Chapter One
Introduction

1.1.1 History:

Hydraulic technology began during antiquity long before the great works of such investigators such as Leonardo da Vinci (1452–1519), Galileo Galilei (1564–1642), Evangelista Torricelli (1608–1647), Blaise Pascal (1623–1662), Isaac Newton (1642–1727), Daniel Bernoulli (1700–1782), and Leonhard Euler (1707–1783). The history of hydraulic technology even began long before Archimedes (287–212 BC). [1] In 1648, a French physicist named Blaise Pascal realized that pressure on a confined fluid exerted an equal force in all directions, and those forces could be harnessed. It was not until 1738, when Daniel Bernoulli put this to use by pressurizing water in pumps and mills using the Bernoulli principal. Almost sixty years later, in 1795, Joseph Bramah patented the first hydraulic press in England, paving the way for the industrial revolution to automate things from printing presses to cranes, to machines for cutting and stamping, and thus automating the manufacturing process.

Hydraulic systems have been created from the work of great minds like Blaise Pascal, Joseph Bramah, Leonardo da Vinci and Galileo Galilei. Hydraulics eventually found their place in the modern world with wide-reaching and powerful applications.

1.1.2 Who Invented Hydraulics?

At the start of the 17th century, the study of hydraulics advanced with Simon Stevin's discovery of the hydrostatic paradox and the study of non-moving water, and Galileo Galilei's observations on gravity. Galileo studied gravitational acceleration, which played into the movement of water. His students included Evangelista Torricelli, who applied this knowledge to liquid jets and the liquid barometer, and Benedetto Castelli, who rediscovered the principle of continuity.

The Frenchman Blaise Pascal started work on mechanical calculators and became one of the first two inventors of the device. He made contributions to mathematics — such as Pascal's triangle — and studied hydraulic fluids. Building off the work of Torricelli and studies on vacuum space, Pascal came up with his law in 1648. Pascal's Law says that if pressure is applied to a fluid inside of a closed system, the pressure will be equally transmitted in all directions. Essentially, the pressure within a closed system stays constant. This principle laid the groundwork for some of the most critical hydraulic innovations in the industrial world. It defined how energy is harnessed and therefore this principle is the basis for most modern hydraulic systems. Pascal's work led to the invention of the hydraulic press and provided an extremely valuable principle for anything that works with fluid movement.

About a century and a half later, Joseph Bramah patented the hydraulic press in 1795. In this invention, he used Pascal's discovery to multiply a small amount of force and create large amounts of pressure capable of powering machinery and lifting very heavy objects. Part of what makes the hydraulic press so useful is that a hydraulic press uses small, flexible tubing.

In 1738, Daniel Bernoulli published his book Hydrodynamica, in which he described how water behaves under certain conditions and how it reacts to equilibrium, pressure and speed. Bernoulli's principle was based on his studies of energy conservation. Bernoulli worked closely with the mathematician Leonhard Euler, who may have derived the Bernoulli equation first. He also developed several important hydraulic equations and a hydraulic turbine.

In 1838, William George Armstrong, a man considered the grandfather of modern hydraulic power, began to experiment with hydraulics and developed a rotary engine. Unfortunately, no one cared for it at the time. He then discovered what became known as the Armstrong effect, or creating an electric charge from the escaped high-pressure steam of a boiler. He later designed a crane powered by hydraulics with a reciprocating ram. Armstrong modified an existing crane to use a town's water supply as a source of power. He started a business using this arrangement and began to manufacture cranes with this method. Later, Armstrong also developed the hydraulic accumulator which accomplished several goals. It bypassed the need for reservoirs, allowed for much higher pressures and created a system for hydraulic power to move between widely spaced hydraulic devices.

1.1.3 History of hydraulic technology during antiquity:

1.1.3.1 Hydraulic technology for irrigation:

About 6,000–7,000 years ago, farming villages of the Near East and Middle East became urban centers. During the Neolithic age (ca. 5700–2800 BC), the first successful efforts to control the flow of water were driven by agricultural needs (irrigation) and were implemented in Mesopotamia and Egypt. Being one of the most predictable rivers in the world, the Nile River flood is seldom sudden or abrupt and is timely, in contrast to the floods of the Tigris and Euphrates Rivers. Ideally the Nile would rise to bank-full stage by mid-August in southern Egypt, with the northern most basins being flooded 4–6 weeks later. In contrast the Tigris and Euphrates floods occurred in April or May, which was too early for the fall planting because the summers were too hot. Also, the ancient Mesopotamian valley lacked good drainage and experienced many floods. The consequence was that the ancient Mesopotamians had to build canals to divert water from the rivers, to develop their canal irrigated agriculture. Sedimentation in many of the canals was such a critical problem that it was easier to abandon these canals and build new ones. The large-scale diversion of water by humans probably had its origin in ancient Mesopotamia.[1]

1.1.3.2 Artificial basin irrigation and lift irrigation:

Artificial basin irrigation, established in Egypt by the first Dynasty (ca. 3100 BC), included deliberate flooding and draining using sluice gates and contained water by longitudinal and transverse dikes. This form consisted of a network of earthen banks, some parallel to the river and some perpendicular to the river that formed basins of various sizes. Floodwaters were diverted into the basins where the water was allowed to saturate the soil with the remaining water drained off to a down-gradient basin or to a canal. After the draining process was completed in a basin, crops were planted. Basins were supplied with water by feeder canals. The bed level of the feeder canal was midway between low Nile and ground level with a natural downstream slope less than the slope of the Nile. Dikes (levees) separated the basins with controls (masonry regulators) on the earthen embankments to control the flow of water into the basin. The basins were very level as a result of the water laden alluvium that deposited in the basins. During years of low flow in the Nile, basins were drained into the next downstream basin instead of back to the river. [1]

1.1.4 Hyraulic technology for early urban centers:

1.1.4.1 Beginning of bringing of water to urban centers:

The sources of water for urban centers during early civilizations [Bronze Age (4000–1100 BC)] included canals connected to rivers, rainwater harvesting systems, wells, aqueducts, and underground cisterns. In ancient Mesopotamia, during the Bronze Age, urban centers of the Sumer (Sumerian) and Akkud (Akkadian) (third millenium BC) had a canal(s) connected to the Euphrates River or a major stream for both navigation and water supply for daily uses. In Mari a canal connected to the city from both ends and passed through the city. Servant women filled the 25 m3 cistern of the palace with water supplied by the canal. Later on other cisterns were built in Mari and connected to an extended rainfall collection system. Terracotta pipes were used in Habuba Kebira (in modern Syria), a Sumerian settlement in the middle Euphrates valley in the middle of the IVth millennium BC. Mohenjo-Daro was a major urban center of the Indus Civilization during the early Bronze Age, located about 400 km north of Karachi, Pakistan. This was a planned city built around 2450 BC and serviced by at least 700 wells. In the third millennium BC time period the Indus civilization had bathrooms in houses and sewers in streets. The Mesopotamians were not far behind. [1]

