Chapter - 2

UNIT I FLUID POWER PRINICIPLES AND HYDRAULIC PUMPS

Basics of Hydraulics – Pascal’s Law – Principles of flow – Friction loss – Work, Power and Torque Problems.

BASICS OF HYDRAULICS

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. 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’slaw is illustrated in figure 5.1.1. The force given by fluid is given by the multiplication ofpressure and area of cross section. 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.

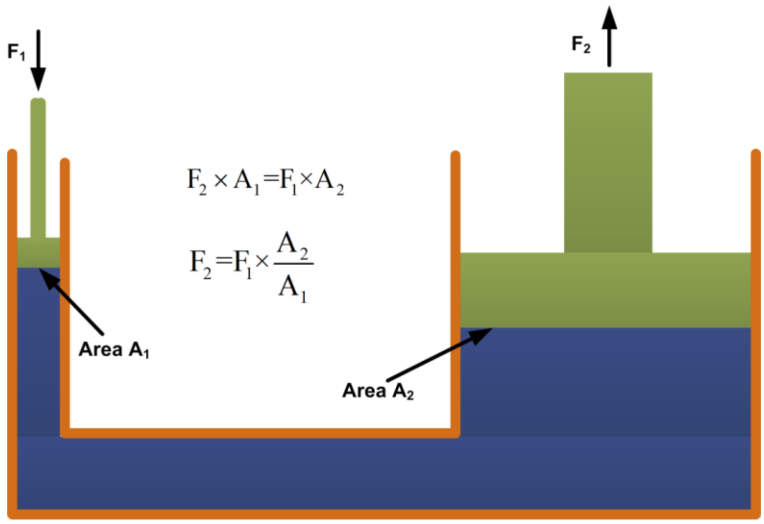


Figure 1.2.1 Principle of hydraulic system

PASCAL'S LAW

Pascal's Law states that the pressure applied to a fluid in a closed container is transmitted equally to all points in the fluid and act in all directions of the container. Pascal's Law is applicable to both solids and liquids.

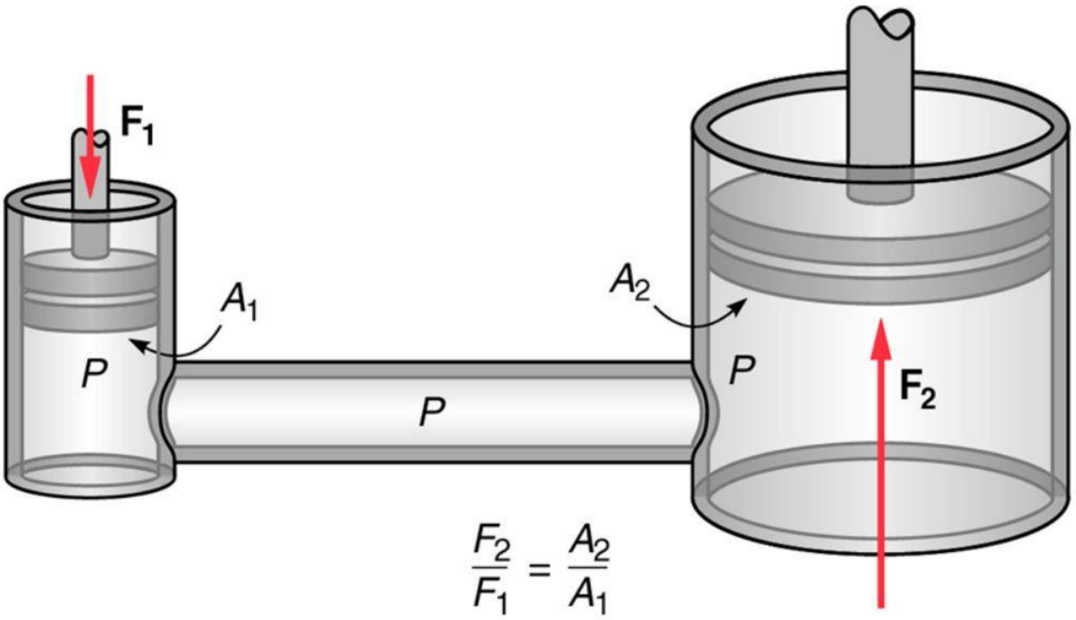


Figure 1.2.2 Principle OF Pascal's Law

The law was proposed by Blaise Pascal, a French Physicist and Mathematician. He observed that when a fluid is at rest, the same amount of pressure is applied at all the points which are at the same height. Now, we get to know that pressure is not a vector quantity; and, therefore, it can not be assigned any direction. If we begin to consider that fluid is a horizontal bar with a uniform cross-section and it is in a state of equilibrium, then there will be an equal and balanced force which will be exerted at the two ends. However, if we consider that an unequal force is acting on the horizontal bar, in that case, the liquid will have some net force acting on it and it will flow. Therefore, it can rightly be said that since the liquid does not flow, it definitely has equal pressure acting on it at all the points.
The mathematical representation of the law is as follows:

$F = PA$; where F=applied force, P=pressure transmitted, and A=cross-sectional area.

