Vol.2.
DESIGN AND MANUFACTURING OF HYDRAULIC CYLINDERS

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Chapter - 8

Introduction to Hydraulic Cylinder

Hydraulic cylinder is most important part of a hydraulic press. It develops the necessary force require to carry out a pressing operation. As cylinder is one of the most important parts of a press, hence we will discuss it in detail in this chapter.

8.1 Definition: -

The hydraulic cylinder is a positive displacement reciprocating hydraulic motor, which converts the energy of a fluid into the kinetic energy of the moving piston.

In other words we can say a hydraulic cylinder is a device which converts the energy of fluid which is in a pressure form into linear mechanical force and motion.

8.1.1 Type of Hydraulic Cylinders:

Hydraulic cylinders could be classified into two broad categories.

i. Single action cylinders.

ii. Double action cylinders.

Single action cylinder can be defined as "Cylinder in which displacement in one direction is by working fluid pressure and in the other direction by external force.

Single action cylinder can take power-stroke only in single direction. That is either it can develop necessary force in forward stroke of cylinder or return stroke of cylinder, depending on its construction. The non-productive direction of cylinder stroke is achieved by various means such as self-weight (gravity), spring, auxiliary cylinder etc.

Double action cylinders are those in which forward as well as reverse strokes are actuated by fluid pressure.

Double action cylinder can develop power-stroke in both forward and reverse direction.

In figure 8.1 when oil supplied in port A, cylinder will develop force in forward direction. Return stroke is achieved by gravity and spring. While in figure 1.2, when oil is supplied in port A, cylinder will take forward power stroke and when oil is supplied in B-port, then cylinder will take power stroke in reverse direction.

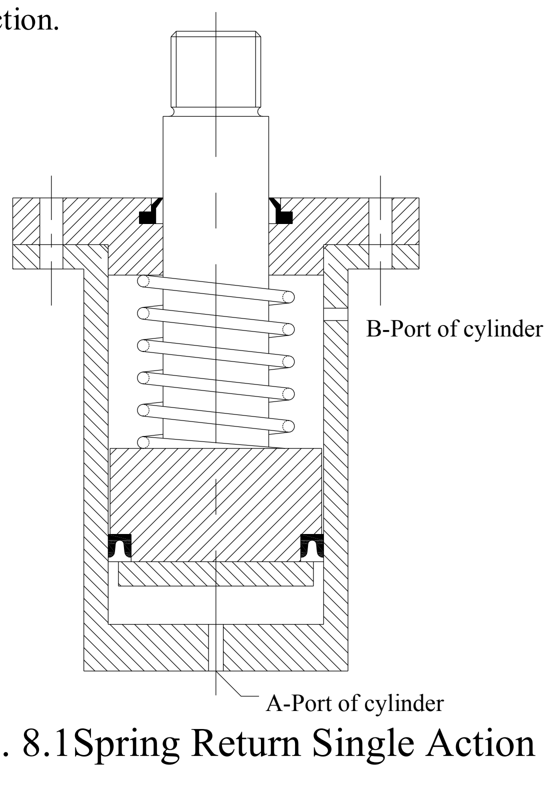


Figure No. 8.1Spring Return Single Action Cylinder

1. Piston Rod: -

When diameter of piston rod is almost equal to piston diameter then generally it is called as RAM. But in general all large size of piston rods are called "RAM". Piston rod is a mechanical member, which transmits kinetic energy, which got developed at piston, to the work-piece. It is circular in cross-section in case of double action cylinder, as hydraulic sealing is required between piston rod and guide bush. In ram type of single action cylinder, piston rod is also circular in cross action, while in piston type single action cylinder in which sealing is not required between piston rod and guide bush, piston rod may be of any type of cross section. For example in case of lock nut type of single action jack, piston rod has thread on its entire length. Piston-rod is also called as plunger. It could extend from both the end of cylinder, and it could be hollow also. Piston-rod could be attached to other component by means of threading, eye bolt type arrangement, or groove and split coupling arrangement etc.

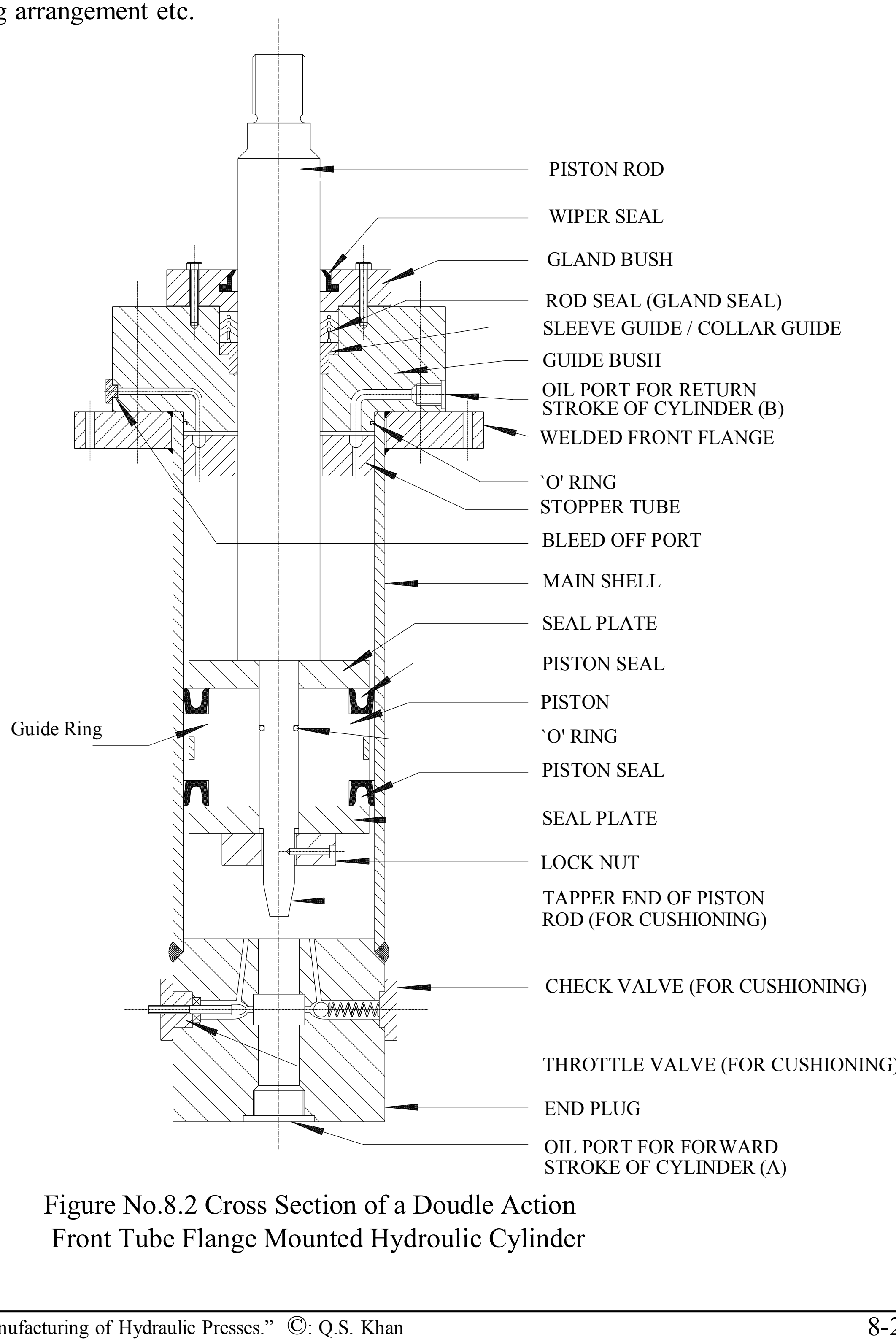


Figure No.8.2 Cross Section of a Doudle Action
Front Tube Flange Mounted Hydroulic Cylinder

2. Wiper Seal: -

These are used to avoid entry of dust particle in cylinder. When these seal softly wipe the rod then it is called wiper seal and when they are stiffly and forcefully rub the piston rod to avoid entry of dust particle in cylinder then they are called “scraper”.

3. Gland-Bush: -

Gland-bush is used to retain gland seal, accommodate wiper seal, and provide guide to piston rod. It is an optional component; it could be merged with Guide-bush. That means guide-bush can also accommodate rod seal, wiper seal and can provide guide to piston rod. We provided separate gland-bush for convenience in manufacturing, controlling dimension accurately, and stronger design.

Making grove in Guide-bush and maintaining tolerance and surface finish is too difficult, so by using gland bush we make an open step for accommodating seal and solve this problem.

Guide-bush is made from mild steel, while guiding piston rod requires bearing material. So instead of making complete guide bush of bearing material we make gland-bush of bearing material, Which is smaller in size as compared to guide-bush, and hence we save money.

Strips and bush could be used to provide guide to piston-rod in Guide bush, instead of making separate gland bush. But long guides provided by gland-bush which are made from bearing material are much stronger and gives long life as compared to thin and short bushes and strips Filled in guide-bush.

4. Rod Seals: -

These are also called as Gland seals. It is a device which is used to avoid the leakage of working fluid or air from the periphery of piston-rod, Generally it is used to stop leakage between piston rod and guide-bush of cylinder.

5. Removable Guide Bush (Sleeve Guide): -

This is inserted in guide-bush before seals. This gives additional guide to Piston - Rod. It is also called sleeve guide or collar guide.

6. Guide-Bush: -

It is also called as “Head End”, “Rod-end”, “front-end:, or “front-Face” (of cylinder). This is a cylinder end enclosure, which covers the annular area or the differential area between the cylinder bore area and piston rod area.

In addition to functioning as end-closer, it also could be used for mounting cylinder, providing oil-port, accommodating bleeding and cushion arrangement, and providing guide to piston rod.

7. Oil Port: - A port is an internal or external terminus of air or fluid passage in hydraulic or pneumatic component.

In hydraulic cylinder, oil ports are provided to feed pressurised oil. It may be threaded or bolted type, and its size depends on the flow of oil thought these oil ports and inside diameter of cylinder

8. Cylinder-Tube-Flanges: -

These are circular or rectangular rings, threaded and welded to the outside diameter of cylinder tube. When this is fixed at front-end of cylinder then it is called Front-Tube-Flange. It may be used for bolting of guide-bush and cylinder mounting, in case of Front-Tube-Flange mounted type of cylinder.

When it is fixed to the rear-end of cylinder (end-plug side), then it is called “Rear-Tube-Flange” of cylinder. It may be used for bolting of End-Plug and cylinder mounting in case of Rear-Tube-Flange mounted cylinder.

9. 'O' Ring:-

it is a ring with round cross-section, and used to stop leakage between mating components.

10. Stopper Tube: -

When cylinder has long stroke, and in fully extended condition of Piston-rod, if there is a chance of buckling of piston-rod or any damage to cylinder, then piston-rod is always kept sufficiently inside cylinder, so that the gland-bush and piston, which provide guide to piston-rod are sufficiently apart from each other, and provide good cantilever support against bending and buckling.

A piece of pipe, which floats freely between piston and guide-bush, and stop ram from taking its full stroke, is called stopper-tube.

11. Air-Bleed-Off-Port:-

Air may get trapped in cylinder. This air may be due to cavitations and de-aeration in oil, or air present while assembling and commissioning of cylinder. Trapped air gives spongy operation, jerks, and loss of control on cylinder movement. To remove trapped air small tapped holes are provided in end-plug and guide-bush, which always remains plugged. To release air these plugs are loosened allowing air to escape to atmospheres. When air is completely removed then oil started leaking-out from these plugs, then plugs are tighten again.

This process of removing air till oil starts coming out is called bleeding and the port provided for this purpose is called "air-bleed-off-port".

12. Main Shell: -

It is also called "cylinder-tube", or "cylinder-pipe", or "cylinder-body". It has circular inside cross-sectional area. It receives, confines, and direct the fluid under pressure to piston or ram so that the pressure energy in fluid gets converted into kinetic energy of the moving piston or ram. The cross-section area of cylinder-tube withstands radial as well as longitudinal stress developed due to the fluid-under-pressure. It also provides guide to ram or piston.

13. Seal Plates: -

These are round rings or plates, used to retain piston-seal on piston.

14. Piston Seal: -

These are hydraulic seals used to avoid leakage between piston and inside diameter of cylinder tube.

15. Piston: -

Piston is circular in cross-section. It slides in main shell, and provides guide to piston rod at one-end (piston-end). Piston has provision and means to avoid leakage between cylinder and piston, and because of this feature, when fluid-under-pressure when enters in main shell in one direction, piston gets pushing force in other direction. Hence it assists in conversion of pressure energy in fluid to kinetic energy

16. Lock Nut:-

To avoid losing of piston from piston-rod these lock nuts are provided.

17. Guide-Ring: -

These are flat rings of plastomeric material. And used in piston, guide-bush, and gland-bush to avoid metal to metal contact, and act as guide. All mechanical property of guide-rings are similar to bearing material.

18. Cushioning:-

As per the requirement of hydraulic system, piston-rod may travel at extremely high speed in its stroke range. On completing its stroke if piston hits guide-bush or end-plug with same high speed then it will damage the whole cylinder. Hence special arrangements are made in piston and end-covers to reduce the speed of piston-rod as it completes its stroke. This process of deceleration of piston or piston-rod is called cushioning.

Cushioning is achieved by throttling the rate of exhaust or return of oil, from cylinder. Cushioning may be fixed type or variable type; Detail about arrangement of cushioning will be discussed in design of cylinder.

19. End-Plug: -

It is also called as "Cap-End" "Cover - End" or "Rear - End" (of cylinder) this is a cylinder-end enclosure which completely cover the cylinder-bore-area. In addition to providing end enclosure, end plug also could be used for mounting of cylinder, providing oil port, making arrangement for bleeding, and cushion etc.

For more knowledge about terms used for hydraulic cylinder, and other items kindly refer IS:10416:1982 which describes about 855 terms related to oil hydraulic.`

8.2 Classification of Hydraulic Cylinders

Basically there are only two types of hydraulic cylinder, namely single action cylinder and double action cylinder. These two principal types of hydraulic cylinders have been modified in so many ways as per requirement of industry, convenience in manufacturing, economy and duty cycle. Some of them are described as follow.

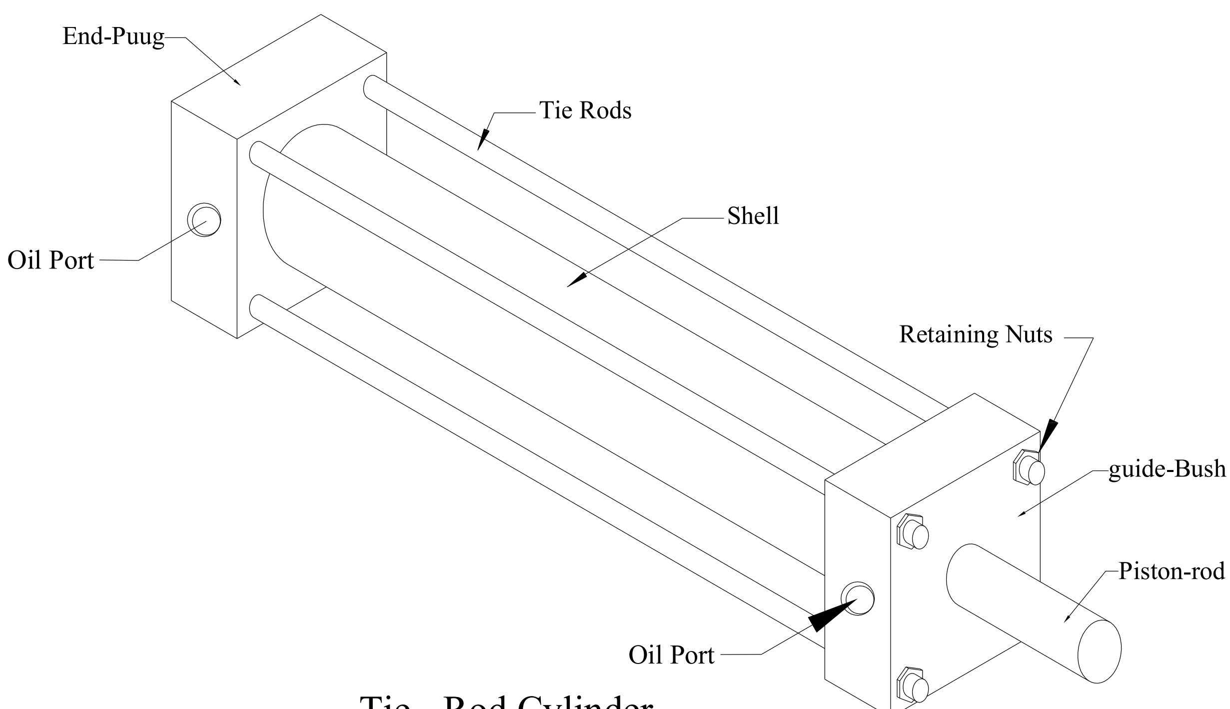
8.1.1 Classification based on Body Construction of Hydraulic Cylinder: -

On construction basis hydraulic cylinders could be divided in to five categories.

1. Tie - Rod Construction.
2. Threaded Construction.
3. Bolted Construction.
4. One Piece welded construction.
5. Costume Build Cylinder with combination of above mentioned constructions.

8.2.2 Tie - Rod Construction: -

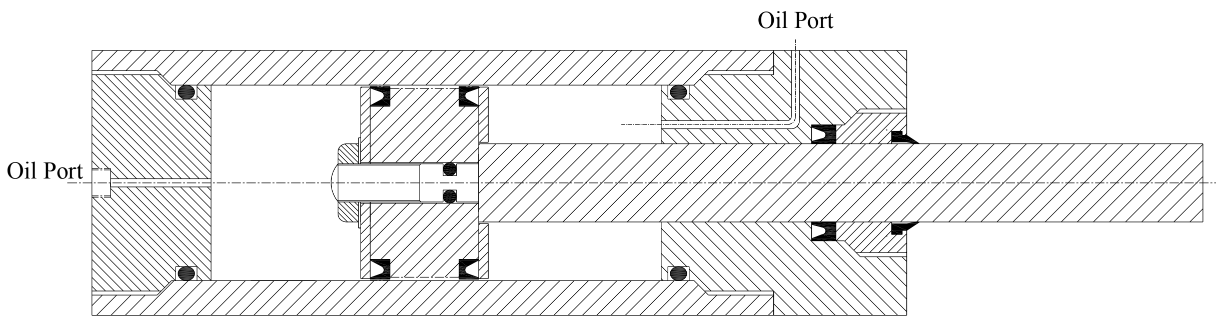
This type of construction is most widely used in industry. ISI standard also generally refers to one of this type of construction. As all the components are only machined and assembled together and not welded. Hence planning manufacturing, quality control, assembly, and maintenance are more convenient than other types of construction. As long tie rods are used to hold all the component together hence special care required to tighten them, and safe guard against loosening in operation. Like standard valves and pumps, these types of cylinders are also manufactured as standard hydraulic component, and used for low to medium pressure and low to medium duty operation for general purpose, and machine tool industry.



