Pascal's Law - Pressure Viscosity

Objectives: At the end of this lesson you shall be able to
- **state Pascal's Law**
- **understand the concept of force multiplication**
- **state many functions of hydraulic fluids**
- **define the term viscosity.**

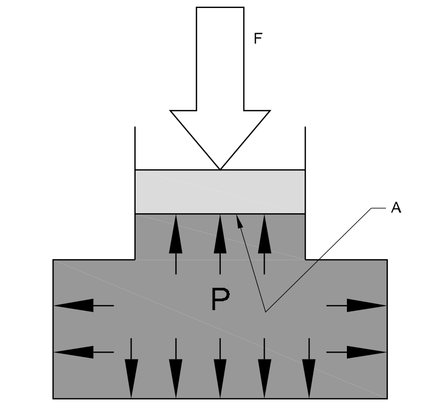
Pascal's law (Blase Pascal, 1623-1662)

Pascal's law is the central law for the development of a number of machines, such as hydraulic brakes, hydraulic jacks, etc. The law states that 'pressure exerted on a fluid is transmitted equally in all directions, acting with equal force on equal areas'. The following sections explain how a pressure is developed in a hydraulic system with the application of a force through a pump mechanism and how a force is developed with the application of the pressure through an actuator mechanism.

Hydraulic Pressure

is the result of the resistance offered to compression when an incompressible oil medium is squeezed by the application of a force. This pressure is transmitted equally throughout the medium in all directions, according to the Pascal's law.

Fig 1



DEVELOPMENT OF PRESSURE

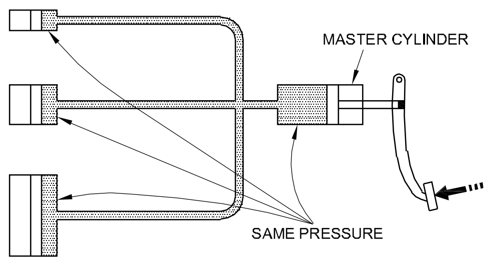
Figure 1 shows a cylinder chamber with a definite volume of oil and a piston. A force (F) is applied to the oil through the piston. When the oil is pushed, its pressure (P) increases in direct proportion to the applied force and inverse proportion to the piston area (A). Pressure can, therefore, be defined as the force acting per unit area. That is,

$$P = \frac{F}{A}$$

A typical Application of Pascal's Law

A feature of hydraulic theory can be seen in the illustration in Figure 2. which demonstrates the pressure in the master cylinder is transmitted equally to all wheel cylinders as per the Pascal's Law.

Fig 2



AN APPLICATION OF PASCAL'S LAW

Units of Pressure: There are many units of pressure, such as Pascal (Pa), bar, pounds per square inch (psi), Kg/ cm^2, etc., used in industrial world. Some of the most important units of pressure are highlighted below:

1 Pascal	= 1 N/m^2
1 bar	= 100000 Pa = 10^5 Pa (100 kPa)
1 bar	= 14.5 psi
1 bar	= 1.02 kgf/cm^2
1 kgf/ cm^2	= 0.981 bar

Hydraulic Force

When a pressure (P) is applied onto the area (A) of a cylinder piston, a force (F) is developed. The amount of force developed is equal to the area times the applied pressure. That is,

$$F = P \times A$$

Example 1: What will be the pressure required to lift 75000 N using a hydraulic cylinder with an effective area of 0.0103 m^2?

Force, F	= 75000 N
Area, F	= 0.0103 m^2
Pressure, P	= F/A
	= 75000/0.0103 Pa
	= 7281553 Pa = 72.8 bar

Exercise 1: Calculate the approximate force, a hydraulic cylinder can apply, if it has a diameter of 5.1 cm and is connected to a 200 bar circuit.

Force Multiplication

Figure 3 shows an arrangement of two cylinders with piston areas A_1 and A_2 ($A_2 > A_1$) respectively. These two cylinders are interconnected by a pipeline. Oil is enclosed in the cylinder chambers and in the pipeline. When the plunger piston A_1 is applied with a force F_1, a pressure (say P1) is developed in the oil, which acts equally in all directions through the oil. It means that the same pressure (P1) acts on the ram piston A_2. This causes the development of a force (say F_2). The governing equations for the forces developed in the cylinders are as follows:

$$F_1 = P \times A_1$$

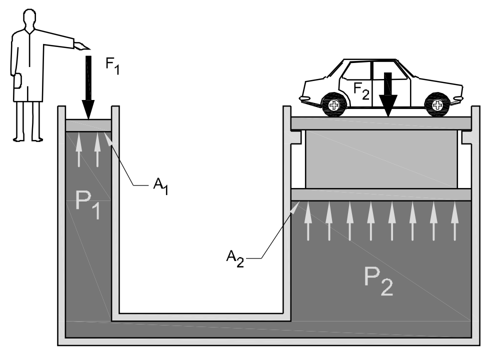
$$F_2 = P \times A_2$$

Therefore,

$$F_2 = F_1 \times (A_2 / A_1)$$

We can see that by controlling the area ratio (A2/ A1) a larger output force can be obtained from a smaller input force. This principle is also used in many hydraulic machines. For example, a hydraulic jack used to lift cars at service stations, brakes in vehicles, etc., use the force multiplier principle for power amplification.

Fig 3



ILLUSTRATING THE CONCEPT OF FORCE MULTIPLICATION

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Example 2

To understand the idea of force multiplication, consider figure 1.1, where applied force, F1= 25 N, cross sectional area of plunger, A1 = 10 cm2, ram piston area A2 = 100 cm2. What will be the force F2 required to lift the car placed on the ram platform?

