Chapter Three
System Implementation

3.1 Introduction

The controlled movement of parts or a controlled application of force is a common requirement in the industries. These operations are performed mainly by using electrical machines or diesel, petrol and steam engines as a prime mover. These prime movers can provide various movements to the objects by using some mechanical attachments like screw jack, lever, rack and pinions etc. However, these are not the only prime movers. The enclosed fluids (liquids and gases) can also be used as prime movers to provide controlled motion and force to the objects or substances. The specially designed enclosed fluid systems can provide both linear as well as rotary motion. The high magnitude controlled force can also be applied by using these systems. This kind of enclosed fluid based systems using pressurized incompressible liquids as transmission media are called as hydraulic systems.

3.2 Hydraulic System

The hydraulic system works on the principle of Pascal's law which says that the pressure in an enclosed fluid is uniform in all the directions. The Pascal's law is illustrated in Figure 3.1. The force given by fluid is given by the multiplication of pressure and cross section area. As the pressure is same in all the direction, the smaller piston feels a smaller force and a large piston feels a large force. Therefore, a large force can be generated with smaller force input by using hydraulic systems [8].

$$F_2 \times A_1 = F_1 \times A_2 \tag{3.1}$$

$$F_2 = F_1 \times \frac{A_2}{A_1} \tag{3.2}$$

Where F: force

A: area

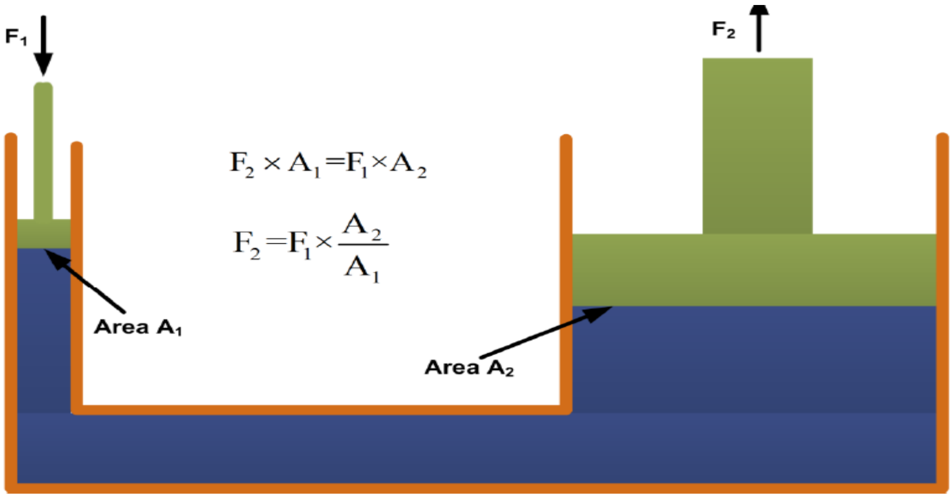


Figure 3.1: Principle of hydraulic system

The schematic of a simple hydraulic system is shown in Figure 3.2. It consists of:

• A movable piston connected to the output shaft in an enclosed cylinder.

• Storage tank.

• filter.

• Electric pump.

• Pressure regulator.

• Control valve.

• Leak proof closed loop piping.

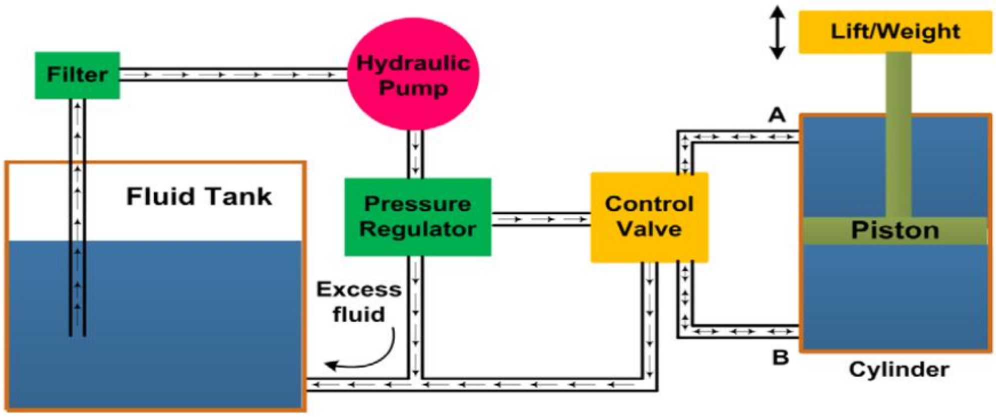


Figure 3.2: Schematic of hydraulic system

The storage/fluid tank is a reservoir for the liquid used as a transmission media. The liquid used is generally high density incompressible oil. It is filtered to remove dust or any other unwanted particles and then pumped by the hydraulic pump, as well as a void damage to the cylinder (actuator) and valve. The capacity of pump depends on the hydraulic system design. These pumps generally deliver constant volume in each revolution of the pump shaft. Therefore, the fluid pressure can increase indefinitely at the dead end of the piston until the system fails. The pressure regulator is used to avoid such circumstances which redirect the excess fluid back to the storage tank. The movement of piston is controlled by changing liquid flow from port A and port B. The movement of piston is controlled by changing liquid flow from port A and port B. The cylinder movement is controlled by using control valve which directs the fluid flow. The fluid pressure line is connected to the port B to raise the piston and it is connected to port A to lower down the piston. The valve can also stop the fluid flow in any of the port. That means the cylinder movement is controlled by a three position change over a control valve:

1. When the piston of the valve is changed to upper position, the pipe pressure line is connected to port A and thus the load is raised.
2. When the position of the valve is changed to lower position, the pipe pressure line is connected to port B and the thus the load is lowered.