1.1.4.2 Minoans:

The Minoan culture flourished during the Bronze Age in Crete. A systematic evolution of water management in ancient Greece began in Crete during the early Bronze Age, i.e., the Early Minoan period (ca. 3500–2150 BC). Wells, cisterns, water distribution, fountains, and even recreational functions existed. In prehistoric Crete rivers and springs provided people with water. Starting the Early Minoan period II (ca. 2900–2300 BC), a variety of technologies such as wells, cisterns, and aqueducts were used. Also, the Minoan architecture included flat rooftops, light wells, and open courts played an important role in the water management. The rooftops and open courts acted as catch basins to collect rainwater from which it flowed to storage areas or cisterns. [1]

1.1.5 Romans:

Romans were more pragmatic than their Greek predecessors in the manner that they planned and constructed the water supply systems. They built what can be called mega water supply systems including many magnificent structures. Sources of water for the Greeks were predominantly groundwater as they avoided surface water because of hygienic reasons. The magnificent aqueducts built by the Romans were supplied by either surface water or ground-water. Water sources for the Roman systems included not only springs but reservoirs that were developed by building dams. One of the Roman systems that I classify as a mega sys- tem was at ancient Augusta Emerita, at present day Merida, Spain. This system included two reservoirs, now known as the Cornalvo dam and the Proserpina dam. The Proserpina dam is an earthen dam, approximately 427 m long and 12 m high. The Cornalvo dam is an earthen dam, approximately 194 m long and 20 m high with an 8 m dam crest. [1]

1.1.5.1 The Roman mega hydraulic projects:

The Romans built what can be called mega water supply systems including many magnificent structures. Four of the magnificent mega water systems that were not described herein include: the water system of aqueducts and dams to Merida, Spain (ancient Augusta Emerita), the system of aqueducts with various structures to Lyon, France (ancient Lugdunum); the system of aqueducts to Rome, and the aqueduct of Nimes (ancient Nemausus). There are many others that include the components of the Roman systems. See Hodge (1992) and, among many other references for details of these systems. The Romans did not add to science like the Greeks: however, they contributed tremendously to the advancement of engineering. They also invented new technologies such as the Roman concrete (opus caementitium) which allowed the construction of long canals, very large bridges and long tunnels in soft rock. The Greeks lacked the technology of the Roman concrete which was needed for the mega projects.

1.1.5.2 Roman hydraulic devices:

The force pump, a water lifting device, was invented by Ctesibius of Alexandria (ca. 270 BC) as mentioned previously. Roman force pumps were more technically complex than other ancient water lifting devices. Two cylinders mounted vertically were connected near their bases by a horizontal pipe with a single upright delivery pipe at the center of the pipe. Bronze flap valves (intake valves) were hinged at the bottom of each cylinder so they would open inwardly into the cylinder. A bronze piston was placed inside each cylinder so that when it was lifted (the up stroke) from the base of the cylinder, water entered through the flap valve and filled the cylinder. When the piston was forced downward (down stroke) water entered the transverse pipe connecting the two cylinders as the intake valve at the base of the cylinder closed. The upright delivery pipe had a one-way flap valve at its base which kept water moving in the vertical direction. The pistons in the two cylinders were moved by means of a connecting rod attached to opposite ends of a single lever. This allowed the pistons to work reciprocally so that when one piston was down the other was up. [1]

1.1.6 Conclusions:

The development of hydraulic technology has been traced, beginning with its infancy in the development of irrigated agriculture and water supply for urban centers. We have looked at some of the major advances that occurred in hydraulic technology during antiquity (before the end of the Roman Empire), long before the development of the laws of conservation used in modern day design of hydraulic structures. Considering the hydraulic structures that were built by the ancients, they had a remarkable observation of nature and were able to draw conclusions from their observations. During antiquity, the achievements of hydrau- lic technology was related to efforts to reduce labor and costs, rather than concepts related to conservation and the environment.

A comparison of the achievements in hydraulic technology during antiquity with the contemporary practices is an excellent example and motivation for the environmental and conservation issues of our present time. Some of the ancient technologies discussed are still being used successfully for present day rural communities in Africa, India, Iran, Jordan and others. Also, water problems exist in many parts of the world that could be solved by using ancient or traditional methods. Have we really listened to the ancients? One example to point out is the overuse and misuse of technologies such as irrigation canals by the ancients which led to salinization of agricultural fields and the consequential effects such as the migration of people in search of new lands. The drying of the Aral Sea in present times is one example of our not listening. There are many others. As stated by Mariena Mondelli Montandon in The Water Atlas by Pietro Laureano, "Often the farmers, who are 'the salt of the earth' have simply forgotten the methods used by their ancestors. They have been blinded by the philosophy of 'having it all and all at once' that Western people have unfortunately spread around the world.

1.2.1 Essential components of a hydraulic system

The complexity of a hydraulic system depends on its specific use, however all hydraulic systems have the same basic components.

As an overview, hydraulic fluid is pumped from the reservoir into the rest of the system, creating hydraulic power. The pressurized fluid then passes through valves and flows to the actuator where hydraulic power is converted to mechanical energy to achieve the desired function.

Below we will go through each of the components and describe their function within the overall system.

1.2.1.1 Reservoir Oil Tank

The reservoir holds the incompressible fluid, which is usually hydraulic oil. It also protects the fluid from getting contaminated, which is critical to ensure the hydraulic system functions optimally.

1.2.1.2 Piping

Piping is simply, but importantly, the hollow structures that carry the hydraulic fluid from one location to another within the system.

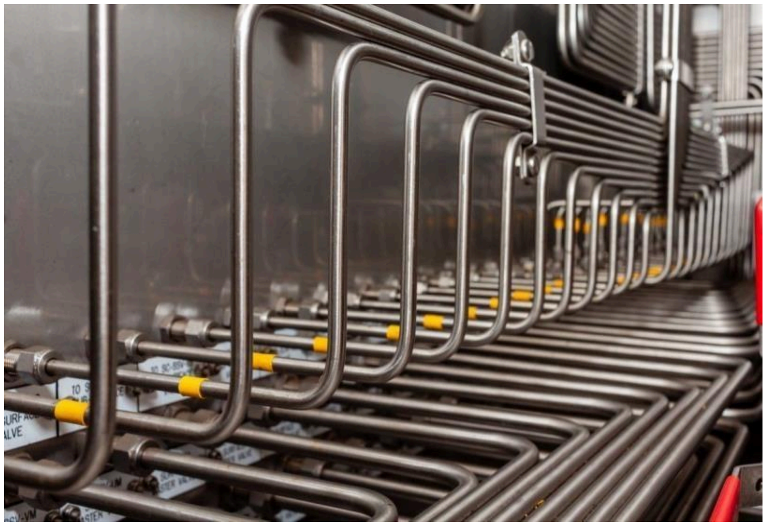

Fig1.1.Piping.

1.2.1.3 Hydraulic Pump

The role of hydraulic pumps is to force the hydraulic fluid from the reservoir to the rest of the circuit.

Firstly, the pump creates a vacuum at the pump inlet which forces the fluid from the reservoir into the pump. Next, the pump pushes the fluid to the pump outlet and then forces it into the rest of the hydraulic system.

The different types of hydraulic pumps are:

1.2.1.3.1 Fixed displacement pumps

These pumps have an unchangeable flow rate, so every stroke moves the same amount of fluid. They are good for jobs with a single action that are repeated for long periods. Examples include gear, gerotor and screw pumps.

Fig 1.2.Fixed displacement pumps.