Solution:

Pressure $P_1 = F_1 / A_1 = 25/10 = 2.5$ n.cm^2

$P_1 = P_2 = 2.5$ n.cm^2

Therefore, $F_2 = A_2 P_2$

= 100 x 2.5 N

= 250 N

Exercises 2: A hydraulic car lift used in a service station has an input pump piston and an output plunger to support a loading platform. The pump piston has a radius of 0.012 m and the loading piston has a radius of 0.15 m. The total weight of the car and the plunger is 25000 N. If the bottom surfaces of the piston and plunger are at the same level, what input force is required to lift the car and output plunger? What pressure produces this force? [Ans: 160 N, 3.536 bar]

Oil Flow

A hydraulic system, with a pump pushing oil continuously through a pipeline, produces a oil flow between any two points in the pipeline as long as there is a pressure difference between these two points.

Flow Rate

Flow rate of oil is a measure of the volume of the oil passing a point per unit of time. It is usually measured in m^3 per minute or in other units.

Hydraulic Oil

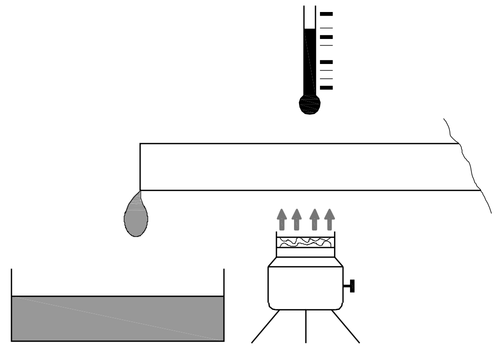
Hydraulic oil is the lifeblood of any hydraulic system. Its primary function is to transmit power from one part of the system to the other part. Apart from this function, it has to lubricate the internal moving parts of system components, seal clearance between the moving parts, and act as a heat transfer medium, as it flows through the system. Oil is usually composed of base stock ad many additives. Mineral-based oils (i.e., petroleum-based oils) are used in a majority of applications. The purpose of using additives in oil is to improve the performance of the oil for a give application. Oil's resistance to flow, expressed in terms of its viscosity, is an important parameter that must be considered.

Hydraulic oils are susceptible to the problem of contamination as they are generally used in harsh environments. Presence of particulates, water, air, and their reaction products in hydraulic oil can adversely affect the performance of these systems. Therefore, the most important requirement of any hydraulic system is to maintain its oil medium in a clean state. Hydraulic filters are used to remove solid contaminants in hydraulic oil.

Viscosity (Fig.4)

Viscosity is a measure of a liquid's resistance to flow. Thicker oil has more resistance to flow and possesses a higher viscosity. Viscosity is affected by temperature. Oil viscosity decreases as the temperature of oil increases.

Fig 4



ILLUSTRATING THE EFFECT OF TEMPERATURE ON VISCOSITY

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A property, that describes the difficulty with which oil moves under the force of gravity, is called kinematic viscosity. It is measured in terms of stokes.

Stoke (St): This is the CGS unit of kinematic viscosity, equivalent to square centimeter per second (cm^2/s.) The more customary unit of kinematic viscosity is the centistokes (cSt). One cSt is one one-hundredth of a stoke. The relations amongst various units of kinematic viscosity are summarized below:

* 1 stoke = 1 cm^2/s

* 1 cSt = 0.01 Stoke

* 1 cSt = 1 mm^2/s

Hydraulic system

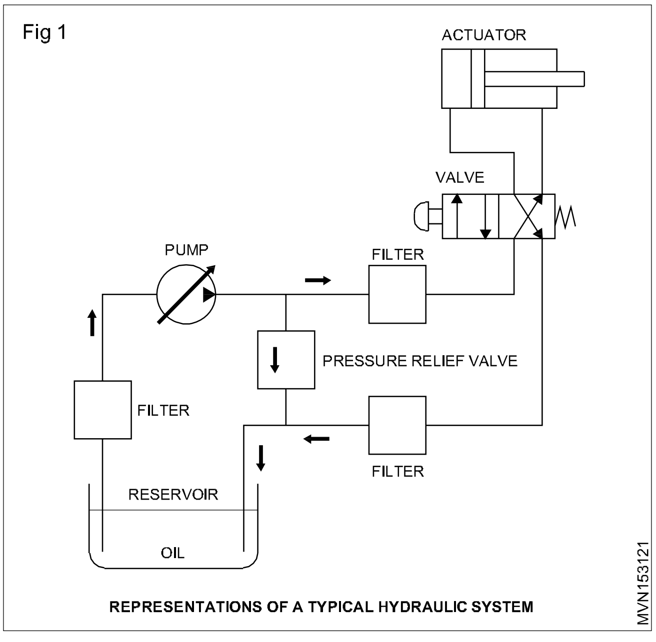
Objectives: At the end of this lesson you shall be able to
- **appreciate a typical hydraulic system**
- **understand the components of a hydraulic power pack**
- **explain the working of a hydraulic pump.**

A Typical Hydraulic System

A typical hydraulic system is shown in the schematic diagram of Figure 1. The system is a closed system and comprises a power pack, control valves, and actuators. The hydraulic power pack consists of a hydraulic pump coupled to engine, a reservoir filled with oil, and a pressure relief valve (PRV). The pump pushes the oil into the closed system. It develops a high pressure, when the pump flow encounters some opposition. Therefore, the mechanical energy provided by the prime mover of the pump is converted into hydraulic energy. This energy is transmitted to hydraulic actuators through the oil medium. Hydraulic actuators, such as cylinders, are used to convert the hydrostatic energy back to mechanical energy. Hydraulic valves are used to control the direction and the speed of the actuators. The pressure relief valve is used to limit the pressure in the system.

