HYDRAULICS AND PNEUMATICS

Chapter – 1

UNIT II HYDRAULIC ACTUATORS AND CONTROL COMPONENTS

Hydraulic Actuators: Cylinders – Types and construction, Application, Hydraulic cushioning.

ACTUATORS:

It is a device used for converting hydraulic energy into mechanical energy. The pressurized hydraulic fluid delivered by the hydraulic pump is supplied to the actuators, which converts the energy of the fluid into mechanical energy. This mechanical energy is used to get the work done.

TYPES OF ACTUATORS:

1. Linear Actuators (Hydraulic cylinders)
2. Rotary Actuators (Hydraulic motors)
   a. Continuous rotary actuators
   b. Semi rotary actuators

HYDRAULIC CYLINDERS:

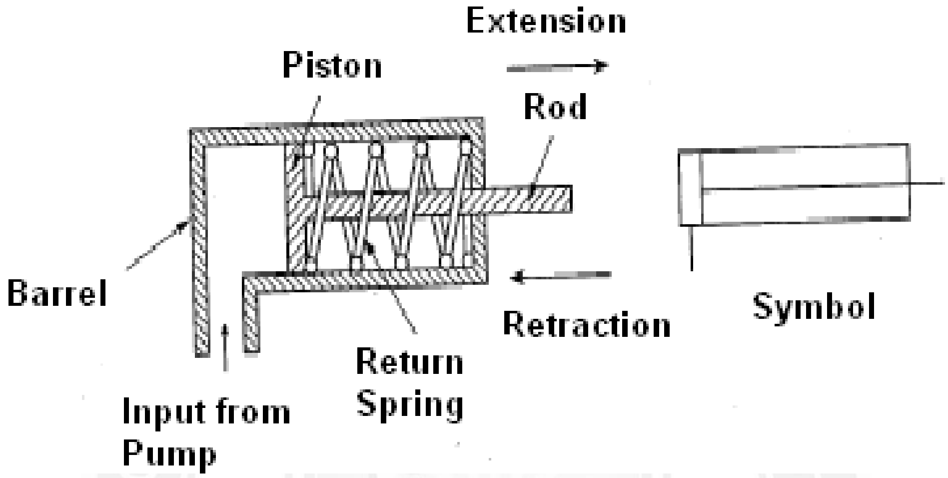
A hydraulic cylinder is a device, which converts fluid power into linear mechanical force and motion. It usually consists of a movable element, a piston and a piston rod operating within a cylinder bore.

TYPES OF HYDRAULIC CYLINDERS:

1. Single acting cylinders
2. Double acting cylinders
3. Telescoping cylinders
4. Double rod cylinder
5. Tandem cylinder

SINGLE ACTING CYLINDER:

A single acting cylinder is designed to apply force in only one direction. It consists of a piston inside a cylindrical housing called barrel. Attached to end of the piston is a rod which extends outside. At the other end (Blank end) is a port for the entrance and the exit of oil. A single acting cylinder can exert a force only in the extending direction, as fluid from the pump enters through the blank end of the cylinder. Single acting cylinders do not hydraulically retract. Retraction is accomplished by using gravity or by the inclusion of a compression spring at the rod end.

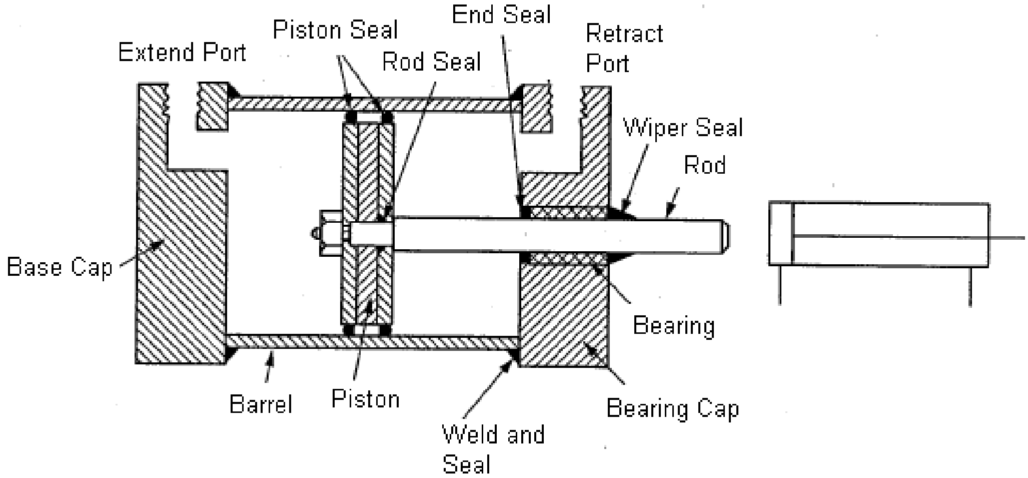


Advantages and Disadvantages:

