

SECTION 1, CHAPTER 10.

PRINCIPLES OF HYDRAULICS AND PNEUMATICS

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HYDRAULICS

Introduction

1. Liquid under pressure provides a convenient method of remote control and operation of certain mechanisms. Such mechanisms are commonly said to be hydraulically operated when the primary function of the hydraulic fluid is the transmission of force and power by pressure.

2. **Hydraulics** may be defined as the science relating to the behaviour of liquids under various conditions, and it may be subdivided into **Hydrostatics** and **Hydrodynamics**. The word 'hydrostatic' originally meant 'pertaining to water at rest', but it has, however, as applied to a hydraulic system, acquired a wider meaning which now includes systems of any kind in which the fluid is virtually a flexible strut, irrespective of how fast it moves. Hydrodynamics is

that part of the mechanics of liquids which deals with liquids in motion, e.g. use of the fluid as a vehicle of kinetic energy, or the motion of bodies through liquids.

Compressibility of Liquids

3. Liquids are practically incompressible: this basic fact is responsible for the positive action associated with hydraulic operation. This means that when a liquid is subjected to pressure, the reduction in volume is small, so small in fact, that when considering the operation of hydraulic components, the reduction in volume due to pressure can be neglected. As an example of the small degree of compressibility of liquids, a pressure of about 5,000 lb. per sq. in. would reduce the volume of a quantity of a typical liquid by 1 per cent. The same pressure applied to air, initially at atmospheric pressure, would compress it into about 1/300th of its original volume (Fig. 1).

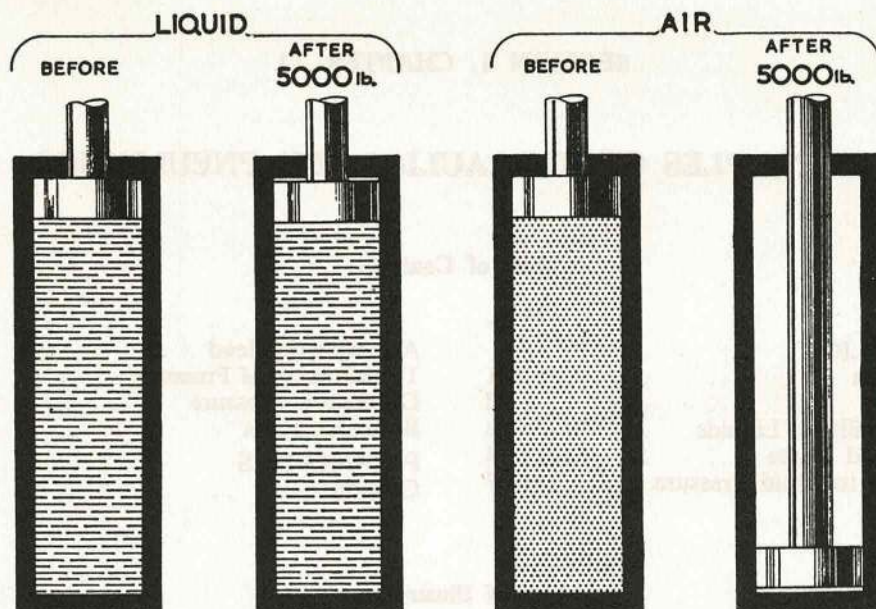


Fig. 1. COMPRESSIBILITY

Pressure and Force

4. Pressure is normally quoted, as in the preceding paragraph, as so many pounds per square inch. This is a measure of the

5. The term "pressure" is generally used to mean "intensity of pressure", but it is sometimes used to mean "total effective pressure", it being possible usually to decide from the context which meaning is intended. It is

