Hydraulics Manual for Fishermen

Power Transmission Components

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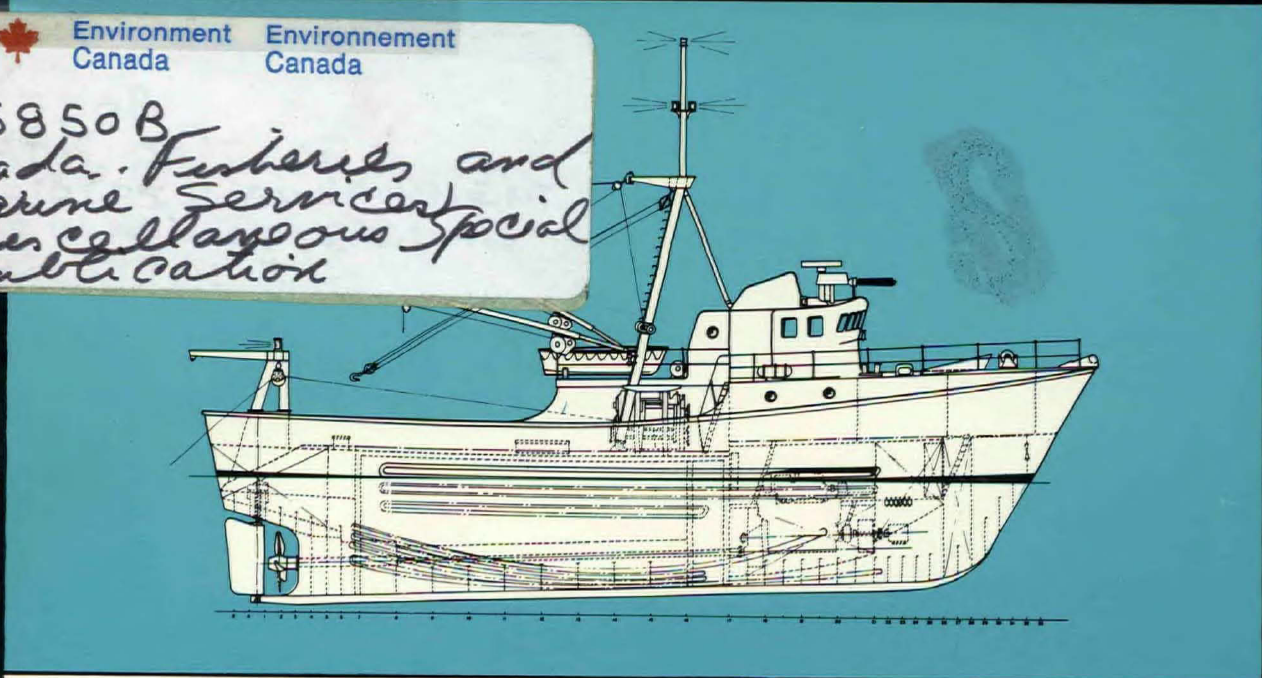

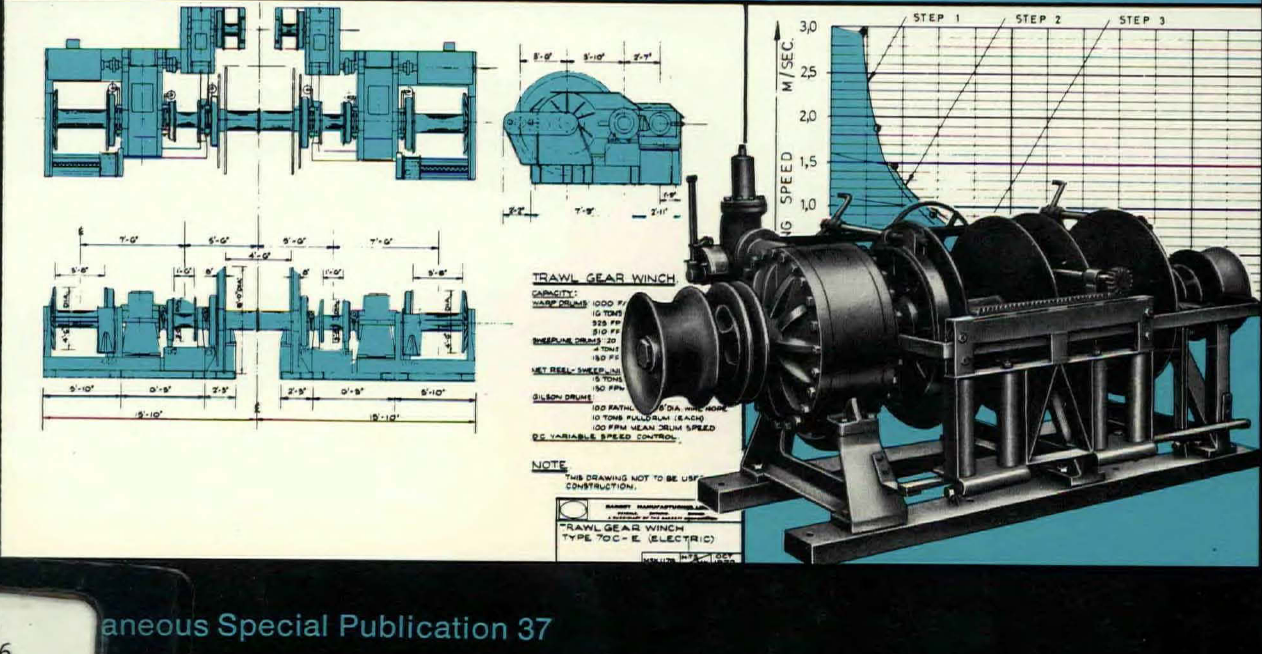

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Hydraulics Manual for Fishermen[1]

Booklet

2

Power Transmission Components

Department of Fisheries and the Environment
Fisheries and Marine Service
Fishermen's Services Branch
Ottawa, Canada K1A 0E6

DEPARTMENT OF FISHERIES AND THE ENVIRONMENT
FISHERIES AND MARINE SERVICE
Ottawa 1978

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FOREWORD

If the fisherman is to achieve a good standard of living he must obtain a good profit from his catch. He has little control over the number of fish available or the demand for his product; his expertise is catching fish. To do this efficiently it is necessary to have good but not necessarily the most expensive equipment. However, the equipment must be safe, efficient, reliable, durable, and economical. Deck machinery helps men handle nets and process fish and this machinery needs a source of power. Because the power must be transmitted, the prime mover and transmission have to be as reliable as the machinery. It is a common opinion that machines and prime movers are reliable but that the weak link is the transmission, particularly when it is hydraulic. There is some justification for this opinion because in the past many mistakes have been made in the design and installation of hydraulic transmissions. However, transmission of power by hydraulics is especially suited to the needs of deck machinery. Properly designed and installed it is safe and dependable, and is good enough for use in large aircraft. But to be successful, a hydraulic transmission must be designed, installed, and maintained by knowledgeable people.

This Manual consists of six separate Booklets. They outline the ideas, materials, and methods used to create a safe, efficient, and reliable hydraulic power transmission. Generally, the discussion of each topic is brief and, no doubt, some points are missed; however, the intention is to help the practical worker understand hydraulics. Although written mainly for mechanics, the Manual should also be of value to system designers and draftsmen because it emphasizes practical requirements. The mechanic must have some knowledge of the principles behind the design of hydraulic power transmissions, appreciate the great need for cleanliness inside the system, and the necessity to keep the operating temperature at a reasonable level. He should understand how the various components work, and how to carry out necessary troubleshooting and repair procedures. Special knowledge and skill are needed by the hydraulic systems mechanic and this Manual will supply some of that knowledge. Skill will be obtained when he applies this knowledge to his work.

Fishermen's Services Branch
Fisheries and Marine Service
Department of Fisheries and the Environment

1. INTRODUCTION

When power is transmitted by hydraulics, a liquid carries the power of an engine to the machine. The engine drives a pump that forces liquid through the pipes to an actuator; the actuator then converts the liquid power back to mechanical power suitable for driving the machine. However, hydraulic transmissions can do more than just transmit the brute power of an engine. Hydraulic transmissions can give fingertip control to the operator of a winch or other equipment where power requirements may vary from 1 to 200 HP or more. To give such fine control, the hydraulic actuator's speed and effort (or torque) must be controlled and, to do this, components are needed to regulate the liquid flow and pressure. The liquid, the actuator, the pump, and the liquid control components can be considered a group because they are the essential components in the system that convert mechanical power into liquid power and back to mechanical power. In addition to these power transmission components, a practical hydraulic system needs a reservoir and piping to hold the liquid, a filter to keep the liquid clean, and often a cooler to keep it cool. These components can be considered a group and called liquid conditioning components because they determine the quality of the liquid.

In this Booklet power-transmitting components for a practical hydraulic system will be discussed. Liquid conditioning components will be considered in Booklet 3.

2. CONSTRUCTION OF POWER TRANSMISSION COMPONENTS

The pump, control valves, and actuator are mechanical devices. They often work at pressures up to 5000 pounds per square inch (psi) and, because of this, are of rugged construction. The casings of components are made from high-strength aluminum alloys, cast iron, or steel. The moving parts inside are made from hardened steel. If a component is to work freely there must be clearance around the moving parts, but as operating pressures increase the running clearances have to be carefully controlled to prevent excessive leakage. There are two methods of preventing high-pressure liquid from leaking; by using soft seals or piston rings that take up all the clearance between parts, and by using seals that make the clearances between moving parts as small as possible. The soft seals are used mainly on large or slow-moving parts. The small clearance type of seal is used on small and fast-moving parts. The idea is to obtain as close a fit as possible without causing the parts to bind. For example, the clearance gap around a 1-inch (in.) diameter plunger in a control valve would not be more than .0005 in. (half a thousandth of an inch). That doesn't seem very large, but compared with clearances in ball or roller antifriction bearings and heavily loaded plain journal bearings, which can be as small as .00002 in. (20 millionths of an inch), it is large, yet these are typical clearances found in modern, high-performance hydraulic power components. Obviously the components in this equipment must be assembled with care and precision, yet properly installed they are as robust as a bulldozer.

