DOCUMENT RESUME

ED 112 259   CE 005 285

TITLE   Tractor Hydraulics. A Teaching Reference.
INSTITUTION   American Association for Vocational Instructional
                Materials, Athens, Ga.; Farm and Industrial Equipment
                Inst., Chicago, Ill.
REPORT NO   VT-102-063
NOTE   48p.; Illustrations have color keying which will not
                reproduce

EDRS PRICE   MF-$0.76 HC-$1.95 Plus Postage
DESCRIPTORS   *Agricultural Machinery; Fluid Power Education;
                *Hydraulics; Instructional Materials; *Manuals; Power
                Mechanics; *Tractors; Trade and Industrial
                Education

ABSTRACT
        The manual was developed to help provide a better
understanding of how and why hydraulic principles serve the purposes
of weight reduction, increase of physical effort, and more precise
control to machines of all types. The four components that are
necessary to have a workable hydraulic system--a reservoir, a pump, a
valve, and a motor (cylinder) are described in detail. Special
emphasis is given to farm and industrial equipment applications.
(VA)

Tractor Hydraulics

(VT 102 063)

A Teaching Reference

Available through the cooperative efforts of the . . .

FARM and INDUSTRIAL EQUIPMENT INSTITUTE

and the

AMERICAN ASSOCIATION FOR VOCATIONAL INSTRUCTIONAL MATERIALS

CONTENTS

INTRODUCTION

THE Wright brothers shifted their weight on a seat to control their early airplane. Later models employed wires to the movable surfaces of wings and tail, which were pulled by hand or foot levers to control the flight. The size, weight and complexity of modern military and commercial machines require a much more powerful and flexible means of control. Present day farm and industrial equipment is also larger, more powerful and performs more jobs than it did only a few years ago.

These are only a few of the many kinds of modern mechanical units which would not be practical had not a better means of control been found. Application of the age old principles of hydraulics has provided designers with a practical means to reduce weight, multiply physical effort and furnish more precise control to machines of all types. This has been a major factor in achieving greater factory and farm production per manhour. The uses to which hydraulics are being put increases daily.

This manual has been developed to help provide a better understanding of how and why hydraulic principles serve these purposes.

DEFINITION OF HYDRAULICS

Hydraulics may be defined, in a strict sense, as the science of fluid forces. In modern usage, hydraulics has come to mean the use of fluid to transfer power, or to change a power source into useful force.

While modern farm and industrial equipment hydraulic uses are relatively new, the use of hydraulic forces — water power, for example, dates back to early times. In the seventeenth century, Pascal discovered the fundamental law upon which modern machine hydraulics is based. Simply stated, Pascal's law is that pressure applied at any point in a static fluid is the same in all directions and acts with equal force on equal areas (Illust. 1).
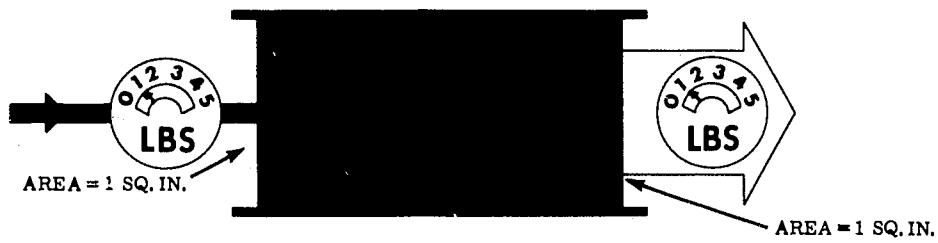
1. PISTONS OF EQUAL AREA; OUTPUT FORCE EQUALS INPUT FORCE.

AREA = 1 SQ. IN.
AREA = 1 SQ. IN.
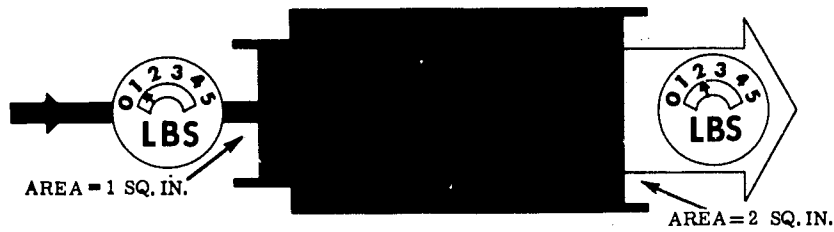
2. OUTPUT PISTON AREA INCREASED; OUTPUT FORCE IS INCREASED.

AREA = 1 SQ. IN.
AREA = 2 SQ. IN.

AREA = 2 SQ. IN.
AREA = 1 SQ. IN.
AREA = 4 SQ. IN.
AREA = 3 SQ. IN.
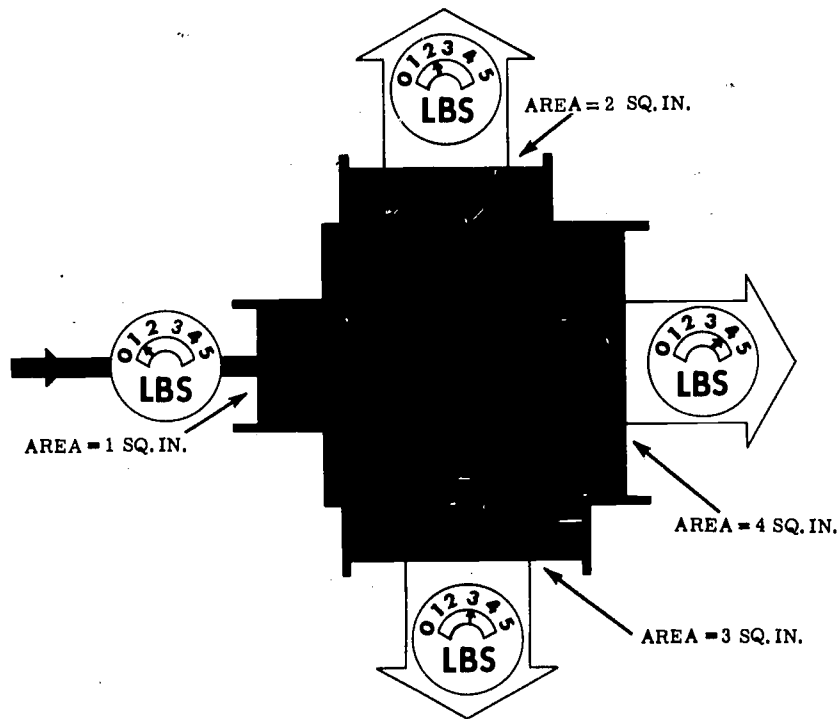
3. MULTIPLE PISTONS: OUTPUT FORCES PROPORTIONAL TO PISTON AREAS.

Illust. 1—Application of Pascal's law.

Since fluids are nearly incompressible, the application of Pascal's law means that mechanical forces may be transmitted, multiplied, or controlled by means of fluids under pressure. One of the earliest applications of the principle was the hydraulic press shown in Illust. 2.

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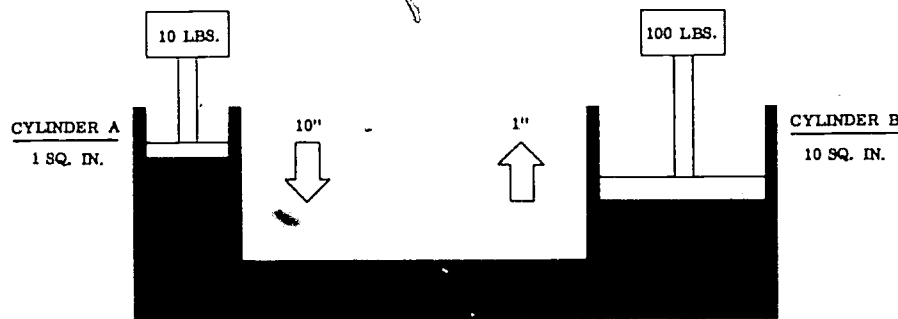
Illust. 2.—Principle of early hydraulic press.

It was not until the late eighteenth century that pistons and cylinders could be made with close enough "fit" to make full use of hydraulic principles. The development of present-day hydraulic systems dates from about 1900.

Hydraulics offer a simple method of applying large forces with a flexibility of controls that is practically limitless. Hydraulic equipment is so versatile that it can be easily adapted to provide multiples of interdependent and coordinated motions of force which would be economically impossible by mechanical linkages.

Some of the main features that make hydraulics so adaptable are:

1. Simplicity in design.
2. Extreme flexibility as regards location of components.
3. Complete automation of sequence is possible.
4. Simplicity of speed control.
5. Limitless variety of speeds, controls, and forces.
6. Reduction of wear on moving parts by: (a) Controlled acceleration and deceleration; (b) automatic release of pressure at overload; (c) absence of vibration; (d) automatic lubrication.
7. Efficient and economical to operate.
8. Large forces can be controlled by much smaller ones.
9. Power and friction losses are comparably small.

No mechanical device is perfect, and hydraulics have some drawbacks also:

1. Pressures often are very high. Two or three thousand p.s.i. is not uncommon. High pressures require heavy tubing, tight joints, and intelligent maintenance.
2. Operating efficiency can be severely reduced, or operation halted, by rust, corrosion, high temperatures, dirt, and the products of fluid deterioration.
   Cleanliness is all-important!

HYDRAULIC THEORY

Some knowledge of hydraulic theory is necessary in order to fully understand the application of hydraulics to farm and industrial equipment and the reasons that these applications act as they do.

1. Incompressibility
   Fluids are very nearly incompressible. For this reason, fluid in a confined space can be used to transmit force. By Pascal's law, when pressure is exerted by a piston in a cylinder, the pressure is transmitted undiminished throughout the fluid.

Although fluid is said to be incompressible, in a high-pressure hydraulic system, fluid does compress slightly. For example, at 3,000 p.s.i., fluid "loses" about 1.2 percent of its volume.

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This is a minor item of concern mainly to design engineers.

2. Multiplication of Forces

Pascal's law explains the ability of confined fluid to multiply forces. Since the pressure at any point in confined fluid is the same in all directions, the total thrust on any piston can be computed by multiplying p.s.i. by the area of the piston head in square inches.

For example, fluid in a closed system, brought to a pressure of 100 p.s.i. by means of a small pump, will exert a thrust of 500 pounds on a piston with an area of five square inches. Thus, a small force exerted on the fluid of a hydraulic system may be multiplied into a greatly increased work force.

3. Hydrostatic and Hydrodynamic

Hydraulic power may be classified in two general categories: Hydrostatic: where the potential (static) energy of fluid under pressure is used to perform work. Examples: the hydraulic press, hydraulic brakes, hydraulic lifts, hydraulic motors. This includes most of the present applications of hydraulics to farm and industrial equipment.

Hydrodynamic: where the kinetic (dynamic) energy of fluid in motion is used to perform work. Examples: the hydraulic coupling, the torque converter.

BASIC SYSTEM

Modern hydraulic systems on many types of equipment seem complicated, and some are. Actually, however, their fundamental design is quite simple. This can be illustrated by building up a basic system, piece by piece. (Illust. 2.)

In Illustration 2, it will be noticed that, if the piston in cylinder A is moved ten inches, it will displace 10 cubic inches of fluid (10 inches movement times 1 square inch piston area). Since fluid is essentially incompressi-

ble, the displaced fluid will go to cylinder B. To find the distance this piston would be moved, simply divide 10 cubic inches by the area of piston B (10 square inches), and the distance will be found to be one inch.

To alter this illustration of Pascal's law into a hydraulic system, it is necessary to change the design of cylinder B, add a spring to provide a force against which the piston will push, and straighten out the connecting tubing, as in Illust. 3.
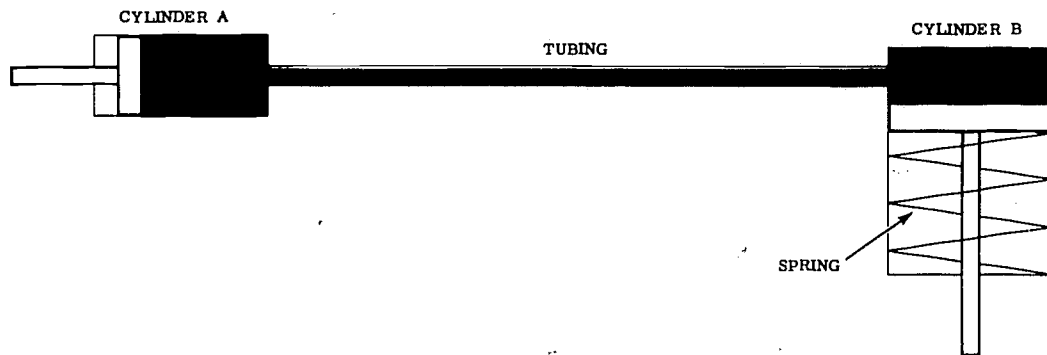
Illust. 3—Simple hydraulic press with spring added.

In this illustration, cylinder A is actually a simplified hand pump, and any force developed by it will exert a greater force on the piston in cylinder B, according to the previously explained multiplication of forces. Several strokes of the hand pump will be required to move piston B through its complete stroke.

the spring will force the piston up and the fluid will be delivered back to the reservoir.

Because it is usually desired to operate such a cylinder at frequent intervals, a motor driven pump is added (Illust. 5). As the rotary pump supplies fluid continuously, the

Illust. 4—Reservoir and check valves added.

This necessitates an additional quantity of fluid, which can be obtained from a reservoir, as shown in Illust. 4. Also, check valves are needed to permit the fluid to be pumped from the reservoir (which is at atmospheric pressure), to the cylinder at an increased pressure.

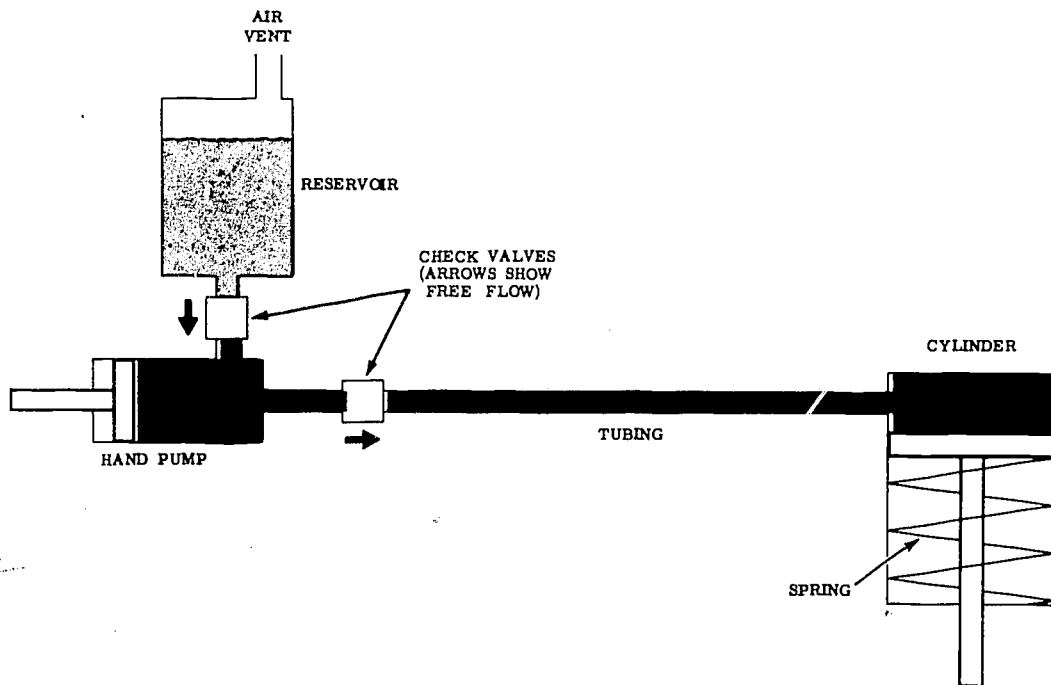The system shown in Illust. 4 would be impractical, since once the piston is extended, the fluid cannot get back to the reservoir. For this reason, a directional control valve and a return line to the reservoir must be installed as in Illust. 5. A directional control valve is a device capable of directing the flow of fluid in one of several directions. When the valve is in the position shown by the solid lines, the fluid may be pumped into the cylinder and the piston will be forced down. When the valve is in the position indicated by the dotted lines,

check valves have been removed. However, a relief valve has been added.

Illust. 5 represents a simple hydraulic system which is operable. If it is advisable to use a cylinder which does not contain a spring to return the piston to its "home" position, a four-way directional valve installed as shown in Illust. 6, so that fluid can be supplied to either end of the piston. Then, regardless of which side of the piston pressure is applied, the fluid on the opposite side of the piston will return to the reservoir.

The relief valve, added in Illust. 5, is a fundamental part of nearly all hydraulic systems.

Without a relief valve, the pump would have to be stopped at the exact moment the

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piston reached the end of its stroke (in either direction), or when the directional valve is placed in a position that stops the flow of fluid. If the pump were not stopped, the pressure in the system would quickly build up to a point where rupture of parts or stalling of the driving motor would occur. The relief valve is set at a predetermined pressure, according to the system involved, so that excessive pressure will cause it to open and allow fluid to escape to the reservoir.