3. When the valve is at center position, it locks the fluid into the cylinder (thereby holding it in position) and dead. Ends the fluid line (causing all the pump output fluid to return to tank via the pressure relief).

The leak proof piping is also important due to safety, environmental hazards and economical aspects [8].

3.2.1 Hydraulic Principle

- First, liquids are practically incompressible. Example: If you have a glass jar filled to the top with a liquid, you will not be able to put a stopper in the jar. If you force the stopper in, the jar will shatter. What this means in a HWH hydraulic system is if the pump is running, the fluid has to go somewhere. If the system is functioning properly, a jack should be extending or a room extension should be extending or retracting. If nothing is moving with the pump running, the system pressure should rise to the point where the fluid will flow across a relief valve back to the pump reservoir. (Simply put, if a hydraulic cylinder is moving, the fluid in the system is moving OR to make a hydraulic cylinder move, the fluid in the system has to move.)
- Second, fluids transmit pressure in all directions. Pressure in fluid has no one specific direction. The flow of fluid is directional. The direction fluid flows in a system can be changed by opening or closing valves but pressure in the system just is. In the Figure 3.3, the piston is pushing the fluid out of the cylinder. The direction of flow is to the hole in the end of the cylinder but the pressure in the cylinder is the same at the piston and on the walls of the cylinder as it is at the hole in the end of the cylinder.

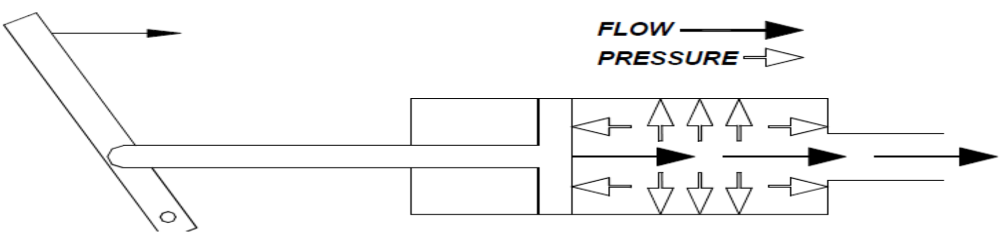


Figure 3.3: Diagram show the direction of the fluid

- Third, fluid can provide a great increase in work force. This is the main reason HWH has chosen to use hydraulic systems instead of electric motors, electric actuators, pulley and gear systems, etc. The formula used to calculate force is:

  F (force) = P (pressure) x A (area) (3.3)

  Force is figured in pounds, pressure is figured in psi (pounds per square inch) and area is the square inches of the movable rod or piston in the cylinder.

  The capacity of a leveling jack or room mechanism is essential knowledge when figuring the correct jack or mechanism needed to lift and level a coach or move a room.
- Fourth, is the effect change in temperature can have on fluid. Note that water reacts differently than oil. When the temperature of a fluid is increased (gets hotter), the volume of the fluid increases. As the temperature decreases (cools), the volume of the fluid decreases. This is called "thermal expansion or contraction". If you take a jar filled with fluid at room temperature and place it over a burner, the fluid will flow over the side of the jar as the temperature of the fluid increases. If you take a jar filled with fluid at room temperature and put it in the freezer, the level of the fluid will drop as the fluid cools. The same thing happens in our hydraulic systems. The thermal expansion and contraction can make the leveling jacks extend or retract slightly and to a lesser extent cause some issues in room extension systems.

  Remember, if the temperature of the fluid in a system increases, the volume of the fluid in that system increases the pressure in the system can also increase. That extra fluid has to go somewhere. If the temperature decreases, the volume of fluid decreases. That would be the same as the fluid moving. It is possible that a cylinder may move.

3.2.2 Hydraulic Components

One of the keys to diagnosing anything understands what the different components of the system are used for and how they function. There are four main parts to a HWH hydraulic system, the pump, which moves the fluid, the valves, which direct the fluid, the hoses, which transfer the fluid and the cylinders, which transform the moving fluid into a function such as leveling a vehicle or moving a room.

- Hydraulic Pump

The combined pumping and driving motor unit is known as hydraulic pump. The hydraulic pump takes hydraulic fluid (mostly some oil) from the storage tank and delivers it to the rest of the hydraulic circuit. Pressure is created when there is resistance to the flow the pump creates. In general, the speed of pump is constant and the pump delivers an equal volume of oil in each revolution. The volume of oil being moved changes with the speed the gears turn. The faster they turn the greater the volume of oil that is moved. The amount and direction of fluid flow is controlled by some external mechanisms. In some cases, the hydraulic pump itself is operated by a servo controlled motor but it makes the system complex.