3. LEAKAGE

It is understandable and expected that leakage occurs in hydraulic power components but there is no need for any leakage to get on a deck. There are two types of leakage. One is internal and the other is external.

The leakage that occurs when liquid escapes from high-pressure spaces to low-pressure spaces in a component is known as *internal leakage.* This leakage lubricates moving parts and is discussed in Section 2. The liquid is pressurized to overcome the actuator load, but power is wasted if the liquid leaks back to a low-pressure portion of the system without first working on the actuator. When oil leaks through clearances inside the component it gets hot and heats up the component and the system. This heating effect can be demonstrated by gradually closing off the outlet flow of a running pump with a throttle valve. The pressure of the liquid rises as the valve is closed, but as the liquid passes through the valve the pressure drops and the liquid and valve become hot.

External leakage comes from worn seals and badly made joints and can drip on the deck. It drips off components, is messy, hazardous, and completely wasteful. External leakage is unnecessary and should not be tolerated because it can be prevented by good workmanship.

4. PRACTICAL HYDRAULIC LIQUID

Transmission of power by hydraulics depends on the use of properties common to all liquids. They flow easily and are incompressible, but not all liquids are suitable for use in today's high-performance equipment. Pumps, control valves, and actuators work at high speeds and loads. They are mechanical devices that need proper lubrication and have to be kept cool. They must work with a liquid that inhibits corrosion and retains its high quality for a long time, in spite of wear and tear.

4.1 What is Wrong With Water?

Much progress has been made since man first realized force and motion could be transmitted by water, the most convenient liquid. The invention of tools such as the water lift pump and hydraulic jack paved the way for the design of components capable of transmitting high powers by means of liquids. As the pressure and operating speeds increased, water became impractical and a more suitable liquid had to be found. The advantages of water as a hydraulic liquid are: it is readily available, a good coolant, safe to use, and does not cause pollution. Its main disadvantages are: it is a very poor lubricant, it is corrosive, and it is generally too thin or runny and leaks easily through the smallest clearance in a component.

4.2 Hydraulic Oil

The liquid most commonly used in today's hydraulic power systems is a mineral base oil. It has the best combination of qualities desirable in a hydraulic liquid. It is a good lubricant, it does not corrode metal parts, and it does not leak as readily as water.

Oil can be obtained in various thickness grades. The thickness of an oil is an indication of its viscosity or reluctance to flow. Thick oil has a high viscosity and a thin oil a low viscosity. Lubricating oils are graded by the Society of Automotive Engineers (SAE) and the type most suitable for hydraulic power systems is a number 10 or 20 oil, which is approximately the grade used in the crankcase of an automobile engine. Automobile crankcase oil is widely used in hydraulic systems but is not usually the best choice. Less expensive oils, specially manufactured for hydraulic systems, are readily available. They contain certain additives to protect iron and steel components from rusting and to fight oxidation of the oil. These are called "R" and "O" hydraulic oils.

4.2.1 Antirust Additive Normally rust does not form in a system filled with lubricating oil, but small amounts of water often become trapped in the oil and can corrode internal surfaces. The antirust additive helps oil to cling much tighter to the surface of metal parts and gives them better protection.

4.2.2 Oxidation When oil is heated and comes in contact with certain metals such as copper, or is mixed with the oxygen in air or water, it gradually breaks down, loses its lubricating qualities, and starts to create varnish and sludge. In this condition, oil is unsuitable as a power-transmitting liquid and must be replaced with fresh oil. The antioxidation additive slows down this process and increases the useful life of the oil many times compared with that of untreated oil.

4.2.3 Antiwear Additive Component manufacturers often insist that an antiwear additive be included in oil for their equipment. This additive increases the strength of the oil film and helps prevent oil from being squeezed out of small clearances when components are heavily loaded. It is also useful during start-up conditions, particularly in cold weather. When the hydraulic transmission is shut down, oil stops circulating and tends to drain from bearing clearances resulting in metal-to-metal contact. When the system is started, wear occurs on the moving parts as they rub against each other. When metal contact starts to take place, antiwear additive coats the metal surfaces with a tough, slippery film. When a transmission is started this film provides sufficient lubrication for the moving parts until the normal supply of lubricating oil has time to build up and separate the surfaces.

4.3 Oil Viscosity Characteristics

Oil is used in hydraulic systems because it is a good lubricant. If it is too thick it is difficult to force around the circuit, and if too thin leakage through internal clearances in components is excessive. Unfortunately, the thickness (or more correctly the viscosity) of the oil changes with temperature. If oil gets too cold it freezes solid, and although this happens at temperatures much lower than the freezing point of water, it can be a problem for machinery that is started in cold weather. Once started, the equipment and oil warm up and the problem disappears, but it is important to make sure that the hydraulic oil is still a liquid at start-up on the coldest day. Oil companies refer to the freezing point of oil as the pour point. The pour point temperature is not the same for all oils, and it is wise to select one that freezes at least 11 Celsius degrees (20 Fahrenheit degrees) below the lowest air temperature likely to occur. For example, assume that the lowest air temperature where machinery is likely to be used is –18°C (0°F); then select an oil with a pour point no higher than –29°C (–20°F). An SAE 10 oil has a pour point of about –34°C (–30°F), SAE 20 oil has a pour point of –29°C (–20°F), and SAE 30 oil has a pour point of –18°C (0°F). These figures show that an SAE 10 oil would be acceptable, and that SAE 20 and SAE 30 oils should be avoided if the minimum system temperature at start-up is likely to be as low as –18°C (0°F).

4.4 Operating Temperature

As the operating temperature of oil increases, its service life is reduced. It is necessary to choose a maximum operating temperature that, all things considered, is reasonable and does not seriously reduce the life of the oil. It is accepted that the temperature of oil in a system reservoir should be kept below 54°C (130°F). Oil thickens in low temperatures and requires higher pressure to force it around a circuit. And, as stated above, as long as the starting temperature remains well above the pour point the problems associated with cold oil operation disappear as the system warms up.

4.5 Selecting Most Suitable Oil

Hydraulic oils equivalent to SAE 10 crankcase oil are available with additives to fight rust, oxidation, and wear. These oils are readily obtainable from all major oil companies and are suitable for use with standard high-speed hydraulic pumps and motors (components that rotate at 1000–2500 revolutions per minute (rpm)).

There is a range of hydraulic motors widely used for driving large winches called high-torque, low-speed (HTLS) motors. These will be discussed later, but in general they require oil that has a slightly higher viscosity than is needed for high-speed components. At 38°C (100°F) an SAE 10 hydraulic oil is satisfactory for both high-speed and low-speed equipment, but at 54°C (130°F) it is too thin for low-speed motors. For this service the operating temperature of the oil should be reduced to 41°C (105°F), or an SAE 20 hydraulic oil used. Both methods would bring the viscosity to an acceptable level.

4.6 How Viscosity is Measured

The viscosity of hydraulic transmission oil is measured in Canada and the United States by means of the Saybolt Universal viscosimeter. A quantity of oil is placed in a container and heated to a certain temperature — there is more than one standard temperature for these tests. Then 60 millilitres (ml) are allowed to run through a short, small-bore calibrated tube. The time in seconds for this small amount of oil to drain away is the viscosity in Saybolt Seconds Universal.

5. HYDRAULIC ACTUATORS

The hydraulic system actuator is the component connected to the machinery. There are three types of hydraulic actuators, the cylinder, the motor, and the rotary actuator. They all receive oil from a system and use it to drive an output shaft, but the shaft of each type of actuator moves in its own special way.

The cylinder shaft, or piston rod as it is usually called, moves in and out of the cylinder body with a straight-line movement. That is, it has reciprocating motion and, therefore, is used to operate systems that open doors and hatches, and luff and slew booms.

The hydraulic motor shaft rotates continuously and is used to drive winches, conveyors, and other machines that require a continuous rotary drive.

The rotary actuator shaft does not move in a straight line, nor does it rotate continuously. The shaft rotates one way and then the other, usually through less than one complete revolution. This is called oscillating motion. The rotary actuator is used to slew booms and for jobs that require rotation through part of a circle. The rotary actuator and the cylinder often can be used to do the same job (Fig. 1).

5.1 Actuator Force and Torque

An actuator is chosen according to how much force or how much torque it must apply to the machine.