1.2.1.3.2 Variable displacement pumps

These pumps can change the flow rate of the fluid and outlet pressure. They can power a variety of complex equipment, but they are more expensive and require more attention than fixed displacement pumps. Examples include piston pumps and vane pumps.

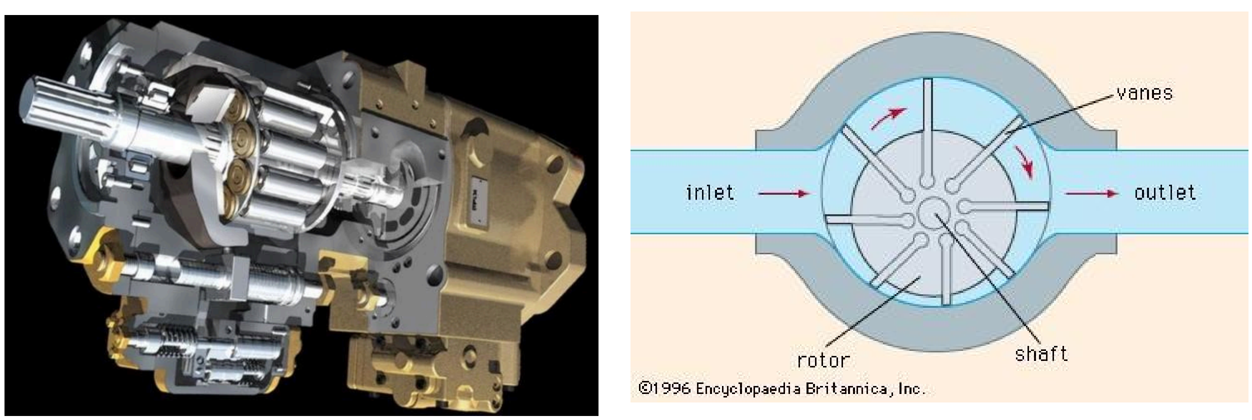

Fig 1.3.Variable displacement pumps.

1.2.1.3.3 Hand or manual hydraulic pumps

These pumps are operated manually by the hand and foot.

Fig1.4.Hand hydraulic pumps.

1.2.1.4 Power source

An electric motor or other power source is required to make the mechanical elements of the pump work.

1.2.1.5 Hydraulic Actuator

A hydraulic actuator is the component which changes the hydraulic power in the fluid into mechanical power to achieve the desired action.

The actuator can be a:

- Hydraulic cylinder which creates linear movement (movement in a straight line).
- Hydraulic motor which creates torque (a twisting force) and rotation.

1.2.1.6 Valves

Valves control the pressure, flow rate and direction of the fluid moving through the circuit. There are many types of valves with specific functions. We will outline the most common below.

1.2.1.6.1 Pressure control valves

Pressure control valves limit the pressure within the system to protect all the components from damage.

One type is the pressure relief valve. It is normally closed but opens when system pressure exceeds a maximum value. It will then direct the fluid back to the reservoir to keep the system's pressure below the maximum level.

Another type, called the pressure reducing valve, stops flow to a particular area of the system until the pressure is below the maximum level.

A sequence valve makes sure a certain level of pressure is reached in one section of the system before another is activated.

To prevent losing control over a load, a counterbalance valve is used to create a backpressure in the return line.

1.2.1.6.2 Flow control valves

As the name suggests, flow control valves influence the rate at which the fluid flows throughout the system. This is achieved by decreasing or increasing the diameter of the opening the hydraulic fluid flows through.

Flow control valves are used to affect how fast the movement produced by the actuator is.

1.2.1.6.3 Direction control valves

Direction control valves can stop, start and change the direction of the flow of hydraulic fluid. The simplest of these valves is called a check valve and it allows the hydraulic fluid to flow in one direction, while blocking fluid flow in the other direction.

Direction control valves can vary in the number of ports they have and the number of flow paths they allow. A spool type valves, controls the direction of flow, but is not limited to one direction.

1.2.1.7 Filters

Filters prevent the hydraulic system from being contaminated. This is essential to ensure the system works effectively and safely. Without a filter, a hydraulic system's components may wear down quickly and pipes may get blocked.

A suction line filter stops any contaminants in the reservoir fluid getting into the rest of the hydraulic system. It is located at the input side of the hydraulic pump.

A return line filter cleans out any contamination in the hydraulic fluid at the end of the return line.

1.3.1 Types and applications of hydraulic systems:

Nowadays, hydraulic systems have a wide range of applications in our daily life. The common applications of the hydraulic system perform lifting, holding and gripping. Hydraulic systems will transmit power using the pressure of incompressible fluids. In most of the cases, the fluid is taken from a reservoir using pumps. These are simple, safe, and economic systems that can be controlled easily and accurately. Providing constant force regardless of the speed is an advantage of the hydraulic system.

Open loop hydraulic system and closed loop hydraulic system are the two types of fwill be fluid flow but no pressure. For a closed loop system when the pump operates there will be pressure for fluids. The fluid will flow continuously between the pump and the actuator without entering the reservoir for a closed loop system. Whereas, for an open loop system, the fluid flow from the actuator to the reservoir and then fresh fluid flow towards the pump inlet. Open loop systems use a directional control valve and closed-loop system use an additional pump called charge pump or feed pump. Less heat generation is the advantage of open loop hydraulic system and precise response of actuation is the advantage of the closed-loop hydraulic system.

In order to eliminate the presence of foreign contaminants and to assist fluid flow, all open loop hydraulic circuits will use sealed or pressurized reservoirs. Conventional open loop hydraulic circuit used a large reservoir to allow air bubbles to escape from the fluid used.

The internal combustion engine, bomb calorimeter, reciprocating air compressor, refrigerating systems, piston-cylinder arrangements without valves, Rankine cycle (operating fluid is continuously evaporated and condensed), etc. are examples of the closed-loop hydraulic system. Turbine, compressor, pump, boiler, heat exchangers, etc. are examples of the open loop hydraulic system.

For simple applications, open loop hydraulic systems are efficient and cheaper. But for complex applications having independently working multiple subsystems, closed-loop hydraulic systems will be a better choice.

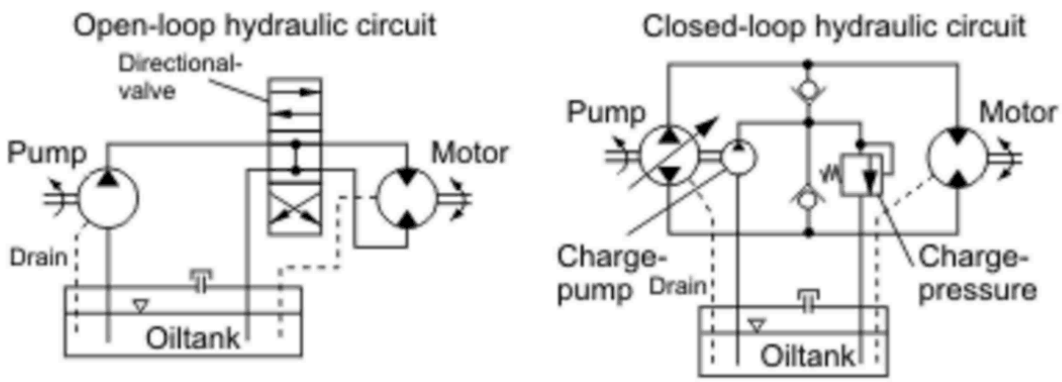

Fig 1.5.Open and closed loop hydraulic circuits.