The hydraulic pumps are characterized by its flow rate capacity, power consumption, drive speed, pressure delivered at the outlet and efficiency of the pump. The pumps are not 100% efficient. The efficiency of a pump can be specified by two ways. One is the volumetric efficiency which is the ratio of actual volume of fluid delivered to the maximum theoretical volume possible. Second is power efficiency which is the ratio of output hydraulic power to the input mechanical/electrical power. The typical efficiency of pumps varies from 90-98% [8].

Hydraulic pumps are required to generate the high fluid pressures of 500 to 3000 psi (3500 kPa to 21000kPa) used in industrial applications. Three basic types of hydraulic pumps (and motors) are available; piston pumps, vane pumps, and gear pumps. Pumps use an external source of energy (typically an electric motor) to pressurize the hydraulic fluid [9].

These are mainly classified into two categories:

1. Non-Positive Displacement Pumps

These pumps are also known as hydro-dynamic pumps. In these pumps the fluid is pressurized by the rotation of the propeller and the fluid pressure is proportional to the rotor speed. These pumps can not withstanding high pressures and generally used for low-pressure and high-volume flow applications.

2. Positive displacement pumps

These pumps deliver a constant volume of fluid in a cycle. The discharge quantity per revolution is fixed in these pumps and they produce fluid flow proportional to their displacement and rotor speed. These pumps are used in most of the industrial fluid power applications. The important advantages of positive displacement pumps over non-positive displacement pumps include capability to generate high pressures, high volumetric efficiency, high power to weight ratio, change in efficiency throughout the pressure range is small and wider operating range pressure and speed.

There are two main problems that are very damaging to a pump, contaminated or improper type of oil and cavitations. Contaminated oil should be an obvious problem. Contamination can damage the pump gears or interior pump housing surfaces. Cavitation occurs when there is an insufficient supply of oil to meet the needs of the pump (not enough fluid in the tank or a plugged breather cap). This allows air or vapor spaces in the oil as it goes through the pump gears and creates an absence of lubrication on pump components. This will cause flaking of the gears and pump housing surfaces, causing yet more damage. When gear and housing surfaces are damaged, this allows fluid to "slip" by the gears reducing the amount of flow the pump can create. This in turn can reduce the system pressure.

- Hydraulic Actuators

Is a device used to convert the fluid power into mechanical power to do useful work. The actuator may be of the linear types (e.g., hydraulic cylinder) or rotary types (e.g., hydraulic motor) to provide linear or rotary motion, respectively. Three types of actuators are common in hydraulic applications:

hydraulic motors, linear cylinders, and rotary actuators. Hydraulic motors are similar in design and construction to pumps, except that the high pressure fluid is used as the energy source to drive an external load. In fact, most pumps will act as motors if the flow direction is reversed. Linear cylinders are probably the most common type of hydraulic actuator. Rotary actuators are essentially a hybrid between hydraulic motors (with continuous rotary motion) and linear cylinders (with finite linear motion), since they provide a limited rotary motion.

- Pressure Regulation

The pressure regulation is the process of reduction of high source pressure to a lower working pressure suitable for the application. It is an attempt to maintain the outlet pressure within acceptable limits. The pressure regulation is performed by using pressure regulator. The primary function of a pressure regulator is to match the fluid flow with demand. At the same time, the regulator must maintain the outlet pressure within certain acceptable limits.

The schematic of pressure regulator and various valves placement is shown in Figure 3.4. When the valve V1 is closed and V2 is opened then the load moves down and fluid returns to the tank but the pump is dead ended and it leads to a continuous increase in pressure at pump delivery. Finally, it may lead to permanent failure of the pump. Therefore some method is needed to keep the delivery pressure P1 within the safe level. It can be achieved by placing pressure regulating valve V3 as shown in Figure 3.4. This valve is closed in normal conditions and when the pressure exceeds a certain limit, it opens and fluid from pump outlet returns to the tank via pressure regulating valve V3. As the pressure falls in a limiting range, the valve V3 closes again.