1. The single acting cylinders are very simple to operate, and compact in size.
2. The single acting cylinders with spring return cannot be used for larger stroke length.

DOUBLE ACTING CYLINDER:

A double acting cylinder is capable of delivering forces in both directions. The barrel is made of seamless steel tubing, honed to affine finish on the inside surface. The piston which is made of ductile iron contains U cup packing to seal the leakage between the piston and the barrel. The ports are located in the end caps which are secured to the barrel by tie rods. The load of the piston rod at the neck is taken by a rod bearing, which is generally made of brass or bronze.



A rod wiper is provided at the end of the neck to prevent foreign particles and dust from entering into the cylinder along with the piston rod. When the fluid from the pump enters the cylinder through port 1, the piston moves forward and the fluid return to the reservoir from the cylinder through port 2. During the return stroke the fluid is allowed to enter the cylinder through port 2 and fluid from the other side of the piston goes back to the reservoir through port 1.

SPEED OF A HYDRAULIC CYLINDER:

Every hydraulic cylinder has its own economical and practicable range of speeds. If the speed of the cylinder is increased beyond this limit, the sudden stoppage of the piston will create shock load on the piston head, piston rod and other mechanical parts causing serious damages. The high speed will also create difficulty in the accurate positioning of the movable parts. So at the time of deciding the speed of a hydraulic cylinder, proper care is to be taken in the design stage itself.

The maximum speed of the piston rod is limited by the rate of fluid flow in and out of the cylinder and the ability of the cylinder to withstand the impact forces which occur when the piston movement is arrested. In an un-cushioned cylinder it is normal to limit the maximum piston movement is arrested. In an un-cushioned cylinder it is normal to limit the maximum piston velocity to 8m/min. This value is increased to 12m/min for a cushioned cylinder and 45m/min is permissible with high speed cylinders. Oversized ports are necessary in cylinders that are used in high speed applications.

Velocity equations:

Consider a double acting cylinder

D – Diameter of thepiston

d – Diameter of piston rod

A – Area of Blank end - $\frac{\pi D^2}{4}$

a- Piston rod area - $\frac{\pi d^2}{4}$

Q – Input flow rate

q_E – Flow rate from rod end of the cylinder when extending

q_R – Flow rate from blank end of cylinder when retracting

Rod End Area – (A-a) = $\frac{\pi}{4}(D^2-d^2)$

1. When Piston rod is extending:

Piston velocity $V_E = \frac{Q}{A} = \frac{q_E}{(A-a)}$

Thus $q_E = Q\frac{(A-a)}{A} = Q\frac{(D^2-d^2)}{D^2}$

Thus as the piston rod is extending, the flow rate of the fluid leaving the cylinder is less than the flow rate of fluid entering the cylinder.

2. When piston rod is retracting:

Piston velocity $V_R = \frac{Q}{A-a} = \frac{q_R}{A}$

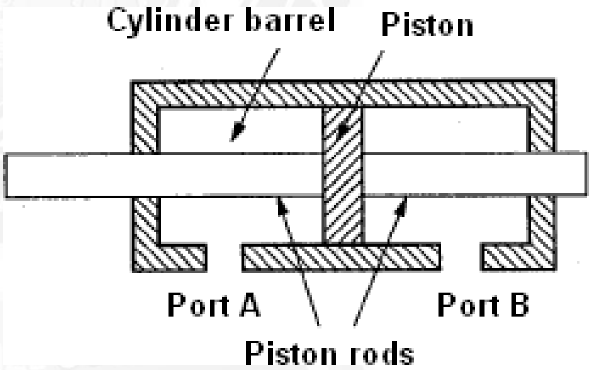
Thus $q_R = Q\frac{A}{(A-a)} = Q\frac{D^2}{(D^2-d^2)}$

Thus when the piston rod is retracting, the rate of fluid leaving the cylinder is greater than the flow rate of fluid entering the cylinder.