All system components are interconnected through fluid conductors, such as pipes, tubing and/or hoses, for the leak-free transmission of the hydraulic power. The pressurized oil media must be positively confined in the system, through the use of effective seals, for the efficient utilization of the power. Contaminants should not be allowed to accumulate in the system. Filters are used to remove contaminants in the oil medium.

Fig 1

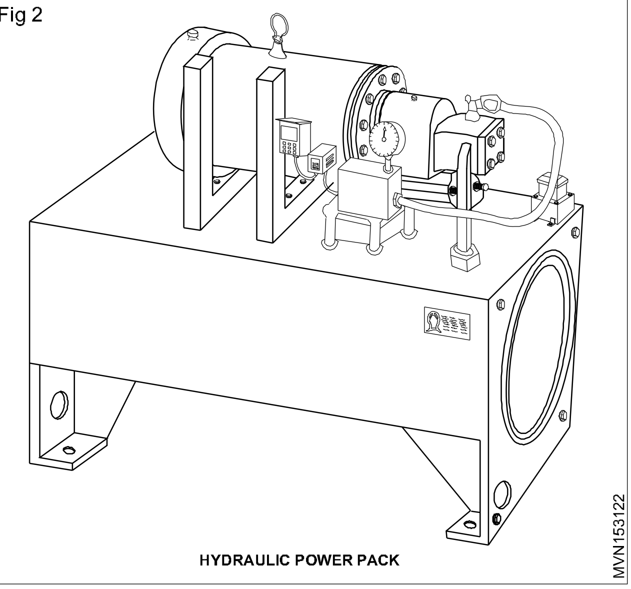


REPRESENTATIONS OF A TYPICAL HYDRAULIC SYSTEM

Reservoir (Fig 2)

A hydraulic power pack, employed in a hydraulic system, transforms the power conveyed by its prime mover into hydraulic power, at pressures and flow rates as required for all system actuators. It is usually a compact and portable assembly that contains components necessary to store and condition a given quantity of oil, and to push a part of the oil into the system. The essential components are reservoir (tank), pump, relief valve, pressure gauge etc. A reservoir is essentially a container that stores a sufficient quantity of oil required for the system. A well-designed reservoir in a hydraulic system allows most of the foreign matter to drop out of the oil and assists in dissipating heat from the oil.

Fig 2



HYDRAULIC POWER PACK

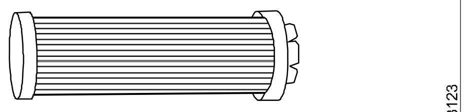
Oil Filter (Fig 3)

Impurities can be introduced into a system as a result of mechanical wear, and external environmental influences. For this reason filters are installed in the hydraulic circuit to remove dirt particles from the hydraulic oil. The reliability of the system also depends on cleanliness of oil.

Pressure Relief Valve (Fig 4)

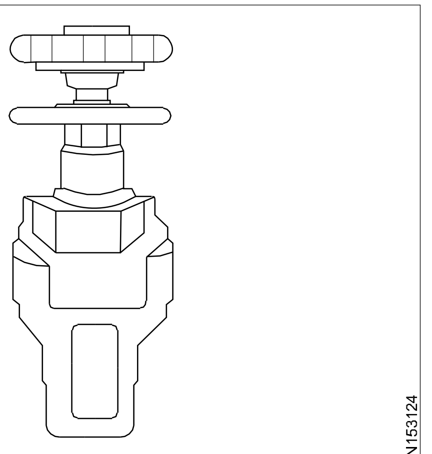
A pressure relief valve (PRV) is used in a hydraulic system to limit the maximum working pressure of the system to a safe value in order to protect operating personnel against injury and system components against any damage.

Fig 3



HYDRAULIC FILTER ELEMENT

Fig 4



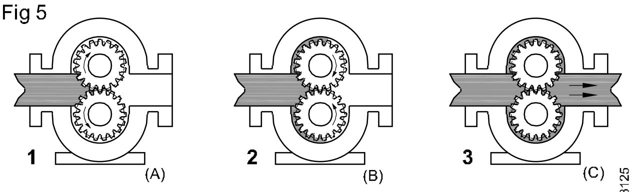
PRESSURE RELIEF VALVE

External Gear Pump (Fig 5)

Figure 5 illustrates the operation of an external gear pump with the help of its schematic diagrams in three critical positions. It basically consists of two close-meshing identical gears, enclosed in a close-fitting housing. Oil chambers are formed in the space enclosed by the gear teeth, pump housing, and side plates. Each of the gears is mounted on a shaft supported on bearings in the end covers. One of the gears - called the drive gear - is coupled to a prime mover through its drive shaft. The second gear is driven, as it meshes with the driver gear.

