Fluid Power Actuators

4.1 HYDRAULIC ACTUATORS

In any hydraulic circuit, the required mechanical motion is obtained from actuators that form the last and important limb in the circuit. The required motion may be either linear or rotary. Based on the type of motion, the actuators can be classified as shown in Figure 4.1. The actuators used to get the linear motion are called the *hydraulic cylinders*. The actuators used to get the rotary motion are known as *hydraulic motors*.

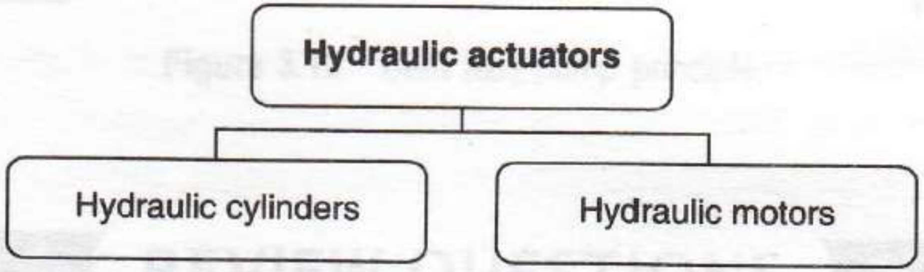

Figure 4.1 Classification of hydraulic actuators.

In the first part of this chapter, we will take up hydraulic cylinders and study their working principles and concepts, and in the second part, we will go through the details on hydraulic motors.

4.2 HYDRAULIC CYLINDERS

4.2.1 Types of Hydraulic Cylinders

Hydraulic cylinders are classified based on construction as well as on application as in Figure 4.2.

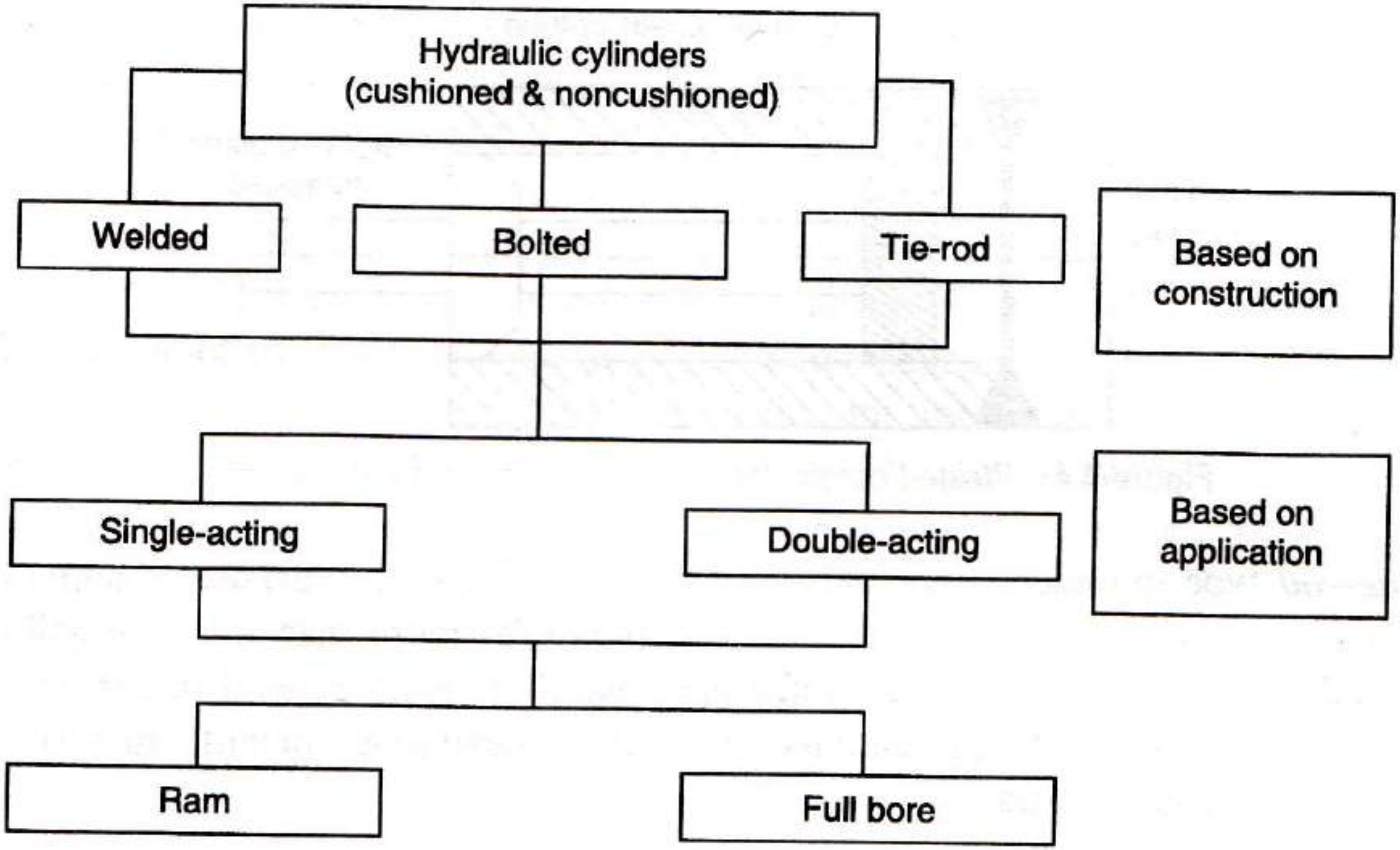

Figure 4.2 Classification of hydraulic cylinders.

4.2.2 Construction of Hydraulic Cylinders

Hydraulic cylinders are assembled/constructed in different ways. Depending on the application and pressure, one or other type of cylinders can be selected. Based on how the cylinder components are assembled/constructed, hydraulic actuators can be of:

(i) Bolted design (Figure 4.3)
(ii) Welded design (Figure 4.4)
(iii) Tie-rod design (Figure 4.5)

In a *bolted construction*, the cap end is bolted to the cover of the cylinder. The other end can also be bolted to the cover.

