Adjustable cushioning in hydraulic cylinders: In case of cylinders with adjustable cushioning, the oil passage at the cushioned end is throttled by way of a needle valve so that the extent of restriction of passage size can be adjusted. The needle valve is a precision component and fits into the passage of the port hole and only the adjusting knob is seen on the cylinder cover.

4.3 HYDRAULIC MOTORS

The principle of a hydraulic motor, stated in a simple manner, is that it is a reverse of a hydraulic pump. A hydraulic pump, driven by a prime mover, pumps out hydraulic oil. The pumping action is performed by a rotating element in the pump. It is the reverse of the pump action that takes place in the hydraulic motor. Hydraulic oil is supplied to the motor through its inlet port and this hydraulic oil under pressure imparts a rotary motion to the internal element of the motor. This internal element is connected to the shaft, from which the rotary motion is transmitted to any other driven member.

The concept is similar to that of turbines where a jet of fluid moves the blades of the turbine and the blades forming an integral part of a shaft get the rotary movement.

4.3.1 Principle of Working of Hydraulic Motors

Figure 4.16 shows a pump driven by an electric motor. From the hydraulic pump, one line goes to the directional and other control valves. One branch line goes to a pressure relief valve and then back to the reservoir.

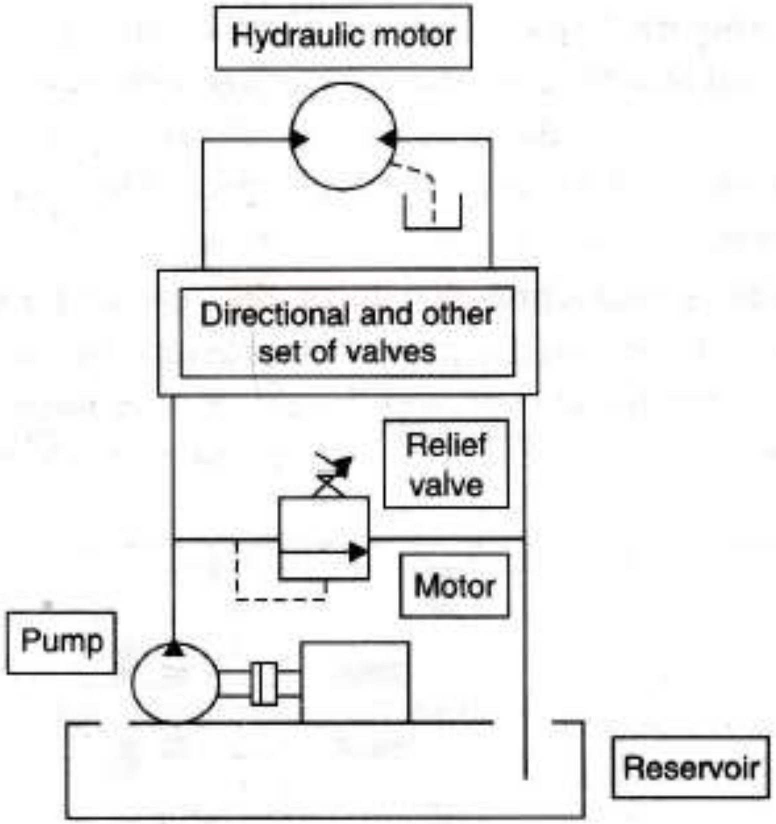


Figure 4.16 Working of hydraulic motors.

There is a line connection from the bank of valves to the hydraulic motor. The hydraulic motor has two dark triangles inscribed on it with their bases touching the circles and their apexes pointing to the centre. This shows that the hydraulic motor is bi-directional.

The hydraulic oil from the pump line through the valves impinges on the cam surfaces/pistons of the hydraulic motor and makes the rotating element of the motor to rotate. The rotating element fixed on to the drive shaft also rotates. The oil then returns to the reservoir through the valves.

4.3.2 Types of Hydraulic Motors

The hydraulic motors are available in different types. Based on the application requirement we have to choose one or more of them. The types of hydraulic motors are given in Figure 4.17.