1.3.1.1 Open and Closed Hydraulic Systems Difference:

Open loop hydraulic systems are suitable for low-pressure applications (below 3000psi) and closed loop systems can operate under high pressure with less fluid flow.

Closed loop systems have more control options, and the direction can be reversed without using valves.

Closed loop systems are more difficult to diagnose, and repair compared with open loop systems.

Continuous pressurization of the system is eliminated in the case of an open loop system.

Some designed hydrostatic transmission will be there in closed-loop systems. [3]

1.3.2 Hydraulics Applications:

Industrial: Electro hydraulics is the mechanism used for controlling the industrial applications of hydraulics. Precise and fast response is an advantage of this. Plastic processing machinery, steel making and primary metal extraction applications, automated production lines, machine tool industry, paper industries, loaders, crushers, presses, textile industry machinery, etc. are some of the examples of industrial hydraulics.

Mobile Hydraulics: In mobile hydraulics, the hydraulic system is controlled manually. Building and construction equipment like cranes, excavators, backhoe, earth moving equipment, etc., tractors, irrigation system, material handling equipment, tunnel boring equipment, rail equipment, etc. are some examples of mobile hydraulics.

Automobiles: Hydraulics have many interesting applications in the automobile industry. Most of the important work using the principle of hydraulics. Power steering, shock absorbers, windshields, and brake are the common applications of hydraulics in vehicles. Two-post lifts and four-post lifts are used in the automobile industry to lift vehicles for servicing and inspecting.

Marine Applications: Hydraulics plays an important role in maintaining the stability and control of ships. Steering gears, bow and stern thrusters, engine room maintenance systems including pumps and jacks, deck machineries like cranes, winches, hatch covers, mooring drums and others are examples of hydraulics in the marine industry.

Aerospace Applications: Airplanes, rockets, spaceships, etc. use hydraulic systems for various applications. Aerospace industry uses hydraulics for adjusting wings, retraction and extension of landing gears, opening/closing of doors, brakes, steering, etc.

Mining: Hydraulic fracturing is one of the advanced mining technologies used for extracting unused gases/oils beneath the earth surface. In this approach, a high-pressure mixture of water, sand and other chemical additives are passed into the crack. [3]

1.3.2.1 Examples of Hydraulic System

1.3.2.1.1 Hydraulic Lifts:

Hydraulic lifts are used for moving goods or people vertically. Scissor lifts, two-post lifts, four-post lifts, carousel lifts, and mezzanine lifts are different types of hydraulic lifts used. Hydraulic lifts are used in automobile, shipping, waste removal, and construction applications. Cables are not used with these lifts. So, it eliminates the risk of the dead-drop situation.

A ram, pump, motor, and valve are the main components of a hydraulic lift. The pump, motor, and fluid are kept in a machine room. The pump will exert pressure on the piston for moving the lift upwards and the lift moves downwards when the valve opens. For stopping the lift on particular floors, the power to the pump is disconnected.

1.3.2.1.2 Hydraulic Brakes:

Braking system of the vehicle is an important example of hydraulics. They are classified based on frictional contact mechanism (drum brake and disk brake) and brake force distribution (single acting and double acting).

Master and slave cylinders, lines, pads, brake fluids, and rotor are the components used for the hydraulic braking system. The commonly used brake fluids are dot fluid or mineral oil. While pressing the foot on the brake pedal, this will exert pressure to the fluid inside the brake lines. According to Pascal’s principle, this pressure passing through the brake lines will exert pressure on another cylinder causing the vehicle's brake shoes and pads to contact.

1.3.2.1.3 Hydraulic Steering:

Hydraulic power steering is an important part of the vehicles that help to change the direction of the vehicle to left or right. This system reduces the effort of drivers and absorbs road shocks. Control valve, pinion gear, pressure/return lines, piston, and rack housing are the primary components used for hydraulic power steering. The clockwise and anti-clockwise direction of the steering wheel will open and closes the valve attached to the rack housing. This will push fluid from the reservoir into the rack housing.

1.3.2.1.4 Hydraulic Jacks:

Hydraulic jacks are stronger and can lift heavier loads. Bottle jacks and floor jacks are classifications of hydraulic jacks. A hydraulic jack comprises of a cylinder and pumping system for storing and transferring hydraulic fluid. The pumping system contains a hand-powered or mechanically powered pump for applying pressure on the fluid. The one-way valve pushes the fluid towards the jack cylinder and does not allow to flow back. The working is based on Pascal's principle (the pressure inside a closed surface will be equal).

1.3.2.1.5 Heavy Equipment:

Hydraulics based heavy equipment will have more strength and ability to move quickly. Most of the construction industry uses such equipment. Bulldozers, backhoes, log splitter, shovels, loaders, forklifts, and cranes are some machineries used. In backhoes and excavators, the movement of the arm is based on hydraulics. Bulldozers use a hydraulic system for the movement of blades. Dump truck lifts the box part of the truck using hydraulics.

1.3.2.1.6 Airplanes:

Hydraulics is applied in airplanes and jet planes in many instances like adjusting wings, retraction and extension of landing gears, opening/closing of doors, brakes, steering, etc. The operating pressure will vary from 200 psi to 5,000 psi depending on the hydraulic system. Hydraulics have many advantages like the cost-effective, easy to maintain, efficient working under all condition.

1.3.2.1.7 Shock Absorber:

This is a device used to absorb and damp shock impulses. A cylinder with hydraulic oil and a piston is the components used for developing shock absorber. The piston will move up and down based on the compression and expansion of the string.

1.4.1 Hydraulic control systems:

One of the most important considerations in a hydraulic system is control. A hydraulic system controls the transmission of energy.

It transforms the mechanical energy of a prime motor into fluid energy. It controls the fluid configuration and transforms the fluid energy into mechanical work at specified locations.

Hydraulic systems feature high power density, sensitive response and precision of control, especially when operating under computer control. Thus, they have been widely used as the energy transmission control systems in aircraft, ships, construction machinery, machine tools and others.

Therefore, it is indispensable for a mechanical engineer to become versed with hydraulic control technology. The technology is mainly associated with fluid mechanics and control theories, but it is related to the wider field of engineering as well.

Pressure control is achieved in hydraulic systems by metering the flow of a fluid into or out of a constrained volume.

Relief valves and pressure-reducing valves are not pressure controllers. They limit or reduce pressure, but they do not really control pressure to a desired value.

1.4.2 Hydraulic control devices:

For any hydraulic system to function as required, a proper selection of control components is quite essential. Fluid power is primarily controlled with the help of control devices called valves. The selection of these control devices involves not only choosing the right type but also the size, actuating technique and its remote-control capability. In this chapter, we shall review in detail the working of various control devices in hydraulic systems that are as listed below: [4]

1.4.2.1 Control valves:

A control valve is a valve used to control fluid flow by varying the size of the flow passage as directed by a signal from a controller.

1.4.2.2 Servo valves:

An electrohydraulic servo valve (EHSV) is an electrically operated valve that controls how hydraulic fluid is sent to an actuator. Servo valves are often used to control powerful hydraulic cylinders with a very small electrical signal. Servo valves can provide precise control of position, velocity, pressure, and force.

