations between the gear box proper and the spindle head (head stock). It also depends upon the purpose, of the machine tool and its type and size.

8.22. Screw Cutting on Lathe by Using Change Gears

During screw cutting the spindle of the lathe provides the rotational movement and the lead screw provides the axial movement necessary to generate a helix. Usually a gear train is used as a drive between the spindle and lead screw. Fig. 8.20 shows a simple change gear train in which the idler gear only controls the direction of rotation of the driver and driven gear and does not affect the speed of rotation.

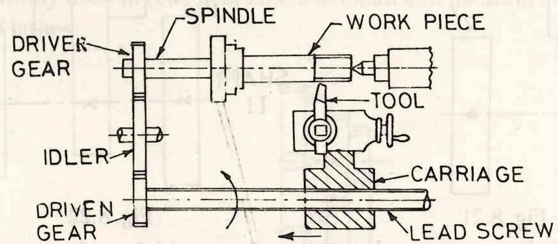


Fig. 8.20. The 'CHANGE' gear train.

8.23. Methods for Changing Speed in Gear Boxes

The following arrangements are made for engaging the various transmissions in gear boxes to change the speeds :

(*i*) Gear boxes with change (slip) gears.

(*ii*) Gear boxes with sliding gears.

(*iii*) Gear boxes with sliding key mechanism.

(*iv*) Gear boxes with friction clutches. Change gears are used when the spindle drive is to be changed over comparatively in frequency for different operations in mass and lot production. The principle drawback of change gears is that a great deal of time is lost in changing speeds. Gear boxes with sliding gears are quite commonly used in general purpose machine tools whereas gear boxes with jaw clutches are commonly used in heavy machine tools. Speed changes by means of friction clutches is used mainly in the group transmissions of small and medium size turret lathes.

8.24. Sliding Gears Arrangement

Sliding gears type gear boxes are quite commonly used because of their reliability and simplicity. They can transmit heavy torque and can run at high speeds. These are widely used in general purpose machine tools. These gear boxes have sliding cluster gears and the gears not participating in the transmission of power to the spindle in a given engagement are not in mesh and are consequently not subject to wear during this time.

Fig. 8.21 shows a sliding cluster of two gears 1 and 2 fitted on a splined shaft 1. The gears 1′ and 2′ are keyed to shaft II. Sliding cluster can be slided along the splined shaft so that at one stage gear 1 and 1′ are in engagement to obtain a particular speed of shaft and then the gear 2 and 2′ can be brought in engagement to obtain second speeds of the shaft II.

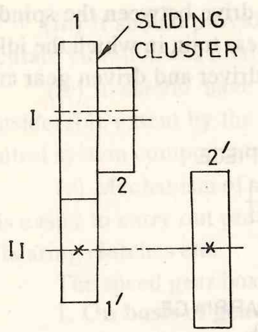


Fig. 8.21

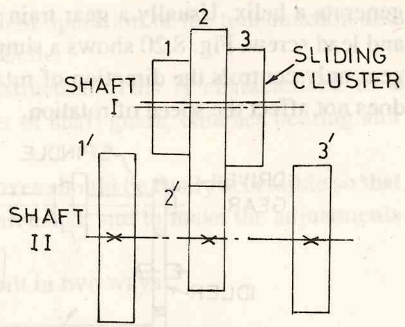


Fig. 8.22

Fig. 8.22 shows a three step sliding cluster which can be moved to bring gear 1 in mesh with gear 1′, gear 2 in mesh with gear 2′ and gear 3 in mesh with gear 3′ to obtained three speeds of shaft II.

Fig. 8.23 shows an all geared head stock in which the different spindle speed are obtained by shifting the position of gears with the help of a sliding gear mechanism. Such a gear box is designed to give spindle speeds in geometrical progression. A simple design of a nine speed all geared head stock

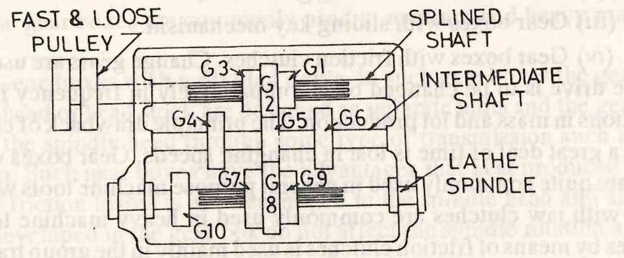


Fig. 8.23

is shown in the above figure. Spur gears G_1, G_2 and G_3 are mounted on the splined shaft whereas gears G_4, G_5 and G_6 are mounted on the intermediate shaft and the lathe spindle carries a cluster (combination) of gears G_7, G_8 and G_9. Power from the driving motor is transferred to the splined shaft through fast and loose pulleys. Gears G_1, G_2 and G_3 can be brought in mesh with spur gears G_4, G_5 and G_6 respectively with the help of a lever and gears G_7, G_8 and G_9 can be brought in contact with gears G_4, G_5 and G_6 respectively with the help of another lever. Finally the power is thus transferred to lathe spindle which can have nine speeds. Gear 10 called translating gear is used to transmit motion to lead screw and feed shaft.

8.25. Sliding Key Mechanism

This mechanism consists of a hollow shaft into which a slotted rod. Carrying the key is located and by end wise movement the rod pulls the key into the key ways of various gears in turn so that any one of a nest of gears is driven by the sliding key.

Fig. 8.24 shows a sliding key type gear box. This arrangement is commonly used in feed gear boxes of small and medium size drill presses and turret lathes.

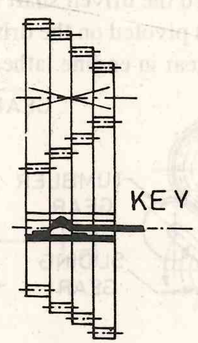


Fig. 8.24

8.26. Feed Gear Boxes

Feed gear box is a part of the feed mechanism. The drive of the feed mechanism may be powered by a separate electric motor or from the head stock spindle through a gear, chain or belt transmission. The feed gear should be arranged near to the working zone especially when the feeds are changed frequently. Feed gear boxes are classified in accordance with the type of geared mechanism they use to set up the feeds.

(*i*) Feed gear boxes with change gears.
(*ii*) Feed gear boxes with sliding gears.
(*iii*) Feed gear boxes with intermediate gear cones and sliding keys.
(*iv*) Feed gear boxes with gear cone and tumbler gear (Norton type).
(*v*) Feed gear boxes of the Meander type.

The various factors that influence the structure and construction of feed gear boxes are as follows :

(*i*) Purpose of machine tool.
(*ii*) Number of feed steps.
(*iii*) Range of feeds.
(*iv*) Absolute value of rates of feed.
(*v*) Rate at which feeds are to be changed.
(*vi*) Type of feeds series (geometrical series or arithmetic series).
(*vii*) Nature of feed motion (continuous or intermittent)

(*viii*) Required accuracy of the feed rates.

(*ix*) Loads applied to the feed gear box.

8.27. Norton Gear Box

In this gear box different speeds of drived shaft are obtained by engaging the tumbler gear with each gear of gear cone fitted on the driving shaft. The sliding gear is keyed the driven shaft and meshes with the tumbler gear which is held in a bracket pivoted on the driven shaft. This gear box (Fig. 8.25) is widely used as feed gear in engine lathes.

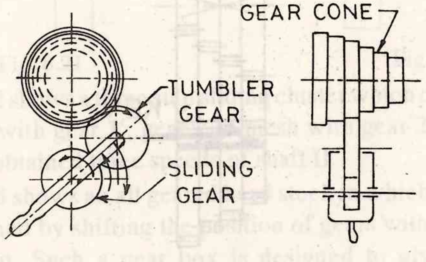
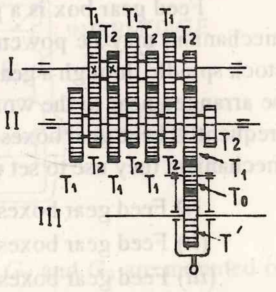


Fig. 8.25

8.28. Feed Gear Box of Meander Type

It is a three shaft mechanism made up of a series of identical double cluster gear and a sliding gear with a tumbler gear (Fig. 8.26). In this gear box all the cluster gears rotate continuously in mesh including cluster gears which do not participate in a particular engagement. If the gears have teeth T_1, T_2, T_0 and T_1 then the following series of transmission ratios (r) are obtained.



$$r_1 = \frac{T_1}{T_2} \times \frac{T_1}{T'} = k \cdot \frac{T_1}{T_2}$$

where $\frac{T_1}{T'} k$

Fig. 8.26

$$r_2 = \frac{T_1}{T_2} \cdot \frac{T_2}{T'} = \frac{T_1}{T'} = k$$

$$r_2 = \frac{T_2}{T_1} \times \frac{T_1}{T'} = k \times \frac{T_2}{T'}$$

$$r_4 = \frac{T_2}{T_1} \times \frac{T_2}{T'} = k \left(\frac{T_2}{T_1}\right)^2$$

$$r_5 = \frac{T_2}{T_1} \times \frac{T_2}{T_1} \times \frac{T_2}{T_1} \times \frac{T_1}{T'} = k \left(\frac{T_2}{T'}\right)^3$$

and so on.

8.29. Clutched System

A clutch can be used to transfer power from the driving shaft I to driven shaft II. The clutch (H) can slide on splined shaft. When the clutch (Fig. 8.27) is connected at left the speed (N_2) of driven shaft is given by

$$N_2 = N_1 \times \frac{T_1}{T_1'}$$

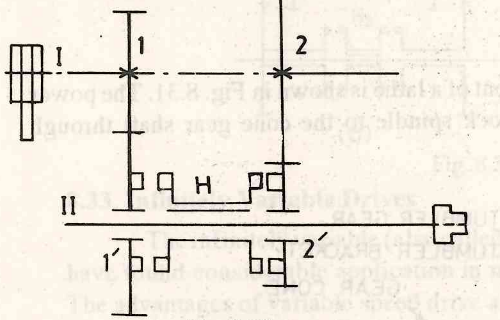


Fig. 8.27

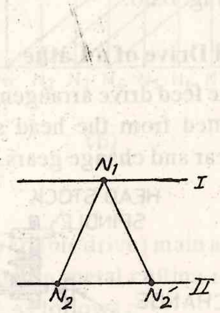


Fig. 8.28

where N_1 (R.P.M.) is the speed of shaft I and T_1 and T_1' are teeth on gear I and I′ respectively. Similarly when the clutch is connected to right gear the speed (N_2') of shaft II is given by

$$N_2' = N_1 \cdot \frac{T_2}{T_2'}$$

where T_2 and T_2' are the teeth on gear 2 and 2′ respectively (Fig. 8.28).

8.30. Ruppert Drive

It is a clutched drive, Fig. 8.29 shows a ruppert drive. This drive uses two clutches (H_1 and H_2) and six gears 1, 1′, 2, 2′, 3 and 3′. It gives four speeds.

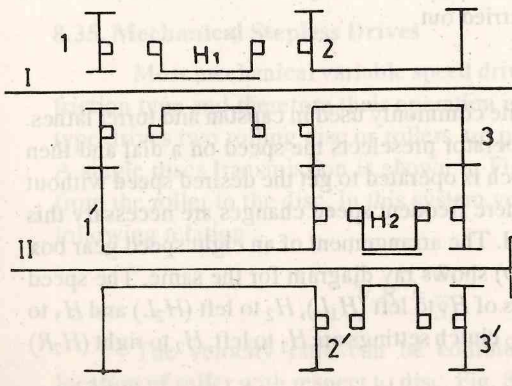


Fig. 8.29

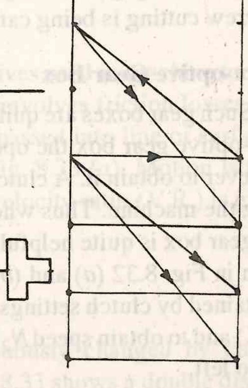


Fig. 8.30

When clutch H_1 is towards left and clutch H_2 is also towards left, the output shaft will have one speed. When clutch H_1 is towards right and clutch H_2 is towards left the output shaft II will have second speed. When the clutch H_1 is towards right and H_2 is also towards right the output shaft will have third speed and when clutch H_1 is towards left and clutch H_2 is towards right the output shaft will have fourth speed. A typical ray diagram for this drive is shown in Fig. 8.30.

8.31. Feed Drive of a Lathe

The feed drive arrangement of a lathe is shown in Fig. 8.31. The power is transmitted from the head stock spindle to the cone gear shaft through tumbler gear and change gears.

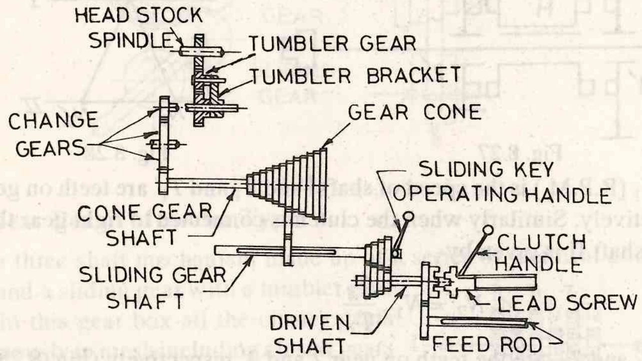


Fig. 8.31

Gear cone has 12 gears and 12 speeds can be obtained on sliding gear shaft with the help of sliding gear. With the help of four gears mounted on sliding gear shaft and sliding key operating handle the driven shaft can be given 48 speeds. Therefore, 48 different feeds can be provided. Lead screw can be engaged or disengaged with the help of clutch. Lead screw should be used when screw cutting is being carried out.

8.32. Pre-optive Gear Box

Such gear boxes are quite commonly used in capstan and turret lathes. In a pre-optive gear box the operator preselects the speed on a dial and then pulls a lever to obtain it. A clutch is operated to get the desired speed without stopping the machine. Thus where frequent speed changes are necessary this type of gear box is quite helpful. The arrangement of an eight speed gear box is shown in Fig. 8.32 (*a*) and (*b*) shows ray diagram for the same. The speed N_1 is obtained by clutch settings of H_1 to left (H_1L), H_2 to left (H_2L) and H_3 to left (H_3L) and to obtain speed N_2 clutch settings are H_1 to left, H_2 to right (H_2R) and H_3 to left.

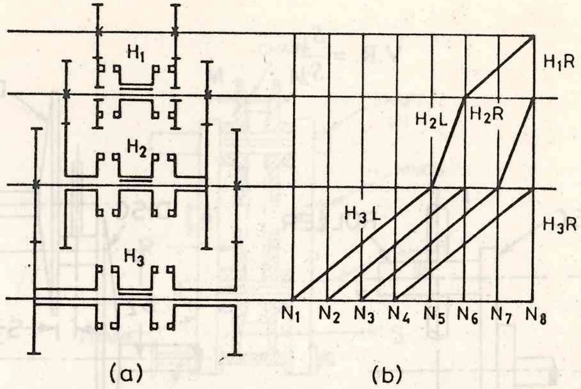


Fig. 8.32

8.33. Infinitely Variable Drives

The infinitely variable (also called variable drive) main and feed drives have found considerable application in modern metal cutting machine tools. The advantages of variable speed drive are as follows :

(*i*) It becomes possible to set up the optimum cutting conditions (speed and feed) with higher accuracy than with a stepped drive.

(*ii*) The speeds can be changed rapidly without stopping the machine. This saves the handling time in machine operation and thus promotes an increase in the production capacity of a machine tool.

(*iii*) A more uniform quality of surface finish is attained.

(*iv*) Variable speed friction drives used in machine tools operate much more quietly than gear or chain drives.

8.34. Types of Infinitely Variable Drives

Various methods are in use for stepless variation of the rates of the working motions. Mechanical, hydraulic and electrical stepless drives are often used to minimise speed loss by having infinite number of speed steps.

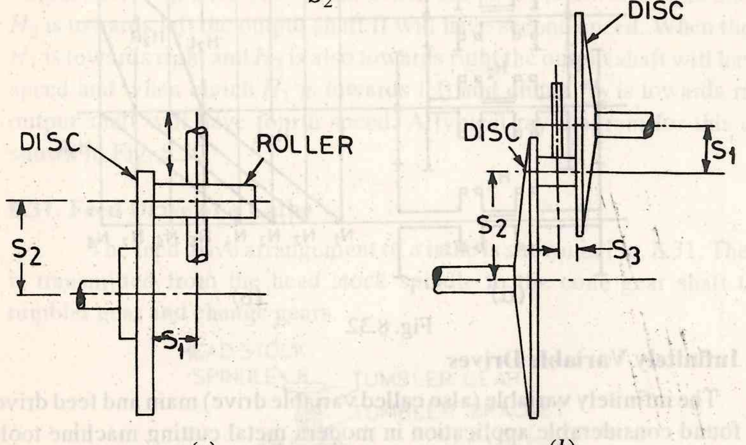
8.35. Mechanical Stepless Drives

Most mechanical variable speed drives used in machine tool are of the friction type and therefore their operation involves friction losses. In friction type drives two rolling disc or rollers are passed into line or surface contact. A single discs transmission is shown in Fig. 8.33 (*a*). Motion is transmitted from the roller to the disc. In this system velocity ratio (V.R.) is given by the following relation :

$$\text{V.R.} = \frac{S_1}{S_3}$$

The velocity ratio can be continuously changed by changing the location of roller with respect to disc. Fig. 8.33 shows a double disc transmission system in which the velocity ratio is given by

$$V.R. = \frac{S_1}{S_2}$$



(a) (b)

Fig. 8.33

Fig. 8.34 shows Reeves variable speed transmission system. This system consists of a pair of pulleys connected by a V-shaped belt, each pulley further being made up of two conical discs. These discs can slide along the shaft and rotate with the shaft. In order to adjust the diameter of pulleys the two discs on the shaft are made to approach each other so that diameter is increased or they are made to recede so that diameter can be reduced. In this manner the ratio of driving diameter to driven diameter can be easily changed and therefore any desired speed can be obtained without stopping the machine tool.

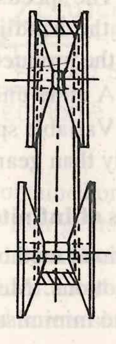


Fig. 8.34

8.35.1. P.I.V. Drive

Positive Infinitely Variable (P.I.V.) drive is a positive torque transmission arrangement. In this system there are two chain wheels, an endless chain, a frame, and a screw. The screw has left hand and right hand threads. The chain wheels have variable pitch circle diameters. One wheel has a pair of cones M and N and other wheel has a pair of cones R and S. The cones can be displaced axially and by doing so the effective diameters can be changed and thus the transmission ratios between shafts A and B are changed. By rotating screw the levered frames get moved thus changing the location of the chain pulley as shown in Fig. 8.34 (a).

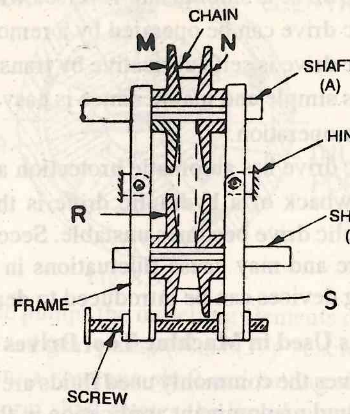


Fig. 8.34 (a)

8.36. Electric Stepless Drives

It is obtained by the electrical motor which is used to drive the various operational movements of machine tools. A 3 phase A.C. motors are commonly used for driving the machine tools. The selection of motor depends upon the starting characteristics, speed adjustment possibilities and power and torque characteristics.

8.37. Hydraulic Drives

Hydraulically actuated machine tools offer great flexibility of speed and feed control, elimination of shock and possess the ability to stall against obstruction thus protecting parts or tools from breakage. Hydraulic actuation also permits slip or slowing up of motion when the cutting tool is over loaded.

The important elements of a hydraulic transmission are as follows :

(*i*) Pumps
(*ii*) Cylinders
(*iii*) Direction-control valves
(*iv*) Pressure valves
(*v*) Throttles.

Hydraulic drives are quite commonly used to obtain infinitely variable rates of rectilinear motion in machine tools. A hydraulic drive is rarely used for rotary motion in a machine tool because of its high cost and low efficiency after wear. The various advantages and disadvantages of hydraulic drives are as follows :

Advantages. (*i*) A hydraulic drive has a wide range of speed variation.

(*ii*) In a hydraulic drive both magnitude and direction of speeds can be easily changed.

(*iii*) A hydraulic drive is smooth and reverses without shock.

(*iv*) A hydraulic drive can be operated by a remote control.

(*v*) A hydraulic drive is self-lubricative by transmission.

(*vi*) Its design is simple and maintenance is easy.

(*vii*) It is quite in operation.

(*viii*) A hydraulic drive has automatic protection against over loads.

The major drawback of a hydraulic drive is that at low speeds the operation of the hydraulic drive becomes unstable. Secondly the oil viscosity varies with temperature and may cause fluctuations in feed and speed rates although compensating devices can be introduced to deal with this difficulty.

8.38. Hydraulic Fluids Used in Machine Tool Drives

In hydraulic drives the commonly used fluids are mineral or petroleum oils. Mineral oil has found predominant application in the hydraulic drives of metal cutting machine tools. The oil used should be sufficiently homogeneous as to its chemical composition. The main service property used in selecting and comparing oils is the Viscosity Index which shows the change in the viscosity of an oil with its temperature. An oil with higher viscosity index is preferred. A substantial increase in viscosity index can be achieved by the application of special synthetic oil additives. The hydraulic fluids should not contain matters which are inflammable in nature.

8.39. Elements of a Hydraulic System

The various elements of a hydraulic system are as follows :

(*i*) Pressure producing unit, *i.e.* pump.

(*ii*) The element making use of the pressure, *i.e.* hydraulic motor (cylinder and piston).

(*iii*) Controlling elements such as valves.

(*iv*) Storage and transmission elements such as tank, pipeline etc.

Pumps. The pump develops the pressure or head of the working fluid by expanding mechanical energy. The pressure most commonly used in hydraulic machine tools varies from 5 to 80 kg/cm^2. The various types of pumps used in a hydraulic drive are as follows :

(*i*) Reciprocating pumps

(*ii*) Rotary pumps.

In reciprocating pump the liquid is displaced due to the reciprocating motion of the impelling elements (pistons or plungers).

Fig. 8.35 shows a variable delivery plunger pump. Arrows show the direction of piston displacement for the instantaneous position shown. Rotary pumps are of two types :

(*a*) Purely rotary type

(*b*) Rotary piston pumps.

