Fluid Power Part 1 Hydraulic Principles

An Online Continuing Education Course for Engineers

Course Number: M-4025

Credit: 4 Hours / 4 PDH / 4 CPD

Chapter 1

Introduction to Fluid Power

Fluid power is a term which was created to include the generation, control, and application of smooth, effective power of pumped or compressed fluids (either liquids or gases) when this power is used to provide force and motion to mechanisms. This force and motion maybe in the form of pushing, pulling, rotating, regulating, or driving. Fluid power includes hydraulics, which involves liquids, and pneumatics, which involves gases. Liquids and gases are similar in many respects. The differences are pointed out in the appropriate areas of this course.

This course presents many of the fundamental concepts in the fields of hydraulics and pneumatics. A brief summary of the contents of this course is given in the following paragraphs:

Chapter 2 covers the characteristics of liquids and the factors affecting them. It also explains the behavior of liquids at rest, identifies the characteristics of liquids in motion, and explains the operation of basic hydraulic components.

Chapter 3 discusses the qualities of fluids acceptable for hydraulic systems and the types of fluids used. Included are sections on safety precautions to follow when handling potentially hazardous fluids, liquid contamination, and control of contaminants.

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ADVANTAGES OF FLUID POWER

The extensive use of hydraulics and pneumatics to transmit power is due to the fact that properly constructed fluid power systems possess a number of favorable characteristics. They eliminate the need for complicated systems of gears, cams, and levers. Motion can be transmitted without the slack inherent in the use of solid machine parts. The fluids used are not subject to breakage as are mechanical parts, and the mechanisms are not subjected to great wear.

The different parts of a fluid power system can be conveniently located at widely separated points, since the forces generated are rapidly transmitted over considerable distances with small loss. These forces can be conveyed up and down or around corners with small loss in efficiency and without complicated mechanisms. Very large forces can be controlled by much smaller ones and can be transmitted through comparatively small lines and orifices.

If the system is well adapted to the work it is required to perform, and if it is not misused, it can provide smooth, flexible, uniform action without vibration, and is unaffected by variation of load. In case of an overload, an automatic release of pressure can be guaranteed, so that the system is protected against breakdown or strain. Fluid power systems can provide widely variable motions in both rotary and straight-line transmission of power. The need for control by hand can be minimized. In addition, fluid power systems are economical to operate.

The question may arise as to why hydraulics is used in some applications and pneumatics in others. Many factors are considered by the user and/or the manufacturer when determining which type of system to use in a specific application. There are no hard and fast rules to follow; however, past experience has provided some sound ideas that are usually considered when such decisions are made. If the application requires speed, a medium amount of pressure, and only fairly accurate control, a pneumatic system may be used. If the application requires only a medium amount of pressure and a more accurate control, a combination of hydraulics and pneumatics may be used. If the application requires a great amount of pressure and/or extremely accurate control, a hydraulic system should be used.

SPECIAL PROBLEMS

The extreme flexibility of fluid power elements presents a number of problems. Since fluids have no shape of their own, they must be positively confined throughout the entire system. Special consideration must be given to the structural integrity of the parts of a fluid power system. Strong pipes and containers must be provided. Leaks must be prevented. This is a serious problem with the high pressure obtained in many fluid power installations.

The operation of the system involves constant movement of the fluid within the lines and components. This movement causes friction within the fluid itself and against the containing surfaces which, if excessive, can lead to serious losses in efficiency. Foreign matter must not be allowed to accumulate in the system, where it will clog small passages or score closely fitted parts. Chemical action may cause corrosion. Anyone working with fluid power systems must know how a fluid power system and its components operate, both in terms of the general principles common to all physical mechanisms and of the peculiarities of the particular arrangement at hand.

HYDRAULICS

The word *hydraulics* is based on the Greek word for water, and originally covered the study of the physical behavior of water at rest and in motion. Use has broadened its meaning to include the behavior of all liquids, although it is primarily concerned with the motion of liquids.

Hydraulics includes the manner in which liquids act in tanks and pipes, deals with their properties, and explores ways to take advantage of these properties.

DEVELOPMENT OF HYDRAULICS

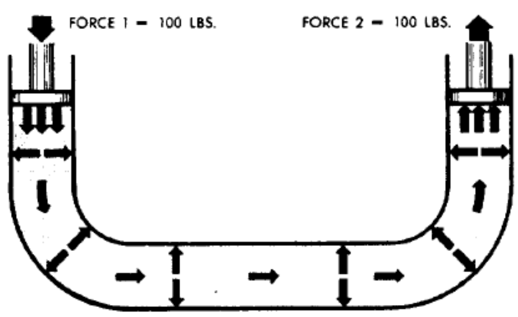
Although the modern development of hydraulics is comparatively recent, the ancients were familiar with many hydraulic principles and their applications. The

Egyptians and the ancient people of Persia, India, and China conveyed water along channels for irrigation and domestic purposes, using dams and sluice gates to control the flow. The ancient Cretans had an elaborate plumbing system. Archimedes studied the laws of floating and submerged bodies. The Romans constructed aqueducts to carry water to their cities.