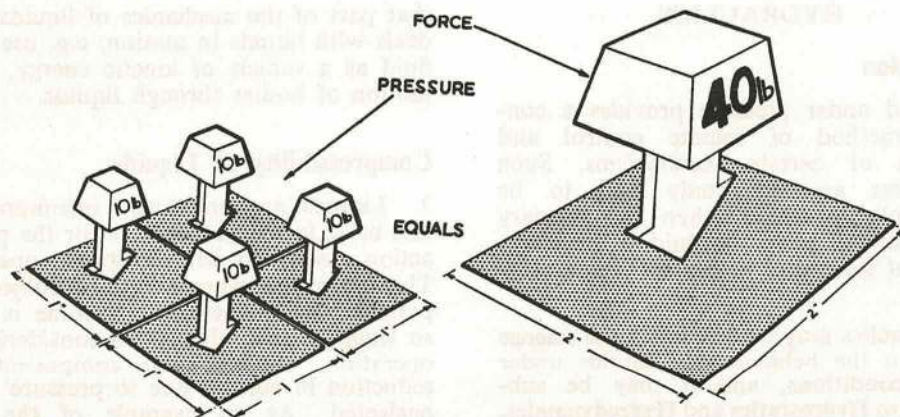


Fig. 2. PRESSURE ON A SURFACE

intensity of pressure; the total pressure (in pounds) acting on a surface is equal to the intensity of pressure (in pounds per square inch) multiplied by the area of the surface (in square inches) as shown in Fig. 2.

preferable however, for the term "force" to be used when referring to total effective pressure, and for the term "pressure" to be used as an abbreviation of "intensity of pressure".

6. Thus, force is the load a substance is called upon to bear, and it can cause a change in direction or speed of motion of the substance; it is usually quoted in pounds. Pressure refers to the force and the area to which it is directed; it is defined as force per unit area, i.e. pounds per square inch.

represent a pressure acting on a flat circular surface such as the piston of a jack. The force acting on the surface is equal to the pressure multiplied by the area. For example, if the pressure is 100 lb. per sq. inch and the area is 5 sq. inches, the force is 500 lb.

9. The force on any surface in a given direction is equal to the pressure multiplied by the *projected area* of the surface in that

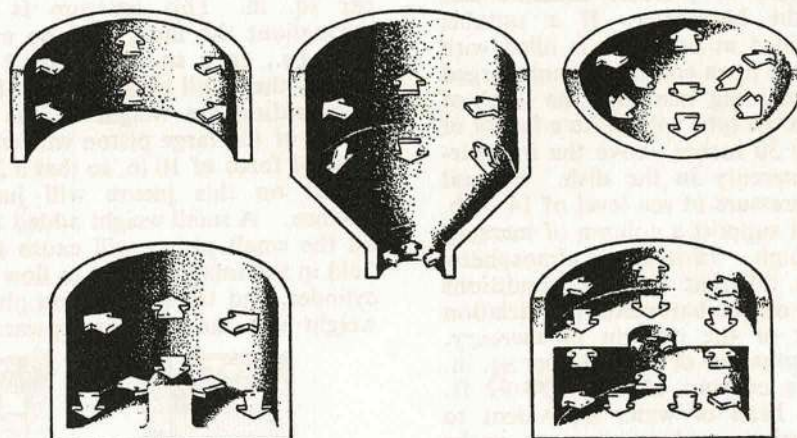


Fig. 3. FLUID PRESSURE

Force Due to Fluid Pressure

7. Another important fact is that when enclosed fluid is subjected to pressure, a corresponding pressure is felt immediately throughout the fluid and the pressure acts everywhere at right-angles to the surfaces of the vessel containing the fluid. Fig. 3 shows sections through various surfaces with arrows indicating the direction in which the pressure acts on different parts of the surface.

direction. A stationary quantity of liquid cannot exert a force in one or two directions only; it must exert forces on its surroundings in all directions. Further, a liquid can only exert forces on its surroundings if it is under pressure, and it can only be under pressure if it is enclosed so that it cannot escape freely; the only exception to this is the force produced by the weight of the liquid, but in many systems the quantity of liquid is so small and the working pressure so high that any forces which are due to weight can be ignored.