Tie - Rod Cylinder
Figure No. 8.2.2

8.2.3 Threaded Construction: -

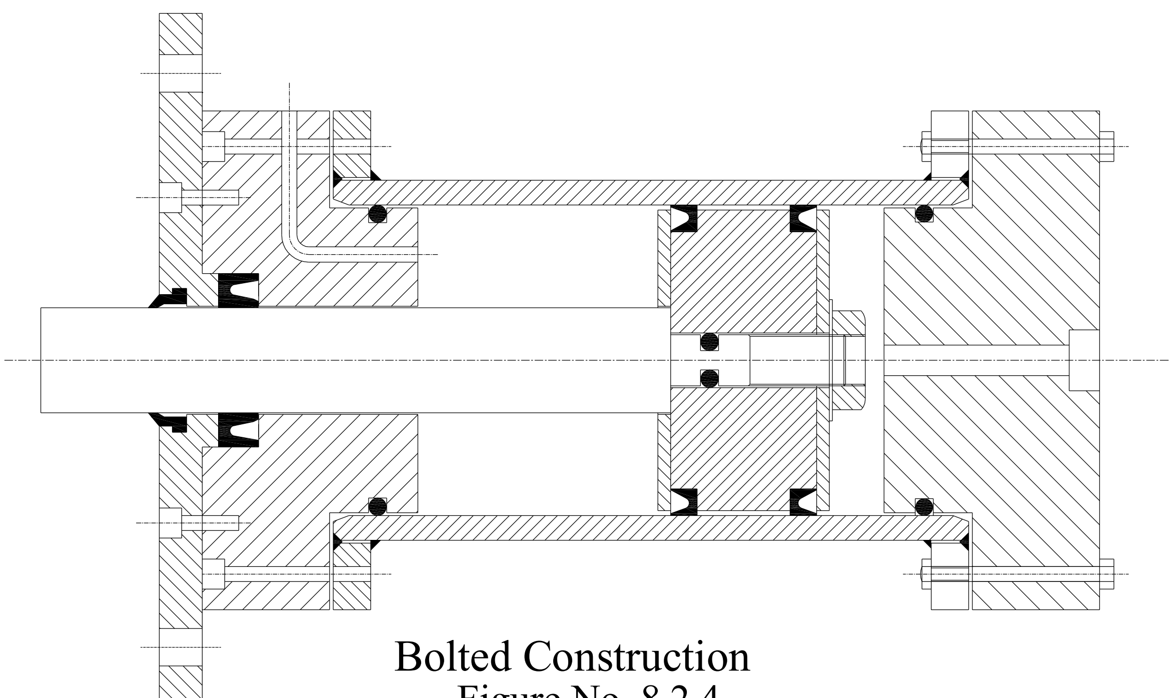
This construction is similar to tie-rod construction, but more compact, stronger, and requires more accuracy and care in manufacturing and quality control. In this design both ends are assembled with cylinder tube by threading, as shown in following design.
These are used for medium to heavy-duty operation, and widely used in earth moving machinery.



Threaded - Head Cylinder
Figure No. 8.2.3

8.2.4 Bolted Construction: -

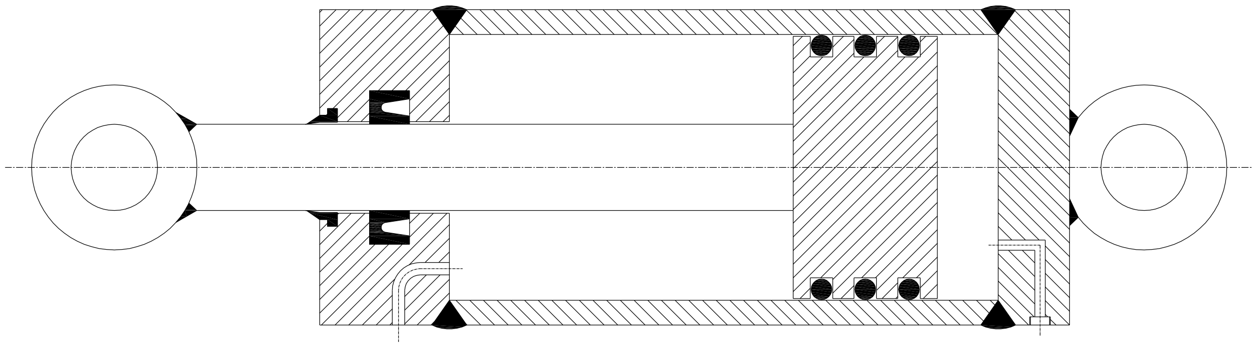
This type of construction involves welding of flanges to cylinder tube, and bolting of end cover to the welded flange. Similar to tie rod construction these are also designed and manufactured as standard hydraulic component and widely used in industry.



Bolted Construction
Figure No. 8.2.4

8.2.5 One Piece - Welded Cylinder: -

Similar to shock - absorber, in this design the end covers and cylinder tube are welded together. These are economical but cannot be repaired. There are used for low pressure; agriculture machinery application.



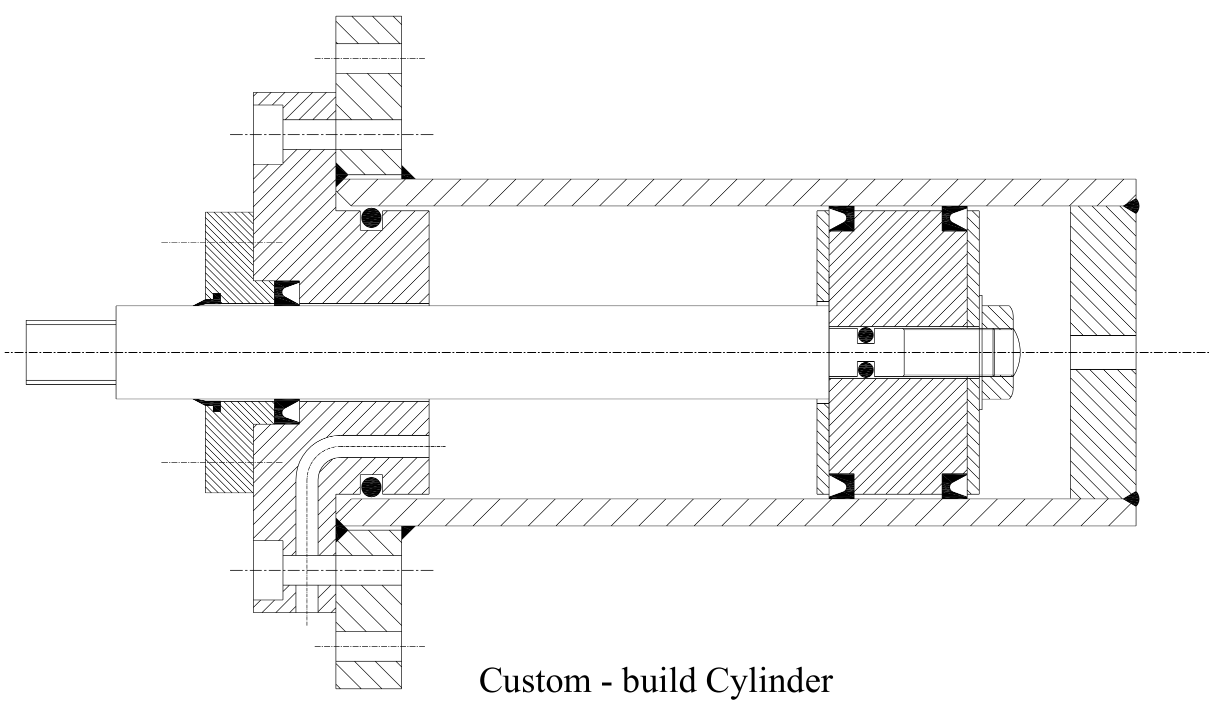
One Piece - Welded Cylinder

Figure No. 8.2.5

8.2.6 Custom - Build Cylinder: -

In this type of cylinder, various type of construction are mixed together to suit the requirement. One of the most widely used combination is welded cap-end cover, bolted head-end cover, with front tube flange mounting.

In case of high capacity cylinder when it is steel cast or machined from solid steel forging, then end cover and front flange may be integral part of cylinder tube. Cylinder with this type of construction widely used in hydraulic press.



Custom - build Cylinder

Figure No.8.2.6

8.3 Classification based on operating features of Hydraulic cylinder

8.3.1 Single Action Cylinder: -

This is the simplest type of cylinder and used since introduction of water hydraulic. In this type of cylinder, ram or piston-rod have such construction that their displacement in one direction is by fluid force and in other direction by external force.

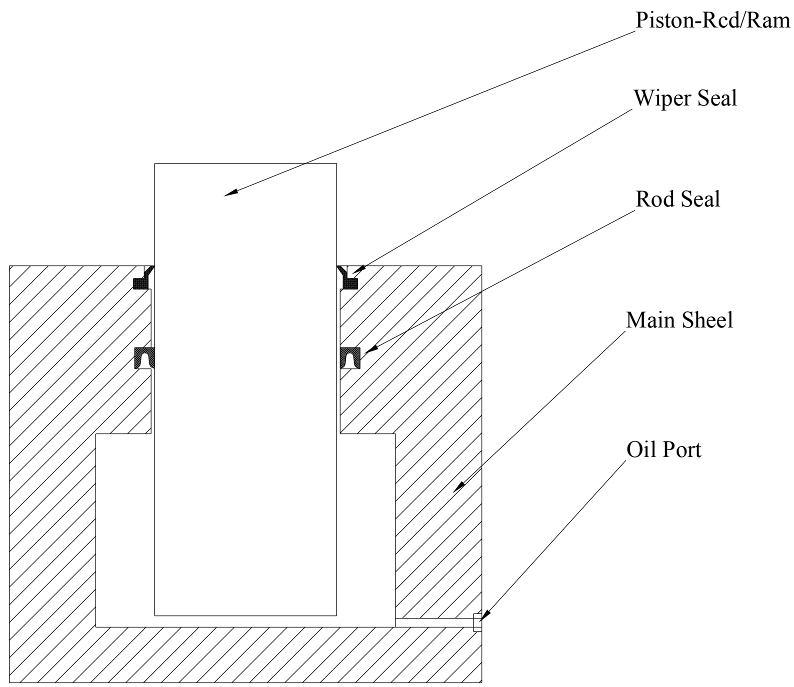


Figure No. 8.3.1

ıravity return single action cylinder

8.3.2 Double Action Cylinder: -

This type is most widely used cylinder in industry. In this type of design the stroke of piston rod in forward as well as in reversed direction is due to fluid pressure, as shown in figure 2.2

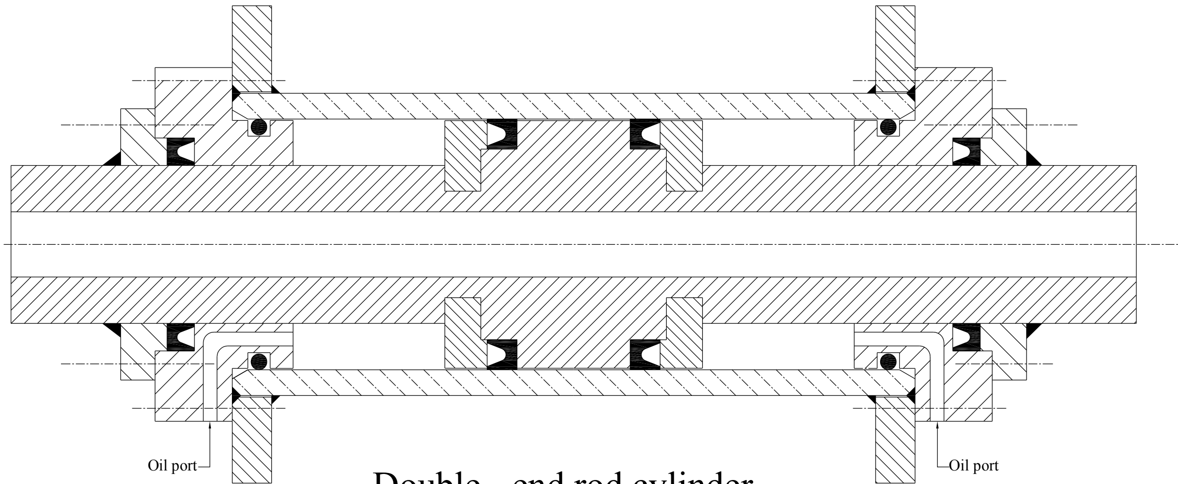
8.3.3 Differential Cylinder: -

When cross-section area of Piston-rod (Ram) is half the cross - sectional area of cylinder bore of double action cylinder, then such cylinders are called Differential Cylinder.

When differential cylinders are connected to regenerative hydraulic circuit then it gives same (equal) forward and return speed.

8.3.4 Double - End Rod Cylinder: -

In this type of cylinder piston rod extends from both the ends of cylinder. As annular area on both ends are same, hence it moves with same speed in its forward and return stroke. Sometime piston is made hollow to pass the work-piece or another machine element through it.

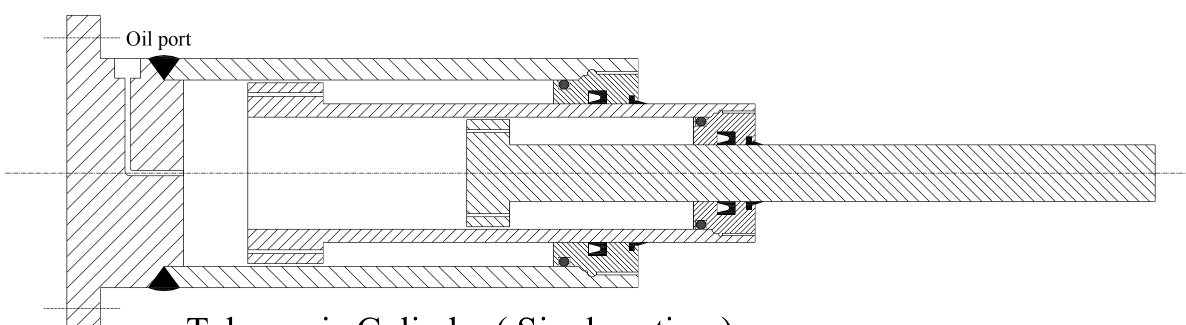


Double - end rod cylinder
(With hollow ram)
Figure No. 8.3.4

8.3.5 Telescopic Cylinder: -

This type of cylinder provides long stroke from short body. Total stroke length may be as much as four to six times longer than collapsed length of the cylinder. Telescopic cylinders are single as well as double action. The force out-put varies with stroke. We get maximum force on first stage when full piston area is used, while minimum force at the end of stroke.

These types of cylinders are used in dumper-truck, hydraulic mobile crane, and

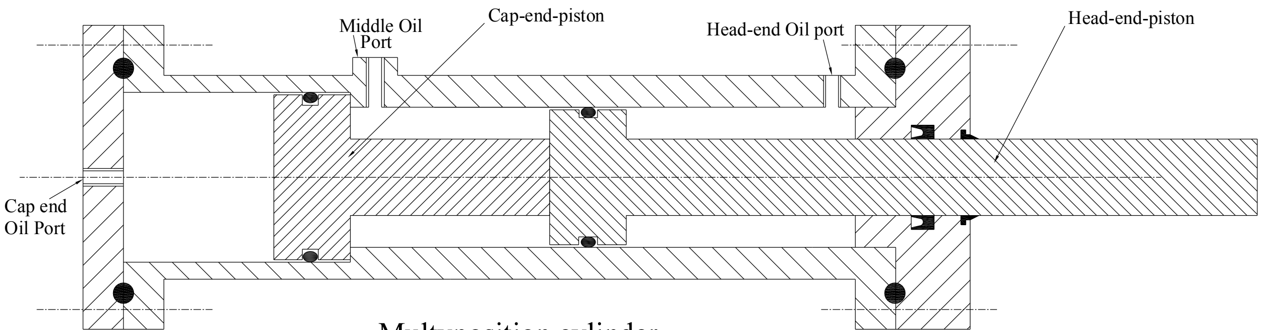


Telescopic Cylinder (Single action)

Figure No. 8.3.5

8.3.6 Multi position Cylinder: -

These type of cylinders provide special motion by moving two or more pistons inside the cylinders. For example, in three-position cylinder as shown in following diagram, on pressurizing the cap-end-oil port the cap-end piston-rod forces against the head- end-piston, and moves it to some portion of its stroke (generally about half of its total travel).



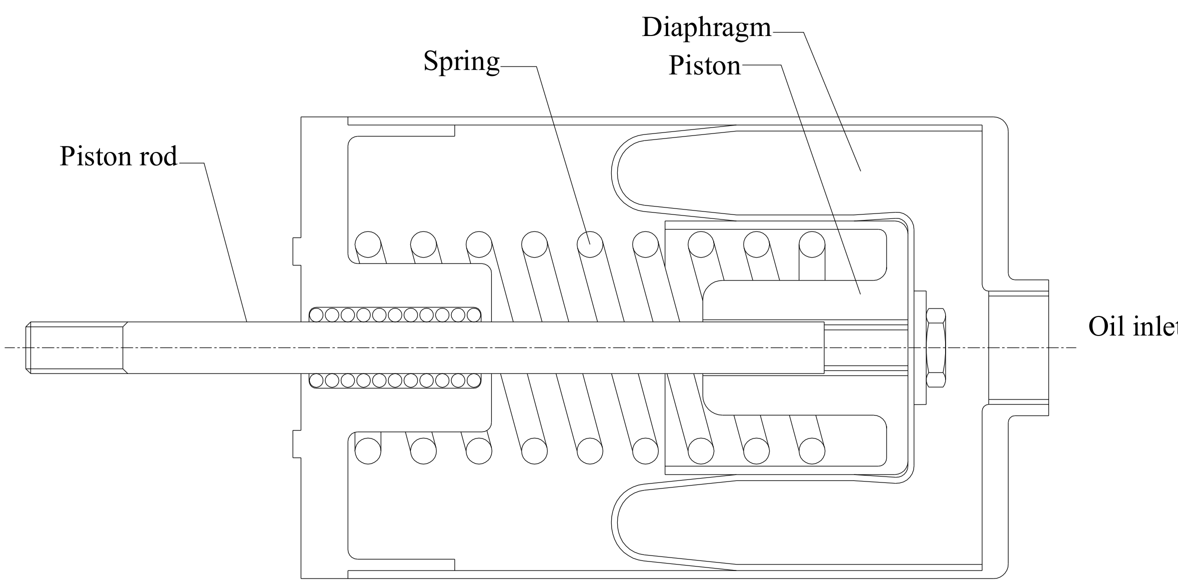
Multyposition cylinder

Figure No. 8.3.6

By Pressurizing the middle oil port, oil pressure separates the head-end-piston from the cap-end rod, and force the head-end-piston to full extension. Three-position cylinders are often used to actuate multi position valves or to shift gears in machine tools.

8.3.7 Diaphragm Cylinder: -

Diaphragm cylinders are used in either hydraulic or pneumatic service for applications that require low friction, no leakage across the piston, or extremely sensitive response to small pressure variations. They are frequently used as pneumatic actuators in food and drug industries because they require no lubrication and do not exhaust a contaminating oil dust. Spring- return models shown in figure should not be pressurized in the reverse direction because reversals can pleat the diaphragm and shorten its life. Double-acting actuators with twin diaphragm are available for application requires pressure in both directions.



Diaphragm Cylinder

Figure No. 8.3.7

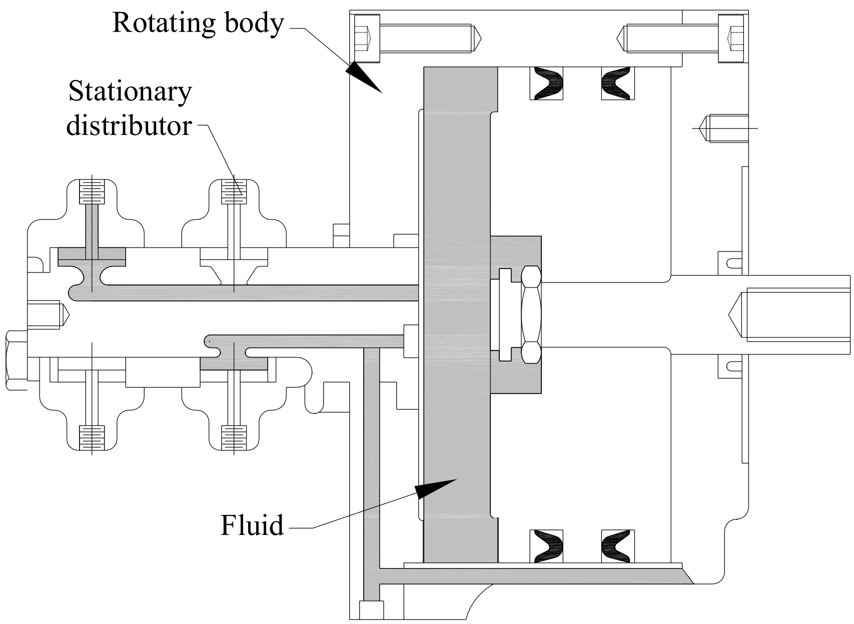
8.3.8 Rotating cylinder: -

Rotating cylinders impart linear motion to a rotating device. They are often used to actuate rotating chucks on turret lathe.

In this type of cylinder, complete cylinder assembly may rotate along with mating components. Special journals, thrust bearing etc. are used to guide piston-rod and to reduce friction while rotating. Fluid is supplied through special stationary distributor.

(like rotary joints)Generally relative rotary motion between cylinder and piston are avoided as high pressure seal would then be subjected to both rotary and linear wear force. But with low RPM they can have relative rotary motion.