SPECIAL TYPE CYLINDERS:

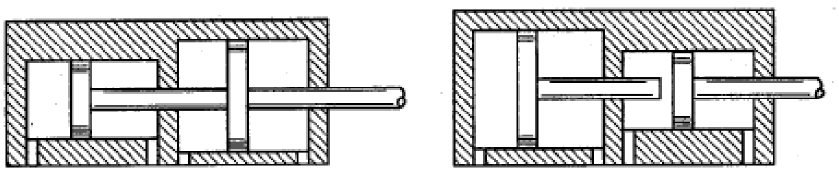
DOUBLE ROD CYLINDER:

It is a cylinder with single piston and a piston rod extending from each end. This cylinder allows work to be performed at either or both ends. It may be desirable where operating speed and return speed are equal.



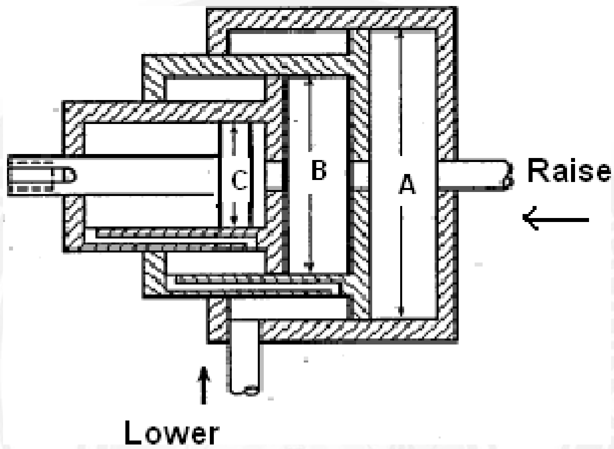
TANDEM CYLINDER:

It design has two cylinders mounted in line with pistons connected by a common piston rod. These cylinders provide increased output force when the bore size of a cylinder is limited. But the length of the cylinder is more than a standard cylinder and also requires a larger flow rate to achieve a speed because flow must go to both pistons.



TELESCOPING CYLINDER:

They are used where long work strokes are needed. A telescoping cylinder provides a relatively long working stroke for an overall reduced length by employing several pistons which telescope into each other.

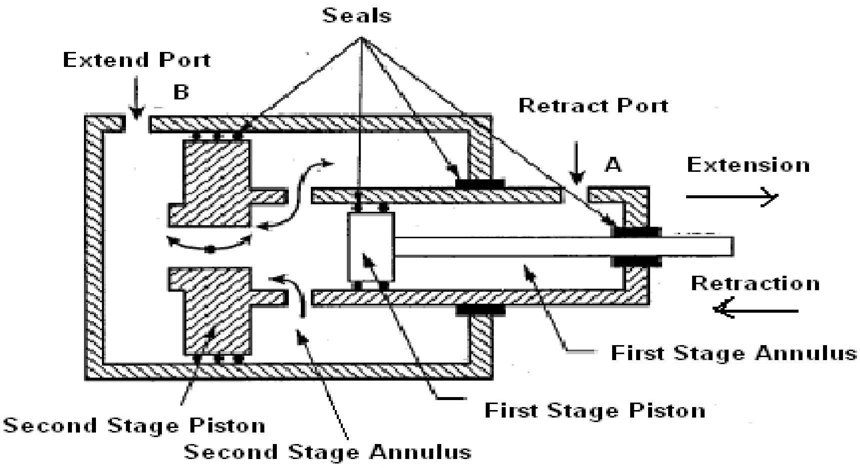


Since the diameter A of the ram is relatively large, this ram produces a large force for the beginning of the lift of the load. When ram A reaches the end of the stroke, ram B begins to move. Now ram B provides the required smaller force to continue raising the load. When ram B reaches the end of its stroke, then ram C moves outwards to complete the lifting operation. These three rams can be retracted by gravity acting on the load or by pressurized fluid acting on the lip of each ram.

TWO STAGE DOUBLE ACTING TELESCOPING CYLINDER:

Retraction stroke: During the retraction stroke, the fluid is fed into the first stage annulus via retract port A. therefore the first stage piston is forced to the left until it uncovers the fluid ports connecting this with the second stage annulus. This, in turn, moves the larger piston to the left until both the pistons are fully retracted into the body of the cylinder.