Fig. 4. FORCE ON A PISTON

8. In hydraulic operation, the engineer is not usually interested in the directions in which the pressure acts at all points of a surface, but in the total effect of the pressure on the surface. Thus, in Fig. 4, the arrows

Atmospheric Head

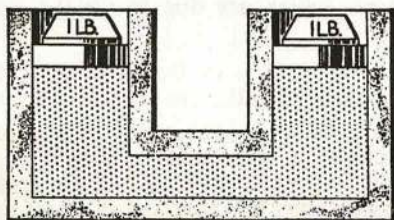
10. The pressure at any point in a liquid is proportional to the vertical distance of that point below the free surface, and the pressure at the point may be expressed in terms of the height of a column of the liquid. This method of expressing pressures as so many inches or feet of liquid is frequently used in hydraulics, in place of the more usual lb. per sq. in. or lb. per sq. ft. For a given

pressure, the height of the equivalent column of liquid depends, of course, on the density of the liquid used; the greater the density, the shorter the column required to produce the given pressure. The liquids most commonly used are mercury and water and a pressure may be denoted as so many inches of mercury, or so many feet of water. In such cases the height is said to be the *head* of liquid which would produce the pressure.

11. This method of pressure measurement is used in the barometer. If a suitable glass tube, sealed at one end, is filled with mercury and the open end is then submerged in a dish containing mercury, the level of the mercury in the tube will fall to a height of approximately 30 inches above the free surface of the mercury in the dish. Normal atmospheric pressure at sea level of 14.7 lb. per sq. in. will support a column of mercury 29.92 inches high. Variation of atmospheric pressure with different weather conditions is thus shown on the barometer by variation of the height of the column of mercury. Atmospheric pressure of 14.7 lb. per sq. in. will support a column of water 33.92 ft. high, i.e. the head of water equivalent to normal sea level atmospheric pressure, or the *atmospheric head*, is approximately 34 feet.

Transmission of Pressure

12. It is accepted that fluid pressure acts equally in all directions; also that the load which can be moved by a piston depends upon the pressure and the area of the piston. Consider a vessel containing a quantity of liquid, and having two open cylinders, each containing a sliding piston (Fig. 5). If the pistons have the same area and a force is applied to one piston, then an additional force of equal magnitude must be applied to the other piston in order to maintain balance.

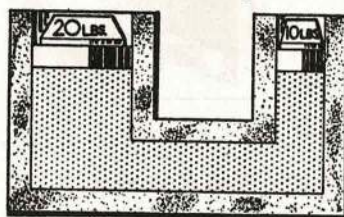


Area of each Piston = 2 sq. in.
Fig. 5. HYDRAULIC PRINCIPLE

13. Now consider the conditions if one piston was half the area of the other. To maintain balance, the force applied to the

small piston must be half the force applied to the large piston. This principle was discovered by Joseph Bramah (1749-1814) who invented a hydraulic press.

14. Fig. 6 shows the application of fluid pressure in a simple form of hydraulic machine. The area of one piston is 1 sq. in., and the area of the other is 2 sq. in. The 10 lb. weight pushing down on the 1 sq. in. area piston will set up a pressure of 10 lb. per sq. in. This pressure is transmitted throughout the fluid, and on every sq. in. area, i.e., on a sq. in. of the 2 sq. in. area piston, there will be a force of 10 lb. Thus, disregarding the weight of the fluid, each sq. in. of the large piston will experience an upward force of 10 lb. so that a 20 lb. weight placed on this piston will just maintain balance. A small weight added to the 10 lb. on the small piston will cause some of the fluid in the small cylinder to flow to the large cylinder, and the large piston plus the 20 lb. weight will move in an upward direction.



Area of Pistons—Large = 2 sq. in.
Small = 1 sq. in.

Fig. 6. SIMPLE HYDRAULIC MACHINE

15. The movement of the piston is often transmitted to the mechanism to be operated by means of a piston rod projecting through one end of the cylinder. Suitable arrangements, which are here ignored, have to be made to enable the piston rod to slide through the end of the cylinder without leakage of fluid, and leakage from one side of the piston to the other must also be prevented.