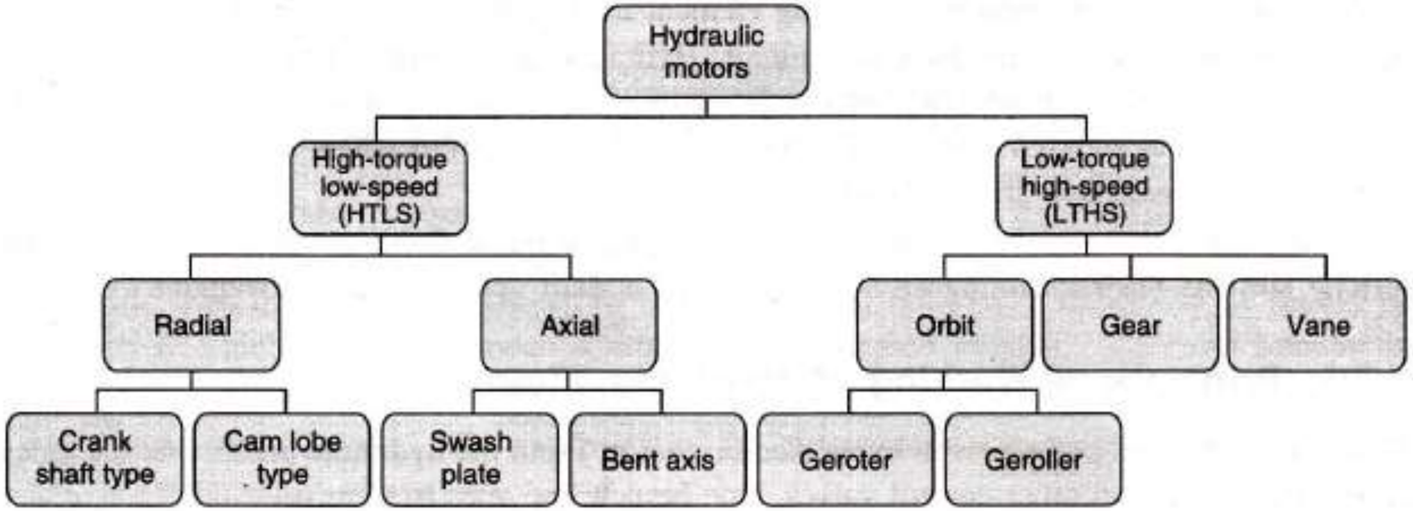


Figure 4.17 Types of hydraulic motors.

The first thing in selecting the hydraulic motors is the choice between HTLS motor and LTHS motor. Table 4.1 gives the application details for the selection of HTLS and LTHS motors.

Table 4.1 Application details for the selection of HTLS and LTHS motors

Type of motor	*Applications*
LTHS (Low-torque high-speed)	High speed, but steady loads Example: Fan, drives of special purpose machines etc.
HTLS (High-torque low-speed)	Moving heavy loads at fairly constant lower speeds Example: Crane, winches etc.

Table 4.1 gives only the broad guidelines for choosing the right type of hydraulic motor for the given application. However, the actual process of selection involves consideration of all the parameters of applications to pinpoint the right type of a hydraulic motor.

The parameters that we should know before going for the selection of the any particular type of hydraulic motor can be listed as:

(i) Torque output required

(ii) Speed range required

(iii) Work cycle, i.e. how long, at what speed and torque range, the motor is to operate

(iv) Working atmosphere, i.e. heat, dust level, vibration, etc.

Once the above-mentioned factors have been taken care of, the final selection of the type of motor depends on:

(a) Displacement (cm^3/revolution)

(b) Working pressure

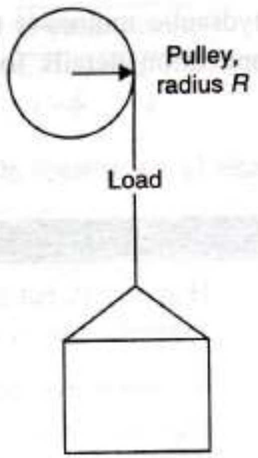
A manufacturer's catalogue, when consulted, would give the motor sizes in terms of their displacement/pressure/torque etc.

4.3.3 Further Selection Criteria for Hydraulic Motors

The *displacement* of hydraulic motor is a main criterion for the selection of motors. It gives the details on the amount of fluid required to turn the motor output shaft by one revolution. The quantity displacement is expressed in terms of cubic centimetres per revolution (cm^3/revolution).

Torque is the force component of the motor output. It is defined as the turning or twisting effort. The torque at the motor shaft is equal to the load multiplied by the radius. For example, the torque requirement of raising a load with the pulley is illustrated in Figure 4.18.

While selecting the size of the hydraulic motor, it will be useful to plot the torque vs speed characteristics. We can identify the higher torques needed in one particular cycle and accordingly base our selection of motor to meet that higher requirement of torque.



$$T = F \times R$$

where T = torque in kg·m, F is load in kg, and R is radius in m

Figure 4.18 Torque development in pulley.