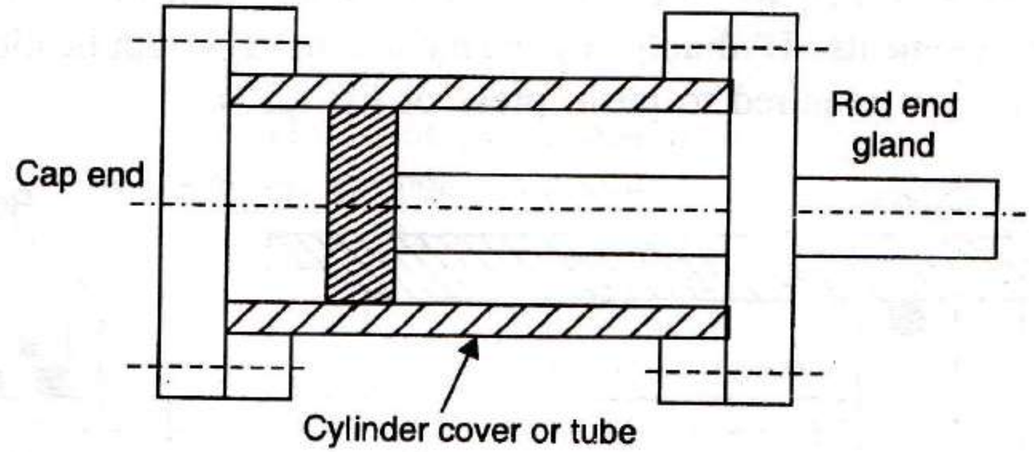

Figure 4.3 Bolted constructions on both the ends.

A *welded cylinder* is one where the cap of the cylinder is welded on to the tube of the cylinder and the other end is normally threaded onto the tube or the cover of the hydraulic cylinder.

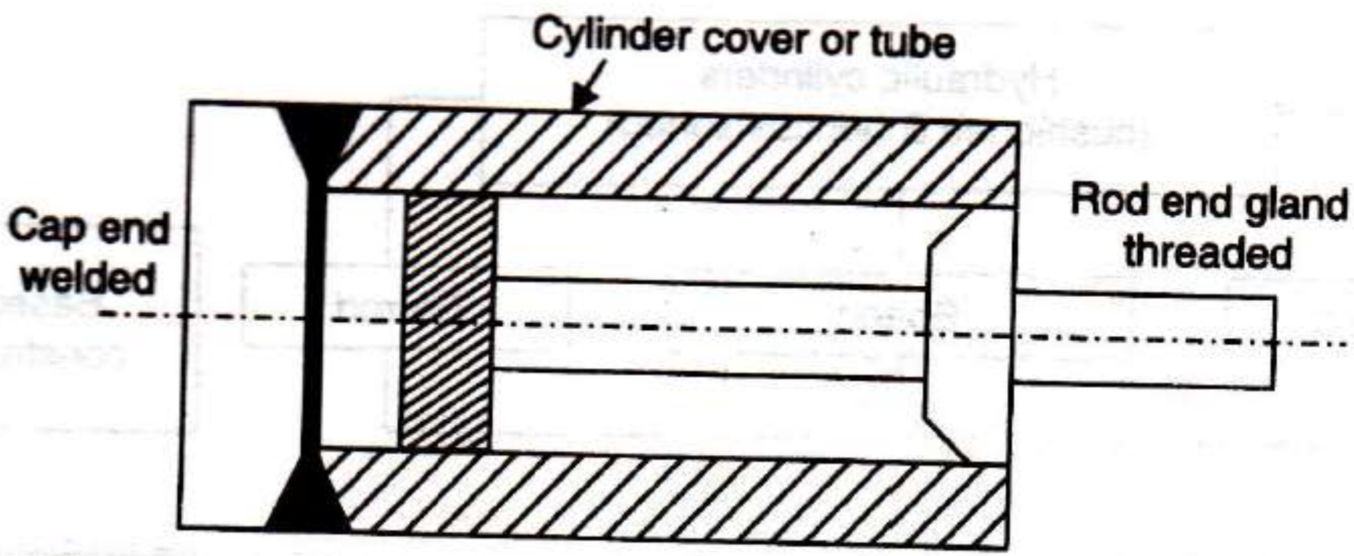

Figure 4.4 Welded construction with gland threaded at the rod.

The *tie-rod* type cylinders find more applications in Special Purpose Machines (SPMs) where the working pressure is about 70 bars. For pressures more than this, normally, welded types of cylinders are used. It should be noted here that there is no general rule that the welded type cannot be used in SPM applications. It is also possible to manufacture tie-rod type cylinders for more than 70 bars.