5.1.1 Force Force means the amount of direct push or pull that is exerted. Cylinders exert a direct push

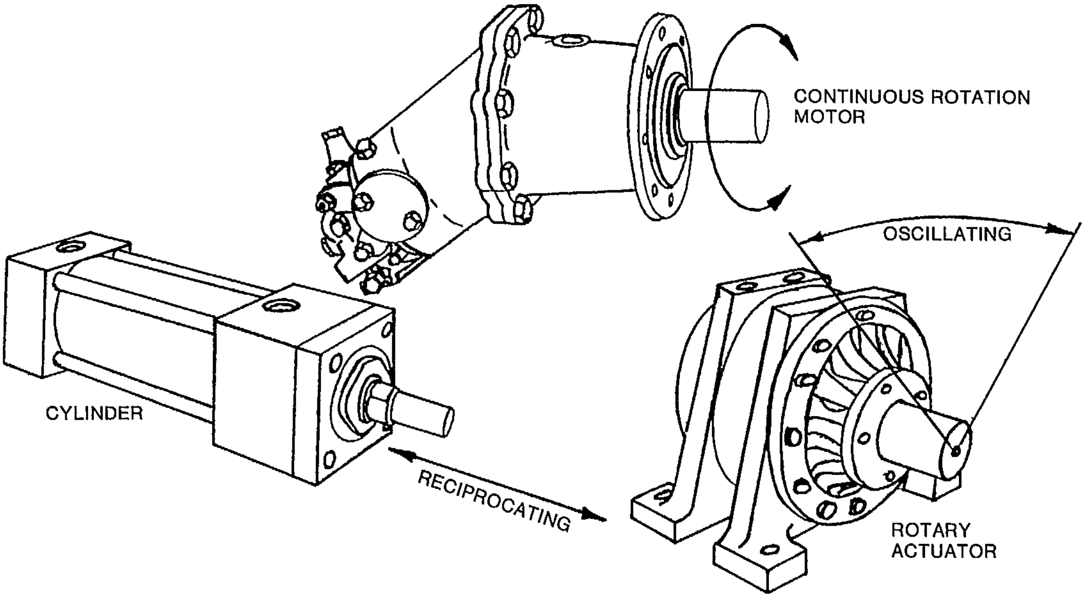

Fig. 1. Motions of hydraulic actuators

or pull on the load so they only deliver force. Force is measured in pounds (lb) in English units and in kilograms (kg) in metric units.

5.1.2 Torque This is the amount of twisting effort exerted by a shaft, and as both the motor and the rotary actuator have shafts that rotate and do not move axially, they can only deliver torque. Torque is measured in units of pounds-inches, that is, it is made up of two parts. The first part is pounds force (the same as exerted by a cylinder), but this is multiplied by the second part, inches, a measure of distance. Imagine a hydraulic motor with a sprocket and chain mounted on its shaft. When the shaft is rotated, one side of the chain tightens and develops a pulling force. This force acts on the teeth of the sprocket, which are offset from the center of the shaft by the radius of the sprocket. This amount is the "distance" part of the torque figure. If the sprocket has a radius of 3 in. and the chain develops a pull (tension) of 200 lb, the torque on the motor shaft would be 200 lb times 3 in. or 600 lb-in. This can be converted to lb-ft by dividing by 12 (12 in. = 1 ft) to give 50 lb-ft.

To sum up, force is a direct push or pull that acts directly on the actuator shaft. Torque is the twisting effect of a force that is offset from the actuator shaft, and is found by multiplying the amount of force by the amount it is offset from the center of rotation.

5.2 Sizing an Actuator

Before a hydraulic actuator can be sized, the amount of force or torque to be applied to the machine has to be known, and a reasonable hydraulic pressure selected. When these have been established the actuator size can be calculated.

5.2.1 Displacement The displacement of a cylinder is simply the volume (the number of cubic inches) of oil needed to move the piston from one end of the cylinder to the other. Displacement is not usually important in cylinders. However, the displacement of a hydraulic motor or rotary actuator is very important, because the torque the actuator will produce is calculated from this. The displacement of a hydraulic motor or a rotary actuator is different from that of the cylinder — it is the volume of oil needed to turn the shaft one complete revolution and is given in units of cubic inches per revolution.

5.2.2 Sizing a Motor The size of a hydraulic motor or rotary actuator is given by its displacement, and if the torque needed by the machine and the pressure drop across the motor ports is known, the displacement of a suitable motor can be estimated from the following formula:

$$\text{Motor displacement (cubic inches per revolution)} = \frac{\text{torque (lb-in.)} \times 8}{\text{hydraulic pressure (psi)}}$$

Friction inside the motor prevents some of the energy from being converted into torque. The displacement of a motor has to be increased to overcome the effect of friction and the formula allows for friction losses inside the motor.

5.2.3 Sizing a Cylinder The area of the piston and not the cylinder's displacement determines the size of a cylinder. This is easily calculated if the force required and the operating pressure are known.

$$\text{Piston area (square inches)} = \frac{\text{cylinder force (lb)} \times 1.2}{\text{hydraulic pressure (psi)}}$$

Friction affects the operation of cylinders just as it affects the operation of motors, and a cylinder must be made larger to take account of this. The formula allows for this by increasing the piston area 20% over the theoretically ideal area.

When the piston area is known, the diameter can be calculated from the formula for the area of a circle. Alternatively, the direct conversion of area to diameter of a circle is readily available from tables.

5.3 Cylinders

These are the simplest hydraulic actuators. They are simple in construction and motion, but, because they must be capable of operating at high speed and pressure, they are carefully engineered and manufactured. Hydraulic cylinders can be either double acting or single acting.

5.3.1 Single-Acting Cylinder This actuator has only one moving part, the shaft (see Fig. 2). In a single-acting cylinder the shaft is sometimes called a ram. Oil pumped into the cylinder body forces the ram to slide out of the body, and the ram can retract only when the oil is drained from the cylinder. The single-acting cylinder has only one oil connection and this acts as both the inlet and outlet port.

5.3.2 Double-Acting Cylinder If a piston is attached to the end of the ram inside a single-acting cylinder, the result is a double-acting cylinder (Fig. 3). There is still only one moving part and that is the piston with the attached rod, or piston rod as it is called in a

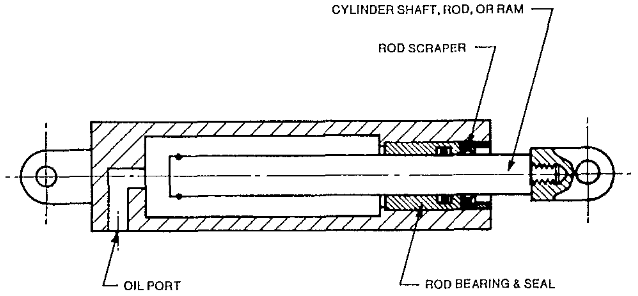

FIG. 2. Single-acting cylinder

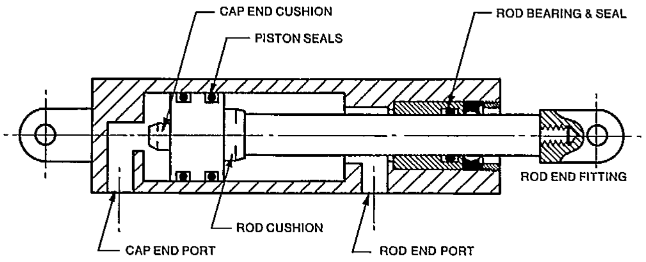

FIG. 3. Double-acting cylinder

double-acting cylinder. The piston is a close fit inside the cylinder bore and carries seals to prevent leakage. An oil connection port is provided at each end of the cylinder body that makes it possible for the oil to move the piston in either direction and the piston rod can then pull or push a load. The piston must be close-fitting, which means the bore of the double-acting cylinder must be accurately machined and highly polished so there is as little friction and wear of sliding parts as possible.

5.3.3 Piston Rod Bearing and Seals All cylinders operate by moving the piston rod in and out of the cylinder body. When the rod is retracted inside the cylinder it is fully protected against corrosion and physical damage but when extended it is exposed to both dangers. The rod passes through a bronze bearing and seal in the end of the cylinder. The bearing supports the rod and the seal prevents oil from leaking out and air, dirt, and water from entering the cylinder. The rod seal is the cylinder's only defence against leakage and system contamination, so it is essential to keep the seal in good condition. To reduce friction and seal wear as much as possible, the steel cylinder rod is hardened, accurately machined, and chromium plated. The chrome plate reduces bearing friction, and protects the rod against corrosion. However, when extended the highly finished rod is exposed and subject to physical damage. When a rod with a damaged surface moves in and out of the cylinder body it quickly destroys the sealing ability of the rod seal. Therefore, the rod must be given special care and protection.

In addition to the rod seal, a rod wiper is installed where the rod leaves the cylinder body. It fits closely around the rod, and wipes off dirt and water as the rod retracts, and, therefore, protects the rod bearing. The wiper is usually a hard, rubberlike material, but when the rod is subjected to heavy icing, it is sometimes advisable to use a rod scraper of hard bronze or similar material.

5.3.4 Piston Seals Seals fitted around a piston prevent leakage past the piston when it is loaded, and keep friction as low as possible. The effective operation of these seals is important. A leaking piston seal allows a load hanging on the rod to lower, the oil that leaks is heated, and the system loses efficiency. Soft rubberlike seals capped with low-friction Teflon® material are leak resistant and readily available. Cast-iron piston rings are often used and may be satisfactory if the cylinder does not have to support a raised load for long periods.

5.3.5 Cylinder Cushions When oil flows into the port of a double-acting cylinder, the piston is forced along the bore and this forces the oil on the other side back to the reservoir. When the piston reaches the end of the stroke it slams into the cylinder cap unless preventive measures are taken. One device used to slow the piston down before it reaches the end of its stroke is cushions. A "cushioned" cylinder is shown in Fig. 4. A cushion is a tapered plug fitted on one or both sides of the piston, as required. As the piston reaches the end of its stroke the plug enters the oil discharge port and chokes off the outlet flow. The tapered cushion closes the hole gradually and allows the piston to be gently decelerated. Two important points to remember about cylinder cushions are:

1) Cushions only work at the extremes of cylinder travel and are ineffective if the piston does not travel to the end of the cylinder.

2) Apply cylinder cushions cautiously and follow recommendations from the cylinder supplier.

5.3.6 Cylinder Construction The two types of cylinder construction are the tie-rod type and the mill type.

The *tie-rod* cylinder is so named because the end caps are attached to the cylinder barrel by means of tie rods. Figure 4 illustrates a typical tie-rod cylinder construction. An end cap is located on each end of the cylinder barrel and held by several tie bolts that span the length of the cylinder. Four tie bolts are used for cylinders with diameters less than 10 in., and more are added for larger cylinders. When the bolts are tightened the barrel is compressed between the end caps and securely held.