16. A simple example will now be considered of a jack as shown in Fig. 7, being used to lift a weight, and the following values will be assumed:—

Area of piston ..	10 sq. in.
Cross-sectional area of piston rod ..	2 sq. in.
Length of stroke ..	12 in.
Weight of load ..	1000 lb.
Delivery of pump ..	240 cu. in. per min.

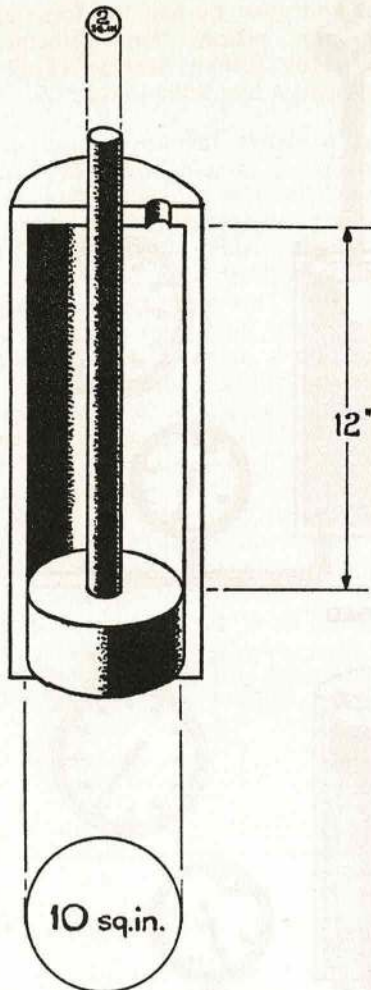


Fig. 7. SIMPLE JACK

17. When the piston is stationary and part-way up the cylinder (Fig. 8), the force of 1000 lb. due to the load is acting downwards on the piston rod and is balanced by an equal force due to the pressure of the fluid under the piston. As the area of the piston is 10 sq. in., the fluid pressure necessary to produce the balancing force is

$$\frac{1000 \text{ lb.}}{10 \text{ sq.in.}} = 100 \text{ lb. per sq. in.}$$

18. In order to raise the load, more fluid must be pumped into the jack and, as the fluid is virtually incompressible, the piston must then move upwards. The quantity of fluid required to raise the load from the

bottom to the top of the jack (Fig. 9) is equal to the area of the piston multiplied by the stroke; i.e. 10 sq. in. $\times$ 12 in. = 120 cu. in. Using the pump assumed in para. 16, which delivers 240 cu. in. per min., the time taken to raise the load 12 in. will be

$$\frac{120 \text{ cu. in.}}{240 \text{ cu. in. per min.}} = \frac{1}{2} \text{ min.} = 30 \text{ secs.}$$

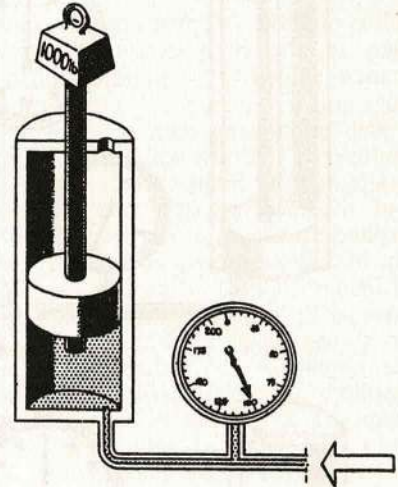


Fig. 8. BALANCING FORCE

19. When the same jack is inverted so that the load is hanging from the piston rod (Fig. 10), the pressure required to lift the load and the time taken will both be altered owing to the presence of the piston rod in the working side of the cylinder. The area on which the pressure is now acting to support the load is the area of the piston minus the cross-sectional area of the piston rod, i.e. 10 sq. in. $-$ 2 sq. in. = 8 sq. in. The fluid pressure will therefore be $\frac{1000 \text{ lb.}}{8 \text{ sq. in.}} = 125 \text{ lb. per sq. in.}$

This is higher than in the arrangement of Fig. 8 because the effective area of the piston is smaller.