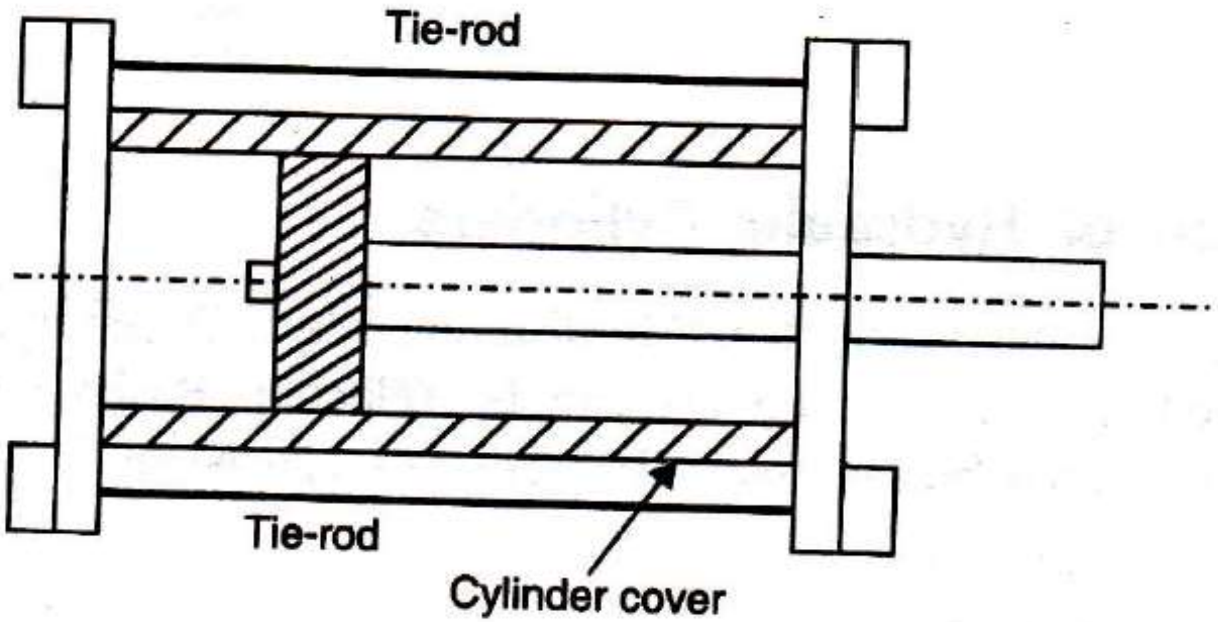

Figure 4.5 Tie-rod type where both the cap and rod ends are tied together by the tie-rods and are bolted.

Constructional parts of hydraulic cylinders (welded type): Hydraulic cylinders are also known as linear actuators and are identified by their simple design, i.e. not complicated in terms of the number of components. Perhaps, it is the best understood element by the users compared to the other hydraulic elements. Hydraulic cylinders are used in applications where linear reciprocating movements are required to push, press or lift loads.

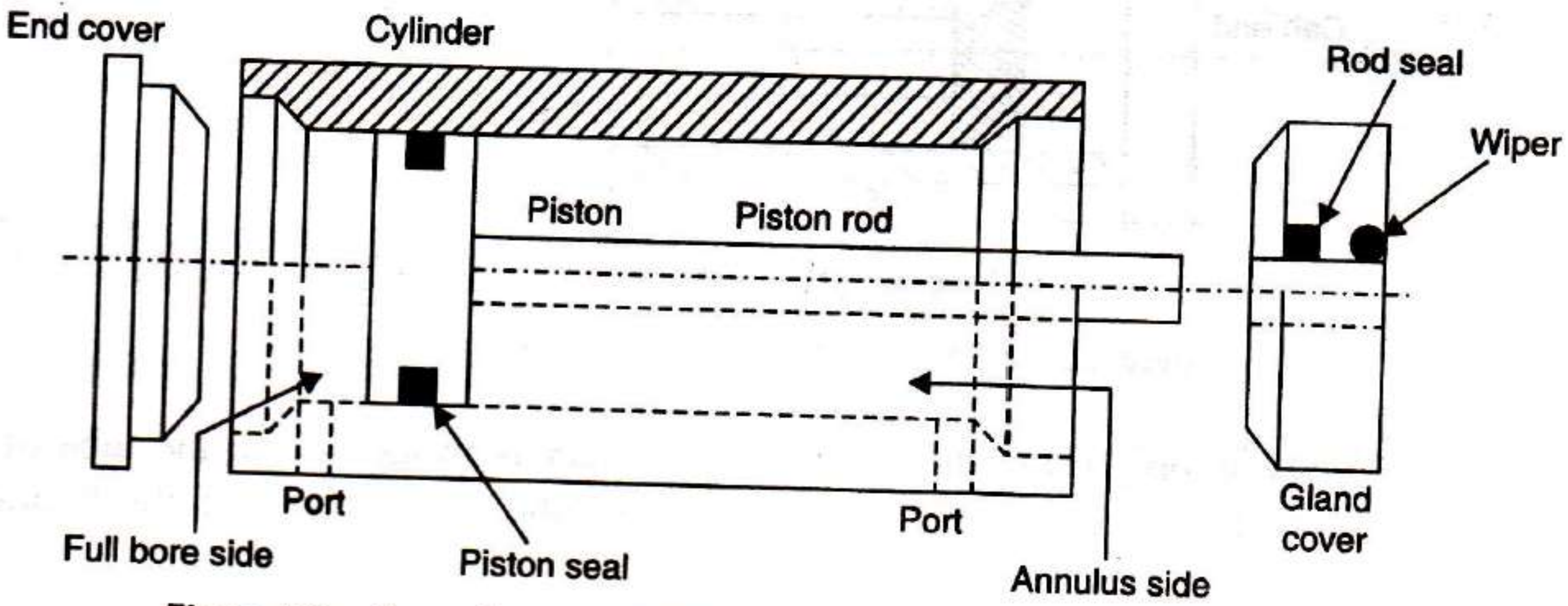

Figure 4.6 General constructional arrangement/parts of a hydraulic cylinder.

Figure 4.6 gives the general construction and part details of a welded-type hydraulic cylinder. All these parts are common for all types of cylinders. Only the way of assembly and the dimensions would differ from type-to-type.

The main part of the hydraulic cylinder is the tubular metal *cylinder cover* of definite wall thickness within which the piston reciprocates. The material and wall thickness are so decided to withstand the hydraulic pressure it is subjected to during the working of the cylinder. It has to be totally leak-proof to avoid pressure drop and maintenance problems. The inner surface of the tube is honed (a finish machining process) so that the inner tube is very smooth and the piston seals have a complete contact for proper sealing. The smooth surface finish also avoids the possible damaging of the seal when the piston reciprocates inside the cylinder.

The *end cover* is fitted onto the one of the end walls of the cylinder. The fitment between the end cover and the cylinder should be leak-proof.