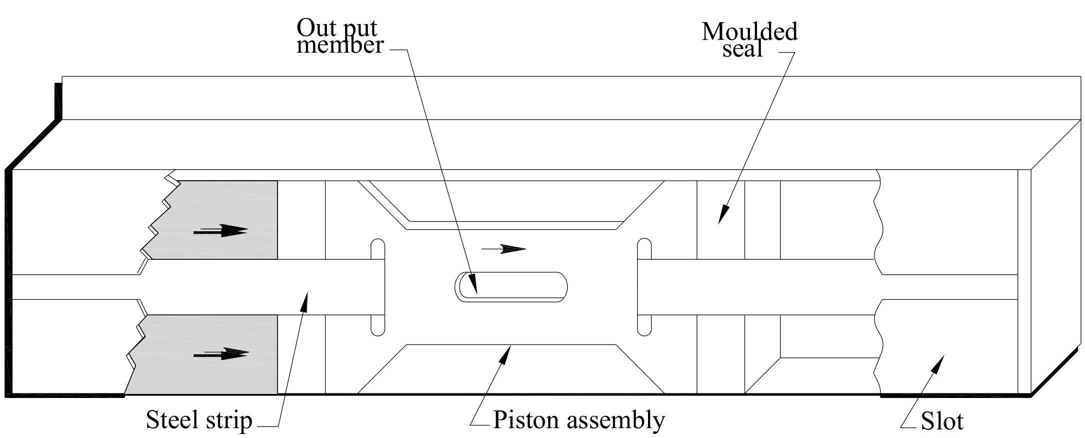
Hydraulic rotating cylinder and hydraulic torque motor are two different units. Hydraulic rotating cylinder only imparts liner motion to a rotating device. While torque motor impart rotary motion to a device to be rotated.



Rotating Cylinder
Figure No.8.3.8

8.3.9 SLOTTED CYLINDER (Rod less):-

In slotted cylinder, piston extends through a slot in the side of the cylinder. The slot is sealed with a spring-steel strip that is threaded through the piston assembly. So far sloteded cylinders are available for pneumatic system but not hydraulic system.



Slotted Cylinder
Figure No. 8.3.9

8.3.10 Compound Cylinder: -

Compound cylinder consists of a secondary cylinder inside the main primary cylinder to improve the performance of main primary cylinder.

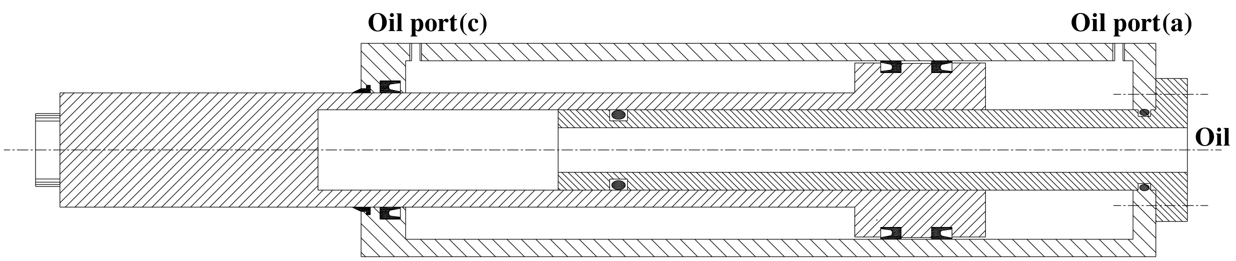
Cross - section of a simple of compound cylinder is shown in following figure. In this cylinder we can have three forward speeds and pressing force.

1) We get Maximum speed and minimum force when pump is connected to only B port, and A & C is connected to tank.

2) Medium speed and force is achieved when A is connected to pump and B & C is connected to tank.

3) Minimum speed and maximum force is achieved by connecting A & B to pump and C to tank.

4) Single speed return speed is achieved by connecting C to pump & A & B to tank.



COMPOUND CYLINDER

Figure No. 8.3.10

8.3.11 Intensifier: -

This is a type of compound cylinder. Which is used to boost the pressure of working fluids. Intensifier may be a part of hydraulic circuit, in which pump initially supplies hydraulic fluid at low to medium pressure to carry out all the operation and function of a hydraulic system and when high pressure required then with the help of medium pressure hydraulic fluid and intensifier, high pressure is developed. (fig.___)

Now-a-days readily available and economical. Piston pump can develop up to 630 Bar. Some sophisticated pump can also develop up to 1000 Bar. But when oil at 1500 Bar or 2000 bar pressure is continuously required then such type of intensifier is used.

In following example using low pressure pump very high pressure oil can be supplied to cylinder

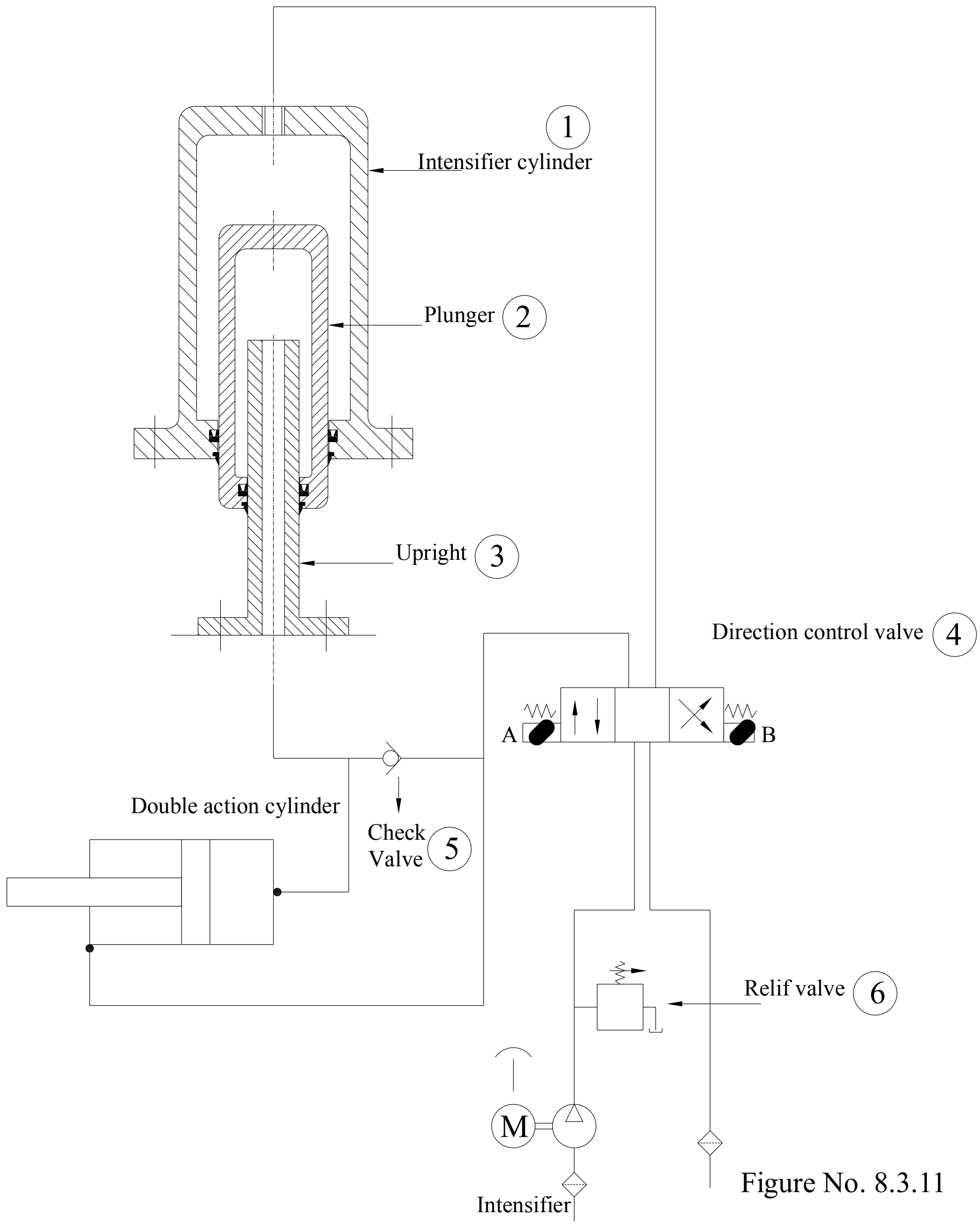


Figure No. 8.3.11

E] Operation Principle: -

I) When direction control valve Actuated to (A) piston, oil from pump passes to return side of cylinder. Spring of check valve No.(5) is so strong that it does not allow oil to enter forward port of cylinder and upright (3) unless. Cylinder gets fully retracted.

II) After full retraction of cylinder , oil passes from check valve (5) and enters in upright (3), which cause plunger (2) to retract.

III) In fully retracted condition of cylinder and plunger (2) system is ready for forward stroke cylinder.

IV) When solenoid is activated to B-position. Oil from pump is directed to forward port of intensifier cylinder. This cause plunger (2) to more down and transfer oil in upright (3) to port for forward stroke of

V) If area of intensifier cylinder (1) in A1 and pump pressure is P1, Area of upright (3) is A2 , them pressure P2 got developed in up-right will be By this simple method method very high pressure could be developed by using simple low pressure

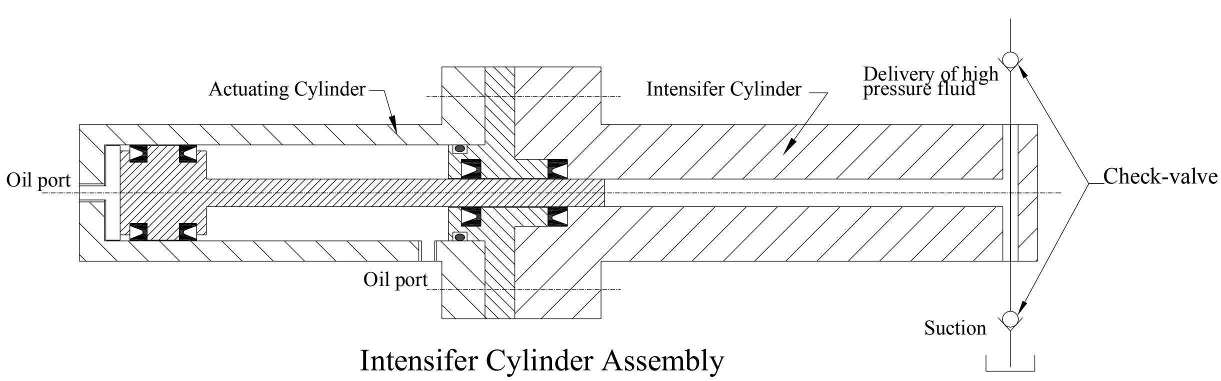
8.3.12 Hydro-Pneumatic Reciprocating Pump: -

This is also a type of compound cylinder, it consist of a double acting pneumatic cylinder and a single action hydraulic cylinder with common piston rod. Pneumatic cylinder is completely made from non-magnetic material such as aluminum, brass or non-magnetic stainless steel. Piston ring of pneumatic cylinder consists of an additional magnetic ring. Out side cylinder tube two "Proximity switches" are provided at both ends of cylinder tube. When piston with magnetic ring passes near the proximity switch, it actuate. Proximity switch closes the electrical circuit and supply of current to the coil of pneumatic direction control valve to actuate it. Pneumatic direction control valve is detention type, that is once it get energized it changes its position, and even after its coil gets de-energised, it remain in same position, and do not changes its position, unless other side of coil is energised to changes it's direction.

In operation, pressurized air is supplied to four-way-two-position pneumatic direction control, which operates cylinder, as cylinder takes its stroke, and piston with magnetic ring moves across the "Proximity switch" it temporarily energies coils of direction control valve for the reverse direction of cylinder. As reverse stroke progress, even though direction control valve get de-energized but do remain in same position due to its detention characteristic. When reverse stroke reaches its end, piston passes through the other "Proximity switch", it get operated for a very short period of time. But in that short period it energies coil of direction control valve for forward stroke and again change the direction of cylinder. That is how it changes direction of stroke and cylinder keep on reciprocating. This reciprocating pneumatic cylinder connected to a single action type of hydraulic cylinder, with two-check valve, which on its retraction stroke suck oil, and on its forward stroke deliver oil under pressure.

The simple system we have described is by using magnetic ring, Proximity switch and detention type Direction control valve. Reciprocating pumps are also available which are with out Proximity switch, and use only special pneumatic direction control valve. In one such system, pneumatic cylinder has cushion like arrangement at its both end. When piston reaches the end of its stroke the pressure of air trapped between piston and end-cover increases slightly more than supplied air pressure. This extra pressure is used to change the direction of detention type direction control valve. In operation spool of direction control valve get equal air pressure at its both end and remain in balance, but at the end of stroke increase in pressure of the air-trapped in cushion chamber off balance it and changes its direction.

So on this principle cylinder keeps on reciprocating and keep on pump flanged at pressure as reciprocating pump.



Intensifer Cylinder Assembly
Figure No. 8.3.12

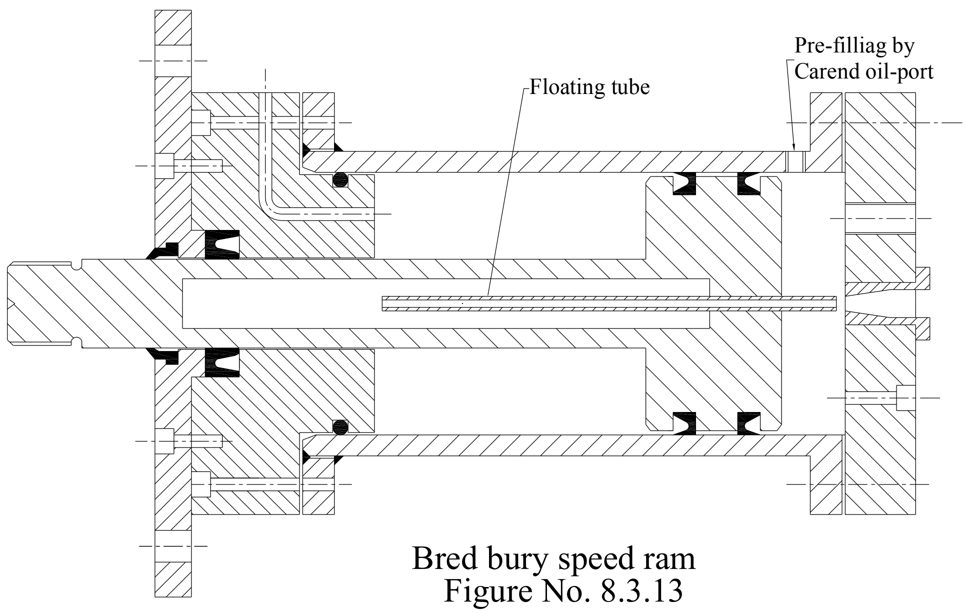
8.3.13 Bred Bury Speed Ram: -

This is also a type of compound cylinder, in which ram of secondary cylinder is a free-floating tube. Refer figure.

Primary cylinder is similar to convention at double action cylinder, but with hollow ram. A tube freely float in this hollow ram, and held freely at some distance from inlet oil port. Oil is injected through a nozzle at high velocity in the tube. When oil come out from other end of tube inside hollow ram at high velocity, as velocity decreases, pressure increases. This pressure forces tubes out of hollow ram, and presses it firmly on the opening of nozzle. This allows all the oil injected by nozzle to pass on to hollow ram and force it out at high speed. As ram take its stroke at high speed the volume of cap end cylinder is filled by oil through a large size of pre-fill valve, to avoid cavitations.

As main ram (hollow ram) reaches its full stroke, some arrangement is made to leak the pressurized oil getting injected in hollow ram to main cap-end area of cylinder, to develop full pressure and force. This may be achieved by providing a side hole in tube or making it taper at the end and increase the clearance.

This cylinder gives very high speed with very small capacity pump and motor. Speed ram is developed by Mr. Farel bred bury, and m/s. Broughton Redman Engineering Ltd. Birmingham is Licensees to manufacture these cylinder commercially.

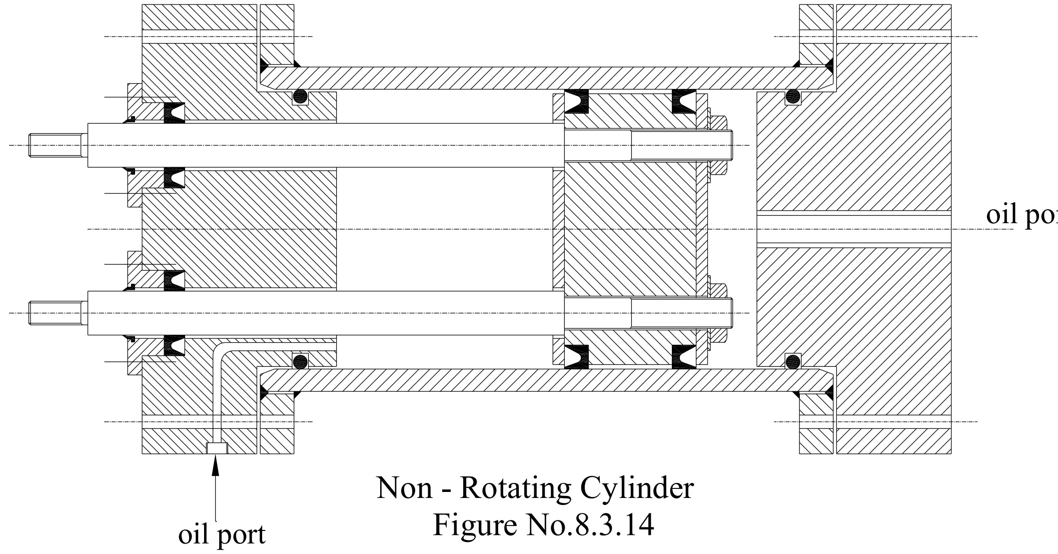


Bred bury speed ram
Figure No. 8.3.13

8.3.14 Non - Rotating Cylinder: -

Cylinder, piston, piston-rod, guide-bush, gland-bush all these components have circular guide. When piston and piston rod take their stroke more, they are free to rotate. Hence alongwith a desired linear motion, there is also an undesired rotary motion of piston rod along its central axis. When a cylinder is assembled in hydraulic press and piston - rod is coupled to moving platen, this rotary motion gets arrested. But when cylinder is not assembled in hydraulic press, and is required to perform independently in various operations such as marking, punching, indexing etc. and rotary motion of piston-rod not desired then piston-rod is guided externally. But this additional and external guide takes lots of space and is a costly affair.

Hence non-rotating type of cylinders has been developed. It is similar to conventional double action cylinder with three piston rods. All the three piston rod are coupled to same piston, and passes through guide-bush, gland-bush etc. While manufacturing such cylinders, too much precaution has to be taken regarding quality control. But if made correctly then these are economical and convenient to use, and give good performance.



Non - Rotating Cylinder
Figure No.8.3.14

8.3.15 Hydro - Pneumatic Cylinder: -

These are very important type of cylinders used extensive in industry for such operations which require high production, very short production cycle, They require small stroke of cylinder under load, such as punching reverting, marking etc.

Hydro-pneumatic cylinder is a compound cylinder in which a pneumatic cylinder and hydraulic cylinder are assembled together in a special way.

Following figure and description will explain it various component and operation.

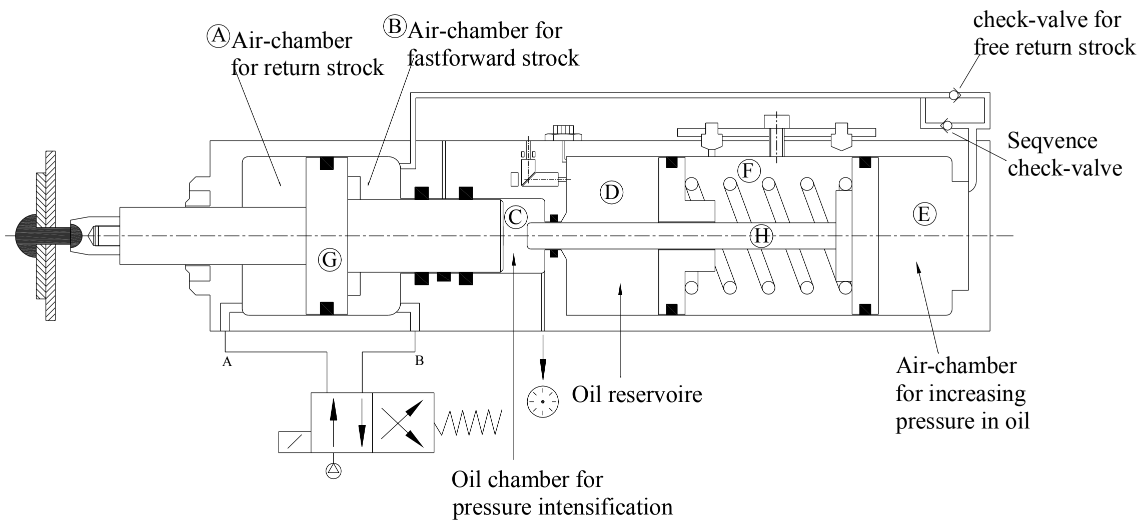


Figure No.8.3.15

1] System start with revetting plunger at retracted position, and valve in switch-off condition.