All hydraulic systems can be broken down into simplified diagrams as shown in Illusts. 5 and 6, adding units as necessary. Multiple pistons, multiple pumps with a common reservoir, rotary power units, or any combination of components is possible with proper valving and flow design.
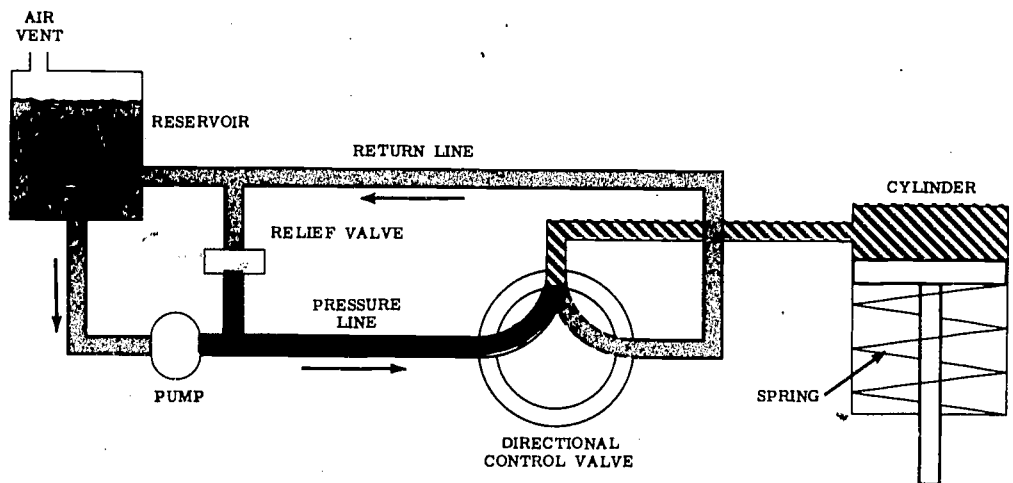
Illust. 5—Directional control valve, rotary pump, relief valve, and return line added.
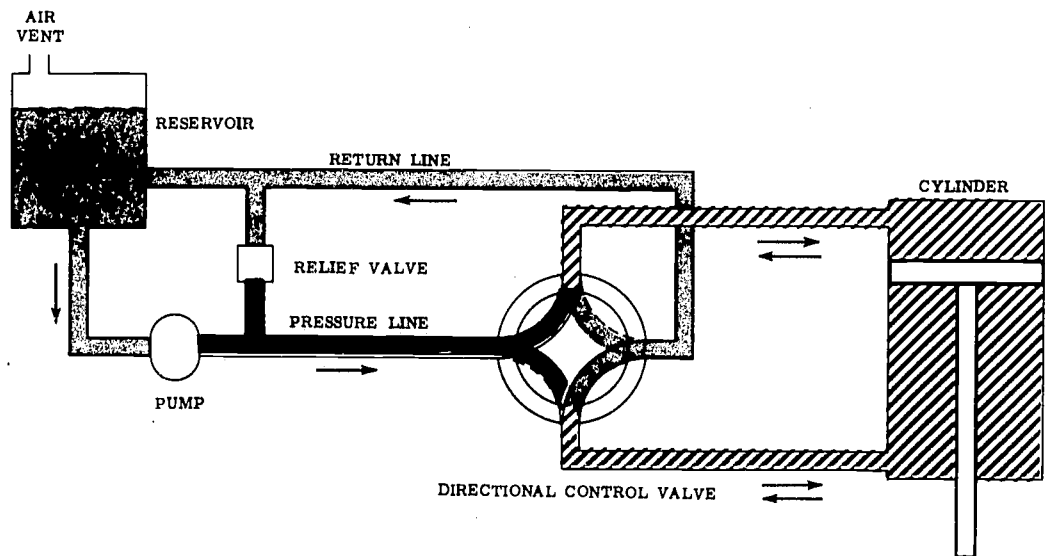
Illust. 6—Four-way valve and double acting piston added.

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RESERVOIR

Every hydraulic system must have a reservoir. In most farm and industrial equipment applications, the reservoir is a built-in unit. For the sake of compactness, some compromises with ideal design are made. Ease of cleaning, large capacity, ideal return line, baffle and filter installation are often impossible to obtain with built-in reservoir systems.

The size of the reservoir depends on the amount of fluid required to operate the system. An ideal size is two or three times the capacity per minute of the pump, except where extra large cylinders or heat problems require

may be required to accomplish this—see page 32.)

4. Allow air and foreign matter to separate from the fluid.

The design characteristics shown in Illust. 7 may be incorporated, in one form or another, in any hydraulic reservoir.

Most of these features are self-explanatory; however, some emphasis should be placed on some of them. All openings into the reservoir should be sealed to prevent the entry of dirt, water and other contaminants.

The vertical baffle plate (if used) with openings at the bottom, helps to segregate return fluid from that entering the pump.
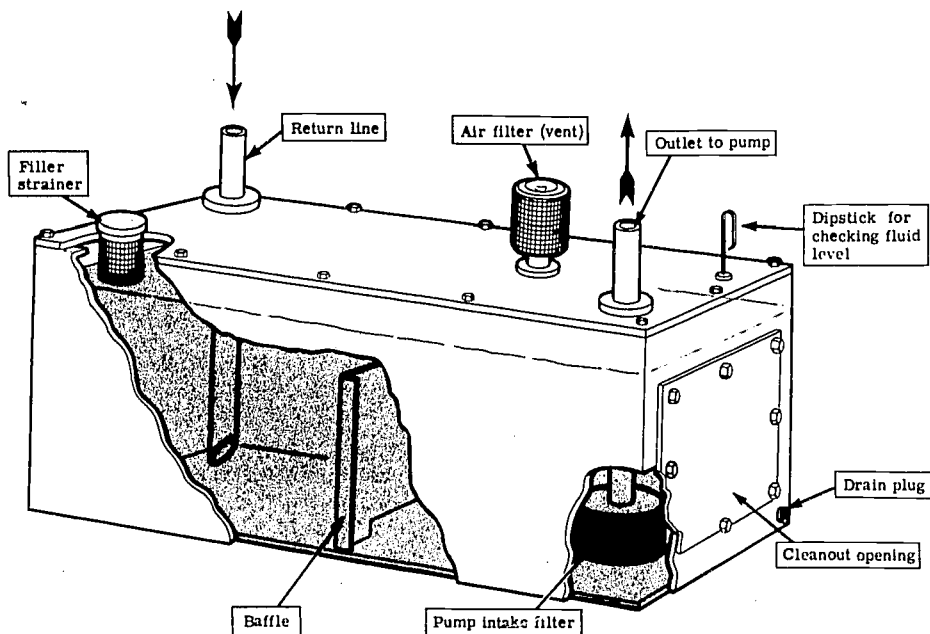
Illust. 7—A drawing of the ideal features of a fluid reservoir.

greater quantities. At any rate, the reservoir should be large enough to:

1. Hold all of the fluid that can drain back into the reservoir by gravity flow.

2. Maintain the fluid level *above* the opening of the suction line at all times.

3. Dissipate excess heat generated during normal operation. (An accessory oil cooler

This allows slower and more complete fluid circulation, and helps air and foreign matter separate from the fluid.

If a pump intake filter is provided, it should be mounted at least one inch away from the sides or bottom of the reservoir.

The dipstick, or fluid level plug, whichever is used, should show the proper level when the pump is not running, with the cylinders

collapsed. Too little fluid will allow air to enter the pump; too much will not provide sufficient air space, and may cause damage to the reservoir. The dipstick or plug *must* fit tightly in the reservoir.

The filler hole must be tightly capped, and a strainer-equipped funnel should be used to keep contaminants out of the reservoir when adding fluid. The drain plug should be located in such a manner that *all* the fluid will be drained when it is removed.

An air vent, or breather, which may be fitted with a filter, is very important. As fluid is moved to and from the hydraulic reservoir, air will be sucked in and pushed out by the fluctuating level of fluid in the reservoir. Filtered air helps prevent moisture, dirt, and other contaminants from reaching the fluid.

HYDRAULIC PUMPS

The pump is the power supply of the hydraulic system, and it is a precision-built unit, of rugged design and high quality materials.

At this point it is well to mention that installation, trouble-shooting, and operating instructions for hydraulic pumps must be followed to the letter.

Design features, tolerances, and lubrication requirements that are not "spelled out" have been taken into consideration. It is advisable that service personnel take advantage of the experience and research that have been put into these manuals.

Pumps are commonly thought of as compressors, but this is not true of hydraulic pumps. Since fluids are virtually incompressible, except at extremely high pressures, the pump serves only to *transmit* force.

In the very simplest type of system, such as hydraulic brakes, force is merely transmitted from one point to another. Pushing down on the brake pedal moves the master cylinder piston toward the discharge end of the cylinder, and fluid flows under pressure to the cylinders at the wheels. Through one simple movement, force is transmitted from one point to other points.

Rods, shafts and levers can, and are, used to obtain the same effect; however, fluid-filled lines give more desirable results.

In the hydraulic braking system, fluid flow stops when all the brake shoes make contact with the brake drums. In this case, the primary purpose of the pump (master cylinder) is to transmit force hydraulically. In more complex hydraulic systems, the pump provides a steady flow of fluid under pressure, thus giving both transmission of force *and* motion.

Pumps may be classified into two types, based on performance: (1) Fixed delivery when running at a given speed, and (2) Variable delivery when running at a given speed.

At the present time, most farm and industrial equipment pumps are of the fixed delivery type.

Variable delivery pumps are usually run at a constant speed, and are so designed that the volume output can be easily varied from zero to maximum. These pumps are more complex, therefore more expensive, than constant delivery types, so their use is limited to applications where the variable delivery feature is a necessity.

Clearances are extremely critical in hydraulic pumps, as in most hydraulic system components. The formation of contaminants in even tiny amounts can result in operating difficulties. The efficiency of a hydraulic pump depends upon a minimum of wear throughout its life. Abnormal wear, for example, causes increased internal slippage of the fluid in the pump. (Internal slippage is internal leakage from the high pressure side of the pump—through the pump parts.) This results in

power loss, reduced output, and increased operating temperature.

Since the hydraulic fluid is nearly always the lubricant for the moving parts of the system, it is essential that the recommended fluid be used in the system.

The principles of operation of most of the common types of hydraulic pumps are described on the following pages. Illustrations, in many instances highly simplified, will help explain how these pumps put fluids in motion.

RECIPROCATING PUMPS

Pumps with reciprocating piston action (this classification does not include the rotary piston pumps covered later) are useful in extremely high pressure applications because of low leakage losses and in applications where large volumes of fluid are required.

The pulsating nature of the discharge from reciprocating pumps may cause objectionable vibration in many installations. Pumps with three or more cylinders on the same shaft are designed to reduce pulsation by overlapping the pumping strokes of each cylinder, in much the same manner as internal combustion engines.

Most of these pumps are of the fixed displacement type, although one variation is provided with a stroke-transformer which permits variable delivery by varying the length of the piston stroke. Reciprocating pumps are capable of operating under adverse conditions (such as extreme cold and heat), are comparatively trouble-free and will handle tremendous pressure. Illust. 8 is a self-explanatory schematic of a simple reciprocating pump.

EXTERNAL GEAR PUMPS

External gear pumps are of the constant delivery type, and operate on the simple principle that as gears revolve, fluid trapped in between the gear teeth and the housing is carried from the suction (inlet) side to the discharge (outlet) side of the pump. (Illust. 9). One gear is driven, the other "follows." External timing is not necessary.

The efficiency of this pump is largely determined by the close fit of the working parts.

CHECK VALVES   CHECK VALVES
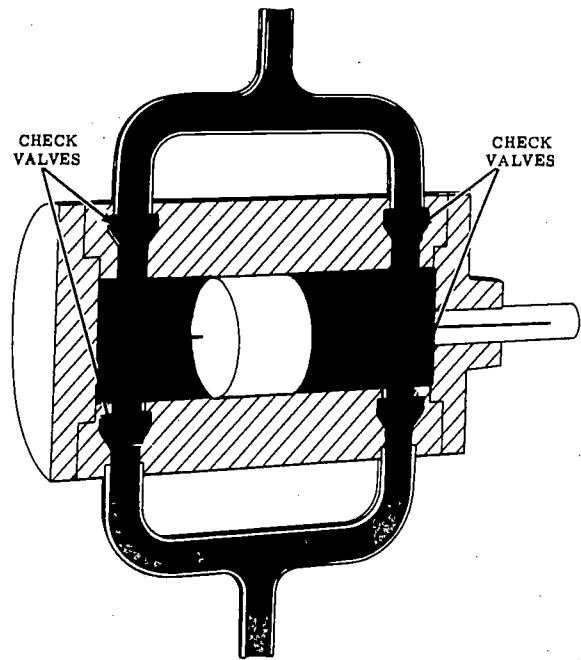
Illust. 8—A reciprocating pump showing the principal working parts.

2. Fluid is picked up and carried in these spaces to the outlet side of the pump.

3. Mating teeth displace fluid and force it through outlet.

1. Parting gears create slight suction here that helps to draw in fluid.

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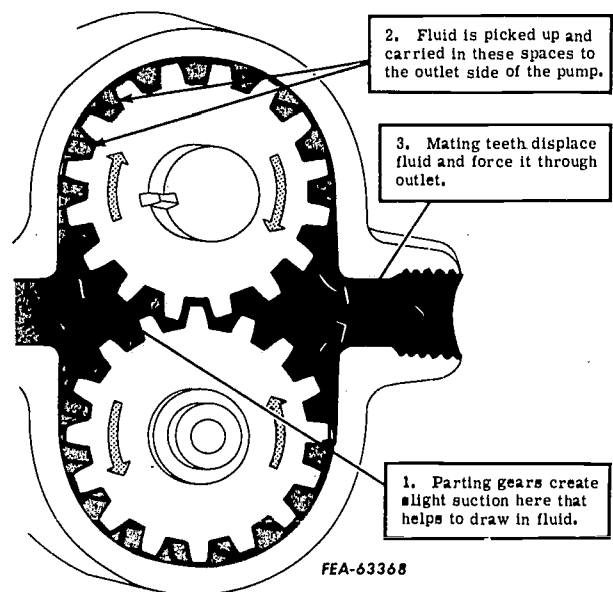
Illust. 9—Operating principle of the external gear pump.

They are used principally where relatively low pressures, volumes, economy of cost, and restricted space are factors.

More quiet and somewhat smoother operation plus slightly higher pressures may be obtained by using helical or herringbone gears.

Pressures up to 3000 p.s.i. are available by "pressure loading" loose fitting bearings so that a balance is set up between pressure within the gear cavity and the thrust of the bearings against the gears. This enables the pump to be driven at very high speeds, with increased pump efficiency.

Gear pumps have a tendency to churn fluids, which may raise their temperature. This action hastens the mixture of contaminants with the fluid.

INTERNAL GEAR PUMPS

Internal gear pumps are a modification of the gear pump principle, in that pressure is developed by trapping fluid between meshing gears. Either the internal gear or the external ring may be the driven member. See Illust. 10.

The crescent shaped block (Illust. 10) acts as a division between suction and discharge.

FLUID OUT
(PORT NOT SHOWN)

FLUID IN
(PORT NOT SHOWN)

Illust. 11—Internal gear pump.

Internal gear pumps have about the same effect on fluid as the external gear pumps already described.

GEAR-LIKE PUMPS

Gear like pumps are similar to both gear types, in that they have rotating members with lobes resembling teeth, which inter-mesh (Illust. 12).

FLUID IN

INNER GEAR
(DRIVEN)

OUTER GEAR

STATIONARY
CRESCENT
DIVIDER

Illust. 10—Internal gear pump.

1. Timing gears such as these. . .

2. are required to drive these gear-like rotors, because the shape of the rotor teeth makes it impossible for one rotor to drive the other.

3. Fluid drawn in here is carried through the pump and discharged at the other side in the same way as in a simple gear pump.

Illust. 12—Operating principle of a gear-like pump.

In another design, (Illust. 11) the crescent is omitted and sealing of discharge from suction is accomplished by having the teeth in constant sliding contact throughout the cycle. Also, there is one less tooth on the internal gear than on the external ring. See Illust. 11.

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One rotor cannot be used to drive the other, so external timed driving gears are necessary. *They are generally used for transferring fluids, not for providing pressure in a hydraulic system.*

Other forms may be used in a gear like pump, such as two lobe or three lobe cams.

SCREW PUMPS

Screw pumps are simple, rugged and are capable of working at very high speeds. They are especially useful in handling fluid with a great deal of entrapped air. This type of pump is not used to provide hydraulic power. It is used for transferring fluids from one point to another. The operating principle is outlined in Illust. 13.

VANE PUMPS

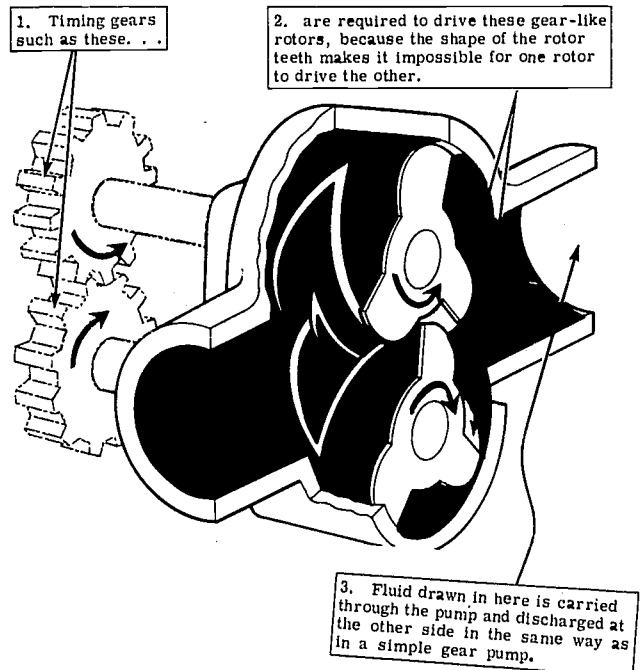Vane pumps are a popular means of producing hydraulic power. Unless special adaptations are made (see below) they are constant delivery type pumps. They produce a reasonably steady flow. Vane pumps are capable of handling large volumes of fluid at relatively high pressure. Wear does not greatly reduce efficiency because the vanes will move farther out in their slots to maintain contact with the

3. Fluid is drawn in here. . .

4. and carried along in these spaces

5. to the discharge.

2. are rotated by this driving screw. . .