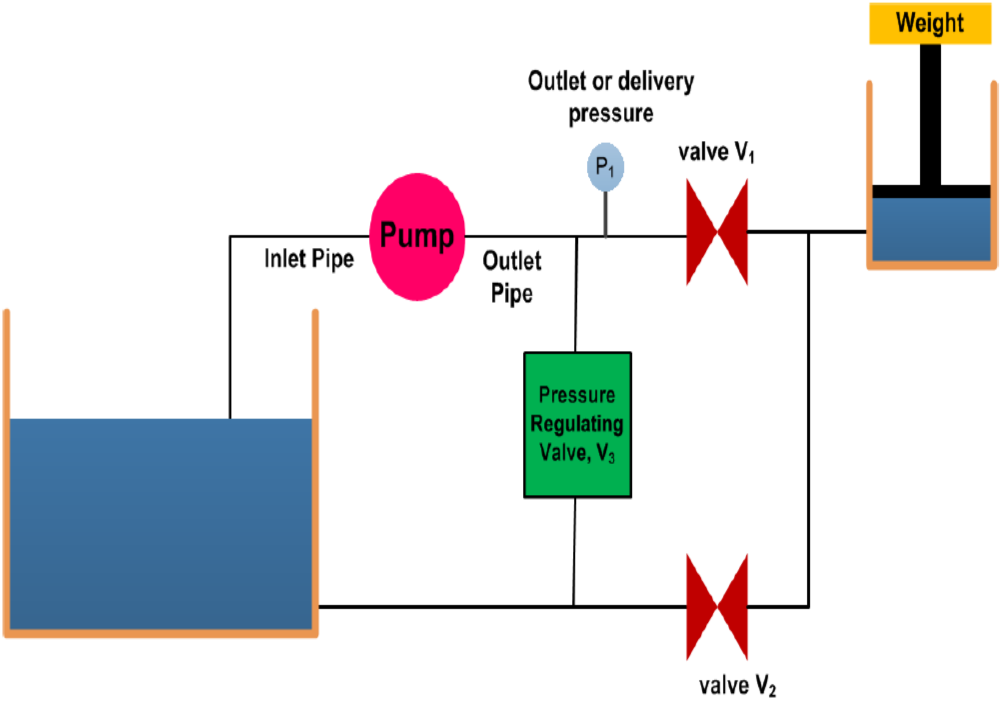


Figure 3.4: Schematic of pressure regulation

When valve V1 is closed, the whole fluid is dumped back to the tank through the pressure regulating valve. This leads to the substantial loss of power because the fluid is circulating from tank to pump and then pump to tank without performing any useful work. This may lead to increase in fluid temperature because the energy input into fluid leads to the increase in fluid temperature. This may need to the installation of heat exchanger in to the storage tank to extract the excess heat. Interestingly, the motor power consumption is more in such condition because the outlet pressure is higher than the working pressure.

- Valve

Several different types of valves are used in hydraulic systems. Valves can be categorized as either:

1. Pressure control valves (pressure relief, sequence, unloading, counterbalance, pressure reducing).
2. Flow control (fixed restriction, variable (needle), compensated, flow divider).

3. Directional control (check, shuttle, two/three/four way, manual (shut-off), electrohydraulic servo valve).

Pressure control valves: that pass flow to other portions of a hydraulic circuit is called sequence, unloading, or counterbalance valves depending upon the application. Pressure control valves are used to limit or reduce system pressure. A pressure reducing valve is used to provide a downstream source of fluid at a reduced pressure, much like a voltage regulator in an electrical circuit. Pressure control valves can be adjustable or set at a specific pressure that cannot be changed.

Flow control valves: are used to limit the amount of hydraulic fluid flow. By changing the flow, the speed a component moves can be controlled. We use fixed flow control, adjustable flow control and a variable flow control valve. The variable flow valve is called the velocity valve and is used in leveling systems to slow the retraction of the jacks when they are under a load. As the load decreases, the valve opens to allow a more natural flow of fluid back to the tank. This makes it so the vehicle will not drop so fast when the valves are first opened to retract the jacks. Adjustable flow valves are used to slow down room movement and fixed flow valves are used on step cover cylinders and the 500/510 computerized leveling system when stabilizing the vehicle.

Directional control valves (DCVs): are used to control the path that the hydraulic fluid flow uses as it flows from the pump back to the reservoir. Two-, three-, and four-way directional control valves can be actuated by a variety of different means including manual operation (levers, pedal, or palm buttons), electrical solenoid, cam operation, spring returns, and pilot operation. Check valves are flow control devices that allow fluid flow in one direction, but completely prevent flow in the reverse direction (which is very similar to the action of a diode in an electrical circuit) [9].

- Cylinder

The cylinders convert hydraulic power into mechanical power to level a vehicle or move a room or other component. There are two basic types of cylinders, single-acting (one way) and double-acting (two way) cylinders show in the Figure 3.5. When discussing either the single-acting or double-acting cylinder, we will refer to the ends of the cylinder as the cap end or rod end of the cylinder. The rod end is the end the rod extends from and the opposite end is the cap end.