In addition to the above we must also consider the following for the selection of hydraulic motors:

(i) Continuous working cycle or intermittent use or occasional use of the motor.

(ii) The sequence of pressure and speeds at which the motor will operate.

(iii) The length of time of each phase of the sequence.

(iv) The frequency of cycles during the work period.

(v) Working atmosphere—dusty/dirty or chemically-aggressive or standard conditions.

Armed with all the above data, we can select the motor size from any of the standard hydraulic motor manufacturer's catalogue.

We shall now see some popular types of motors in use.

4.3.4 Gear Motors

Gear motors fall into the category of high-speed low-torque motors (HTLS). There are two types of hydraulic gear motors. They are:

1. External gear motors
2. Internal gear motors

It is quite possible that some students may get confused about these types. In the external gear type, the gears are external to each other and mesh to produce the movement. In the internal gear arrangement, there is one meshing gear inside the other one.

External gear motors: As mentioned and as per Figure 4.19 the two gears mesh, and both these gears are enveloped in a casing. The gears and the housing are made and machined with very fine tolerances such that no leakage of hydraulic fluid is possible.

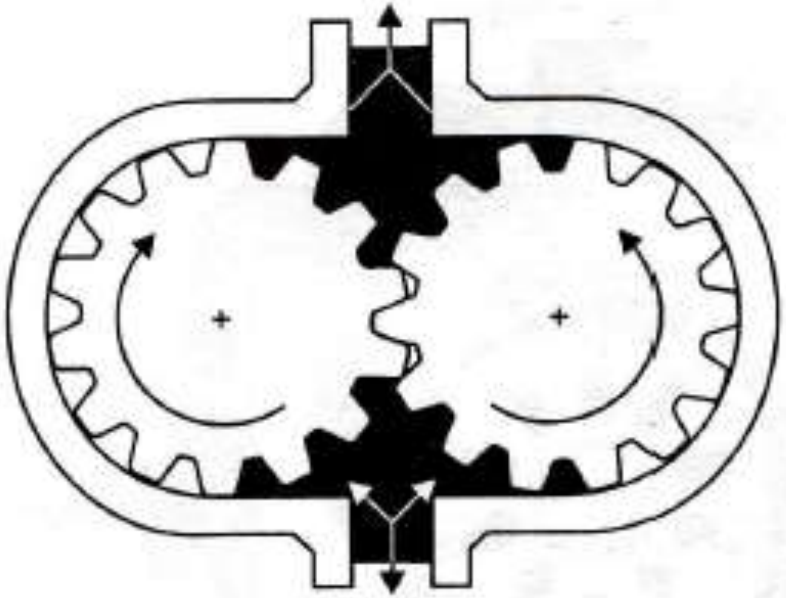


Figure 4.19 External gear motor.

Hydraulic fluid under pressure enters as shown and pushes or forces the idler gear to rotate. The meshing and rotation of this gear makes the other one to rotate and this driven gear is connected to the output shaft.

Note that the path of the fluid is through the periphery of the gears and not through the meshing portion of the gears.

Internal gear motors: In internal gear motors, the meshing of gears takes place with the bigger gear housing the smaller gear inside its hollow space available. The gears are specially designed in such a way that the outer teeth surface of the inner gear is meshing with the inner surface of the outer gear (Figure 4.20).

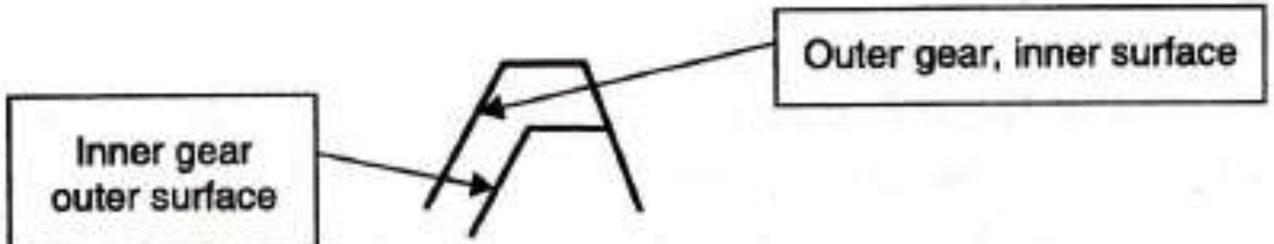


Figure 4.20 Internal gear motor—meshing of teeth.