The gears rotate in opposite directions when driven by the prime mover, and mesh at a point in the housing between the inlet and outlet ports. When the gears rotate in the housing, the diverging teeth create an expanding volume at the inlet side of the pump. This creates a partial vacuum

Fig 5



SCHEMATIC DIAGRAMS ILLUSTRATING THE OPERATION OF AN EXTERNAL GEAR PUMP

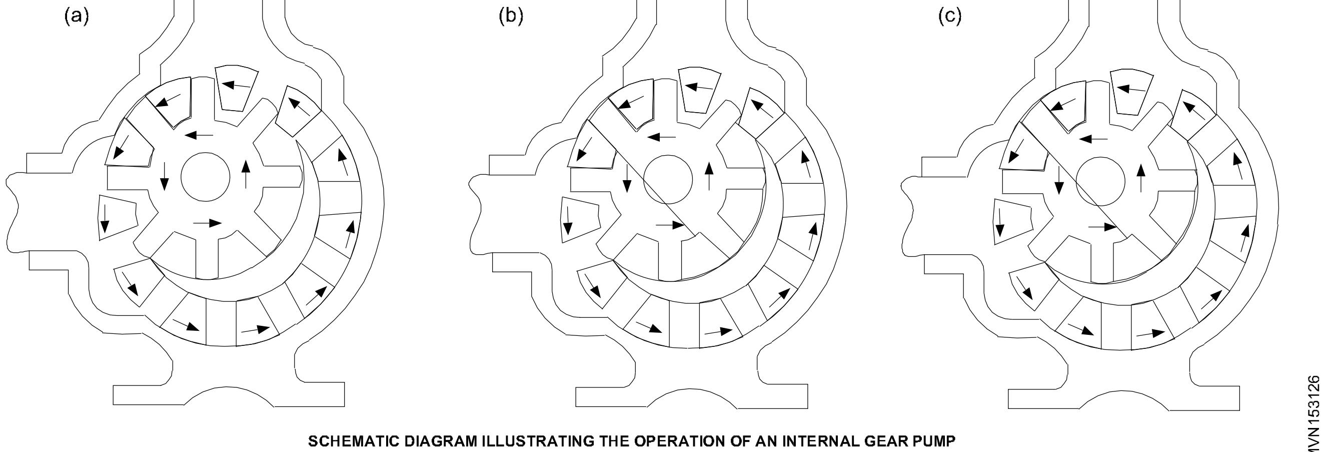
at the inlet chamber of the pump, which draws oil into the chamber from the system reservoir [Figure 5(a)]. The oil then travels around the periphery of the rotating gears as two streams [Figure 5(b)]. Since the pump has a positive internal seal against leakage, the oil is positively ejected out of its delivery port [Figure 5(c)]. Therefore, when run by the prime mover, the intermeshing gears displace a fixed volume of oil from the suction side to discharge side in one revolution of the drive shaft and crate a flow.

Internal Gear Pump

Figure 6 illustrates the operation of an internal gear pump with the help of its schematic diagrams in three critical positions. This pump consists of an outer rotor gear, an inner spur gear, and a crescent-shaped spacer, all enclosed in a housing. The inner gear with less number of teeth operates inside the rotor gear. The gears are set eccentric to each other. The stationary crescent spacer is machined into the space between these gears and separates them. The spacer divides the oil stream, and acts as a seal between the suction and discharge ports.

Any one of the gears can be driven through a shaft supported on bearings. Both the gears rotate in the same direction, when power is applied to the drive shaft. The rotation of gears causes the teeth to un-mesh near the inlet port and consequently a partial vacuum is created at the inlet chamber of the pump, which draws oil into the chamber from the system reservoir [Figure 6(a)]. Oil trapped between the inner and outer gear teeth on both sides of the spacer is carried from the inlet port to the delivery port, as the gears rotate [Figure 6(b & c)]. Since the pump has a positive internal seal against any leakage, the oil is positively ejected out of the delivery port.

Fig 6



SCHEMATIC DIAGRAM ILLUSTRATING THE OPERATION OF AN INTERNAL GEAR PUMP

Hydraulic Actuators, DC Valves, Non return valves and another valves

Objectives: At the end of this lesson you shall be able to
- **explain different types of hydraulic actuators**
- **explain the symbol and working of hydraulic DC valves**
- **explain the symbol and working of non-return valve**
- **explain the symbol and working of an adjustable type throttle valve.**

Hydraulic Actuators

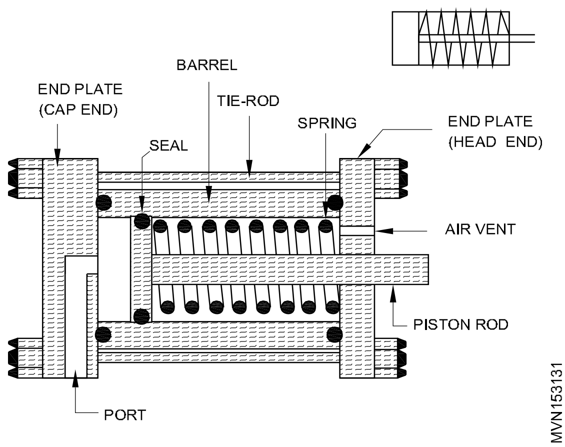
A linear actuator, is used in hydraulic system, it converts hydraulic power into a controllable linear force or motion.

Single-acting Hydraulic Cylinders

A single-acting cylinder is designed to exert force hydraulically in one direction - either on its extension stroke or on its retraction stroke. It utilizes some other force to complete the motion in the other direction. It can be seen that the single-acting cylinder is capable of performing work only in one direction of its motion and hence the name single-acting cylinder.

The cross-sectional view of a single-acting cylinder is shown in Figure 1. It consists of a barrel, a piston-and-rod assembly, a spring, end-caps, a set of seals, and a port. Oil chamber is formed in the cylinder with the barrel, piston, and the piston-side end-cap. The piston-and-rod assembly is a tight-fit inside the barrel and is biased by the spring. The port is integrated into its cap-end to permit or to relieve the system oil. Application of a hydraulic pressure through the port moves the piston-and-rod assembly in one direction to provide the working stroke. The piston-and-rod assembly moves in the opposite direction, either by a spring force or by gravity, or even by exerting an external force. In a cylinder with a spring-assisted retraction, the spring is designed not to carry any load, but, to retract the piston-and-rod assembly with sufficient speed.Figure 1 A schematic diagram showing the cross-sectional view of a single-acting cylinder.