The *piston* and the *piston rod* may be either integral with each other or joined together by bolting or welding. The piston and rod are machined and hard chrome-plated components. Plating is done to avoid rusting and to offer smooth surface as the piston slides in and out in a reciprocating movement. A smooth outer surface due to plating of the rod also makes the rod side to last longer. The piston has grooves on its outer surface for housing *piston seals*. The piston seals ensure that there is no leakage of hydraulic oil from the full-bore side of the cylinder to the annulus side of the cylinder.

The *gland cover* is threaded on to the cylinder. In the gland, the *rod seal* is kept inside a groove machined in its body. This prevents the hydraulic oil from leaking outside. There is also a *wiper* in a groove machined in the gland cover. The function of the wiper is to make sure that the dirt, to which the piston rod is exposed, is wiped off its surface while it is sliding into the cylinder cover.

The *ports* are the holes through which the hydraulic oil enters the cylinder or gets out of the cylinder.

4.2.3 Single-acting and Double-acting Cylinders

Hydraulic cylinders are also available as single-acting or double-acting. Single-acting cylinders, as the name implies, are those in which the oil under pressure moves the piston/piston rod in only one direction. The movement in the other direction is by way of a spring force (refer to Figure 4.7) or by the external or self-weight of the piston/piston rod. A single cylinder will have only one port for the oil to flow inside the cylinder. A double-acting cylinder has two oil ports for oil inflow/outflow and the oil acts on the full bore side as well as on the annulus side of the cylinder.

In the applications where the users feel that the self-weight of the piston rod or spring force can be used to bring the piston back to its original position, then they can opt for a single-acting cylinder. The main advantage of the single-acting cylinder is that the cost of it can be at least 30% less than that of the double-acting cylinder. This is because in a single-acting cylinder the inner surface of the tube (cylinder cover) need not be honed and the piston seals may not be required. These deletions reduce the cost of the cylinder.

In the case of the double-acting cylinder, when the oil flow is on the full bore side, the piston rod extends and when the oil is admitted through the rod-end side of the port, the piston rod retracts. A double-acting cylinder is more commonly used than the single-acting cylinder.

The following figures indicate the single-acting and double-acting cylinders.

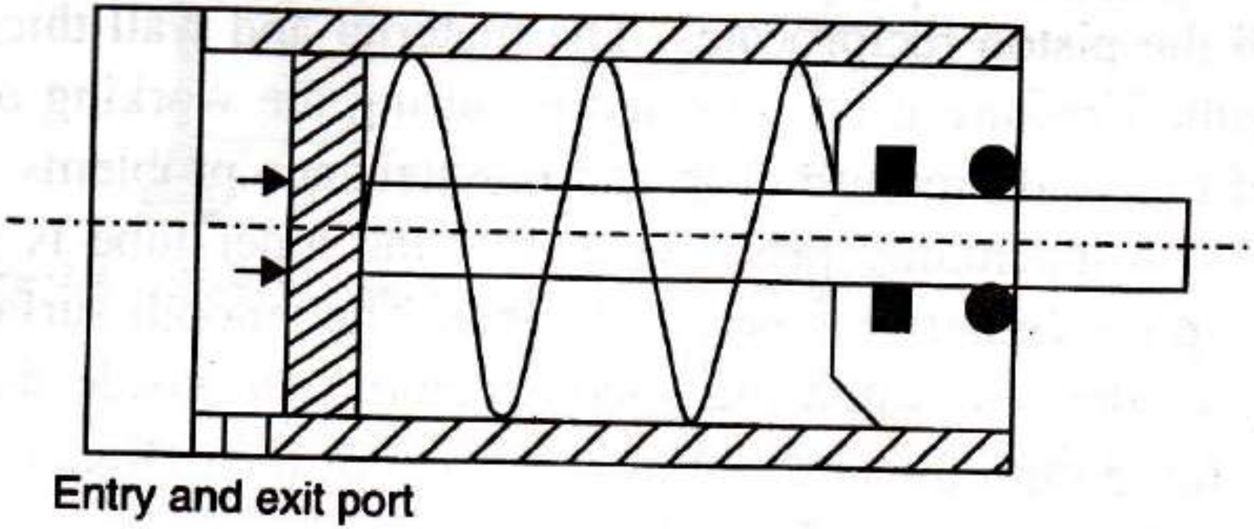

Figure 4.7 Single-acting cylinder with spring.

In the spring type of cylinders (Figure 4.7), when the oil is supplied into the cylinder the piston is pushed to the right and because of that the spring gets compressed. When the oil supply to the cylinder is stopped the pressure exerted on the piston becomes less and less. Once the exerted oil pressure becomes less than the spring compression pressure, the spring expands and the cylinder retracts.

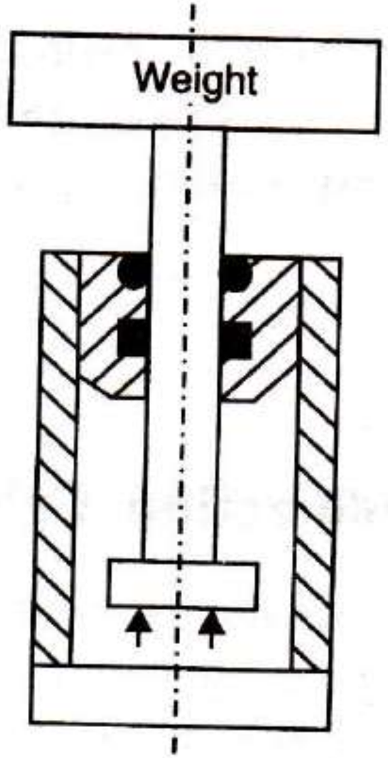

Figure 4.8 Single-acting cylinder with self-weight.