2] To start system solenoil valve is energies, which cause supply of air in chamber.(B) which is air chamber for a forward stroke. In this energized condition of solenoil chamber (E) which is air chamber for increasing pressure in oil is also get connected to air - pressure line. But due to sequence check-valve, air does not enter in this chamber up to a set pressure (may be 5 bar). Because of this oil get sucked in chamber (C) from (D) which is oil reservoir chamber. Spring (F) expand when oil is sucked from chamber (D) to chamber (C). This also creates low pressure in chamber (E) and favorable condition for cracking sequence check-valve.

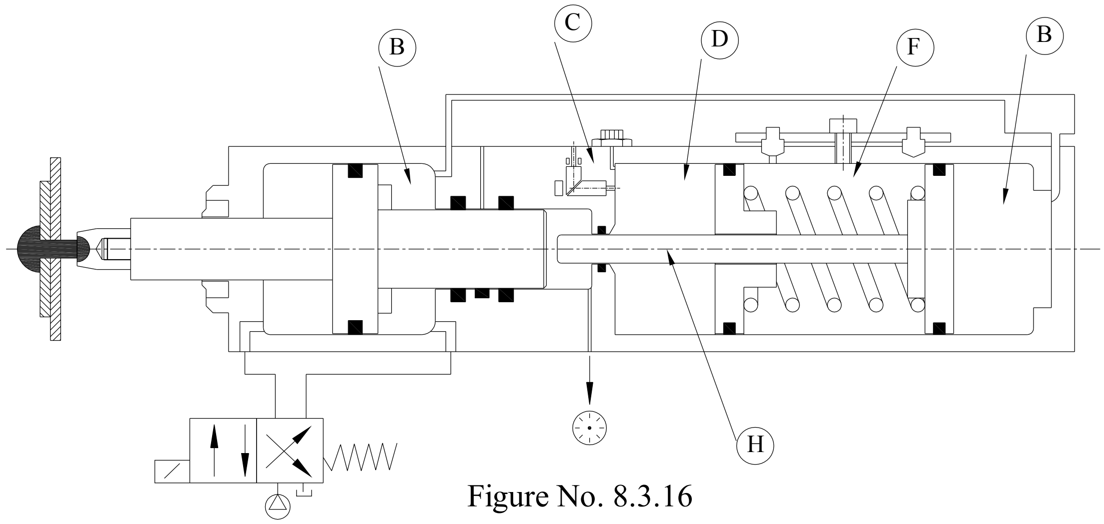


Figure No. 8.3.16

3] When reveting punch senses some resistance, air pressure increases and over come resistance offered by sequence check valve, and pressurised air enter in chamber (E). This causes plunger
(H) to enter in chamber (C). As soon plunger (H) enter the opening of chamber (C), oil get trapped in chamber (C) due to oil seal and fine clearance. When air pressure further increases in chamber (E) it exert more force on plunger (H). This causes increase in pressure in oil in chamber (C).

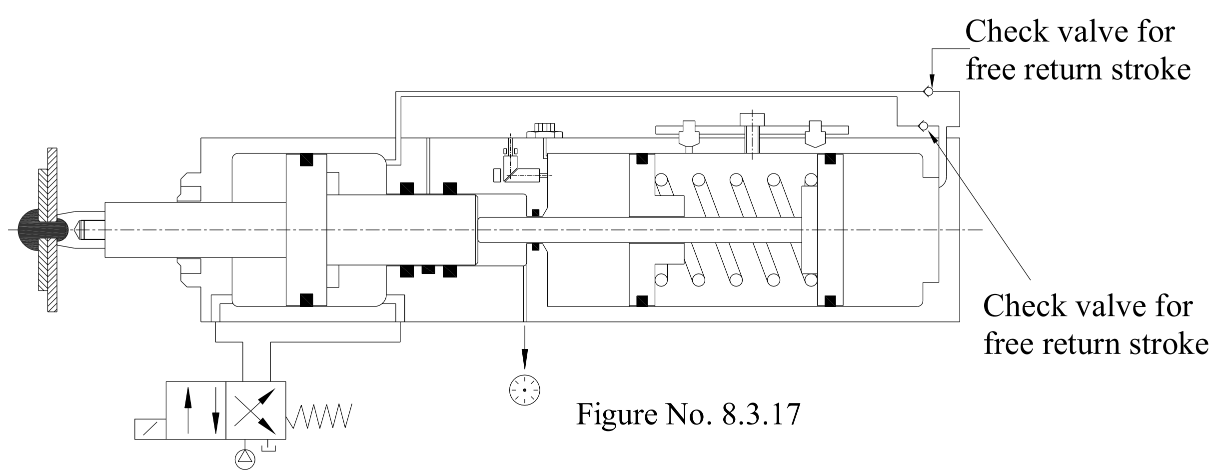


Figure No. 8.3.17

4] As soon as reveting get completed, solenoil valve get de-energized, which connect chamber (B) and (E) to atmosphere, and chamber (A) to compress pressure. This causes plunger (G) and (H) to retract under pressure of air and oil and transfer of oil from chamber (C) to (D).

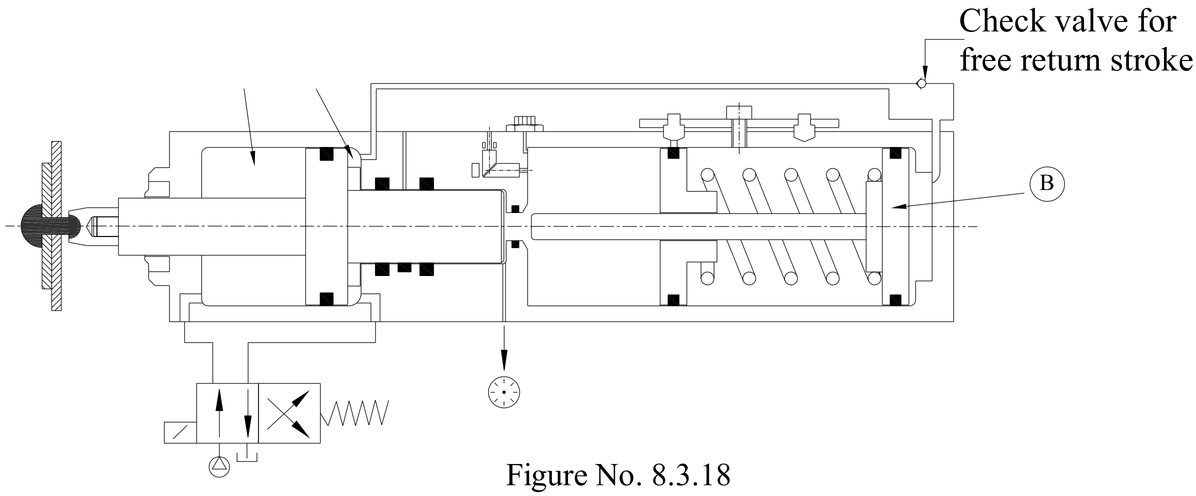


Figure No. 8.3.18

8.3.16 Duplex Cylinder: -

These are two standard double action cylinder with independent direction control valve. These cylinder are mechanically connected to each other with a common central axis. By this arrangement we get number of piston-rod position depending on application.

8.3.17 Tendum Cylinder: -

In case of tendum cylinders we have two or more cylinders with inter connected piston assemblies.

8.3.18 Adjustable Stroke Cylinder: -

In this type of cylinder we have external mechanical arrangement, such as thread and lock-nut etc., to adjust and stop travel of piston-rod at desirable position.

8.4 Design of a Hydraulic Cylinder

8.4.1 Importance of safe design: -

Hydraulic cylinder is actuated by hydraulic fluid at very high pressure. Any failure of cylinder may cause an explosion or ejection of a high velocity jet of oil, which may cause extensive damage to property and fatal injury to human being. Hence most precaution should be taken while designing a hydraulic cylinder. Author knows and has seen many accidents, which has cause lose of life,

He has described few accidents in chapter of “accidents by hydraulic system”. Hence study thoroughly the theoretical and practical aspect of design and then manufacture hydraulic cylinder.

8.4.2 Design of Cylinder Tube: -

In designing cylinder tube, we basically calculate it's inside diameter and wall thickness. Inside diameter and wall thickness depends upon capacity of cylinder and working pressure. In following paragraphs we will study how to determine these parameters.

8.4.3 Capacity of Hydraulic Cylinder:-

Capacity of a hydraulic cylinder is decided by the purpose for which cylinder is going to be used. For example, if a cylinder is to be designed for deep drawing press to draw a particular utensil. Then the capacity of cylinder will depend upon the size of utensil and thickness and mechanical property of material to be drawn.

Hence before designing a cylinder it's capacity is determined, considering the operation it has to perform.

8.4.4 Working Pressure: -

Working pressure of a system can vary from minimum possible to 700 Bar or more. It is selected on two factors.

1. Size Constraint of cylinder
2. Type of valves and pump to be used in system.

1] Size Constraint of cylinder

a) Rubber molding presses are generally up-stroke presses, with larger presses table mounted directly on piston rod. To support press-table firmly piston-rod should be of sufficiently large diameter. For large piston-rod diameter, cylinder Inside Diameter should be more. Keeping same pressing capacity if Inside Diameter of cylinder has to be increased then pressure has to be reduced.

So to support large size of table, working pressure of system reduced.

b) Jacks are used for lifting various vehicles and equipment. Generally they are lifted and placed in position by hand. For convenience in handling the weight of jack should be low. To reduce weight the size of jack is reduced. For keeping same lifting capacity and to reduce size, working presses of jack is increased to as high as 700 Bar.

Hence in this case working pressure increased to reduce the size of cylinder.

Similarly in most of the cases the space and size restriction in equipment where cylinder has to be fitted, influence the selection of working pressure.

If there is no restriction on size of cylinder, then pressure is decided by type of hydraulic valves and pump to be used in system. Type of valve and pump to be used is decided by.

a) Monetary budget.
b) Automation of system.
c) Type of equipment.

When budget is too low for manufacturing a hydraulic system, then gear or vane pump is used. These pumps give optimum performance and continue pressure below 175 Bar. Hence for such pumps, system pressure is kept 175 bar or less then that.

For common budget when piston pump is to be used then pressure could be kept up to 350Bar.

When system is to be used along with control panel. Then solenoid operated direction control valves has to be used. Such valves are designed for 315 Bar to 350 Bar. But they give optimum performance below 300 Bar. Hence when solenoid operated direction control valve is to be used then pressure is selected bellow 300 Bar.

For system like jacks, where size is to be kept minimum. And there is no automation, then using piston pump or hand pump, pressure as high as 700 Bar can be achieved, and selected.

Hence before designing a cylinder-tube we decide two factors i.e. capacity and working pressure. And once these two are decided then using various theories and formulas we can calculate inside diameter of cylinder and wall thickness.

First we will discuss various theories and formulas for theoretically calculating the required dimension of cylinder tube. Then we will discuss the practical part of it. That is how to manipulate the theoretically calculated size so that practically it is possible, feasible and economical to manufacture the hydraulic cylinder tube.

8.4.5 Theoretical Design of Main Shell OR Cylinder Tube: -

Cylinder tubes are divided in to two categories.

1) Thin Cylinder Tube
2) Thick Cylinder Tube

For simplicity we will call cylinder tube as cylinder only in this chapter. When ratio of cylinder bore to wall thickness is more than 10 then it is called thin cylinder. And when it is equal to or less than 10 then it is called thick cylinder. Equations to calculate wall thickness, and assumption made to used them are different, hence we will discuses them individually as follow.

8.4.6 Design Of Thin Cylinder: -

The analysis of stress induced in thin cylinder is made on the following assumptions

The effect of curvature of the cylinder wall is neglected.

The tensile stresses are uniformly distributed over the section of the walls.

The effect of the restraining action of
the heads at the end of the cylinder tube is neglected.

Whenever a cylinder is subjected to an internal pressure, it is likely to fail either by splitting up into two cylinders (splitting circumferentially) or splitting it up into two troughs (splitting longitudinally). As shown in figures. No.

Hence the wall of thin cylinder when subjected to internal pressure has to withstand following two types of tensile stress.

a) Circumferential or hoop tress.
b) Longitudinal stress.

a) Circumferential or hoop tress:
Consider thin cylinder subjected to internal pressure. Tensile stress acting in a direction tangential to the circumference is called circumferential stress or hoop stress. It is a tensile stress in longitudinal section. And expressed as

P = Intensity of Pressure (Kg/cm²)
d = Inside diameter of cylinder (cm)
t = Thickness of cylinder(cm)
ft = Circumferential stress or hoop stress
in the cylinder (Kg/cm²)

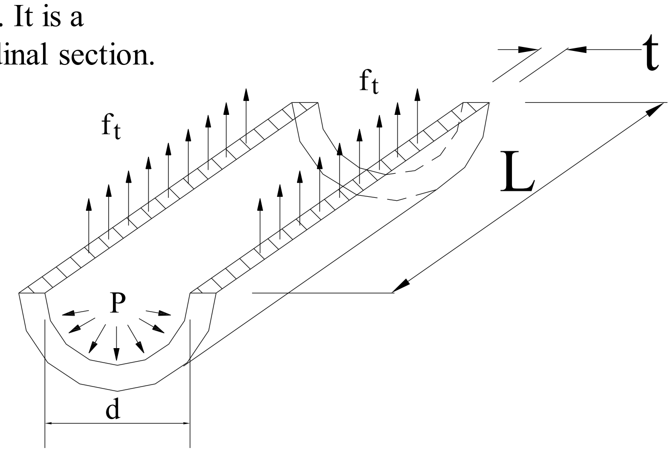
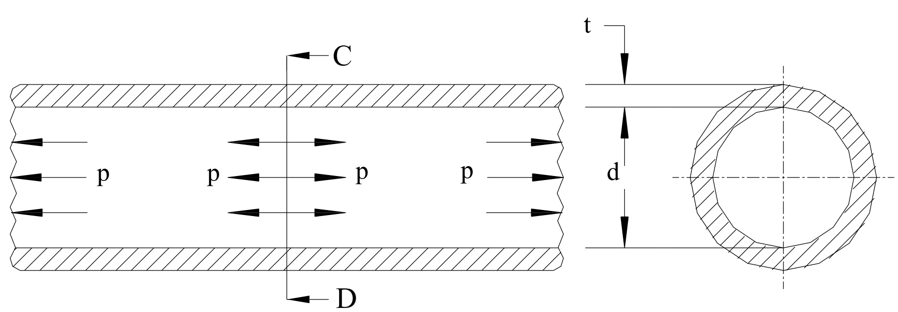


Figure No.8.4.1

In a closed vessel, tensile stress acting in the direction of the axis is the called longitudinal stress. It is stress acting on the circumferential section CD as shown in following figure.



Section CD

Figure No. 8.4.2

Longitudinal Stress (ft) could be expressed as = f

8.4.5 Thin Spherical Shells: -

Sometime the end cover of casted cylinder is in spherical shape. When thin spherical shell subjected internal pressure tensile stress get developed in its wall, the thickness is calculated by following equation.

$$f_t = \frac{Pd}{4t}$$

When P = Intensity of Pressure (Kg/cm²)
d = Inside diameter of shell (cm)
t = Thickness of shell (cm)
ft = permissible Tensile stress in shell material (Kg/cm²)

8.4.8 Design Of Thick Cylinder: -

In case of thin cylinder, stress assumed to be uniformly distributed over the section of wall, but in case of thick cylinder same assumption cannot be made. In case of thick cylinder stress distribution are as follow.

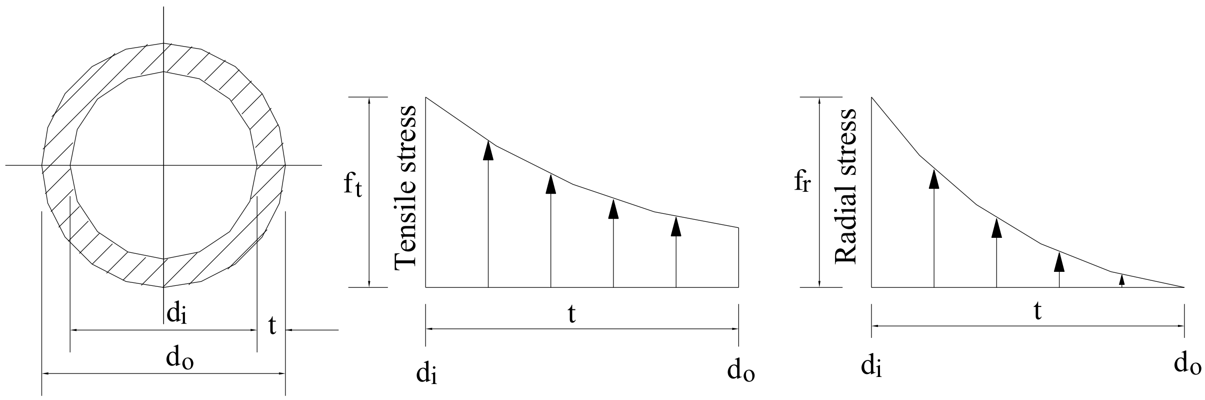


Figure No. 8.3.3

Maximum radial stresses are generally equal to the internal pressure, and it is maximum at inner surface of cylinder.

fr (max) = -p.

For calculating tangential stress following four equations are used.

1) Lame's equation: -

$$ft(max) = \frac{P\,(d_o^2 + d_i^2)}{(d_o^2 - d_i^2)}$$

$$t = \frac{d_i}{2}\left(\sqrt{\frac{f_t + P}{f_t - P}} - 1\right)$$

Lame's equation is used for designing cylinder of brittle material and it depends on maximum-stress theory of failure, and could be used for open as well as closed cylinder.

2) Brinie's equation: -

Brinie's equation depends upon the maximum strain theory of failure. That is failure will occur when the strain reaches a limiting value. According to this theory the wall thickness of cylinder is.

$$t = \frac{d_i}{2}\left[\sqrt{\frac{f_t + (1 - \mu)P}{f_t + (1 + \mu)P}} - 1\right]$$

This equation is generally used for open-end cylinder made of ductile material, such as gun-barrels.

3) Clavarino's equation: -

This equation is similar to Birnie's equation, but applies to closed-end cylinder made of ductile material. According to this equation the thickness of a cylinder.

$$t = \frac{Pd_i}{2}\left[\sqrt{\frac{f_t + (1-\mu)P}{f_t - (1+\mu)P}} - 1\right]$$

4) Barlow's equation: -

This equation is generally used for high pressure oil and gas pipes. According to this equation, the thickness of a cylinder.

$$t = \frac{Pd_o}{2f_t}$$

8.3.9 Design of Cylinder End-Plug (Cover Plate): -

Cylinder end-plug may be, threaded, bolted, welded or integral part of cylinder shell. When end-plug is flats in shape, then its minimum thickness can be calculated by following emperical formula.

When di = Inside diameter of cylinder (cm)
k = An empirical cofficient and equal to 0.162
P = Pressure inside cylinder (kg/cm²)
ft = Permissible tensile stress for the materal of the plate (Kg/cm²)

$$t = d_i\sqrt{\frac{kp}{f_t}}$$

8.4.10 Practical way of Selection of cylinder tube: -

Using various equations and theories as mentioned above we calculate various parameters of cylinder tube. But by using theory and equation if we arrive at non-standard dimension of pipe and tube, then we may not get it easily in market, and manufacturing odd sizes are always costly in producing and difficult to maintain. Hence in following paragraph we will discuss the standard parameters of cylinder, and sizes which are easily available in industry and in market.

8.4.11 Inside Diameter of Cylinder as per ISI Standard: -

Indian standard (IS : 8208-1976) recommend following sizes of inside diameter of cylinder.
8,10,20,25,32,40,50,63,80,100,125,160,200,250,320,400., Hence if possible we select inside diameter as per ISI standard.