Mill-type cylinders do not use tie rods to attach end caps. A flange is attached at each end of the cylinder barrel, either welded or locked in place by some means, and the end caps are bolted to the flanges. Figure 5 shows mill-type cylinder construction.

5.3.7 Standard Cylinders The tie-rod type double-acting cylinder is the usual and accepted design in the hydraulic power industry. Mounting dimensions, rod sizes, and cylinder bore sizes have been standardized so that cylinders of several manufacturers may be interchanged, and replacement cylinders are, therefore, more readily available.

5.3.8 Cylinder Rod Loading Hydraulic cylinders are components of straight-line, push–pull actuators and are engineered to take end loads safely. They are

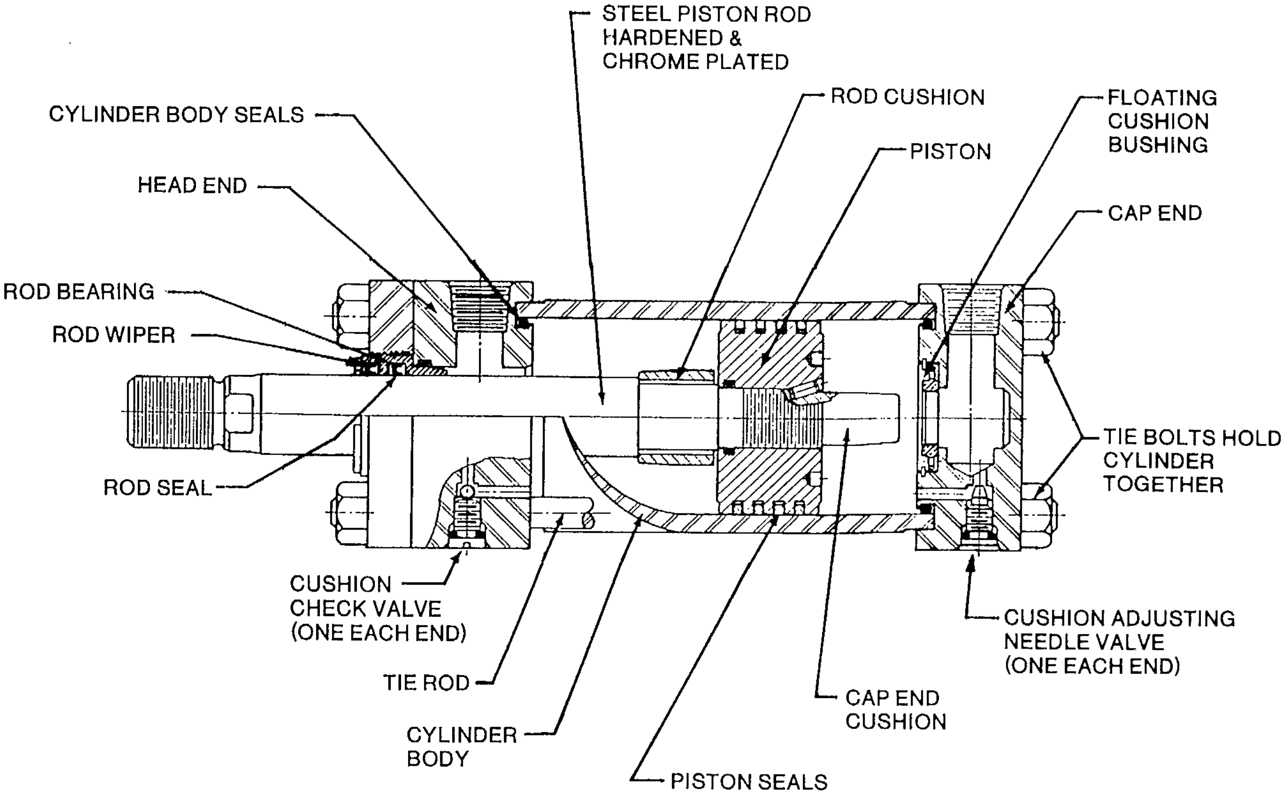

FIG. 4. Tie-rod type, double-acting cylinder

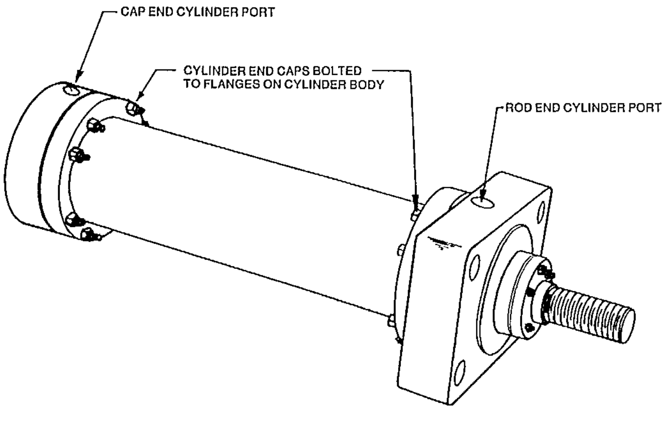

FIG. 5. Mill-type cylinder

not designed to take side loads. Side loading of the piston rod will cause rapid wear of the rod bearing, rod-bearing seal, piston seals, and cylinder bore. Because of this, cylinders should never be used as structural members and should always be free to align themselves with the load.

5.4 Hydraulic Motors

When a winch is in use it rotates in one direction, then reverses and runs in the opposite direction. It must be driven by an actuator that provides a continuously rotating drive. This can be done by a hydraulic motor that rotates continuously in either the clockwise (cw) or counter-clockwise (ccw) direction as required. Hydraulic motors can operate at speeds that can be as slow as 1 rpm and as fast as 4000 rpm. Although it is possible to operate most hydraulic motors over a large speed range, it is not possible to maintain a high level of efficiency over the entire range. As it is essential that the motor convert the largest possible proportion of the hydraulic power entering it into mechanical power, highly efficient motors are necessary and must be specially designed for either low-speed or high-speed operation. Motors that operate at speeds below 500 rpm are called low-speed motors and those that operate at speeds above this are called high-speed motors.

Three fundamental types of hydraulic motors are widely used: the hydraulic gear motor, the vane motor, and the piston motor. The names indicate the devices that make each of them work. Motors differ in cost, flexibility of application, and performance. For example, gear motors are available only as fixed displacement units. When such a motor receives a certain flow rate of oil it produces a fixed output speed that cannot be altered. Vane motors are available only as fixed displacement units, and their performance and cost are about the same as those of gear motors. They can, however, operate at lower speeds and tend to be quieter, but are less rugged, heavier, and more sensitive to shortcomings in the type and condition of oil than gear motors. Piston motors are the most versatile and can be obtained either as fixed or variable displacement units. Variable displacement means that the volume of oil used by the motor to produce one revolution of its shaft can be varied. Piston motors are generally the most efficient, but are considerably more expensive as they are more complex in construction.

5.4.1 Operation and Construction of a Hydraulic Gear Motor *Operation* A gear motor is a pair of cogs or spur gears meshed together, mounted on bearings, and enclosed in a housing. The housing must fit closely around the tips of the gear teeth and against the ends of the teeth, but must not prevent the gears from turning easily. There are two oil ports in the housing, one on each side of the line of mesh of the gears (Fig. 6). When oil is fed into an oil port it fills the spaces between the gear teeth. As it cannot get past the gears, the pressure of the oil rises and tends to force the gears to turn. The force on the teeth is tangential to the gears and they rotate in opposite directions to relieve the pressure. When the oil in a filled tooth space moves from the inlet port into the shelter of the housing (which fits closely around the tips of the gear teeth), it is free to lose pressure and is expelled from the tooth space as the gear teeth go back into mesh. It is then discharged from the discharge port.

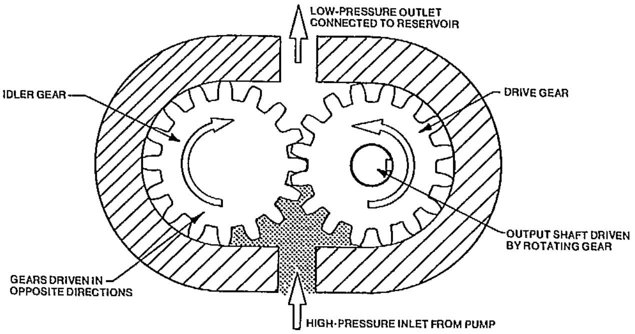

FIG. 6. Principle of gear motor

The greater the number of teeth the more pressure pulses there are in each revolution of the gear and the smoother the gears rotate. Normally, one gear shaft is extended to provide a drive shaft that can be easily connected to a machine.

Construction The gear motor has few parts and is the simplest hydraulic motor (Fig. 7). The simplicity of its construction does not mean the motor is inefficient or performance is poor. Modern, high-performance gear motors have been thoroughly developed to operate at high speeds and pressure, yet remain low in price. The main parts of the gear motor are the two spur gears that mesh together and are driven by oil entering the inlet port in the casing. The gears must be small if the motor is to be compact, but strong enough to operate at high pressure. Their journal bearings must also be strong and highly finished to withstand the high bearing loads and give good life. To meet these requirements, the gears are specially designed and accurately made from hardened, high-strength steel. The bearings that support the gears must withstand heavy loads when the motor is operating at high pressure and must be carefully selected. Plain journal bearings, properly designed, have a much higher load capacity than rolling bearings, but needle roller bearings are often used for this purpose. The casing that surrounds the gears and bearings forms the body of the motor and is designed to withstand the working pressures. It has to fit closely around the gears to keep the internal leakage to a minimum and is manufactured from either high-strength aluminum or cast iron. The gear motor has only two moving parts, is simple, rugged, and withstands severe service conditions.