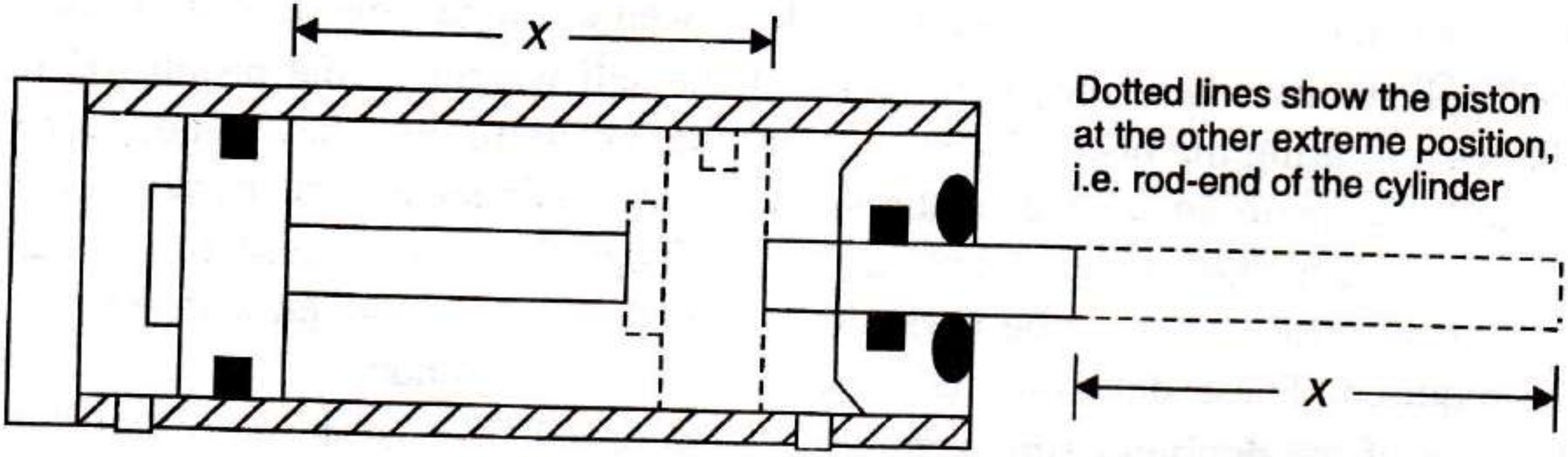

Figure 4.9 Double-acting, welded-type cylinder.

In Figure 4.8 we see a single-acting cylinder, where the return stroke is effected by the load or the weight attached to the piston rod. Note that there is a piston head instead of the piston itself. The oil will act on the piston head to raise the piston/piston rod (ram). There is no need of the spring in this case.

Figure 4.9 shows a double-acting, welded-type cylinder. In this figure, X is the stroke length of the cylinder—it is the length covered by the piston or the piston rod from its one extreme position to the other extreme position. This terminology is common for all types of cylinders.

It should be remembered here that a double-acting cylinder can also be used as a single-acting cylinder, though there can be provision for retraction of the piston by oil. Some users use a double-acting cylinder by using the hydraulic oil pressure for extension of the piston/piston rod and for retraction they use the self-weight or the load pressure.

4.2.4 Special Hydraulic Cylinders—Telescopic and Tandem

The hydraulic cylinders can also be custom-made depending on the specific application or the requirements of the customers. However, certain types of special cylinders are more common in usage.

Telescopic cylinders Hydraulic cylinders are fixed to machines or on the chassis of the vehicles to move the load. In some situations it is possible that the customer needs a stroke length (the length through which the piston rod moves from one extreme position to the other extreme position) and a standard cylinder constructed for this purpose is longer than the space available for its fitment (Figure 4.10).

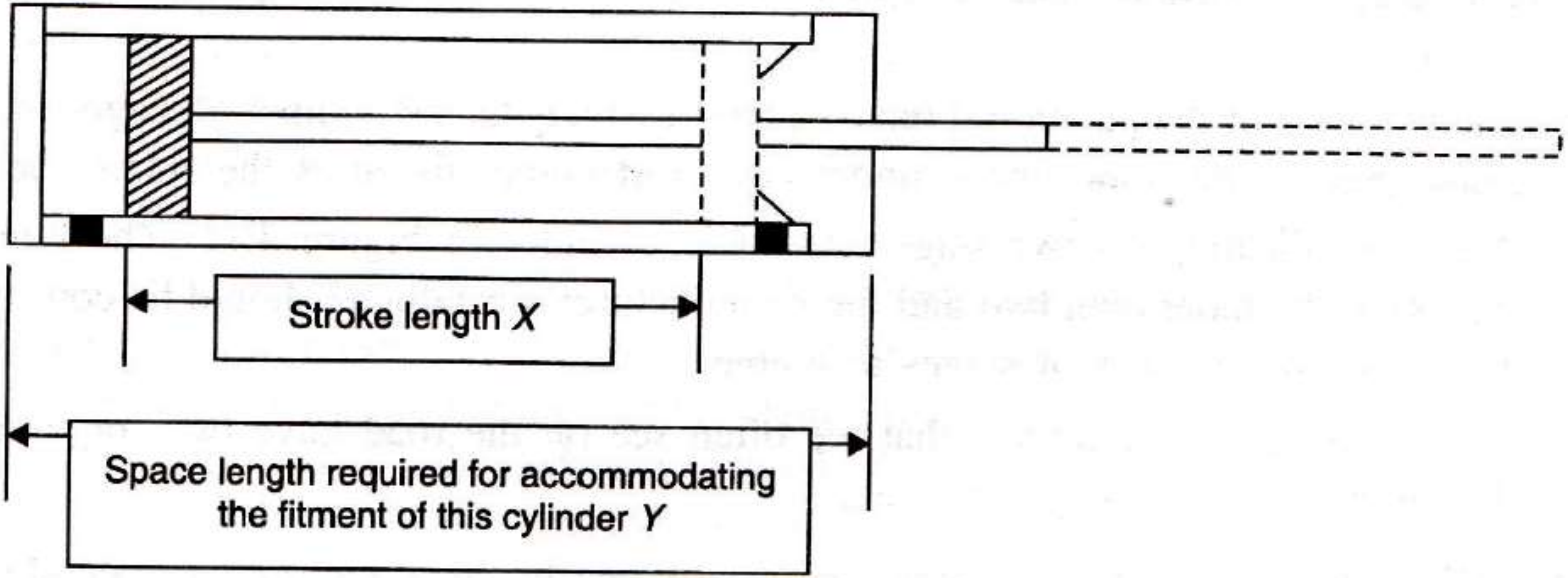

Figure 4.10 Standard cylinder.