8.4.12 ID of Cylinder as per Preferred Number: -

If by calculation we arrive at figure, which is in-between two standard ISI sizes. And small standard size may not be feasible and higher size may not be possible. In such case we decide the value of inside diameter which matches with value of numbers in preferred number series such as R5, R10, R20, R40 or derived sizes from it. (See chapter on preferred number for detail.

8.4.13 ID of Cylinder as per availability of Seamless Pipe: -

Even if we round off the dimensions of inside diameter of cylinder as per basic series of preferred number. Then that size may not be available in market. Making a pipe by boring a solid round is not an easy job, and impossible if length of pipe is more. Hence we should know which standard size is available in market. Our design and drawing should based on such sizes only, other wise it may not be economical and possible to manufacture a cylinder shell.
ASTM standards are world famous and recognized, hence good quality pipe made on such standards are more easily available from local and international companies.
ASTM has defined many standard nominal bore diameters. For each nominal bore sizes they have defined ten various thicknesses, and named it as Schedule. They have given a number to each schedule such as10,20,30,40,60,80,100,140, 160. Out of 10 schedules we generally use schedule 80 & 160 in hydraulic application. In Annexure we have given complete detail of pipe as per ASTM standard.
Indian standard has also defined various nominal bore diameters. And instead of classifying each nominal bore into ten schedules, they have classified it in to three categories, namely light duty, medium duty, and heavy duty.
In Annexure we have also described pipes as per Indian standard . If we design and select the inside diameter of cylinder and its wall thickness as per the standard pipes available in market, and machine it as per preferred series or advice by ISI Standard, then manufacturing and maintenance of hydraulic cylinder will be much more convenient and economical.

8.4.14 ID of Cylinder as per Seal: -

Seal are available in standard dimension. Care should be taken that the final dimension of cylinder is also as per the availability of standard seal. Seals of odd dimension also could be made, but than keeping spare, and maintenance will be always a problem.

8.4.15 Manufacturing of Cylinder Tube: -

Selection of cylinder tube material depends upon.

1. Constraint about size of cylinder, and its design.
2. Working medium.

If size of cylinder has to be reduced keeping the tonnage (pressing capacity) same. Then working pressure has to be increased. As working pressure increase corresponding hoop stress also increase. To cope up with higher stress either wall thickness has to be increased or material with higher allowable stress has to be selected. To reduce over all size mostly material with higher allowable stress are selected. Such as plain carbon steel or low or medium alloy steel. But these materials are difficult to weld.
If working medium of hydraulic cylinder is of corrosive in nature, then brass or stainless steel seamless pipe are used.
If there is no constraint about size, and working fluid is also not corrosive, then for such standard working condition seamless pipe of low carbon steel is used, in which carbon percentage is between 0.15 to 0.35%. Indian standard, and standard of other countries such as ASTM, DIN, BS and other standards have defined more than 10 various groups of materials for seamless pipe, with varying percentage of carbon and other element. But most widely used material is ASTM. A106 grade B. For more detail refer chapter "Material used in Hydraulic Presses".

a. Machining: -

For manufacturing of hydraulic cylinder tube, we cut pipe to the length, then machine it by turning, and boring its inside diameter on lathe machine. Then hone it on honing machine. As per IS-2709-1965 by honing it is possible to control tolerance limit up to H4 to H5. But the requirement

of fitting tolerance in cylinder is that cylinder tube inside diameter and piston outside diameter should have normal to easy running fits. Hence inside diameter of cylinder tube is made as per H7 to H9 tolerance grade and piston outside diameter as per f8 to e8 tolerance grade. Selection of tolerance grade depend upon inside diameter, length of cylinder tube, working pressure, duty cycle, and how critical the system is.
By honing operation we can achieve surface finish up to 0.2 micron but for optimum result Ra value is kept between 0.4 to 0.8 micron and tool mark at 45%%D to central axis.

The roughness of cylinder ID & its reason:-

Hydraulic cylinder inside diameter surface roughness we keep 0.4 to 0.8 micron Ra value for standard operation. Roughness should not be less than 0.2 mm Ra. Because hydraulic seal rubs the cylinder inside diameter under pressure, if roughness is more friction will be more and seals will fail due to wear and tear. But if roughness is too less, then such smooth surface do not retain oil film which can cause increase in friction between seal and cylinder due to dry running, which again cause heat generation and seal life get reduced.
Surface of cylinder must retain some oil film for seal lubrication. Surface roughness 0.4 to 0.8 micron and honing tool mark at 45%%D to central axis gives optimum result.

Extra Protection of Cylinder Tube Inside Surface: -

Piston rubs against the cylinder inside diameter, which is honed surface. Piston also has bearing material lining hence do not damage the honed surface. Hence for general purpose, and common hydraulic application cylinder tubes are only honed, and used. But in those cases when cylinder may not be used for long period, then the honed surface may get damage due to atmospheric moisture and corrosion. In such case it is hard-chromplated. Pneumatic cylinders are also chrome plated as air contains moisture.
In those cases where honed cylinders tube may or may not be used for hydraulic cylinder. But has to under go most server service condition, then to protect its honed surface it is nitrated. Nitrating make skin of cylinder inside diameter very hard, and corrosion resistance. For example gun-barrels, Barrel's of plastic extrudes etc. But for nitrating material of cylinder should be of capable of getting heat treated. For example alloy steel EN41B is used for barrel for plastic extrusion.
For further detail about hard-chrome plating and nitrating refer chapter on "Surface Protection " and "Heat Treatment".

Welding of Hydraulic Cylinder: -

Most critical welding in hydraulic press is a welding of end plug of hydraulic cylinder. Hence we will particularly study welding procedure of end-plug.

Design And Welding Procedure: -

Step 1. Calculate and decide the thickness of end-plug by equation.
Step 2. First end-plug is threaded and fitted in cylinder then welded. Calculate the number of thread required to takes the full load coming on end-plug.
Load on end-plug (W) = $0.785 x di^2 x p$
Load on end-plug is support by threads.

$$W = dt \times 3.14 \times Pt \times n \times fs$$

Where di = Inside diameter of cylinder (cm)

P = Working pressure (kg/cm²)

dt = Pitch circle diameter (cm)

Pt = pitch of thread on end-plug

n = Number of thread required

fs = Permissible shear stress of

material of end-plug (kg/cm²) Hence by above equation thickness of end-plug and number of thread is calculated.

Make threading and fit end-plug in cylinder

Step 3. For welding, prepare the welding joint while machining the end-plug and cylinder.

Step 4. Tighten the thread to maximum extent. So that end-plug do not have clearance for movement under pressure. Threads are for taking load, and welding though can take load, but use them only for making joint leak proof.

Step 5. Heat the joint and cover remaining portion of cylinder to avoid heat loss. Heat between 100%%DC to 200%%DC.

Step 6. Use low hydrogen electrode for welding. Bake welding electrode before welding.

Step 7. Run first weld as shown in figure.

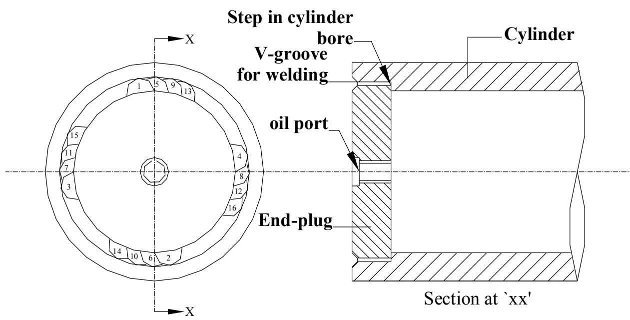


Figure No. 8.3.4

Step 8. In case of large cylinder use penning to over come pulling of end-plug on one side due to shrinkage in weld deposit. For penning, weld a small portion, clean the flux, take a blunt chisel, and hammer the weld deposit with such a blow that it flatten the weld deposit. Do all this when weld deposit is still at sufficient high temperature. Repeat this till welding completed.

Step 9. When welding gets completed cover the whole cylinder, so that full cylinder get slowly cooled. In no condition cold water or any thing fall on heated welding joint. Neither it should left in cool breeze for air cooling.

By natural cooling fine-grain structure will get produce, which are ductile and soft. Even if coarse grain get produced which has less strength, then also it does not matter, as load is taken by thread and not welded joint.

All cylinders expand when pressurized and contract on releasing pressure. If rate of cooling allowed to be vary fast then martensite grain structure will get produced in welded joint, which are very hard, brittle and welding will crack on cylinder pressurization.

Step 10. Next day when cylinder get cooled downed clean welded joint, and inspect for any crack developed. Test it and if it is found OK them said cylinder can be used for further operation.

Step 11. If welding cracks than remove all weld deposit, check chemical composition of cylinder tube and end-plug, and select welding electrode and welding procedure as per the requirement of that grade or type of material.

Any welding done on a cracked weld deposit tends to crack again hence it is better remove all old crack weld deposit before welding again.

Step 12. Use low hydrogen-electrode of grade E 7016 for welding. If welding is cracking even after using E7016 electrode as per standard procedure, then use electrode for stainless steel welding such as AWS/SFA:E309-17 electrode. As these electrode are for welding high alloy steel to un alloy so in majority of cases cracking problem get solved by using them.

Some fact and figure to be remembered while calculating the force developed by cylinder.

1] There is a drop in pressure, when oil passes through orifice, bends, and pipe line. hence what ever pressure get developed at pump outlet will not be same at cylinder inlet, but it will be lower them that and difference will be corresponding to pressure drop.

2] Oil returning to the tank from other port of cylinder may not be at atmospheric pressure, but it will have some back-presssure. Back pressure may be intentionally developed by counter-balance value or check-valve or it may get developed naturally due to throttling, checked return line etc. Back pressure will counter-act the force developed by cylinder.

3] Hydraulic seal such as chevron-packing, O-ring etc. are pre-compreased at the time of assembly. Under pressure they get energised and further pressure against mating parts. Hence after resistance against motion between cylinder piston, and piston-rod. This resisting force reduces the effectiveness of force developed by cylinder.

1) Force developed by cylinder (ignoring pressure drop)

$$f_t = PA - P_b A_r \text{ kgf.}$$

2) Sum of friction force and force due to back pressur.(kgf)

$$SF = F_f + P_b A_r$$

3) Actual out-put force kgf.

$$f_a = PA - Sf$$

4) $\text{Velocity} = V_t = \frac{Qc}{6A} \text{ m/sec}$

5) Acual Velocity $V_a = Qc - Q_{\ell 1} / 6A$ M/Sec

(Output flow from cylinder $Q_o = v_o Ar + Q_{\ell 1} - Q_{\ell 2}$)

$Q_{\ell 1} =$ Interport leakge in lit/min

$Q_{\ell 2} =$ External leakge in lit / min

6) power input to the cylinder (kw)

$$P \text{ input} = PQ_c / 612 \text{ kW}$$

7) power output from cylinder (kw)

$$P \text{ output} = F_c V_a / 102 \text{ kw}$$

8.5 Piston Rod

Piston rod transfers the force developed at piston to work piece. This force may be pushing or pulling. Piston rod is designed to transfer these forces along its central axis. It is not designed or expected to take any side bending load.
As the force acts through its central axis only, hence when length of piston rod is shorter, then the cross-section required to transfer force within safe stress limit can be calculated using basic simple formula such as.
Force to be transfer = cross-section area x permissible compressive or tensile stress.

$$W = (0.785)\ d2 \times f$$

But for longer piston rod same above mentioned formula can be not used. As piston rod fails at much lower stress value by buckling.
For calculating various parameters of long piston rod, following formulas could be used.

End condition of Piston Rod	**Buckling Load For Solid Circular**
Outer end of rod hinged	$^2 E R^2 / 2 L^2$
Outer end of rod free	$^2 E R^2 / 16 L^2$
Outer end of rod fixed	$^2 E R^2 / L^2$

Taking into consideration manufacturing process of cylinder, its rigidity required in service, installation
condition and other factors, it is advisable to keep the ratio of the piston-rod length to it's diameter less then 20.
Factors affecting the selection of size of piston-rod: -

By means of engineering formulas and graphs we can find the minimum diameter required for the piston rod. But actual size must be decided after referring to following factor.

a) ISI / ISO Standards
b) Availability of Seals
c) Pulling force required keeping inside diameter of cylinder same.
d) Type of piston and piston rod assembly.

1. ISI Standard: -
ISI standard has suggested following sizes of piston rod. 6, 8, 10, 12, 14, 16, 18, 20, 22, 25, 28, 32, 36, 40, 45, 50, 56, 63, 70, 80, 90, 100, 110, 125, 140, 160, 180, 200, 220, 250, 280, 320, 360.
Up-to 70mm size of piston rods are available in ground and hard chromplated condition in market
2. Availability of Seals: -
If Rod size could not be selected as per ISI, then rod size should be selected as per standard seal available in market. For example on calculation if we got piston rod diameter as 239, which is much higher than 220 and much less than 250, in such case if should be rounded off to 240.
Nowadays machined seals are also available by which we can make any size of seal within few minutes. So we can keep any size of piston-rod, then also keeping some standard in design is always better.

3. Rod size required for pulling load: -
Sometime cylinder has to perform pulling operation. For higher pulling force annular area between

cylinder-bore and piston rod should be more. Keeping inside diameter of cylinder minimum possible, for larger annular area diameter of piston rod has to be small. Keeping the pulling load same, if diameter of rod has to be reduced, then piston rod should be of alloy steel.

Hence before selecting diameter, pulling force, required strength of alloy steel to be used, and heat-treatment of alloy-steel has to be studied and selected carefully.

4. Integral type of piston-rod and piston assembly: -

When piston and piston rod are integral type. Then keeping larger size of piston rod is more advisable, as raw material selected is of piston diameter. We machine it, and remove material to reduce diameter to make piston-rod as per calculation. If diameter is kept higher then time of machining will be saved, strength of piston-rod will increases. As annular area between piston-rod and cylinder will decrease, return speed of cylinder will also increase.

Only precaution is to be taken that the annular area of piston which is between piston-rod and cylinder inside diameter, and which will presses against guide-bush and apply full load in case of fully extended stroke, must be sufficiently large. This ensures that the compressive stress developed remain in safe limit. If annular area is less and compressive stress crosses the safe limit then both piston and guide-bush will yield, and guide-bush may grip the piston-rod and damage its outer smooth surface.

Material used for piston rod: -

Generally ground and hard-chrome plated rod of C40 or EN8-B grade material and in standard size is available in market and widely used for piston-rod. Piston-rod can also be made from, cast-iron (for larger size and short length of piston-rod under compressive load) mild steel, alloy steel, stainless steel, etc, depending upon application and various parameter. Nowadays stainless steel of 304 grade in ground and polished condition are also available, which are much better than C40 grade piston rod.

Manufacturing of piston rod: -

a) Raw materials of higher size made by forging etc. are tested for its chemical composition. It is also tested ultrasonically for internal crack etc.

b) Raw material turned, ground, and hard-chrome plated.

c) Generally the thickness of plating is kept about 50 micron. Hardness of coating about 55-60 RC.

d) Plated shaft is polished to achieve 0.1 to 0.4 micron Ra, surface finish.

e) Piston rods are generally machines as per f8 tolerance grade. Depending precision it also could be machined as per g8 or h8 tolerance grade.

f) Smooth chamfer should be given at all sharp edges for easy assembly of seals. No sharp groove should be provided to avoid stress concentration. Threading etc. should be made as per ISI standard.

g) All ready to assemble piston rods should be applied with anti-rust solution, and wrapped up properly to avoid any rusting or damage to polished surface.

h) Thickness of chrome plating on piston-rod surface is generally uneven after plating. Hence in case of precise equipment, piston rod should be ground again after plating.
More chromium get deposited at both end of piston rod, hence when grinding after plating is not required, then at both end, diameter should be reduced by 0.1mm to 0.2 mm in 20mm length, to compensates excess chromium deposition.

I) In general C-40 grade material in use for making piston-rod. In British standard it is D grade En-8 material, which contains 0.44% carbon.

J) Bent piston-rod should not be used. 0.5mm run-out in 1 meter length is permissible limit of its strengthens.

8.5.1 PISTON

Piston is a sliding part of cylinder, which is attached to piston rod. It accommodate hydraulic seals to avoid leakage between cylinder and piston. It is also fitted with guide-ring, wear rings, or piston itself may be made from bearing material to protect the honed inside surface of cylinder.

Piston withstands the full load developed by pressurized oil and transfers it to the piston rod. It is the first member, which bear and transfer the load, hence it should be designed accordingly for its satisfactory performance.

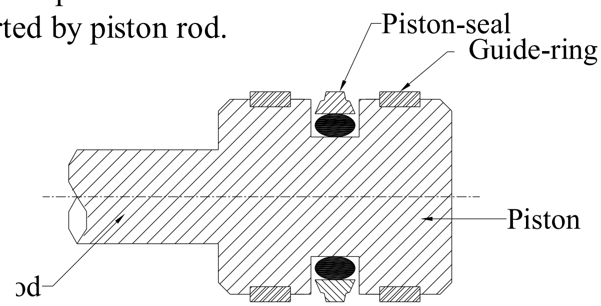
Design of Piston: -

According to the attachment with piston rod, piston can be classified in two categories.

a) Piston as integral part of piston rod.

b) Piston simply supported by piston rod.

Integral type of piston rod: -



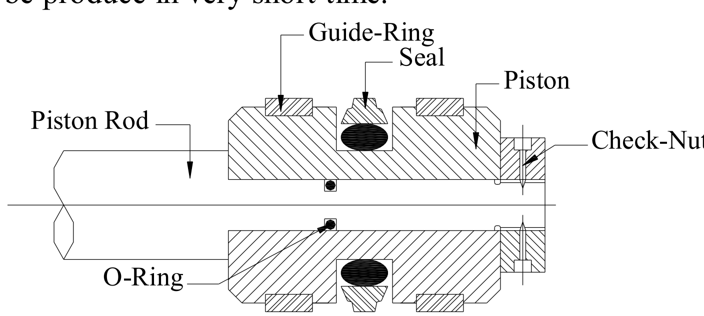
Piston as integral part of Piston-rod
Figure No. 8.5.1

Integral type of piston and piston rod arrangement is generally used for large size of piston rod, and high capacity cylinder. And in any cylinder this arrangement will be more economical where length of piston rod is short and diameter of piston rod is very close to inside diameter of cylinder. This arrangement is more sturdy than supported type. Perfect alignment also always remain between piston, piston rod, cylinder tube, guide-bush, hence more life to seal and less wear and tear to guides.

Simply supported type of piston or assembled type of piston: -

This type piston is attached to piston rod by means of threads or simply assembled on end of piston rod and retained by check-nut.

This type of assembly is most-widely used in industry, as it is convenient for mass-production of piston of standard dimension. Piston rod is also mass produce as straight ground and hard-chrome plated rods. As Inside Diameter of cylinder, Outside Diameter of piston rod and seals etc. are all as per Indian or international standard, so whenever a cylinder is to be made then tube and piston rod are cut as per required stroke, and piston and other component which are same for a particular Iiside Diameter of cylinder are assemble together. Hence a good quality cylinder of standard dimension could be produce in very short time.



Piston assembled on Piston Rod
Figure No. 8.5.2

Calculation of piston dimensions: -

1. Outside Diameter of piston is as per the Inside Diameter of cylinder tube, and machined generally with f8 grade of tolerance. If piston is of simply supported type then Inside Diameter of piston should be machined as per H7 to H9 standard and surface finish also should be good as o-ring rub against it.
2. Thickness of piston depends upon the load which has to be transfer. Under load piston may fail in two way. First by bending load and second by shear stress. We will study how to calculate the thickness of piston to withstand these two types of load satisfactorily as follow.

Thickness of piston subjected to bending: -

Outside diameter of piston is as per inside diameter of cylinder. The oil under pressure applies uniform load on its complete projected area. While piston is supported on its other side only at small annular area of piston-rod. As there is large un-supported areas, hence piston is subjected to bending stress, which tends to bend piston and make it a dish like structure.