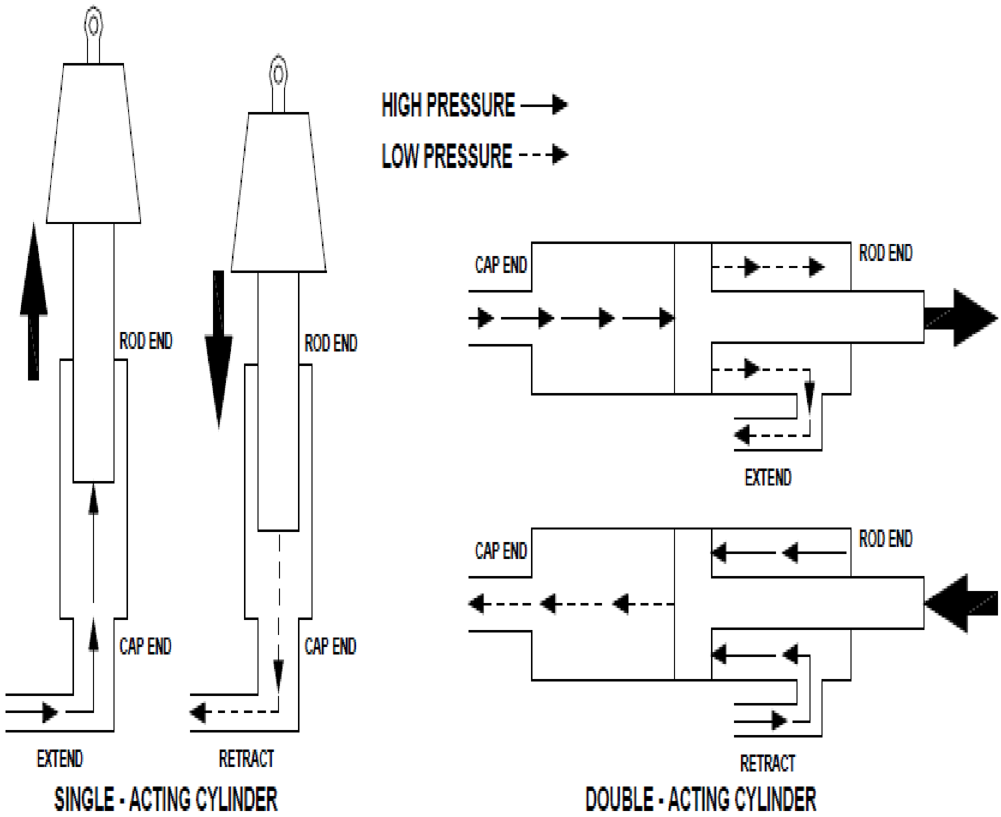


Figure 3.5: Types of cylinder

Single- acting cylinder: provide force in only in one direction, when the rod is extending. There is only one inlet fitting for fluid. It is at the cap end of the cylinder. When the rod is retracted, fluid is pushed out of the cylinder through the same fitting. The hydraulic pump in the system only runs when the rod is extending. A force such as gravity or the use of a spring is used to retract the rod. Single-acting cylinders are easier and less expensive to build and maintain. In most cases, it is easier to retract a single-acting cylinder than a double-acting cylinder in the case of an electrical or hydraulic failure.

Double- acting cylinder: provide force both when extending and retracting. There is an inlet/outlet fitting at the cap end and rod end of the cylinder. The rod is equipped with a sealed piston that isolates the cap end from the rod end of the cylinder. To extend the cylinder, system valving directs fluid under pressure into the cap end of the cylinder and releases fluid from the rod end of the cylinder returning the fluid to the reservoir. To retract the cylinder, system valving directs fluid under pressure into the rod end of the cylinder and releases fluid from the cap end of the cylinder returning the fluid to the reservoir show in the Figure 3.6. The double-acting cylinder is also used when a regenerative hydraulic circuit is used. The double-acting cylinder is more complicated and expensive to produce.

The cylinder bore must be precisely honed to maintain a good piston seal between the cap and rod end. Leakage by the piston seal in a double-acting cylinder will cause a cylinder to become weak and may cause cylinders to creep out. The sizing of the rod and piston may need to be larger to maintain the proper lifting capacity yet give adequate side load capabilities. It takes more or different valving to operate the double-acting cylinder. It also requires two hoses to each cylinder instead of the one required for a single acting cylinder. The use of a double-acting cylinder does eliminate the need for a return spring arrangement.

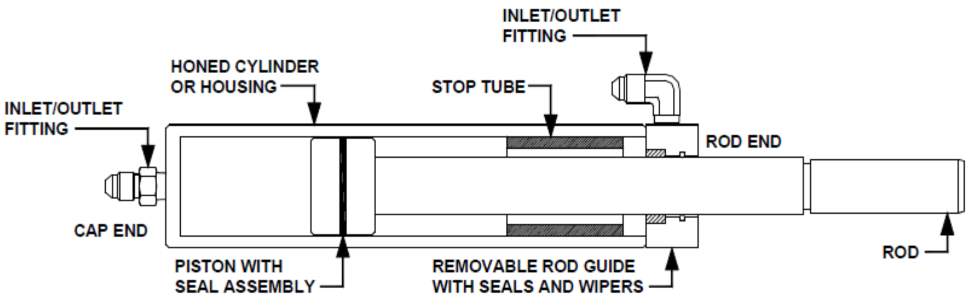


Figure 3.6 Double- acting cylinder

- Hoses

Hoses are used to transfer fluid through the system. In lever controlled systems, from the pump to the valves then to the cylinders. In button or switch controlled systems, the valves and pump are one unit called the power unit. The hoses transfer the fluid between the power unit and the cylinders in the system. Although short pieces of steel tubing are used for some applications, HWH uses several different sizes and ratings of flexible hose depending on the flow and pressure requirements of the system. In some cases a smaller, more flexible hose or steel tube may be used because of space limitations or bending requirements of a mechanism.

3.2.3 Graphical representation of hydraulic

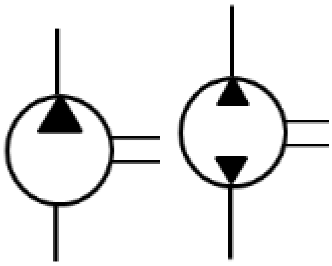
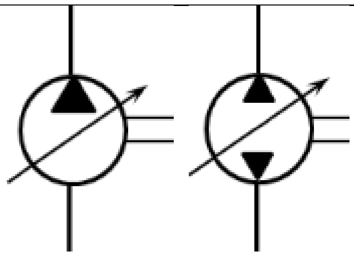
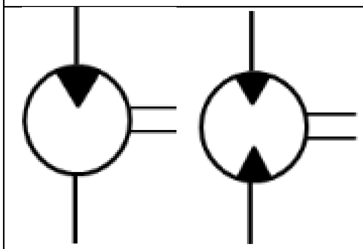
The hydraulic elements such as cylinders and valves are connected through pipelines to form a hydraulic circuit. It is difficult to represent the complex functioning of these elements using sketches. Therefore graphical symbols are used to indicate these elements. The symbols only specify the function of the element without indicating the design of the element. Symbols also indicate the actuation method, direction of flow of air and designation of the ports.