Only one set of teeth is shown in Figure 4.20. The inner gear will have one tooth less than the outer gear and is mounted a little eccentric to the outer gear. The oil gets entrapped between the spaces of the teeth and pushes the teeth and the gear begins to rotate. The driven shaft is connected to the inner gear and the hydraulic drive is thus obtained.

4.3.5 Vane Motors

As mentioned earlier the hydraulic motors are almost the reverse of an equivalent pump.

In the vane pump, we have seen that a central housing accommodates vanes that trap the liquid to transport it from the inlet to the outlet. In vane motors, the pressurized liquid impinges on the surface of the vanes and make the vanes move. These vanes slide in and out of the central housing. The vanes in turn rotate the housing itself. The driven shaft is connected to the housing and we get a rotary motion and torque on the shaft. These motors fall into the high-speed low-torque category (Figure 4.21).

See Figures 3.10 and 3.11 for clarity—only visualize here that the pressurized fluid is supplied at the input end and this fluid acts on the surface of the vanes.

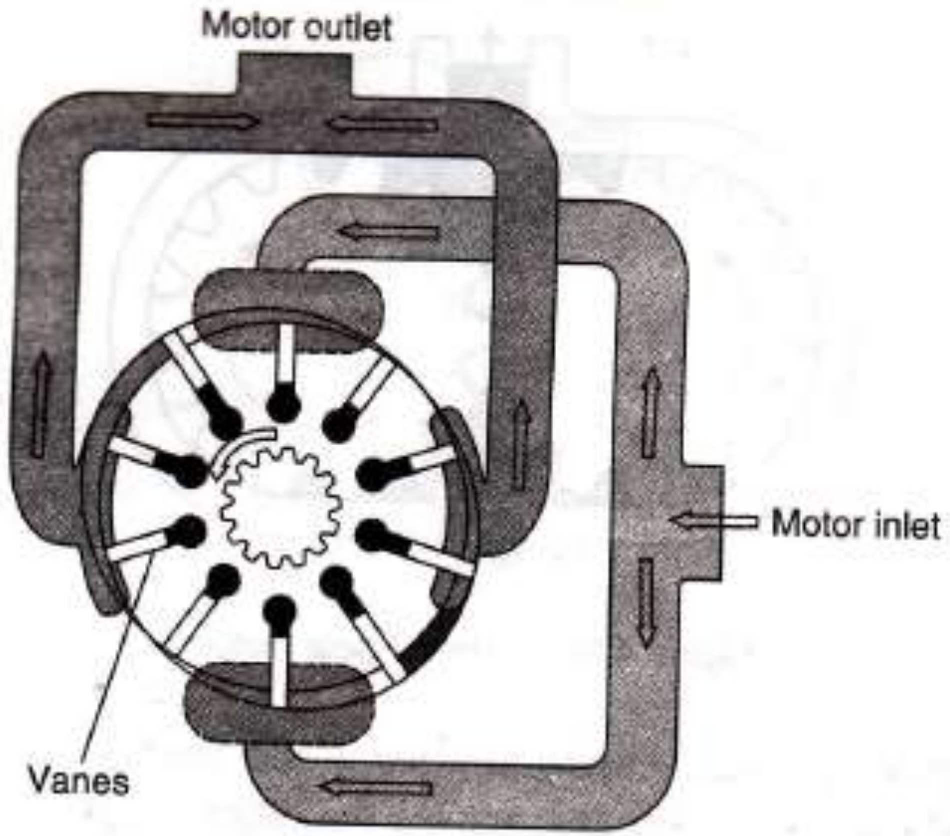


Figure 4.21 Vane motor.

4.3.6 Piston Motors

The piston motors are available in high-torque and low-speed category. These are available in three configurations.

1. Axial or in-line piston motors
2. Radial piston motors
3. Bent axis motors

We have discussed in the previous chapter all the above types of pumps. The figures therein almost hold good for the respective types of motors. Here, the reverse of the pump process takes place, i.e. the pressurized fluid acts on the piston surfaces to impart and translate the torque to motion.

Piston motors have better efficiency compared to the other types of motors and are also opted for their ability to meet higher-torque applications (Figure 4.22).