After the breakup of the ancient world, there were few new developments for many centuries. Then, over a comparatively short period, beginning near the end of the seventeenth century, Italian physicist, Evangelista Torricelle, French physicist, Edme Mariotte, and later, Daniel Bernoulli conducted experiments to study the elements of force in the discharge of water through small openings in the sides of tanks and through short pipes. During the same period, Blaise Pascal, a French scientist, discovered the fundamental law for the science of hydraulics.

Pascal's law states that increase in pressure on the surface of a confined fluid is transmitted undiminished throughout the confining vessel or system (fig. 1-1). (This is the basic principle of hydraulics and is covered in detail in chapter 2 of this course.)

For Pascal's law to be made effective for practical applications, it was necessary to have a piston that "fit exactly." It was not until the latter part of the eighteenth century that methods were found to make these snugly fitted parts required in hydraulic systems. This was accomplished by the invention of machines that were used to cut and shape the necessary closely fitted parts and, particularly, by the development of gaskets and packings. Since that time, components such as valves, pumps, actuating cylinders, and motors have been developed and refined to make hydraulics one of the leading methods of transmitting power.



Use of Hydraulics

The hydraulic press, invented by Englishman John Brahmah, was one of the first workable pieces of machinery developed that used hydraulics in its operation. It consisted of a plunger pump piped to a large cylinder and a ram. This press found wide use in England because it provided a more effective and economical means of applying large forces in industrial uses.

Today, hydraulic power is used to operate many different tools and mechanisms. In a garage, a mechanic raises the end of an automobile with a hydraulic jack. Dentists and barbers use hydraulic power, through a few strokes of a control lever, to lift and position their chairs to a convenient working height. Hydraulic doorstops keep heavy doors from slamming. Hydraulic brakes have been standard equipment on automobiles since the 1930s. Most automobiles are equipped with automatic transmissions that are hydraulically operated. Power steering is another application of hydraulic power. Construction workers depend upon hydraulic power for the operation of various components of their equipment. For example, the blade of a bulldozer is normally operated by hydraulic power.

Hydraulics and pneumatics are combined for some applications. This combination is referred to as *hydropneumatics.* An example of this combination is the lift used in garages and service stations. Air pressure is applied to the surface of hydraulic fluid in a reservoir. The air pressure forces the hydraulic fluid to raise the lift.

STATES OF MATTER

The material that makes up the universe is known as *matter.* Matter is defined as any substance that occupies space and has weight.

Matter exists in three states: solid, liquid, and gas; each has distinguishing characteristics. Solids have a definite volume and a definite shape; liquids have a definite volume, but take the shape of their containing vessels; gases have neither a definite shape nor a definite volume. Gases not only take the shape of the containing vessel, but also expand and fill the vessel, regardless of its volume. Examples of the states of matter are iron, water, and air.

Matter can change from one state to another. Water is a good example. At high temperatures it is in the gaseous state known as steam. At moderate temperatures it is a liquid, and at low temperatures it becomes ice, which is definitely a solid state. In this example, the temperature is the dominant factor in determining the state the substance assumes.

Pressure is another important factor that will affect changes in the state of matter. At pressures lower than atmospheric pressure, water will boil and thus change into steam at temperatures lower than 212° Fahrenheit (F). Pressure is also a critical factor in changing some gases to liquids or solids. Normally, when pressure and chilling are both applied to a gas, the gas assumes a liquid state. Liquid air, which is a mixture of oxygen and nitrogen, is produced in this manner.

In the study of fluid power, we are concerned primarily with the properties and characteristics of liquids and gases. However, you should keep in mind that the properties of solids also affect the characteristics of liquids and gases. The lines and components, which are solids, enclose and control the liquid or gas in their respective systems.

CHAPTER 2

FORCES IN LIQUIDS

The study of liquids is divided into two main parts: liquids at rest (hydrostatics) and liquids in motion (hydraulics).

The effects of liquids at rest can often be expressed by simple formulas. The effects of liquids in motion are more difficult to express due to frictional and other factors whose actions cannot be expressed by simple mathematics.

In chapter 1 we learned that liquids have a definite volume but take the shape of their containing vessel. There are two additional characteristics we must explore prior to proceeding.