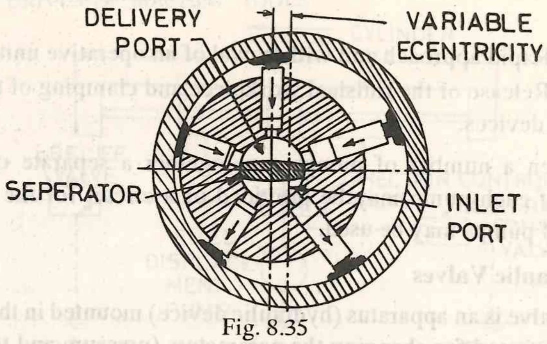


Fig. 8.35

In purely rotary type pumps the impelling elements only rotate such as in screw pump (Fig. 8.36) and gear pump (Fig. 8.37). A screw pump consists of a two worms welded into a common shaft and having right hand and left hand threads. When the worm shaft rotates the liquid supplied to the worms from the right and left flows towards the middle where the discharge pipe is arranged. A gear pump has two gears each with not more than 8 to 12 teeth to ensure a tighter mesh. As the gears rotate the liquid from the suction pipe is caught up by the teeth and is carried between their spaces to the discharge pipe.

Gear pumps find application in the hydraulic system of machine tools operating at medium and low pressure and at high speeds such as grinders and honing machines. Gear pumps are fixed delivery pumps, *i.e.* they deliver a constant volume at a constant pressure.

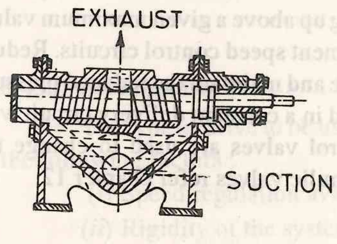


Fig. 8.36

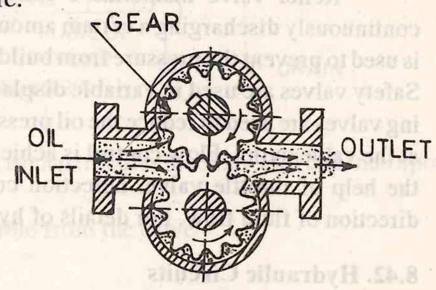


Fig. 8.37

In rotary piston pumps the impelling elements (plungers) reciprocate in addition to rotation in respect to the rotary cylinder body.

The selection of a pump depends upon delivery and pressure developed by the pump. The minimum delivery of pumps used in hydraulic drives of machine tool has been taken as 3 litres per minute and maximum delivery as 400 litres/minute.

8.40. Pump Operation Methods

In the hydraulic systems of machine tools pumps may be run both single and dual and in series or parallel. Series pump operation is used to increase the pressure in the system whereas parallel operation is preferred to increase delivery and to obtain rapid traverse motions such as (*i*) Rapid approach and withdrawal of an operative unit.

(*ii*) Release of the finished workpiece and clamping of the next black in handling devices.

When a number of pumps run together a separate circuit for the operation of each pump may be provided or a circuit for the simultaneous operation of pumps may be used.

8.41. Hydraulic Valves

A valve is an apparatus (hydraulic device) mounted in the path of fluid flow and designed for changing the parameters (pressure and volume) of the fluid flowing in the hydraulic system. Each valve has an operative number which is actuated either by an external force (adjustable valves) or by the fluid passing through it (non-adjustable valves). The force acting on the valve changes the cross-sectional area of the opening in the valve and thus the parameters of the fluid are controlled.

Following types of valves are used to control the pressure of the fluid :

(*i*) Relief valves

(*ii*) Safety valves

(*iii*) Reducing valves.

Relief valve maintains a constant pressure at the valve intake by continuously discharging a certain amount of oil back to the tank. Safety valve is used to prevent the pressure from building up above a given maximum value. Safety valves are used in variable displacement speed control circuits. Reducing valves are used to reduce the oil pressure and maintain the reduced pressure at the valve outlet. Flow control is achieved in a constant delivery circuit with the help of throttle valve. Direction control valves are used to change the direction of fluid flow. For details of hydraulic valves refer chapter 12.

8.42. Hydraulic Circuits

Two types of hydraulic circuits are most commonly used :

(*i*) open circuit

(*ii*) closed circuit.

In open circuit the exhaust oil returns to the reservoir. This methods is preferred because the oil is kept cooler due to the larger volume used. Fig. 8.38 shows an open circuit using fixed displacement pump. The piston speed being controlled by flow rate control valve (throttle valve) in the return line. In a close circuit the exhaust oil returns directly to the pump for re-circulation, leakage being made up by separate supplies.

Fig. 8.39 shows a close circuit using a variable displacement pump to give different rates of table traverse.

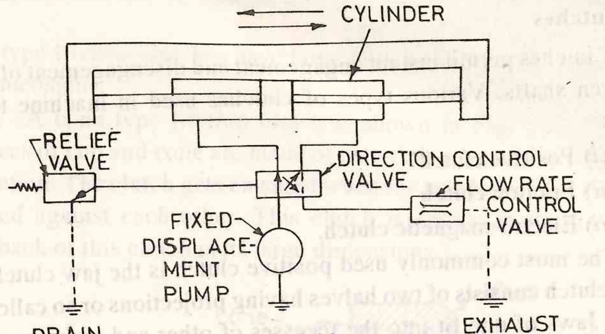


Fig. 8.38

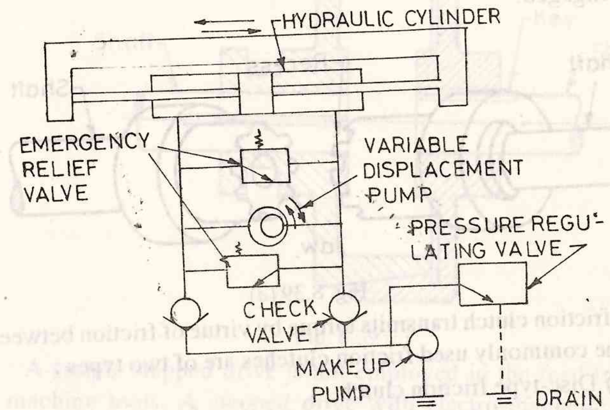


Fig. 8.39

8.43. Selection of Drive

The type of drive to be used for a particular machine tool depends upon the following factors :

(*i*) Speed regulation available from the drive

(*ii*) Rigidity of the system

(*iii*) Uniformity in motion

(*iv*) Efficiency of the drive

(*v*) Reliability

(*vi*) Initial cost

(*vii*) Maintenance cost.

8.44. Hydraulic Drive for Shaper and Milling Machine

The hydraulic drive for shaper and milling machine have been explained in chapter 12.

8.45. Hydraulic Valves

Various hydraulic valves used in hydraulic drive have been explained in chapter 12.

8.46. Clutches

Clutches permit instant engagement and disengagement of the driving and driven shafts. Various types of clutches used in machine tools are as follows :

(*i*) Positive clutch

(*ii*) Friction clutch

(*iii*) Electro-magnetic clutch.

The most commonly used positive clutch is the jaw clutch Fig. 8.39 (*a*). The clutch consists of two halves having projections or so called jaws and recesses. Jaws of one fit into the recesses of other and *vice versa* when the clutch is engaged.

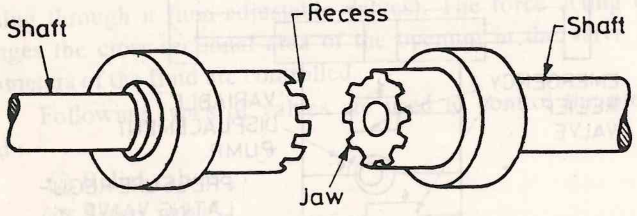


Fig. 8.39 (*a*)

A friction clutch transmits torque by virtue of friction between the two halves. The commonly used friction clutches are of two types :

(*i*) Disc-type friction clutch

(*ii*) Cone-type friction clutch.

Fig. 8.39 (*b*) shows a disc type friction clutch. When the sleeve is moved towards left it exerts an axial force which is multiplied by the lever arrangement and applied on the friction discs. The discs get pressed against each other and the clutch gets engaged to transmit rotation between two shafts.

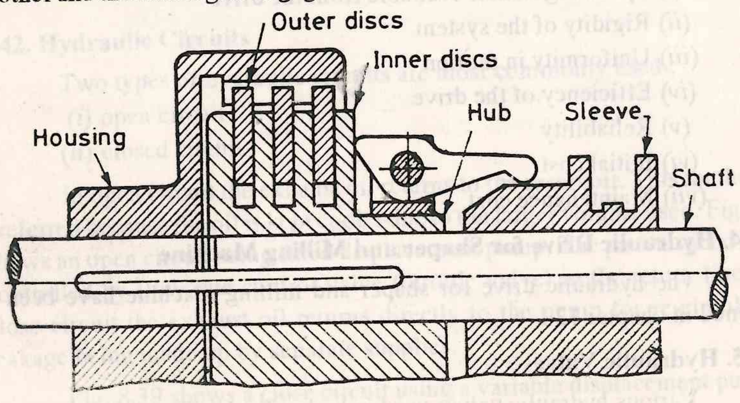


Fig. 8.39 (*b*)

Disc type friction clutches have large load carrying capacity with small over all dimensions.

A cone type friction clutch is shown in Fig. 8.39 (*b*). The tapered surfaces of cup and cone are made of materials which have a large coefficient of friction. The clutch gets engaged when the two halves *i.e.* cup and cone are pressed against each other. This clutch is simple in design but the major drawback of this clutch is its large dimensions.

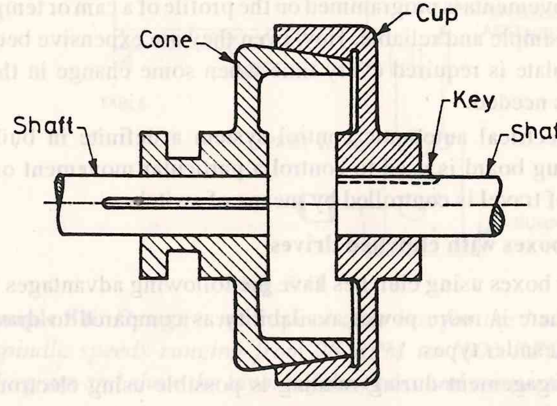


Fig 8.39 (*c*)

A simple stepped drive is not employed in the feed transmission of N.C. machine tools. A stepped drive with electro-magnetic clutches also known as electromagnetic drive is often used. Electromagnetic clutches permit automatic changing of feed rate.

8.47. Control Systems in Machine Tools

They are used to generate to controlling movements which are essential for carrying out a machining process in accordance with technical specifications of the part being machined. Two main functions of control system are as follows :

(*i*) To change speed and feeds

(*ii*) To provide the working and auxiliary motions in the desired sequence necessary for machining a particular part.

Machine tools are also provided with safety controls to prevent damage to the machine tool and cutting tool during execution of primary auxiliary motions.

Machine tool control system generally consists of the following :

(*i*) a control member to initiate the controlling movements

(*ii*) a transmission which transmits the controlling movements to the operative member.

(*iii*) an operative member which finally executes the movement

Automatic control systems can be classified as follows :

(*i*) Mechanical automatic control systems using cams or templates.

(*ii*) Electrical automatic control systems using limit switches and plug boards.

(*iii*) Numerical automatic control systems using punched paper tape, magnetic tape etc.

In mechanical automatic control systems the required sequence of operative movements is programmed on the profile of a cam or template. These systems are simple and reliable. How even they are expensive because a new cam or template is required every time when some change in the operative movement is needed.

In electrical automatic control system a definite in built electrical circuit on plug board is used to control a particular movement or operation. The length of travel is controlled by means of switches.

8.48. Gear boxes with clutched drives

Gear boxes using clutches have the following advantages

1. There is more power availability as compared to draw-key type, Norton or Meander types.

2. Engagement during running is possible using electromagnetic or friction clutches.

3. It enables driving and driven gears to be arranged co-axially leading to compact and efficient gearbox layout.

4. In N.C. machine tools gear boxes are essential for speed control.

Example 8.6. (*a*) *Sketch a hydraulic drive for a horizontal broaching machine.*

(*b*) *Sketch a kinematic structure for a cylindrical grinding machine with hydraulic table feed movement.*

Solution. Fig. 8.40 shows a typical hydraulic drive for a horizontal broaching machine in which the broach is pulled through the work piece by a hydraulic force.

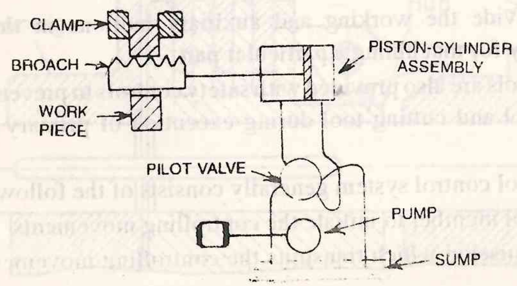


Fig. 8.41 shows the kinetic structure for a cylindrical grinding in which table feed movement is achieved hydraulically.

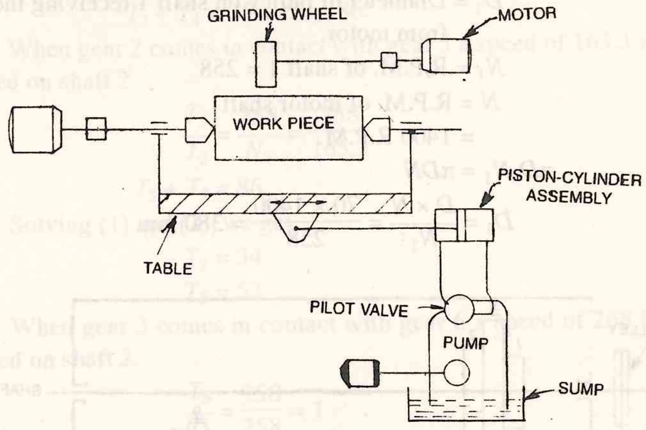


Fig. 8.41

Example 8.6. *Design a nine speed gear box for the head stock of a lathe, the spindle speeds ranging from 28 RPM to 1000 RPM. Draw the structural diagram and show the layout of the gears and connection to motor.*

Solution. Let the speed by in G.P.

n = Number of speed steps = 9

N_1 = Minimum speed = 28 RPM

N_9 = Maximum speed = 1000 RPM

ϕ = Geometric progression ratio

$$= \sqrt[n-1]{\frac{N_9}{91}} = \sqrt[8]{\frac{N_9}{N_1}}$$

$$= \sqrt[8]{\frac{1000}{28}} = 1.56'$$

N_1 = 28 R.P.M.

N_2 = 28 × 1.56 = 43.7

N_3 = 43.7 × 1.56 = 68

N_4 = 106

N_5 = 165.3

N_6 = 258

N_7 = 402.5

N_8 = 628

N_9 = 1000 R.P.M.

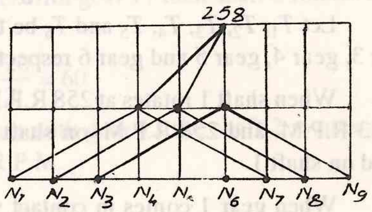


Fig. 8.42

A typical speed diagram (ray diagram) is shown in Fig. 8.42.

$$n = 9 = 1 \times 3 \times 3$$

Let us use a 3 phase 140 R.P.M., 440 V, 50 cycles/sec motor.

D = Motor shaft pulley diameter = 70 mm (say)

D_1 = Diameter of pulley on shaft 1 receiving the drive from motor.

N_1 = R.P.M. of shaft 1 = 258

N = R.P.M. of motor shaft

= 1400 R.P.M.

$$\pi D_1 N_1 = \pi D N$$

$$D_1 = \frac{D \times N}{N_1} = \frac{70 \times 1400}{258} = 380 \text{ mm}$$

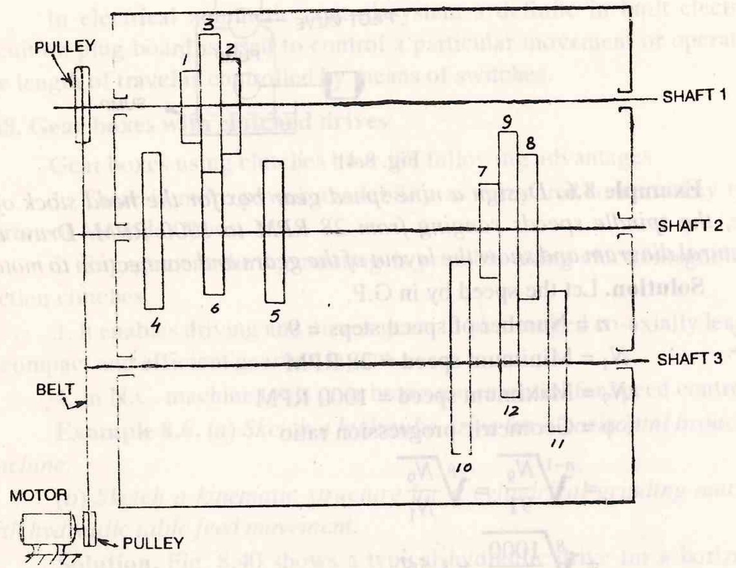


Fig. 8.43

Let T_1, T_2, T_3, T_4, T_5 and T_6 be the number of teeth on gear 1, gear 2, gear 3, gear 4, gear 5 and gear 6 respectively.

When shaft 1 rotates at 258 R.P.M. it is required to obtain 106 R.P.M., 165.3 R.P.M. and 258 R.P.M. on shaft 2. The cluster of gears, 1, 2 and 3 is fitted on shaft 1.

When gear 1 comes in contact with gear 4 a speed of 106 R.P.M. is obtained on shaft 2.

$$T_1 = 25 \text{ (say)}$$

$$\frac{T_4}{T_1} = \frac{258}{N_4} = \frac{258}{106}$$

$$T_4 = \frac{27 \times 258}{106} = 61$$

$$T_1 + T_4 = 25 + 61 = 86.$$

When gear 2 comes in contact with gear 5 a speed of 165.3 R.P.M. is obtained on shaft 2.

$$\frac{T_5}{T_2} = \frac{258}{N_5} = \frac{258}{165.3} \quad ...(1)$$

$$T_5 + T_2 = 86 \quad ...(2)$$

Solving (1) and (2), we get

$$T_2 = 34$$

$$T_5 = 52$$

When gear 3 comes in contact with gear 6 a speed of 268 R.P.M. is obtained on shaft 2.

$$\frac{T_6}{T_3} = \frac{258}{258} = 1$$

$$T_6 + T_3 = 86$$

$$\therefore \quad T_6 = T_3 = 43$$

For shaft 2 and shaft 3.

When gear 7 comes in contact with gear 10, the shaft 2 rotates at 258 R.P.M. and shaft 3 rotates at 68 R.P.M.

$$\frac{T_7}{T_{10}} = \frac{68}{258} = 0.263$$

where T_7 = Number of teeth on gear 7

T_{10} = Number of teeth on gear 10.

Let $T_7 = 25$

$T_{10} = 95$

$$T_7 + T_{10} = 25 + 95 = 120$$

When gear 8 comes in contact with gear 11 then shaft 2 rotates at 258 R.P.M. and shaft 3 rotates at 258.

$$T_8 = T_{11} = \frac{120}{2} = 60$$

When gear 9 comes in contact with gear 12 the shaft 2 rotates at 258 R.P.M. and shaft 3 rotates at 1000 R.P.M.

$$\frac{T_9}{T_{12}} = \frac{1005}{258} = 3.87$$

$$T_9 + T_{12} = 120$$

$$T_9 = 96$$

$$T_{12} = 24.$$

Structural diagram is shown in Fig. 8.44.

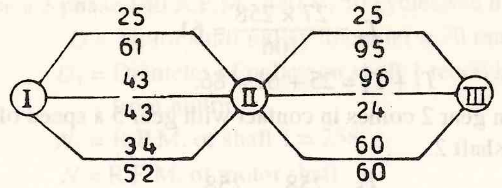


Fig. 8.44

8.49. Flow chart for gear box

Flow chart is used to trace power paths and to indicate stage by stage out puts in a qualitative manner.

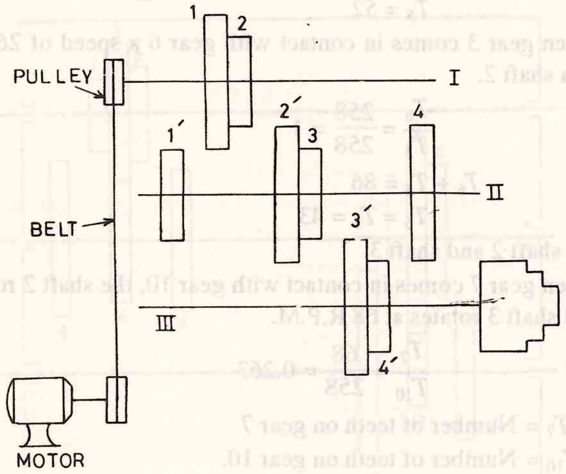


Fig. 8.45

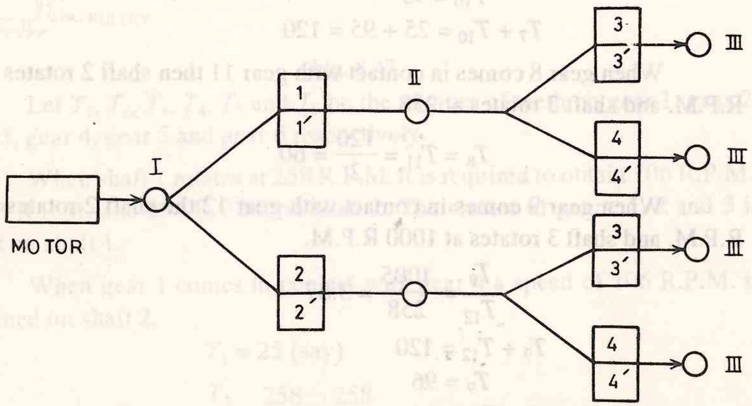


Fig. 8.46

Fig. 8.45 shows a gear box for four out put speeds and Fig. 8.46 shows flow chart for this gear box.

When gear 1 meshes with gear 1′ then the two speech are obtained at out put shaft by meshing gears 3 and 3′ and gears 4 and 4′ similarly when gears 2 and 2′ mesh together two. Speeds are obtained by meshing gear 3 with 3′ and gear 4 with 4′.

I = Input shaft

II = Intermediate shaft

III = Output shaft.

PROBLEMS

8.1. What is a kinematic drive ? How is it obtained ?

8.2. Explain steped drive and stepless drive.

8.3. Explain the following :

(*a*) Ray diagram

(*b*) Speed spectrum in geometric progression.

(*c*) Speed spectrum in arithmetic progression.

8.4. State the basic rules for layout of gear boxes having sliding clusters.

8.5. Explain the following methods of obtaining different speeds of machine tool spindle :

(*a*) Cone pulley arrangement (*b*) Cone pulley drive by back gears

(*c*) Speed gear boxes.

8.6. Write short notes on the following :

(*a*) Screw cutting on lathe using change gears.

(*b*) Norton gear box. (*c*) Feed gear box of Meander type.

(*d*) Ruppert drive. (*e*) Feed drive of a lathe.

(*f*) Infinitely variable drives. (*g*) Mechanical stepless drive systems.

(*h*) Electric stepless drives.

8.7. Explain hydraulic stepless drives.

8.8. Explain open and closed circuit used in hydraulic drive.

8.9. Write short notes on the following :

(*a*) Hydraulic valves

(*i*) Relief valves (*ii*) Safety valve

(*iii*) Reducing valve.