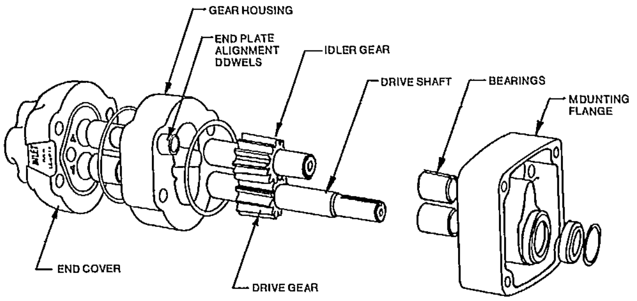

FIG. 7. Exploded view of gear motor

5.4.2 Operation and Construction of a Vane Motor *Operation* The heart of a vane motor is a thick steel disk containing about a dozen radial slots. A flat plate or vane is fitted into each slot so the vane is free to slide in and out. The steel disk and sliding vanes are mounted inside a hardened steel ring with a bore that is not truly circular but distorted slightly to form an oval. This is the cam ring and is fixed to the motor body, but the slotted disk (the rotor) and sliding vanes are mounted on a shaft that rotates in ball bearings. The rotor is positioned inside the cam ring, and small springs fitted at the inner end of each vane force the vanes out to contact the bore of the cam ring. When the rotor shaft is turned, the vanes remain in contact with the inside surface of the cam ring and move in and out as they follow its oval shape. As a vane moves out of the rotor, the size of the chamber between the rotor and cam ring increases, it then decreases when the vane is pushed back in. Imagine that oil is fed into the rotor and cam ring assembly in the two zones where the vanes are moving out of the rotor, the chambers are expanding in these zones and fill with the oil. These chambers are on opposite sides of the rotor. The oil pushes on the vanes and causes the rotor to rotate. The oil pushes on the rotor too, but as it acts with equal force on the opposite side of the rotor, these radial forces cancel each other, and, unlike the situation in

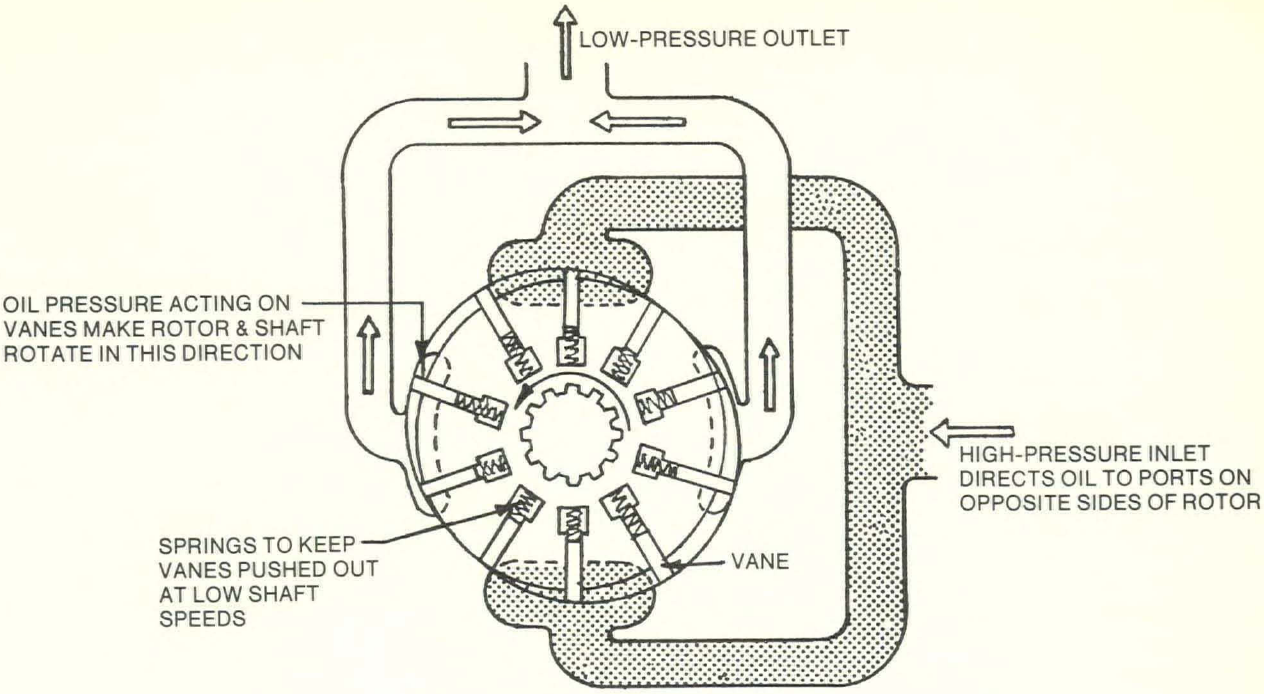

FIG. 8. Balanced vane motor — principle of operation

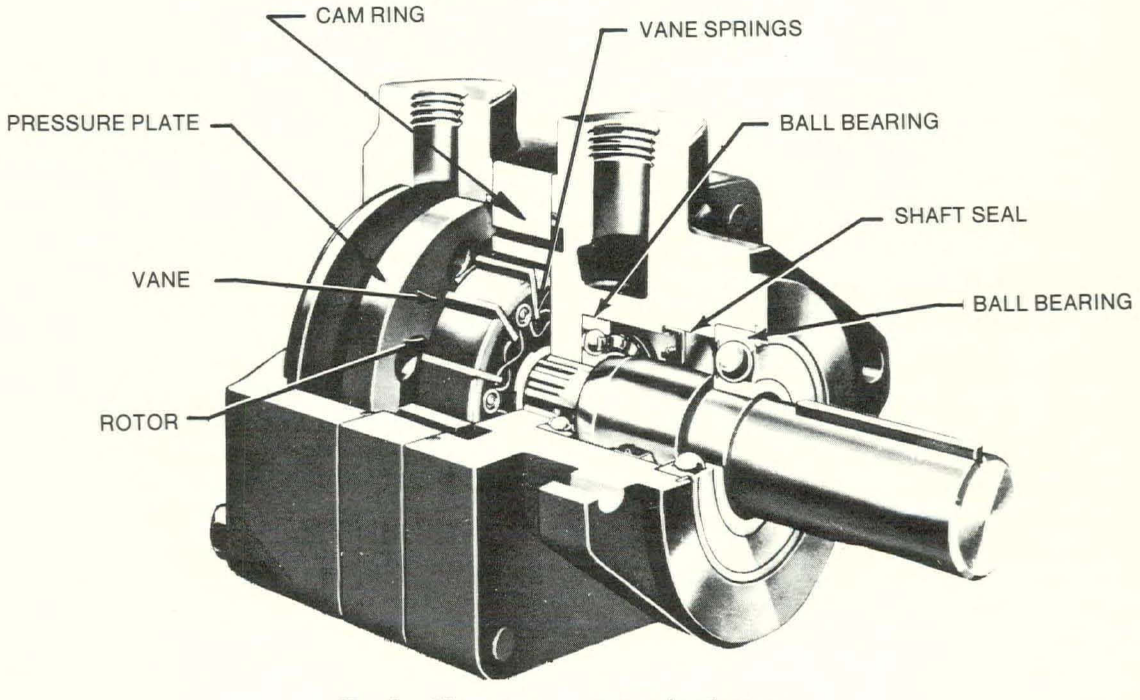

FIG. 9. Vane motor construction features

the gear motor, little load is placed on the shaft bearings. In the next quarter turn the vanes are pushed back into the rotor and outlet ports must be provided to allow the oil to be ejected. Continuous rotation of the rotor is assured because as each vane moves into the discharge region another enters the drive region (Fig. 8).

Construction A typical vane motor is shown in Fig. 9. The most important parts are in the rotor and cam ring cartridge. These parts consist of the rotor (usually high-strength cast iron), the vanes (about 12 hardened steel flat plates), and the hardened steel cam ring. Often the pressure plates that close both ends of the rotor and cam ring assembly are included in the cartridge assembly. The only other components are the motor body (usually high-strength cast iron), the shaft of high-strength steel, bearings, and a few seals. It is usually the parts in the cartridge that wear, and these assemblies can be purchased separately so the motor may be rebuilt when necessary. The cartridge components make the vane motor more complex than the gear motor. The rotor, cam ring, and vanes are all precision-built components that rub or slide on each other. It is the number of sliding components that makes the vane motor more sensitive to the type and condition of oil.

5.4.3 Operation and Construction of a Piston Motor *Operation* The action of the hydraulic piston motor is somewhat similar to that of an internal combustion engine. The engine's crankshaft is driven by several pistons that act one after the other to give continuous rotation. The hydraulic motor shaft is driven the same way, but instead of having expanding gases in the cylinders, pressurized oil forces the pistons against the crankshaft to make it rotate. Hydraulic piston motors use the reciprocating action of the simple hydraulic ram to give the shaft smooth, continuous rotation. The piston motor provides the most convenient design for applications in which the case rotates. It is the most suitable design for variable displacement motors and for high-pressure operation.

Construction Few modern hydraulic motors resemble internal combustion engines. The in line and V arrangements of cylinders are rare but the radial arrangement of pistons is used in certain high-torque, low-speed (HTLS) hydraulic motors. In radial piston motors, between five and ten single-acting pistons are housed in cylinders mounted like the spokes of a wheel around the shaft (Fig. 10).