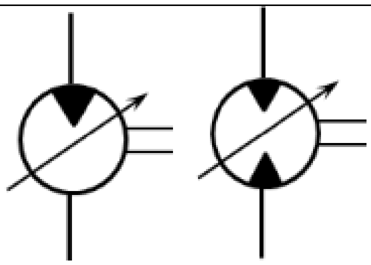
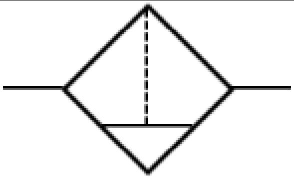
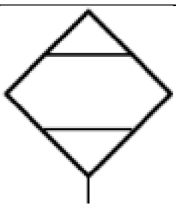
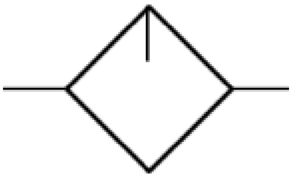
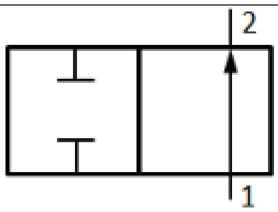
The symbol used to represent an individual element display the following characteristics:

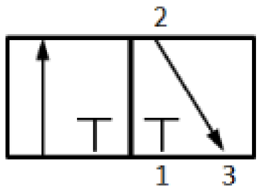
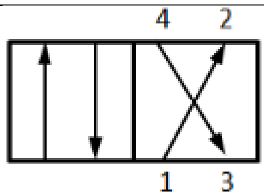
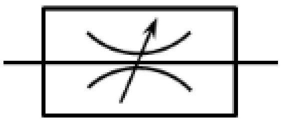
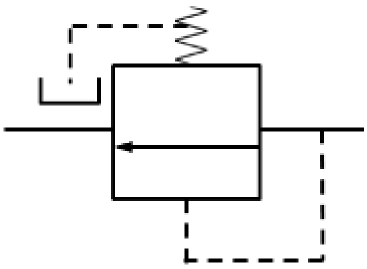
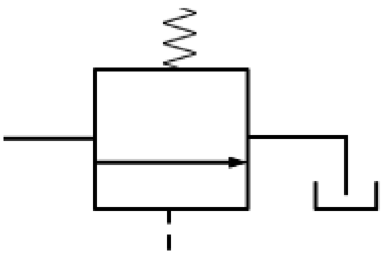
- Function
- Actuation and return actuation methods
- Number of connections
- Number of switching positions
- General operating principle
- Simplified representation of the flow path

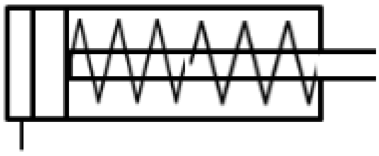
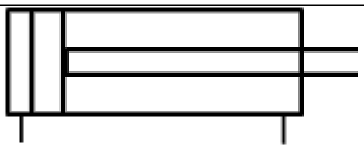
The graphical representation, designation and explanation of various components and equipments used in hydraulic system are given in Table 3.1.

Table 3.1 Graphical symbols of hydraulic elements and equipments

Symbol	Designation	Explanation
	Hydraulic Pump	One direction and two direction of rotation with constant displacement volume
		One direction and two direction of rotation with variable displacement
	Hydraulic Motor	One direction and two direction of rotation with constant displacement volume

		One direction and two direction of rotation with variable displacement
	Air Filter	This device is a combination of filter and water separator
	Dryer	For drying the air
	Lubricator	For lubrication of connected devices, small amount of oil is added to the air flowing through this device
	Direction Control Valves (DCVs) 2/2 way valve	Two closed ports in the closed neutral position and flow during actuated position

	Direction Control Valves (DCVs) 3/2 way valve	In the first position flow takes place to the cylinder In the second position flow takes out of the cylinder to the exhaust (Single acting cylinder)
	Direction Control Valves (DCVs) 4/2 way valve	For double acting cylinder all the ports are open
	Flow Control Valve	To allow controlled flow
	Pressure Reducing Valve	Maintains the reduced pressure at specified location in hydraulic system
	Unloading Valve	Allows pump to build pressure to an adjustable pressure setting and then allow it to be

		discharged to tank
	Single Acting Cylinder	Spring loaded cylinder with retraction taking place by spring force
	Double Acting Cylinder	Both extension and retraction by hydraulic force

3.3 Applications of Hydraulic Systems

The main applications of hydraulic system can be classified in five categories:

1. Industrial: Plastic processing machineries, steel making and primary metal extraction applications, automated production lines, machine tool industries, paper industries, loaders, crushes, textile machineries, R and D equipment and robotic systems etc.