(*b*) Hydraulic fluids used in machine tool drives.

8.10. The spindle speed change gear for a drilling machine has to comply with the following specifications :

Maximum diameter of drill = 20 mm.

Minimum diameter of drill = 5 mm.

Maximum cutting speed of smallest drill = 28 m/min.

Minimum cutting speed of largest drill = 20 m/min.

Six spindle speed, motor speed = 2800 R.P.M.

Sketch a suitable ray diagram for the layout of the spindle drive and determine the ratios of the gear teeth of the engaging pairs. The H.P. of the machine may be taken as 2 H.P. and the minimum member of teeth on a gear as 17.

(A.M.I.E., 1974)

8.11. Design the head stock gear box of a turret lathe having arrangement for nine spindle speeds ranging from 34 R.P.M. with $\phi = 1.58$. Only layout and not a full drawing of the gear box should be shown. The H.P. of the machine may be taken at 6 and minimum number of teeth on the gear as 17. The motor rotates at 1410 R.P.M. Draw a suitable and admissible structure developing the corresponding ray diagram and hence select the optimal layout and calculate the gear ratios. *(A.M.I.E., 1975)*

8.12. (*a*) What are the differences between structure diagram and ray diagram.

(*b*) A six speed gear box is required to be designed for transmitting 10 H.P. with speed ranging from 400 R.P.M. with $\phi = 1.25$.

Select an optimum ray diagram and hence calculate the gear sizes, module and width of gears. Calculate the shaft sizes and sketch the gear box.

(A.M.I.E., 1979)

8.13. Describe the following :

(*a*) Pre-optive gear box. (*b*) P.I.V. drive.

8.14. Describe individual drive and group drive for machine tools.

8.15. Describe the selection of electric motors for the machine tools drives.

8.16. Describe unilateral and bilateral speed diagrams.

8.17. Write short notes on the following :

(*i*) Speed range ratio.

(*ii*) Common ratio (ϕ) and its standard values.

(*iii*) To determine number of teeth on gears.

8.18. What is a clutch ? Sketch and describe various types of clutches use in machine tools.

8.19. Write short notes on the following :

(*i*) Kinematic functions of machine tool.

(*ii*) Group drive and individual drive of machine tools.

8.20. Discuss control systems in machine tools.

8.21. Describe flow chart for gear box.

8.22. Discuss the general requirements of machine tool design.

8.23. Describe methods to reduce :

(*a*) axial dimensions

(*b*) radial dimension of speed gear boxes.

8.24. Write short notes on the following :

(*i*) Selection of drive for machine tools.

(*ii*) Types of speed boxes.

(*iii*) Types of feed boxes.

(*iv*) Advantages of gear boxes with clutched drive.

9

Newer Machining Processes

9.0. Introduction

In recent years a number of new materials have been developed which are being commonly used in space research, missiles and nuclear industry. These materials are more strong, hard, tough, heat and wear resistant and cannot be machined by conventional machining processes. This has led to the development of new metal removing processes called Newer Machining Processes or Unconventional Machining Processes. These processes are not affected by strength hardness, toughness and brittleness of materials and can produce intricate and complicated shapes on the workpiece.

These processes are widely used for :

(*i*) Machining materials which are difficult-to-machine conventionally.

(*ii*) Producing complex surfaces effectively and efficiently.

(*iii*) Producing very high surface qualities.

9.1. Classification

These newer machining processes can be classified into various groups according to the following factors :

1. Type of energy required to shape the materials :

(*a*) Chemical (*b*) Electrical

(*c*) Thermal (*d*) Magnetic

(*e*) Mechanical.

2. Medium for energy transfer

(*a*) Electrons (*b*) Radiation

(*c*) Plasma (*d*) Electrolyte

(*e*) High velocity.

3. Mechanism of material removal :

(*a*) Mechanical erosion (*b*) Ion displacement

(*c*) Vaporisation (*d*) Fusion.

The various newer machining processes are as follows :

(*i*) Electrochemical machining (E.C.M.)

(*ii*) Electrochemical grinding (E.C.G.)
(*iii*) Electrical discharge machining (E.D.M.)
(*iv*) Ultra Sonic machining (U.S.M.)
(*v*) Abrasive jet machining (A.J.M.)
(*vi*) Electron beam machining (E.B.M.)
(*vii*) Lesser beam machining (L.B.M.)
(*viii*) Plasma arc machining (P.A.M.)
(*ix*) Hot machining
(*x*) Electromagnetic forming
(*xi*) Explosive forming
(*xii*) Hydro forming.

These new techniques of machining are quite diverse in nature and differ from each by their characteristics feature of design operation and field of application. However they have the common property of being based on a non-mechanical, physical metal removing phenomenon.

The various advantages of newer machining processes as compared to conventional machining processes are as follows :

(*i*) The physical and mechanical properties of the work material do not predominentally affect the quality of the surface and the productivity of the process.

(*ii*) As there is no physical contact between tool and work therefore the dimensional accuracy achieved is better.

(*iii*) It is not essential that the cutting tool should be made up of material harder than the workpiece material.

(*iv*) Heavy and large machine tools are not required to machine large size workpieces.

(*v*) Simple kinematic motions are required for the different machines.

9.2. Electrochemical Machining (E.C.M.)

It is also called electrolytic machining or anodic cutting. This process is quite commonly used for shaping hard metals or for resharpening of cementing carbide cutting tools. This process is based on principles of Faraday and Ohm. In this process an electrolyte cell is formed by the workpiece (anode) and tool (cathode) in the midst of a flowing electrolyte in a very small gap of 0.025 cm between the two. The metal removal is due to the ion migration towards the tool. The tool is provided with a passage for circulating the electrolyte with sufficient velocity to flush off the metallic ions from the cutting zone. The work is generally kept stationary and the tool is fed in a linear direction. The electrolyte used is generally an aqueous solution of common salt. Sodium nitrate solution is also used. This process is ideally suitable for the production of deep holes and profiled cavities in electrically conducting materials. (Fig. 9.1).

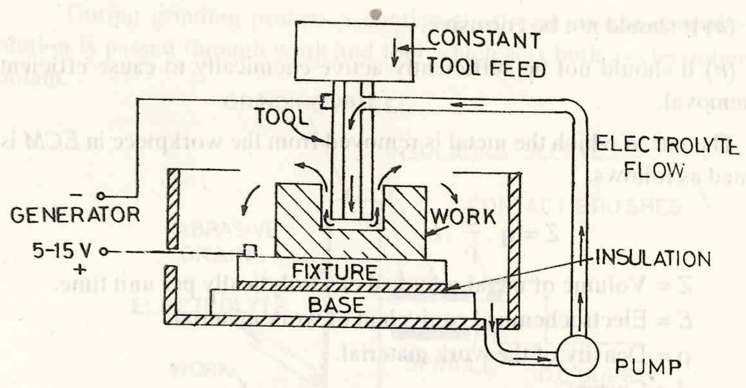


Fig. 9.1. Electrochemical Machining.

The various advantages of this process are as follows :

(*i*) As the tool does not come in contact with the work, therefore tool wear is practically nil.

(*ii*) The metal is removed at a much faster rate.

Electrochemical machining is quite suitable for the following machining operations :

(*i*) To machine through holes of any cross-section.
(*ii*) To mach.ne delicate external shapes such as turbine blades.
(*iii*) To machine blind holes and shaped cavities such as in forging dies.

The materials commonly used in the manufacture of tools are aluminium, bronze, brass, copper and stainless steel.

The electrolyte used perform the following functions :

(*i*) Completes the electric circuit between tool and workpiece.
(*ii*) Allows desirable machining to occur.
(*iii*) Carries away products of reaction from the zone of machining.
(*iv*) Carries away heat generated during chemical reactions.

The electrolyte should have the following properties :

(*i*) High electrical conductivity
(*ii*) Chemical stability
(*iii*) High specific heat and low viscosity.

In *ECM* the electrolyte serves the following two functions :

(*i*) It provides the medium by which electrolysis takes place.

(*ii*) It removes the heat that is generated in the working zone as a result of the flow of a high current through the electrodes and through the electrolyte itself. The quantity of electrolyte flowing should be sufficient to prevent the boiling point of the liquid being reached.

The following two aspects of chemical nature of the electrolyte should be considered.

(*a*) It should not be corrosive.

(*b*) It should not be sufficiently active chemically to cause efficient metal removal.

The rate at which the metal is removed from the workpiece in *ECM* is calculated as follows.

$$Z = \eta \cdot \frac{E}{\rho} \cdot I$$

where Z = Volume of metal removed electrolytically per unit time.

E = Electrochemical equivalent of work material.

ρ = Density of the work material.

I = Current

η = Current efficiency *i.e.* fraction of current actually effective in electrolysis.

The tool feed speed is given by

$$V = \frac{Z}{A} = \eta \cdot \frac{E}{\rho} \cdot \frac{I}{A}$$

where V = Total feed speed.

A = Area of work surface exposed to electrolysis.

$\frac{I}{A}$ = Current density.

The current density is limited by the capacity of the supply as well as the capacity of workpiece material, the tool material and the electrolyte to carry the current. The highest metal removal rate by this process varies between 0.3 to 1.4 cubic inch per minute.

9.3. Electrochemical Grinding (E.C.G.)

Electrochemical grinding also known as electrolytic grinding is being widely used for the grinding of tungsten carbide tips. This process is preferred as compared to the conventional grinding because higher metal removal rates are possible by this process. This process is more economical in the use of abrasives which is particularly important if the abrasive is expensive like diamond grit. This process is based on electrochemical machining method. In this process the metal is removed both by electrochemical decomposition and abrasion of metal. In fact 10% of the work metal is removed by abrasive cutting and 90% by electrolytic action. The wheel employed is made of fine diamond particles in metal matrix. The grinding wheel and its spindle are insulated from rest of the machine and are connected to the negative terminal of a low voltage D.C. Supply (Fig. 9.2). The particles of grinding wheel slightly project out from the surface of wheel and come in contact with the workpiece with very little pressure.

During grinding process a continuous stream of non-corrosive salt solution is passed through work and tool which acts both as electrolyte and coolant.

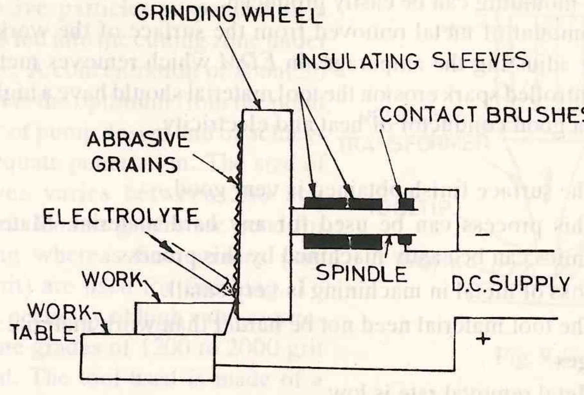


Fig. 9.2

9.4. Electrodischarge Machining (E.D.M.)

In this process the metal is removed from the workpiece due to erosion caused by rapidly recurring spark discharges taking place between the tool and work. Fig. 9.3 shows the mechanical set up and electrical circuit for electrodischarge machining.

A thin gap of about 0.025 mm is maintained between the tool and workpiece by a servo system. Both tool and workpiece are submerged in a dielectric. Kerosene is a very common type of liquid dielectric although gaseous dielectrics are also used in certain cases. The tool is made cathode and workpiece as anode. When the voltage across the gap becomes sufficiently high it discharges through the gap in the form of a spark in an interval of from 10 to micro seconds. The moment spark occurs sufficient pressure is developed between work and tool as result of which a very high temperature is reached and at such a high pressure and temperature some metal is melted and erroded.

This process is used for shaping carbide dies and punches to give any shape or profile.

In *EDM* power supply controls the spark frequency, energy and voltage.

The electrolyte (Dielectric) acts as an insulator or barrier to the current flow. Once the break down voltage of dielectric is reached, a spark is generated by the flow of amperage across this gap.

The dielectric also acts as a coolant during machining. Forcing the coolant through the gap between workpiece and tool removes the particles which are then filtered before the dielectric is re-used.

This method is quite useful to machine cavities or intricate shapes in very hard materials. Blind cavities in dies used in die casting, stamping, forging and injection moulding can be easily produced.

The amount of metal removed from the surface of the work piece is controlled by adjusting the amperage. In *EDM* which removes metal by the process of controlled spark erosion the tool material should have a high melting point and be a good conductor of heat and electricity.

Advantages

(*i*) The surface finish obtained is very good.

(*ii*) This process can be used for any hard material. Materials like carbide, ceramics can be easily machined by this process.

(*iii*) Loss of metal in machining is very small.

(*iv*) The tool material need not be harder than work material.

Disadvantages

(*i*) Metal removal rate is low.

(*ii*) Power requirement is high.

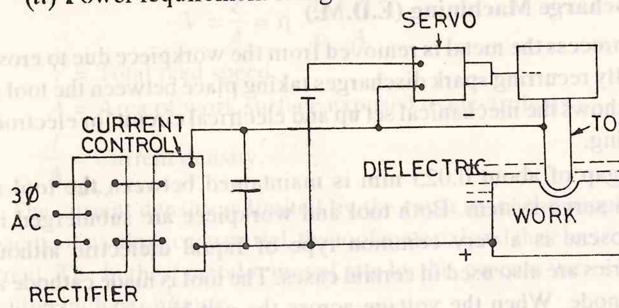


Fig. 9.3

In electrical machining processes such as ECM, Electrolytic grinding and EDM the tool material can be softer than the work material and metal removal rate is independent of the hardness of work material. These are the notable advantages of these processes. One important limitation of these processes is that the work material must be an electrical conductor.

9.5. Ultrasonic Machining (U.S.M.)

In this process the tool is made to vibrate with high frequency on to the work surface in the midst of slurry of abrasive in very fine grit suspended in water. The abrasive used are born carbide, silicon carbide or aluminium oxide. As shown in Fig. 9.4 high frequency current drives a magneto strictive transducer converting electrical energy into mechanical energy. The tool oscillates linearly at ultrasonic frequencies of from 15,000 to 30,000 cycles per second while immersed in a liquid slurry. During cutting the tool performs hammering on abrasive particles which are continuously circulated between the tool and work and thus under the impact of the tool, the abrasive particles perform metal removing operation. The adequate flow of slurry is maintained

by a pump. The slurry which is made of abrasive particles suspended in a liquid is fed into the cutting zone under pressure. A concentration of about 30 per cent is the optimum from the point of view of pump design and of achieving adequate penetration. The size of abrasives varies between 200 and 2000 grit. Coarse grades are good for roughing whereas finer grades (say 1000 grit) are used for finishing. To achieve accuracy of high values extremely fine grades of 1200 to 2000 grit are used. The tool used is made of a material that is easily machined such as brass or so soft steel. This process can be used to produce holes or cavities in hard and brittle materials. Tool steels, ceramics, cemented carbides, precious stones and gears can be easily machined by this process. The accuracy of the finished profile obtained by this depends upon the tool accuracy but may be as high as 0.003 mm.

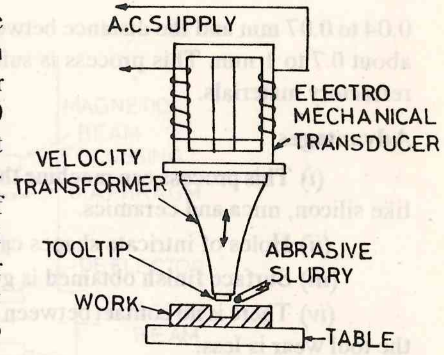


Fig. 9.4

In this process the sonic velocity (*V*) for a given solid material is calculated by using the following formula :

$$V = \frac{E}{\rho} \left[\frac{m(m-1)}{(m^2 - m - 2)} \right]^{1/2}$$

where E = Young's modulus

$\frac{1}{m}$ = Poisson's ratio

ρ = Density of material.

Proper tool material should be selected so that tool does not fail or wear out because of vibrations. Tough maleable materials like alloy steels and stainless steel prove satisfactory.

9.6. Abrasive Jet Machining (A.J.M.)

This process makes use of a focused stream of abrasive particles carried by a high pressure gas (CO_2 or N_2) or air at a velocity of about 200 to 400 m/second. The stream passes through a nozzle and strikes the workpiece as a pressure of about 2 to 8 kg/cm^2 (Fig. 9.5). The material from the workpiece is removed by erosion. The metal removal rate depends upon flow rate and size of abrasive particles. The size of abrasive particles varies from 10 to 50 microns. The abrasive particles should be of irregular shape. The commonly used abrasives are aluminium oxide, silicon, carbide, dolomite and glass. The inside diameter of the nozzle through which the abrasive particles flow is about

0.04 to 0.07 mm and the distance between nozzle mouth and the workpiece is about 0.7 to 1 mm. This process is suitable for machining supper alloys and refractory materials.

Advantages

(*i*) This process can machine thin sections of hard and brittle materials like silicon, mica and ceramics.

(*ii*) Holes of intricate shapes can be produced in the workpiece.

(*iii*) Surface finish obtained is good.

(*iv*) There is no contact between tool (nozzle) and workpiece, therefore, the tool wear is less.

Disadvantages

(*i*) Metal removal rate is low.

(*ii*) A suitable dust collecting system is required.

(*iii*) The abrasive may get embedded into the workpiece surface.

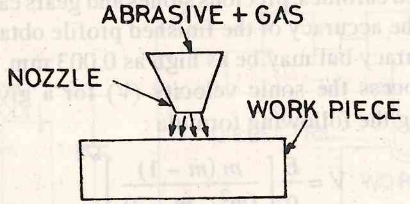


Fig. 9.5

9.7. Electron Beam Machining (E.B.M.)

The electron beam is a stream of negatively charged particles which are generated, accelerated and to some extent focused inside a device called electron gun. An electron gun consists of a cathode which serves as the source of electron, an anode which is kept at ground potential and through which the high velocity electrons pass and a grid cup which is negatively based with respect to the filament. The beam of electron is emitted from the tip of hot cathode. It is accelerated towards the mode by the high potential applied between the anode and cathode.

In this process a high energy beam of electrons from electron gun is focused on the workpiece. This beam heats, melts and vaporises the work material at the point of bombardment. The process is carried out in a vacuum and means are provided to place the workpiece in a sealed compartment (Fig. 9.6). This process is successfully used for drilling holes in difficult materials. The electron beam can be controlled very accurately and machining tolerances of 0.005 mm are possible. This process is quite suitable for materials having a high melting point combined with low thermal conductivity. Although the process does not offer the advantage of high rates of metal removal but it can be used to cut very delicate shapes.

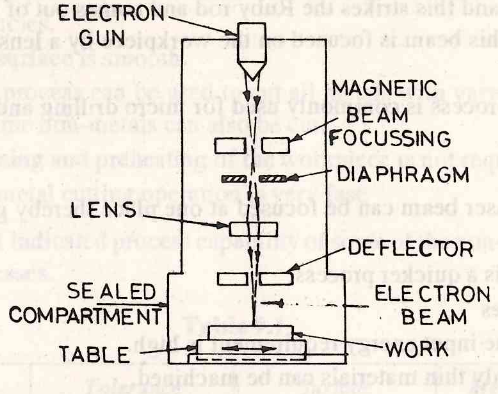


Fig. 9.6

The speed (V) of electron when under control of electric field is given by the relation

$$V = \sqrt{\frac{2e}{m}} \times E \text{ m/sec}$$

where E = Voltage of electric field in volts

m = Mass of electron in kg

e = Charge of electron in coulomb.

The total power (P) for a beam of current I amperes is given by

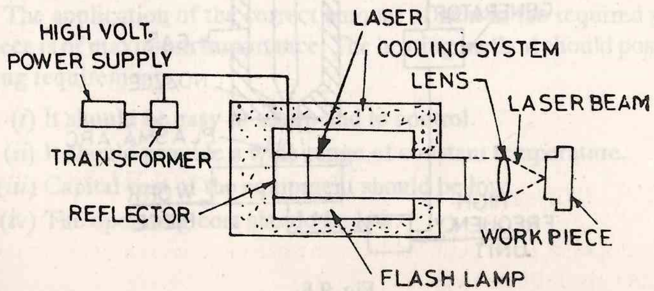
$$P = E, I \text{ watts.}$$

The force (F) of the beam from the electron beam on the molten metal is given by the relation

$$F = 0.34\, I \sqrt{E} \text{ dynes.}$$

9.8. Laser Beam Machining (L.B.M.)

This process uses a laser beam (a narrow beam of coherent, monochromatic light) which is focused on the workpiece by a lens to give extremely high energy density to melt or vaporise any material. A laser usually called ruby rod is used for the production of laser beam. As shown in Fig. 9.7 when electrical energy is discharged into the flash lamp, there is a powerful



burst of light and this strikes the Ruby rod and comes out of it in the form of laser beam. This beam is focused on the workpiece by a lens provided in the system.

This process is commonly used for micro drilling and micro-welding of materials.

Advantages

(*i*) Laser beam can be focused at one place thereby generating lot of heat.

(*ii*) It is a quicker process.

Disadvantages

(*i*) The input energy requirement is high.

(*ii*) Only thin materials can be machined.

9.9. Plasma Arc Machining (P.A.M.)

This process is based on the formation of a plasma, an ionised conducting gas, by striking of an electric arc between a tungsten electrode and the metal to be cut. In this process an electric arc is produced between a cathodic electrode and an anodic nozzle and then a gas which may be hydrogen, nitrogen or a mixture of these is introduced into the arc chamber. As the molecules of the gas pass through the arc chamber they absorb energy from the arc and the gas is dissociated into atoms and in some cases into ions. This ionised gas is impinged on the workpiece at a high velocity. The temperature of this hot ionised gas called plasma is about 10,000 to 20,000. The cutting is accomplished by first melting the work surface and then by blasting away the molten metal by plasma (Fig. 9.8), plasma arc cutting is quite commonly used in the cutting of aluminium alloys, copper and highly alloyed steels. Plasma arc cutting process can cut plain carbon shells four times faster than ordinary flame cutting torches. On the machining side, plasma arc has been used for rough turning of very difficult materials.

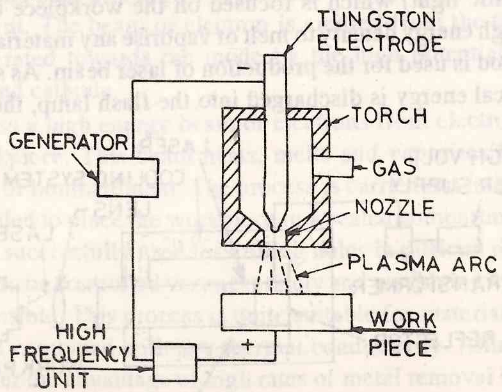


Fig. 9.8

Advantages

(*i*) In this process only a small hear zone is created in this reducing distortion tendencies.

(*ii*) The surface is smooth.

(*iii*) This process can be used to cut all metals with varying degree of economy and some non-metals can also be cut.

(*iv*) Cleaning and preheating of the workpiece is not required.

(*v*) The metal cutting operation is very fast.