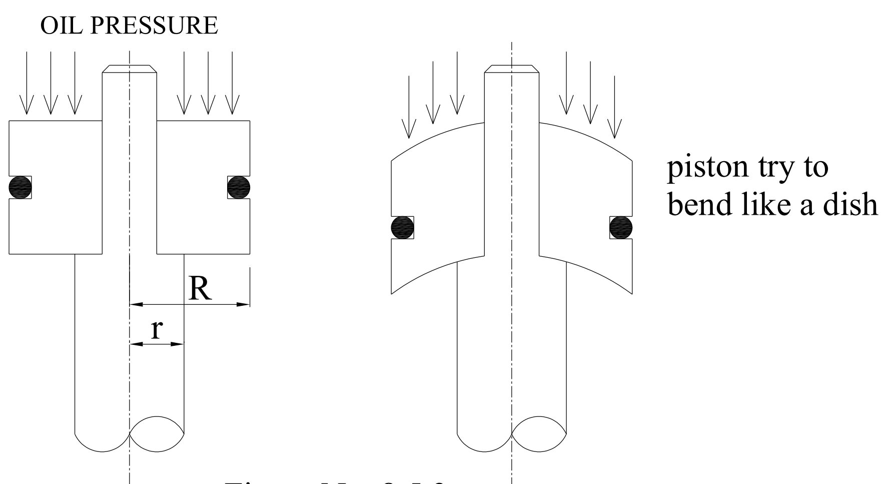


Figure No. 8.5.3

following empirical formula can be used to calculate the thickness of piston.

where t = thickness of piston
c = an empirical constant
w = total load on piston
f_t = safe tensile stress of piston material

Empirical constant C depends upon.

a) Ratio of piston out side diameter and piston-rod diameter.
b) Type of piston and piston rod assembly that is integral type or simply supported type.

Value of C can be selected from following table.

Type of Piston	R/r ratio					
Simply supported type						
Integral type						

Thickness of piston subjected to shear:-

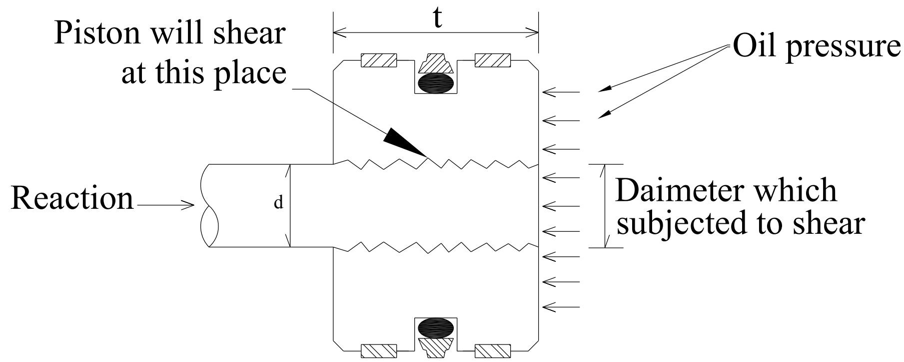


Figure No. 8.5.4

Piston will also be subjected to shear stress. Hence thickness of piston should be sufficient to resist the failure by shearing. Minimum thickness of piston required to resist them could be calculated as fallow.

Load on piston =Inside area of cylinder x Working pressure

$$\frac{\pi}{4} \times D^2 \times p = \pi \times d \times t \times fs$$

$$t = \frac{D^2 \times p}{4 \times d \times fs}$$

Circumferencial area resisting shear = x d x t

If we know the permissible shear stress limit of material of counstruction of piston rod then thickness of piston can be calculated by following equation.

Load on piston =shear resistance offered by piston.

Where D = Cylinder ID
p = Working Pressure
d = Ram diameter
fs = Shear stress
t = Thickness of Piston

Figure and fact to be remember while designing and making piston: -

1. Piston is supported by piston rod. The annular area of contact between piston and piston rod withstand compressive load. If the compressive stress developed exceeds the yield stress of piston or piston rod material then material of that annular area will fail. Hence care should be taken that piston supported on large annular area and compressive stress which will get developed at full load will be within safe limit.
2. Cylinder ID is honed to 0.4 mm Ra value; OD of piston also may be smoothly machined. When they rub each other, oil film squeezes out between them, which leads high friction and localized heating. Hence piston OD should have fine grooves on its surface to retain oil between piston and cylinder.
3. As a thumb rule the thickness of piston should be kept atleast between 60 to 80% size of Inside Diameter of cylinder. That means for 100mm ID of cylinder, thickness of piston will be atleast 60 to 80mm.This is because larger piston gives better guidance to piston rod. Also some-time due to side load on piston rod, piston rubs and applies localized pressure on inside diameter of cylinder. Because of large contact area, the localized bearing stress or crushing stress (compressive

stress) get distributed on large area and get reduce and do not crosses the yield stress limit.

4. To avoid seal plates ,and for easy assembly of new types of compact seals piston could be made in two-piece as shown in following figures.

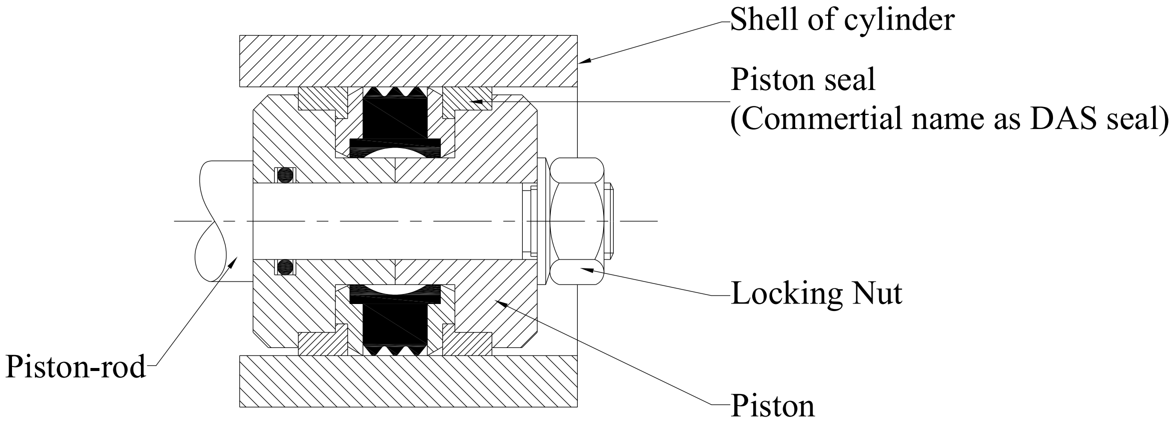


Figure No. 8.5.5

Material of construction: -

Piston could be made from Mild Steel, Aluminum, Bronze, gray cost iron etc., depending upon application and fluid used in system. But precaution should be taken that only bearing material should rub the inside surface of cylinder. Hard material may damage the smooth inside surface of cylinder. Continuously casted gray iron is one of the most favorable and widely used material for piston.

8.6 GUIDE-BUSH

It is also called as "Head End", "Rod-End", "Front-End", "Front-face" of cylinder. This is a cylinder end enclosure, which covers the differential area between the cylinder bore and piston rod.

In addition to covering front end of cylinder, guide-bush also provides "Oil Port", guide to piston rod and seal pocket to gland-seal, o-ring and cushioning arrangement.

In fully extended stroke of piston rod, piston also apply full force developed by cylinder on guide-bush, hence it is designed accordingly to withstand such load.

Determining the size of Guide-Bush: -

Guide-bush provides guide to gland-bush, accommodate gland-seal, guide-ring, oil port, cushioning arrangement. Guide bush it-self is guided in cylinder bore. Hence thickness should be sufficient for all above matter. Thickness of guide-bush is determined as follow.

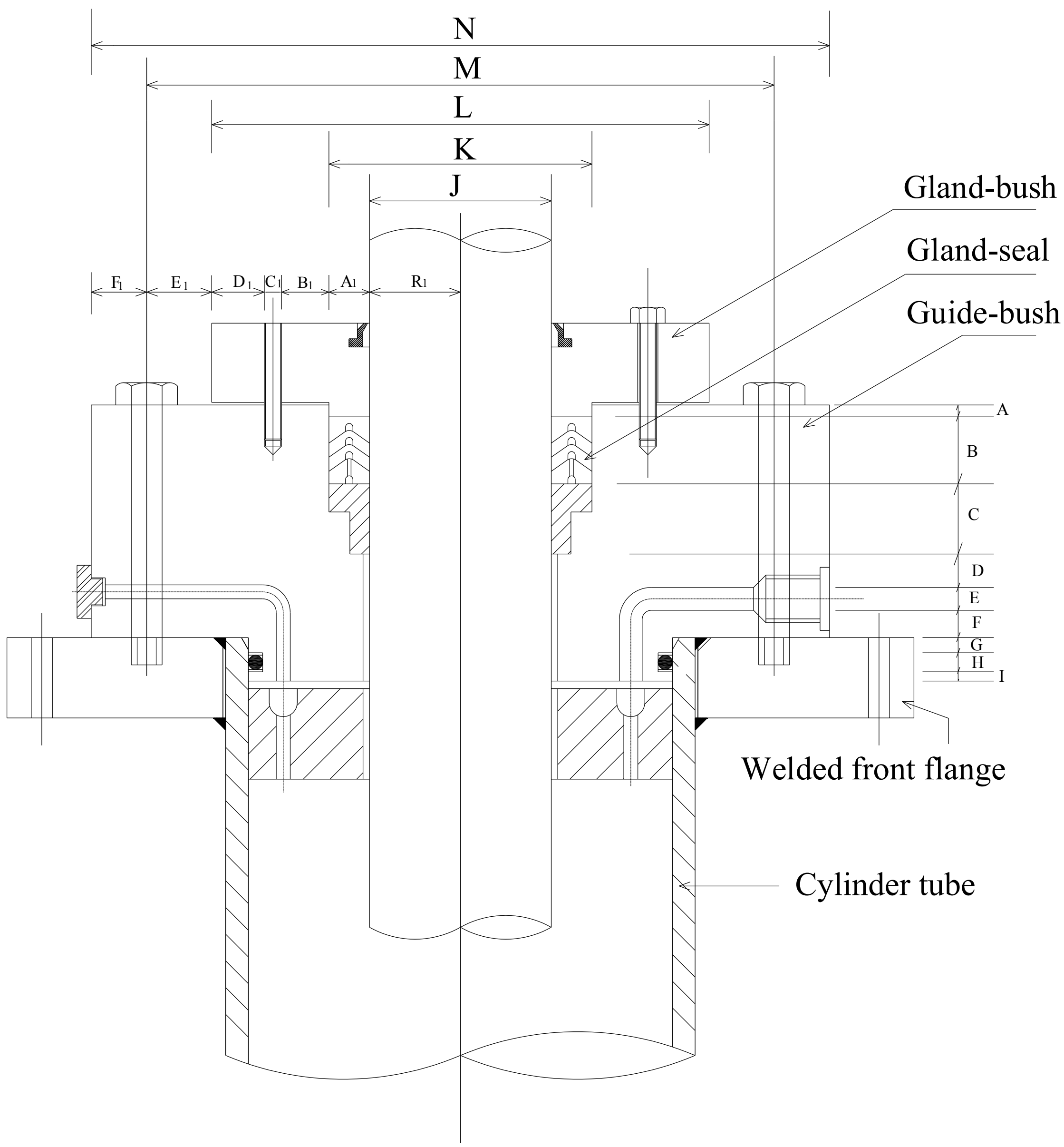


Figure No. 8.6.1

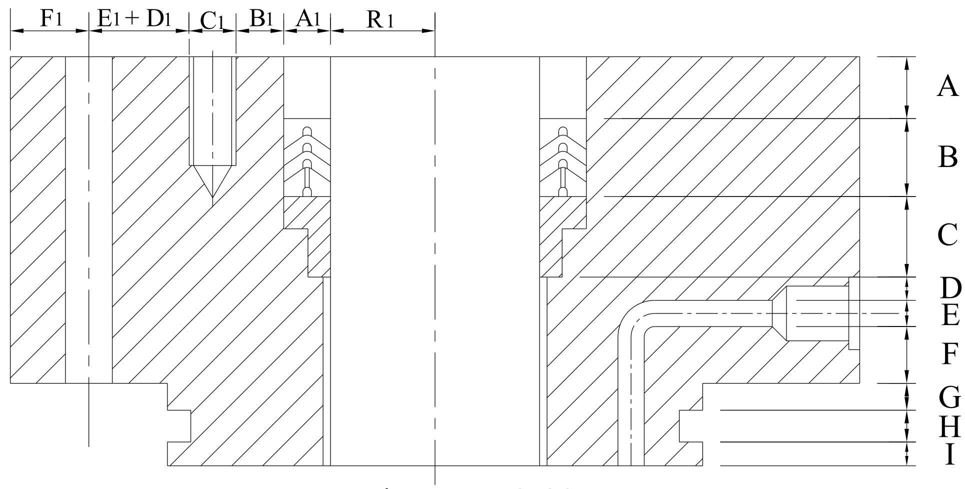


Figure No. 8.6.2

A = This much thickness is required to provide guide to gland-bush.That means Gland-Bush is inserted in Guide-Bush up to the length (A).

B = This thickness depends upon the thickness of seal used.

C = This thickness of guide-bush is according to the length of removable guide-bush (Sleeve guide / collar guide)

D = This thickness should be equal to the wall thickness of a pipe with inside-diameter equal to the drill hole of oil port.

E = This thickness is equal to the hole diameter of oil port. Diameter of oil port is decided by the maximum volume of oil passing through it, at recommended velocity. Recommended velocity is 1.6 to 3.0 meter per second, and oil flow depends on pump discharge. Considering these two-parameter diameters could be calculated.

Cross section area of hole x velocity = pump discharge

F = This thickness also should be minimum to the wall thickness of a pipe with inside-diameter equal to the hole diameter of oil port. In addition if oil port it to be thread, then thickness should have sufficient and should have good space between welded front flange and guide-bush to fix spanner and tightening of adopter.

G = This thickness should be sufficient that guide-bush get some guidance in cylinder, and o-ring groove remain some distance from taper provided for easy assembly of piston and piston seal in cylinder.

H = This thickness is decided by o-ring and guide-ring used. It should be equal to the recommendation of o-ring manufacturers.

I = This thickness should be sufficient to provide additional guide to guide-bush. When piston presses against guide-bush thickness should be strong enough to withstand it, otherwise it will deform and damage to o-ring groove causing leakage.

Hence thickness of guide-bush will be equal to sum of A to I.

To calculate diameter of guide-bush we have to consider piston-rod diameter, seal and bolt required to fasten the guide-bush and gland-bush. Their detail is as follow.

R1 = This is piston-rod radius, it is calculate and fixed before design of guide-bush.

A1 = This is width of seal used as gland-seal.

B1 =Gland-bush is bolted to guide-bush, for which holes are drilled and taped in guide-bush. The inside diameter of seal pocket is subject to full system pressure. If wall thickness between inside diameter of seal pocket and drilled and tapped holes is not sufficient then it will rupture at this location. Hence sufficient wall thickness should be provided between inside dia of seal pocket and tapped hole for gland-bush.

C1 = Gland-bush is bolted to guide-bush firmly to withstand the ejection force acting on seal. The number and size of bolt required are calculated as per this force. Dimension C1 depends upon this calculation.
D1 = The head of bolt should not project-out of the out-side diameter of gland-bush. The dimension D1 is as per the head of bolts used.
E1 = Guide-bush are bolted to the welded flange. These bolts are other than bolts of gland-bush, while deciding pitch circle diameter for bolts for guide-bush care should be taken that their should be sufficient space between head of bolt and gland-bush, to fix spanner and tighten the bolts. Dimension E1 is determined considering these facts.
F1 = This dimension is decided as the head of bolts used.(similsr to D1)

Hence the outside diameter of guide-bush will sum of on R, A1, B1, C1, D1, E1, and F1.

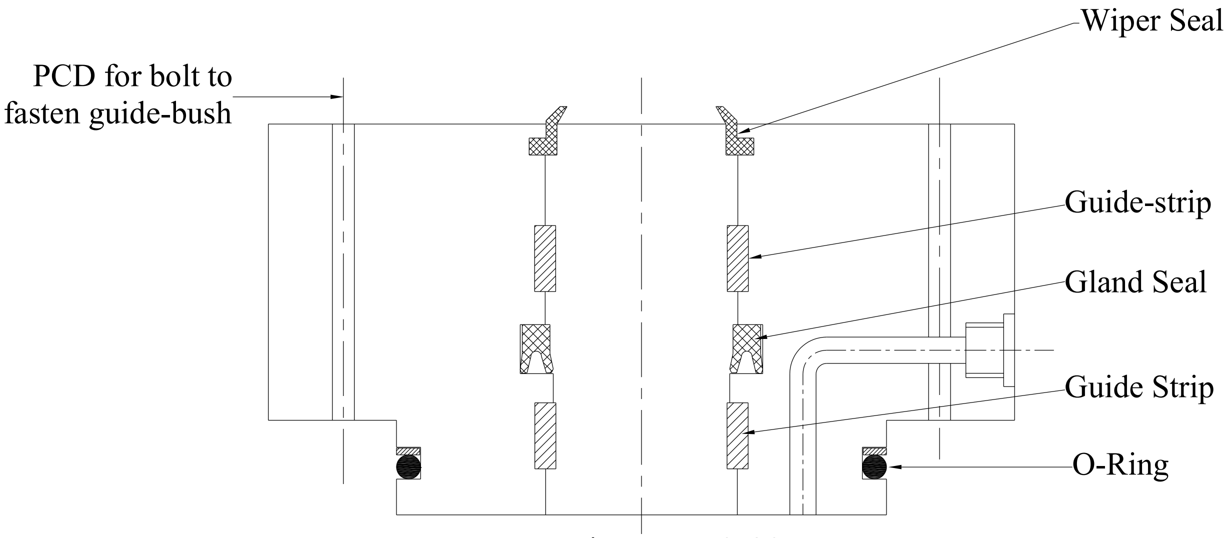


Figure No. 8.6.3

Guide-Bush for small size cylinder

Guide-bush as per above sketch dose not require gland-bush as guide-strip and seal pocket are provided in guide-bush its at.

Calculation for determining thickness of Guide-Bush

Guide-bush could be considered as a round simply supported plate, which is supported at pitch circle diameter (M) of fattening bolts. On other side it get uniform pressure on area equal to annular area between piston rod and cylinder inside diameter.

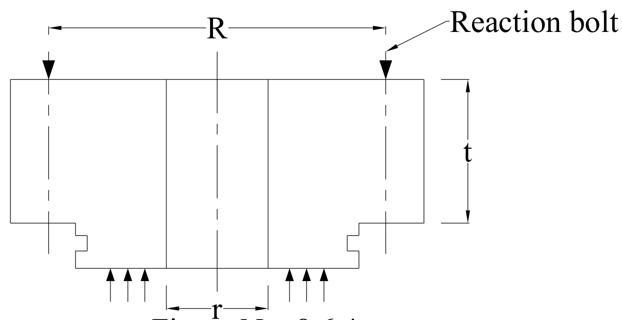


Figure No. 8.6.4

By following Emperical formula we can calculate the thickness

$$t^2 = \frac{CXW}{f_t}$$

Where t = Thickness of Guide-bush

C= Emperical constant

W= load acting of Guide-bush (This is equal to force developed by cylinders)

ft = Perimisible tensile stress

Value of C could be selected from following table

Ratio of $\frac{R}{r}$	1.25	1.5	2	3	4	5
Value of C	0.592	0.976	1.44	1.88	2.08	2.195

CONCLUSION:

1] We find minimum thickness as per requirement of Guide-bush which is sum of A to I.

2] We find thickness as per required strength as per above mentioned emperical formula.

3] We decide final thickness value which is higher in above two calculation.

Material used for guide-bush: -

As guide-bush directly do not touches the piston-rod, and it has to withstand the full load of cylinder, hence it is generally made from M. S. or C40. Steel casting of EN-8 grade is also used for standard cylinder manufactured in large quality.

Important guide-lines: -

a) Guide-bush directly or indirectly guides the piston rod. Hence guide-bush should be perfectly concentric to the cylinder tube. Any eccentricity will damage the whole cylinder.

b) Piston presses against guide-bush at full load developed by cylinder at fully extended stroke condition. Because of this load guide-bush surface try to yield and bulge-out. Because of this on inner diameter it try to grip the piston rod, and outer diameter is try to seize with cylinder bore. Care should be taken that annular area between piston rod and cylinder bore is sufficiently large to reduce the bearing or crushing stress. Also sufficient chamfer or clearance between piston rod and guide-bush should be given so that there should not be any seizer or metal to metal contact in case of any material deformation.

c) In case of using new type of seals and guide-ring etc. the surface roughness and tolerance should be as per recommendation. Tolerance grade is generally H9f8 and roughness in seal pocket should be between 0.8 to 0.16 m Ra depending on type of seal.