1.4.2.3 Hydraulic fuses:

In hydraulic systems, a fuse (or velocity fuse) is a component which prevents the sudden loss of hydraulic fluid pressure.

1.4.2.4 Shock absorbers:

A shock absorber or damper is a mechanical or hydraulic device designed to absorb and damp shock impulses. It does this by converting the kinetic energy of the shock into another form of energy (typically heat) which is then dissipated.

1.4.3 Advantages and Disadvantages of Hydraulic control:

There are many unique features of hydraulic control compared other types of control.

1.4.3.1 Some of the Advantages are the following:

1. The hydraulic fluid acts as a lubricant and makes possible long component life.
2. Hydraulic actuators may be operated under continuous, intermittent, reversing, and stalled conditions without damage.
3. Open and Closed loop control of hydraulic actuators is relatively simple using valves and pumps.

1.4.3.2 Some of The Disadvantages are the following:

1. Small allowable tolerances result in high costs of hydraulic components.
2. It is impossible to maintain the fluid free of dirt and contamination. Contaminated oil is the chief source of hydraulic control failures.
3. Hydraulics are not flexible, linear, accurate, and inexpensive as electromechanical devices in the manipulation of low power signals. [4]

1.5.1 The Classification of Power Systems:

Power systems are used to transmit and control power. This function is illustrated by Fig. 1.5.1
The following are the basic parts of a power system.

1. Source of energy, delivering mechanical power of rotary motion. Electric motors and internal combustion engines (ICE) are the most commonly used power sources. For special applications, steam turbines, gas turbines, or hydraulic turbines are used.

2. Energy transmission, transformation, and control elements.

3. Load requiring mechanical power of either rotary or linear motion. In engineering applications, there exist different types of power systems: mechanical, electrical, and fluid. Figure 1.2 shows the classification of power systems.

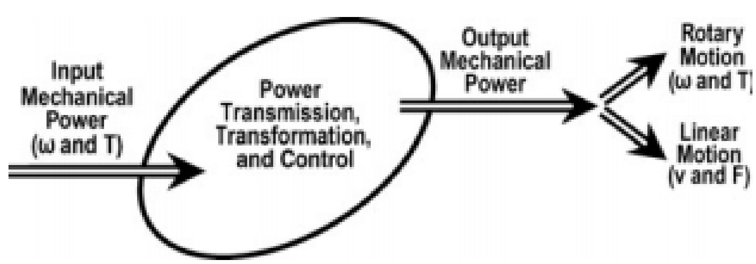

Fig1.6.fuction of a power system.

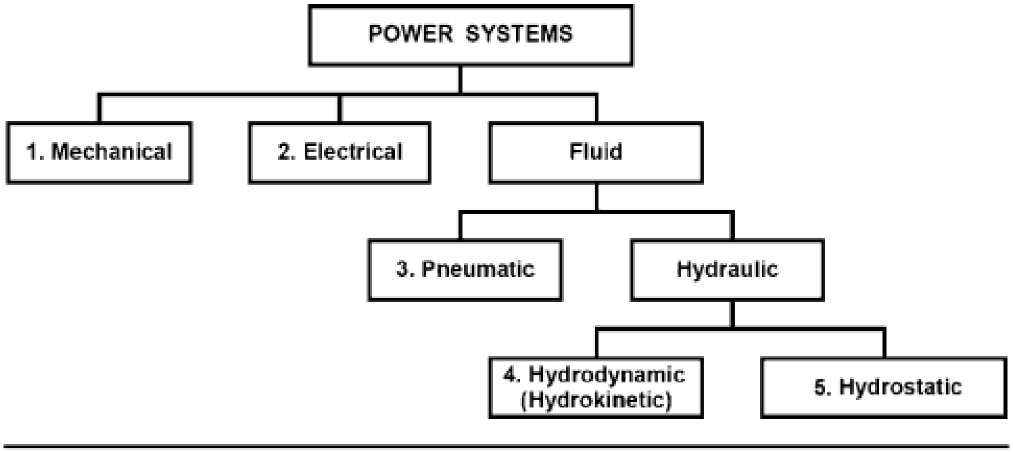

Fig1.7.Classification of power systems.

1.5.2 Hydraulic Power Systems:

Hydraulic power, also called Fluid Power, power transmitted by the controlled circulation of pressurized fluid, usually a water-soluble oil or water–glycol mixture, to a motor that converts it into a mechanical output capable of doing work on a load. Hydraulic power systems have greater flexibility than mechanical and electrical systems and can produce more power than such systems of equal size. They also provide rapid and accurate responses to controls. As a result, hydraulic power systems are extensively used in modern aircraft, automobiles, heavy industrial machinery, and many kinds of machine tools. [2]

The hydraulic power systems transmit mechanical power by increasing the energy of hydraulic liquids. Two types of hydraulic power systems are used: hydrodynamic and hydrostatic.

1.5.2.1 Hydrodynamic Power Systems:

Hydrodynamic (also called hydrokinetic) power systems transmit power by increasing mainly the kinetic energy of liquid. Generally, these systems include a rotodynamic pump, a turbine, and additional control elements. The applications of hydrodynamic power systems are limited to rotary motion. These systems replace the classical mechanical transmission in the power stations and vehicles due to their high power-to weight ratio and better controllability.

There are two main types of hydrodynamic power systems: hydraulic coupling and torque converter.

1.5.2.1.1 Hydraulic Coupling:

A hydraulic coupling is essentially a fluid-based clutch. It consists of a pump, driven by the input shaft, and a turbine, coupled to the output shaft. When the pump impeller rotates, the oil flows to the turbine at high speed. The oil then impacts the turbine blades, where it loses most of the kinetic energy it gained from the pump. The oil re-circulates in a closed path inside the coupling and the power is transmitted from the input shaft to the output shaft. The input torque is practically equal to the output torque.

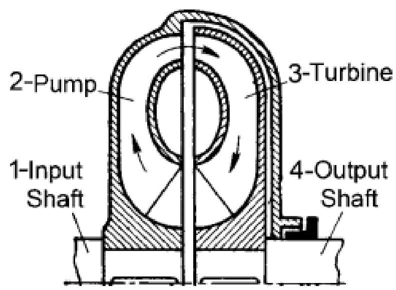

Figure 1.8.Hydraulic Coupling.

1.5.2.1.2 Torque Converter:

The torque converter is a hydraulic coupling with one extra component: the stator, also called the reactor. The stator consists of a series of guide blades attached to the housing. The torque converters are used where it is necessary to control the output torque and develop a transmission ratio, other than unity, keeping acceptable transmission efficiency.

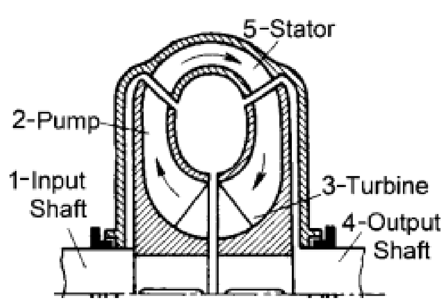

Figure1.9.Torque Converter.

1.5.2.2 Hydrostatic Power Systems:

In the hydrostatic power systems, the power is transmitted by increasing mainly the pressure energy of liquid. These systems are widely used in industry, mobile equipment, aircrafts, ship control, and others. This text deals with the hydrostatic power systems, which are commonly called hydraulic power systems. Figure 1.5.5 shows the operation principle of such systems.