Fig 1

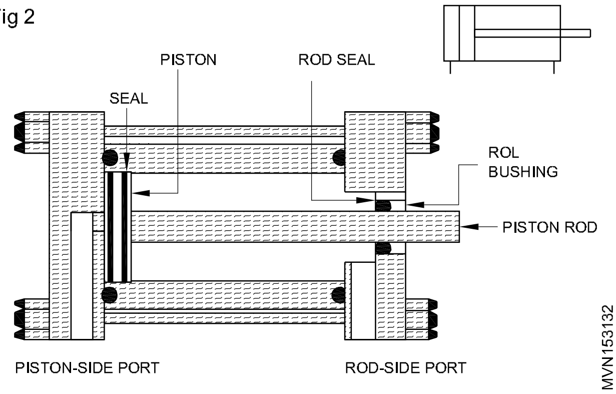


Double-acting Hydraulic Cylinders

Double-acting hydraulic cylinders, like single-acting cylinders, are also linear actuators. A double-acting cylinder can perform work in both directions of its motion, and hence the name double-acting cylinder.

Cross-sectional view of a double-acting cylinder (Fig.2)

Fig 2



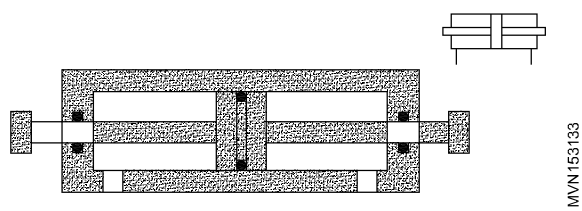
A cross-sectional view of a double-acting hydraulic cylinder is given in Figure 2. It consists of a barrel, a piston-and-rod assembly, end-caps, a set of seals, and two ports. The double-acting cylinder has oil ports on both ends, namely piston-side port and piston-rod-side port. Application of a hydraulic pressure through the piston side port extends the cylinder, provided that the pressure from the piston-rod side is relieved. In the same way, application of a hydraulic pressure through the piston-rod side port retracts the cylinder, provided that the pressure from the piston side is relieved.

Double Rod-end Hydraulic Cylinders

A double rod-end cylinder has piston-rods extending out of the cylinder at both ends, as shown in Figure 3. It has equal areas on both sides of the piston.

A double rod-end hydraulic cylinder (Fig.3)

Fig 3



2/2-way Directional Control (DC) Hydraulic Valve

Simplified sketches of a 2/2 - DC (way) valve are shown in Figure 4. The valve consists of housing with a sliding spool, a compression spring. The spool is designed to slide in a close-fitting bore of the valve body. The groove between lands on the spool provides leak-free flow paths between the ports. The operation of the valve is explained with the help of the two views of the valve in its normal and actuated positions. Figure 4: Cross-sectional views of a 2/2-DC hydraulic valve in its normal and actuated positions.

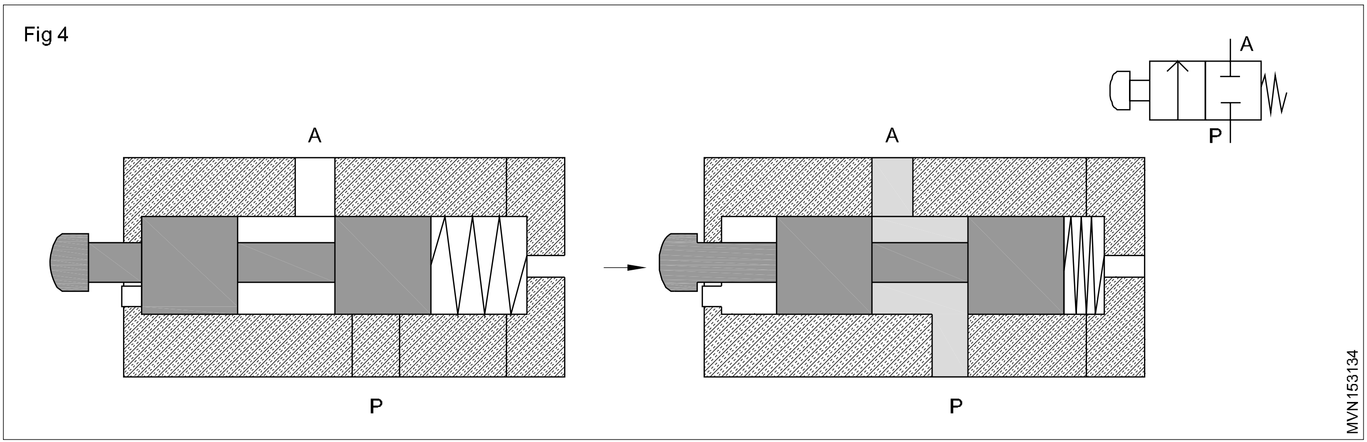


Fig 4(a) Normal position

Fig 4 (b) Actuated position

Fig.4 Cross-sectional views of a 2/2 - DC hydraulic valve in its normal and actuated positions

In the normal position of the valve, as shown in Figure 4(a), both the pressure port P and the working port A are blocked. In the actuated position of the valve, as shown in Figure 4(b), the working port A is open to the pressure port P. Once the actuating force is removed, the compression spring brings the spool back to its normal position.