Table 9.1 indicated process capability of some of the non-conventional machining processes.

Table 9.1

Process	*Tolerance (μm)*	*Surface finish CLA (μm)*	*Metal removal rate (mm^3/min)*
ECM	50	0.1—2.5	1500
EDM	15	0.2—12	800
EBM	25	0.4—2.5	1.6
LBM	25	0.4—1.25	0.1
PAM	125	Rough	7500
USM	7.5	0.2—0.5	300

9.10. Hot Machining

In this process the component is heated before being machined. The shear strength of a metal decreases at elevated temperature as compared to that at room temperature. Therefore, the force required on the tool is lower for cutting hot metal as compared to the force required to cut a metal at room temperature. The carbide tools are preferred in hot machining as compared to high speed steel tools because the cutting edge of high speed steel tool gets deformed at higher temperatures. This process is quite commonly used to machine high strength, high hardness and high temperature resistant materials which are difficult to machine by conventional methods.

The application of the correct amount of heat in the required place of workpiece is of maximum importance. The heating method should possess the following requirements :

(*i*) It should be easy to set up and to control.

(*ii*) It should provide a wide range of constant temperature.

(*iii*) Capital cost of the equipment should be low.

(*iv*) The operating cost should be low.

The various methods of heating commonly used are as follows :

(*i*) Furnace heating (*ii*) Flame heating
(*iii*) Induction heating. (*iv*) Arc heating.

In furnace heating the workpiece is heated in a gas or electrical furnace the temperature of which has been raised to that of required for the cutting operation. The workpiece is then removed and is then placed in a vice or fixture on the machine. In flame heating the workpiece is heated by means of a gas flame while it is mounted on the machine. In induction heating, the heating current is induced on the workpiece by transformer action by means of a primary coil which is designed to cover the area to be machined and which is mounted to provide the heat zone in the workpiece. An induction heating set up for milling operation is shown in Fig. 9.9. Induction heating method is easy to control and maximum cleanliness can be maintained in process. Although it is costly method but it is the most efficient method as it heats only a small zone ahead of the tool. Arc heating method is quite suitable for turning and milling operations. In arc heating an arc is struck between the surface and carbon electrodes. Arc heating is used for the machining of refractory and non-magnetic materials which need cutting temperature over 540°C. The main disadvantage of arc heating is the difficulty experienced in maintaining a constant temperature.

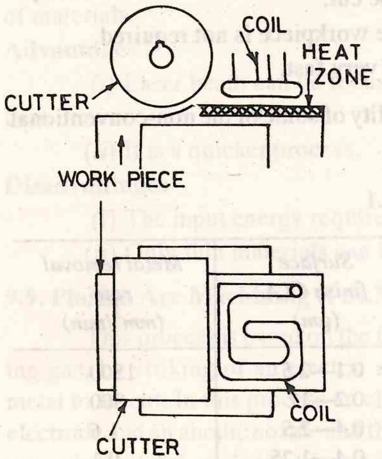


Fig. 9.9

9.11. Explosive Forming

In this process sheet metal is formed to the counter of a prepared die by explosive impact. This process makes use of an explosive which is detonated and its energy transmitted to the workpiece through a fluid. The commonly used fluid is water as it is cheap, convenient to use and has reduced compressibility water also acts as shock dampner. The cylinder contains water. The explosive which is immersed in water and located at a predetermined distance from sheet metal black is detonated and the shock waves generated force and stretch the metal to the shape of the die (Fig. 9.10). It is desirable to exhaust the air from the die before firing the charge because normally the air is trapped between the sides of the die and the component thereby preventing a faithful reproduction of the die form being generated. Die is usually made up of spheroidal graphite iron. This process has been used successfully for

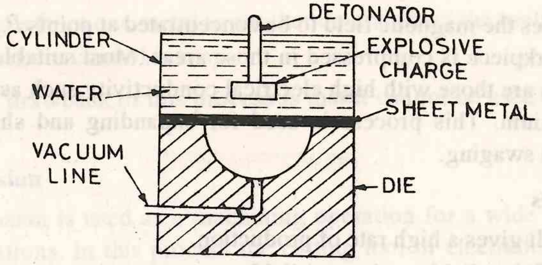


Fig. 9.10

forming complex sheet metal parts for jet aircraft engines guided missiles, nuclear and rocket requirements. Another application of this process is to form large paraboidal reflectors for radar installations. Materials like aluminium alloys, copper, low and medium carbon steels, stainless steels, titanium etc. can be easily explosive formed.

Advantages

(*i*) By this process sheet metal is formed into shapes which cannot be produced economically by other conventional processes.

(*ii*) Investment cost in dies is low.

(*iii*) Components can be made to close tolerances.

(*iv*) Tough materials as well as ductile materials can be explosive formed.

(*v*) One die can be used to produce parts in varying thickness.

Disadvantages

(*i*) The process should be conducted at safe and remote places because a lot of sound and noise is produced and precautions are to be taken as explosion hazards exit.

(*ii*) Labour cost is more.

This process is also known as high energy rate forming (HERF).

9.12. Electro Magnetic Forming (E.M.F.)

It is the process of electrically forming conducting metals of moderate thickness by the use of a precisely controlled electromagnetic force. The principle of electromagnetic forming is that when an electric current flows in a conductor, it establishes a magnetic field, also a magnetic flux field can produce an electro-motive force in a conductor. As shown in Fig. 9.11 the magnetic field

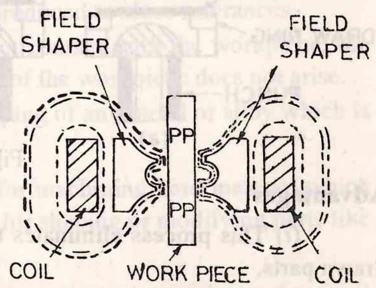


Fig. 9.11

shaper causes the magnetic field to be concentrated at points *P* with the effect that the workpiece is compressed in those areas. Most suitable materials for this process are those with high electrical conductivity such as copper, silver and aluminium. This process is used for expanding and shaping, tubing, coining and swaging.

Advantages

(*i*) It gives a high rate of production.

(*ii*) It is reliable and controllable.

(*iii*) Maintenance cost is low.

(*iv*) It is a simple and clean process and the component surface does not suffer any contamination.

(*v*) Tools used are simple and there is no tool wear.

9.13. Hydro Forming

This process is used to produce sheet metal components by using a controlled hydraulic pressure. The sheet metal is formed about the punch not by impact but by pressure and is accomplished by hydraulic fluid contained in a cavity in the ram and held by a flexible diaphragm. As shown in Fig. 9.12 (*a*) the blank is placed in the draw ring. Then the upper member is lowered so that the flexible diaphragm is in the contact with the blank [Fig. 9.12 (*b*)]. Then the punch is pushed upward into the die cavity forcing the metal blank to draw in around the punch against the pressure of hydraulic fluid. The sheet metal takes the form of the punch under the application of opposing and increasing forces [Fig. 9.12 (*c*)]. The punch is then lowered and the required component is obtained [Fig. 9.12 (*d*)]. The draw ring is made up of mild steel and punch is made up of cold working steel.

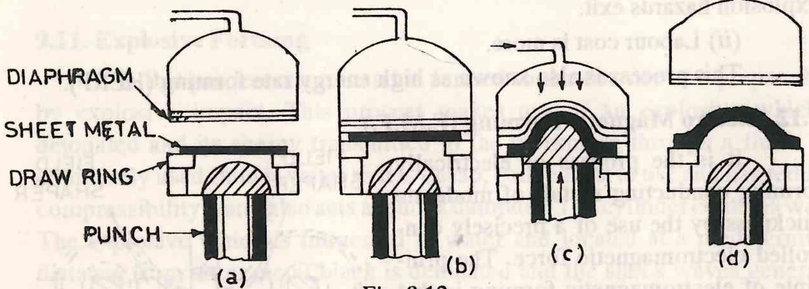


Fig. 9.12

Advantages

(*i*) This process eliminates the need for expensive tooling for deep drawn parts.

(*ii*) In this process the fluid pressure can be controlled easily. The forming of different depths in the same components can be performed easily.

(*iii*) Changes from one metal to another do not affect the tooling.

(*iv*) The process control is easy.

The main drawback of this process is that it cannot be used for large scale production.

9.14. Spark Erosion

Spark erosion is used as a machining operation for a wide range of industrial applications. In this process the cutting tool or electrode is made with negative potential and workpiece with positive potential. Spark is produced between the electrode and the workpiece. Fig. 9.13 shows diagrammatic view of circuit used on spark erosion machines.

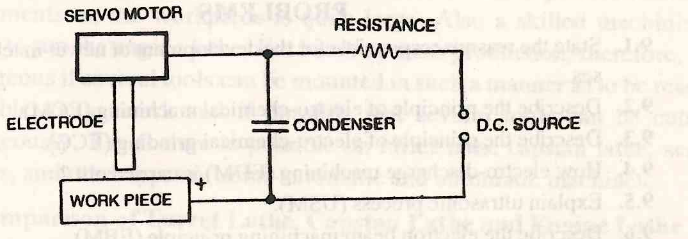


Fig. 9.13

When voltage becomes sufficient high to break the gap between the electrodes, the capacitor is immediately discharged in the form of spark, in the gap, and the capacitor is recharged. The greater the spark, the greater will be the size of particles removed from the workpiece. The resistance can be included in the circuit to control the time at which the voltage across the gap begins to increase again. A servo-motor is used to provide a controlled feed to the cutting electrode.

Advantages

(*i*) The capital cost of the equipment compares favourably with the more conventional metal cutting machines.

(*ii*) Parts of intricate form can be produced to close tolerances.

(*iii*) As the electrode is not in direct contact with the workpiece, the need for heavy clamping to secure rigidity of the workpiece does not arise.

(*iv*) This process is suitable for shaping of any metal or alloy which is a sufficiently good conductor of electricity.

(*v*) This process is quite suitable for machining hard material which are not normally readily machineable and for shaping or modifying parts like dies, moulds after hardening.

Some of the features of spark erosion, electrolytic (electrochemical) machining and ultra sonic machining can be compared as follows (Table 9.2).

Table 9.2

Feature	*Spark Erosion*	*Ultra sonic machining*	*Electrolytic machining*
Capital cost	Moderate	Moderate	High
Operating labour	Low	Low	Low
Tool cost	Low	Very low	Low
Machine Maintenance	Moderate	Moderate	Moderate
Surface finish and accuracy	Good	Very good	Very good
Power for cutting	High	High	Medium

PROBLEMS

9.1. State the reasons responsible for the development of newer machining processes.

9.2. Describe the principle of electro-chemical machining (ECM).

9.3. Describe the principle of electro-chemical grinding (ECG).

9.4. How electro-discharge machining (EDM) is carried out ?

9.5. Explain ultrasonic process (USM).

9.6. Describe the electron beam machining principle (EBM).

9.7. Describe laser beam machining process. State its advantages and disadvantages.

9.8. Describe the principle Plasma arc machining (PAM) state its advantages and disadvantages.

9.9. Describe the principle of hot machining.

9.10. What is explosive forming ? Describe it in detail. State its advantages and disadvantages.

9.11. Describe the principle of electro-magnetic forming (EMF).

9.12. Describe the principle of hydro-forming.

9.13. Describe the principle of abrasive jet machining (AJM). State its advantages and disadvantages.

9.14. State the functions of electrolyte in ECM.

9.15. Describe the principle of spark erosion. State the advantages of this process.

10

Capstan, Turret and Automatic Lathes

10.0. Introduction

An engine lathe is not preferred for batch and mass production because the time taken for changing and setting the tools and time required for making measurements on the workpiece is quite large. Also a skilled machinist is required to run the engine lathe. For batch or mass production, therefore, it is advantageous if several tools can be mounted in such a manner as to be readily presentable to the work and if possible that several tools can be cutting simultaneously. The feature is possible on turret lathe capstan lathe, screw machines, and other types of semi-automatic and automatic machines.

10.1. Comparison of Turret Lathe, Capstan Lathe and Engine Lathe

These lathes are compared as follows :

(*i*) Turret lathe differs from the engine lathe in that the tail stock of the engine lathe is replaced by a hexagon turret which permits the mounting of multiple tools.

(*ii*) The second difference between engine lathe and turret lathe is the substitution of the square turret of the compound rest. The cross slide is made long enough to permit the mounting of another tool post of square turret at the rear of the slide. The turret may be indexed automatically so that each tool can be presented to the workpiece in rapid succession.

(*iii*) The labour cost required to operate an engine lathe is more than turret and capstan lathe. In turret and capstan lathe the cutting tools required for a particular components are preset to stops by a skilled setter enabling the machine to be operated by an unskilled worker producing components quickly and relatively cheaply.

(*iv*) The overhead changes of turret or capstan lathe are generally more than engine lathe because of higher investment, power and maintenance costs.

10.2. Difference Between Capstan and Turret Lathe

(*i*) In capstan lathe the hexagonal turret is carried on a slide mounted in a saddle bolted to the bed of the lathe (Fig. 10.1) whereas in a turret lathe the hexagonal turret is mounted on a slide directly on the bed (Fig. 10.2).

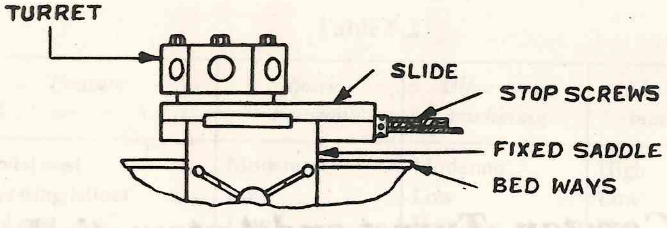


Fig. 10.1

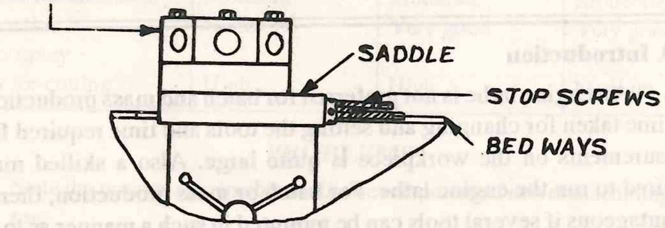


Fig. 10.2

(*ii*) In capstan lathe the turret heat is mounted on a short slide with only a limited amount of travel. In turret lathe the turret saddle bears directly on the bed of lathe and therefore can traverse full length of the bed if required.

(*iii*) A capstan lathe is usually a small or medium size machine whereas the turret lathe is suitable for long and heavy work.

(*iv*) Capstan lathe is suitable for bar work whereas larger and heavier chucking works are generally handled on a turret lathe.

10.3. Principal Parts of a Capstan and Turret Lathes

The various parts of capstan lathe are shown in Fig. 10.3 and Fig. 10.4 shows the various parts of a turret lathe.

The head stock of turret and capstan lathes houses a speed gear box similar in construction to the same unit as in an engine lathe but providing a

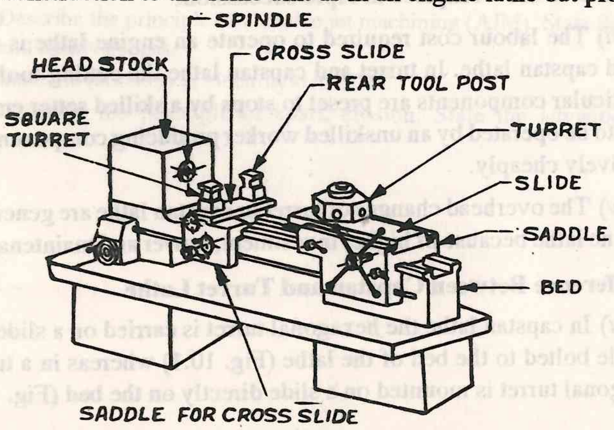


Fig. 10.3

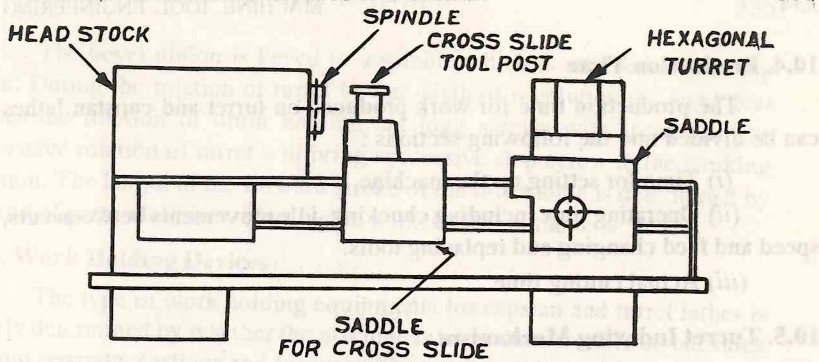


Fig. 10.4

narrower range of spindle speed variation and fewer speed steps. One of the chief characteristics of turret head stock is the provision for rapid stopping, starting and speed changing in order that the maximum advantage is taken by the operator of the most advantageous cutting speed for any job and at the same time to minimise the loss of time in speed changing, stopping and starting. The bed is a box shaped grey iron casting with a system of well developed internal stiffening ribs. The turret saddle and cross-slide travel along the ways on the top of the bed. The feed gear box may have a device enabling the feeds to be changed without stopping the lathe. The aprons of the cross-slide and turret saddle serve to provide hand and power traverses of these units in the cross and longitudinal directions. The longitudinal and cross feed movement of turret saddle and cross slide are regulated by adjustable stops. These stops enable different tools fitted on the various faces of turret to move by a predetermined amount for performing different operations on repetitive workpieces. The cross slide carriage is of two types :

(*i*) Reach over type.

(*ii*) Slide hung type.

The construction of reach over or bridge type of cross slide carriage is more rigid and allows a second tool holder to be mounted at the rear. The slide hung type carriage is generally fitted with heavy duty turret lathe where the saddle rides on the top and bottom guide ways on the front of the lathe bed.

10.3.1. Working and Auxiliary Motions

The working motions of a turret or capstan lathes provide rotation of spindle carrying workpiece and feed motions for the longitudinal travel of the turret and cross-travel of the cross-slide carrying the cutting tools. Auxiliary motions are as follows :

(*i*) Swivelling (indexing) of the turret for bringing the tools, consecutively into the cutting motions.

(*ii*) Feeding out and clamping the bar stocks.

(*iii*) Rapid approach and withdrawal of the turret, cross slide etc.

10.4. Production Time

The production time for work produced on turret and capstan lathes can be divided into the following sections :

(*i*) Time for setting up the machine.

(*ii*) Operating time including chucking, idle movements between cuts, speed and feed changing and replacing tools.

(*iii*) Actual cutting time.

10.5. Turret Indexing Mechanism

Fig. 10.5 illustrates the principle of turret indexing mechanism. The turret is mounted on a vertical spindle that rotates in suitable bearings in turret slide. An indexing ratchet and index plate are fastened to the spindle. A plunger actuating cam and an indexing pawl are seated in recesses in the bed of the lathe. The plunger and plungers ring are housed in an extension of the turret saddle. The cam has a projecting lug *L* and the plunger carries a projecting plunger pin in such a way that the pin clears the body of the cam but contacts the lug *L*. The pawl has a projecting pin *P* to engage the ratchet. As shown in

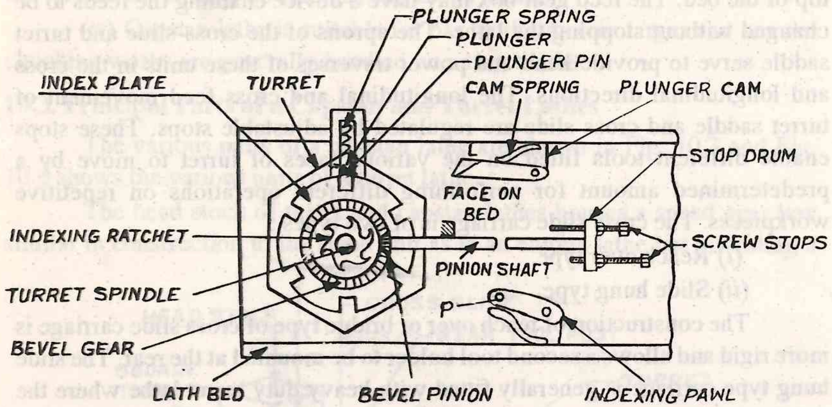


Fig. 10.5

the figure the turret saddle is in its forward operating position the plunger is seated in a notch of index plate and holds the turret rigidly in position. Then as the turret moves towards the backward position the cam lifts plunger out of the notch in the index plate due to riding of the plunger pin and thus unlocks the index plate. By this time the projecting pin *P* of pawl makes contact with a tooth of ratchet and causes the ratchet to rotate and thus turret gets rotated through one-sixth of revolution. Then the plunger is forced into the notch by the spring and locks the turret in the new position so that the turret holding the next tool is fed forward. The pawl spring releases the pawl from the ratchet.

The bevel pinion is keyed to a spindle which is attached to the stop drum. During the rotation of turret by one-sixth of revolution the level gear causes the rotation of drum holding six long screws with locknuts. The successive rotation of turret will bring successive stop screw to the working position. The length of the forward stroke of the turret slide is determined by the end of particular screw abutting on a fixed face on the lathe bed.

10.6. Work Holding Devices

The type of work holding equipments for capstan and turret lathes is largely determined by whether the machine is to produce work from bar stock or from separate castings and forgings. The work (castings and forgings) are held with an independent chuck or self-centring chuck. The self centring (universal) chuck is much faster to operate. When component are turned and parted off from a bar fed through the hollow spindle of the machine, a collet chuck is used. The collet may be operated mechanically or automatically (hydraulic or pneumatic). Moving a lever in one direction releases the collet so that bar stock may move forward to expose the required length when it registers against a stop in the hexagon turret. When the lever is moved in the opposite direction the collet is closed. This can usually be done without stopping the rotation of spindle.

A collet chuck should satisfy the following requirements :

(*i*) It should provide concentric clamping with a radial run out not exceeding 0.01 to 0.04 mm.

(*ii*) Reliable holding of stock with normal size errors.

(*iii*) Constant length of bar feed.

(*iv*) Constancy of the plastic properties of the collet.

(*v*) Jaws of collet should have high wear resistance.

The commonly used collets are as follows :

(*i*) Push out type collet with a front taper (Fig. 10.6). It is simple in construction and there is a simple joint between the collet tube and collet. This collet has the disadvantages that a lack of concentricity in clamping exists and the bar stock may slip back.

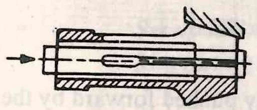


Fig. 10.6

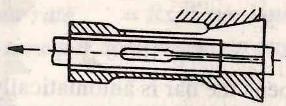


Fig. 10.7

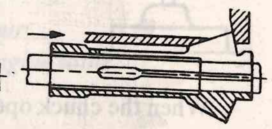


Fig. 10.8

(*ii*) Drawback type collet with a back taper (Fig. 10.7). This collet is preferred because it ensures proper centring of stock and jamming during bar feed does not take place.