2. Mobile hydraulics: Tractors, irrigation system, earthmoving equipment, material handling equipment, commercial vehicles, tunnel boring equipment, rail equipment, building and construction machineries and drilling rigs etc.

3. Automobiles: It is used in the systems like breaks, shock absorbers, steering system, wind shield, lift and cleaning etc.

4. Marine applications: It mostly covers ocean going vessels, fishing boats and navel equipment.

5. Aerospace equipment: There are equipment and systems used for rudder control, landing gear, breaks, flight control and transmission etc. which are used in airplanes, rockets and spaceships.

3.4 Advantages and Disadvantages of Hydraulic System

The main advantages and disadvantages are:

3.4.1 Advantages

- The hydraulic system uses incompressible fluid which results in higher efficiency.
- It delivers consistent power output which is difficult in pneumatic or mechanical drive systems.
- Hydraulic systems employ high density incompressible fluid. Possibility of leakage is less in hydraulic system as compared to that in pneumatic system. The maintenance cost is less.
- These systems perform well in hot environment conditions.

3.4.2 Disadvantages

- The material of storage tank, piping, cylinder and piston can be corroded with the hydraulic fluid. Therefore one must be careful while selecting materials and hydraulic fluid.
- The structural weight and size of the system is more which makes it unsuitable for the smaller instruments.
- The small impurities in the hydraulic fluid can permanently damage the complete system, therefore one should be careful and suitable filter must be installed.
- The leakage of hydraulic fluid is also a critical issue and suitable prevention method and seals must be adopted.
- The hydraulic fluids, if not disposed properly, can be harmful to the environment.

3.5 Design of Hydraulic System

The design of hydraulic system using:

3.5.1 Ladder diagram

Consider the simple hydraulic system shown in Figure 3.7. Pressurized hydraulic fluid is available to the simple two positions, four-way solenoid valve, as indicated by the dark arrow symbol. In the configuration shown the hydraulic cylinder will retract fully. The solenoid valve shown is activated by an electrical current passing through the solenoid coil. This type of simple ON/OFF programming has traditionally been done by relay control systems, like that shown on the right. This schematic diagram represents a type of programming frequently referred to as ladder logic. The two parts of a relay (coils and contacts) are both shown in this diagram. Electrical current passing through the coil of the relay **(**denoted by the circle element CR-1**)** closes one of these sets of contacts (CR-1B) which allows current to flow through the solenoid, SOL-A. Another set of contacts, CR-1A, is used to "hold" the contacts closed once they have been energized. A momentary contact push-button PB-1 **(**normally open or N.O.**)** is provided for initiating motion. When PB-1 is pressed, current flows through the actuating circuit of relay CR-1, which closes the output contacts (CR-1A and CR-1B).

Relay CR-1 remains energized until the limit switch, LS-1, is activated by the cylinder. When this limit switch is activated, the current flow through the control relay CR-1 is interrupted, and the contacts CR-1A and CR-1B both open. The solenoid SOL-A is de-energized, therefore the spring shifts the solenoid back to the right position, which causes the cylinder to retract. The circuit is inactive until a subsequent pressing of the push-button PB-1 [9].

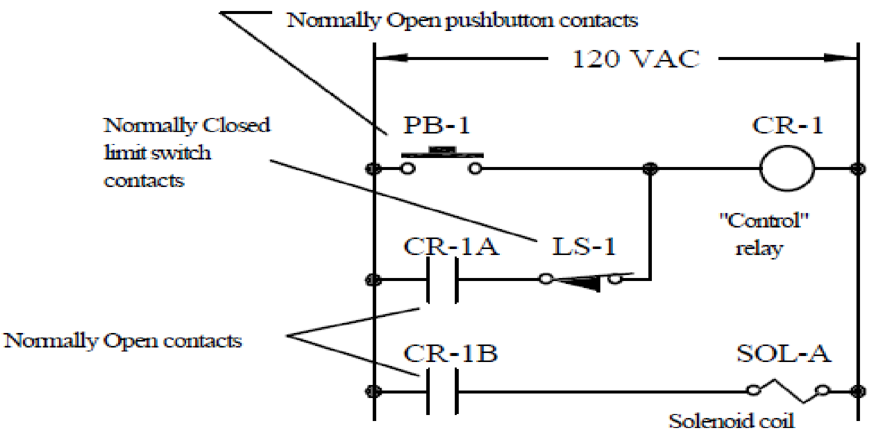


Figure 3.7: Simple hydraulic with ladder logic

3.5.2 PLC ladder diagram

One of the disadvantages of the relay logic systems of the previous section is the difficult nature of the programming. The program logic is hard-wired by the interconnection of the relays, limit switches, and pushbutton inputs. Changing the task performed by the simple system of Figure 3.8 requires that the circuit be physically rewired. For circuits with only three or four components this is not difficult. Programmable logic is implemented using a microcomputer instead of the hard-wired logic of the conventional hard-wired relay system. The major criteria for specifying PLC's are the number of input contacts that can be read and the number of output switches that can be controlled.