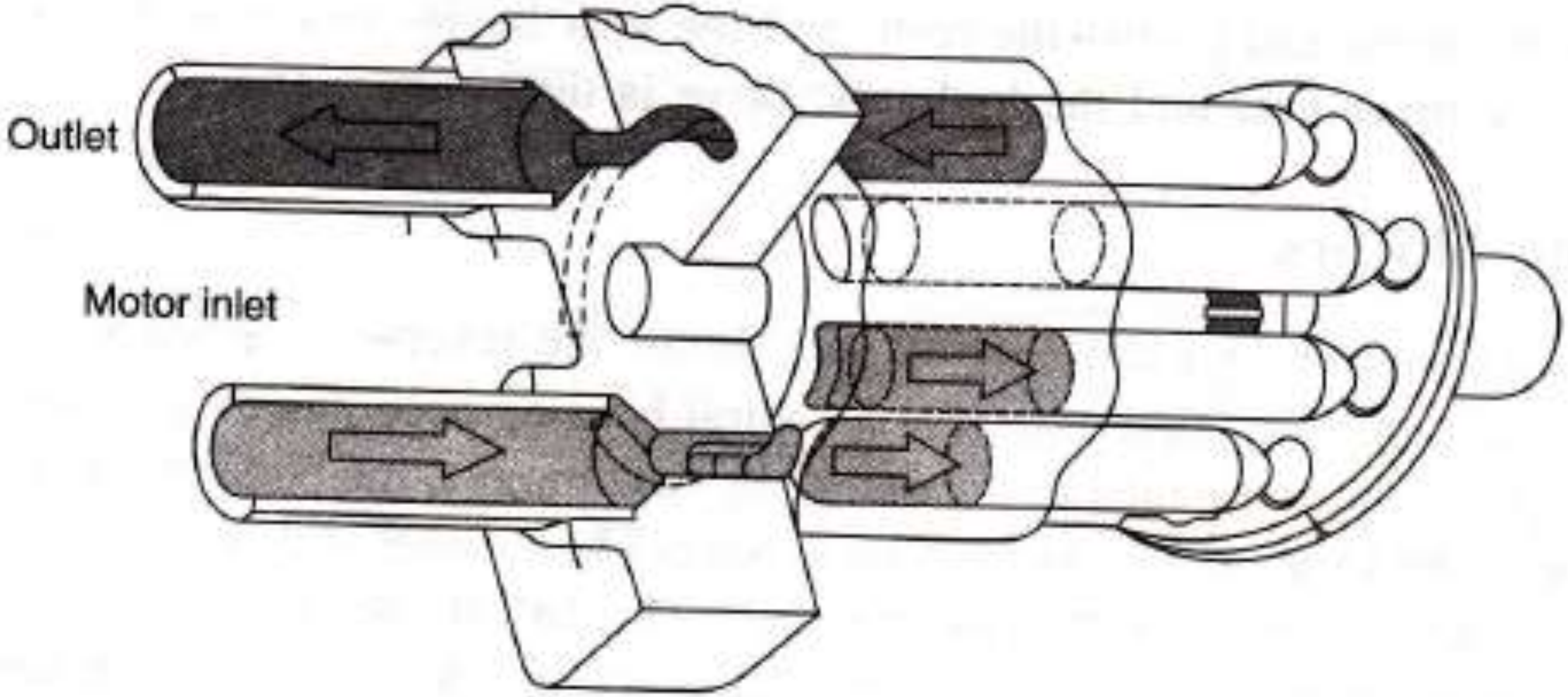


Figure 4.22 Piston-type motor.

4.3.7 Useful Formulae

The following formulae are useful in the selection of hydraulic motors:

(a) Torque in kg·m = Displacement × Pressure

$$= \frac{(\text{cm}^3/\text{rev}) \times (\text{bar})}{628} \acute{\eta}_m$$

(b) Speed of hydraulic motor in rpm $= \dfrac{\text{Flow (l/min)} \times 100}{\text{Displacement (rev)}} \acute{\eta}_v$

where, $\acute{\eta}_m$ is volumetric efficiency of the hydraulic motor, and $\acute{\eta}_v$ is the mechanical efficiency of the hydraulic motor.

4.3.8 Hydraulic Motors in Circuits

We have seen hydraulic circuits, building up from element to element. These circuits incorporate hydraulic cylinders as the actuating elements. We shall now see how to use a hydraulic motor in a hydraulic circuit (Figure 4.23).

(i) In the hydraulic circuit, if you need the hydraulic motor with a free shaft rotation, then we must use a direction control valve with a spool that has all its ports connections in the neutral position.