(*iii*) Stationary type collet with a back tapper (Fig. 10.8). This collet also ensures precise bar feed since the collet is not displaced axially in clamping.

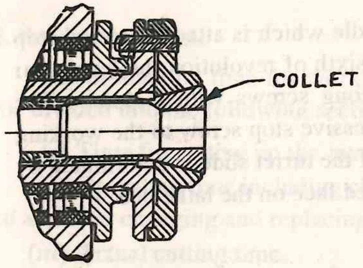


Fig. 10.9

Collets are made from spring steel the jaws of the collet are expanded slightly so that the bar stock is freely fed out when the collet is open. Fig. 10.9 shows a draw in collet chuck. The chuck is fitted with hand or automatic means for drawing the collet into the chuck. The tapper faces close the collet and cause it to grip the work.

10.7. Bar Feeding Mechanism

There are number of methods used for feeding the bar immediately after the collet releases the work without stopping the machine to reduce the setting time. Fig. 10.10 shows a method in which the bar is fed with the help of wire rope and weight. In this method a guide bar is fixed to the rear of the head stock. A rotating sleeve is mounted on the guide bar to carry the rear end of the bar stock. One end of the wire rope is tied to the sleeve and the other end carries a weight.

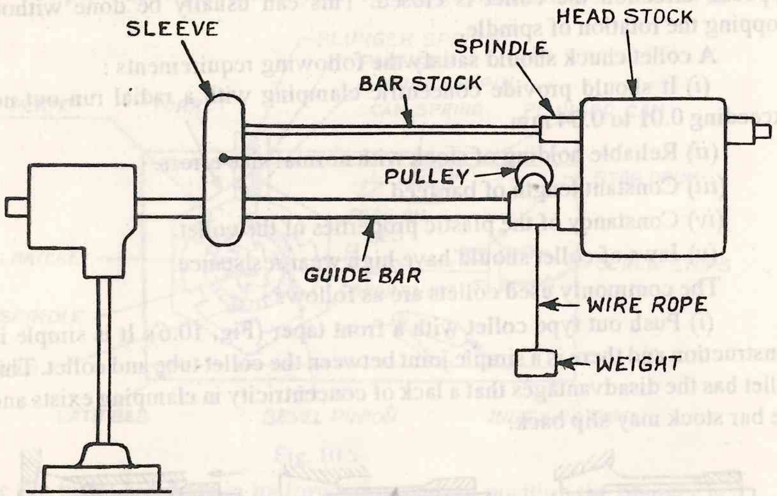


Fig. 10.10

When the chuck opens the bar is automatically pushed forward by the weight and sleeve.

Fig. 10.11 shows the principle of the operation of spring collet when a semi-automatic feeding device is used. In the beginning the bar is clamped in the collet Fig. 10.11 (*a*) then the collet is advanced Fig. 10.11 (*b*) releasing the bar. The feeding finger is a split spring steel tube which grips the bar with a force considerably less than that exerted by the collet but still sufficient to carry the bar forward when the collet is released [Fig. 10.11 (*c*)]. The feeding finger

pushes the bar to its farthest position and the collet moves to the left and clamps the bar. Levers on head stock are used to control the movements of both collet and feed finger.

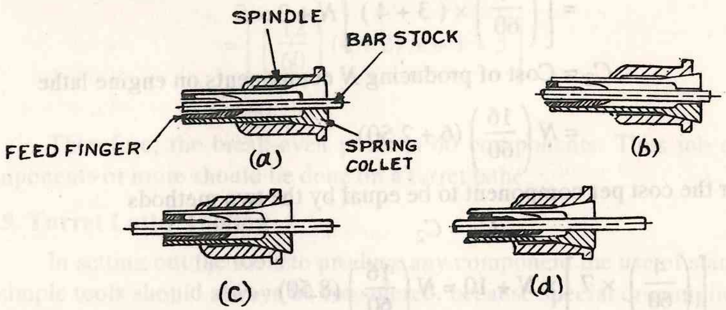


Fig. 10.11

10.8. Economics of Turret Lathe

A turret lathe is economical if the cost of producing a given part on such a lathe including machine and set up costs is less than the cost of producing it on a regular engine lathe. The operator of an engine lathe is paid more than the operator of a turret lathe. But the overhead charges of a turret lathe are more than engine lathe. The choice whether an engine lathe or turret lathe should be used is based on a comparison of the cost of producing parts by both methods.

Example 10.1. *A manufacturing organisation has two alternatives to manufacture the given quantity of a component. A turret lathe and an engine lathe are available. The records show the following data :*

Machine time per component of turret lathe
= *4 minutes*
Turret lathe operator rate
= *Rs. 3 per hour*
Turret lathe overhead including interest on capital
= *Rs. 4 per hour*
Set up time for turret lathe
= *2 hours*
Set up labour rate = *Rs. 5 per hour*
Machining time per component on engine lathe
= *16 minutes*
Engine lathe operator rate
= *Rs. 6 per hour*
Lathe overhead including interest on capital
= *Rs. 2.50 per hour.*

How many components would be required in a lot to justify the use of the turret lathe ?

Solution. Let N = Number of components

C_1 = Cost of producing N components on turret lathe

$$= \left[\left(\frac{4}{60}\right) \times (3+4)\right] N + 2 \times 5$$

C_2 = Cost of producing N components on engine lathe

$$= N\left(\frac{16}{60}\right)(6 + 2.50)$$

For the cost per component to be equal by the two methods

$$C_1 = C_2$$

$$\left[\left(\frac{4}{60}\right) \times 7\right] \times N + 10 = N\left(\frac{16}{60}\right)(8.50)$$

$$N = 5.5 \text{ or } 6 \text{ components.}$$

Thus a lot of 6 components or more should be done on a turret lathe.

Example 10.2. *A manufacturing company is to manufacture 45 components to fill an order. A turret lathe and an engine lathe are available. The record shows the following data :*

Turret lathe. *Machining time*	= *4 minutes*
Direct labour cost	= *Rs. 3 per hour*
Overhead cost	= *Rs. 4.50 per hour*
Set up time	= *6 hours*
Set up labour rate	= *Rs. 5.50 per hour*
Engine lathe. *Machining time*	= *12 minutes*
Direct labour cost	= *Rs. 4 per hour*
Overhead cost	= *Rs. 2 per hour*
Set up time	= *1 hour*
Set up labour rate	= *Rs. 5 per hour.*

Determine if the job should be done on the turret lathe or engine lathe.

Solution. N = Number of components

C_1 = Cost of producing on turret lathe

$$= \text{Rs.} \left[\left(\frac{4}{60}\right)(3 + 4.50) N + 6 \times 5.50\right]$$

C_2 = Cost of producing on engine lathe

$$= \text{Rs.} \left[\left(\frac{12}{60}\right)(4 + 2) N + 1 \times 5\right]$$

Break even point occurs when

$$C_1 = C_2$$

$$\left[\left(\frac{4}{60}\right)(3 + 4.50) N + 6 \times 5.50\right]$$

$$= \left[\left(\frac{12}{60}\right)(4 + 2) N + 1 \times 5\right]$$

$$N = 40.$$

Therefore, the break-even point is 40 components. Thus job of 40 components or more should be done on a turret lathe.

10.9. Turret Lathe Tooling

In setting out the tools to produce any component the use of standard or simple tools should always be considered, because special or complicated tools are expensive. The following factors should be considered during turret lathe tooling :

(*i*) Number of components to be made
(*ii*) Set up time
(*iii*) Work handling time
(*iv*) Machine controlling time
(*v*) Machining time
(*vi*) Tool cost
(*vii*) Set up labour rate
(*viii*) Lathe operator labour rate.

Set up time is the time required by the tool setter to set the various cutting tools and work holders in the turret lathe. Work handling time is the time required for putting work into and removing it from the lathe. Machine controlling time is that required to manipulate the controls which reverse and rotate the turret, and change speeds etc. Machining time is that during which the metal is cut. It should be minimised by using proper tools, feeds and speeds and by using simultaneous cuts.

Example 10.3. *Describe the tooling set up required to produce the component shown in Fig. 10.12.*

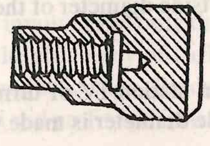


Fig. 10.12

Solution. Fig. 10.13 shows the sequence of operations for machining the given component. The various operations are as follows :

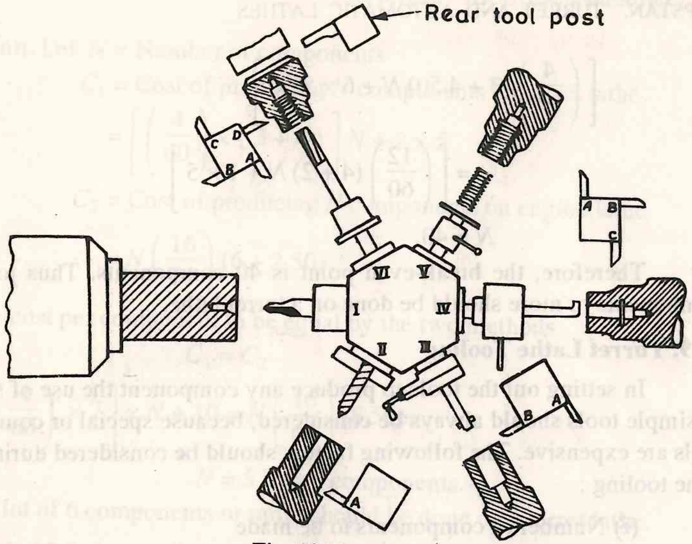


Fig. 10.13

Operation I

The bar stock is fed against the stock stop provided at station I of the turret and then the collet clamps the bar. Now the turret is pulled back slightly and end of the bar stock in centre drilled with the help of a retractable combination centre drill counter sink provided in stock stop. The centre drill acts as a guide for the drill at station II of the turret.

Operation II

The hole is produced in the component with the help of a drill and the outside diameter turned with a turning tool. The drill is fitted at station II of the hexagon turret. Front face of the component is finished with the help of facing tool at station *A* of the square turret. Tool at station *A* carries out turning also.

Operation III

Now a boring bar fitted at station III of the hexagon turret is used to enlarge the diameter of drilled hole and a tool fitted at station *B* of square turret is used as a finishing tool for outside diameter of the component.

Operation IV

A recessing tool fitted at station IV of turret is used for cutting the thread recess. The second outside diameter is made with a tool at station *C* of the square turret.

Operation V

A tap provided at station V of turret is used to produce threads.

Operation VI

A reamer is used to fine finish the hole beyond the thread recess. The small outside diameter of the component is finished with a tool fitted at station *D* of the square turret. A parting off tool fitted on the rear tool post is used to part off the component.

10.10. Vertical Turret Lathe

It has a circular table equipped with both removable chuck jaws and T-slots for clamping the work. A cross rail provided on the vertical column carries a five or six sided turret mounted on a slide. The cross rail can be moved be up and down and be fixed at any desired position. The slide carrying the turret can move to and fro along the rail and therefore the position of turret can be adjusted. One or two side heads with square turrets are provided to machine the workpiece from the side. Such latches are designed for chucking type work. Where the workpiece is too large and heavy.

10.10.1. Automation

Automation is defined as any means of helping the workers perform their tasks more efficiently. By automation the operations are done uniformly and effectively which attain better accuracy and finish. Automation gives an opportunity to the worker to handle more than one machine in a given time. This raises productivity. In automation the human participation is replaced by mechanical or electrical technologies.

Automation is a technology of working in which handling methods, process and design of products are intergrated to utilise economically justifiable mechanisation of thought and effort to achieve automatic and self regulating chain of process. The major part of the automatic operations of a machine tool is covered by automatic drives and controls.

The aim of automation is cost reduction in large scale production technology. The efficiency of a manufacturing facility can be measured in the following three basic ways :

(*i*) Manufacturing cost

(*ii*) Productivity

(*iii*) Profit.

Manufacturing cost involves not only the cost of machining, assembly etc. but is also affected by the efficiency of various manufacturing processes, labour cost and quality of product design. Productivity refers to the efficiency with which labour is utilized and profit is affected by changes in manufacturing costs or productivity.

Labour cost is often the greatest element in the total cost of product and automation helps reducing the labour cost and thus, a decrease in product cost is achieved.

The advantages of automation are as follows :

(*i*) There is an increase in productivity.

(*ii*) The unit cost is reduced as larger number of components can be manufactured in shorter time.

(*iii*) There is an improvement in accuracy.

(*iv*) There is a better resource utilisation.

(*v*) Reduced floor space, maintenance and inventory requirements.

Automation reduces the physical effort required of the operator, frees him of tediously repeated movements and from physical stresses.

The controlling factors which determine the type and the degree to which automation is to be used are as follows :

(*i*) Quantity

(*ii*) Quality.

Quantity means rate of manufacturing the components in a given time.

Automatic machines are preferred for mass production of the components.

Quality means the accuracy with which the components are to be manufactured.

Components with higher quality will be costly. The cost of accurate automatic machine tools is also more.

The various disadvantages of automation are as follows :

(*i*) Initial cost is higher providing additional features in machine tools.

(*ii*) Skilled personnels are required for maintenance of automatic machine tools. This increase maintenance cost.

10.11. Automatic Machines

Automatic machines are used to increase production rate. In such machine both the workpiece handling and metal cutting operations are performed automatically.

Automatic control of the operating cycle is effected with the aid of a cam shaft carrying cams of various shapes linked through a system of levers, gears and other transmissions operative mechanism. The function of the operator is only to inspect a few components after regular intervals and to renew the bar stock when it is exhausted.

The labour cost is minimum in such machines. Machine tools in which automaticity is achieved by mechanical means are productive and reliable. Machine tools with numerical (programmed) control of the operating cycle using stored numerical data or tape or punched cards are an exception among automatic machine tools since they can produce small and medium size components.

10.12. Operating Cycle of Automatic Machine Tools

The operating cycle of automatic machine tools is made of periodically repeated movements of the main and auxiliary working members of machine tool. The main working members of the machine tool participate directly in the cutting process. Movement of main and auxiliary members takes place in a definite sequence, according to definite laws of motion and at definite sections of the paths.

The cycle of automatic machine tools is usually of closed type *i.e.* at the end of the cycle each working member comes to a position which is its initial point in the next cycle.

10.12.1. Types of automatic machines

The classification of the automatic machines depends upon the following factors :

(*i*) Nature of work

(*ii*) Type of blank to be machined

(*iii*) Operation to be carried out

(*iv*) Processing capacity

(*v*) Machining accuracy desired

(*vi*) Design features

Automatic machines are of two types :

(*i*) Single spindle automatics

(*ii*) Multispindle automatics.

Single Spindle Automatics

The commonly used single spindle automatics are as follows :

(*a*) Automatic cutting off machine

(*b*) Swiss type automatic screw machine

(*c*) Turret type automatic screw machine.

10.13. Automatic Cutting off Machine

Such machines can perform operations like facing, form turning chamfering and cutting off. Fig. 10.14 shows the principle of operation of an automatic cutting off machine. Two cross-slides are located on the bed at the front end of the spindle. The stock is clamped in the collet chuck of the rotating spindle. A stock stop is provided which is automatically advanced in time with the spindle axis at the end of the cycle. The stock is fed out by the bar feeding mechanism up to the stop. The various operations are carried out by feeding the tools on cross slides which are acuated by cams on a camshaft through a system of levers. These machines are used to produce short components of small diameter and simple shape from bar stock.

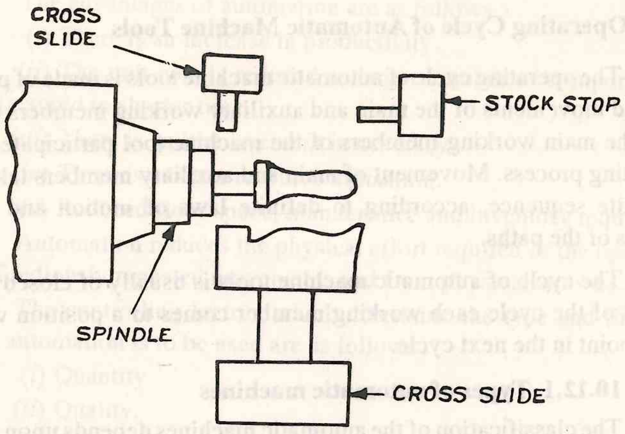


Fig. 10.14

Some of the typical parts produced by automatic cutting off machines are shown in Fig. 10.15.

Fig. 10.15

10.14. Swiss Type Automatic Screw Machine

Very accurate machining can be done with these machines. These machines once were used primarily for machining bar stock in making small parts such as screws, bolts, bushings etc. and therefore were called screw machines. But now they are used for producing a wide variety of parts from bar stock. Fig. 10.16 shows the principle of operation of a Swiss type automatic screw machine. The bar stock is clamped in rotating spindle in a collet chuck.

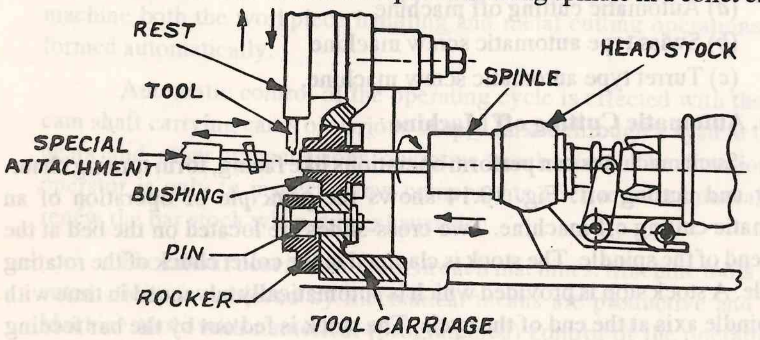


Fig. 10.16

The tool is clamped on rest mounted on a support which moves back and forth in a stationary carriage on the bed of the machine. The tool support is accurated by a rocker arm and lever from a cam controlling radial move-

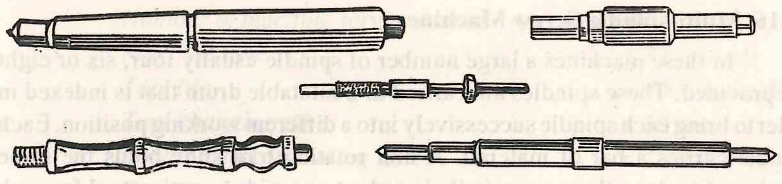


Fig. 10.17

ments. The head stock can move longitudinally on the bedways. Two or three vertical tool rests arranged radially are provided. Rocker has two tools and can have a rocking motion about the pin. A special attachment is provided on the left hand side of the bed to carry out operations like, boring, drilling threading etc. The bar stock passes through a guide bushing mounted in tool carriage secured on the bed. Some of the typical parts produced by this machine are shown in Fig. 10.17.

10.15. Turret Type Automatic Screw Machine

They are used to manufacture components from bar stock. In this machine a turret head is provided at the right end of the bed and carries a hexagon turret which can hold six tools. Two cross-slides (front and rear) are provided for cross feeding tools. A vertical slide is provided above the work spindle. A stationary head stock is provided at the left end of the bed and carries a spindle which can rotate in either direction. All these tools are automatically fed at the correct times during the cycles by cams mounted on a cam shaft. The bar stock is advanced to a stop automatically at the beginning of each cycle and then clamped in that position. These tools are fed automatically to carry out different operations. Although these machines were designed for producing screws but now-a-days they are being used to manufacture a wide variety of components.

Cams are used to index, rapid traverse and retract the hexagon turret.

Fig. 10.18 shows the operation of the turret slide. The cam operates a gear segment which further actuates the rack. The rack in turn causes the motion of the turret slide. The spring withdraws the slide to its initial position when the roller reaches a low point on the cam.

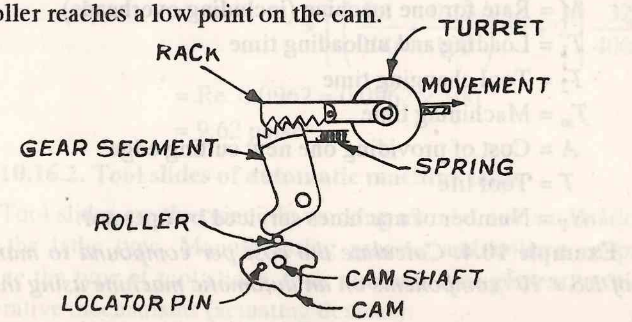


Fig. 10.18

10.16. Multi-spindle Screw Machines

In these machines a large number of spindle usually four, six or eight are provided. These spindles are carried in a rotatable drum that is indexed in order to bring each spindle successively into a different working position. Each spindle carries a bar of material. A non rotating tool slide holds the same number of tools as there are spindle in order to provide a cutting tool for each spindle. A cross-slide is provided at each spindle position so as to feed a tool from the side to carry out operations like facing, grooving, knurling and cutting off. The bars are loaded into hollow spindles. The tool slide is moved forward and cross-slides moved inward so that the various tools cut simultaneously. All the motions are controlled automatically. On completion of a particular operation the tool slide and cross-slides are moved backward and spindles indexed by one position by rotating the spindle drum so that the next operation can be carried out.

These machines seldom maintain accuracy as good as single spindle machines because of the errors in indexing of the spindles and large number of fittings. The time of production per component is considerably reduced in such machines. These machines are suitable when a very large number of components (say from 2000 to 5000 in a lot) are to be manufactured.

10.16.1. Economics of automatic machines

Automatic machines are used in both mass and large batch production. The cost of production per component is calculated as follows :

$$C = \frac{S}{N} + (R + M) \times T_1 + \left(\frac{R}{N_1} + M\right) T_m + [(R + M)T_2 + A]\frac{T_m}{T}$$

where C = Cost of production per component

S = Cost of setting up the machine

N = Batch size

R = Operator's rate (including overheads)

M = Rate for one machine (including overheads)

T_1 = Loading and unloading time

T_2 = Tool changing time

T_m = Machining time

A = Cost of providing one new cutting edge.

T = Tool life

N_1 = Number of machines serviced by operator.

Example 10.4. *Calculate the cost per compound to manufacture a batch of 1.8×10^5 components on an automatic machine using the following data :*

Number of machine serviced by one operator	= 5
Machine time	= 32 seconds
Tool life	= 4000 seconds
Tool changing time	= 60 sec.
Loading and unloading time	= 1 second
Operator's rate	= 0.1 paisa per sec.
Rate for one machine	= 0.13 paisa per sec.
Cost of providing one new cutting edge	= Rs. 2
Cost of setting up the machine (including manufacture of cam etc.)	= Rs. 600.

Solution. $N_1 = 5$

$T_m = 32$ seconds

$T = 4000$ seconds

$T_1 = 1$ sec.

$T_2 = 60$ sec.

$R = 0.1$ paisa per sec.

$M = 0.13$ paisa per sec.