3/2-Directional Control (DC) Hydraulic Valve

A 3/2-DC (way) valve has three ports and two switching positions. The cross-sectional views of a spool type 3/2-DC valve in its normal position as well as actuated position are shown in the simplified sketches of Figure 5. The pressure port is blocked in the normal position of the valve, as shown in Figure 5(a). In the actuated position of the valve, as shown in Figure 5(b), the working port A is open to the pressure port P and closed to the tank port T. The 3/2-way valves can be used to control single-acting hydraulic cylinders.

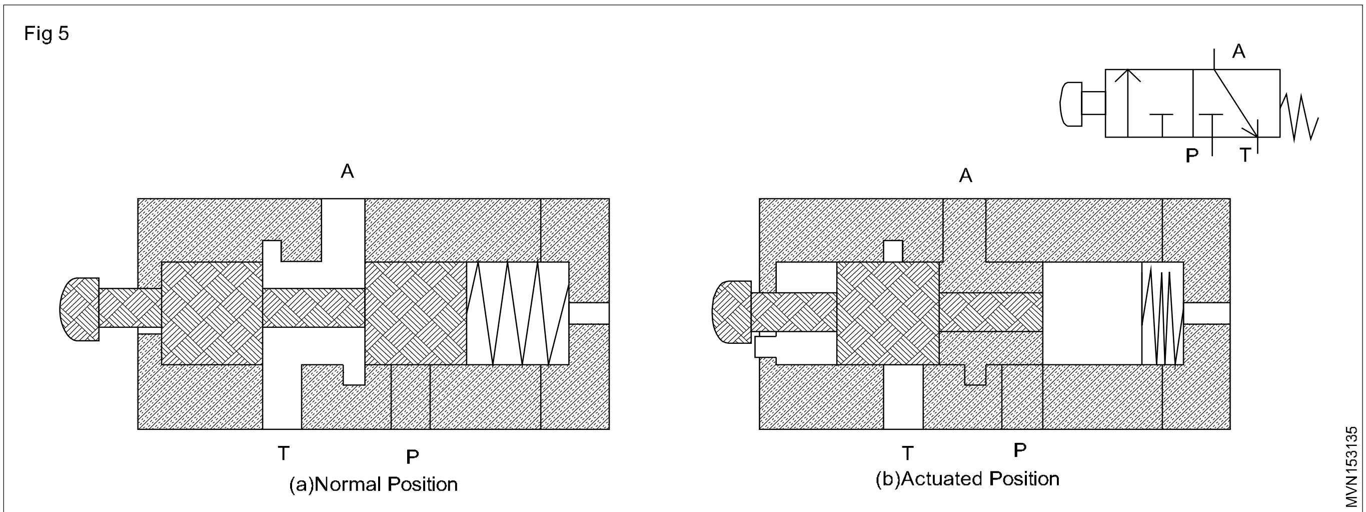


Figure 5: Cross-sectional views of a spool type 3/2-DC hydraulic valve (NC type) in its normal and actuated positions

Example 1: A single-acting hydraulic cylinder is to clamp a component when a push-button valve is pressed. As long as the push-button is pressed, the cylinder is to remain in the clamped position. If the push-button is released, the cylinder is to retract to its home position. Develop a hydraulic circuit to implement the control task using a fixed-displacement pump and a 3/2-Dc valve.

Solution

Two positions of the hydraulic circuit, for implementing the control task given in Example 1, in the normal and actuated positions of the DV valve, are shown in Figure 6. The power supply unit consists of a hydraulic pump driven by an electrical motor, a reservoir and an integral pressure relief valve. The pump can be set by using a separate pressure relief valve (PRV), as shown.