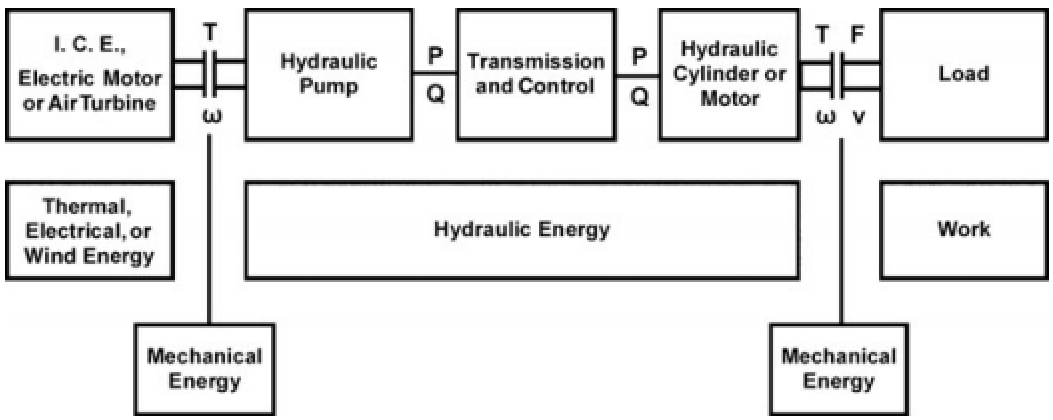

Figure 1.10.Power transmission in a hydraulic power system.

1.5.3 The Advantages and Disadvantages of Hydraulic Systems:

The main advantages of the hydraulic power systems are the following:

1. High power-to-weight ratio.
2. Self-lubrication.
3. There is no saturation phenomenon in the hydraulic systems compared with saturation in electric machines. The maximum torque of an electric motor is proportional to the electric current, but it is limited by the magnetic saturation.

4. High force-to-mass and torque-to-inertia ratios, which result in high acceleration capability and a rapid response of the hydraulic motors.

5. High stiffness of the hydraulic cylinders, which allows stopping loads at any intermediate position.

6. Simple protection against overloading.

7. Possibility of energy storage in hydraulic accumulators.

8. Flexibility of transmission compared with mechanical systems.

9. Availability of both rotary and rectilinear motions.

10. Safe regarding explosion hazards.

Hydraulic power systems have the following disadvantages:

1. Hydraulic power is not readily available, unlike electrical.

Hydraulic generators are therefore required.

2. High cost of production due to the requirements of small clearances and high precision production process.

3. High inertia of transmission lines, which increases their response time.

4. Limitation of the maximum and minimum operating temperature.

5. Fire hazard when using mineral oils.

6. Oil filtration problems.

Chapter Two
Theoretical Analysis

2.1 Tank

2.1.1 Sizing and selection

Reservoir size (m^3) =3*pump flow rate(m^3/min)   (2.1)

2.2 Pump:

Equations for pump:

Volumetric displacement

$V_d=(\pi/4)(Do^2-Di^2)L$ (2.2)

Theoretical flow rate

$Q_{th}=V_d*N$ (2.3)

Volumetric efficiency (η_v)

$\eta_v=$ (actual flow rate produced by pump)/(theoratical flow rate pump should produce)$=Q_a/Q_{th}$ (2.4)

Mechanical efficiency (η_m)

η_m= (pump output power assuming no leakage)/ (actual power delivered to pump)
(2.5)

$$\eta_m = \frac{p \cdot Q_{th}}{T_a \cdot N} \qquad (2.6)$$

η_m= (theoretical torque required to operate pump)/ (actual torque delivered to pump)
(2.7)

$$\eta_m = T_{th}/T_a \qquad (2.8)$$

Theoretical torque (Tth)

$$T_{th}\,(N.m) = \frac{V_d\,(m^3) \cdot P\,(pa)}{2\pi} \qquad (2.9)$$

Actual torque (T_a)

$$T_a = \frac{\text{actual power delivered to pump (watt)}}{N\,(rad/sec)} \qquad (2.10)$$

Overall efficiency (η_o)

η_o= (actual power delivered by pump)/ (actual power delivered to pump) (2.11)

$$\eta_o = \frac{p \cdot Q_a}{T_a \cdot N} \qquad (2.12)$$

$$\eta_o = \eta_v \cdot \eta_m \qquad (2.13)$$

2.2 Actuators

2.2.1 Hydraulic cylinder

$$A_p\,(m^2) = \frac{\pi}{4}(D\ cyl)^2 \qquad (2.14)$$

$$A_r\,(m^2) = \frac{\pi}{4}(D\ rod)^2 \qquad (2.15)$$

Extension stroke calculations:

Force (N) = pressure (N/m^2)*Piston area (m^2) (2.16)

Velocity (m/min) = (input flow (m^3/min))/ (piston area (m^2)) (2.17)

Theoretical time=distance/velocity (2.18)

Retraction stroke calculations:

Force (N)= pressure (N/m^2)*(Piston area (m^2)-Rod area(m^2)) (2.19)

Velocity (m/min) = (input flow (m^3/min))/ ((Piston area (m^2)-Rod area (m^2))) (2.20)

Theoretical time=distance/velocity (2.18)

Hydraulic power developed:

Power (Kw) = input flow rate (m^3/sec)* Pressure (KPa) (2.21)

2.2.2 Hydraulic motor

Equations for motor:

Volumetric displacement

$V_d = (\pi/4) (D_o^2 - D_i^2) L$ (2.22)

Theoretical flow rate

$Q_{th}=V_d*N$ (2.23)

Volumetric efficiency (η_v)

η_v= (theoretical flow rate motor should consumes)/ (actual flow rate consumed by motor)= Q_{th}/Q_a (2.24)

Mechanical efficiency (η_m)

η_m= (actual torque delivered by motor)/(theoretical torque should motor deliver) (2.25)

$\eta_m=T_a/T_{th}$ (2.26)

Theoretical torque (T_{th})

T_{th} (N.m) = (V_d (m^3)* P (pa))/2π (2.27)

Actual torque (T_a)

T_a= (actual power delivered to pump (watt))/ (N (rad/sec)) (2.28)

Overall efficiency (η_o)

η_o= (T_a (N.m)*N (rad/sec))/ (p (pa)*Q_a (m^3/sec)) (2.29)

$\eta_o=\eta_v * \eta_m$ (2.30)

2.3 Valves

2.3.1 Valves Selection Criteria

Piping Arrangement

Piping diameter

Fluid Flow rate

Type of control required

Inlet pressure

Fluid Specific Gravity and type

Coefficient of flow

Presser difference between the valves ends

Selection Calculations

Q = Flow Rate

Cd = Flow Coefficient

SG = Specific Gravity

P_1= Pressure inlet

P_2= pressure outlet

$$C_d = Q \sqrt{SG/ (P_1-P_2)} \qquad (2.31)$$

Chapter Three
Experimental Analysis

3.1 Introduction

The hydraulic test rig primary function is to simulate physical loading situations that occur in real-world applications and it will be used for educational purposes. It consists of reservoir, hydraulic fluid, external gear pump, and actuators such as electrical motor and double acting cylinder, hydraulic motor and valves.