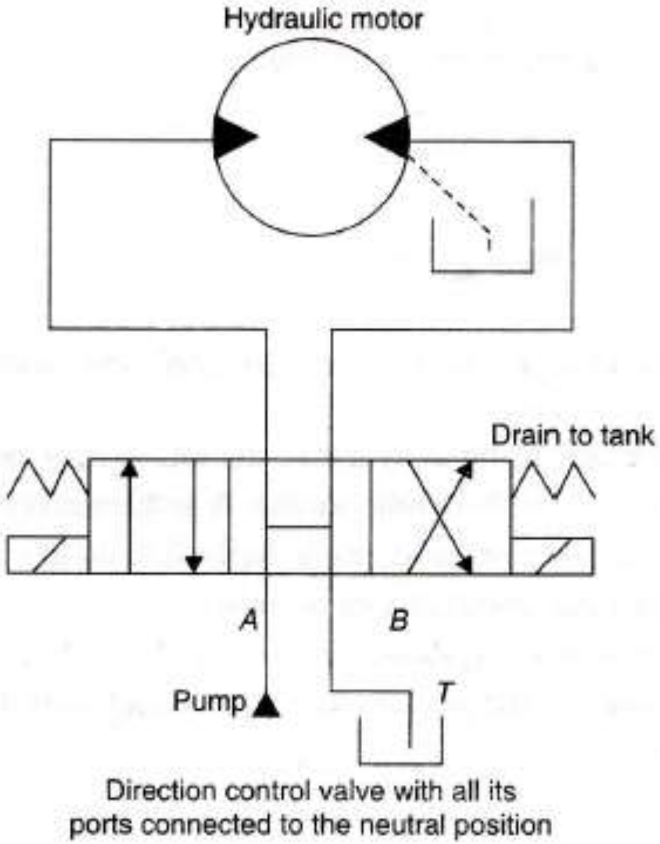


Figure 4.23 Hydraulic motor circuit connection.

(ii) In case the hydraulic motor is to be used to lower a load (e.g. winch operation), the load may act in the same direction as that of the hydraulic motor rotation and this can result in the shaft tending to run with the load. This could mean a reduction in pressure at the motor inlet port, and overrunning of the hydraulic motor.

To take care of such eventualities, we must incorporate an over-centre valve in the circuit as shown Figure 4.24. As the shaft tends to overrun, there is no free passage available for the oil to flow into the tank and hence, the oil in the outlet line builds up pressure and the passage is opened by the pilot pressure line from the input side of the motor. The building up of pressure will control the descent of the load.