1. As these screws. . .
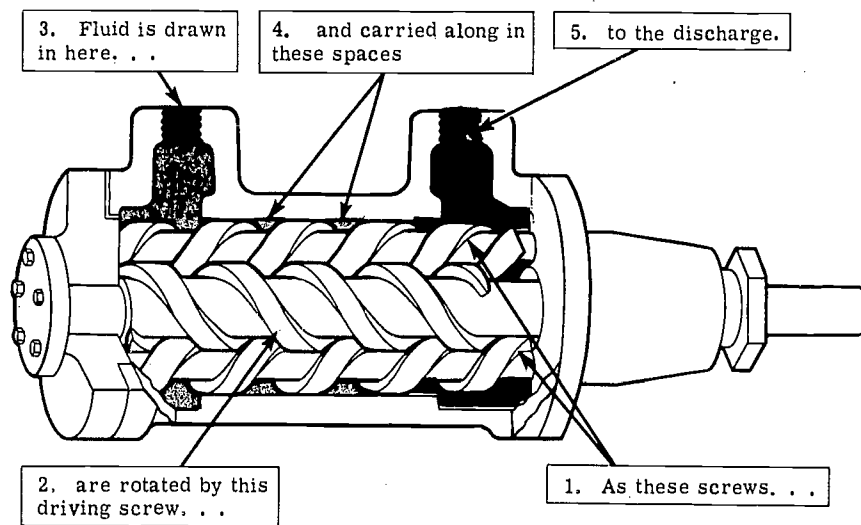
Illust. 13—Operating principle of the screw pump.

1. As this rotor turns counter-clockwise. . .

2. these vanes are thrown out by centrifugal force and fluid pressure. . .

3. against this oval-shaped housing.

5. Conversely, over areas covered by these discharge ports, the volume between adjacent vanes decreases as rotor turns, thus fluid is forced out of the pump.

4. The volume between adjacent vanes increases as the rotor turns over areas covered by these intake ports. Thus, fluid is drawn into the pump.

Illust. 14—Operating principle of the vane type pump.

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housing. Dirt and sludge may cause the vanes to stick in their slots, thus seriously affecting operation. For operating principle, see Illust. 14.

The pump in Illust. 14 is called a "hydraulically balanced" pump because it has two each diametrically opposed inlets and outlets.

In another design, the rotor is mounted eccentrically with respect to a circular housing. See Illust. 15.

VANES
SLIDE IN
SLOTS

FLUID PRESSURE BEHIND THE
VANES AIDS CENTRIFUGAL
FORCE TO HOLD THEM AGAINST
THE BODY SURFACE

Illust. 15—Vane pump with the rotor mounted eccentrically to a circular housing.

A further refinement will give the variable delivery feature to this pump. By adding a spring-loaded pressure plate and a movable inner housing, delivery can be either governor or hand controlled. See Illust. 16.

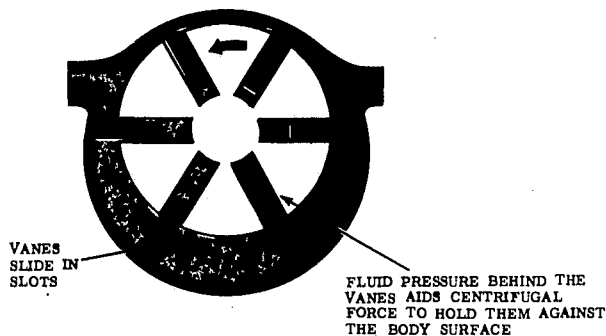## RADIAL PISTON PUMPS

Radial piston pumps are compact and rugged. They are capable of high pressure, high volume and high speed, and are very efficient. Because of the large number of closely fitted

ATTACHED TO
OUTER CASING
OF PUMP

GOVERNOR VARIES
ECCENTRICITY OF
PRESSURE RING

PRESSURE
RING
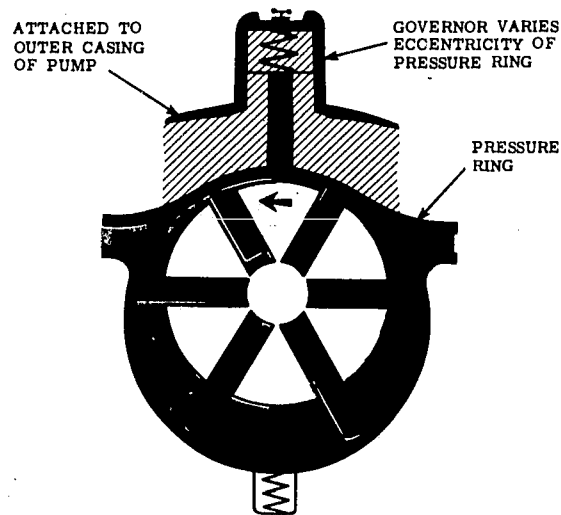
Illust. 16—Governor operated, variable delivery, vane type pump.

3. In this circular housing.

4. Assuming clockwise rotation, fluid is drawn in through these ports. . .

2. this rotating cylinder block mounted eccentrically. . .

These parts do not rotate.

1. Pump pistons reciprocate as they are carried around by. . .

5. and discharged through these ports.

Spindle serves as a barrier between low and high pressure fluid.
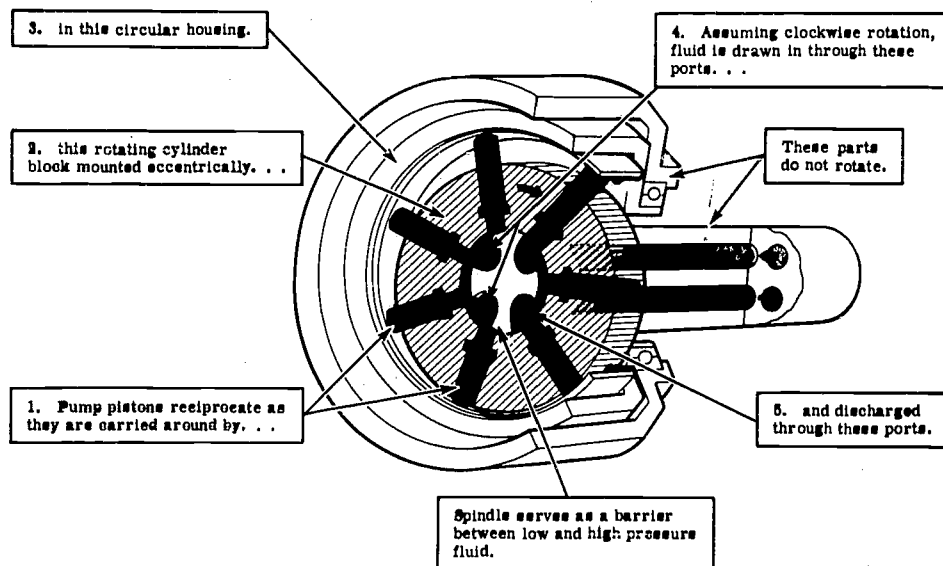
Illust. 17—Operating principle of the radial piston pump.

parts, wear is an extremely important consideration. Fluid recommended for use in systems with radial piston type pumps must be clean and it must contain properties to lubricate the closely fitted parts. (Illust. 17).

Unless special valving design is used, radial piston pumps generally have an odd number of pistons.

Radial piston pumps may be given the variable delivery feature by making it possible to adjust the eccentricity of the rotor to the circular housing—either manually or governor controlled.

AXIAL PISTON PUMPS

Axial piston pumps have the same general characteristics as radial piston pumps. Instead of the pistons being mounted at right angles to the driving shaft, they are parallel to it. (Illust. 18)

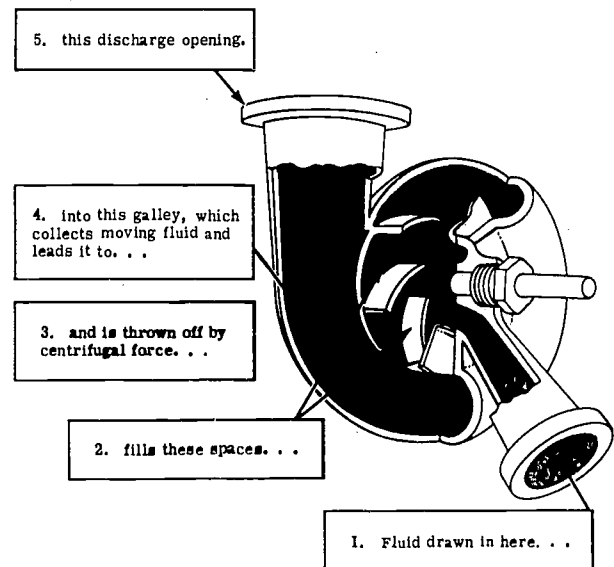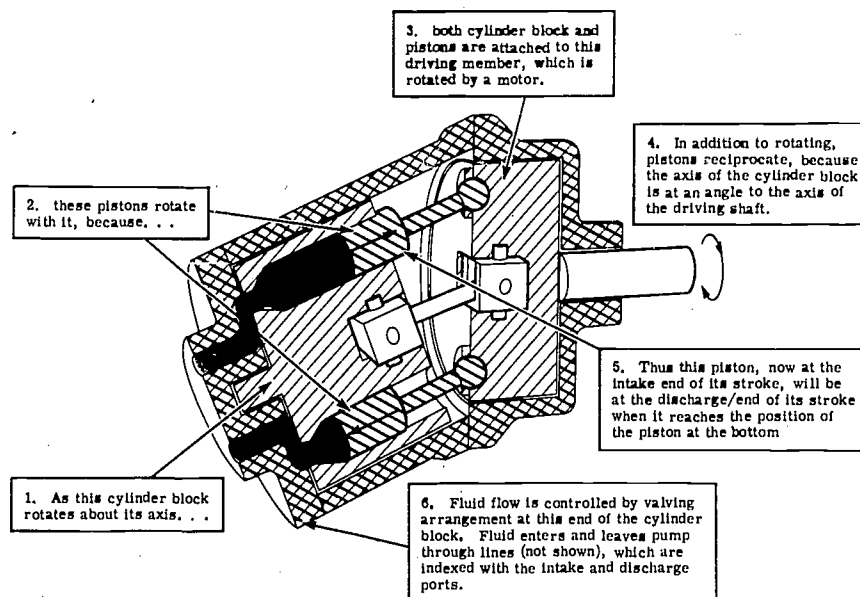Pump body design variations provide the variable delivery feature by making it possible to alter the angle of the cylinder block to the driving member during operation. Either manual or governor controls may be used.

CENTRIFUGAL PUMPS

Centrifugal pumps (Illust. 19) are of the constant delivery type and are unique in that they deliver a completely non-pulsating flow of fluid. It is impossible to overload them because the fluid in the pump will start to rotate with the blades if the design pressure is exceeded. They are not often used to develop

5. this discharge opening.

4. into this galley, which collects moving fluid and leads it to. . .

3. and is thrown off by centrifugal force. . .

2. fills these spaces. . .

1. Fluid drawn in here. . .

Illust. 19—Operating principle of the centrifugal type pump.

3. both cylinder block and pistons are attached to this driving member, which is rotated by a motor.

4. In addition to rotating, pistons reciprocate, because the axis of the cylinder block is at an angle to the axis of the driving shaft.

2. these pistons rotate with it, because. . .

5. Thus this piston, now at the intake end of its stroke, will be at the discharge/end of its stroke when it reaches the position of the piston at the bottom

1. As this cylinder block rotates about its axis. . .

6. Fluid flow is controlled by valving arrangement at this end of the cylinder block. Fluid enters and leaves pump through lines (not shown), which are indexed with the intake and discharge ports.

Illust. 18—Operating principle of the axial piston type pump.

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hydraulic pressure. They are better adapted for transferring large quantities of fluids. Centrifugal pumps are most often found in engine cooling systems.

COMBINATION PUMPS

Many hydraulic applications involve two or more distinct functions of the hydraulic fluid. Multi-stage pumps are used to provide fluid at more than one pressure. For example, a machine that requires rapid movement to engage the work, followed by slow, high pressure work force uses large volume, low pressure flow for rapid travel, and low volume, high pressure flow for the work force. This can be provided by a two pressure (two-stage) pump such as the one shown in Illust. 20.

Combination pumps may also be used where pressure higher than that available
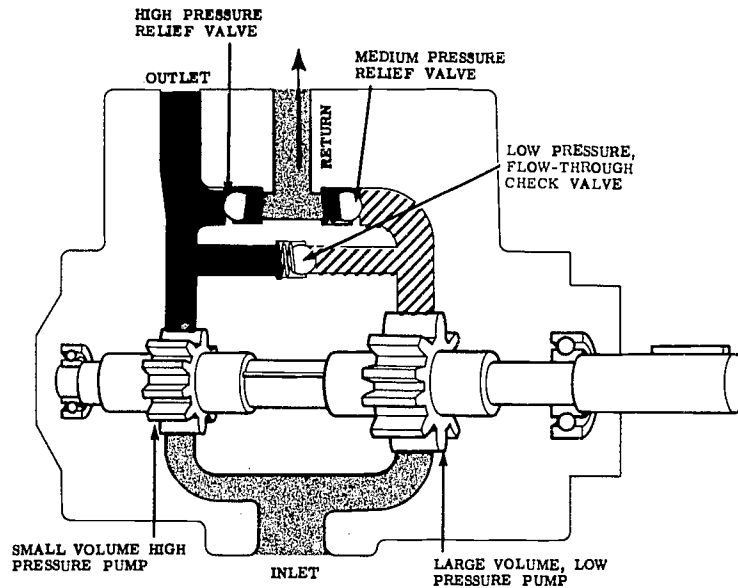
Illust. 20—A two pressure gear type pump.
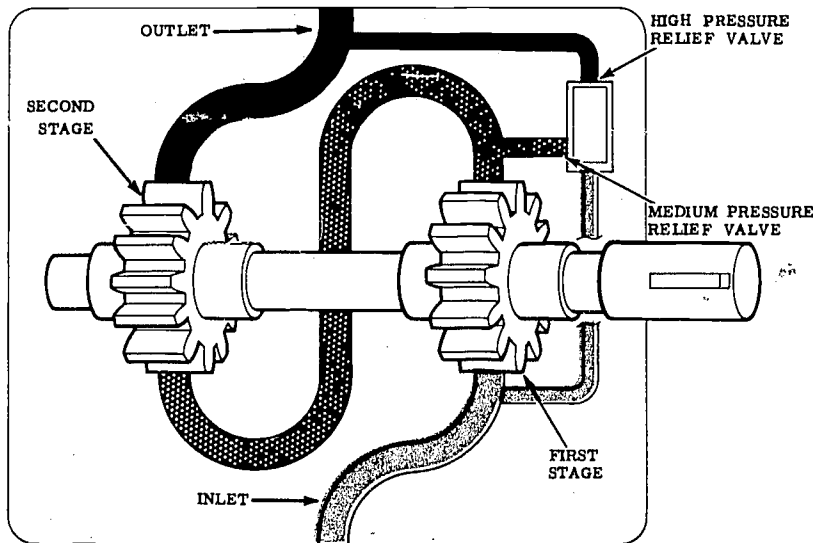
Illust. 21—A two-stage series pump.

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from a single pump is desired. Two single-stage pumps operated in series will give this effect. See Illust. 21.

Greater volume of fluid delivery is also possible in this manner.

A duplex system (not illustrated) consists of two pumps, mounted on the same shaft, with a common reservoir, but each having separate suction and delivery lines. This is the adaptation used for tractor hydraulics (large volume pump) and power steering (low volume pump).

Another adaptation of the combination pump idea is found in hydraulic transmissions, many of which use a "multi-stage" centrifugal pump arrangement. This will be discussed later in the manual.

HYDRAULIC VALVES

It was mentioned earlier that hydraulic systems are basically simple and they are, if the presence of many valves, of several types, is not allowed to confuse understanding.

Nearly all the valves used in hydraulic systems may be classified in these three categories:

1. Directional control
2. Volume control
3. Pressure control

Leakage of fluid past the moving parts of valves may occur, and may be objectionable if back pressures build up. In some designs, this fluid may be internally drained to the suction side of the pump, or to the reservoir.

Hydraulic fluid is generally the lubricant for valves, as with pumps, and clearances are again extremely small, so use of *clean* fluid, of the recommended type, is essential.

Control of valves may be manual, mechanical, electrical, pneumatic, or hydraulic. Circuits can be constructed so that the entire sequence is automatic.

Until recently, valves were the only means of controlling fluids in a hydraulic system. With the advent of "variable delivery" pumps, certain valves in systems having this type of pump may be eliminated. However, valves are still the most important method of controlling fluid pressure and flow, and obtaining wide flexibility in hydraulic systems.

Specific types of valves are described and illustrated in the following section. Valves used in hydraulic systems are usually more detailed, and their applications more complex —usually with elaborations and additions to the basic valve—but the basic operating principles will be the same. If the basic operation of a valve is understood, then its refinements will be more easily understood.