20. The quantity of fluid required to move the piston through its full stroke will be smaller than in the example dealt with in para. 18, since the piston rod occupies part of the space. The volume required if there were no piston rod would be 120 cu. in. (para. 18), but the piston rod takes up 2

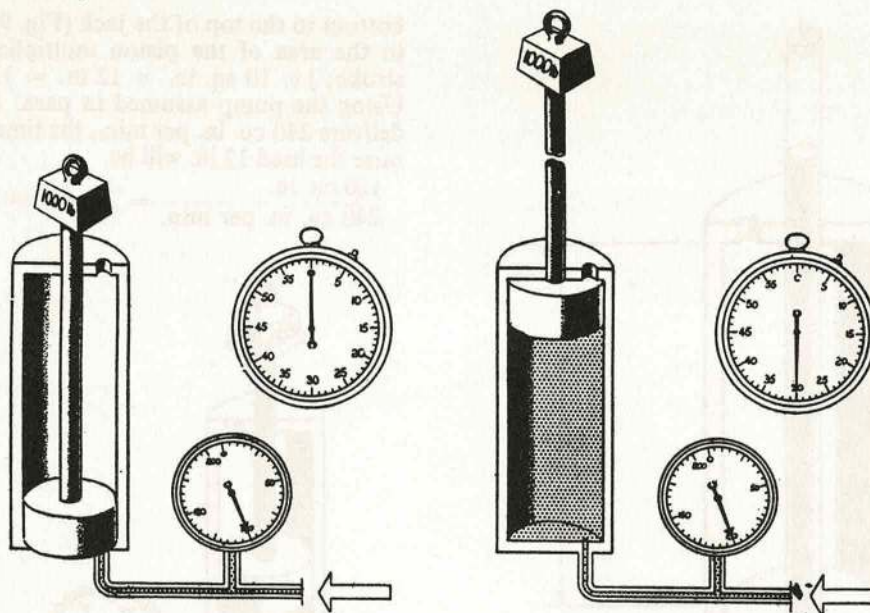


Fig. 9. RAISING THE LOAD

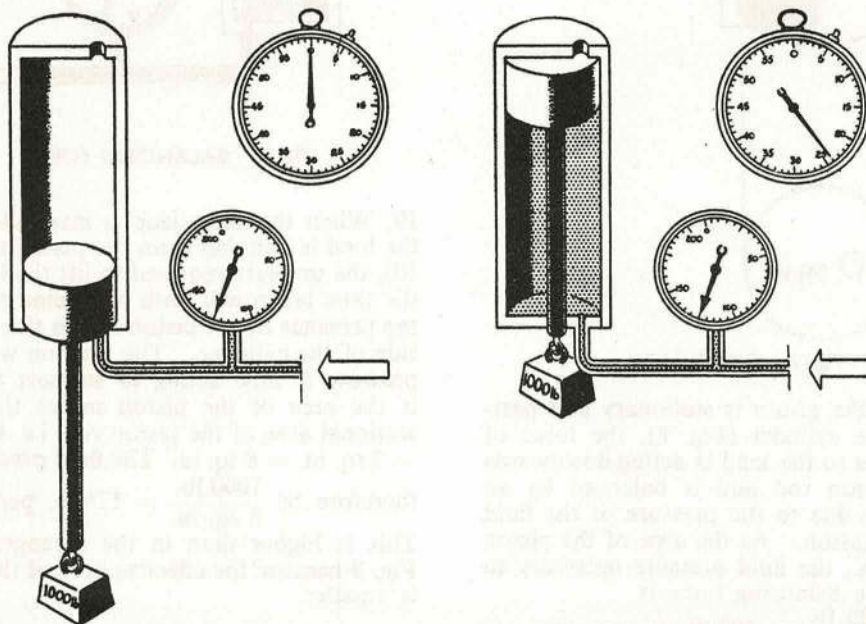


Fig. 10. LIFTING THE LOAD

sq. in. $\times$ 12 in. = 24 cu. in. of this volume,
leaving only 96 cu. in. to be filled with fluid.
The time taken to raise the load using the
same pump as before will therefore be

$$\frac{96 \text{ cu. in.}}{240 \text{ cu. in. per min.}} = \frac{2}{5} \text{ min.} = 24 \text{ secs.}$$