A = Rs. 2

S = Rs. 600

$N = 1.1 \times 10^5$

$$C = \frac{S}{N} + (R + M)T_1 + \left(\frac{R}{N_1} + M\right) T_m + [(R + M)T_2 + A]\frac{T_m}{T}$$

$$C = \frac{600}{1.8 \times 10^5} \times \left(\frac{0.1}{100} + \frac{0.13}{100}\right) \times 1 + \left(\frac{0.1}{120} + \frac{0.13}{100}\right) + 32 \times \left[\left(\frac{0.1}{100} + \frac{0.13}{100}\right) 60 + 2\right] \frac{32}{4000}$$

$$= \text{Re. } 0.0962 = 0.0962 \times 100$$

$$= 9.62 \text{ paise.}$$

10.16.2. Tool slides of automatic machine tools

Tool slides are the principle working members of automatic machine tool of the lathe type. Manufacturing process and volume of production determine the type of tool slides, their number, arrangement, motion cycles and operative mechanisms (actuating devices).

The tool slides of the single spindle automatic screw machines are classified according to the following features :

(*i*) In respect to arrangement as central (along the spindle axis) and cross slides in the horizontal plane, or vertical, inclined or fan like for the vertical tool slides.

(*ii*) In respect to direction of travel.

(*iii*) In respect to kinematics of their motion as slides with rectilinear travel and rocking slides.

Each tool slide has its independent feed from a special cam.

10.16.3. Methods of increasing production capacity

The production capacity of automatic machine tools can be increased by reducing machining time. Following methods are used to reduce machining time.

(*i*) Machining several workpieces simultaneously.

(*ii*) Employing carbide tipped cutting tools to enable high velocity machining to be used.

(*iii*) Providing independent spindle speeds and rates of feed at each station.

(*iv*) Overlapping working travel motions in time.

(*v*) Reducing the time required to readjust the tools.

(*vi*) Reducing the number of idle travel motions and by increasing the speed of idle travel motions.

10.17. Cams

In automatic and semi-automatic lathes the automaticity is achieved by mechanical means based on cam drives. The cam shaft carries cams of various shapes. When the cam shaft rotates the cams actuate the various operative mechanisms. Cams are of two types :

(*i*) Plate cams

(*ii*) Cylinder cams.

Plate cams are used to transmit motion with a short stroke and in a plane square to the axis of rotation of cam. Fig. 10.19 shows a plate cam. A

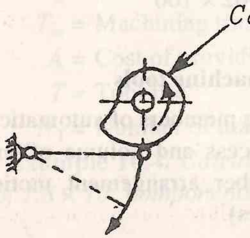


Fig. 10.19

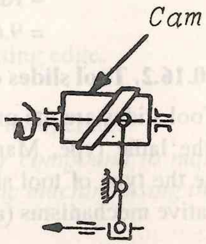


Fig. 10.20

cylinder cam is used to transmit motion with a considerable longer stroke and in a plane parallel to or passing through the axis of rotation of the cam. Fig. 10.20 shows a typical cylinder cam.

10.18. Layout of Cams

An important operation in the tooling up of automatic lathes is the layout of cams. The layout of cams is dealt with in the following stages :

(*i*) Determine the sequence of operations.

(*ii*) Calculate r.p.m. of the work spindle.

(*iii*) Determine the tools to be used.

(*iv*) Establish the cutting speed according to the material to be machined and operations to be carried out.

(*v*) Determine the travel of each tool.

(*vi*) Determine the feed per revolution of the work spindle for each tool.

(*vii*) Determine the number of revolutions of work spindle for each operation.

(*viii*) Establish the number of revolutions of work spindle required to complete one component.

(*ix*) Determine the hundredth of cam surface for each operation.

(*x*) Draw the tool layout and set of cams.

10.19. Numerical Control of Machine Tools

Numerical control (NC) is considered to be an improved control for machine tools that provides higher productivity. Today industry demands faster production in harder and tougher materials to unprecedented tolerances. Conventional machine tools manual or automatic cannot meet these demands and the answer to the problem has been found in what is called the numerical control of machine tools. This technique saves time, eliminates burdensome tasks and increases overall productivity.

Numerical control is a method of controlling of motions of machine tool components by means of coded instructions in the form of numbers on tapes or punch cards. The information stored in the tapes or cards can be read by automatic means and converted into electrical signals which operate the electrically controlled servo-system. The servo-system permits the slides of the machine tool to be driven simultaneously at the required speed in the required direction to carry out the different operations. Fig. 10.21 shows the scheme of a numerically controlled machine tool.

The programme is recorded on a tape or punch card. Punched tape is then directed to the machine control unit (M.C.U.) which converts the information into electrical signals and sends them to electrically controlled servo-systems which are used to drive the slides of machine tools at the appropriate speed and directions.

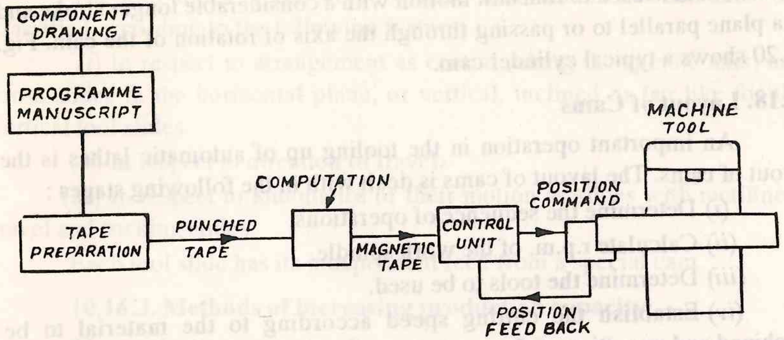


Fig. 10.21

Numerical control has caused a virtual revolution in the discrete metal parts manufacturing industry. The success of N.C. has led to a number of extensions of numerical control concepts and technology. Four of the more important developments are as follows :

(*i*) Direct numerical control (D.N.C.)
(*ii*) Computer numerical control (C.N.C.)
(*iii*) Adaptive control (A.C.)
(*iv*) Industrial Robots.

N.C. technology has made it possible to reduce cost of production by reducing the production time. This in turn is mainly directed towards the reduction of non-productive time such as (*a*) set up time, (*b*) work piece handling time, (*c*) tool change time, (*d*) lead time.

Other features of N.C. machine tools are :

(*i*) reduced fixturing
(*ii*) ease of making workpiece design changes
(*iii*) improved accuracy
(*iv*) reduced human error
(*v*) greater manufacturing flexibility.

10.20. Basic Components of an N.C. System

The basic components of an N.C. system are as follows :

(*i*) Program of instructions.

It is a set of directions which will tell the machine tool what to do. It is coded in numerical or symbolic form on some type of input medium such as one inch wide punched tape.

(*ii*) Controller unit also called machine control unit (MCU).

It consists of the electronics and hardware that read and interpret the program of instructions and convert it into mechanical action of the machine tool.

The various elements of MCU are as follows :

(*a*) Tape reader.
(*b*) Data buffer.
(*c*) Signal output channels to the machine tool.
(*d*) Feed back channels from the machine tool.

(*iii*) Machine tool or other controlled process.

It performs the useful work.

A machine tool consists of the following :

(*a*) Work table and work fixtures.
(*b*) Spindle.
(*c*) Cutting tools.
(*d*) Motors and controls for drives.
(*e*) Other auxiliary equipment needed in machining operation.

10.20.1. The Numerical Control (N.C.) Procedure

During manufacturing on NC machines the following steps should be accomplished.

(*i*) *Process planning.* This is listing of the sequence of operations to be performed during manufacturing of a part. This also lists the machines through which the part to be made is routed. Fig. 10.21 (*a*) shows a typical planning sheet. [Fig. 10.21 (*a*) on next page]

(*ii*) *Part programming.* The part programmer is responsible for planning the sequence of machining steps to be performed by N.C. system and to document these in a special format.

Part programming is carried out in two ways

(*a*) Manual part programming
(*b*) Computer assisted part programming.

(*iii*) *Tape preparation.* A punched tape is prepared based on the instructions listed in part program prepared by part programmer.

(*iv*) *Tape verification.* The tape is checked for its accuracy. It is checked by two methods.

(*a*) To try out the tape on the machine tool to make the part using a foam or plastic as the material for tryout. The errors detected in tape are then removed.

(*b*) To run the tape through a computer program which will indicate the contents of the tape and errors in the tape can thus be checked.

(*v*) *Production.* The corrected tape is then used for manufacturing the parts on the NC machine.

The operator loads the raw material on the machine tool and adjusts the position of the cutting tool relative to workpiece. The N.C. system then takes over and machines the part according to the instructions on the tape.

Job No. ....
Sheet No. ....

PLANNING SHEET

Date
Dept.
Prepared By

Machine tool ....
Operation No. ....

Tool number	Loading order	Tool length offset switch	Tool radius correction switch	Spindle speed Rev./min.	Spindle speed Range	Feed rate mm/min.	Feed rate Code

Fig. 10.21 (a)

10.21. Numerical Control (NC) Systems

The two basic systems of numerical control as follows :

(i) Open loop system (ii) Closed loop system.

Open loop system. This system does not have a feedback device and therefore the actual position of the tool slide or work table is not measured and verified.

As shown in Fig. 10.22 the information is fed from the operator control console to the tape reader which picks off the discrete bits of information from the tape and then feeds them to the distribution control unit the information is then directed to the servocontrol unit for a particular axis (*X*-axis, *Y*-axis, *Z*-axis

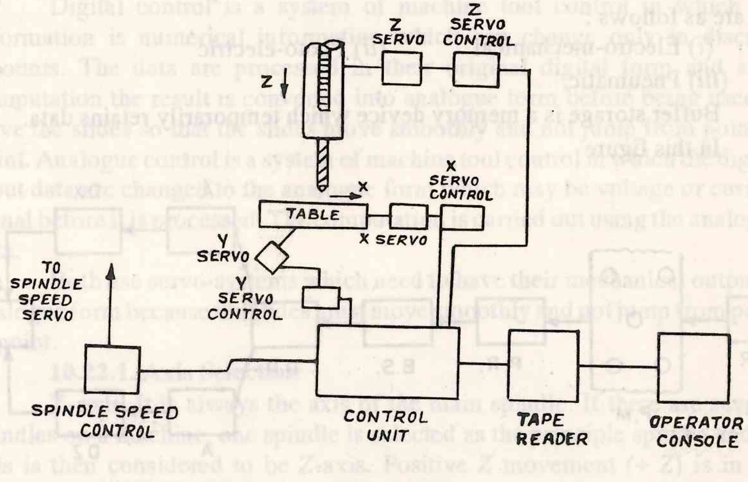


Fig. 10.22

etc.) control and finally the command is transferred to the servo-motor in the form of electric impulses or signals. The servo-motors control the machine table (slide) movement, the cutter head movement etc.

Closed loop system. This system is generally used because this system ensures that the slides have taken up the desired position (Fig. 10.23). This is

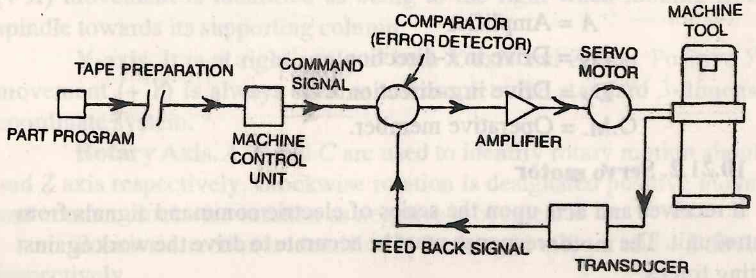


Fig. 10.23

done by measuring the actual position of the slides by transducer attached to each axis. The transducer converts the motion as directed from linear or rotary motion to an electrical impulse. This impulse is fed back to the control unit as a check on the input signal. There should be no difference between input signal and feedback signal. If there is any difference between the two, the correction is made by comparator and then the operation is carried out.

10.21.1. N.C. System for Turning

Fig. 10.23 (*a*) shows N.C. system for simple turning on lathe. When part program medium (punched tape) is passed through program reader the coded instructions are transferred into electrical signals which are used to control the various machine tool functions. Punched tape readers commonly used are as follows :

(*i*) Electro-mechanical (*ii*) Photo-electric
(*iii*) Pneumatic.

Buffer storage is a memory device which temporarily retains data.

In this figure

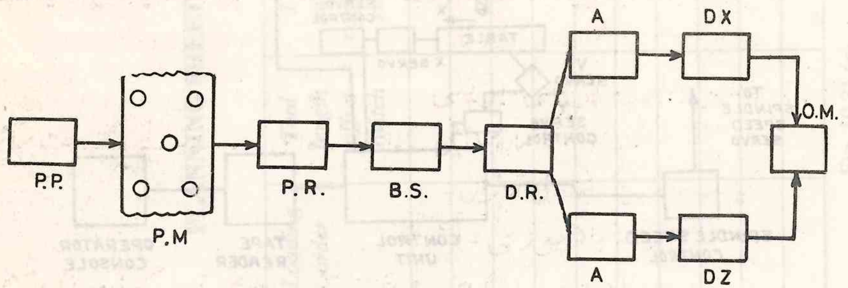


Fig. 10.23 (*a*)

P.P. = Part Program
P.M. = Program Medium
P.R. = Program Reader
B.S. = Buffer Storage
D.R. = Decoder
A = Amplifier
D_X = Drive in *x*-direction
D_Z = Drive in *z*-direction
O.M. = Operative member.

10.21.2. Servo motor

It receives and acts upon the series of electric command signals from the control unit. The motor response must be accurate to drive the work against the cutting forces.

There are two types of servo motors :

(*i*) High frequency electric servo-motors.

(*ii*) Hydraulic servo motors.

A high frequency servo motor is similar in operation to the normal type of induction motor used upon machine tools at a frequency of 0 Hz. However, a servo motor is operated on a three phase supply at 400 Hz giving full power at 167 revolutions per second.

In hydraulic servo motor fluid is pumped into the motor under frequency which causes the rotor to turn. A hydraulic servo motor of 2.25 kW gives an accuracy of response of 0.005 mm.

10.22. Digital and Analogue Control

Digital control is a system of machine tool control in which the information is numerical information which can change only in discrete amounts. The data are processed in their original digital form and after computation the result is converted into analogue form before being used to drive the slides so that the slides move smoothly and not jump from point to point. Analogue control is a system of machine tool control in which the digital input data are changed to the analogue form which may be voltage or current signal before it is processed. The computation is carried out using the analogue data.

Both use servo-systems which need to have their mechanical output in analogue form because the slides must move smoothly and not jump from point to point.

10.22.1. Axis Selection

Z-axis. It is always the axis of the main spindle. If there are several spindles on a machine, one spindle is selected as the principle spindle and its axis is then considered to be *Z*-axis. Positive *Z* movement (+ *Z*) is in the direction that increase the distance between the workpiece and the tool.

X-axis. It is always horizontal and is always parallel to the holding surface.

If *Z*-axis is horizontal as in turning centres positive *X*-axis (+ *X*) motion is to the right when looking from the spindle towards the workpiece.

If *Z*-axis is vertical as in vertical milling machine the positive *X*-axis (+ *X*) movement is identified as being to the right when looking from the spindle towards its supporting column.

Y-axis. It is at right angle to both *X*-axis and *Z*-axis. Positive *Y*-axis movement (+ *Y*) is always such as to complete the standard 3-dimensional coordinate system.

Rotary Axis. *A*, *B* and *C* are used to identify rotary motion about *X*, *Y* and *Z* axis respectively. Clockwise rotation is designated positive movement and counter clockwise rotation as negative movement.

Positive direction is identified by looking in + *X*, + *Y* and + *Z* directions respectively.

10.22.2. XYZ Code

Let $X = 15$
$Y = 20$
$Z = 60$

Depending upon the type of computer, these values may be written as

(*i*) *X* 15 *Y* 20 *Z* 60

or (*ii*) *X* 1500 *Y* 2000 *Z* 6000.

10.22.3. Numerical Control Programming Systems

Numerical control programming can be divided into two main systems as follows :

(*i*) Point to point (PTP) system.

(*ii*) Continuous path system.

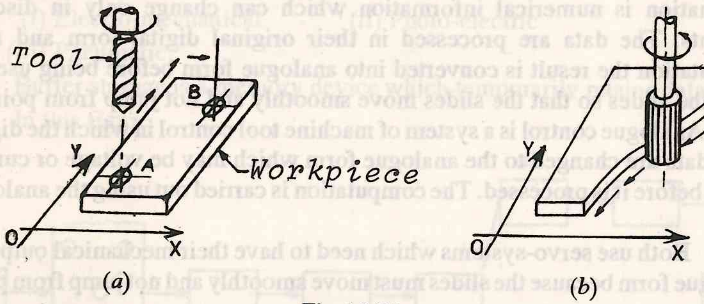


Fig. 10.24

Fig. 10.23 (*a*) shows point to point system and Fig. 10.23 (*b*) shows continuous system.

10.23. Point to Point or Positioning System

Point to point control is used in vertical drilling machines, jig, bores and tapping machines. The object of this system is to move a machine tool table (and hence the work) through rectangular co-ordinates according to a programme so that the different machining operations are carried out at the programmed points where the table stop.

10.24. Continuous Path System or Contouring System

In this system tool remains in contact with the work and generates a continuous surface in space. In this system the position of tool relative to the workpiece must be continuously controlled while workpiece is being machined. This system is used in milling machines.

The preparation of part programme for NC machine tools with contouring controls is more complicated than for those with finite positioning controls.

Coordinate positional control is used in drilling, jig boring, turret drilling and milling. Continuous path control is used in milling or flame cutting contours, grooving, boring, and cam milling.

In the contouring systems the simultaneous movements of the tool and workpiece are coordinated to generate the desired profile. Contouring NC machine tools can machine not only straight lines at angle but also complicated profiles. The profile is approximated by elementary straight lines, arcs of circles, or segments of parabola to describe the locus of tool cutting edge.

Generally all contouring N.C. machine tools are equipped with a feed back arrangement. Contouring N.C. machine tool are expensive than point to point control principled machine tools.

10.24.1. Part programming (P.P.)

It is the plan proposed for manufacturing a part on N.C. machine tool. Programming can either be done manually or with the help of a computer. But in most cases the program is written manually called manual part programming (MPP). Programming involves the detailed step by step listing of operations that the N.C. machine with perform. These steps are written in a definite order and form in what is known as manuscript. One who writes these instructions is designated as part programmer.

While making the part program the programmer first studies the drawing of the part and then decides the sequence of operations, the cutting tool to be used, the path of cutter, speeds, feeds and other necessary information like starting and stopping of the machine etc. The above information is entered in a program sheet in a particular format acceptable by the machine tool control unit combination. The information given on the program sheet is punched on to a paper tape or magnetic tape according to a standard code. This input information punched on the tape is then fed to the machine control unit (MCU).

The program for machining a particular workpiece depends not only upon the workpiece shape and dimensions but also upon the N.C. machine tool on which it is machined. The program for machining a workpiece on one N.C. machine tool may differ from program for machining the same workpiece on another N.C. machine tool because of difference between formats of the machine tools.

Manual programming jobs can be divided into two categories :

(*i*) Point to point jobs

(*ii*) Contouring jobs.

Manual part programming is ideally suited for point to point applications.

Manual part programming becomes extremely tedious task and is subject to errors in case of complex workpieces. Therefore for more complex workpieces computer assisted programming is preferred. This saves time and results in more accurate and more efficient part program. The computer automatically punches the tape in proper tape format for the particular N.C. machine. The part programmer's responsibility in computer assisted part programming consists of the following two basic steps :

(*i*) Defining the workpiece geometry
(*ii*) Specifying the operation sequence and tool path.

In addition to part geometry and tool motion statements, the programmer must also provide other instructions to operate the machine tool properly.

10.24.2. Data required for part programming

To prepare the manuscript for manual part programming, the following data is required :

(*i*) Machine tool specifications
(*ii*) Specifications of tools
(*iii*) Specifications of workpiece materials
(*iv*) Speed and feed tables.

The programmer (person who prepares part program) on obtaining the component drawing decides about the sequence of operations, speeds, feeds for various operations and determines the magnitude of various motions desired. He prepares the planning sheet and writes the instructions in a coded form which is acceptable to the controller of the machine tool.

10.24.3. Input media

The part program is converted into an input medium acceptable to the machine control unit (MCU). The most common types of input media are as follows :

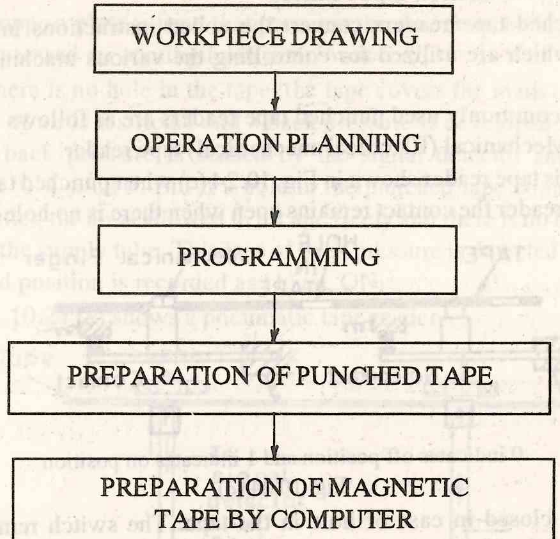
(*i*) Magnetic tape
(*ii*) Punched paper tape
(*iii*) Punched cards
(*iv*) Floppy discs.

10.25. Tapes

Two types of tapes are used in numerical control (NC) of machine tools :

(*i*) Punched paper tape
(*ii*) Magnetic tape.

In punched paper tape a punched hole can represent 1 and absence of hole can represent 0. Punched paper tapes are cheap and are convenient means of transmitting drawing information to computer. In magnetic tapes magnetised spots on tape surface are used. More information can be recorded on magnetic tapes and they can be read at a speed faster than is possible with punched tapes. Magnetic tape is used as the media for storing the input data and the preparation of data confirms to the sequence shown follows :



The standard width of paper tape is 25.4 mm. The tape has eight rows of holes plus sprocket holes. Each row of holes lengthwise of the tape is referred to as a channel. Each of the eight channels are numbered 1 through 8.

The code according to which these holes on tape are punched has been standardised by

(*i*) EIA (Electronic Industries Association)
(*ii*) ASCII (American Standard Code for Information Interchange).
(*iii*) ISO (International Standard).

The punched tape as per standard code represents the part program characters on its eight tracks. The tape is usually punched on a teletype machine (a typing cum punching machine).

Punched tape is the most commonly used programming medium in N.C. machine tools. These tapes are available in 200 mm diameter rolls and are made of paper, plastics and or a plastic and aluminium sandwich. As compared to magnetic tape the punched tape has the following advantages :

(*i*) Low cost of (*a*) tape
(*b*) program reader
(*c*) perforator.
(*ii*) no hazard of accidental distortion of the coded information.
(*iii*) Ease of detecting damage to the tape.

The programme is punched on the tape on a perforator. The perforator is a key board instrument like a type writer or computer aided punching machine.