COCK VALVES

Cocks are very simple valves, usually in small sizes. They are used to bleed air out of a system, turn gauges on and off, drain a system,
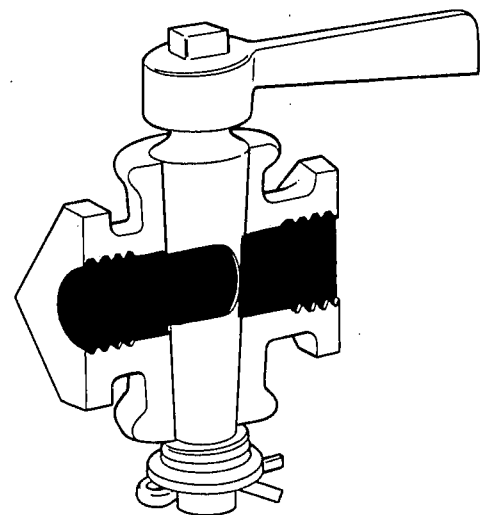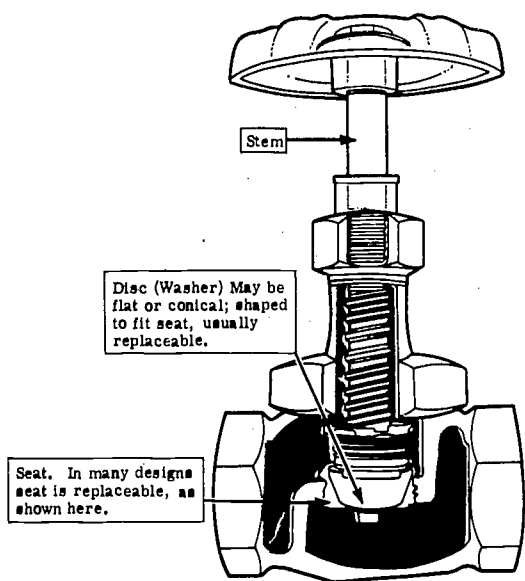

Illust. 22—A cock valve in the open position.

etc. Illust. 22 shows a cock in the open position. A quarter-turn of the handle will shut it off. The one illustrated is designed for moderate pressures. Modification will enable cocks to be used at much higher pressures.

GLOBE VALVES

Globe valves are also very simple in design, and very reliable (Illust. 23). They should be used either fully open or fully closed, as leaks along the stem are more likely in an intermediate position. Particles of dirt on the seat or disc (washer) usually cause leakage when

the valve is closed, but will not seriously hamper operation. Globe valves offer some resistance to flow, and may cause turbulence in the fluid.

GATE VALVES

Gate valves have several advantages over globe valves. Mainly, at full open position, they offer almost no resistance to flow, and they are easily controlled with automatic mechanisms. From their design, (Illust. 24), note that serious wear may occur at partially opened positions, as fluid flowing past the

Stem

Disc (Washer) May be flat or conical; shaped to fit seat, usually replaceable.

Seat. In many designs seat is replaceable, as shown here.

Illust. 23—A globe valve in the closed position.

Stem. In design shown, stem rises as valve is opened. Large valves often have stationary stems on which disc moves up and down.

Disc. Design varies Some discs are solid, others split.

MAY BE REPLACEABLE

Seat

Illust. 24—A gate valve in the closed position.

FLOW IN THIS DIRECTION ONLY
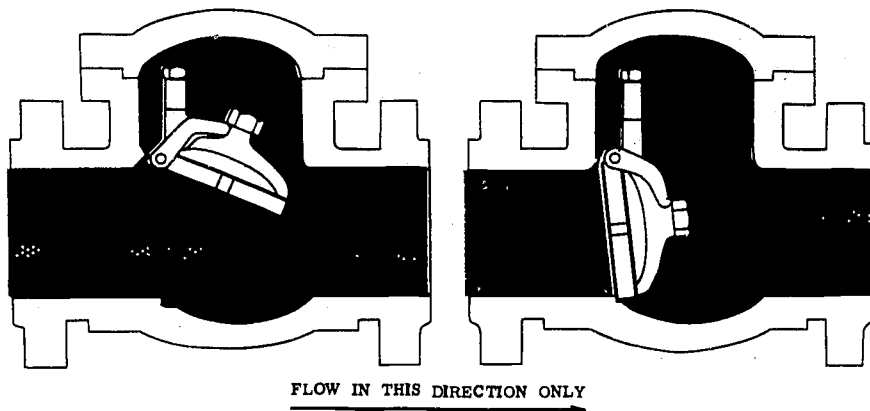
Illust. 25—Action of a flapper valve.

valve parts will erode them. Particles of dirt can interfere with the movement of the gate.

The gate of the valve may be a solid wedge or a two piece "disc" with an eccentric action on the discs, so that tightening the valve stem spreads the discs apart for a tighter fit on their seats.

FLAPPER VALVES

Flapper valves are essentially check valves in that they permit flow in only one direction. They are obtainable in all sizes—very small to very large. They offer little resistance to flow when fully open. (Illust. 25). Although they are usually installed so that gravity and pressure close them, they are sometimes equipped with a spring to start the flapper toward its closed position. The back pressure causes the flapper valve to seal tightly.

BALL VALVES

Like flapper valves, ball valves permit flow in just one direction, so they also are often used as check valves. Their design and operation prevents their use in the larger sizes (above 1" ball size is unusual). They are often spring-loaded, so that a certain predesigned pressure is required to open them. This adaptation may sometimes be adjustable, and is called a pressure relief valve. (Illust. 26). Dirt can easily make a ball valve inefficient. The normal chatter of an operating ball valve can be minimized or overcome by various modifications.
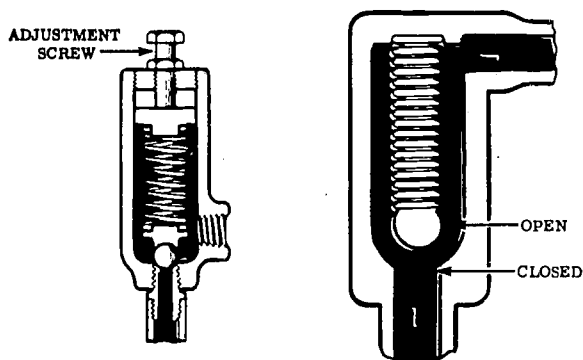
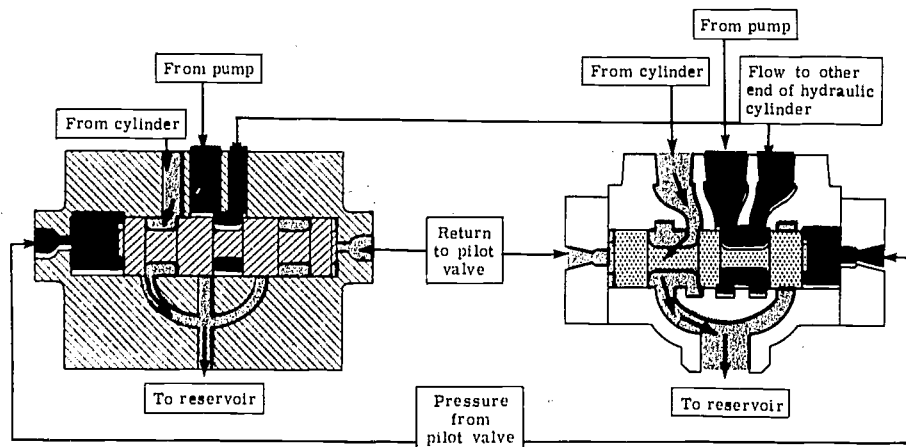Illust. 26—Two designs of the ball valve principle.

NEEDLE VALVES

A needle valve is mainly used for metering fluid flow very carefully and exactly. It can be used in any position from fully closed to fully open, and is usually manually operated. (Illust. 27). Its design makes it almost impossible to cause an abrupt change in the rate of flow, and therefore it is often used in systems containing any extremely sensitive components. Dirt will easily interfere with its action.
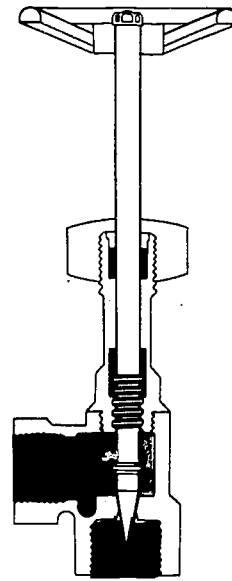
Illust. 27—A needle valve in the closed position.

SPOOL VALVES

Spool valves are used to control direction of flow. They are very popular in hydraulic equipment because of quick, positive action. By increasing the number of "lands" and adding appropriate ports, one spool valve can be made to handle flows in many directions. Also, these valves can be "stacked" so that supply ports of the added valves are in line with the discharge ports of the preceding ones. Grooves are often machined around the lands so that rings of fluid retained in the grooves will help keep the spool centered and will lubricate it. Mating surfaces of spool valves must be accurately machined and fitted. Worn parts will cause leakage and erratic or sluggish action. Dirt will cause sticking and erratic action. If the valve is actuated hydraulically,

OPEN CENTER SPOOL VALVE   CLOSED CENTER SPOOL VALVE

From cylinder
(Cylinder flow shut off)

From pump

From pump

Pump flow
shut off

From cylinder

Valved fluid lines
connected here
provide hydraulic
control of valves

To reservoir

Pump flow
straight through

To reservoir

From pump

Flow to one end
of hydraulic cylinder

From pump

From cylinder

From cylinder

Pressure
from
pilot valve

To reservoir

To reservoir

Return line to pilot valve

From pump

From pump

From cylinder

From cylinder

Flow to other
end of hydraulic
cylinder

Return
to pilot
valve

To reservoir
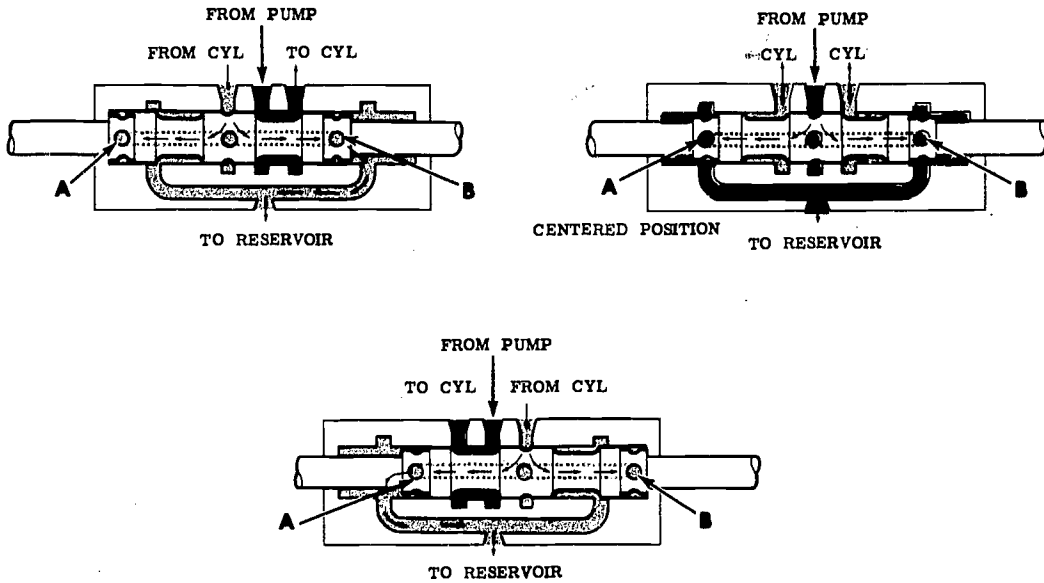
To reservoir

Pressure
from
pilot valve

Illust. 28—Open and closed center spool valves.

20

23

dirt and wear may upset delicate hydraulic balances and thus cause erratic action, or perhaps completely halt operation.
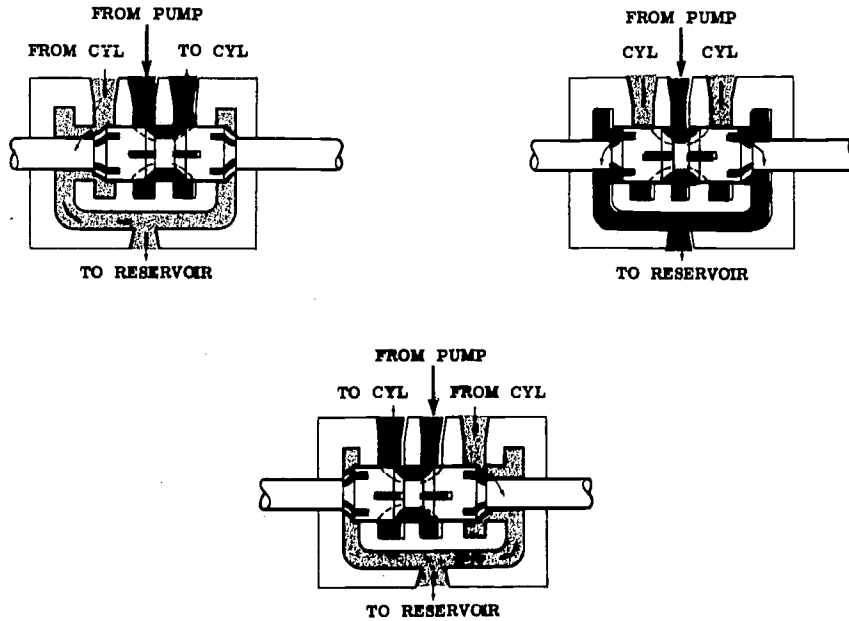
There are two basic types of spool valves—the open center and the closed center. (Illust. 28). The illustration shows that the difference in operation between them is simply that pump flow passes through the open center type in the neutral position, while the cylin-der ports are blocked. In the closed center valve illustrated, pump flow is "blocked" in the neutral position and the cylinder ports are open (float position). In some designs, all three ports are blocked.

The operating principle of these valves is the same, whether the effect is obtained with bored passages, (Illust. 29) or with slotted lands, (Illust. 30), or with plain lands (Illust. 28).

FROM PUMP
FROM CYL   TO CYL

A   B

TO RESERVOIR

FROM PUMP
CYL   CYL

A   B

CENTERED POSITION   TO RESERVOIR

FROM PUMP
TO CYL   FROM CYL

A   B

TO RESERVOIR

Illust. 29—Open center type spool valve with bored passages.

FROM PUMP
FROM CYL   TO CYL

TO RESERVOIR

FROM PUMP
CYL   CYL

TO RESERVOIR

FROM PUMP
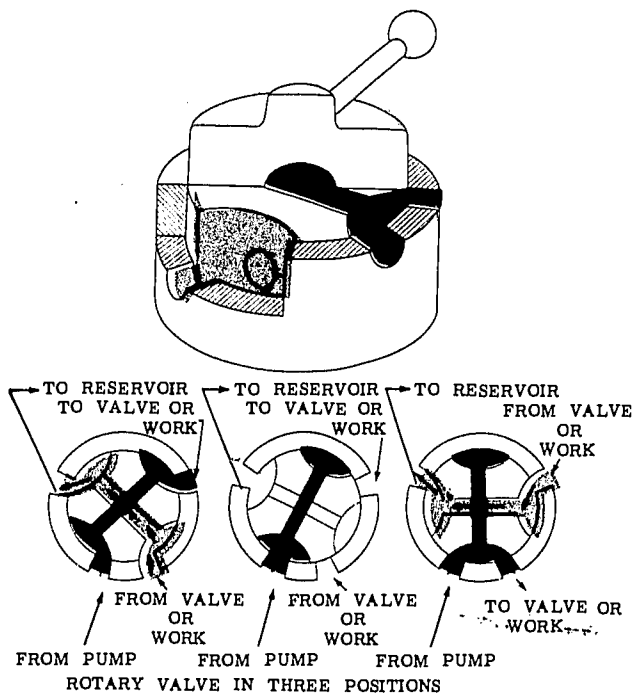TO CYL   FROM CYL

TO RESERVOIR

Illust. 30—Open center type spool valve with slotted lands.

Slotting or notching of the lands in a spool valve is often used as a method of "feathering" the closing or opening of a valve to prevent "fluid hammer" (see page 35) and shock to the system.

Spool valves may be spring or hydraulically balanced. Neutral position can be at either end or on center, as desired. In some installations, a "detent mechanism" is used to hold the spool in work position. This mechanism will hold the spool until its force is overcome, sometimes by hydraulic pressure. Usually, the operator will overcome this force by manipulating the controls.

ROTARY VALVES

Rotary valves are also used to control direction of flow. Sometimes they are used by themselves, but usually they are used as pilot valves to control the movement of spool valves. By adding extra ports and passages it is possible to control flow through several lines with one valve. Rotary valves handle a wide range of pressures and will operate efficiently in the presence of relatively high amounts of dirt

TO RESERVOIR
TO VALVE OR WORK

TO RESERVOIR
TO VALVE OR WORK

TO RESERVOIR
FROM VALVE OR WORK

FROM VALVE OR WORK

FROM VALVE OR WORK

TO VALVE OR WORK

FROM PUMP   FROM PUMP   FROM PUMP
ROTARY VALVE IN THREE POSITIONS

Illust. 31—Operating principle of the rotary valve.

and sludge. Their operating principle is very simple. See Illust. 31.