Differential Pressure

21. Another aspect of the production of
force by fluid pressure is differential pressure
or, more correctly, differential areas. No
new principle is involved, but explanation of
a typical example will clarify the behaviour

of some hydraulic components which might otherwise be puzzling. If fluid is pumped into a jack through the piston head end connection the jack will extend (Fig. 11A), or, if fluid is pumped into the jack through the piston rod end connection the jack will retract (Fig. 11B). When the two connections are coupled together (Fig. 11C) and pressure is applied to both ends at the same time, it might at first be thought that the piston would remain stationary. The jack will of course extend, because there is an unbalanced force on the piston equal to the pressure multiplied by the cross-sectional area of the piston rod.

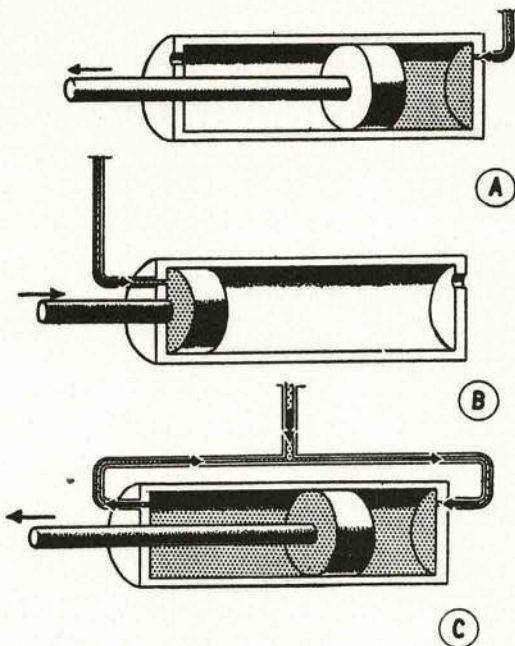


Fig. 11. DIFFERENTIAL AREAS

Bramah's Press

22. Bramah's press, which worked on the principle given in para. 14, provided mechanical advantage. It used a piston of large area at the "load" end, and a piston of small area at the "effort" end, so that a small force raised a heavy load. It should be realised that the gain is offset by the greater distance through which the effort (small piston) will have to push than through which the load (large piston) is moved; also, that

the speed of travel of the large piston will be less than that of the small piston.

23. Fig. 12 shows the application of Bramah's principle in a hydraulic system, the movement of different loads subjected to one pressure. The illustration shows one pressure moving a large and a small piston under their different loads and, in this instance, the pistons move at the same speed. If these conditions are changed, for instance, by the load on either piston being altered, or the area of one piston increased in relation to the area of the other piston, the speed of travel of the pistons will also change.

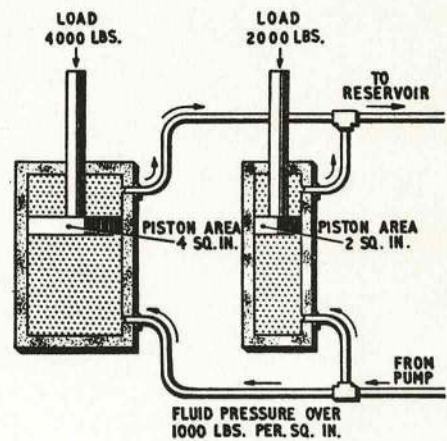


Fig. 12.

APPLICATION OF BRAMAH'S PRINCIPLE

PNEUMATICS

General

24. Pneumatic systems operate in accordance with the same fundamental principles as hydraulic systems, but the medium used in such applications is, however, a gas—usually air—which of course is compressible.