In some HTLS motors and nearly all high-speed motors, the pistons are parallel to the shaft and are held in cylinders joined together to form a cylinder barrel. They are called axial piston motors. The barrel is fixed to the shaft and the pistons are spaced equally around it like the chambers of a six-gun. Oil is fed to half the cylinders and forces their pistons against an angled plate (swash plate) fixed inside the motor casing. When pressurized, the oil in the cylinders forces the pistons to move out of their cylinders and to slide down the sloping face of the swash plate, thus causing the shaft to rotate. As each piston reaches the bottom of the slope the oil supply is cut off and its port is connected to the motor outlet instead. Oil is discharged at low pressure as the cylinder barrel continues to rotate and the piston is forced back into its cylinder by the sloping face of the swash plate (Fig. 11).

The bent-axis motor is another important piston motor. It also has a cylinder barrel and piston assembly that rotates with the motor shaft, but instead of there being a swash plate, the axis of the cylinder barrel and piston assembly makes an angle of approximately 20–35° with the motor shaft. The pistons are connected to a flange on the end of the shaft inside the casing and they force the shaft to turn (Fig. 12).

The piston motor is the most complex hydraulic motor and is more suitable for high-pressure operation than the others. Pistons slide rapidly inside cylinders and can exert great force against the crankshaft or swash plate. Hydraulic thrust loads and bearing loads

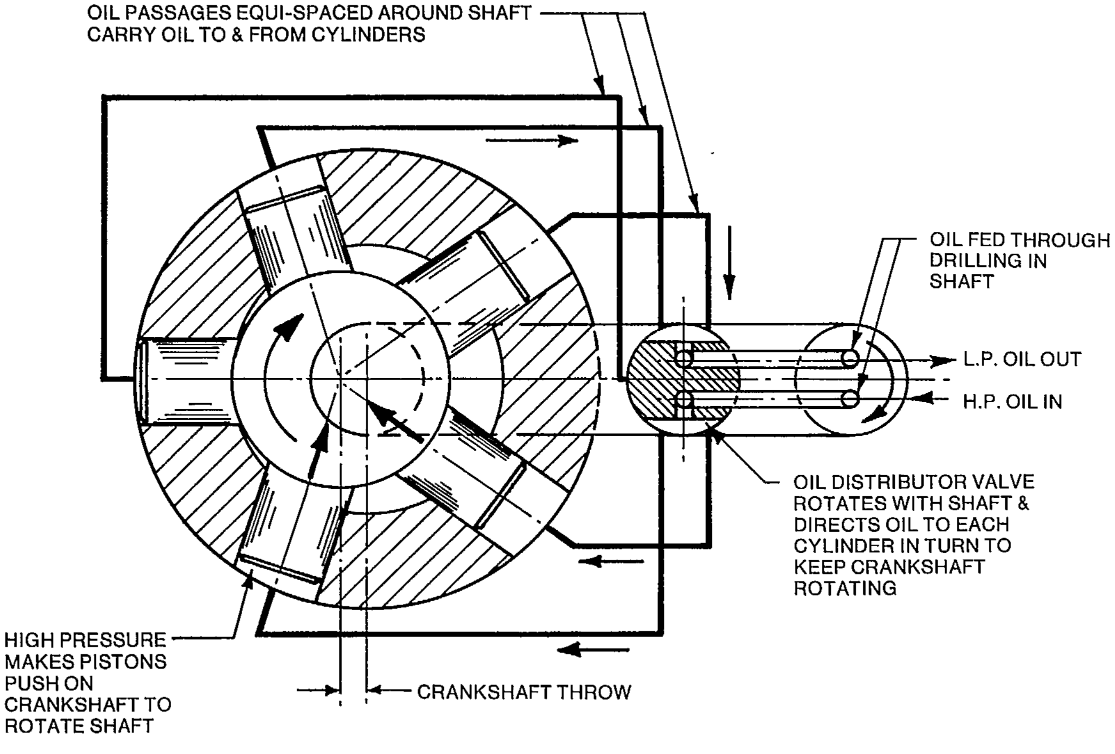

FIG. 10. Principle of radial piston motor

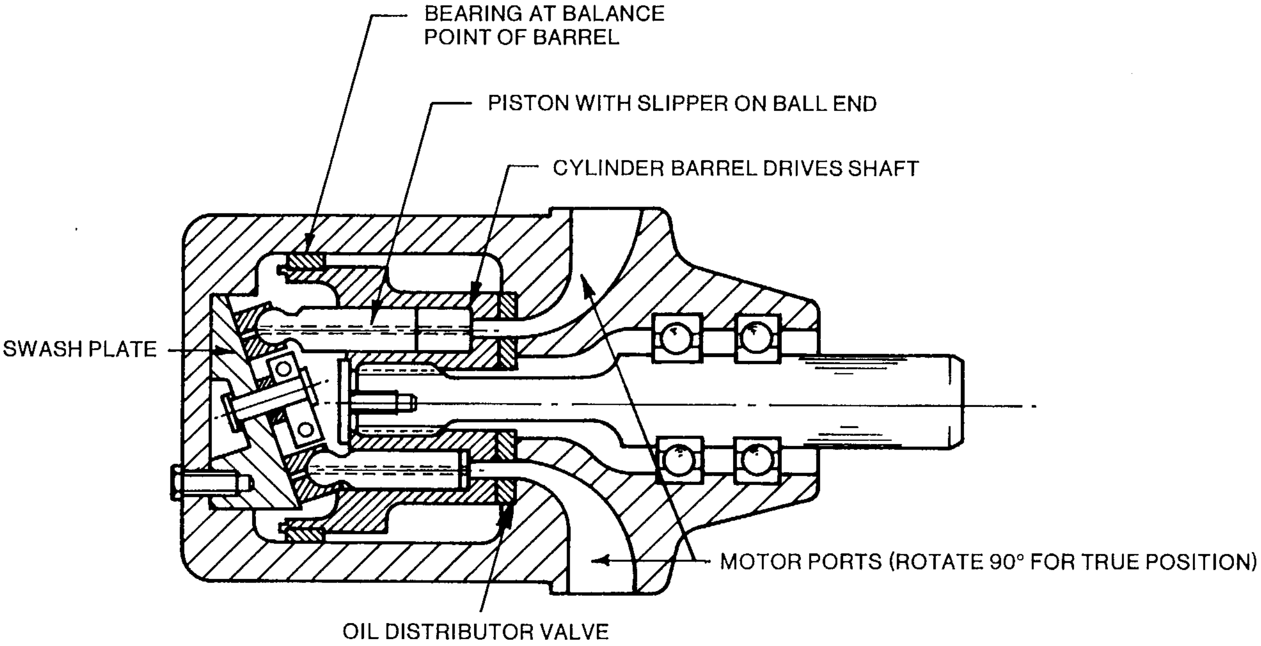

FIG. 11. Axial piston motor

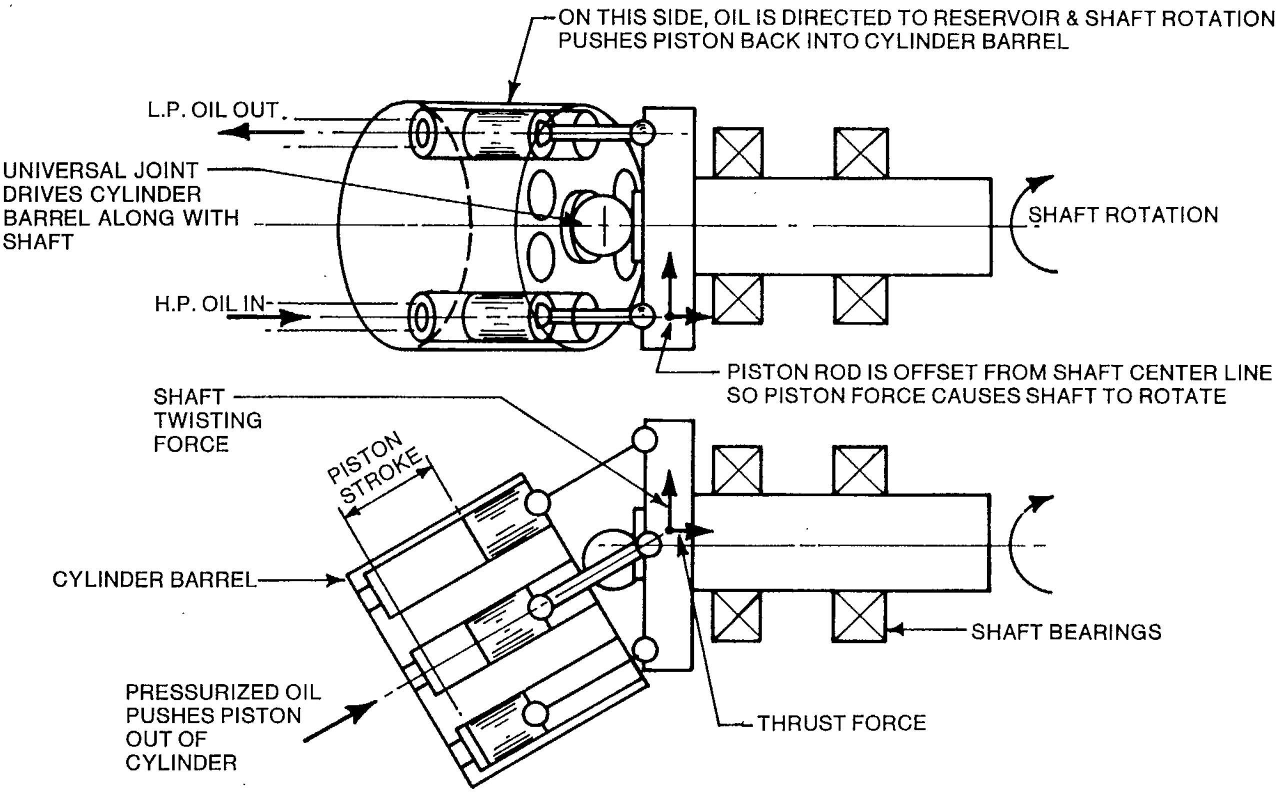

FIG. 12. Principle of bent-axis piston motor

within a motor can be large when pressures are high and internal components must be pressure balanced so that these loads are carried by oil film rather than by direct metal-to-metal contact. Pistons and cylinder parts are accurately made from high-strength, hardened steel to reduce friction, wear, and internal leakage. Motor casings are usually high-strength cast iron.