Rotary valves are usually operated manually, but it is also possible to operate them hydraulically and electrically.
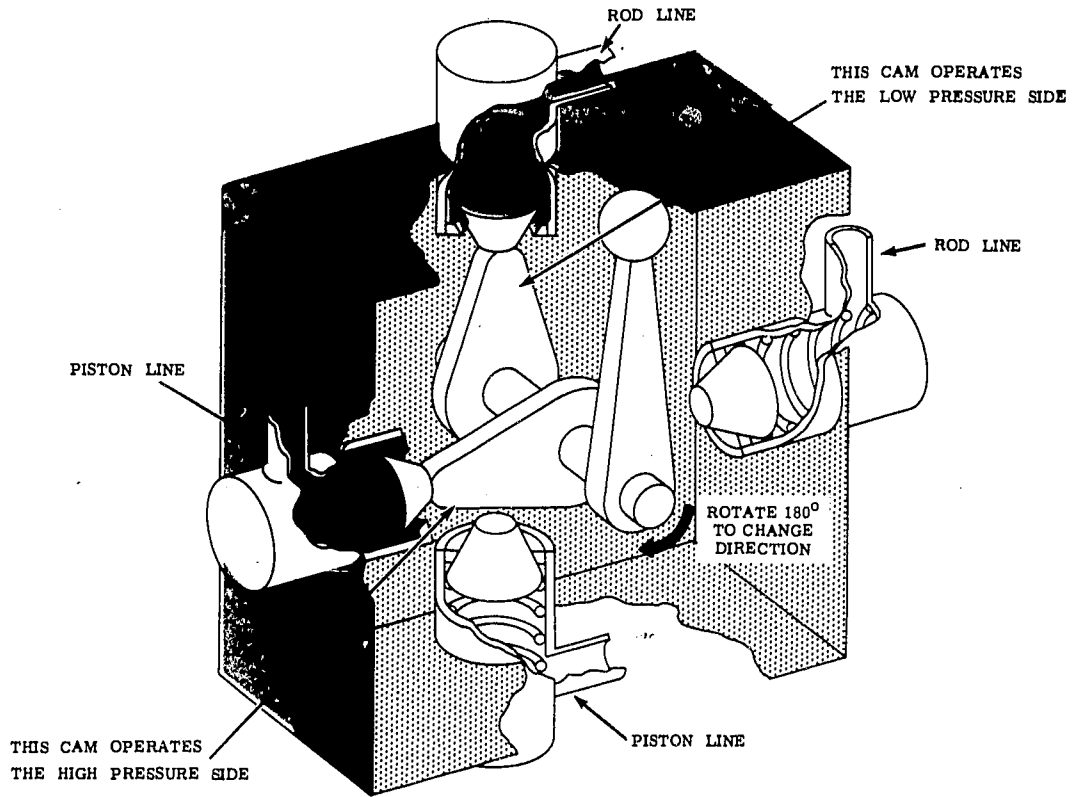
DIRECTIONAL POPPET VALVES

One kind of poppet valve has already been discussed — the simple spring-loaded ball valve. A poppet valve is usually spring loaded. It is any valve which is opened either hydraulically or mechanically, and in which flow of fluid is past the sealing member, through the seat itself. The sealing member of a poppet valve may be ball-shaped, bluntly spear-shaped, mushroom shaped, or any of a number of other shapes.

This discussion is limited to directional poppet valves, which are gaining popularity in farm and industrial equipment applications. They have the advantage over spool type directional valves of being positively seated, thus allowing no leakage past their internal members, and consequent cylinder settling.
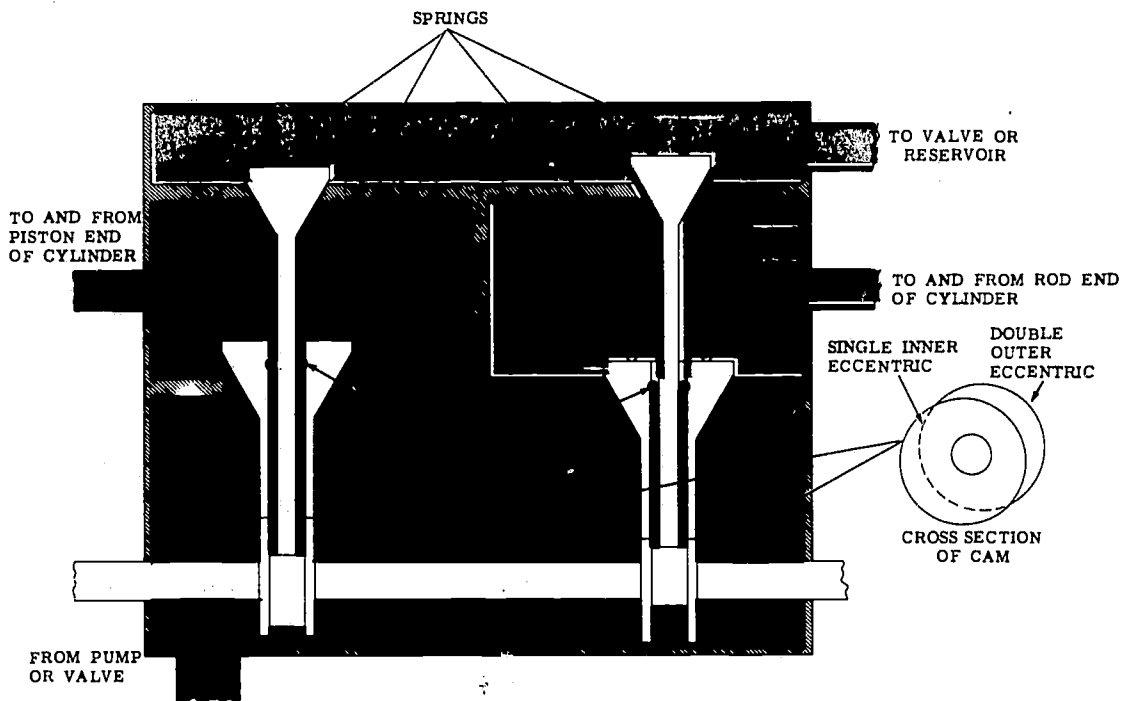
One disadvantage of directional poppet valves is that it is difficult to obtain the fine metering action possible with spool valves. Another is that it is very hard to obtain the shock lessening feathering action possible with spool valves.

The operating principles of the cone type poppet valve (Illust. 32) are very simple. The cams, which may be operated by hand or mechanical means, are turned to open one high pressure valve and one return valve. When cylinder movement in the other direction is desired, the camshaft is turned so that the other two valves in the block are opened.

The operating principle of the mushroom type poppet valve (Illust. 33) is also very simple. As the cam shaft is turned, it overcomes the spring pressure which holds the valves seated, and allows fluid to flow, as directed by the two opened valves. To reverse the flow, the cam shaft is turned until the other two valves are opened.

22

ROD LINE

THIS CAM OPERATES
THE LOW PRESSURE SIDE

ROD LINE

PISTON LINE

ROTATE 180°
TO CHANGE
DIRECTION

THIS CAM OPERATES
THE HIGH PRESSURE SIDE

PISTON LINE

Illust. 32—Cone type cam operated poppet valve.

SPRINGS

TO VALVE OR
RESERVOIR

TO AND FROM
PISTON END
OF CYLINDER

TO AND FROM ROD END
OF CYLINDER

SINGLE INNER
ECCENTRIC

DOUBLE
OUTER
ECCENTRIC

CROSS SECTION
OF CAM

FROM PUMP
OR VALVE

Illust. 33—Mushroom type cam operated poppet valve.

23

COMBINATION

It was mentioned earlier that spool valves may be "stacked" so that more than one operation is possible with one pump and reservoir. This type of valve block is especially well adapted to farm and industrial equipment.

Other combinations are also commonly used, such as, a block with both pressure regulating and check valves, or check valves and directional valves together. Valves are often incorporated into the body of the pump.

These combinations will, unless they are thoroughly understood, confuse the serviceman. It is very important, therefore, to understand the purposes of a valve block and the workings of basic valves, before attempting to tear down a block which has not been seen before.

FLOW CONTROL AND FLOW DIVIDER VALVES

It is relatively easy to understand the operation of a simple relief valve, and what is meant by the term "relief valve." Most valves in any system are relatively easy to understand. However, the terms flow control and flow divider are highly confusing, and their operational differences must be thoroughly understood.

To begin with, flow control valves are a large grouping of valves, which *include* flow dividers. Flow control valves control volume flow, usually through a measured, "designed in" orifice.

Flow dividers perform this function, and also divide the flow into two or more circuits

which operate at different pressure and volume specifications, usually by controlling volume through measured orifices.

Flow divider valves fall into three categories.

The first is the priority type, wherein all the fluid delivered by the pump goes into one part of the system (for example, where the tractor hydraulic pump also supplies fluid to the power steering) until pump delivery builds up to a point where there is extra delivery beyond that required for the priority delivery. The "extra" delivery is then made available to other parts of the system.

Next is the adjustable priority type, which simply means that the delivery to the priority part of the system is adjustable, either externally, with levers, electric solenoids, or hydraulic "positioners," or internally, by changing spring tension in the valve, or changing shims, etc.

The third is the ratio type, wherein there is delivery to all parts of the system (at differing volume and pressure specifications to each part) at all times, but delivery may not be enough to operate the system until the fluid "warms up," or until the power source is operating at full speed.

If pump delivery is lowered for any reason, the ratio type flow delivery valve will cause delivery to lower in all parts of the system at the same rate. Division of flow in the ratio type valve is also accomplished through metered ports or past spring loaded valves within the block.
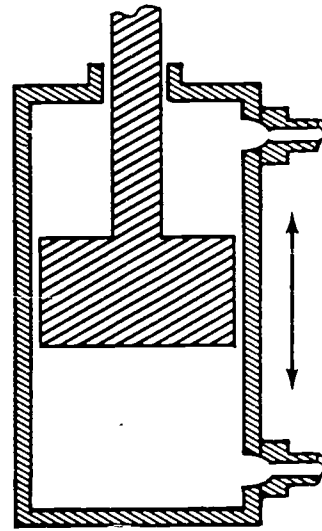
CYLINDERS

The hydraulic cylinder is by far the most popular method of turning fluid under pressure into a work force. Other methods are in use, of course, and will be mentioned later.
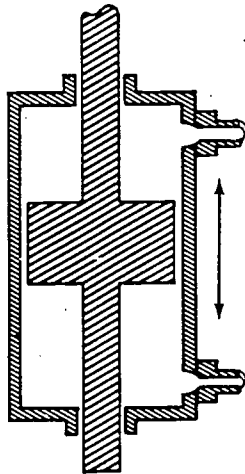
Cylinders may be classified into two general categories—single acting, (Illust. 34) wherein the weight of the load returns the piston to its home position—and double acting, wherein
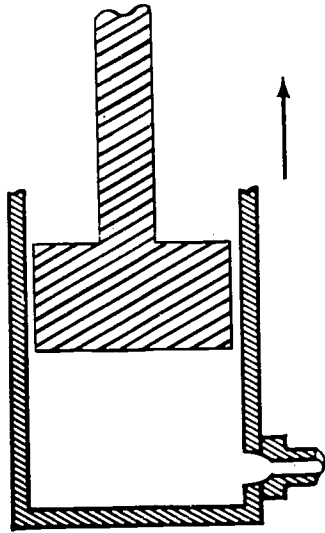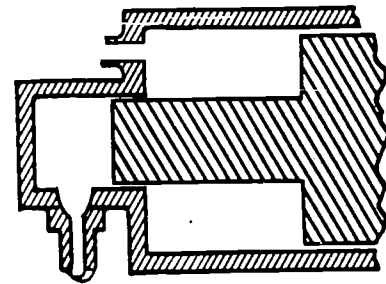
Illust. 34—A single acting hydraulic cylinder.

Illust. 35—A double acting hydraulic cylinder.

Illust. 36—A piston modified to provide equal force in both directions.

Illust. 37—A "stepped piston" type cylinder.

the piston is under pressure in both directions. See Illust. 35.

The double acting cylinder in Illust. 35 is called a differential type because the piston area at the bottom is larger, providing a slower, more powerful force upward, and a faster, less powerful downward stroke because of the difference in piston area, if the same psi is applied to move the piston in one direc-

tion as is applied to move it in the other direction.

If equal force in both directions is desired, the piston rod is designed to extend through both ends of the cylinder. See Illust. 36.

The "stepped piston" provides a means for a rapid approach stroke at low pressure and a slower, more powerful work stroke. A valve admits fluid first against the smaller part of the piston, which moves rapidly until the work is contacted; the entire piston surface takes over for the power stroke. See Illust. 37.
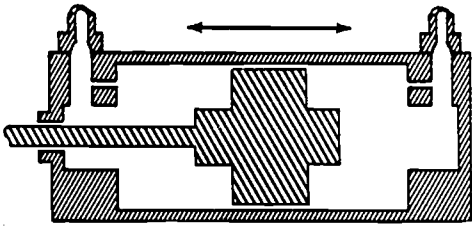
Illust. 38—A hydraulic cylinder with provision for a cushion at the end of the stroke.

Another important refinement of the hydraulic cylinder provides a "cushion" for the end of the stroke of the piston. Since pistons are often under heavy load, and moving rapidly, this is very important in many applications. (Illust. 38). The boss on the piston enters a bore in the end of the cylinder, shutting off the normal discharge port. The remaining fluid is then forced through a smaller port, often adjustable by means of a ball or needle valve.

Some other refinements often found in hydraulic cylinders are as follows:

1. A thermal safety valve, set far higher than system pressure, to relieve any pressures caused by thermal expansion while the system is at rest.

2. Using a double-walled cylinder, to provide fluid passages, instead of external hose or tubing. This is found in many power steering applications, including International Harvester self-propelled combines.

3. Stroke control valves which are adjustable to stop the cylinder at any point in its travel, by shutting off the flow of fluid to the cylinder, or otherwise closing a valve. See Illust. 39.

4. In some cases, the cylinder moves, and the piston is fastened to the base.

5. Another refinement is the telescoping piston. See Illust. 40.

The piston acts as though it were one piece until the outer section reaches its stop, whereupon the inner section will continue to the end of its stroke. They may be designed so that the inner section will move first, followed by the outer section. The speeds of the various sections are dependent upon the square inches of pushing surface in each section, also a designed-in feature.
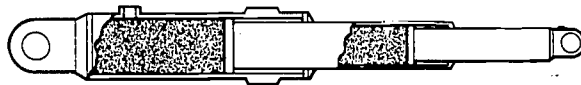
Illust. 40—Cross section of a telescoping piston type cylinder.

Another feature which should be mentioned is that of multiplication of forces, as used especially in fork lifts. See Illust. 41.

Many other design features are possible with hydraulic cylinders—two pistons in one cylinder, internal stroke adjustment, speed variability, and many others, which are of relatively small importance to farm and industrial equipment.

It has been a rather common practice for some dealers and servicemen to attempt to install hydraulic cylinders in applications for

→ PISTON TRAVEL
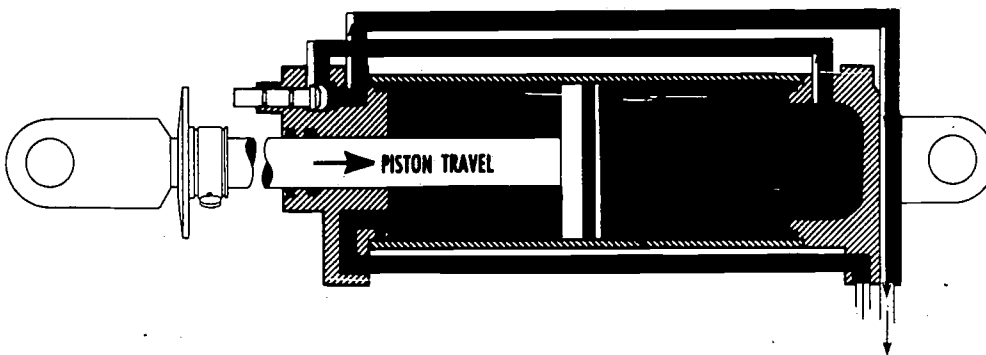
Illust. 39—A hydraulic cylinder with a stroke control valve.

26   29
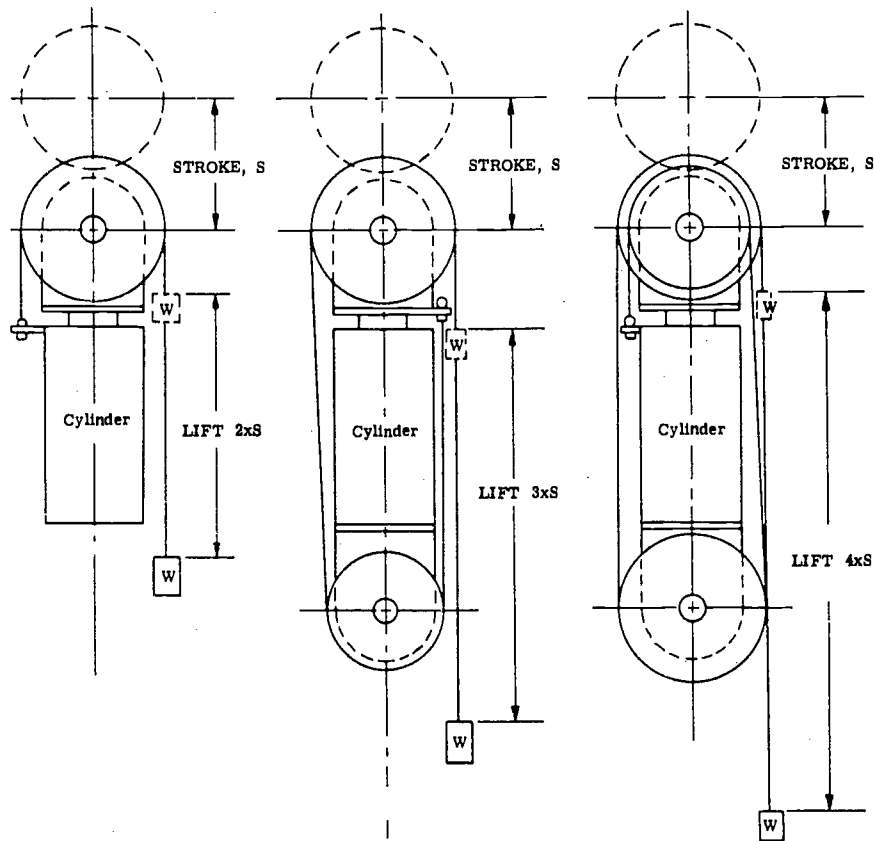
Illust. 41—Principle of using cables or chains and pulleys to multiply length of cylinder stroke.
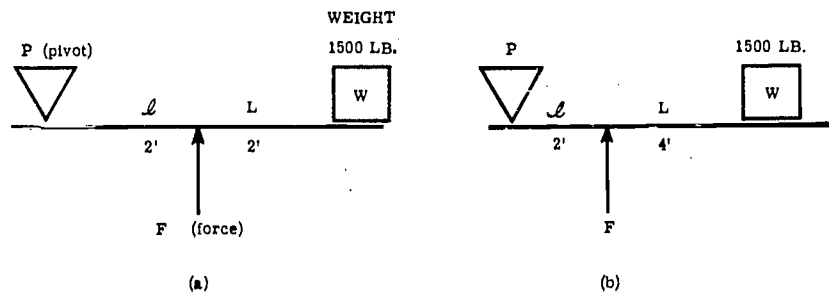
Illust. 42—Basic lever principle.

which no provision has been made for attaching them. Of course, it *is* possible for an implement, wagon, or truck to be equipped with a hydraulic lifting mechanism, with proper strengthening and mounting. However, the attaching points for adding a hydraulic cylinder are *very* critical, and *no* attempt should be made to install one in an application which has no attaching points, without seeking expert advice.