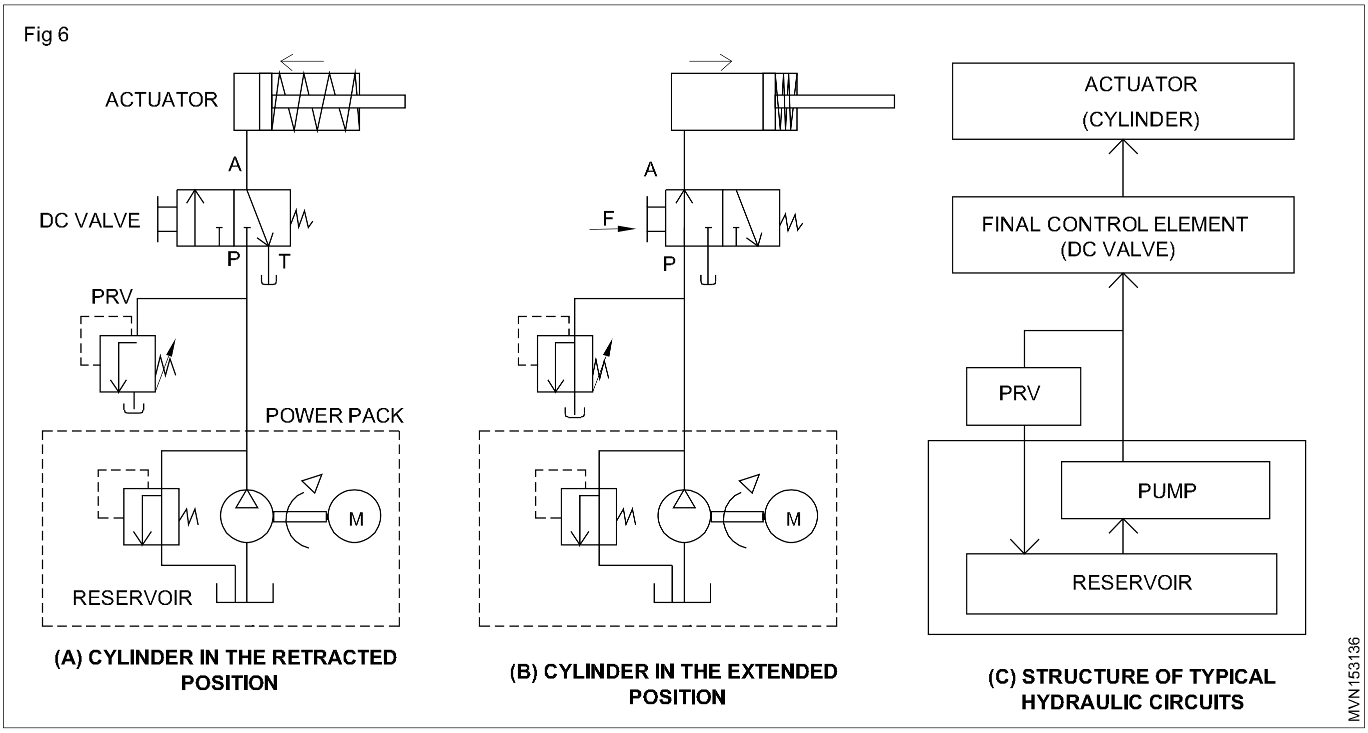


Figure 6: Two positions of the hydraulic circuit for the direct control of a single-acting cylinder, and a typical structure of hydraulic circuits

The single acting cylinder can be controlled by using a manually actuated 3/2 DC valve as shown in the figure. In the actuated position of the valve, as shown in the figure 6(b), the valve allows the flow the pump to the cylinder. The cylinder then extends to its forward direction. When system pressure reaches the setting of the relief valve, pump flow is bypassed over the relief valve against the full system pressure. This maximum pressure limiting action of the relief valve serves to protect the system against over-pressurisation. In the normal position of the 3/2 - DC valve a shown in Fig. 6(a), the valve blocks the flow from the pump to the cylinder. The cylinder then retracts to its home position. A typical structure of hydraulic circuits is given in the block diagram of figure 6(c).

4/2 Directional control (DC) Hydraulic valve

A 4/2 - DC (way) valve has four ports and two switching positions. Simplified cross-sectional views of a manually actuated 4/2 DC valve with spool design, in its normal and actuated positions, are shown in Fig.7. In the normal position of the valve, as shown in Fig.7(a), paths from the pressure port P to the working port B and from the working port A to the tank port T are open. When the valve is actuated, paths from the pressure port P to the working port A and from the working port B to the tank port T are open, as shown in Fig. 7(b). This valve can be used as the main valve to drive a double - acting hydraulic cylinder or a bi-directional hydraulic motor.

Example 2 A double -acting hydraulic cylinder is to extend and clamp a work - piece when a push - button valve is pressed. As long as the push - button is actuated, the cylinder is to remain in the clamped position. If the push button is released, the cylinder is to retract. Develop a hydraulic control circuit to implement the control task. A fixed -displacement hydraulic pump is used as the power source.

Solution

Two positions of the hydraulic circuit for the control task in Example 2 in the normal and actuated positions of the double -acting hydraulic cylinder are shown in Fig. 8. The double - acting cylinder can be controlled by using a manually-actuated 4/2 DC valve. The power supply unit consists of hydraulic pump driven by an electrical motor, a reservoir, and an integral pressure relief valve. The pump delivers pressurized oil to the circuit with constant displacement.

When the valve is actuate as shown in the Fig. 8(b) the system oil flow is directed to the piston side port of the cylinder, and the cylinder extends in the normal position of the valve as shown in the fig. 2(a) the oil flow is directed to the piston - rod side port of the cylinder and the cylinder retracts to its home position. The maximum / operating pressure (say 100 bar) in the system can be set by using a separate pressure relief valve (PRV) as shown.

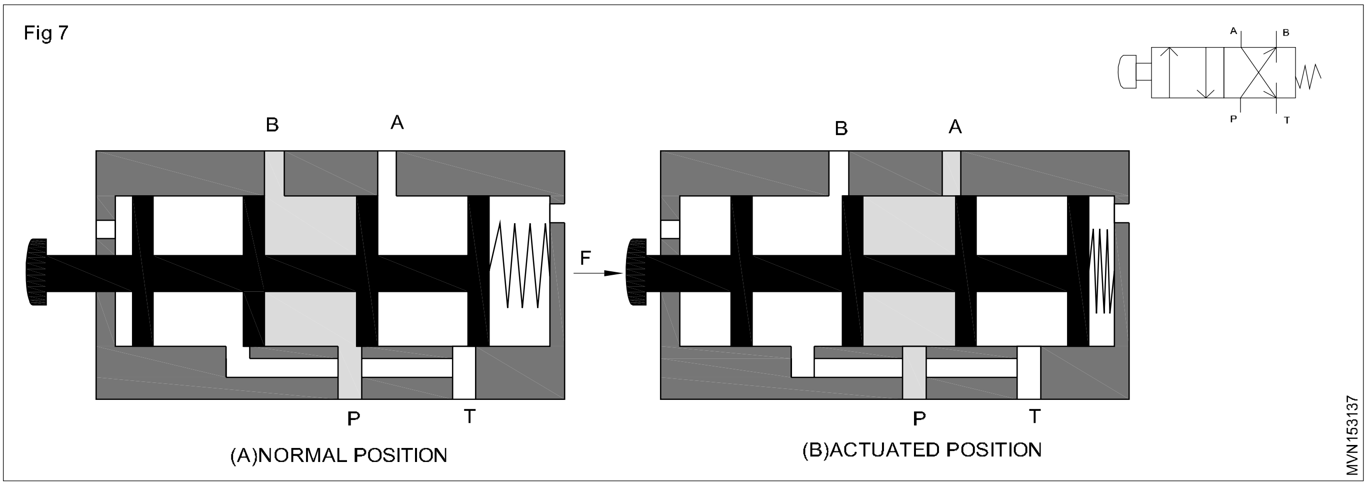


Figure 7: Cross sectional views of a manually actuated 4/2 DC hydraulic valve in its normal and actuated position