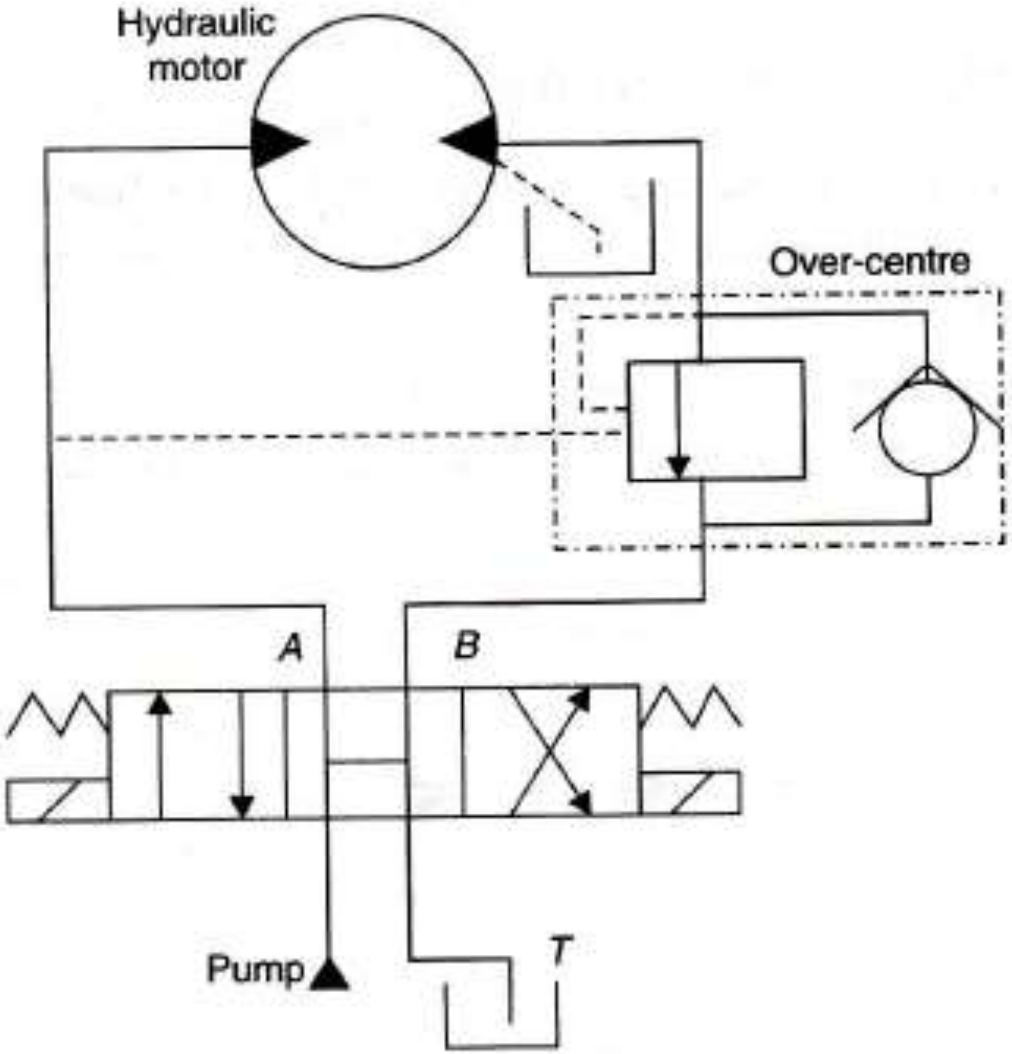


Figure 4.24 Hydraulic motor with over-centre valve.

(iii) At times, when we are using a hydraulic motor, it may be necessary to change the direction of rotation of the hydraulic motor. A sudden reversal of direction will create back pressure on the inlet or outlet ports depending on the initial direction of rotation of the motor. This back pressure can be relieved by providing a cross-port relief on either side of the motor as shown in Figure 4.25. The excess pressure (to back pressure) is relieved by the cross-port relief, which acts in a manner identical to a system relief valve.