Illust. 42 shows the basic lever principle. The formula for figuring the force (F), required to lift the weight (W), is F x l = W x (L + l) (force multiplied by distance from pivot to point of force (l) equals weight multiplied by distance from pivot to weight (L + l). In (a), then, the force required would be F x 2 = 1500 x 4, or F/2 = 6000, or F = 3000 pounds upward force.

In (b), having lengthened the distance (L), F = 4500 pounds, according to the formula.

If an attempt is made to lift 1500 lbs. with a two ton cylinder as in (b), then, obviously, it will not work.

This explains why, after a wagon bed has been rebuilt, the cylinder, which was properly installed for its previous dimensions, sometimes will not handle the rebuilt bed.

With this principle in mind, it is also understandable why a loader will lift a heavy weight part way, and then stop. As the loader arms go up, they also follow an arc which gradually moves the weight farther away from the lifting point, thus increasing the force necessary to raise the load. Also, this is the same thing that happens when the drawbars of a tractor will not lift a load when improperly attached to the tractor, even though the weight may be less than the lifting ability of the drawbar. In simple terms, what has happened in these cases is that distance (L) becomes too great for the lifting force of a given cylinder.

When further complications are added to the problem of attaching a cylinder such as a scissors type lift, or drawbar lift, it becomes even more clear that it is very wise for the dealer or serviceman to get expert advice on installing cylinders.

SEALS AND PACKING
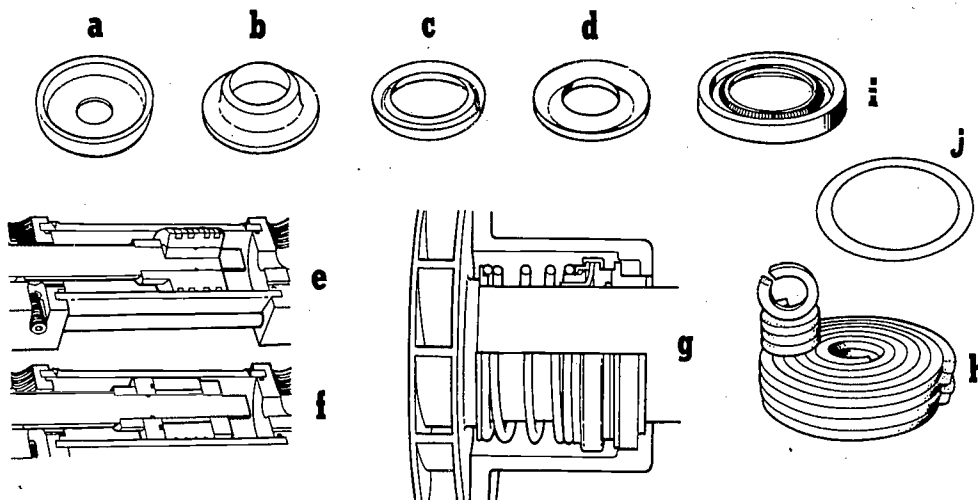
(A) CUP PACKING	(F) NON-EXPANDING METALLIC SEAL
(B) FLANGE PACKING	(G) MECHANICAL SEAL
(C) U-PACKING	(H) COMPRESSION PACKING
(D) V-PACKING	(I) SPRING-LOADED LIP SEAL
(E) EXPANDING METALLIC SEAL	(J) O-RING

Illust. 43—Various types of seals and packing.

None of the components of a hydraulic system so far discussed would operate without proper seals and packing to hold the fluid under pressure in the system. They may be classified as to their use:

1. Static—Used as a gasket to seal non-moving parts.
2. Dynamic—Used to seal moving parts.

They may also be classified according to their shape: U-packing, chevron or V-packing,

O-rings, cup and flange seals, metallic seals, compression packing, mechanical seals, and compression gaskets. (Illust. 43). The type to be used is decided by the manufacturer, and manufacturers recommendations *must* be followed.

O-RINGS

Perhaps the most popular seal in use in farm and industrial hydraulics is the O-ring. It is used as both a static and a dynamic seal, and is usually made of synthetic rubber. It is used in sealing pistons in cylinders, sealing the rod end of the cylinder, sealing moving valve parts (dynamic applications), and in sealing boss or flange type fittings, sealing the various parts of a cylinder together, and to seal pump and valve body sections together (static applications).

They are designed for installation in a groove, so that when they are in use, the meeting members compress the ring about ten percent. In dynamic applications, their life is dependent upon the smoothness of the moving parts, and the closeness of fit. O-rings are not used where they must cross openings or pass corners under pressure. In static applications under high pressure, they are often strengthened by use of a fiber or leather back-up ring, so that they will not squeeze out of their groove. When a back-up washer is used, it is almost always installed on the low pressure side of the O-ring. If two are used, there is one on each side.

"U" AND "V"-PACKING

"U" and "V"-packings (chevron packings) are dynamic seals used to seal pistons and rod ends of cylinders, and to seal pump shafts. They are made of leather, synthetic and natural rubber, plastics, and other material.

They are installed with the open side, or lip, toward the pressure so that pressure will push the lip against the stationary member, to form a tight seal. Chevron packings made up of several single "U" or "V"-packings are used in packing glands, and are very popular for sealing rotating shafts, pistons, and rod ends of cylinders. Packing glands are cases or compressing units that hold this packing in one piece.

CUP AND FLANGE SEALS

Cup and flange seals are dynamic seals, and are made of leather, synthetic rubber, plastics, and other material. Surfaces are sealed by the expansion of the "lip" or beveled edges. They are used in pistons and on piston rods.

MECHANICAL SEALS

These seals are designed to eliminate some of the problems attached to using chevron packing for rotating shafts. They are dynamic seals, made of metal and rubber, usually. Sometimes the rotating portion of the seal is made of carbon, "backed up" with steel.

The seal (Illust. 43) consists of a fixed member (stationary seal) attached to the housing against which a rotating member attached to the shaft revolves. A spring holds the two parts of the seal tightly together. A rubber ring (flange-shaped) or diaphragm is usually included to permit lateral flexibility, and to keep the rotating part of the seal in motion.

METALLIC SEALS

Metallic seals used on pistons and piston rods are very similar to the piston rings used in automotive engines. They may be either expanding or non-expanding. They are dynamic seals, and are usually made of steel.

Unless extremely close tolerances are observed, non-expanding seals are subject to considerable leakage. Expanding seals (for use on pistons) and contracting seals (for use on piston rods) are subject to moderate friction and leakage losses.

Metallic seals are therefore used where economy is a very important factor in the design. Precision metallic seals, however, are not so badly subject to leakage, and are especially well adapted for use in extremely high temperatures.

Since metallic seals of all kinds are more subject to leakage than others, fluid wiper seals in connection with external drains to the reservoir, are often used.

COMPRESSION PACKING

Compression packing (jam packing) is used in dynamic applications, and is made of plastics, asbestos cloth, rubber laminated cotton, fibrous or plastic cores with metallic foil jackets, and vulcanized fibrous binders which are impregnated with grease, graphite, asbestos or metal particles.

It is used for the same purposes, and in much the same manner as "U" and "V"-packings. It comes as coils, and as endless rings sized to fit, from which properly sized pieces may be cut.

Generally, compression packing is suitable for the lower pressures. Lubrication of this type packing is extremely important, as scoring of moving parts will result if it is allowed to run dry.

COMPRESSION GASKETS

Gaskets are suitable, of course, only for static applications, such as assembly of couplings in hydraulic lines, parts of the body of pumps, valves, cylinders, and for sealing covers, etc., on hydraulic reservoirs. A gasketed joint is sealed by the molding of the gasket material into the imperfections of the mating surfaces of the joint.

Gaskets are made of many materials, both metallic and non-metallic, and of course, come in hundreds of shapes.

HYDRAULIC LINES AND FITTINGS

No hydraulic system can be expected to operate without proper connections for moving the fluid between the various units of the system. Hydraulic lines must be designed and installed with the same care applied to the other parts of the system. They should be leakproof and strong enough to stand the maximum pressure, temperature, and vibration of the system involved. They should not be constructed of materials, or designed in a way, that will cause restriction of flow and turbulence.

They should be large enough to carry the maximum pump output without excessive friction losses or turbulence. They should be as short as possible and have as few bends as possible. Hydraulic lines may be of piping, tubing or flexible hose.

PIPING AND TUBING

Piping is usually measured according to its inside diameter, and tubing, by its outside diameter, although there are exceptions to this rule. Choice between piping or tubing and associated fittings is a design decision. Galvanized pipe should never be used, as it is likely to "flake," and these metal chips will cause serious damage.

When installing piping or tubing, make sure the inside is bright and clean. Try to have each segment continuous, and where bends are necessary, they must not be too sharp. The bending radius is ideally not less than three times the I.D. of the tube.

Piping and tubing must be adequately supported to minimize vibration. Vibration, if not compensated for, can set up stresses in the metal which will cause it to rupture.

Copper has been extensively used in the past for hydraulic lines, but its use is diminishing—steel and standard iron pipe is more practical in today's systems.

FLEXIBLE HOSE

Flexible hose is used where the parts connected to each other by the hose must have freedom to move. It is made of synthetic rubber, steel, and sometimes cotton cords in layers. See Illust. 44.
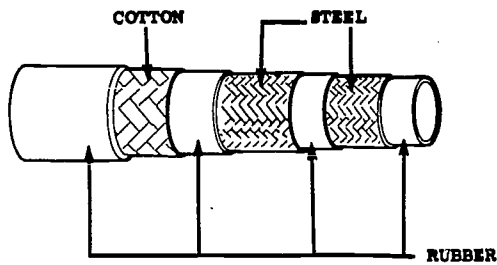
Illust. 44—Cutaway hydraulic hose.

In use, hose should be installed so that no twist of any kind or sharp bends are present. Bending radius should not be less than six times the inside diameter. Also, enough slack should be provided for changes in distance from one part to another, and for changes in relative motion.
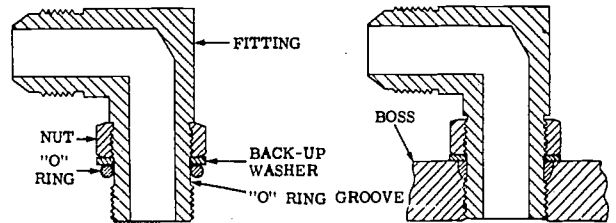
FITTINGS

Good high pressure fittings are fabricated or forged, and are either threaded or flanged for use with piping, or of the compression type for use with tubing. Compression fittings may be of flared or flareless (bite-type) design. (Illust. 45). Due to possibility of leakage, threaded connections are avoided as much as

possible. When they are used, they are often of the boss type, with an O-ring seal. (Illust. 46). Threads must be cut clean and smooth and a protective compound should be used to help seal the threads and protect them from corrosion. Brass fittings do not always require use of a protective compound.

Illust. 46—Boss type hydraulic fitting with an O-ring.

Flanged fittings may be either threaded to the pipe ends or welded. Gaskets of softer material are often used to make a better seal. Fittings with restricted or stepped-up passages should not be used, as they create restriction and turbulence, thereby causing friction losses. Manufacturer's recommendations regarding tubing, hose, fittings, and the use of protective compound during assembly must be followed.
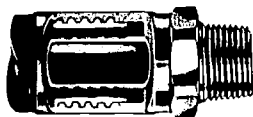
SLEEVE COUPLING FOR FLEXIBLE HOSE
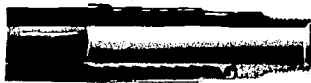
FLEXIBLE HOSE COUPLING
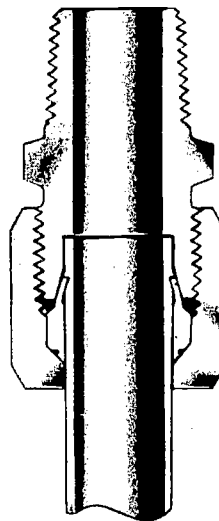
FLARELESS (BITE-TYPE) COUPLING
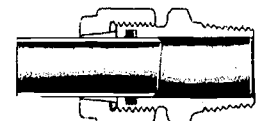
O-RING SEALED FLARELESS TYPE

THREADED COUPLING FOR FLARED TUBING

Illust. 45—Various hydraulic line fittings.

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ACCESSORIES

Several accessories are found in many hydraulic systems. Of these, only two are of great importance in farm and industrial equipment hydraulics.

The heat exchanger, or fluid cooler, is used to remove heat caused by rapidly moving pressurized fluid. This is often necessary to keep the viscosity of the fluid at an operable level, and to keep the temperature of the fluid from reaching a point injurious to the components, especially seals. Also, excessive heat contributes to fluid deterioration.

Coolers are made in separate units which consist of tubes or places in a metal housing through which cooling water circulates. Baffles break up the flow of fluid to provide more cooling surface (Illust. 47). A by-pass line should be provided to prevent excessive build-up of pressure if the cooler becomes clogged.

Coolers may be located in either the return or suction line. It may be a separate system, drawing hot fluid from the reservoir, and returning cool fluid to the reservoir.

The other accessory of importance in this discussion is the filter. Filters or strainers are necessary in modern, precision-fit hydraulic systems. The presence of relatively fine abrasive particles can be very harmful to the system.

Many contaminants harmful to a system will "settle out" in the reservoir, and will then be removed during subsequent cleaning of the reservoir. A wire mesh strainer on the pump intake will often take care of any remaining contaminants.

Where contaminants are still present after these means are applied, one of the following three methods may be employed:

1. Continuous filtration of *all* the fluid by flow through a filter.

2. Continuous flow of *part* of the fluid through a filter.

3. Removing the fluid from the system,
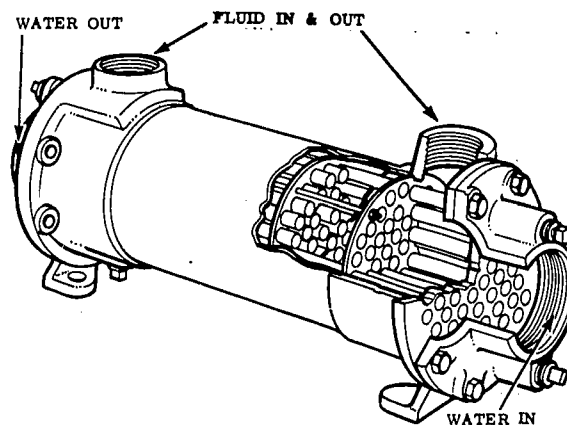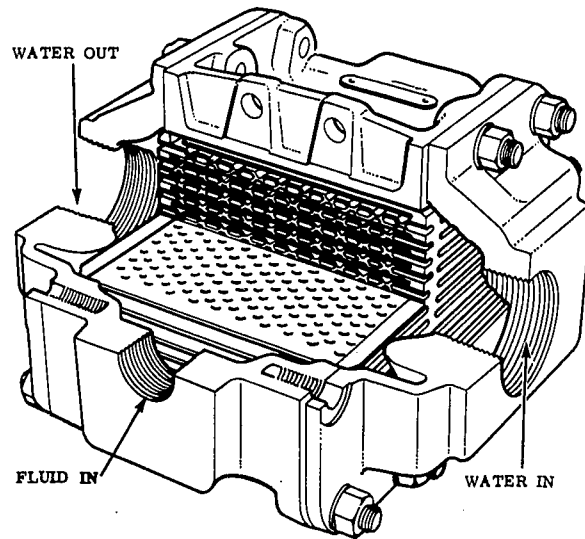
Illust. 47—Cutaway fluid coolers.

purifying it, and returning it to the system.

The last method is not practical in farm and industrial equipment hydraulics, because of the relatively small amount of fluid used in these systems, since the equipment for purifying fluid is rather expensive.

Filters are of three types: mechanical, absorbent, and adsorbent. Mechanical filters contain fine wire mesh, closely stacked metal discs or cloth in the form of a bag. They will remove the relatively large contaminating particles.

Absorbent filters contain porous materials such as cloth, paper, cotton waste, etc. They will remove all contaminating particles, but not products of fluid deterioration.

Adsorbent filters contain chemically treated paper or waste, charcoal, fuller's earth, activated clay, etc., which remove impurities by chemical action. They remove all contaminating particles, and some of the soluble contaminants. Because they also will remove some of the desirable additives in hydraulic fluid, they are not often recommended for hydraulic systems.

Filters may be installed so that they will filter all of the fluid, or only part of it. The latter method is usually preferred, as complete clogging of the filter will not cause stopping of fluid flow. Filters may be mounted so that a "bleed-off" from either the pressure line or return line is filtered or so that fluid passing through the relief valve is filtered. Placement is a design consideration, so detailed information on placement is not within the scope of this manual.

Proper servicing of filters is very important. Mechanical filters must be cleaned at recommended intervals. Absorbent filter "cartridges" must be replaced when necessary. With tolerances and clearances in hydraulic systems getting more and more critical, proper maintenance of the filters and strainers in any hydraulic system is becoming vital. Manufacturer's instructions *must* be followed.

PHENOMENA

There are certain easily misunderstood scientific facts which are responsible for some of the breakdowns in hydraulic systems that have been difficult to discover, explain or overcome.

RUPTURED LINE OR EXPLODED CYLINDER IN SYSTEM AT REST

There are two basic reasons for the rupture of hose or cylinders in a system not in use. One is simply thermal expansion, which is fluid expanding in the system due to an increase in outside temperatures. Depending on many variable conditions, one degree rise in outside temperature may cause an increase in pressure of approximately 50 to 60 psi in a tightly blocked system.