In such applications it is common to look for a telescopic cylinder which can provide a longer stroke length because it can have more than one stage of extension.

In the telescopic cylinder (Figure 4.11), the oil enters through the outer cover of the cylinder and pushes open the first stage of the cylinder, then the oil entering the second stage pushes open the second stage of the cylinder and makes the piston rod extend further.

In effect, the stroke length of the first stage gets added to the second stage extension to get a total stroke length that is much more than that of the single-stage cylinder.

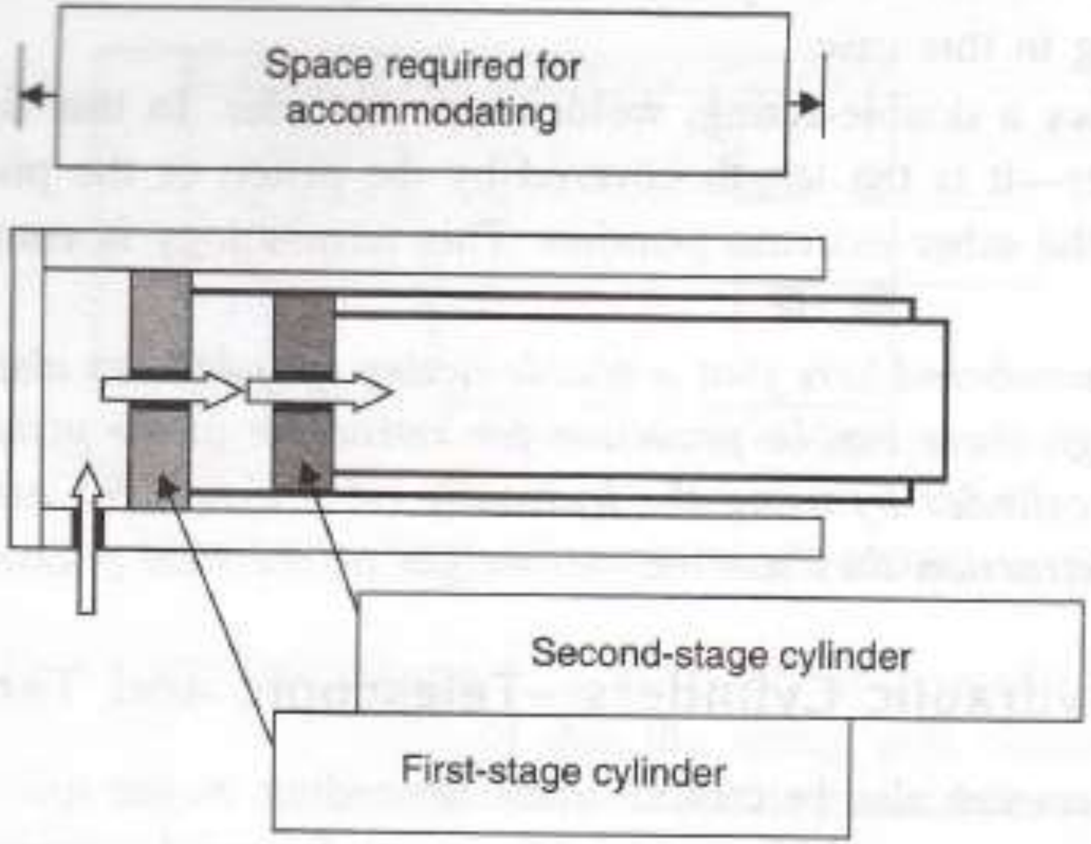

Figure 4.11 Telescopic cylinder.

On the other hand as the first and second stage tubes are within each other the total length required for the cylinder is normally less than that of the standard cylinder.

Generally, most of the telescopic cylinders are single-acting. That is, the extension of the piston rods is by the oil that is pressurized and retraction is by the self-weight of the load.

Hence, we can summarize as follows:

1. The telescopic cylinder can offer much higher stroke lengths compared to the standard cylinder.
2. The diameter of the piston rod reduces progressively as the number of stages increases. Consequently, the force the cylinder can exert comes down as the stages increase.
3. We have illustrated a two-stage telescopic cylinder in Figure 4.11. The number of stages can be more than two and the manufacturer's catalogue should be consulted for the maximum number of stages available.

Most of the dumpers or tippers that we often see on the road have two- or three-stage cylinders for unloading gravel, garbage, etc.

Tandem cylinders: In a few situations, especially in the manufacture of special-purpose machines, the tandem cylinders find applications.

The tandem cylinder is actually two in one construction, i.e. it has one cylinder cover with two pistons and other parts (Figure 4.12).

In tandem cylinders the piston rod diameters are kept the same so that the annulus areas also remain the same. The annulus area is the piston area minus the rod area. This is the effective area on which the fluid exerts pressure.