Figure 3.8 shows a programmable controller ladder logic diagram for the same simple system of Figure 3.7. The "internal" contact labeled 0.1 is connected to the input push-button, PB-1. The limit switch, LS-1, is wired to the input contact 0.2. The internal contact 5.0 replaces the control relay CR-1 and its two pairs of contacts. The output solenoid coil, SOL-A, is connected to the output contact 2.0. By comparing this figure to the relay system of Figure 3-4, the similarities between PLC programming and relay logic is obvious. One simplifying difference is that internal registers **(**such as 0.1, 0.2, and 5.0**)** can be used as replacements for inputs and control relay circuits.

An essentially unlimited number of input contacts and control relay contacts are therefore available, although the number of actual input devices is limited. A finite number of actual outputs (such as 2.0) are available, but their status can be read as many times as needed on other rungs of the ladder [9].

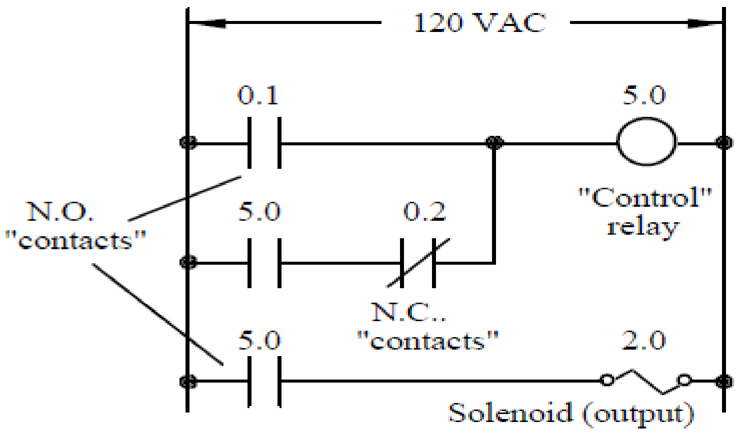


Figure 3.8: Simple hydraulic with PLC ladder logic

Summarize to different between relay and PLC is listed in Table 3.2.

Table 3.2 different between Relay and PLC

Features	Electromechanical Relay	PLC
Size of the controller	Bulky	Compact
Programming	Time consuming	Easy
Flexibility	Rewiring required	Reprogramming required
Cost	Expensive	Less expensive
Maintenance	Poor	Minimum
Fault finding and troubleshooting	Difficult	Easy to identify fault and repair

The hydraulic system types of continues process that means the output is a continuous flow. Examples are a chemical process, a refining process for gasoline, or a paper machine with continues output of paper onto rolls. Process control for these continues processes cannot be accomplished fast enough PLC on-off control. The control system most often used in continuous processes is PID control. PID control can be accomplished by mechanical, pneumatic, hydraulic, or electronic control as well as by PLCs.

Many medium-size PLCs and all large PLCs have PID control functions, which are able to accomplish process control effectively.

3.5.3 Proportional-integral derivative (PID)

PID is an effective control system for continues processes that performs two tasks. First, PID control keeps_the output at a set level even through varying process parameter may tend to cause the output to vary from the desired set point. Second, PID promptly and accurately changes the process level from one set level to another set point level.

A typical PID control system is shown in block diagram form of Figure 3.9. This configuration is the commonly used parallel type.

The controller output signal of Figure 3.9 is utilized through a control system to return the process variable to the set point.

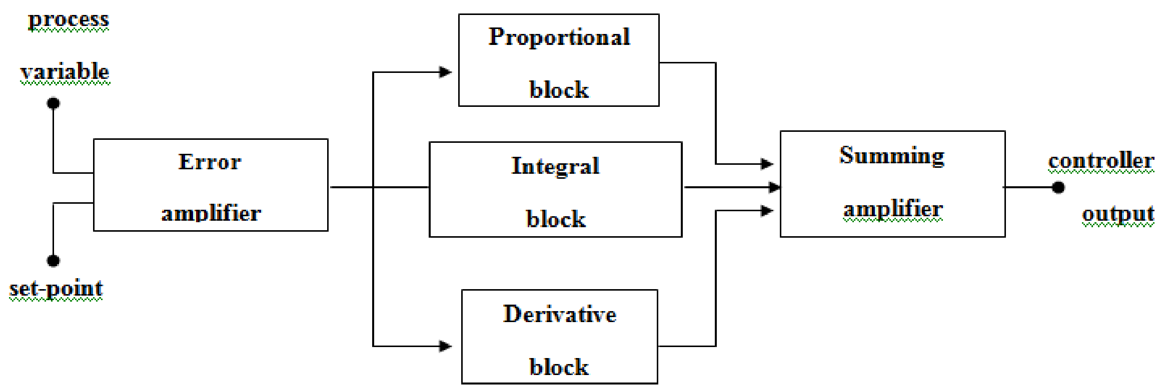


Figure 3.9 Block diagram of a typical PID controller

- **Proportional-integral derivative (PID) transfer function**

Transfer function of PID controller is:

$$G_R(s)=\frac{U(s)}{E(s)}=P+\frac{I}{s}+Ds=K_p\left(1+\frac{1}{T_i s}+T_d s\right) \tag{3.4}$$

The Kp, Ti and Td parameters has been obtained by Ziegler-Nichols method [10]. By changing the value of parameter to obtain the time response of the system [11].