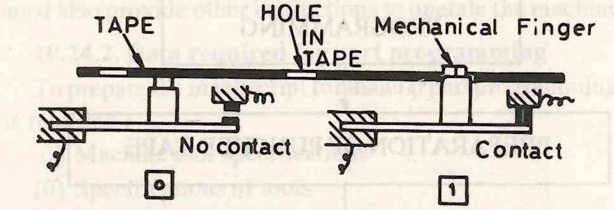
10.25.1. Punched tape readers

Punched tape readers convert the coded instructions into electrical analogues which are utilized for controlling the various machine tool functions.

The commonly used punched tape readers are as follows :

(*i*) Mechanical (Electrical-mechanical) tape reader.

In this tape reader shown in Fig. 10.24 (*c*) when punched tape is passed through the reader the contact remains open when there is no hole whereas the



0 indicates off position and 1 indicates on position

Fig. 10.24 (*c*)

contact gets closed in case of hole in the tape. The switch remains in ON position in case of hole and switch remains in OFF position when there is no hole in tape.

(*ii*) **Optical or photo-electrical tape reader.** This reader, works on the principle that if a beam of light falls on a photo-electric cell, the latter generates an electric signal.

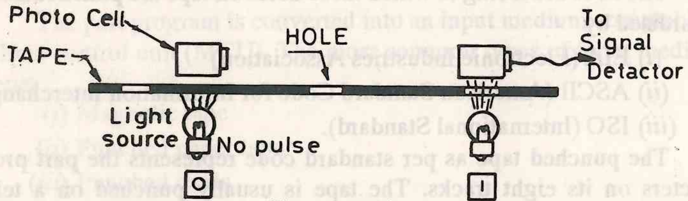


Fig. 10.24 (*d*)

When punched tape is fed between a light source and a series of photo-cells and whenever a hole is present in the tape, light is permitted to reach and energise the corresponding photo-cell which converts the light energy into electrical energy to produce a pulse *i.e.* ON position. The pulse is amplified and processed into a form suited to the circuit. When there is no hole the light from the light source does not reach the photo-cell, and so signal is produced. This position is recorded as OFF. Fig. 10.24 (*d*) shows optical tape reader.

(*iii*) **Pneumatic tape readers.** In pneumatic tape reader, the tape is fed between a series of air jets (8 Nos.), covering the complete pattern of holes which is possible to be punched in a block of information on the tape and tape support plate. The compressed air jets are directed through specially designed tubes which have two openings. The first opening called, main outlet, is near the tape and second opening is connected to a signal detector.

A support plate is used that prevents the tape from being blown away by the compressed air coming from main outlet.

If there is no hole in the tape, the tape covers the main outlet and the free escape of air is restricted and a back pressure is developed in the supply tube. This back pressure is sensed by the signal detector and position is recorded as '0' *i.e.* OFF. But if a hole in the punched tape comes in front of the main outlet, the air is allowed to escape freely and there is no back pressure build up in the supply tube. This loss of back pressure is detected by the signal detector and position is recorded as '1' *i.e.* ON.

Fig. 10.24 (*e*) shows a pneumatic tape reader.

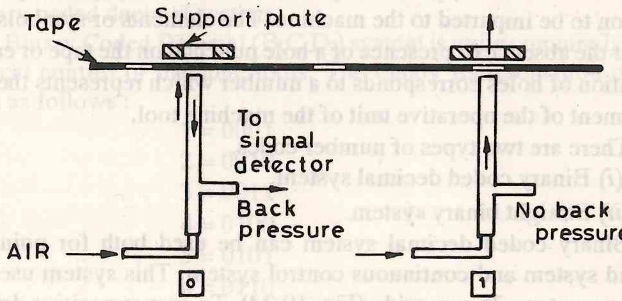


Fig. 10.24 (*e*)

10.25.1. (*a*) Buffer storage

The information read from the tape is stored into the memory of the control system called buffer storage and is processed by the machine step by step.

10.26. Advantages and Disadvantages of Numerical Control

Advantages. The various advantages of numerical control are as follows :

(*i*) A greater accuracy is achieved.

(*ii*) High production rates are obtained.

(*iii*) Expensive jigs and templates are not needed. This reduces the tooling cost.

(*iv*) Time required for setting up the machine is reduced.

(*v*) The amount of human error is greatly reduced and therefore the scrap rate is decreased.

(*vi*) Programming and tape writing takes much less time than making jigs and fixtures and locating gauges. Also the tapes last longer and require much less space than jigs and fixtures.

(*vii*) Operation of the machine does not require a skilled operator. Except for positioning the workpiece on the table the human element is completely eliminated.

(*viii*) The cutting time of total cycle time is as high as 80% in case of N.C. machines as compared to about 30% in case of conventional machines.

Disadvantages. (*i*) Initial cost of numerical controlled machine tools is high.

(*ii*) Machine tools should be rigidly built than conventional machine tool in order to withstand accelerations dictated by servo controls.

(*iii*) Skilled electronics technicians are needed to maintain the electronic controls.

10.27. Codes

Code is a suitable pattern of performations on the tape to represent each instruction to be imparted to the machine. The elements or symbols of a code are either the absence or presence of a hole punched on the tape or cards. Each combination of holes corresponds to a number which represents the specified displacement of the operative unit of the machine tool.

There are two types of number codes.

(*i*) Binary coded decimal system.

(*ii*) Straight binary system.

Binary coded decimal system can be used both for point to point command system and continuous control system. This system uses an eight channel paper tape 25 mm wide (Fig. 10.24). To ensure positive drive for the tape one more channel of holes is provided for the sprocket channels 1, 2, 3

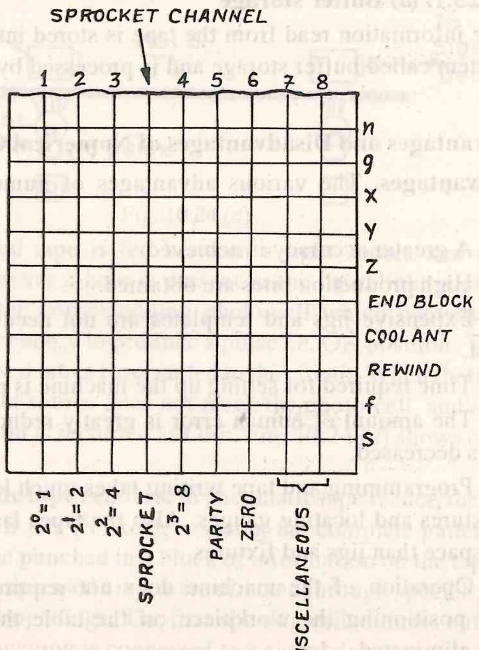


Fig. 10.24

and 4 are used to represent powers of 2 such as channel 1 is $2^0 = 1$, channel 2 represents $2^1 = 2$, channel 3 represents $2^2 = 4$ and channel 4 represents $2^2 = 8$. Only an odd number of holes may be punched in each row. If the data requires that an even number of holes be punched into a particular row another hole should be punched in row 5 which is parity column. Channel 6 is used for zero commands and items such as direction coolant on, coolant off, tape start, tape return are indicated on channels 7 and 8. A particular pattern of holes represents specific command.

Straight binary system is generally used for continuous control. In this system multiple simultaneous motions may be programmed into one row. Therefore, the tape required is much shorter than the length of tape required for binary coded decimal system.

Binary Coded Decimal (B.C.D.) system is quite commonly used in the numerical control of machine tools. The binary representation of numerals 1—9 is as follows :

1 = 0001
2 = 0010
3 = 0011
4 = 0100
5 = 0101
6 = 0110
7 = 0111
8 = 1000
9 = 1001

For example the number 630 can be represented in BCD system as :

6 = 0110
3 = 0011
0 = 0000

10.28. Machine Control Unit (MCU)

Every N.C. machine tool is fitted with a machine control unit (MCU). The MCU may be mounted on the machine tool itself or it may be housed in a separately standing cabinet like body. The MCU can be considered as a special purpose computer that executes the commands mentioned in the part program *i.e.* the program to manufacture a part on the N.C. machine tool. This program, of course, is in the form of an acceptable input medium like paper tape, and magnetic tape, the paper tape being quite commonly used. The MCU converts the information from the tape program into the desired command signals used in the actuation system of the machine tool.

10.28.1. Features of modern N.C. machines

Some of the features of modern N.C. machine are as follows :

(*i*) The structure of NC machine tools should be very rigid to withstand heavy cuts and maintain precision and accuracy for a long period.

(*ii*) Large volume of chips are produced during NC machines operation. To transport these chips NC machines are fitted with chip conveyors.

(*iii*) NC machines are equipped with centralized lubrication system with automatic supply in predetermined quantities.

(*iv*) The spindle drive on modern machines is invariably a DC drive in combination with three or four step gear boxes to get a wide range of spindle speeds.

(*v*) The guide ways used in NC machines are hardened and ground flat guide ways or a ground combination of V and flat guide ways.

(*vi*) Automatic tool changer is a common feature on machining centre.

10.28.2. Tool designing for N.C. machines

There is no need of expensive jigs or fixtures for Numerical Control machine tools because of the accuracy built into an N.C. machine. Jigs and fixtures may be clamps and support blocks in most instances. The need for locating the workpiece relative to the zero point selected is important and must be dealt with when planning even simple holding devices.

The tooling problems becomes one of analysing the job, using great care in programming and setting up the machine.

One of the major advantage of numerical control over conventional machining with fixtures is that changes which need to be made can be done quickly by correcting the tape. It is easier and less expensive than re-working a fixture or scrapping a fixture and making a new one.

10.28.3. Automatic Tool Changer (ATC)

The CNC machines are equipped with automatic tool change facility. This helps the CNC machines to perform a number of operations in a single setting of the workpiece and this will reduce down time in change over from one operation to the next. With the help of A.T.C. the tool is automatically selected and changed based on the tool control function (T-word) in the part program.

Tools are usually stored on drum, chain and egg box type of magazines. To select the correct tool automatically from the magazine and replace it with the one already existing in the machine spindle a tool transfer arm is generally used. This arm shuttles to and fro between the spindle and magazine. The replaced tool carried by the arm can always be returned back to the same fixed place in the magazine. Tool changing time could be as small as four seconds. Tool magazines with upto 60 tools are quite common in our country.

10.29. Development of NC and CNC

This new and increasingly popular method for an automatic control of machine tools has been linked to an industrial revolution Numerical control (NC) means controlling a process by numbers. The letters, symbols or numbers are recorded in code form on a punched card, punched paper tape or a magnetic tape to carry information regarding all the steps of operations for the manufacture of a workpiece on the machine tool. The numerical control (NC) had its experimental beginning in 1949 at the servomechanism Laboratory of Massachusetts Institute of Technology (M.I.T.) where the initial research

project was carried out sponsored by Parson's Corporation and United States Air Force. Between 1955 and 1960 about 500 NC machines were installed in U.S.A. Japan entered the NC commercial scene during mid 60's and by 1971 its NC production was as good as USA. Then countries like USSR, West Germany, U.K. and France also started manufacturing NC machine tools.

In India, in the early 1970's the first indigenously developed NC lathe was built. The Indian machine tool manufacturers after going through the teething troubles and gaining confidence to build NC machines came out in 1979 with a CNC (Computerised numerical control) lathe, a slant bed CNC lathe and vertical machining centres. Around 1982, a horizontal machining centre with automatic tool changer, CNC boring machine, CNC vertical turning machines and CNC travelling wire-cut EDM machines were developed. It is expected that CNC machines would account for at least 25% of all the machines tools produced in India by 1993. At present the number of NC machine tools in India is very small. By 1986 there were about 136 indigenous NC machine tools in operation. In order to increase production of NC/CNC machines tools in our country it is essential to impart training in NC and CNC and to invest in R and D to master the technology of designing and building NC and CNC machine tools with minimum dependence on external sources. With the growth of electronics NC holds a greater promise for the future manufacturing in India.

10.30. Computer Numerical Control (CNC) of Machine Tools

NC systems used on machine tools can be broadly classified as follows :

(*i*) Hard wired or conventional NC

(*ii*) Computer numerical control (CNC) or soft wired NC.

Since 1970, CNC systems have been increasingly replacing the common hard wired MCU. The CNC concept attempts to accomplish as many as possible control functions within computer soft ware. In computer numerical control system a dedicated stored program computer is used to perform all the basic NC functions as per the control program stored in the memory of the computer. Thus machine control data comes direct from the computer memory and not from the continuously read tape in case of hard wired NC system. Fig. 10.25 shows the general configuration of CNC system.

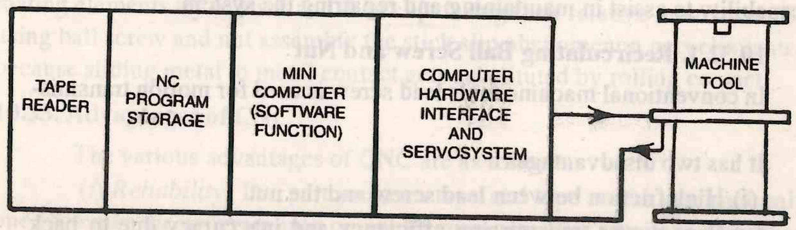


Fig. 10.25

Mini computer together with the associated software now performs the MCU functions of data decoding, control buffering, feed rate control, interpolation and position control.

10.31. Feature of CNC System

CNC system possesses the following special features which make it more popular :

(*i*) In NC system part programming becomes too tedious for complex shaped workpieces whereas in CNC the part programming becomes easy for complex jobs.

(*ii*) It is possible to modify and edit the part program at all stages.

(*iii*) Part program can be stored in the computer memory. The CNC then operates directly from these memories and use of tape reader is greatly reduced.

(*iv*) Part program can be generated directly from an existing part.

(*v*) Flexibility, increased capability and reliability together with reduction in cost and higher productivity make CNC and popular system.

10.32. Functions of CNC

The principal functions of CNC (Computer Numerical Control) are as follows :

(*i*) *Machine tool control.* This involves conversion of the part program instructions into machine tool motions through the computer interface and servo system.

(*ii*) *In-process compensation.* This involves the dynamic correction of the machine tool motions for changes or errors which occur during processing.

(*iii*) Improved programming and operating features.

It helps in achieving the following :

(*a*) Editing of the part programs at the machine.

(*b*) Graphic display of the tool path to verify the tape.

(*iv*) *Diagnostics.* The N.C. machine tools are complex and expensive systems. The complexity increases the risk of the components failures which lead to system down time. CNC machines are often equipped with a diagnostics capability to assist in maintaining and repairing the system.

10.32.1. Recirculating Ball Screw and Nut

In conventional machine tools lead screw is used for motion transmission.

It has two disadvantages :

(*i*) High friction between lead screw and the nut

(*ii*) Poor power transmission efficiency and inaccuracy due to back lash.

In CNC machines the lead screw arrangement is not used because of above mentioned drawbacks.

To overcome these problems recirculating ball screw and nut arrangement shown in Fig. 10.25 (*a*) is used in CNC machines. Here again the approach is to replace sliding friction by rolling friction. The screw thread is a hardened and ground ball race in which the steel ball in the nut circulate. The balls rotate between the screw and the nut and at some point the balls are returned to start of the thread in the nut. The rigidity of the drive system and positioning accuracy can be further improved by pre-loading the nut assembly.

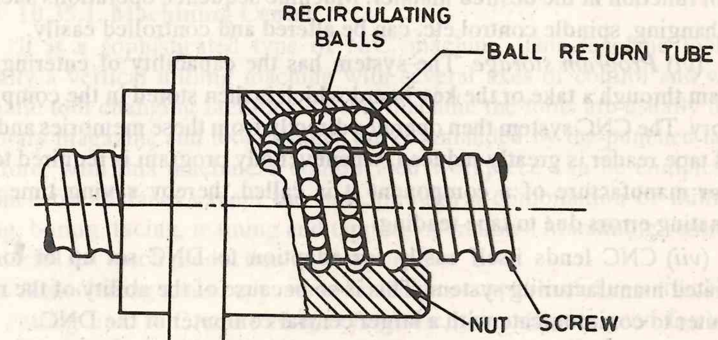


Fig. 10.25 (*a*)

Rigid mounting techniques for bearings are also employed to overcome the problems of backlash.

Various advantages of using recirculating ball screw and nut assembly are as follows :

(*i*) Reversibility

(*ii*) Minimum wear and longer life

(*iii*) High efficiency.

(*iv*) **Stick-slip eliminated.** The stick-slip phenomenon takes place between two lubricated parts. The lubricant tries to cause the mating elements to stick to each other to resist motion and this causes a jerky motion as the mating elements try to stick and then slip during their relative movement. By using ball screw and nut assembly the stick slip phenomenon gets eliminated because sliding metal to metal contact gets substituted by rolling contact.

10.33. Advantages of CNC

The various advantages of CNC are as follows :

(*i*) *Reliability.* The part program tape and tape reader are used only once to enter the program into computer memory. This results in improved reliability.

(*ii*) *Tape editing.* CNC system enables the correcting and optimising (such as speeds, feeds, tool path) the tape during tape try out at the site of machine tool. Thus CNC permits editing modification of program at all stages.

(*iii*) *Units coversion.* Tapes prepared in units of inches can be converted into International system (S.I.) of units.

(*iv*) *Program display.* As all the functions are directly controlled by the computer the current state of program can be extensively displayed on a CRT (Cathode Ray Tube).

(*v*) *Control flexibility.* CNC systems programming can modify the control function in the desired manner. Machine sequence operations such as tool changing, spindle control etc. can be altered and controlled easily.

(*vi*) *Program storage.* The system has the capability of entering the program through a take or the key board which is then stored in the computer memory. The CNC system then operates directly from these memories and the use of tape reader is greatly reduced, whenever any program is required to be run for manufacture of a component it is called thereby saving time and eliminating errors due to tape reading.

(*vii*) CNC lends itself easily for adaption to DNC set up or to the integrated manufacturing system. This is so because of the ability of the mini computer to communicate with a larger central computer of the DNC.

(*viii*) Use of CNC machine tools has reduced the process planning time considerably in proto-type fabrication of complicated components. This has also reduced the vast amount of tedious and time consuming manual calculations in tools and fixtures.

10.34. Direct Numerical Control (DNC)

In this system a central computer is used for part programming and for other data processing operations. Part programming data is transferred from central computer to the mini computer by means of telecommunication lines. The mini computer with its own data files can store active programmes and

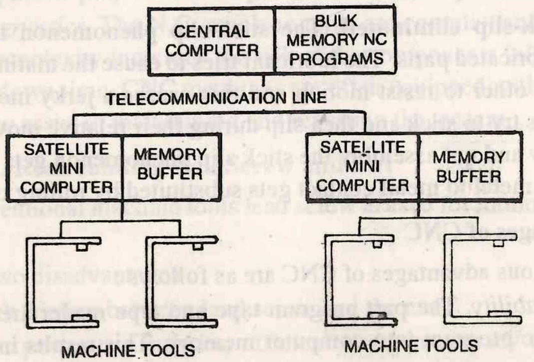


Fig. 10.26

supply to the NC systems as required. The mini computer is assigned to control a group of machine tools. Since a large memory system is required and substantial cabling work is involved interlinking the NC machines to the computer DNC system is expensive and is preferably used in large organisations. Fig. 10.26 shows the general configuration of DNC system. Digital computer is used both in CNC and DNC.

10.35. Major groups of N.C. Machine Tools

Two major groups of N.C. machine tools are as follows :

(*i*) Machining centres

(*ii*) Turning centres.

10.35.1. Machining Centre

It is a sophisticated type of N.C. machine. This machine tool is generally a vertical milling machine with several axes of control and with automatic tool changing facilities. In this machine the tools are usually held in a rotary magazine and tool changes are commanded by the punched tape. Therefore, with this machine a complicated workpiece can be completely machined on all faces except the base through a combination of milling, drilling, boring, facing, reaming and tapping operations. Machining centre is quite useful for batch production of components.

A machining centre appears to be the most capable and versatile N.C. metal cutting tool. N.C. machining centres are generally designed for long hours of continuous operation and thereby accurate performance and productivity are expected to be sustained over long period of time. These centres are of massive construction in order to have enough stiffness so that minimum deviations take place due to large cutting dynamic forces and due to thermal effects because of heat generated from large amount of chips removed. Complex jobs are tackled by modern machining centres having simultaneous control of 3 or 4 linear and 2 or 3 rotary movements as well as positioning capability.

The horizontal turning centre (H.T.C.) is a most useful productive machine for :

(*i*) milling (*ii*) contouring

(*iii*) drilling (*iv*) tapping

(*v*) reaming.

10.35.2. Block and Words in N.C. System

In N.C. system the commands are given to M.C.U. through the tape in blocks of data. The blocks are made of a group of words considered a unit and arranged in a definite sequence.

An N.C. word is a collection of characters such as letters, numbers or symbols. Block is a complete N.C. instruction that can be understood by the machine.

10.35.3. Function Words

On N.C. machine tools the various functions are represented by words. The important functions with their words representations are as follows :

(*i*) **Sequence number function.** This function identifies a block and it is the first word of block. It is represented by letter N plus three digits.

(*ii*) **Preparatory function.** The preparatory function instructs the machine tool to get prepared for the operation to follow.

Preparatory function is represented by letter G plus two digits. There is a provision for coding a total of 100 preparatory functions from G00 to G99.

Some of the preparatory functions with their word codes are indicated in Table 10.1.

Table 10.1

Code	*Function*
G00	Positioning control
G01	Linear interpolation (Normal dimensions)
G02	Circular interpolation, clockwise
G03	Circular interpolation, anticlockwise
G04	Dwell
G05	Hold—The machine motion stops till the operator intervenes
G06, G07	Unassigned
G08	Acceleration
G09	Decleration
G10	Linear interpolation (long dimensions)
G11	Linear interpolation (short dimensions)
G12	Unassigned
G13 to G16	Prepares system to operate on a particular axis
G17	Selects the *XY*-plane for circular interpolation on a system which can operate in only two directions simultaneously
G18	Selects the *XZ*-plane for circular interpolation
G19	Selects the *YZ*-plane for circular interpolation
G20	Circular interpolation, clockwise direction (large dimensions)
G21	Circular interpolation, clockwise direction (small dimensions)
G22 to G29	Unassigned
G30	Circular interpolation, anticlockwise direction, large dimensions
G31	Circular interpolation, anticlockwise direction, small dimensions
G32	Unassigned
G33	Threading mode, constant lead
G34	Threading mode, increasing lead
G35	Threading mode, decreasing lead
G36 to G39	Permanently unassigned to enable the N.C. tool manufacturer to code functions not covered by those specified in this table
G40	Discontinuation of cutter compensation
G41	Cutter compensation—left, cutter to the left of the work surface as seen in the direction of cutter motion
G42	Cutter compensation—right
G43	Cutter offset, inside corner
G44	Cutter offset, outside corner
G45 to G49	Unassigned
G50 to G59	Unassigned and reserved for adaptive control
G60 to G69	Unassigned
G70	Inch programming on N.C. tools which accept dimensions in inches as well as millimetres
G71	Metric programming
G72 to G79	Unassigned
G80	Cancel fixed cycle
G81 to G89	Reserved for fixed cycles such as drilling, counterboring, etc.
G90	Absolute dimension input on a system with provision for both absolute and incremental dimensioning
G91	Incremental dimension input
G92, G93	Unassigned
G94	Feed rate in mm/min (inches/min)
G95	Feed rate in mm/rev (inches/min)
G96	Constant surface speed in m/min
G97	Speed in rev per min
G98, G99	Unassigned

(*iii*) **Dimensional data functions.** The dimensional data is represented by a symbol plus 5—8 digits. The various symbols used are as follows :

X primary *X* dimension
Y primary *Y* dimension
Z primary *Z* dimension
A angular dimension about the *X*-axis
B angular dimension about the *Y*-axis
C angular dimension about the *Z*-axis
U secondary dimension parallel to the *X*-axis
V secondary dimension parallel to the *Y*-axis
W secondary dimension parallel to the *Z*-axis
I interpolation parameter parallel to the *X*-axis
J interpolation parameter parallel to the *Y*-axis
K interpolation parameter parallel to the *Z*-axis

(*iv*) **Feed rate function.** Feed rate is expressed by the letter F plus three digits. The digits may represent the feed rate in mm/min or mm/rev or the magic three code equivalent may be used. If there are no digits to the left of the decimal point then the first digit of magic three code is obtained by substracting from 3 the number of zeros immediately to the right of the decimal point. Table 10.2 shows some values of feed rate and their magic three code equivalent.