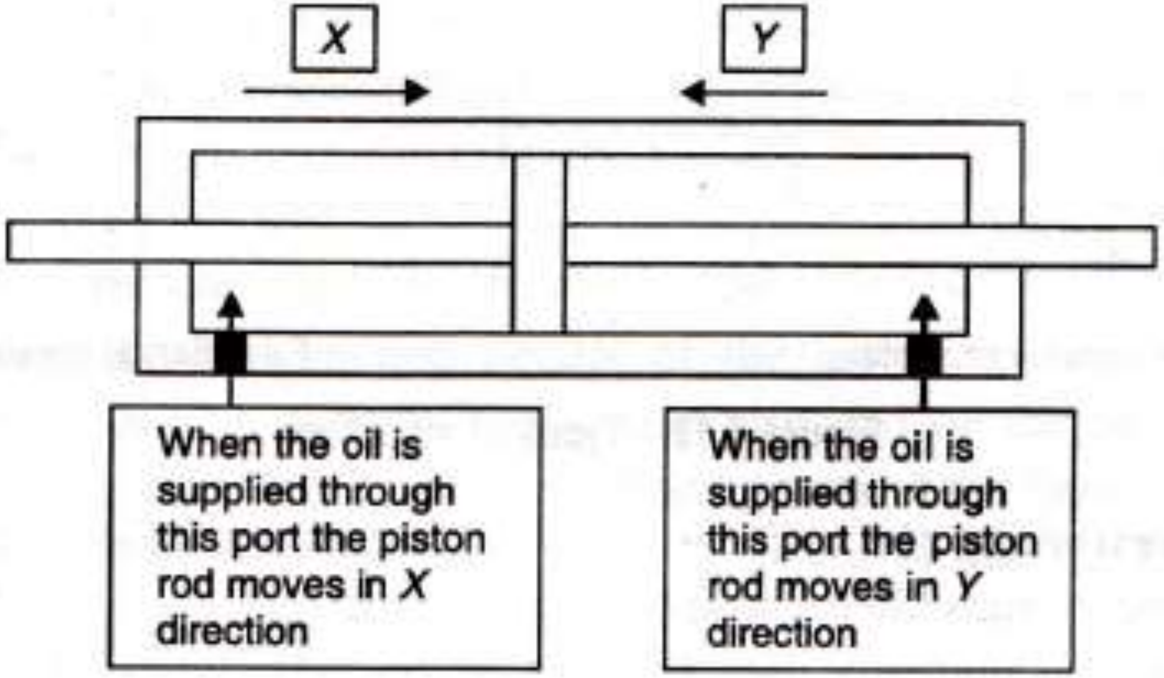

Figure 4.12 Tandem cylinder.

In Figure 4.12 the tandem cylinder illustrated shows the piston rod extended on both the sides of the cylinder. Such cylinders are used in certain special purpose machines. These cylinders have one piston that is connected to piston rods on both its sides.

4.2.5 Specifications of a Hydraulic Cylinder

Hydraulic cylinders are specified by the following parameters:

(i) *Bore diameter of the cylinder:* The working pressure of the cylinder is decided by this specification. A larger diameter has a larger area and hence can help to exerting larger force.

Generally, the manufacturers make use of standard diameter tubes available and they can guide the customers in choosing the correct bore diameter of the cylinder.

(ii) *Piston rod diameter:* The piston rod diameter is selected in line with the bore diameter of the cylinder. A thumb rule is that the rod diameter is almost half the diameter of the bore diameter. At times, it can be decided based more on the stroke length and the load. The manufacturers have standards for both bore diameters and the rod diameters.

(iii) *Stroke length of the cylinder:* The stroke length is the length by which the piston or the piston rod moves from one extreme position to the other extreme position. It is given in the illustration as '*X*'. In the figure, the distance moved by the piston as well as the piston rod is indicated as *X*. They both are one and the same and there can be only one stroke length for one cylinder. If necessary, it is possible for the users to use only a portion of the stroke length for their application.

(iv) *Mounting details of the cylinder:* The cylinders have to be used on the machines and for this purpose they have to be suitably fixed to the machines. This can be done by attaching the provisions for fixing to the cylinders and these attachments are known as mountings. Two of the most popular types of mountings are shown in Figure 4.13.

There are different types of mountings and they are fixed on the cap end of the cylinder and sometimes on both the cap ends as well as the rod end.

(a) Male clevis (b) Female clevis (c) Circular flange

(d) Trunnion (e) Foot mounts

The clevises can also be fitted with bearings or bushes depending on the applications.

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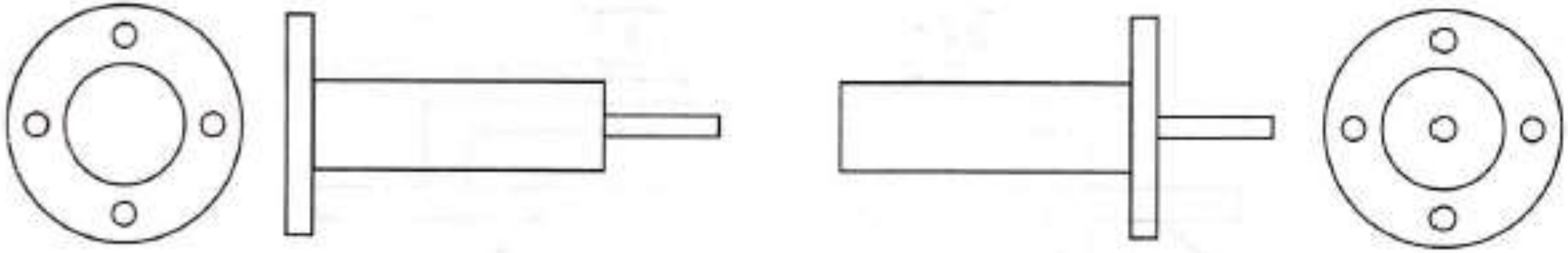

Figure 4.13 Types of mountings.

(v) *Working pressure of the cylinder:* The cylinders are all designed to handle certain loads and accordingly their capacity to handle the pressure is limited by the size of the bore and the rod diameter, the thickness of the tube (cylinder cover) etc.

(vi) *Test pressure of the cylinder:* While testing the cylinder, it is tested to a higher pressure than the working pressure and this can be normally one and half-times to two-times the normal working pressure of the cylinder.

(vii) *Cushioning of the cylinder:* The users to specify whether a cushioned or a non-cushioned cylinder is required for their applications. The cushioning slows down the speed of movement of the piston towards the extreme ends of the cylinder.