Unless there is some external leakage in the system, if there is no air in the system, and the fluid is held in one part of the system by check valves, a given increase in temperature may cause some part of the "blocked off" section of the system to rupture. There is only so much room in the cylinder and lines for fluid, and even though fluid is nearly incompressible, if it expands even minutely due to

heat, an escape hatch must be provided, or breakage will occur.

A thermal safety valve is one method used to combat this problem. Another is for the operator to be sure that the system is not left in a "blocked off" position any time that it is at rest. Cylinders should be drained before being put into storage.

The second reason for rupturing in a system at rest is internal leaking of pressure from the piston head end of the cylinder to the piston rod end of the cylinder. (Illust. 48) In this example, 1000 psi is required to hold the implement up. If there were no internal leakage, the pressure at "A" would be at 1000 lb. and the pressure at "B" would be at return line pressure, or perhaps no pressure. Since, in this case, there *is* internal leakage and the system is positively blocked, pressure will transfer past the piston head until a hydraulic "balance" between "A" and "B" is reached. There will be very little, if any, movement of the piston rod in the cylinder. Because of the leakage past the piston head, the system behaves as though the piston head did not exist. The area of the piston rod cross-section,
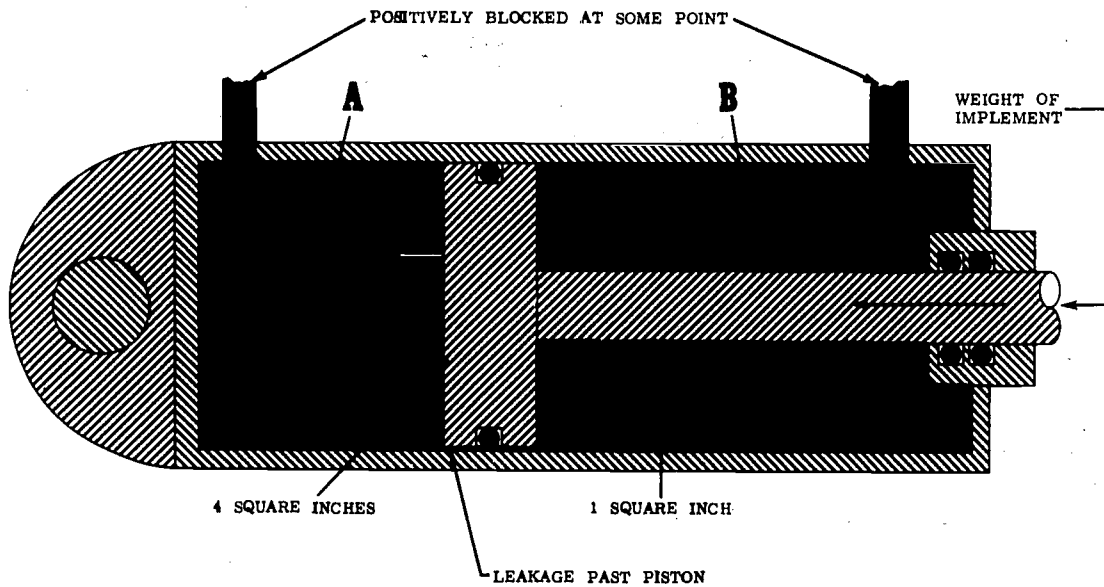
Illust. 48—Effect of faulty piston seal.

therefore, is all that will hold the implement up.

Since the four square inch piston head requires 1000 psi to hold the implement up, the one square inch rod will require 4000 psi to hold it up. This is a simple application of Pascal's law.

Since a system of this sort is ordinarily designed for 2500 to 3000 psi maximum pressure, it is obvious that the fluid will find an escape somewhere in the system, usually by rupturing a hose, although the cylinder could explode, or external seals could break.

A thermal safety valve will often prevent this type of breakdown. The best way, however, of preventing this occurrence is to *always* leave the implement "down" when parking it, whether it's attached to the tractor or not. *This should be emphasized to customers and operators.*

Internal leaks that do not affect operation can, and often do, cause this type of breakdown.

COLLAPSED SUCTION HOSE

Another type of breakdown, seemingly simple, is the collapsed suction hose. It is entirely possible, even probable, that the inner layer of rubber of the suction hose will, when it starts to deteriorate, collapse inward, completely sealing off flow, without showing any symptoms of collapse externally.

A noisy pump, lack of pressure, "spongy" action, or no action at all are indications of a collapsed suction tube, among other things.

PRESSURE DROP CAUSED BY FRICTION LOSSES

Another scientific factor, often misunderstood, which sometimes leads to improper operation, is that of pressure and volume drop caused by friction losses. Every component of any hydraulic system, except the pump itself, causes friction loss in the moving fluid. These friction losses show up in the system mostly in the form of heat.

It is not the purpose of this manual to go into design features, and the subject of friction loss is mostly a designer's responsibility. However, sometimes it is necessary to add hydraulic components to a system for an added implement, or to obtain certain specific responses. In this case, it is advisable for the serviceman and the dealer to know that fric-

tion losses may impair operation. It may be necessary to add a larger pump, larger lines, or different valving in order to overcome friction losses, when other components are added to an existing system, in order to obtain proper operation.

Recommended line diameter must be known and proper lines used in any application.

EFFECT OF USING WRONG SIZE PUMP IN SYSTEM

Since pumps are usually spoken of in terms of G.P.M. or gallons per minute, the term G.P.M. will be used in this discussion. Any serviceman can see that the use of a pump too small in G.P.M. will lead to improper operation.

However, it is also possible to have inoperable conditions with too large a pump. Substituting a larger pump in a given system will, first of all, create greatly increased friction losses. These losses do not increase in direct proportion, so the multiple increase in percentage loss at each point may result in such low pressure and volume at the point of usage as to make the system inoperable. All this additional friction loss will appear in the form of increased heat, in itself a danger to proper operation, as well as to the components, especially the seals, in a system.

In some systems that use hydraulically actuated detent mechanisms, the momentary excessive pressure rise may cause premature unlatching. Other types of malfunction can result from using a pump with too high a G.P.M. rating, such as primary power loss, increased "back" pressure, and increased turbulence in the pump.

Taking these factors into consideration, it is obvious that the recommended pump must be used in a given system, unless an increase in components or number of uses forces the use of a larger pump. In case a larger pump must be added to a system, it may be necessary to increase the size of lines and valves.

THE EFFECT OF "HAMMER" IN A SYSTEM

Everyone has noticed the banging noise that results when a valve is closed suddenly. This effect is called "fluid hammer" and will take place in any system involving moving fluid wherein the fluid flow is suddenly stopped. This effect is not always audible, but it is present.

Hammer, if allowed to continue, can cause rupture of parts in a system, especially by setting up "metal fatigue," so, when it is noticed, an investigation should be made immediately to determine its cause. It is usually overcome in hydraulic systems by slotting valves, using pilot valves to open larger ones, and by "cushioning" the end of a piston stroke or valve closing. Operating the system at higher than recommended pressure will increase the likelihood of hammering. Overcoming hammer is mostly a matter of design.

SYSTEMS

In order to be able to fully understand the application of hydraulics to equipment, it is necessary to understand what is meant by the descriptive terms applied to various kinds of hydraulic systems.

Four components are all that are necessary to have a workable hydraulic system — a reservoir, a pump, a valve, and a motor (cylinder). Review the Basic System Section in the "Introduction" for more detailed information on a basic circuit. The system in the

Introductory section uses a rotary type directional valve, while in most farm and industrial applications, the spool type directional valve is more popular.

Descriptive titles for the various systems discussed in the following text are based on the type of valving used, or its operation, since it would hardly be possible to differentiate the *type* of system by basing its name upon the kind of pump or cylinder used.

BLOCKED RETURN LINE SYSTEM

The first to be discussed is the blocked return line system. (Illust. 49) It uses a lever operated check valve, and will operate a single acting cylinder only. In this system, as the control handle is moved to the right (lift) position, the return to the reservoir (A) is blocked, forcing fluid through the check valve (B) and on to the cylinder. To lower, the
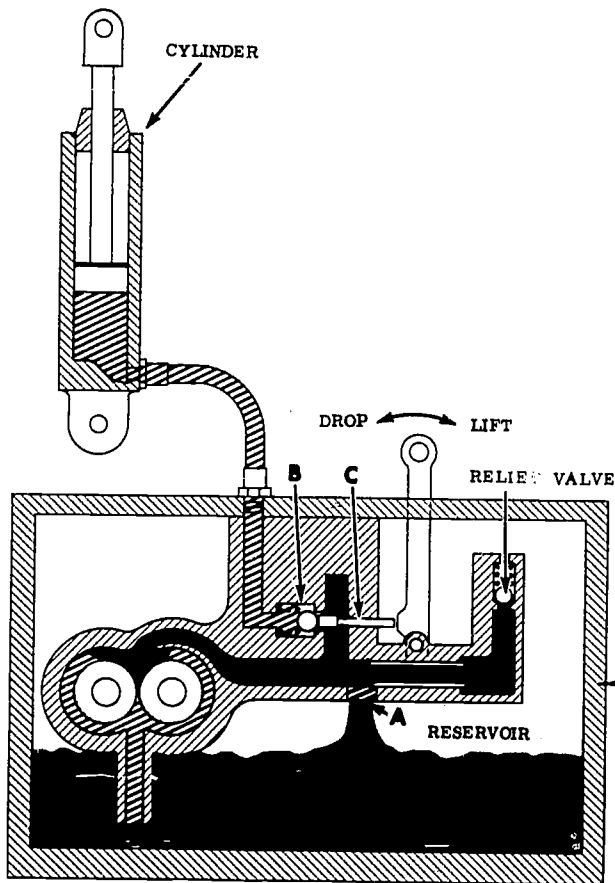
control handle is moved to the left (drop) position, causing the lever (C) to upset the check valve, and allowing the fluid to return to the reservoir as the cylinder piston returns to its home position by gravity.

BASIC OPEN CENTER SYSTEM

The basic open center system (Illust. 50) uses a three or four-way, open center spool valve. The fact that the illustration has drilled passages should not be allowed to confuse the issue—it could have slotted lands or solid lands—it's still a four-way open center spool valve.
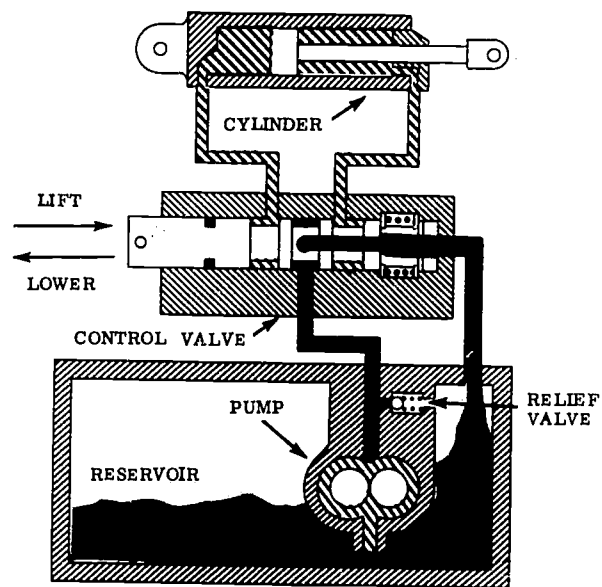
Illust. 50—Basic open center system in the neutral position.

In this system, in the neutral position, the cylinder ports are closed off, and pump flow is directed to the reservoir. Also, in this system, double acting cylinder operation is possible. Action of this valve is described under "Spool Valves" in the valve section of this manual.

TANDEM OPEN CENTER SYSTEM

In this system (Illust. 51) two or more open center spool valves are "stacked" so that the return port of the first valve discharges into the supply port of the second, and so on down the line.
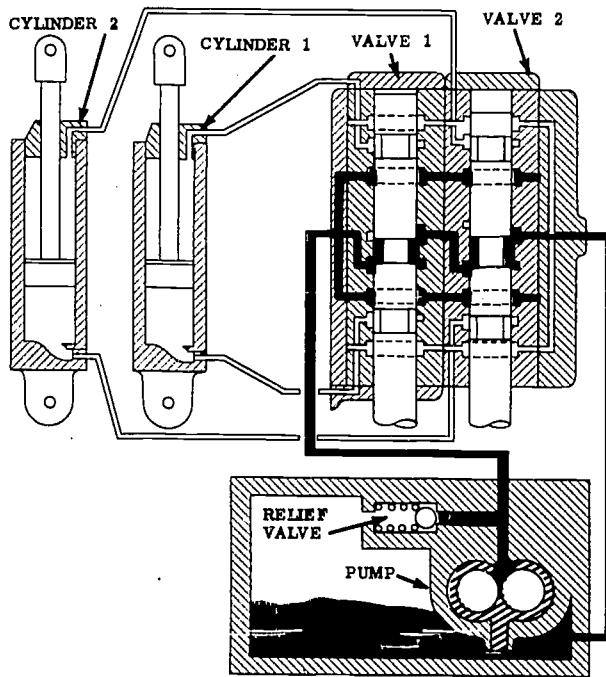
Illust. 51—Tandem open center system in the neutral position.
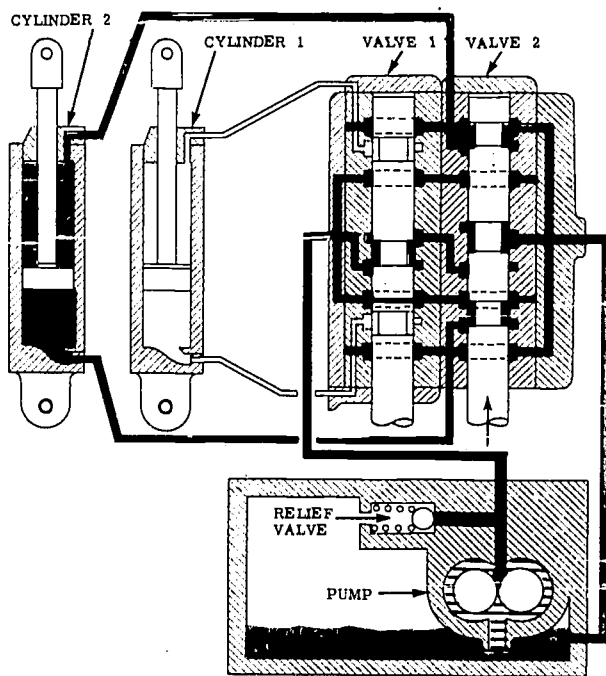
Illust. 52—Tandem open center system with valve 2 activated.

By activating one of the valves in this system, flow will be more easily understood. (Illust. 52) Note that if the first valve had been activated, there will still be flow from the pump to the second one.

This makes it possible to activate two valves at once, but the cylinder with the lightest load will move first—to the end of its stroke—before the more heavily loaded one moves.

THROUGH FLOW SYSTEM

The through-flow system (Illust. 53) may be considered an adaptation of the open center system. In this type of system, the high pressure line is taken through, or past, the first valve block to another open center valve block.

The first valve block is called a "through-flow" or "power beyond" valve. This type of installation is often used when adding another open center valve (or set of valves) to an existing system.
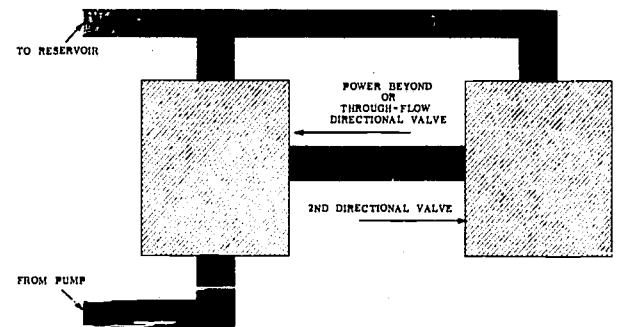
Illust. 53—Through flow system.

CLOSED CENTER SYSTEM

A closed center system employs closed center spool valves, and uses a pressure regulating device to relieve pump pressure when the valve (or valves) is in the neutral position. A familiar variation of the closed center system is the pilot regulated system.

In this system, the directional control valve is a closed center type with all ports blocked in the neutral position. See Illust. 28.

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With all the ports blocked, there is of course, no place for pump delivery to go except through a second unit which is brought into play by the position of the control valve. This second unit, or pressure regulating valve, maintains the system on either high pressure or by-pass pressure. In the neutral position, the small regulator port (A) is closed, so back pressure develops at (B), forcing this valve open, and allowing fluid to flow to the reservoir at low, or by-pass, pressure.

When this port is open, the fluid from the regulator line flows to the return line. The pressure then drops at (B), allowing the valve to close, thus building high pressure in the system.

Other systems are employed, of course, but these are the main types presently used in farm and industrial equipment.

It is sometimes desirable (or necessary) to use combinations of the above systems.

Illust. 54—Pilot regulated system in the neutral position.

HYDRAULIC MOTORS

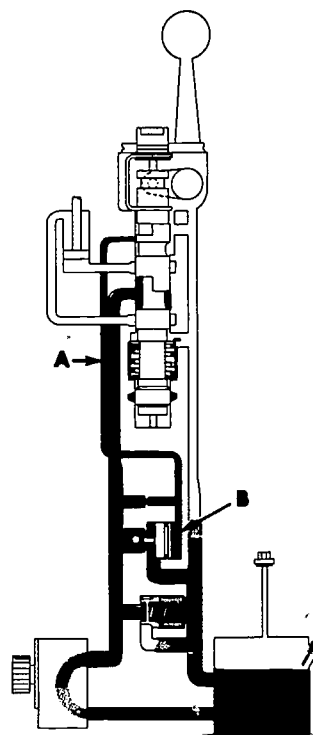Any device which turns hydraulic pressure into usable mechanical force may be considered a motor. Hydraulic cylinders, already covered, are a form of motor. Theoretically any hydraulic pump (except centrifugal) may be used as a motor. Various refinements are necessary, however, to enable any of these pumps to be used as a motor.