Table 10.2

Feed rate (mm/min.)	*Magic three Code equivalent*
0.194	319
0.0259	226
0.0078	178

(*v*) **Tool selection function.** The information regarding tool is give by a word prefixed by the letter T and followed by the numerical code for toc position in the tool turret or tool magazine when automatic tool change (A.T.C.) is used. Each tool pocket on the tool turrent or A.T.C. (automatic too changer) has a distinct tool number. The T-word in the block specifies whicl tool is to be used in operation. The tool number for a particular operation i: specified as T00 to T99.

(*vi*) **Spindle speed function.** The spindle speed is specified either ir revolutions per minute (RPM) or as metres per minute.

If the machine is required to run at 30 mpm the speed will be specified as S30.

(*vii*) **Miscellaneous function.** It is used to specify certain miscellaneous or auxiliary function which does not relate to the dimensional movements of the machine. The miscellaneous functions may be spindle start, spindle stop, coolant ON/OFF etc. These functions are denoted by the letter M plus two digits. Table 10.3 indicates the code of various miscellaneous functions.

Table 10.3

Code	*Function*
M00	Program stop.
M01	Optional stop.
M02	End of program.
M03	Spindle start (clockwise)
M04	Spindle start (anticlockwise)
M05	Spindle stop
M06	Tool change
M07	Coolant on flood cooling
M08	Coolant on (mist cooling)
M09	Coolant off
M10	Clamp (spindle, fixture, slide, etc.)
M11	Unclamp
M12	Unassigned
M13	Spindle start, clockwise direction, coolant on
M14	Spindle start, anticlockwise direction, coolant on
M15	Rapid traverse or feed motion in positive direction
M16	Rapid traverse or feed motion in negative direction
M17, M18	Unassigned
M19	Oriented spindle stop : the spindle stops in a prespecified angular position
M20 to M29	Permanently unassigned
M30	End of tape
M31	Interlock bypass ; temporarily circumvent a normally provided interlock
M32 to M35	Unassigned
M36 to M39	Permanently unassigned
M40 to M45	Gear change
M46, M47	Unassigned
M48	Cancel M49
M49	Bypass override
M50 to M99	Unassigned

(*viii*) **End of block.** The end of block (EOB) symbol identifies the end of instruction block.

10.35.4. Programming Formats

The programming format is the method of writing the words in a block of instruction. The commonly used programming formats are as follows :

(*i*) **Fixed block format.** In this format the instructions are always given in the same sequence. All instructions must be given in every block including those instructions which remain unchanged from the preceding blocks. In these formats data is provided in the program and the identifying address letters are not given but the data must be input in a specified sequence and characters within each word must be of the same length.

(*ii*) **Tab sequential format.** In this format instructions in a block are always given in the same sequence as in case of fixed block format and each word is separated by the TAB character. If the word remains same in the succeeding block, the word need not be repeated but TAB code is required to maintain the sequence of words. Since the words are written in a set order, the address letters are not required.

(*iii*) **Word address format.** In this format each data is preceeded and identified by its address letter. For example, Y identifies the Y-coordinate, F identifies the feed rate and so on. If a word remains unchanged, it need not be repeated in the next block. A typical instruction block in word address format will be as follows :

NO10 X0000 Y0000 F300 S0600 T010.00 M13 EOB

N	Sequence number
G	Preparatory function
X	*X*-coordinate
Y	*Y*-coordinate
F	Feed rate
S	Spindle speed
T	Tool address
M	Miscellaneous function
EOB	End of block.

Example 10.5. (*a*) *Write N.C. program for making the component shown in Fig. 10.26 (a).*

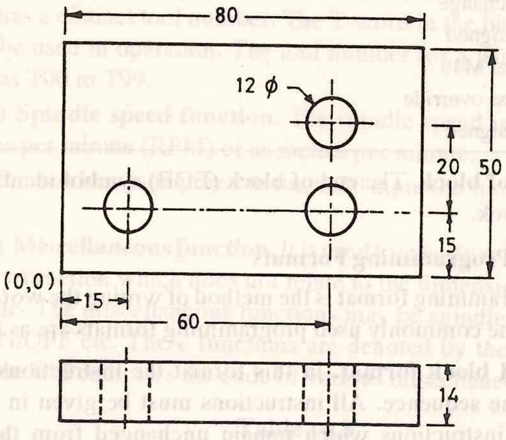


Fig. 10.26 (*a*)

Solution.

N010	G71	G90	G94	Metric Mode Absolute system Feed in mm/min
N020	M03	F200	S1200	Spindle start at 1200 RPM feed rate 200 mm/min
N030	G00	X15.00	Y15.00	Move in rapid to point (15, 15)
N040	G00	Z3.00		Move in rapid to a point 3 mm above the work-piece
N050	G01	Z-14.00		Drill hole
N060	G00	Z 3.00		Move in rapid to point 3 mm above workpiece

N070	G00	X 60.00		Move in rapid to X = 60
N080	G01	Z-14.00		Drill hole
N090	G00	Z 3.00		
N100	G00	Y 35.00		Move to Y = 30
N110	G01	Z-14.00		—
N120	G00	Z 20.00		Move in rapid to a point 20 mm above workpiece
N130	G00	X.00	Y.00	(Move in rapid to X0, Y0)

10.36. CAM

Computer Aided Manufacturing (CAM) is gaining wide acceptance in engineering industries for their ability to create major increase in the productivity. In CAM computers are used to aid the manufacturing processes. Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) were originally developed independently but are now a days being integrated into a single system called CAD/CAM system. In CAD/CAM design can be developed and the manufacturing process can be monitored and controlled from start to finish with single system.

CAM can be defined as the use of computer systems to plan, manage and control of operations of a manufacturing plant through either direct or indirect computer interface with the plant's production resources. Computers also help all functions of management such as process planning, coordination, control of production, inventory, control etc. CNC, DNC and flexible manufacturing systems have number of advantages over traditional methods of manufacturing.

10.37. Transfer Machines

In transfer machines the processing equipment is arranged in order of the sequence of manufacturing operations. Production lines may be non-automatic and semi-automatic and automatic. In automatic transfer machines the operator loads the blanks and usually checks the workpiece.

These machines are provided with some automatic mechanism for moving workpieces from station to station to carry out the various operations. Transferring usually is carried out by the following methods :

(*i*) Rotary transfer system

(*ii*) In-line transfer system.

In rotary transfer system the workpieces are held in fixtures in a continuously rotating table. The rotating table brings the workpieces under different machine (Fig. 10.27). This method is quite compact and permits the workpiece to be loaded and unloaded at a single location without having to interrupt the machining. In the in-line method the workpiece is held in a special pallet or fixture. The fixtures are located and clamped in proper position.

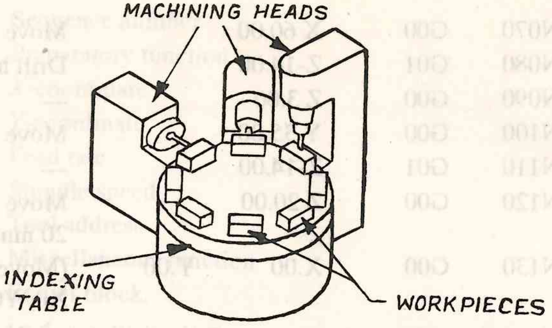


Fig. 10.27

The empty pallets are returned to the starting station by a return conveyor arranged parallel to the main transfer line (Fig. 10.28).

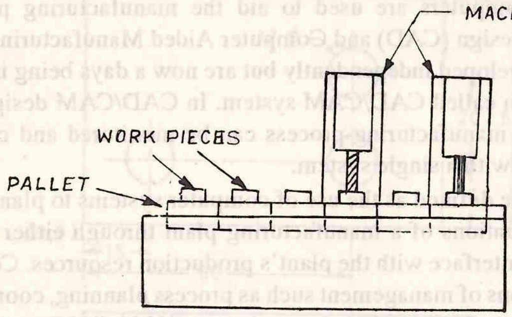


Fig. 10.28

Rotary transfer machines can usually accommodate only six or fewer stations because of restriction on space whereas the size of an in-line machine can be almost unlimited. Sometimes an endless chain that moves intermittently as required is used to transfer workpieces from one station to other station.

The choice of workpieces transferring system depends upon the following factors :

(*i*) Weight of workpiece.
(*ii*) Shape of workpiece.
(*iii*) Nature of manufacturing process.
(*iv*) Machine toolay-out.

The most efficient transfer machine layout depends upon the following factors :

(*a*) Type of part to be machined.
(*b*) Manufacturing process.

10.38. Advantages and Disadvantages

The various advantages of transfer machines are as follows :

(*i*) Higher production rates are achieved.

(*ii*) Less floor space is required.
(*iii*) Less number of operations are required.
(*iv*) The quality of products is considerably improved.
(*v*) The length of production cycle is reduced.

Disadvantages

(*i*) The initial cost of transfer machine is high. It is of great importance that the construction of components to be machined on transfer machine should remain stable for sufficient time to justify the cost of such machine.

(*ii*) Much time is required to change over the machine to handle a different shaped components.

(*iii*) A breakdown of one machine means stoppage of whole of production line.

10.39. Economic Comparison of Various Manufacturing Systems

As shown in Fig. 10.29 the manufacturing cost per component (*C*) depends largely on batch size (*N*). It is observed that manual system is economical for smaller batch size and numerical control is economical both for small and medium batch production.

Automatic system is preferred for medium and large size batch production. The transfer machines are preferred for large size batch components.

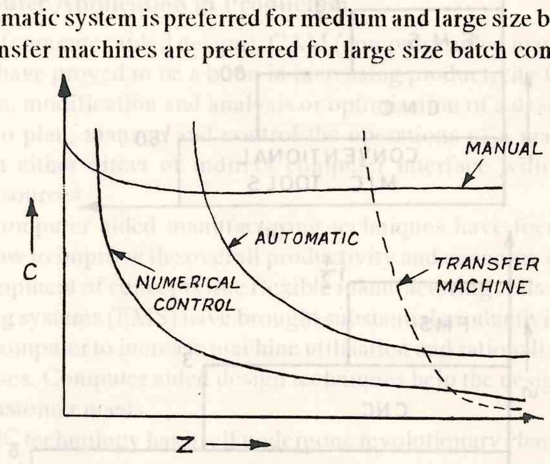


Fig. 10.29

10.39.1. Time Comparison of conventional, CNC and FMS machining methods

Cutting time in CNC ranges from 60 to 75%. In the conventional general purpose machine the cutting time is about 25% of total machining time.

As the CNC machines are very costly, the down time of these machines should be reduced to minimum. In conventional machines the skilled operator is responsible for many inputs to the machine. With increase incomplexity of the component the time to produce the component also increases.

In CNC machines there is reduction in production time and human error and there is greater manufacturing flexibility.

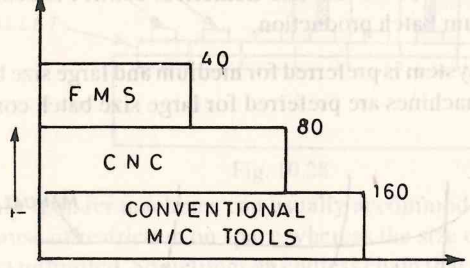
There is reduced lead time. Lead times is the time between the receipt of a design drawing by the production engineer and manufacturer being ready to start production on shop floor, including the time needed for planning, design and manufacture of jigs etc.

FMS (Flexible Manufacturing System) enables increased productivity and lower manning levels. There is flexibility to redesign products to meet changes as per marker requirements without making further investment. There is overall reduction in manufacturing cost. Reduced inventory and lead times are other features of F.M.S.

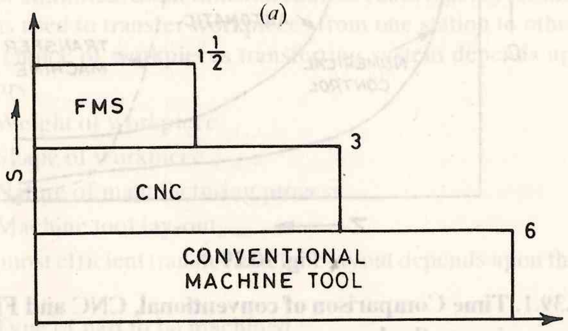
Fig. 10.29 (*a*) shows machining time comparism for FMS, CNC and conventional machine tools whereas Lead time for these manufacturing methods are compared in Fig. 10.29 (*b*).

T = Machining Time (Hours)

S = Lead Time (months)



(*a*)



(*b*)

Fig. 10.29

10.40. Production Capacity of Automatic Machine Tools

Piece output indicates the main index of production capacity of automatic and semi-automatic machine tools.

$$P = \text{Piece output}$$

$$= \frac{3600}{T} \text{ pieces per hour}$$

where T = Calculated time in seconds for machining the workpiece

$$= T_S + \frac{T_C}{N}$$

where T_S = Standard time (time per piece) in seconds.

T_C = Set up time in seconds. It is the time for setting up the machine and for demounting the tools after machining one lot

N = Number of workpieces in one lot.

The value of standard time (T_s) is found as follows :

$$T_S = T_1 + T_2 + T_3 + T_4 + T_5 \text{ seconds.}$$

where T_1 = Machining time in seconds

T_2 = Handling time for moving slides etc., in seconds

T_3 = Servicing time for setting, adjustments, tool changing chip removal etc. for single workpiece in seconds.

T_4 = Fatigue time (seconds) for rest and personal needs of operator

T_5 = Time (seconds) for breakdown, delays etc.

10.41. Computer Application in Production

CAD (computer aided design), CAM (computer aided manufacturing) and robotics have proved to be a boon in increasing productivity CAD assists in the creation, modification and analysis or optimisation of a design whereas CAM helps to plan, manage and control the operations of a manufacturing plant through either direct or indirect computer interface with the plant's production resources.

The computer aided manufacturing techniques have focused on the problem of how to improve the overall productivity and economy of manufacturing. Development of concepts like flexible manufacturing cells and flexible manufacturing systems (FMS) have brought substantial productivity increases by using the computer to increase machine utilisation and rationalise manufacturing processes. Computer aided design techniques help the designer to react speedily to customer needs.

The NC technology has itself undergone revolutionary changes leading to CNC technology.

Overall product cost and quality are governed by the efficiency at every stage, from design to dispatch. Realising this, engineers have tried to improve performance and reliability at every stage of manufacture of a product and here is where application of the computer has led to a revolution in manufacturing technology. Computer based manufacturing methods have helped the manufacturing plants to respond to changing market needs faster and also to diversify the range and variety of products.

10.42. N.C. System for Simple Turning

Fig. 10.30 shows a schematic diagram of a Numerical Control (N.C.) system for simple turning operation on a lathe. The information regarding the movement of cutting tool during turning is coded on a program medium like paper tape in the form of holes. The punched tape is passed through a program reader which indentifies the presence or absence of a hole and sends the corresponding information to the decoder. The decoder generates a pulse every time a hole is sensed. The electrical pulses (signals) so generated are amplified by the amplifier and fed to a stepping motor which makes the lead screw to rotate and then translatory displacement of tool is achieved by means of a screw and nut mechanism.

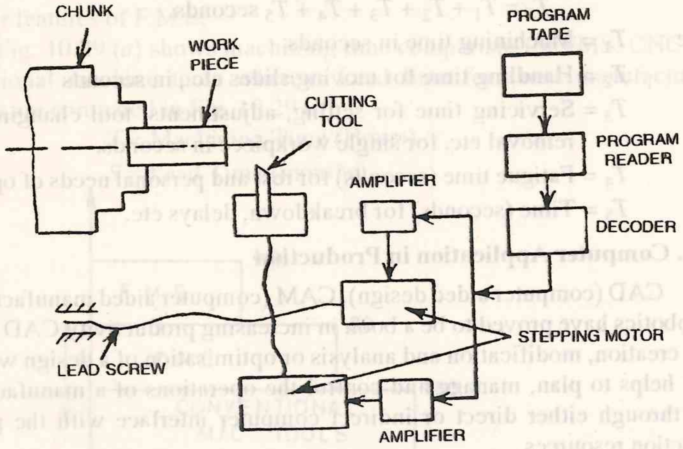


Fig 10.30

Example 10.6. *Explain the following terms as used in numerical control.*

(i) Absolute system.

(ii) Incremental system of dimensioning.

Solution. In N.C. the dimensions of a drawing are measured according to these systems.

In absolute system to the co-ordinates are mentioned in the program with respect to one reference point (Datum).

In incremental system the co-ordinates of a point are mentioned in the program with respect to the previous point.

Fig. 10.31 indicates the typical position of points, *A*, *B* and *C* and their co-ordinate are indicated in Table 10.4.

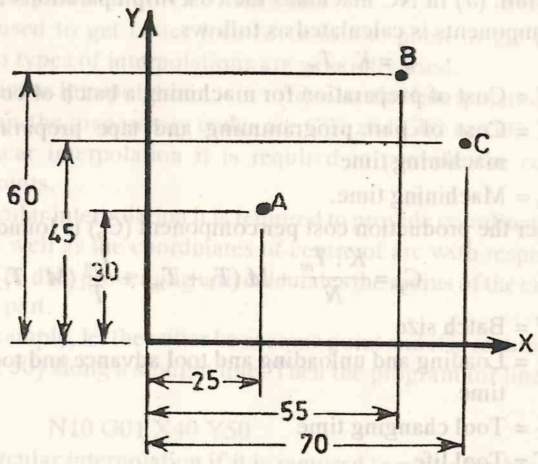


Fig. 10.31

Table 10.4

Point	*X-co-ordinate*	*Y-co-ordinate*
	Absolute System	
A	25	30
B	55	60
C	70	45
	Incremental System	
A	25	30
B	30	30
C	15	− 15

Example 10.7. *(a) Discuss the economically controlled machines.*

(b) The initial cost of an N.C. turret lathe is Rs. 62500 with a pay back period of 3 years. Determine the production cost per component using the following data :

Operator's wages = Rs. 5 per hour

Tool (fitted with disposable carbide type) cost = Rs. 2 per cutting edge.

Setting time = 70 seconds.

Cost of tape preparation and programming per unit of machining time = Rs. 0.30/sec.

*Total cycle time is 2*80 *second out of which 50% is spent an actual chip removal.*

100% overhead are applied to the machine and operator. The lathe is run for 2000 hours per year. The batch size is 30.

Solution. (*a*) In NC machines the cost of preparations for machining a batch of components is calculated as follows.

$$C = K \,.\, T_m$$

where C = Cost of preparation for machining a batch of components

K = Cost of part programming and tape preparation per unit machining time

T_m = Machining time.

Further the production cost per component (C_p) is found as follows :

$$C_p = \frac{K \,.\, T_m}{N} + M\,(T_1 + T_m) + \frac{T_m}{T}\,(M \,.\, T_C + C_t)$$

where N = Batch size

T_1 = Loading and unloading and tool advance and tool withdrawal time

T_C = Tool changing time

T = Tool life

C_t = Cost of a sharp tool

M = Total machine and operator rate.

(*b*) Since 100% overheads are applied to the machine and operator therefore the value of M will be as follows :

$$M = \frac{2 \times 625000}{3 \times 2000 \times 3600} + \frac{2 \times 5}{3600}$$

$$= \text{Re. } 0.06 \text{ per second}$$

Now $T_m = \frac{280}{2} = 140$ seconds

N = Batch size = 30

K = Cost of programming and tape preparation per unit machining time

= Re. 0.30 per second.

T_1 = Loading and unloading, tool advance and withdrawal time

= 140 seconds (assume)

T = Tool life = 280 seconds (assumed)

T_c = Tool changing time

= 70 seconds

C_t = cost of a sharp tool = Rs. 2

C_p = Production cost per component

$$= \frac{K \,.\, T_m}{N} + M\,(T_1 + T_m) + \frac{T_m}{T}\,(M \,.\, T_C + C_t)$$

$$= \frac{0.3 \times 140}{30} + 0.06\,(140 + 140) + \frac{140}{280}\,(0.06 \times 70 + 2)$$

$$= 1.4 + 16.80 + 1.21 = \text{Rs. } 19.41.$$

10.42. (*a*) **Interpolation in N.C. Machines**

It is used to get cutter located from one point to the next. In N.C. machines two types of interpolations are generally used.

(*i*) Linear Interpolation (*ii*) Circular Interpolation.

For this the preparatory codes are G01 and G02 or G03.

In linear interpolation it is required to provide the coordinates of destination points.

In circular interpolation it is required to provide coordinates of destination points as well as the coordinates of centre of arc with respect to starting point of arc. The data processing unit calculates the radius of the circle of which arc forms the part.

For example, let the cutter be at some point and it is required to proceed to a point (40, 50) along a straight line. Then the program for linear interpolation will be

N10 G01 X40 Y50

For circular interpolation if it is required to move further along an arc of a circle whose centre is (0, 0) to a point (60, 0) then the program will be

N11 G02 X60 YOI – 40J – 50

where I, J correspond to the coordinates of the centre with respect to starting point (40, 50).

10.42. (*b*) **Code Numbers for Feed and Speed**

In N.C. machines the important code numbers for feed (mm/Rev.) and speeds (R.P.M.) according to DIN 260250 VDI 3252 are indicated in Table 10.5 (*a*) and Table 10.5 (*b*).

Table 10.5 (*a*)

Code No.	*Feed (mm/Rev.)*	*Code No.*	*Feed (mm/Rev.)*
00	0 (Rest)	17	0.71
01	0.112	18	0.8
02	0.125	19	0.9
03	0.14	20	1.0
04	0.16	21	1.12
05	0.18	22	1.25
06	0.2	:	:
07	0.224	28	2.5
08	0.25		:
09	0.28	50	31.5
10	0.315	51	35.5
11	0.355	52	40
12	0.4	53	45
13	0.45		
14	0.5		
15	0.56		
16	0.63		