The cushioning is done by design, and the cushioning can be at both the ends or only at one end, e.g. at the cap end or at the gland end.

4.2.6 Cushioning in Hydraulic Cylinders

A cushioned cylinder is one where the speed of movement of the piston of the cylinder is dampened at the extreme stroke ends of the cylinder. In a noncushioned cylinder there is no provision to dampen the speed as the piston is nearing the ends of the stroke.

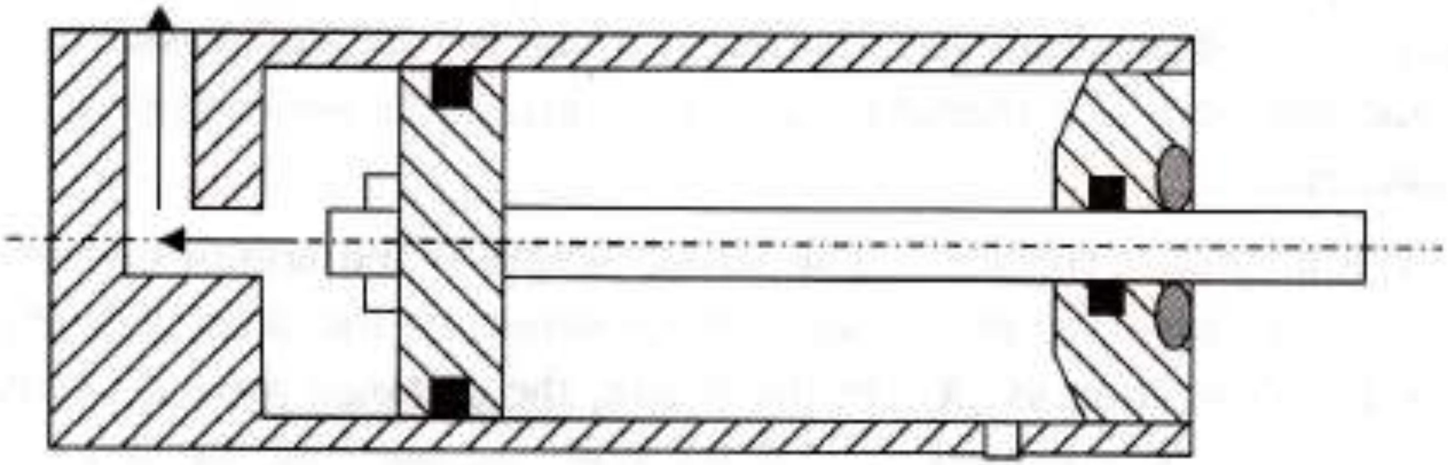

Figure 4.14 Fixed cushioning—front end in hydraulic cylinders.

As mentioned above, cushioning refers to the movement of the piston/piston rod becoming comparatively slower at the end of its stroke. If the piston/piston rod movement slows down at both ends, then the cylinder is known to be cushioned at both ends. Otherwise, it should be specified at which end the cylinder is cushioned. Cushioned cylinders are more popular in applications such as machine tools. There are two types of cushioning:

(i) *Fixed cushioning:* The movement of the piston/piston rod is slower, but this slower speed is not adjustable.

(ii) *Adjustable cushioning:* The movement of the piston/piston rod at the end of the stroke is slower, but this slower speed of movement is further adjustable to a still slower rate of movement or to an increase in the speed to original speed.

The above cylinder (Figure 4.14) is cushioned at the cap end. You can note that there is a projection at the piston end that can enter the oil passage indicated by the arrow. Towards the end of the stroke, near the cap end, the projection of the piston assembly enters this passage and this makes the oil flowing out to have very little space. The reduction in the space for the oil to flow creates back pressure which in turn reduces the speed of the cylinder piston/piston rod.

Figure 4.15 gives the construction details of the rear end fixed cushioned hydraulic cylinder. The cushioning arrangement, the projection provided on the piston at the rod side of the piston, will enter into the right-side port and thereby restrict the flow of oil. This restriction to the flow of oil reduces the speed of motion of the piston inside the cylinder.

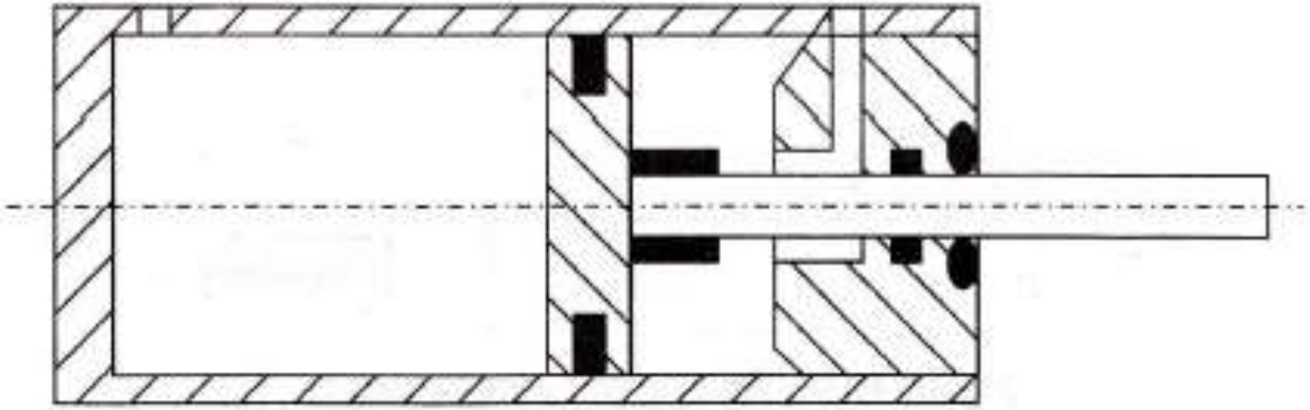

Figure 4.15 Fixed cushioning—rear end in hydraulic cylinders.

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