Liquids are almost incompressible. For example, if a pressure of 100 pounds per square inch (psi) is applied to a given volume of water that is at atmospheric pressure, the volume will decrease by only 0.03 percent. It would take a force of approximately 32 tons to reduce its volume by 10 percent; however, when this force is removed, the water immediately returns to its original volume. Other liquids behave in about the same manner as water.

Another characteristic of a liquid is the tendency to keep its free surface level. If the surface is not level, liquids will flow in the direction which will tend to *make* the surface level.

LIQUIDS AT REST

In studying fluids at rest, we are concerned with the transmission of force and the factors which affect the forces in liquids. Additionally, pressure in and on liquids and factors affecting pressure are of great importance.

PRESSURE AND FORCE

The terms *force* and *pressure* are used extensively in the study of fluid power. It is essential that we distinguish between the terms. Force means a total push or pull. It is the push or pull exerted against the total area of a particular surface and is expressed in pounds or grams. Pressure means the amount of push or pull (force) applied to each unit area of the surface and is expressed in pounds per square inch (lb/in^2) or grams per square centimeter (gm/cm^2). Pressure maybe exerted in one direction, in several directions, or in all directions.

Computing Force, Pressure, and Area

A formula is used in computing force, pressure, and area in fluid power systems. In this formula, P refers to pressure, F indicates force, and A represents area.

Force equals pressure times area. Thus, the formula is written

$$\mathbf{F = PxA} \qquad \text{Equation 2-1.}$$

Pressure equals force divided by area. By rearranging the formula, this statement may be condensed into

$$\mathbf{P} = \frac{F}{A} \qquad \text{Equation 2-2.}$$

Since area equals force divided by pressure, the formula is written

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

Equation 2-3.

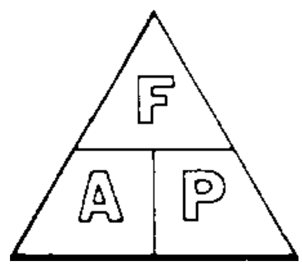


Figure 2-1.—Device for determining the arrangement of the force, pressure, and area formula.

Figure 2-1 illustrates a memory device for recalling the different variations of this formula. Any letter in the triangle may be expressed as the product or quotient of the other two, depending on its position within the triangle.

For example, to find area, consider the letter A as being set off to itself, followed by an equal sign. Now look at the other two letters. The letter F is above the letter P; therefore,

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

Atmospheric Pressure

The atmosphere is the entire mass of air that surrounds the earth. While it extends upward for about 500 miles, the section of primary interest is the portion that rests on the earth's surface and extends upward for about 7 1/2 miles. This layer is called the troposphere.

If a column of air 1-inch square extending all the way to the "top" of the atmosphere could be weighed, this column of air would weigh approximately 14.7 pounds at sea level. Thus, atmospheric pressure at sea level is approximately 14.7 psi.

As one ascends, the atmospheric pressure decreases by approximately 1.0 psi for every 2,343 feet. However, below sea level, in excavations and depressions, atmospheric pressure increases. Pressures under water differ from those under air only because the weight of the water must be added to the pressure of the air.

Atmospheric pressure can be measured by any of several methods. The common laboratory method uses the mercury column barometer. The height of the mercury column serves as an indicator of atmospheric pressure. At sea level and at a temperature of 0° Celsius (C), the height of the mercury column is approximately 30 inches, or 76 centimeters. This represents a pressure of approximately 14.7 psi. The 30-inch column is used as a reference standard.

Another device used to measure atmospheric pressure is the aneroid barometer. The aneroid barometer uses the change in shape of an evacuated metal cell to measure variations in atmospheric pressure

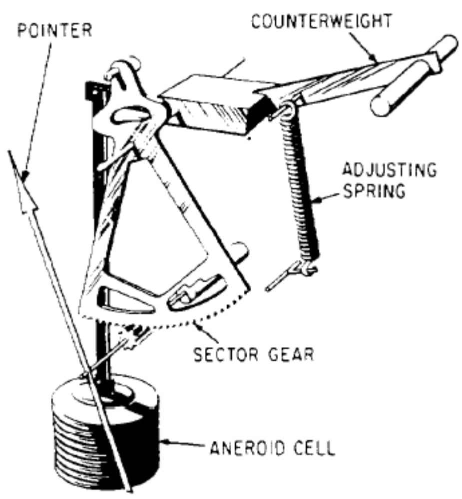


Figure 2-2.— Simple diagram of the aneroid barometer

(fig. 2-2). The thin metal of the aneroid cell moves in or out with the variation of pressure on its external surface. This movement is transmitted through a system of levers to a pointer, which indicates the pressure.