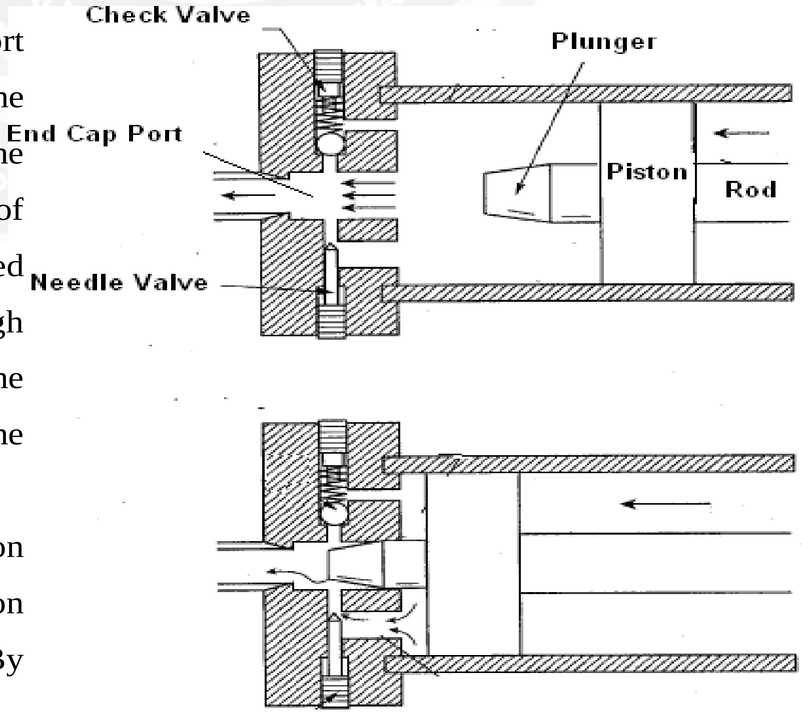
Extension Stroke: During the extension stroke, the fluid is fed through the extend port B. Now the fluid forces both pistons to the right until the cylinder is fully extended.



CYLINDER CUSHIONING:

As long as the piston is moving in the middle range of the cylinder, nothing will hit the piston head. But, due to the inertia forces of the moving parts at the end of the piston travel, the piston will hit the cylinder head at full speed. To overcome this, the designers provide a cushioning arrangement by which the hydraulic cylinder can be slowly retarded or cushioned, during the last portion of the stroke. The figure shows the position of the piston at the start of the cushioning action. In this position, the fluid from the pump enters into the rod end of the cylinder moving the piston towards the left. The fluid from the head end of the cylinder flows freely to the reservoir through the fluid port.

As the stroke nears completion, the cushion nose starts entering in the space of the cylinder head. Due to the taper front of the cushion nose, the fluid port path is gradually closed. So the fluid cannot flow through the port or through the passage of check valve. Now entrapped fluid can escape only through the passage controlled by the needle valve. Thus due to the restricted outflow during the last portion of the stroke, the piston decelerates slowly. By adjusting the needle valve,



rate of deceleration is controlled. For starting the forward stroke of the piston, the fluid is allowed to enter the fluid port. The fluid will now flow from all passages. Thus the full piston area will be subjected to the system pressure.

During deceleration of the load, extremely high pressures will develop within the cylinder cushion. Ideally, the back pressure will be constant over the entire cushioning length. But in practice, the cushion pressure is higher when the piston rod has just entered the cushion.

PROBLEMS:

1. A pump supplies oil at 0.002 m^3/s to a 50mm diameter double acting cylinder and a rod diameter is 20mm. If the load is 6000N both in extending and retracting, find

a. ***Piston velocity during the extension stroke and retraction stroke***
b. **Pressure during the extension stroke and retraction stroke**
c. ***Power during the extension stroke and retraction stroke***

Oil flow rate from pump, $Q = 0.002\ m^3/s$

Diameter of the cylinder, $D = 50mm$

$= 0.05\ m$

Diameter of the rod, $d = 20mm$

$= 0.02m$

Load during the extension and retraction $F = 6000N$

a. Piston velocity during extension stroke $V_E = \frac{Q}{A_P}$

$$= \frac{0.002}{\frac{\pi}{4} \times 0.05^2}$$

$$\mathbf{= 1\ m/s}$$

Piston velocity during retraction stroke $V_R = \frac{Q}{A_P - A_R}$

$$= \frac{0.002}{\frac{\pi}{4} \times (0.05^2 - 0.02^2)} = 1.2\ m/s$$

Cylinder pressure during extension stroke $P_E = \frac{F}{A_P} = \frac{6000}{\frac{\pi}{4}\times 0.05^2} = 30.6$ bar