APPLICATIONS OF PASCAL'S LAW

HYDRAULIC LIFT

A hydraulic lift is versatile in its utility. It has a hydraulic apparatus which is used to lift heavy objects. In the case of hydraulic lifts, force applied creates "lift" and "work." It is based on the principle of equal pressure transmission throughout the fluid. A narrow cylinder (A) is connected to a wider cylinder (B) fitted with airtight pistons filled with an incompressible fluid. The mathematical representation of the Pascal's Law helps in the determination of pressure which can be exerted on the fluid in the piston so as to create enough force for lifting and moving an object. When pressure from piston A is transmitted to piston B, piston B lifts the heavy object like big machines, vehicles. The hydraulic lift technology has widespread applications in the industrial, construction, transport sector, etc.

HYDRAULIC JACKS

Hydraulic jacks, which come under the category of a closed container, follow the principle of Pascal's Law. They are used to lift heavy bodies. The hydraulic jack consists of two cylinders, a larger and a smaller one; and these two cylinders are connected. When its handle is pressed down, a valve closes and the small piston forces the fluid through another valve to a larger cylinder which, then, produces a large force to be transmitted to the load. Therefore, we can say that when force is applied, the pressure is exerted throughout the volume and surface of the cylinder.

The handle is moved up and down repeatedly until the load is sufficiently lifted up by the hydraulic fluid flowing buffer tank to the small cylinder. Hydraulic jacks are highly advantageous in the automotive industry and are often used to lift cars above the ground level for repair and maintenance.

HYDRAULIC BRAKING SYSTEM

One of the most common examples of Pascal's Law is the hydraulic braking system present in the automobiles. Every time you see a car come to a halt, the principle of Pascal's Law comes into action. A number of components form the braking system in cars. When force is applied on the brake pedal, there is a movement of the piston and rod in the master cylinder. A liquid which is known as brake or hydraulic fluid, enclosed in the container, is used to transmit the pressure from the brake pedal to the wheels of the vehicle against the brake discs or brake drums. The frictional force between these force components causes the vehicle to stop. Hydraulic brakes are used in cars, motorcycles and lorries.

HYDRAULIC PUMPS

Hydraulic pumps, which convert mechanical energy into hydraulic energy, facilitate the movement of a fluid, and here, yet again, Pascal's Law comes into play. Hydraulic pumps help in the discharge of fluid. It is equipped with a small cylinder connected to a large cylinder and both the cylinders are filled with oil. Compressed air introduced to the small cylinder exerts a pressure on the surface of the oil. This pressure is transmitted by the oil to the large cylinder where the pressure acts on a large piston to produce a force large enough to lift a car.

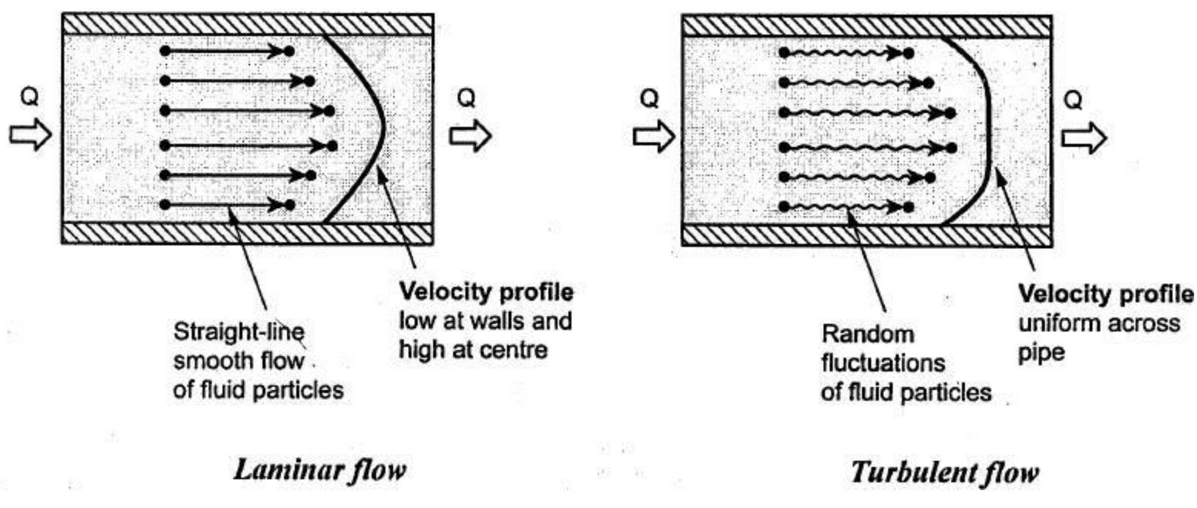
AIRCRAFT HYDRAULIC SYSTEM

Hydraulic power system not only helps in slowing down of aeroplanes on runways but also help in the management of the flaps, landing gear, and flight control surfaces. An aircraft hydraulic system consists of three critical mechanical components and hydraulic fluid. Even a small amount of hydraulic fluid helps in transmitting a large amount of force. The hydraulic fluid in contact with the cylinders/pistons is at different pressure. The oil which is at a relatively higher pressure can be pumped to either side of the piston head. The selector valve helps in controlling the direction of the fluid.