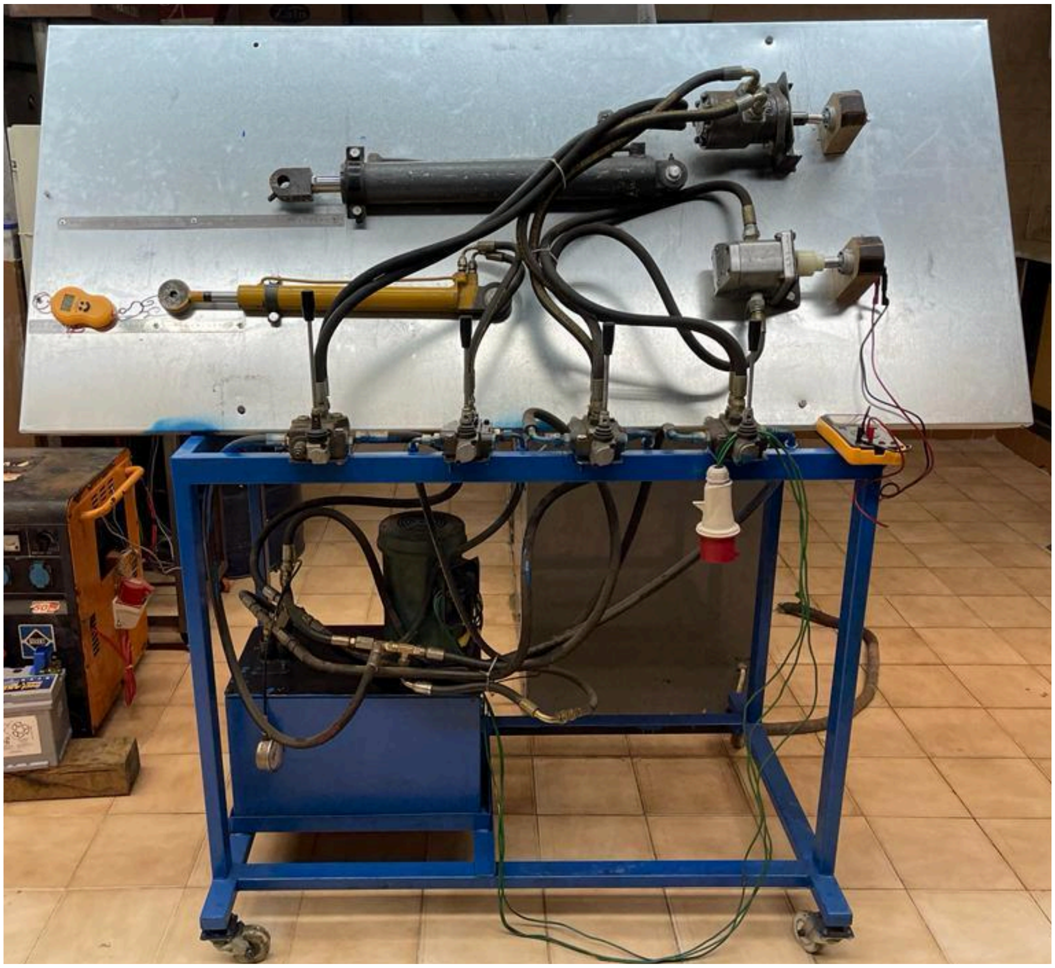

Fig 3.1. The project photo

3.2 The Project Components

- Tank
- External gear pump
- Hydraulic cylinders
- Hydraulic motor
- Valves

3.2.1 Tank

Fig 3.2.Tank

3.2.1.1 Specification

- Oil volume = 36 liter
- The clearance volume = 5.4 liter
- The capacity of reservoir = 41.1 liter
- The material used is steel
- Dimensions = 50 cm *30 cm * 30 cm

3.2.1.2 Functions

1.Storing oil: The hydraulic fluid reservoir (tank) holds excess hydraulic fluid to accommodate volume changes from: cylinder extension and contraction, temperature driven expansion and contraction, and leaks.

2.Cooling oil: A large surface area to transfer heat from the fluid to the surrounding environment.

3.Separation of air from oil: Is also designed to aid in separation of air from the fluid and also work as a heat accumulator to cover losses in the system when peak power is used.

4. Draining of impurities from the bottom of tank: Reservoirs can also help separate dirt and other particulate from the oil, as the particulate will generally settle to the bottom of the tank.

3.2.2 External gear pump

3.2.2.1 Specification

- pump Flow rate=22lit/min
- Volumetric Efficiency=0.98
- N=1500 rpm

o

Fig 3.3. External gear pump

3.2.2.2 Function

Move the oil from the tank to the actuators by valves.

3.2.3 Actuators

3.2.3.1 Hydraulic cylinders

3.2.3.1.1 Hydraulic cylinder 1

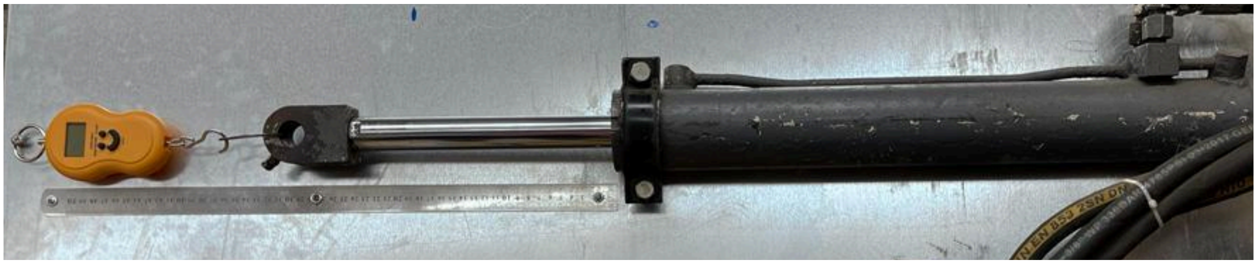

Fig 3.4. Hydraulic cylinder 1

3.2.3.1.1.1 Specification

- Stroke Length = 45 cm
- Cylinder Diameter = 60.73 mm
- Rod Diameter = 30 mm
- Cylinder Length = 57 cm

3.2.3.1.1.2 Function

Create mechanical force in a linear motion.

3.2.3.1.2 Hydraulic cylinder 2

Fig 3.5. Hydraulic cylinder 2

3.2.3.1.2.1 Specification

- Stroke length=35 cm
- Cylinder diameter= 4.2 cm

- Rod diameter=1.9 cm
- Cylinder length=44 cm

3.2.3.1.2.2 Function

Create mechanical force in a linear motion.

3.2.3.2 Hydraulic motors

3.2.3.2.1 Hydraulic motor 1

Fig 3.6. Hydraulic motor 1

3.2.3.2.1.1 Specification

Revolution per minute = 268 RPM

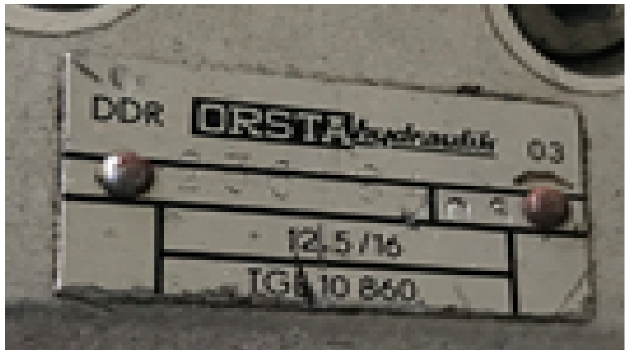

Fig 3.7. Hydraulic motor 1 Specification

3.2.3.2.1.2 Function

To convert hydraulic pressure and flow into torque and angular displacement.