Cylinder pressure during retraction stroke $P_R = \frac{F}{A_P - A_R} = \frac{6000}{\frac{\pi}{4}\times (0.05^2-0.02^2)} = 36.4\,bar$

Cylinder power during extension stroke $= \frac{PE\times Q}{1000} = \frac{30.6\times 10^5\times 0.002}{1000} = 6.12\,kW$

Cylinder power during extension stroke $= \frac{PR\times Q}{1000} = \frac{36.4\times 10^5\times 0.002}{1000} = 7.28\,kW$

2. A hydraulic cylinder has to move a table of weight 13kN. Speed of the cylinder is to be accelerated up to a velocity of 0.13m/s in 0.5 seconds and brought to stop within a distance of 0.02m. Assume coefficient of sliding friction as 0.15 and cylinder bore diameter as 50mm. Calculate the surge pressure.

Initial velocity u = 0m/s

Final velocity v= 0.13m/s

Acceleration $a = \frac{v-u}{t} = \frac{0.13-0}{0.5} = 0.26\ m/s2$

Force required to move the piston = Dynamic force + frictional force

$$= \left(\frac{w}{g}\times a\right) + \mu.w = \left(\frac{13000}{9.81}\times 0.26\right) + 0.15\times 13000$$

= 2294.5N

To overcome this force, the pressure required in the hydraulic cylinder is

$$= \frac{2294.5}{\frac{\pi}{4}\times 0.05^2} = 11.69\,bar$$

From the equation for velocity, acceleration and distance $v^2 - u^2 = 2as$

$$a = \frac{v^2 - u^2}{2s} = \frac{0^2 - 0.13^2}{2\times 0.02} = -0.4225m$$

(The –ve sign indicates that it is deceleration)

The total force required to stop the motion of a cylinder

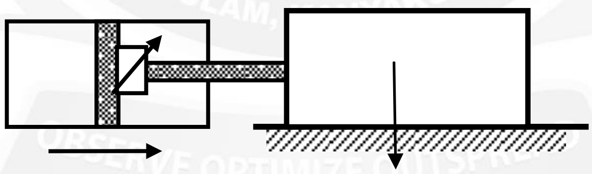
$$= \frac{13000}{9.81} \times 0.4225 + 13000 \times 0.15 = 2510N$$

Then pressure created by this opposing force is

$$= \frac{2510}{\frac{\pi}{4}\times 0.05^2} = 12.78 \text{ bar}$$

Thus surge pressure $P_s = P_1 + P_2 = 11.69 + 12.78 =$ **24.47 bar**

3. A cylinder has a bore of 80mm diameter and a rod of 45mm diameter. It drives a load of 7000N, travelling at a velocity of 15m/min. The load slides on a flat horizontal surface having a coefficient of friction of 0.12. The load is to be decelerated to rest within a cushion length of 20mm. If the relief valve is set at 50 bar, compute the fluid pressure developed in the cushion.



Cushion length s = 20mm = 0.02m

Velocity u = 15 m/min = 0.25 m/s

From the equation of motion,

$v^2 = u^2 + 2as$ (final velocity is zero)

$$a = \frac{-u^2}{2s}$$

Decelerating force to retard load $= \frac{w}{g} \times a = \frac{w}{g} \times \frac{u^2}{2s} = \frac{6700 \times 0.25^2}{9.81 \times 2 \times 0.02}$

= 1067N

Pressure force on blank end $= P \times A = 50 \times 10^5 \times \frac{\pi}{4} \times 0.08^2$

= 25133N

Friction force = μ.w

= 0.12 × 6700

= 804 N

Cushion force = (Pressure force + Decelerating force) – Friction force

= 25133 + 1067 – 804

= 25396N

Fluid pressure developed at the cushion $= \frac{F}{A_P - A_R}$

$$= \frac{25396}{\frac{\pi}{4}(0.08^2 - 0.045^2)}$$

= 74 bar