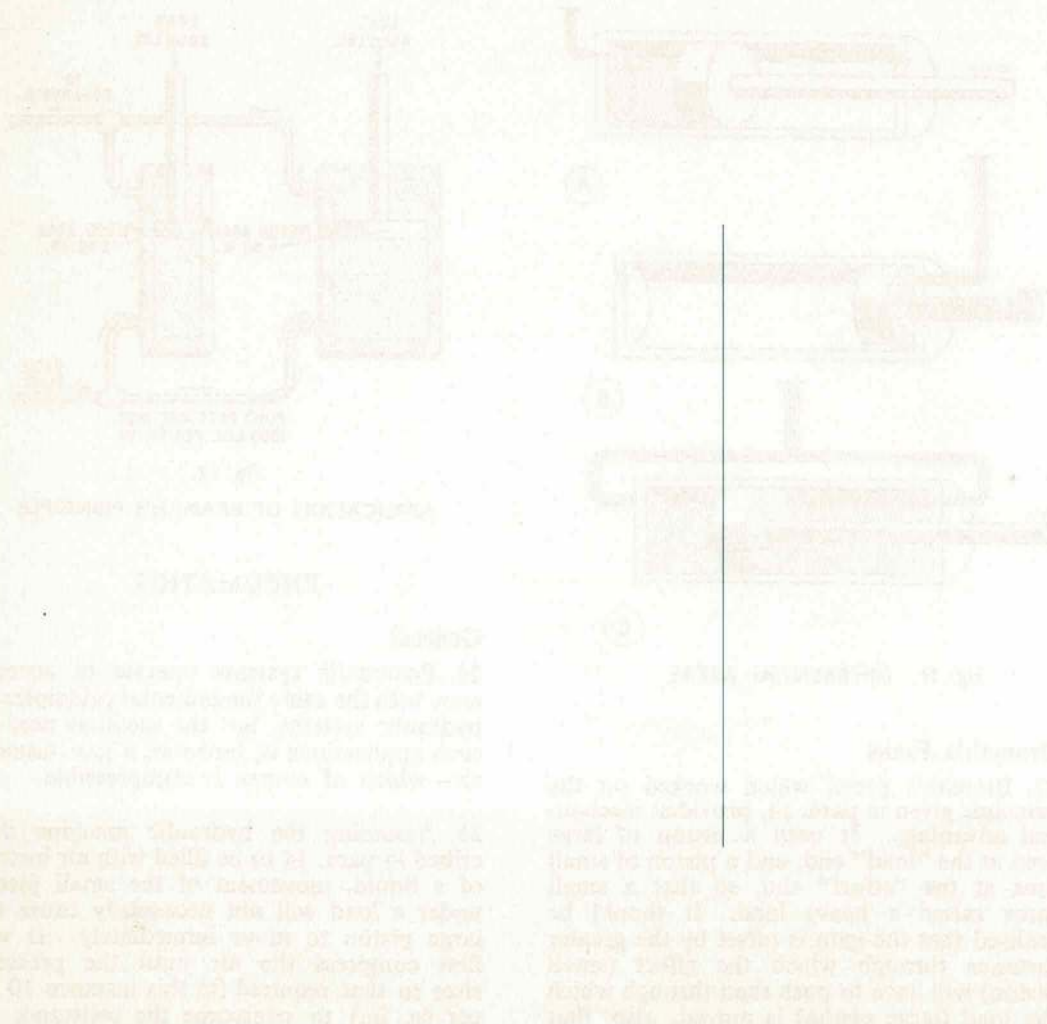
25. Assuming the hydraulic machine described in para. 14 to be filled with air instead of a liquid, movement of the small piston under a load will not necessarily cause the large piston to move immediately. It will first compress the air until the pressure rises to that required (in this instance 10 lb. per sq. in.) to overcome the resistance to

movement of the larger piston. Thus if a weight W (less than 10 lb.) be placed on the small piston, it will move downwards and

compress the air to a pressure of $\frac{W}{A}$ lb. per

sq. in. without causing the larger piston to move. As additional weight is added to the small piston, a point is reached where the

larger piston will move. Further compression of the air does not take place unless the load on the larger piston is increased and necessitates a higher pressure to continue moving it. Thus, pneumatic systems are not positive in action as are hydraulic systems, but this characteristic, or "springiness" of operation is of value in certain applications.





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