8.7 GLAND-BUSH

Gland-bush is used to retain gland-seal, accommodate wiper seal and provide guide to piston rod.

Calculation for dimension: -

1] Diameter of Gland bush is equal to (R1+A1+B1+ C1+D1) X 2. Criteria for selection of value of these figure we have discussed in study of Guide-bush.

2] thickness of gland-bush is also calculated by using same imperical formula described for Guide-bush.

3] Force acting on gland-bush, is equal to projected area of hydraulic seal multiplied by working pressure.

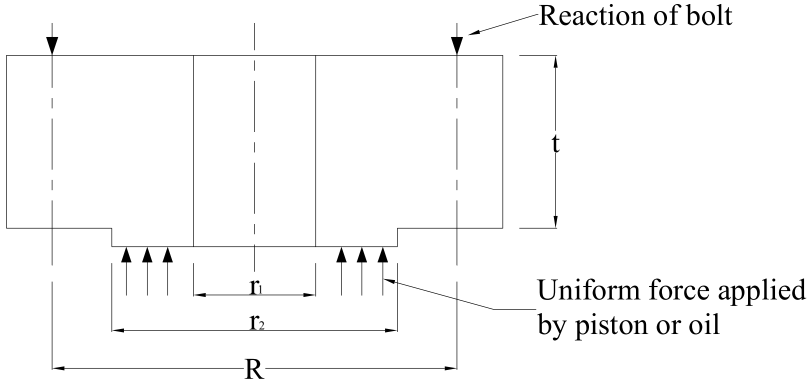


Figure No. 8.7.1

Emperical formula to calculate thickness of gland bush is Force acting of gland-bush = W (r²-r²) x 3.14 x p

$$t^2 = \frac{CXW}{f_t}$$

Where w = force action on gland-bush

t = thickness of gland-bush

f = permissible tensile stress of material

c = Imperical constant which depend on ratio of R and r1

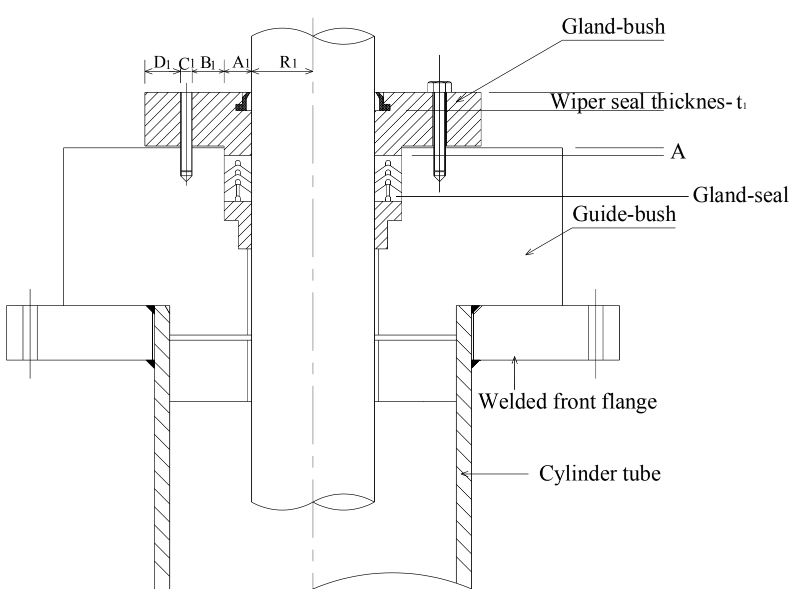


Figure No. 8.7.2

As gland-bush has to withstand load as well as guide to piston rod. Hence in case of large cylinder it is made from M. S. or C 40, and then fitted with phosphase bronze lining or bush, and in case of small cylinder it is made from gray Cast Iron, preferably from continuously cast rod, due to its superior strength and other property.

Important guide-lines: -

1. Nowadays modern type of seal and guide-ring are available which can be directly fitted in guide-bush. Hence gland-bush could be completely eliminated.
2. Gland bush is guide to piston-rod, Hence care should be taken that it remain perfectly concentric to Guide-Bush and cylinder bore.

8.8 END-PLUG

End-plugIt also is called as "Cap-End" "cover-End" or Rear-End of cylinder. This is a cylinder end enclosure, which completely covers the cylinder-bore area. in addition it could be used for mounting cylinder, providing oil port and air-bleed-off-port, accommodating cushioning arrangement etc.

Design of end-plug: - $t = \dfrac{Pd}{4f_t}$

End-plug may be welded or bolted or threaded type. It also may be flat or spherical type. Spherical type end-plug is only made in case of steel-casted cylinder. The thickness of spherical end-plug is calculated as.

In case of flat-end-plug thickness is calculated as.

Material of construction: - $t = d_i \sqrt{\dfrac{0.162\,P}{f_t}}$

For welded type end-plug, if it is to be cut from plate then prefer IS 2062 grade mild steel plate. And if it is cut from bars then use low carbon easily weldable type steel. For bolted type use M. S. or C40 grade steel or other tough material. Avoid hard brittle material.

Important guide-lines: -

1. In general most of the structural failure of cylinder occur at end-plug because.
   - Cylinder expands under pressure.
   - Cylinder expanders at high temperature
   - Micro cracks present in welding propagate and get fully developed in long period.
   - Because of loose thread fitting between cylinder and plug, end-plug tends to move with every pressure cycle, in long run this leads to cracking of welding.

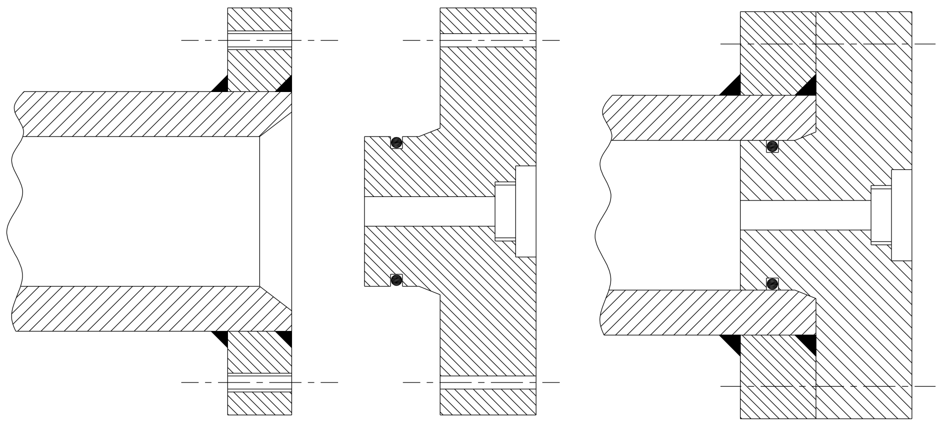
2. Take at least four factor of safety while designing end-plug.
3. Ensure the threading is perfect and it is fully tighten.
4. Pre-heat before welding, and use low-hydrogen electrode for welding. Allow welding to cool slowly. Use penning (Hammering method) for large type of cylinder end welding. Use correct procedure of welding.
5. In case of large cylinder take the load coming on end-plug by threads and consider welding only for making joint leak proof.

Some of the method of the fixing end-plug to the cylinder are as follow

1] Bolted Type:- In this design a flange is first welded to cylinder pipe, then end plug is bolted to flang. Leakage is prevented by either O-ring or U-seal.

2] Threaded design :- In this design end-plug is fixed to main shell by means of threads. In bolted and threaded design leakage is either preventd by O-ring or U-seal. Method of their fixing is on follow.

F

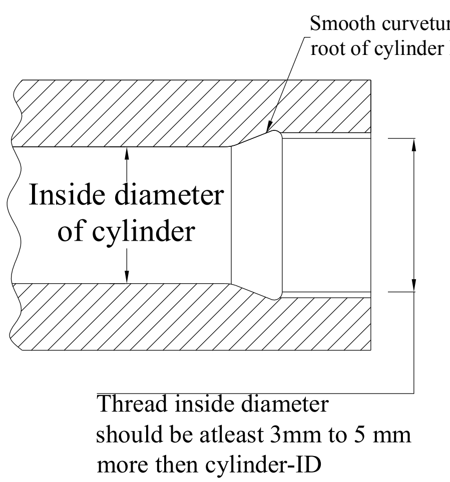


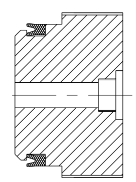
Cylinder-shell with welded flange.

End-plug

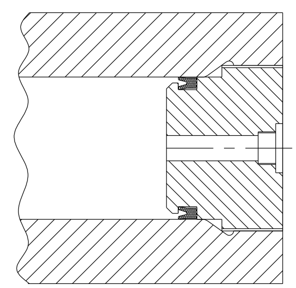
End-plug bolted to cylinder flange

G

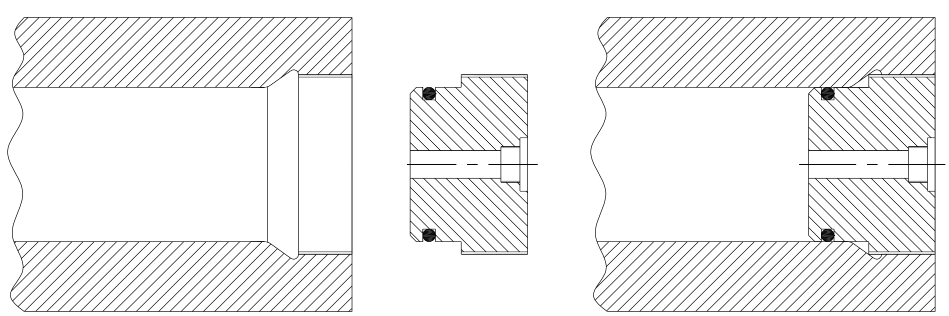




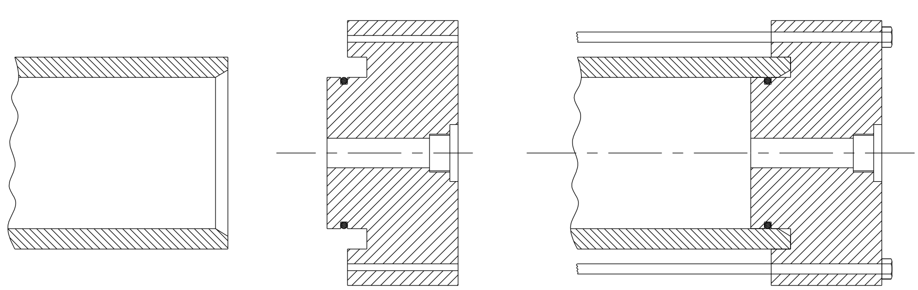
End Pluge



End Pluge fistted in cylinder



End Pluge



Tie-rod design

8.9 FLANGES WELDED TO CYLINDER-TUBE

These are circular or rectangular rings threaded and welded to the outside diameter of cylinder tube. When this is fixed at front-end of cylinder then it is called front-tube flange and may be used for bolting of guide-bush, and cylinder mounting. When it is fixed to the rear-end of cylinder then it is called rear-tube-flange of cylinder and it may be used for bolting of end-plug and also cylinder mounting.

Design of Flange: -

a) Flange is subjected to shear and bending load. When mounting support of cylinder is too close to cylinder-tube outside diameter then bending load is minimum, and as gap increase bending load increases.

We design flange with assumption that its threading will take full force developed by cylinder and Welding is done only to avoid loosening.

Number of threads required in flange to withstand full load can be calculated by following equation .

Load = outside circumference of cylinder tube X pitch of thread X no. of threads X permissible shear stress of flange material.

$$W = p\,D \times P \times n \times fs$$

$$n = W / p\,D \times P \times fs$$

As load, Outside Diameter, pitch of thread, and stress are known, number of thread requires to withstand load can be calculated. When number of threads known than thickness required to have that much number of thread can be calculate, that gives the flange thickness.

a) As per above calculation and thickness, threads can take the load, but to make joint more rigid and avoid loosening of thread we recommend to welds it from both sides.

b) Flange also could be designed based on welding. But most precaution should be taken as this joint will always be subjected excessive stress, and dynamic loading.

c) Always weld flanges before final boring and honing, as cylinder shrinks after welding.

d) Machine both sides of flange, and its faces should be absolutely at 90%%D to the central axis of cylinder.

e) Above mentioned calculation suit to the condition where flange is completely supported, and no bending load come on flange. In case when flange is supported at its edges, bending load is also possible, then thickness is calculated by following formula.

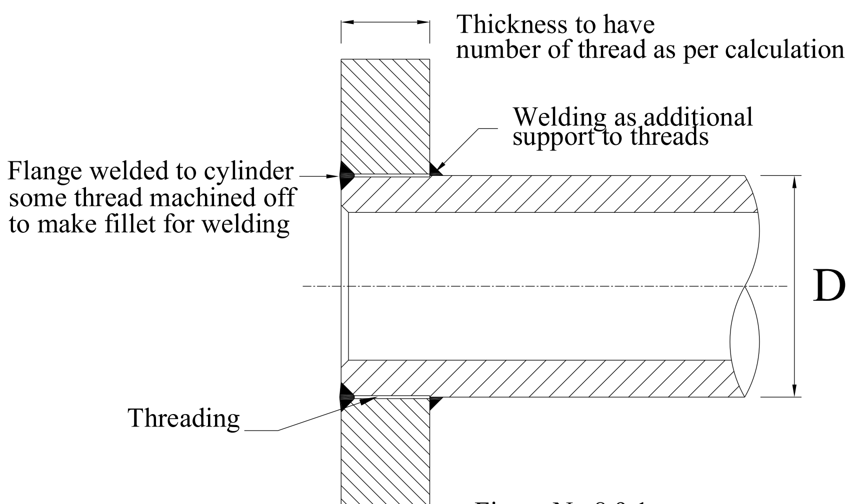
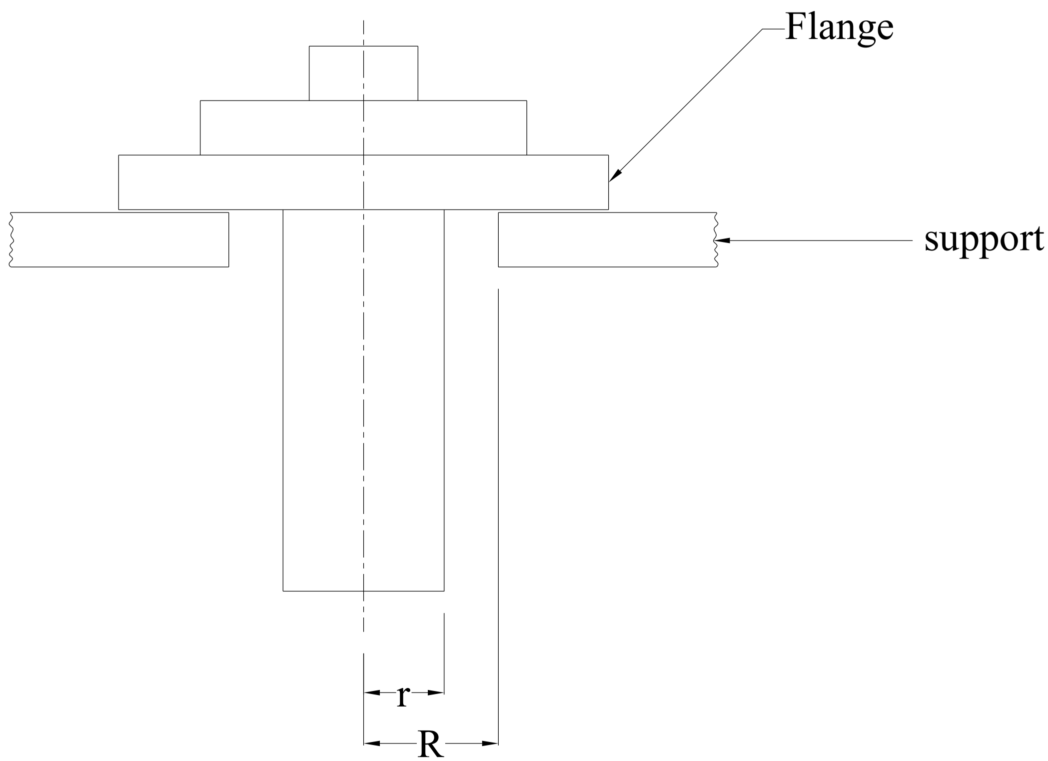


Figure No.8.9.1

$$t^2 = \frac{C \times W}{f_t}$$

t = thickness of flange
c = An empirical constant
w = Total load on flange (Capacity of cylinder)
ft = safe tensile stress of flange material
empirical constant C depends upon, the ratio of oneside diameter of cylinder, and inside diameter of support.



Ratio of r/R

R/r	1.25	1.5	2	3	4	5
C	0.13	0.34	0.740	1.22	1.46	1.61

Figure No. 8.9.2

8.10 SEAL PLATES

Seal plates are round plates, used to retain piston-seal on piston. New types of seals do not require seal plates, but conventional type of seal such as chevron-packing, fiber-impregnated synthetic rubber U-seals etc still require seal plate.

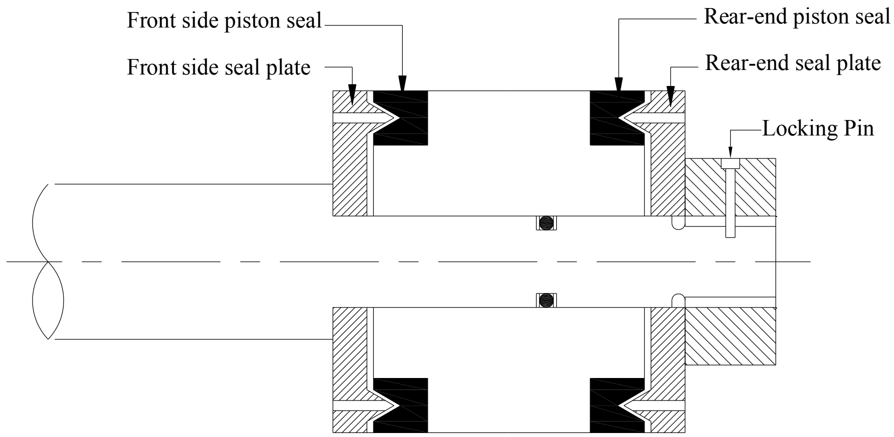


Figure No. 8.10.1

From theoretical point of view there is no load coming on seal plate and it is only to retain seal in its pocket. But in actual practice the load comes on seal plate once seal start wearing-out.

When rear-end piston seal wears-out, oil passes over said seal and piston and acts from rear-side of front side piston seal, which apply load on front side seal plate, similarly when front side seal wears, load comes on rear side seal plate. Hence thickness of seal plat should be sufficient enough to take this load. In case of large cylinder seal plate is bolted to piston. In such case bolts should be strong enough to take the load.

Author has used 10 mm plate for cylinder upto 100mm ID, 20 mm plate for cylinder upto 200mm ID, 30mm plate for cylinder upto 350mm ID, 40mm plate for cylinder upto 650mm ID. Full rated pressure can not act on rear side of seal. But than also considers 20% of pressure for calculating bolts required to hold seal plate, in case of large cylinder.