PRINCIPLE OF FLUID FLOW:

Laminar Flow: It is one in which paths taken by the individual partials do not cross one another and moves along well defined paths. The laminar flow is characterized by the fluid flowing in smooth layers of lamina. This type of flow is also known as streamline or viscous flow because the particles of fluid moving in an orderly manner and retaining the same relative positions in successive cross sections.

Examples:
Flow of oil in measuring instruments
Flow of blood in veins and arteries



Turbulent Flow: It is that flow in which fluid particles move in a zigzag way. It is characterized by continues small fluctuations in the magnitude and direction of the velocity of the fluid particles. It causes more resistance to flow, Greater energy loss and increase fluid temperature due to greater energy loss.

Examples: High velocity flow in a pipe of large size.

REYNOLDS NUMBER:

Osborne Reynolds in 1883 conducted experiments to ascertain the conditions under which a flow through pipe is laminar or turbulent. He applied the dimensional analysis on variables and introduced a dimensionless number called Reynolds number Re. It is given by the following equation to determine whether the flow is laminar or turbulent.

ρ = Density of fluid (kg/m3) V = Velocity of Flow (m/sec)
D = Inside diameter of pipe (m)
υ = Kinematic viscosity of fluid (m2/sec) μ = absolute viscosity of fluid (Ns/m2)

Experiments showed that the flow is laminar when Reynolds number (Re) is less than 2000 and turbulent for Re greater than 4000. And for $4000 < Re < 2000$ then the flow is in transition from laminar to turbulent. It is always desirable to maintain laminar flow in hydraulic system because the chaotic turbulent flow causes more energy loss.

DARCY – WEISBACH EQUATION:

The energy loss due to friction in a hydraulic system results in a loss of potential energy. This potential energy loss leads to a pressure drop or head loss in the system. Pressure or head loss due to friction in pipes carrying fluids are derived using the Darcy-Weisbach Equation.

H_L – Head Loss V – Velocity of Flow
f - Friction Factor, g – Acceleration due to gravity, L - Length of pipe
D – Inner Diameter

During laminar flow the friction is relatively independent of the surface conditions of the inside diameter of the pipe.
The friction factor ‘f’ for laminar flow can be found by the equation

$$\mathbf{f = \frac{64}{Re} \quad when\ Re < 2000}$$

But in turbulent flow friction factor depends on both the Reynolds number and roughness of the pipe.
An American engineer L.F.Moody documented the experimental and theoretical investigation on the laws of friction in pipe flow in form of a diagram.

LOSSES IN VALVES AND FITTINGS:

Pressure drops are also due to valves, expansions, contractions, bends, elbows, tees and pipe fittings. The losses in valves and fittings in hydraulic systems are frequently computed in terms of equivalent length of hydraulic tube. Equivalent lengths can then be substituted in Darcy-Weisbach equation to solve for total pressure loss in the system.

Valve and Fitting	K Factor
Globe Valve Full open Half open	 10 12.5
Gate Valve Full open Half open	 0.19 4.5
Check Valve Poppet Type Ball type	 3.0 4.0
Return Bend	2.2
Standard Tee	1.8
Standard Elbow	0.9
45o Elbow	0.42

CONTINUITY EQUATION:

It states that if no fluid is added or removed from the pipe in any length then the mass passing across different sections shall be same.

A1 V1 = A2 V2

BERNOULLI'S EQUATION:

It states that in a ideal incompressible fluid when the flow is steady and continuous the sum of potential energy, kinetic energy and pressure energy is constant across all cross sections of the pipe.

POWER:

Power is the ratio between the work done and the time taken and can be expressed as

$$P = W / dt$$

WORK DONE

Work done is *the force multiplied with the distance moved by the force* - and can be expressed as

$$W = F s$$

TORQUE

TORQUE is defined as a FORCE around a given point, applied at a RADIUS from that point.

PROBLEM

1. A machine rotates with speed *3000 rev/min (rpm)* and consumes *5 kW*. The torque at the shaft can be calculated by modifying to

$$T = P / 2 \pi n$$

$$= (5\ kW)\ (1000\ W/kW) / 2 \pi\ (3000\ rev/min) / (60\ sec/min)$$

$$= \underline{15.9}\ Nm$$