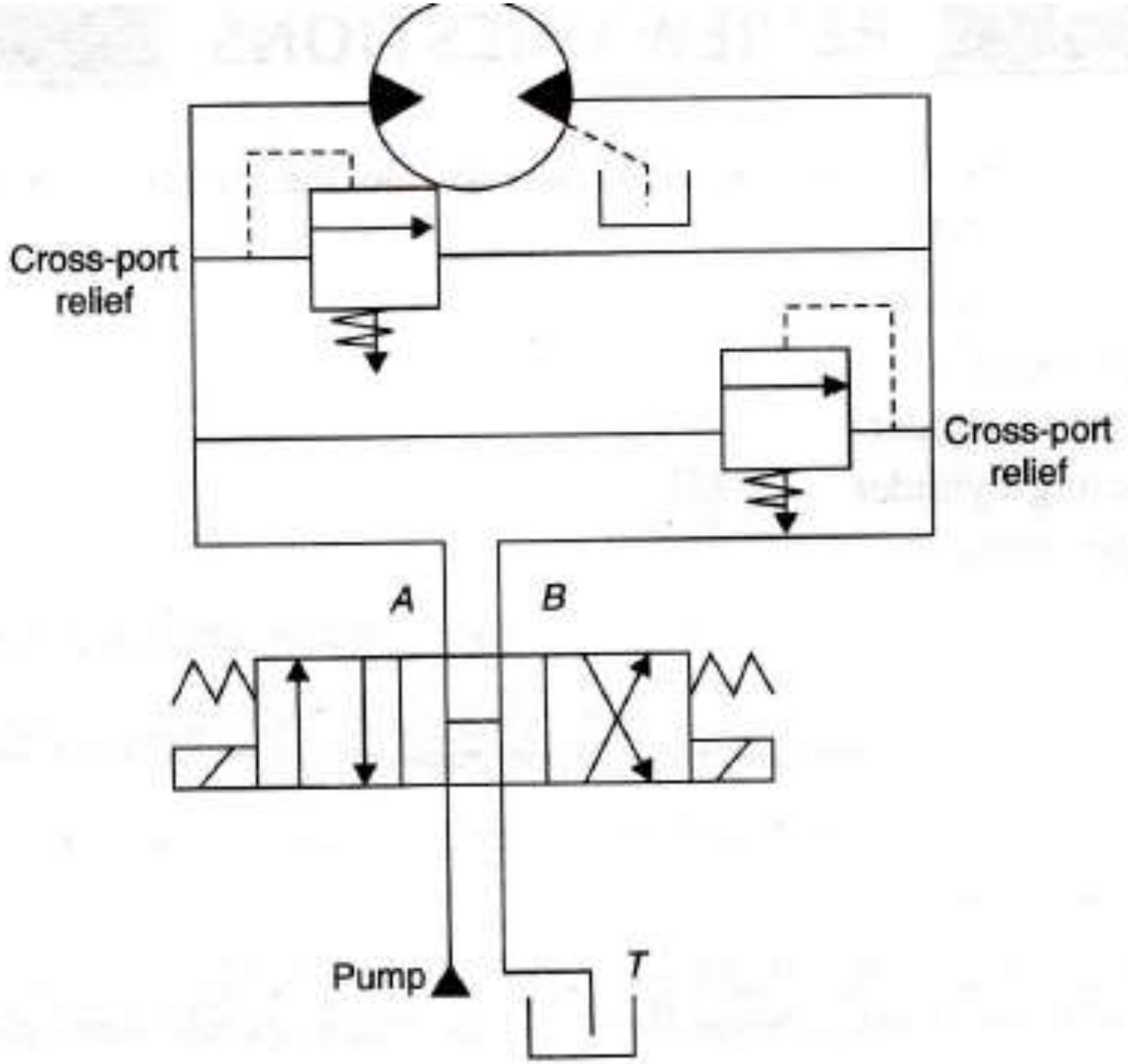


Figure 4.25 Hydraulic motor with cross-port relief.

4.3.9 Comparison of Hydraulic Motor with Electric Motor Drives

Hydraulic motor drives have the following advantages when compared to electric motor drives:

(i) Rapid reversal of direction of rotation is easier.

(ii) Speed variation is very simple in the case of a hydraulic motor, as we just have to add a flow control valve.

(iii) Overload can stall a hydraulic motor, but trips and stops an electric motor.

(iv) Power density, i.e. the power-to-weight ratio is better in the case of a hydraulic motor compared to an electric motor.

(v) Hydraulic motors can be used in environments that are more hostile. Electric motors, because of the windings and sparking possibilities, can only be used where the environment does not pose any danger to the safety of such equipment.

Hydraulic motors, however, pose the following disadvantages:

(i) A hydraulic motor requires a hydraulic power unit. This means we must have a hydraulic pump to be driven by a prime mover so that the pumped oil can be used to drive the hydraulic motor. Therefore, the cost factor is to be considered.

(ii) Hydraulic motor speed is normally further reduced by using a reduction gear box. Usage of reduction gear also involves higher torque at the output shaft. Therefore, the cost of reduction gear is also to be considered.

REVIEW QUESTIONS

1. What are the different types of actuators? Name the category in which each of the following actuators fall:
   (a) Single-acting cylinder
   (b) Vane type motor
   (c) Spring return cylinder
   (d) Double-acting cylinder
   (e) Piston type motor.
2. Mention two applications where single-acting cylinders are used? Can we use double-acting cylinders for single-acting applications? If so, how?

   (*Hint for second part:* Yes. Plug the second port).
3. How does a welded type of cylinder differ from the tie-rod type? Mention the major parts of a tie-rod type cylinder.

4*. What are the technical specifications of a hydraulic cylinder? Can plastic be used to manufacture cylinder covers? Name the materials that are commonly used to manufacture:
   (a) Cylinder covers
   (b) Pistons
   (c) Piston rods
   (d) Tie rods.

5*. Mention the different types of mountings used in fixing the hydraulic cylinders. (Students are advised to have a look at some machines where hydraulic cylinders are used and correlate them with the types they have studied.)

6*. What are the different types of hydraulic motors in use? What is the speed range of the motors commonly available in the industry?

7. What factors will you consider in selecting a hydraulic motor? Mention two applications of usage of hydraulic motor with their types.

8*. The speed of a hydraulic motor is 1200 rpm. This has to be brought down to 70 rpm. How can this be achieved in the field?

9. List the advantages/disadvantages of using hydraulic motors in comparison with electric motors.

10. Draw a simple circuit in which a hydraulic motor is connected. What is the function of the over-centre valve and the other valves used when the direction of speed of the motor is to be reversed?

11. List the applications in which low-torque high-speed motors and high-torque low-speed motors can be used.

12. Why is cushioning needed in a hydraulic cylinder? What is the meaning of fixed and adjustable cushioning?

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*Questions requiring industry interaction.

End of Chapter Four