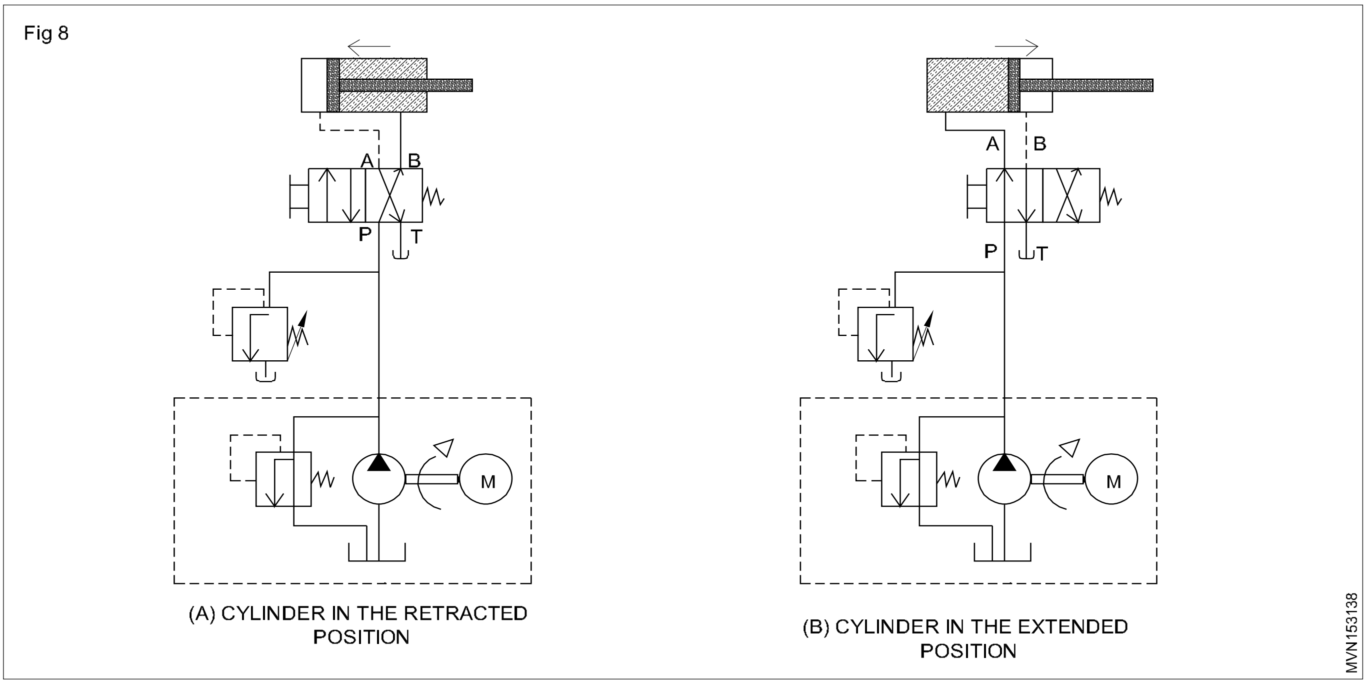


Figure 8: Two positions of the circuit for the control of a double - acting hydraulic cylinder

Non-return Hydraulic Valve

A non-return valve (NRV) is the simplest type of directional control valve used in a hydraulic circuit. The valve preferentially permits flow through it in one direction and blocks the flow in the reverse direction. The basic NRV is the so-called check valve. A hydraulic check valve consists of a valve body and a spring-biased ball poppet or cone poppet, apart from inlet/outlet ports. The spring holds the poppet against the valve seat. Cross-sectional views of these two types of hydraulic check valves are shown in Figure 9.

When the system pressure at the port A is high enough to overcome the spring force, the poppet is pushed off its seat allowing the system oil to flow freely through the valve from the port A the port B with a low-pressure drop across it. The flow through the valve is blocked when the intended flow direction is from the port B to the part A, by poppet reseating.

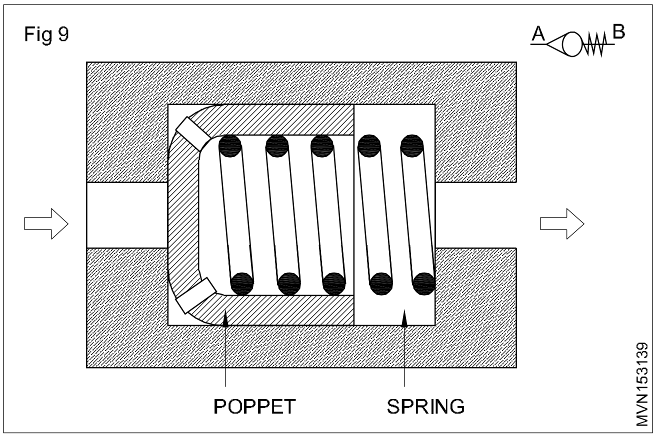


Figure 9: Cross-sectional views of a check valve

Flow Control (Throttle) Valve

A throttle valve is a device with a restriction that offers a resistance to the system oil flowing through it. The throttle valve regulates the flow rate of the system oil. According to the type of restriction, throttle valves are of two types.