3.2.3.2.2 Hydraulic motor 2

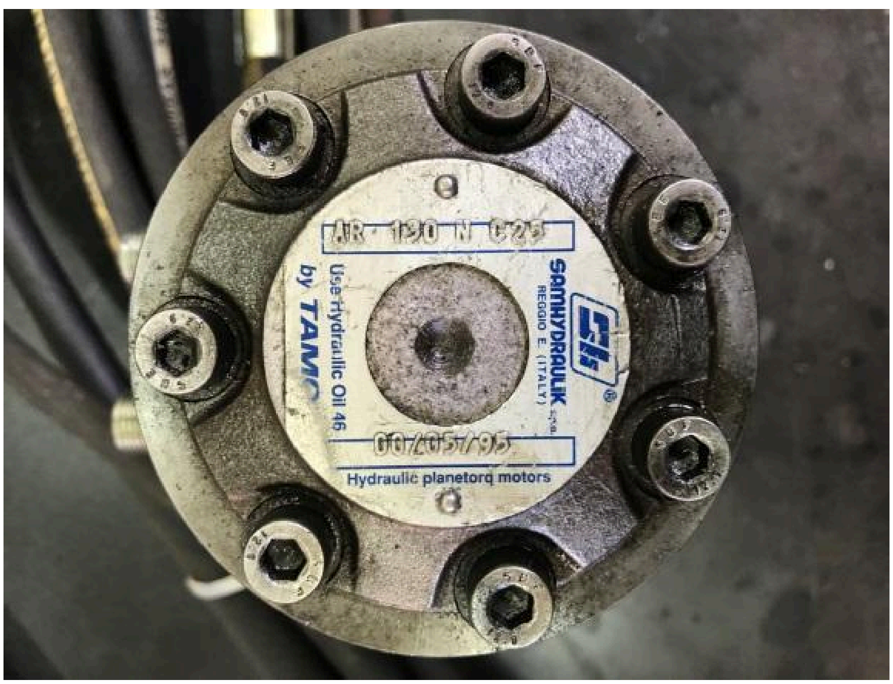

Fig 3.8. Hydraulic Motor 2

3.2.3.2.2.1 Specification

Revolution per minute = 21.4 RPM

3.2.3.2.2.2 Function

To convert hydraulic pressure and flow into torque and angular displacement.

3.2.4 Valves

3.2.4.1 Directional control valve

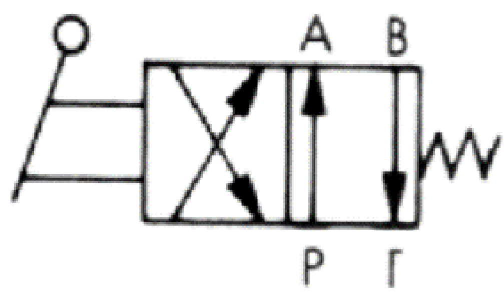

Fig 3.9. Directional Control Valve

Fig 3.10. Directional Control Valve symbol

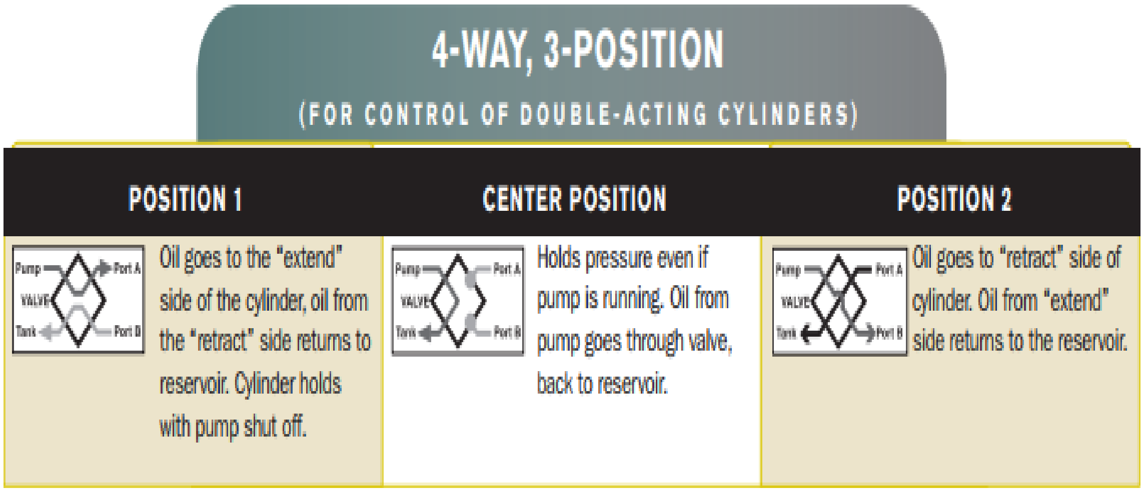

Fig 3.11. Directional control valve positions

3.2.4.1.1 Function

It allows fluid flow into different paths from one or more sources.

3.2.4.2 Pressure relief valve

Fig 3.12. Pressure relief valve

Fig 3.13. Pressure relief valve

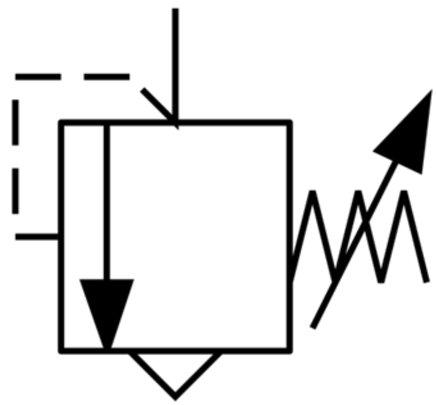

Fig 3.14. Pressure relief valve symbol

3.2.4.2.1 Function

Used to control or limit the pressure in the system to prevent equipment failure.

Chapter Four
Conclusions

Conclusions

Hydraulic test rig is a hydraulic system that shows its components such as tank, hydraulic fluid, electrical motor, external gear pump, actuators, and valves. Every component have its function and they all work together to show us the power that is delivered by the oil through the system. Pump produce flow rate to that actuators convert it to liner or rotational power. Changing the flow rate produce different liner force and velocity by hydraulic cylinder. Also, changing the flow rate produce different angular velocity and torque. From the experiment

The hydraulic motor with smaller gear has higher rotation motion and a lower torque.

The hydraulic cylinder with a bigger diameter has a lower velocity and higher force.

The project showed what is made for that how the hydraulic system works and it can be used to show more students how it works in real life and help them understand it better.

Future work:

Due to a lack of time and resources, many analysis and measurements are inaccurate and needs to be measured again. Also, the pump efficiency over time has decreased which made the oil flow rate decrease and the pump pressure the same, all of these things made the hydraulic circuit run without the maximum performance. Furthermore, we need to check the pressure relief valves and the directional control valve for leakage or damage, finally the hoses and connections need to be checked and cleaned from any impurities.

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