Few Methods of Fixing Seal Plate :-

(1) Bolted Type (For Smaller Capacity Of Cylinder

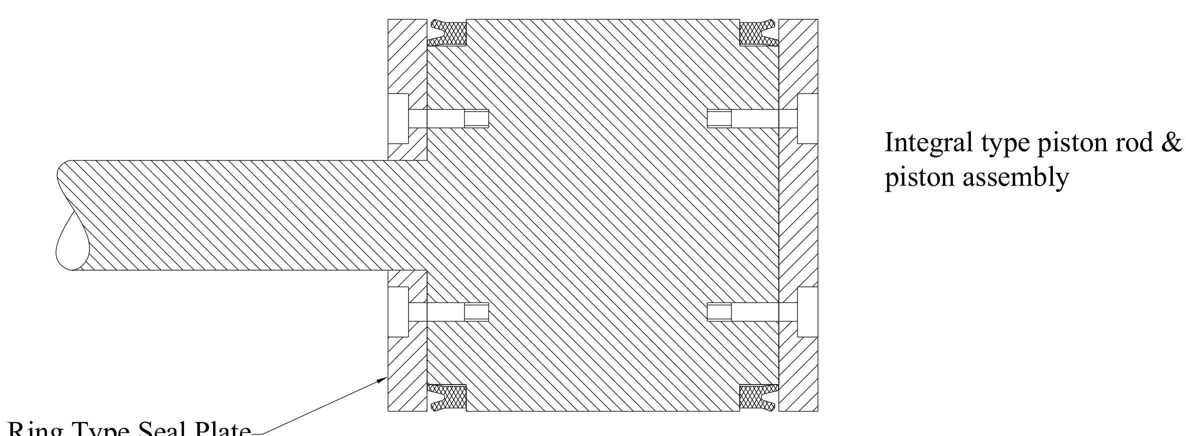


Figure No. 8.10.2

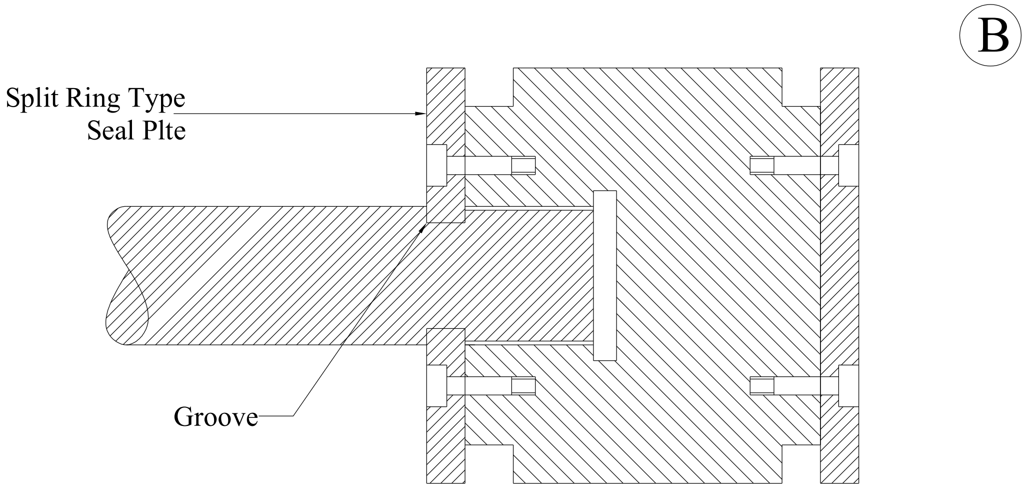
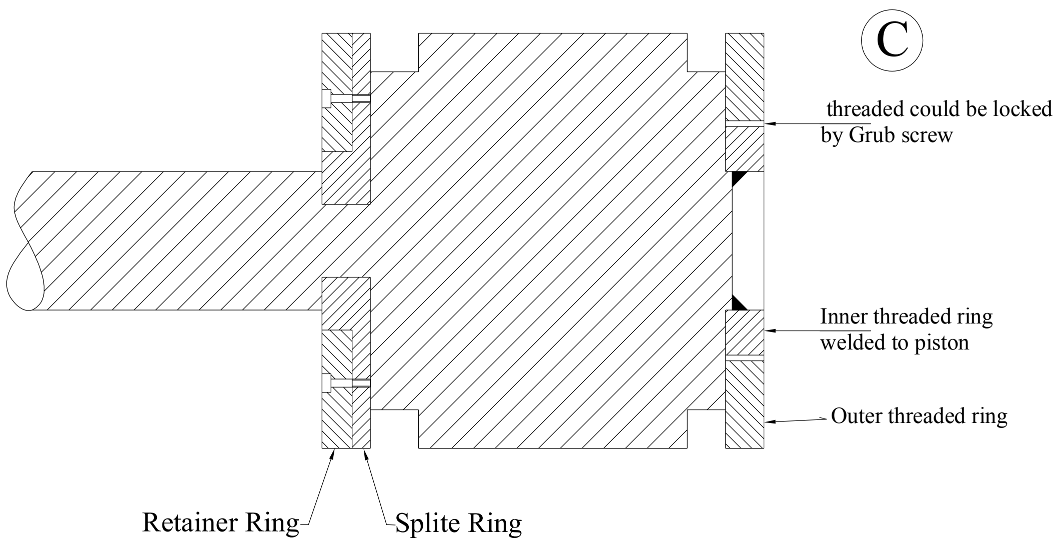
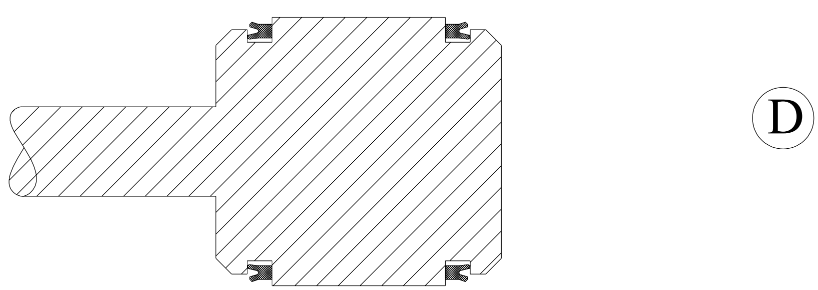
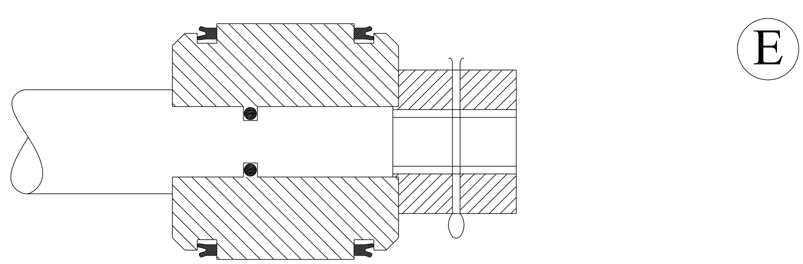


Figure No. 8.10.3







in first three design seal made by polyurathene as well as seal made by fibre impregnated synthatic ruber U-seal or chevron-packing could be used. While in last two method only flxible seal could be used.

Air-Bleed-off-Port: -

This oil port is provided to remove air from cylinder. Basically it is an oil port with threading to plug it firmly. The plug is of special type. It is made in such a way that without completely removing it, and only just loosening it oil or air should start leaking from it. A simplest method is as follow.

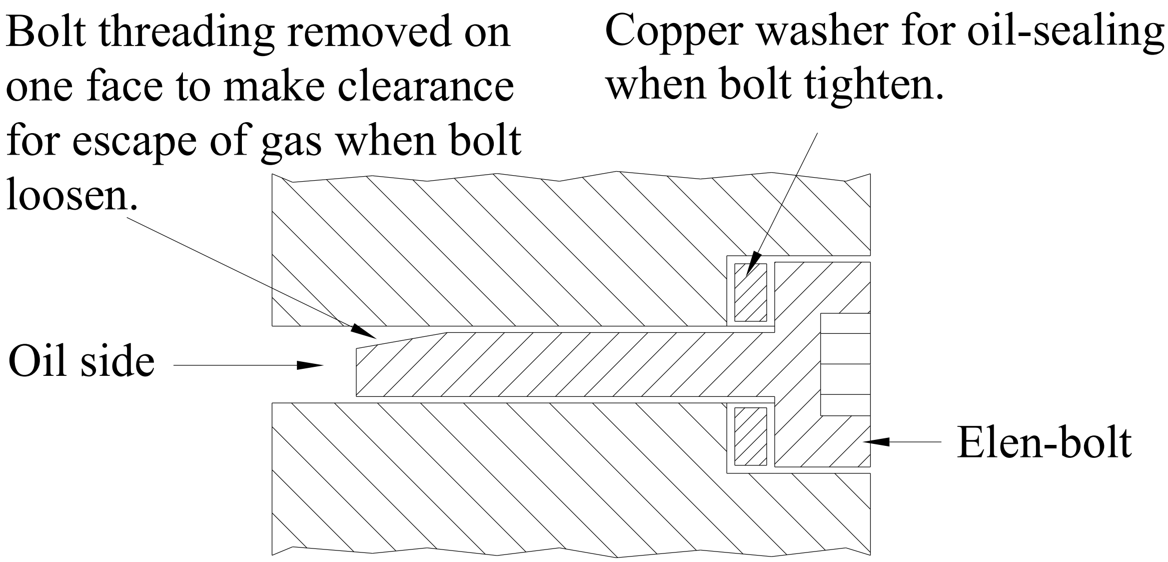


Figure No. 8.10.4

When bolt loosen slightly air will leak-out, as soon as oil start coming out bolt is tighten. The copper washer will give leak-proof sealing when bolt tightens fully.

Stopper tube:-

Stopper tube is used as spacer to keep piston and guide-bush a port at sufficient distance, to increase cantilever strength.

When piston takes its full stroke it presses stopper tube against guide-bush, hence it is subjected to compressive load. Hence it is designed to withstand full load developed by cylinder under compression. It should not yield or buckle.

Inside Diameter & Outside Diameter is as per Ram diameter and cylinder bore, hence its material of construction is to be selected in such a way that with limited cross-section area ultimate compressive stress should remain within safe limit.

Piston-Rod end Connection:-

The end of piston rod may be threaded or may have grooves for holding split coupling. This part of piston rod may have smaller diameter than piston-rod, in addition it has groove and threads where stress concentration may occur. Because of this sometime piston-rod breaks just at the end. Hence care must be taken to design it correctly. Following precaution should be taken while designing it.

1) Calculate minimum diameter require for safe transfer of load in compression as well as in tension using simple basic formula.

Load = Cross-section area X safe stress

Root diameter of thread on piston rod or Root diameter of groove should not be less than this calculated diameter.

2) Calculated length of thread require on piston rod for safe transfer of force.

3) Thread diameter should be less than piston-rod dia, and smooth chamfer should be provided between these two diameters for easy assembly of gland-seal.

4) Piston-rod should have some extended length out of cylinder in retracted position, a n d some flat surface should be machined on its round diameter, to engage spanner on it, for tightening piston and other nuts on piston-rod end threading.

5) When groove provided for coupling then also the diameter should be less at the front portion. Because front end generally get bulged in operation, and after bulging removing guide-bush become a problem.

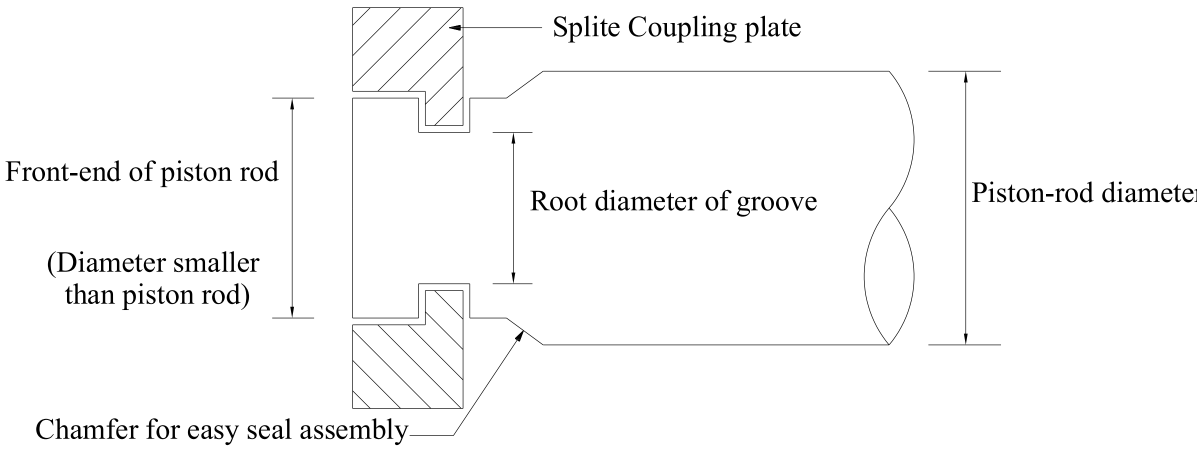


Figure N0.8.10.5

6) In case of coupling type connection, shear load comes on the projected ring at the end of piston-rod. Hence thickness of front-ring should be calculated correctly.

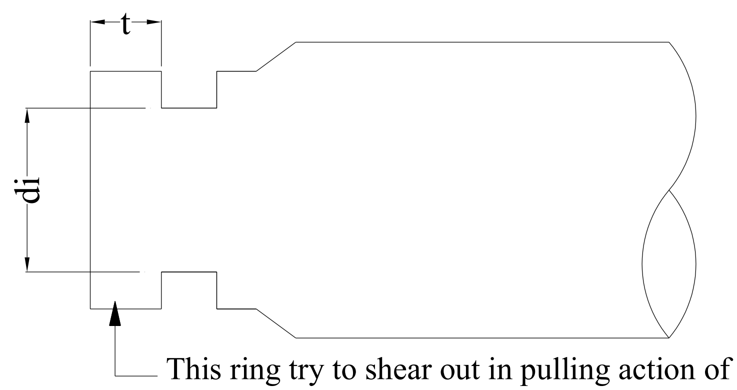


Figure No. 8.10.6

Retraction force = Circumference X thickness X safe shear stress
= di x t x fs
Thickness t should be calculated accordingly.

SEAL & BOLTS

1) Always try to use High tensile bolts of reputed make. Try to use large size of bolt. (aboveM16 Size).

2) Always use spring washer with bolts, as bolts try to losses in operation.

3) Polyurethane seal has large life than old conventional chevron packing or U-seal made from nifrile or neuprine rubber. Hence always use seal made from Polyurethane or superior newly developed materials.

8.11 CYLINDER CUSHIONS

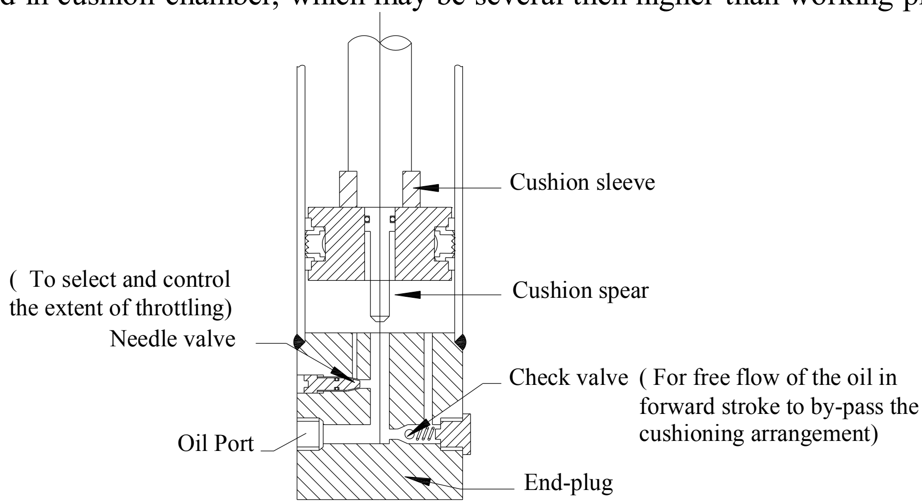
Piston rod may travel at extremely high speed along with dead load. If it hits the end-plug or guide-bush at same speed, then it may damage the whole cylinder. Hence arrangements are made to reduce its speed at the end of stroke. This is achieved by special cushion arrangement.

In cushion arrangement we basically throttle the oil coming out of the cylinder, By doing so we control the piston-rod speed. The back-pressure developed in throttled oil counter act and balances the piston.

There are basically four types of cushion.

1) Straight-Spear Cushion: -

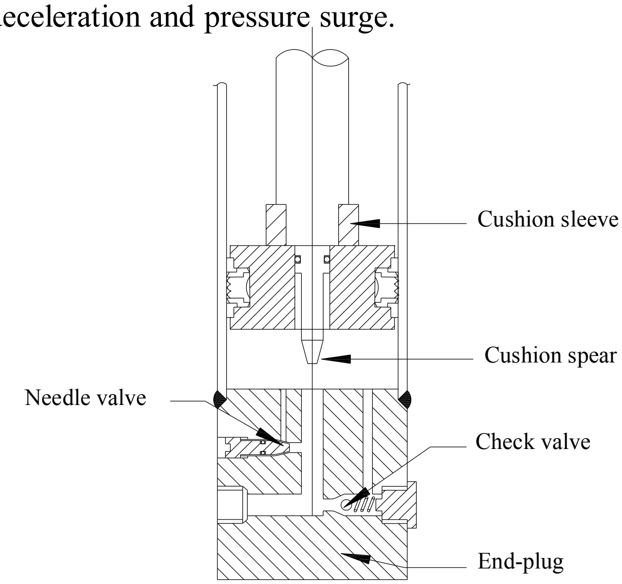
In this arrangement a straight diameter sleeve or projection passes through the oil port to throttle the passage of oil which is going out of cylinder. The disadvantage of this system is that it suddenly blocks the oil passage resulting in sudden deceleration, also there is sudden rise in pressure of oil trapped in cushion-chamber, which may be several then higher than working pressure.



Straight-Spear Cushion
Figure No.8.11.1

2) Tapered-Spear Cushions: -

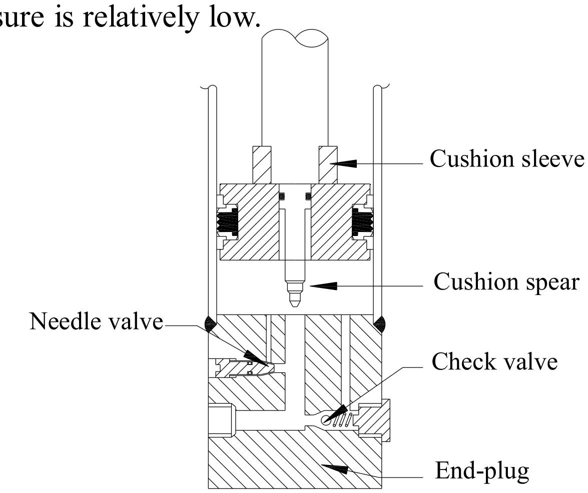
This is similar to straight-spear cushions, except that the spear has a straight taper, (In general 0.5% for initial 65% of cushion stroke and straight in last 35% of stroke) this system eliminate the initial sudden deceleration and pressure surge.



TAPERED-SPEAR CUSHION
Figure No. 8.11.2

3) Stepped-Spear Cushions: -

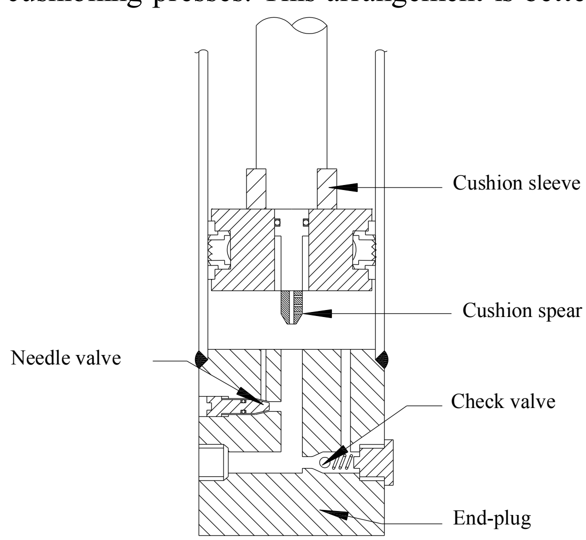
This is also similar to straight-spear cushion, except that two to four steps are machined into the spear. The number of steps depends on bore size, two for small bore, three for intermediate and for four large size of bore cylinder. In this arrangement deceleration could be maintained constant, also the peak cushion pressure is relatively low.



STEPPED-SPEAR CUSHION
Figure No.8.11.3

4) Piccolo Cushions: -

In this arrangement five holes are drilled in straight spear. As straight spear enter the oil path, initially there is more passage for oil to escape through drilled hole. As spear enter more in oil port number of hole decrease. Hence there is a gradual throttle of oil resulting in controlled deceleration and controlled rise in cushioning presses. This arrangement is better than other but costly and difficult to manufacture.



PICCOLO CUSHION
Figure No. 8.11.4

To vary the rate of deceleration additional needle valves are provided to control the oil flow out of the cushion chamber.

As at the end of stroke the oil port become throttled. Hence when oil is pump into the cylinder through same oil port, full discharge of pump can not enter in cylinder due to throttling of oil port, and cylinder start very slowly till the oil port is cleared completely. This may not be desirable in actual system. Hence for immediate start of piston-rod, a check-valve is provided which allow oil to enter in cylinder but block oil passage for oil coming out of cylinder. Hence it do not interfere with cushion process as well as it give full speed right from beginning of stroke.