The atmospheric pressure does not vary uniformly with altitude. It changes more rapidly at lower altitudes because of the compressibility of the air, which causes the air layers close to the earth's surface to be compressed by the air masses above them. This effect, however, is partially counteracted by the contraction of the upper layers due to cooling. The cooling tends to increase the density of the air.

Atmospheric pressures are quite large, but in most instances practically the same pressure is present on all sides of objects so that no single surface is subjected to a great load.

Atmospheric pressure acting on the surface of a liquid (fig. 2-3, view A) is transmitted equally throughout the liquid to the walls of the container, but is balanced by the same atmospheric pressure acting on the outer walls of the container. In view B of figure 2-3, atmospheric pressure acting on the surface of one piston is balanced by the same pressure acting on the surface of the other piston. The different areas of the two surfaces make no difference, since for a unit of area, pressures are balanced.

TRANSMISSION OF FORCES THROUGH LIQUIDS

When the end of a solid bar is struck, the main force of the blow is carried straight through the bar to the other end (fig. 2-4, view A). This happens because the bar is rigid. The direction of the blow almost entirely determines the direction of the transmitted force. The more rigid the bar, the less force is lost inside the bar or transmitted outward at right angles to the direction of the blow.

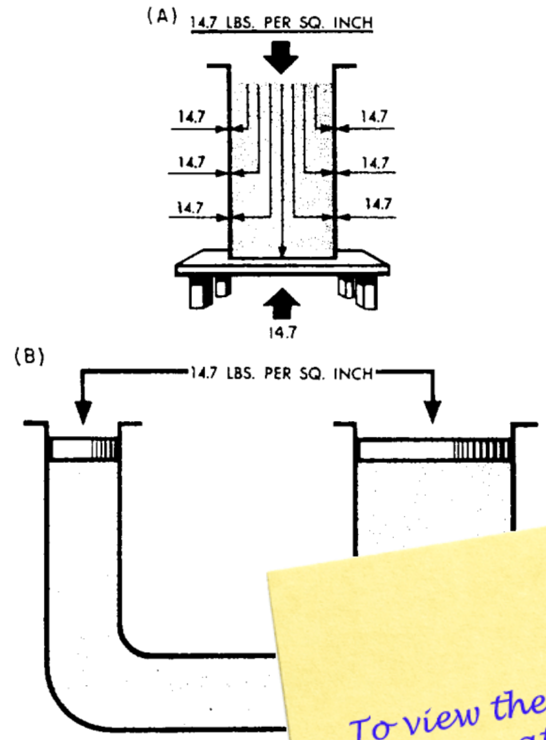
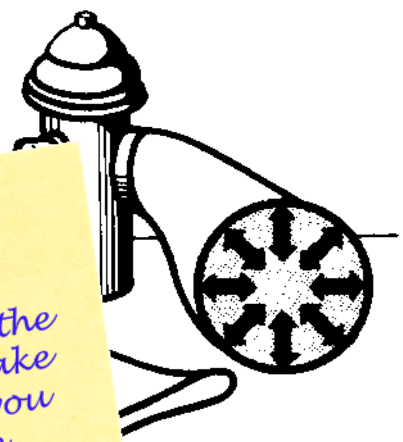


Figure 2-3.—Effects of at

When a force is applied to the end of a column of confined liquid (fig. 2-4, view B), it is transmitted straight through to the other end and also equally and undiminished in every direction throughout the column—forward, backward, and sideways—so that the containing vessel is literally filled with pressure.

An example of this distribution of force is illustrated in figure 2-5. The flat hose takes on



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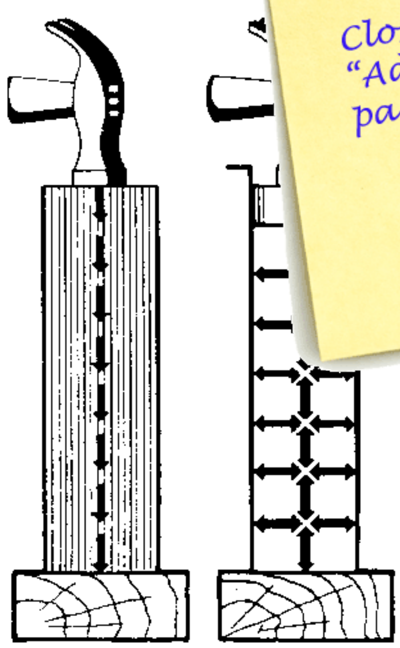

Figure 2-4.—Transmission of force: (A) solid; (B) fluid.