5.4.4 High-Torque, Low-Speed (HTLS) Motors

Winches operate at low speeds, generally less than

100 rpm, but develop very large warp tensions. Most motors are designed to operate at speeds above 1000 rpm, and there is a problem in matching the high-speed operation of a motor with the low-speed needs of a winch drum. The most obvious method is to place a speed-reducing gearbox between the motor shaft and the drum. Thus, an expensive component, the gearbox, is used with a relatively low-cost motor. Cost of the gearbox depends largely on the speed reduction ratio and output torque. The higher the gear ratio the lower the efficiency. The HTLS motor was developed to eliminate losses caused by gearboxes and to create a much smaller package. The idea was to build a motor that would run efficiently at speeds required by a winch, yet develop sufficient torque at a reasonable hydraulic pressure. The type most suitable is the piston motor, and several designs are now in service. Very popular are radial-piston types such as the Hagglund and the Staffa motors, with pistons and cylinders extended radially like the old-fashioned radial-type aero engine (Fig. 10). Carron and Dowty Dowmax motors are examples of the axial-piston design where the pistons are parallel with the motor shaft. The vane-motor principle is used extensively by the Vickers Company.

The largest of these motors can exert enormous torques but rotate at very low speeds. For example, the largest Hagglund motor requires 10 U.S. gallons (gal) of oil to turn the shaft one revolution. It has a maximum speed of only 16 rpm but it will generate a torque of 90,000 lb-ft at an oil pressure of 3000 psi.

A rotating case-type motor is usually preferred for winch operations. With rotating case motors the shaft is held stationary and the case rotates. This is useful for winch-drive applications because the motor case can be bolted directly to the flange of the winch drum or, in some cases, mounted inside the drum. The motor bearings then support one end of the drum. Hagglund and Staffa motors are widely used on large winches whereas Carron motors are used on smaller winches and capstans.

A reduced speed and increased torque can be obtained by connecting a motor shaft to a gearbox. Several types of planetary gearboxes that can be fitted onto the shaft of a high-speed motor are available and manufacturers claim that the combination is a HTLS motor. This is not strictly true because the high torque and low speed come from the gearbox, not from the motor. However, the planetary gear arrangement allows the gearbox shaft to be in line with the motor shaft and it is quite widely used. The Gearmatic winch is an example of the application of this principle. The Char-Lynn Orbit motor is another example of an HTLS motor and is used extensively to transmit low power and works well at approximately 1500 psi. Its design is based on a special type of internal spur gear arrangement that uses a planetary gear train to build a 6:1 speed reduction into the motor.

With such a wide choice of motors the proper selection might seem difficult. Something must be known about each type of motor, the way it is built and its limitations; then it can be a simple matter to select a motor that will do the job reliably and economically.

5.4.5 Side- and End-Load Effects on a Hydraulic Motor Shaft A high-speed motor is generally designed to apply pure torque only, and its bearings are sized to carry the loads generated by the hydraulic pressure inside the motor. Most motors can tolerate some side loading, but in such cases the proposed mounting arrangements should be approved by the supplier. End loading of the shaft is not usually allowed. Harmful side loads will not occur if the motor shaft is connected to the driven machine by a properly aligned flexible coupling, or if it has a splined shaft and is fitted to drive through a separate gearbox. Side loads occur when a gear, sheave, or sprocket is mounted directly on the motor shaft. The tangential force on the circumference of the gear, sheave, or sprocket is felt on the shaft as a side load, which is in turn applied as a load on the motor bearings. Rigid couplings must never be fitted between the motor shaft and machine as this causes very high side loads on the bearings due to the impossibility of keeping the mating shafts in perfect alignment.

High-torque, low-speed motors are larger than high-speed motors and can be fitted with much larger bearings. As a result, some types of HTLS motors can carry heavy side and end loads on the shaft. However, side and end loads on any motor should be avoided wherever possible. Where such loads may occur, it is always necessary to ensure that the motor can sustain them continuously without damage.

5.5 Rotary Actuators

The movement of a door or the slewing of a boom is usually a rotary motion, the same as the turning of a rotary actuator shaft. But because cylinders are almost always less expensive and can usually provide the required action, they are selected wherever conditions permit. However, the rotary actuator is more compact and has the advantage that its working parts are completely enclosed, and it is, therefore, often selected where space is limited or working conditions are likely to cause damage to an extended cylinder rod.

5.5.1 Vane-Type Rotary Actuator A standard cylinder to push or pull a lever (offset from the center of rotation of a device to give a swinging motion) is a good example of the use of the rotary actuator, but if the oil pressure could act directly on the lever, the unit could be much smaller. This has been done in the most common of the rotary actuator designs. The lever is shaped like a vane and connected to the shaft of the rotary actuator. The shaft and vane fit inside a cylindrical housing that also carries a fixed vane of the same length, and end plates prevent oil from leaking past the ends of the vanes. The end plates close each end of the actuator housing and carry bearings that hold the shaft concentrically with the housing bore. Oil ports are tapped into the housing on each side of the fixed vane and oil fed into one or the other of these ports acts directly on the vane fixed to the shaft, which acts like a lever. By fixing the casing of the rotary actuator to the machine's frame, the shaft is forced to rotate until it is stopped by the fixed vane. When oil is applied to the other port the shaft rotates in the reverse direction until stopped once more by the fixed vane. The total travel is less than one revolution because of the thickness of the vanes. The torque developed by the vane-type rotary actuator can be doubled by fitting two vanes on the shaft. However, as there has to be a fixed vane for each moving vane in the actuator, the amount of swing that can be obtained from the double vane model is reduced to about one-quarter revolution (Fig. 13).

5.5.2 Cylinder-Type Rotary Actuator Other types of rotary actuators use hydraulic cylinders in various ways to achieve oscillating motion of the output shaft. One type uses a hydraulic cylinder with a rack gear cut into the piston rod to drive a pinion on the output shaft to obtain rotation (Fig. 14). A second uses hydraulic cylinders to pull chains around a sprocket, and another uses the piston in the hydraulic cylinder as a nut to drive a helical screw on the output shaft. The shaft movement of a cylinder-driven rotary actuator is limited by its stroke, but it is possible to achieve more than one complete revolution of the output shaft with any of the above designs.

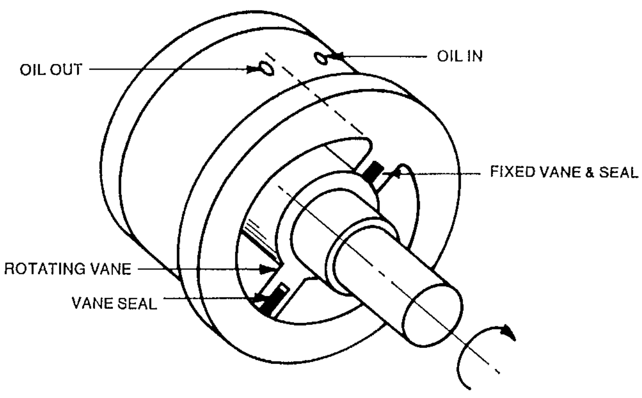

Fig. 13. Vane-type rotary actuator

6. HYDRAULIC POWER TRANSMISSION PUMPS

The small clearances between the pumping parts (the pumping elements) give the hydraulic power transmission pump positive displacement characteristics, that is, internal leakage is very low. To generate flow and pressure, the pump shaft may be hand operated or driven by a continuously rotating engine shaft. Hand-operated pumps are useful when a very small rate of flow is adequate, but usually, when power greater than a man can provide is required and where smooth flow is necessary, the engine-driven rotating shaft pump is usually employed. Rotating shaft pumps are built with several pumping chambers that act one after the other as the shaft rotates to deliver a continuous flow of oil.