In actual use, rotary hydraulic motors are of four types—gear, vane, radial piston and axial piston.

Gear motors can be either the spur gear type or the internal gear or gerotor type. Gear motors must be of hydraulically balanced design.

Vane motors, like the gear type, must be of hydraulically balanced design (see Vane Pumps for explanation) in order to operate properly. The vanes are usually spring-loaded to hold them against their housing.

Radial and axial piston motors are usually used in connection with radial or axial piston pumps. With a variable delivery pump, this combination allows an infinite variety of speeds. By tilting the slide block of the pump past "zero" delivery, it is even possible to obtain reverse rotation of the motor while the pump continues to turn at a constant speed, in the same direction.

Pressures developed in any pump-motor combination are dependent upon the load on the motor. If the design characteristics of the pump and/or motor are exceeded, the system will "lock."

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HYDRAULIC TRANSMISSIONS

Hydraulic transmissions are simply a means for transferring power from a power source to a driven element. The actual delivery of power is by means of fluid under pressure (hydrostatic transmission) or fluid in motion (hydrodynamic transmission) instead of through gears, belts, or other mechanical methods. Advantages of hydraulic transmissions are:

1. Simplicity of design and lower space and weight requirements in many applications.

2. Fast, simple and infinite speed adjustment with power source operating at a constant (most efficient) speed.

3. Fast, smooth acceleration and deceleration.

4. Smooth reversal of motion.

5. Reduction of shock loads to either power source or driven element.

Hydraulic transmissions are of two general types: Hydrostatic and Hydrodynamic.

HYDROSTATIC TRANSMISSIONS

Hydrostatic transmissions combine positive displacement pumps with positive displacement motors—usually both pumps and motors are of the external or internal gear, vane, axial piston or radial piston types. Some of the possible combinations are:

1. Constant delivery pump with constant displacement motor—constant horsepower at constant torque, unless a variable flow control valve is added to the system in order to vary pump delivery, which would give, in effect, variable horsepower.

2. Variable delivery pump with constant displacement motor—variable horsepower at constant torque.

3. Constant delivery pumps with variable displacement motor—constant horsepower at variable torque.

4. Variable delivery pump with variable displacement motor — variable horsepower and variable torque.

Usually, both pump and motor will be enclosed in a common housing, with a built-in reservoir, and with appropriate porting and valving.

HYDRODYNAMIC TRANSMISSIONS

Hydrodynamic transmissions use the energy of fluid in motion to transfer power to a driven element. A centrifugal type pump (impeller) sets the fluid in motion; the moving fluid drives the blades of the driven member (runner) in the same direction. Hydrodynamic transmissions are of two types: hydraulic couplings and torque converters.

HYDRAULIC COUPLINGS

Hydraulic couplings, sometimes called fluid clutches, hydraulic clutches, or fluid drives, can be either constant or variable speed delivery. Variable speed is accomplished by varying the amount of fluid allowed in the circuit. Illustration 55 shows the operating principle of hydraulic couplings.

In this type of hydrodynamic transmission, torque output equals torque input, but speed output is lower, because of friction, and "slip," which is simply loss of motion of fluid internally. The greater the "slip" the greater the power loss in the coupling.

In automotive applications, a fluid flywheel (hydraulic coupling) together with an automatic device for shifting gears, makes up the automatic transmission, allowing smooth acceleration without manual clutching or gear shifting.

TORQUE CONVERTERS

The torque converter (Illust. 56) resembles the hydraulic coupling except that it contains a stationary section, called the stator, which multiplies the torque delivered by the power source. In torque converters, torque output is *greater* than torque input, but speed output, again, is lower. It is used in automotive and

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other applications to permit the power source to operate continuously at its most efficient speed, while selecting automatically the proper output torque for any load.

4. this driven member. Here the fluid's direction of flow is again changed and it flows back to the driving member.

5. In effect, fluid swirl thus formed is an "endless corkscrew of fluid" that moves simultaneously in several directions: it spins as shown by the arrows and also rotates about the axis of the coupling.

3. but this curvature causes fluid to make a turn and flow toward. . .

2. centrifugal force causes fluid to flow toward the circumference at right angles to the axis of rotation. . .

1. As this driving member rotates. . .

Illust. 55—Operating principle of the hydraulic coupling.

4. this set of stator blades changes the direction of fluid flow and feeds fluid to the second set of rotor blades. After second reversal and use of most of remaining energy in third set of rotor blades. . .

3. this set of rotor blades, which use some of the energy in the flowing fluid. Then. . .

5. fluid, with most of its energy spent, flows out here and returns to intake side of pump, and thus. . .

2. this centrifugal pump. As pump rotates, fluid flows toward. . .

6. this shaft turns at a lower speed with a higher torque.

Return Line

Turbine. Designed to run at lower speed than pump.

1. This shaft, driven at relatively high speed and low torque, drives. . .

Illust. 56—Operating principle of the torque converter.

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HYDRAULIC FLUIDS

The purpose of this section of the manual is *not* to describe how to select a hydraulic fluid. This section will merely give the important qualities of a hydraulic fluid, and will serve to emphasize the importance of using the fluids recommended by the manufacturer of the equipment being serviced.

In connection with this discussion, it should be explained that the word fluid as used in this section means oil *with additives*. Oil is a misleading term, as it gives no indication that anything has been added to improve it for hydraulic use, so "fluid" is the word used to indicate that plain oil is not good enough for hydraulic use, generally.

FUNCTIONS OF HYDRAULIC FLUID

First of all, of course, it must be capable of transmitting the power applied to it. It must lubricate the internal moving parts. In many cases, the fluid acts as a sealing medium.

Furthermore, it should be capable of holding its viscosity through a wide temperature range. It should resist oxidation, must protect machine parts against rust and corrosion and should be capable of separating air and water from itself quickly.

VISCOSITY

Viscosity is the measurement of the resistance to flow of a fluid, and is the most important property of any hydraulic fluid. Fluid used must have the correct viscosity at operating temperature, and must have the ability to readily flow to the various parts of the system at the desired rate. Viscosity also has a definite influence on correct lubrication of the moving parts.

Proper viscosity is a balance between (1) a fluid with a high enough viscosity to hold wear to a minimum and reduce internal leakage and, (2) low enough viscosity to permit the fluid to flow readily through the system.

VISCOSITY INDEX

Viscosity of fluids change with temperature. Viscosity changes more in some fluids than in others. Viscosity index is simply a measurement of the rate of change of viscosity over a certain range of temperature. If a fluid becomes thick at low temperatures, and very thin at high temperatures, it has a *low* viscosity index (V.I.). However, if the viscosity remains relatively the same at varying temperatures, it has a high V.I.

From the earlier discussion of the importance of viscosity, it is obvious that, if a given system operates at varying temperatures, a fluid with a high V.I. is desirable. Of course, if a system has nearly the same operating temperature at all times, then the fluid need not have a high V.I. In very few systems can the consideration of V.I. be eliminated, and it is always considered in deciding upon fluid recommendations.

OXIDATION RESISTANCE

Hydraulic fluids, especially in hard service, are likely to combine with oxygen, which leads to decomposition. This chemical combination forms organic acids, which are harmful to the metal parts and many types of seals and packing in the system. This alone may shorten machine life.

Oxygen also combines with fluid to form sludge. This action is multiplied by the presence of water, high temperatures, and some metals used in hydraulic systems. Conditions found in many systems are ideal for hastening oxidation and sludge formation, as a result of contact with air and/or water. Other contaminants, such as dust, dirt, and metallic particles, will also speed up oxygen reaction, which is one reason filtering is so important.

Careful refinement and chemical additives are used to combat oxidation in hydraulic fluids.

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RUST AND CORROSION RESISTANCE

Rusting and corrosion differ in that rusting *adds to* the metal (oxygen fuses with the base metal, making the part larger). Corrosion, however, is an *eating away* of the base metal.

Corrosion, of course, effects the closeness of fit of parts, permitting excessive leakage and causing erratic action. Rusting will effect the smoothness of operation, and the loose chips of rust will cause wear.

To prevent rusting and corrosion, technologists have developed additives which keep these harmful effects to a minimum.

OILINESS

Because of the precision fit of most hydraulic components, only a very thin film of fluid is available to provide lubrication of these parts. To provide this lubrication, the fluid must have good oiliness characteristics. Oiliness is simply a term indicating the ability of a fluid to hold friction between parts to a minimum, and may be further defined as its ability to "stick" to closely fitted, warm parts.

Lubricating ability becomes doubly important when the hydraulic fluid is also expected to lubricate other moving parts in a machine. An example of this is when the rear frame of a tractor is a common sump for the hydraulic system, transmission and final drive. Here, the same fluid that operates the hydraulic system serves to lubricate the transmission and final drive.

WATER SEPARATION

It is practically impossible to keep all water out of a hydraulic system, so it is necessary for the fluid to be able to rid itself of the water quickly.

Popular opinion notwithstanding, oil and water *will* mix, forming an emulsion, which leads to the formation of corrosive compounds. Also, emulsions often have a slimy, sticky, or pasty consistency which interferes with normal operation of valves and other components. Different fluids have varying ability to separate water, and recommended fluids are chosen with this consideration in mind.

FOAMING RESISTANCE

A frequent difficulty often encountered in the operation of hydraulics is the formation of foam in the fluid. This foam is formed by the constant pumping and churning action found in the system, or when the fluid level gets too low. In many systems, turbulence, which leads to the mixing of air with the fluid, is hard to avoid, and foaming becomes a serious problem.

Since the proper operation of any hydraulics system is based on the fact that fluids are basically incompressible, and foam *is* compressible, the formation of foam is a serious detriment to proper action.

Air that enters the system is soluble in fluid to a certain extent. As pressure and temperature increases, the capability of fluid to absorb air increases, but air in solution does not affect compressibility. When pressure is relieved, however, the air will appear as bubbles or foam. Also, if more air is trapped in the fluid than the fluid will absorb, foam will appear.

Foaming is particularly detrimental in fluid couplings and torque converters, as the foam will carry less impact energy than fluid with no air bubbles in it. Recommended fluids contain foam inhibitors to overcome this condition.

ANILINE POINT

Aniline point is the numerical index of a test made with aniline dyes. The aniline dyes used in the test will change color at certain temperatures in a given fluid. The resulting temperature index is called the aniline point of the particular fluid involved. This aniline point index indicates the effect of the fluid being tested upon the synthetic rubber used in seals. A high index indicates that the rubber will swell; low, that it will shrink. Aniline

point is, therefore, a very important consideration in the recommendation of hydraulic fluids.

OTHER PROPERTIES

Most of the following factors have no importance—they are mentioned only to overcome some common misconceptions regarding hydraulic fluids.

Pour point reflects the ability of fluid to flow at low temperatures. Its only importance lies in the fact that hydraulic fluid also lubricates the components of a system. It is necessary, therefore, that fluids used have a pour point corresponding to the lowest *starting* temperature of the system involved.

A.P.I. gravity is merely a way of stating the specific gravity of a fluid, and has very little importance in recommendations.

Color is used by refiners to maintain uniformity of product, and bears *no* relationship to fluid performance.

Flash point is a measurement of the point at which heated fluid vaporizes, and is of no importance except where hydraulic equipment is used in the vicinity of extremely high temperatures. It is used mainly by refiners as a product control.

Carbon residue is the amount of carbon remaining when fluid is subjected to destructive heating, and has no relation to either quality or performance of hydraulic fluids.

Acidity of fluid is a measurement of the amount of acid in it. It has no value in rating new fluids, but is often used in laboratories to help determine the degree of deterioration of fluids which have been in use.

Again, it is emphasized that all the important factors described above are considered in recommendations of fluid to be used, and these recommendations *must* be followed.

SYSTEM MAINTENANCE

Continuing, long term high efficiency of hydraulic systems is very dependent upon proper maintenance. One very important factor is the addition, when necessary, of *only* clean, fresh fluid of the recommended type.

STORAGE OF FLUID

An important factor in the maintenance of fluid is the manner in which it is stored. Illust. 57 shows both improper storage and the manner in which fluid *must* be stored in order to maintain its quality.

DRAIN SCHEDULE

Periodic draining of the entire system is of vital importance. This is the only way to remove contaminants, oxidized fluid, and injurious particles completely from the system.

A drain schedule, as recommended by the manufacturer of the equipment involved, must be maintained. The manufacturer will set forth the method to be used, and the frequency, depending on conditions.
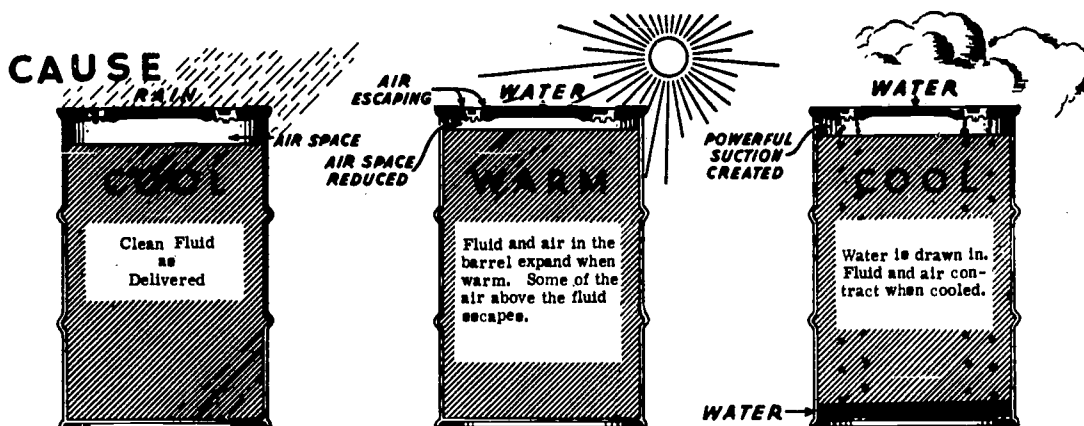
CLEANING THE SYSTEM

The cleaning procedure, when a regular draining schedule is followed, and no gum or lacquer formation is suspected, is very simple.

After the system is drained, solid sediment in the bottom of the reservoir should be removed, and filters must be cleaned or replaced. It may be advisable to flush out the residue of old fluid remaining in the system, especially if the fluid is badly contaminated. For this purpose, use some of the fluid recommended for the system involved. Finally, refill the system with clean fluid of the recommended type.

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If gums and lacquers have been allowed to form, because of neglect of draining schedule, or other reasons, and the components are not functioning properly, (sticky action) it is advisable to remove the parts affected and clean them thoroughly. When cleaning the disassembled parts, extreme care must be taken to prevent harm to closely fitted, finely finished parts. Use of gum solvent or other non-corrosive chemical cleaner is permissible on metal parts only. Do not allow these materials to come in contact with seals and packing. Cleansed parts should be thoroughly rinsed, and protected immediately with a coating of oil.

Most hydraulic systems will have with them on delivery an Operator's Manual or Preventive Maintenance Manual, or both. The recommendations given in these manuals for operation and care must be followed if efficient operation is expected.
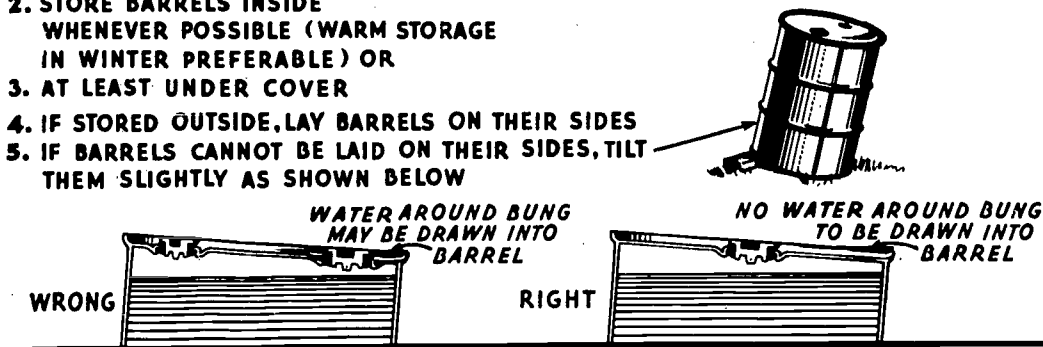
CAUSE

AIR ESCAPING — WATER — WATER

AIR SPACE
AIR SPACE REDUCED
POWERFUL SUCTION CREATED

COOL
Clean Fluid as Delivered

WARM
Fluid and air in the barrel expand when warm. Some of the air above the fluid escapes.

COOL
Water is drawn in. Fluid and air contract when cooled.

WATER→

PREVENTION

1. KEEP BUNGS DRAWN TIGHT

2. STORE BARRELS INSIDE WHENEVER POSSIBLE (WARM STORAGE IN WINTER PREFERABLE) OR
3. AT LEAST UNDER COVER
4. IF STORED OUTSIDE, LAY BARRELS ON THEIR SIDES
5. IF BARRELS CANNOT BE LAID ON THEIR SIDES, TILT THEM SLIGHTLY AS SHOWN BELOW

WATER AROUND BUNG MAY BE DRAWN INTO BARREL

NO WATER AROUND BUNG TO BE DRAWN INTO BARREL

WRONG   RIGHT

Illust. 57—Proper fluid storage principles.

TROUBLE SHOOTING

The following factors are responsible for most complaints of inefficient hydraulic operation:

1. Fluid drain periods not frequent enough.

2. Contamination by cutting or grinding abrasives, air, or water.

3. Air leaks.

4. Failure to use the recommended hydraulic fluid.

5. Packing, gaskets and seals faulty.

6. Inadequate understanding of the components of the hydraulic system.

Locating trouble in any hydraulic system is a job for a well-trained service man. He should be familiar with the equipment used, its construction, and its operation. He should know enough about hydraulic circuits and components to localize the trouble. He must have the proper tools, and he must use them.