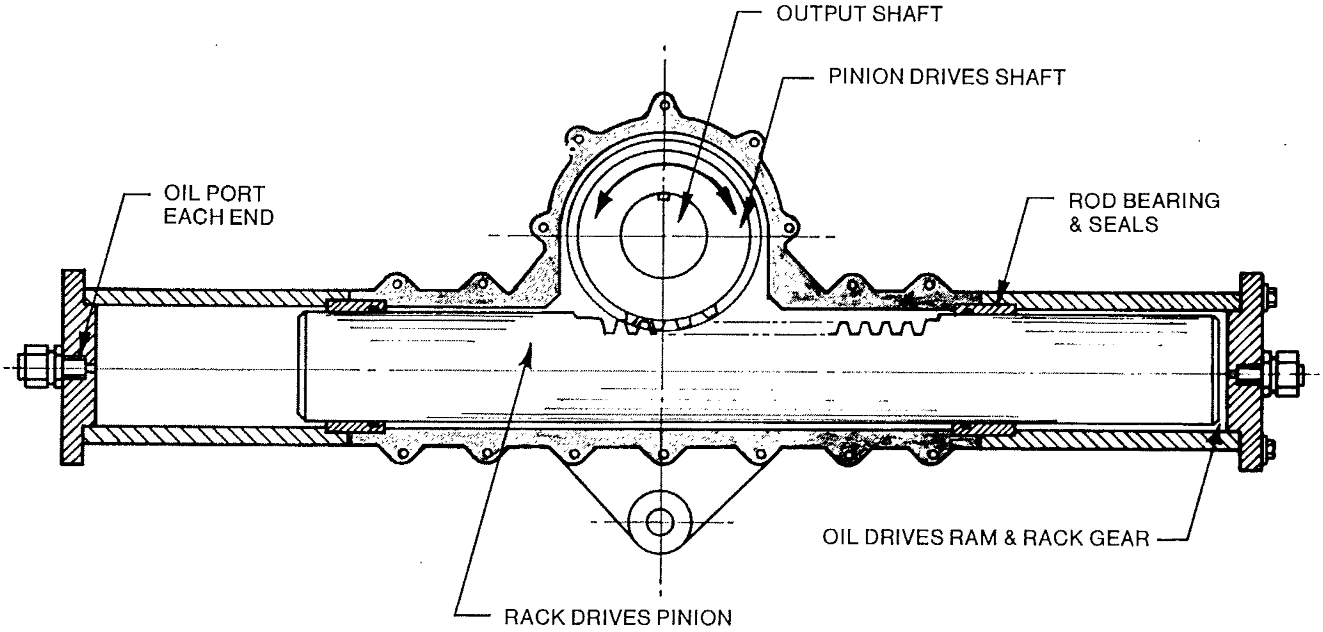

Fig. 14. Rack-and-pinion type rotary actuator

These pumps are generally driven at a constant speed and are available as either fixed displacement or variable displacement types. Fixed displacement means that the volume of oil delivered in one revolution of the drive shaft is always the same and cannot be changed. A variable displacement pump means the volume of oil pumped in one revolution of the shaft can be varied by changing the size of the pumping chambers.

6.1 Volumetric Efficiency

The maximum volume of oil a pump can displace is the amount it discharges at atmospheric pressure (zero load pressure) and is called the theoretical displacement. Normally a pump delivers oil under pressure to a system and, because of internal leakage, the flow rate will drop slightly as pressure goes up. The term volumetric efficiency indicates how well a positive displacement pump maintains flow rate under pressure. It is calculated by dividing the actual discharge flow by the theoretical flow and multiplying the answer by 100. High performance pumps have volumetric efficiencies greater than 95%. This means that if a pump delivers 100 gal per min (gpm) at zero pressure it will deliver 95 gpm or more at maximum rated pressure.

6.2 Hydraulic Power

When a pump is delivering oil under pressure to a circuit, we say it is generating hydraulic power, but in fact it is converting the power of the prime mover (which is mechanical) into oil flow and pressure. Power of any kind (hydraulic, electric, pneumatic, or mechanical) is the "rate at which work is done." The best known measurement of power is horsepower. Years ago James Watt estimated that an average horse could work at the rate of 33,000 ft-lb per minute. That is, it would take a horse 1 min to raise a 330-lb weight 100 ft (Fig. 15). A prime mover delivers mechanical power to its transmission system and when this is a hydraulic system it is convenient to change the units of hydraulic power (ft-lb per minute) into units of hydraulic flow (gpm) and pressure (psi). Power is power whether mechanical or hydraulic and, when it is converted from one type to another, it loses nothing in magnitude provided the efficiency of the conversion is 100%. Only the units in which it is measured change.

$$\text{Mechanical horsepower} = \frac{\text{force (lb)} \times \text{speed (ft/min)}}{33{,}000}$$

$$\text{Hydraulic horsepower} = \frac{\text{oil pressure (psi)} \times \text{flow rate (US gpm)}}{1715}$$

If a pump flow rate and delivery pressure are known the output oil power can be calculated, and this indicates how much power is needed from the prime mover to drive the pump. If all the mechanical power delivered to a pump were converted to hydraulic power, it would be simple to calculate the size of prime mover needed. However, this is never the case and, because of power losses, more power is needed to drive a pump than it delivers as hydraulic power.

6.3 Overall Efficiency

No hydraulic pump is 100% efficient. Some input power is used to overcome friction, and internal

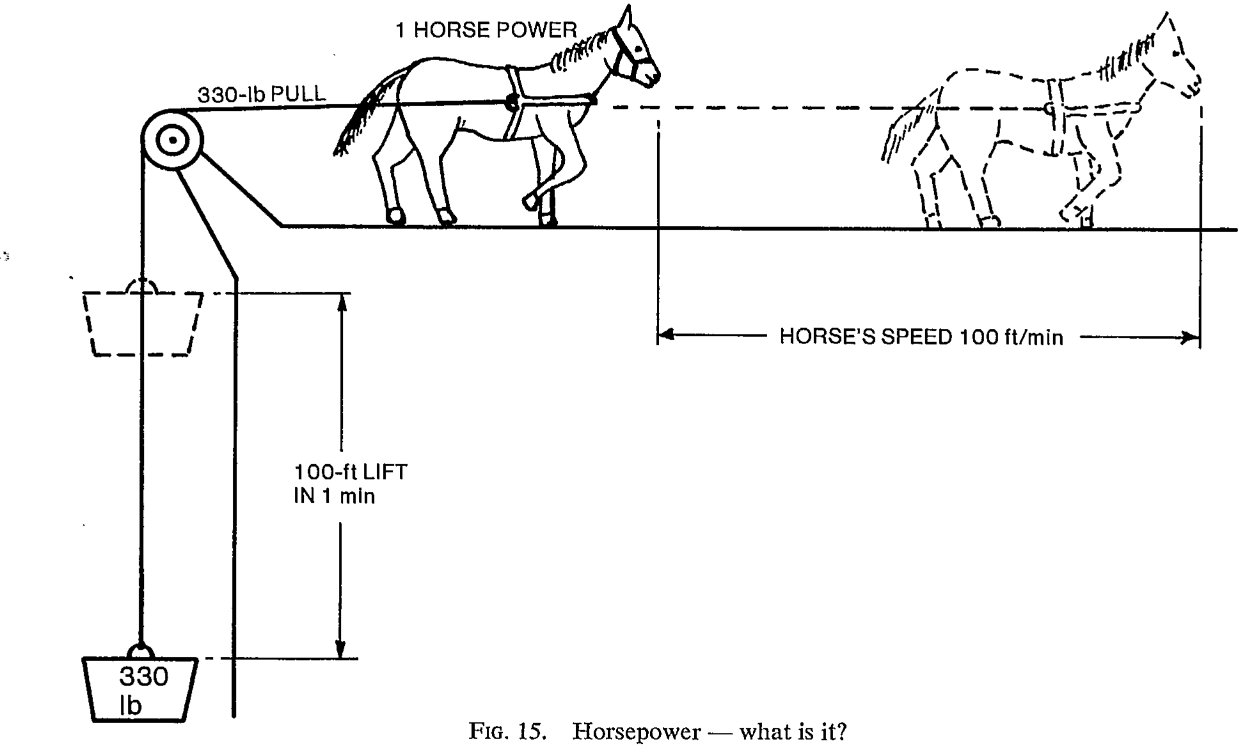

FIG. 15. Horsepower — what is it?

leakage prevents maximum theoretical flow rate from being developed. The term overall efficiency indicates how well the pump converts the mechanical power, which drives the input shaft, into oil flow and pressure. Efficiency is calculated by dividing the output power by input power, that is, oil power divided by prime-mover power. By present day standards, a pump with a peak overall efficiency of 90% is considered good. However, the efficiency of any pump changes with shaft speed, oil viscosity, pump size, and operating pressure. When selecting a pump, check overall efficiency at the expected operating conditions.

6.4 Hand-Operated Pump

The modern hydraulic hand pump is designed to work at pressures greater than 2000 psi and some models develop 10,000 psi, but the ratchet motion of the hand-operated pump handle causes an unsteady flow. (The construction of a typical hand pump is shown in Fig. 16.) Flow rate from the pump can be doubled and made smoother if two pumping pistons are employed instead of one. One way to achieve this is to mount a piston on each end of a rocker arm, which is driven by the pump handle, then when one piston is pumping the other is refilled with liquid. The hand pump is best suited for clamping and for heavy lifting jobs. Where a hand pump is connected to a single-acting ram the assembly is called a hydraulic jack.

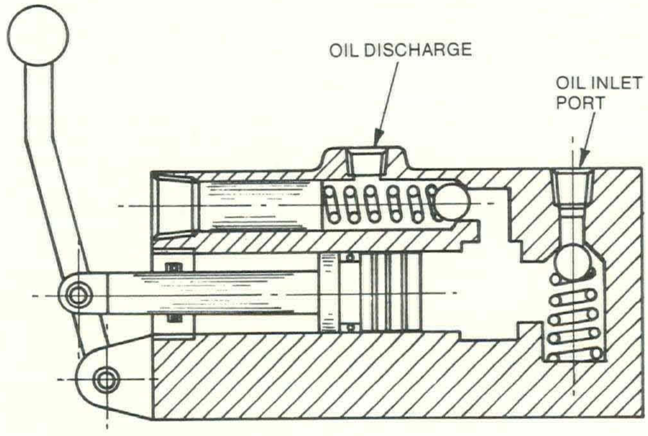

FIG. 16. Single-acting hand pump

6.5 Gear Pump

This is the simplest pump with a rotating shaft, and, like the gear motor, consists of two meshing spur gears that rotate inside a close-fitting housing of aluminum or cast iron. The gears, bearings, and housing of a gear pump often have the same design as those of a gear motor. Oil is induced to enter the inlet port by the flow of oil leaving the inlet chamber in the tooth spaces as they move inside the close-fitting body cavity. At the same time oil is forced out the discharge port by the continuous delivery of oil to the discharge chamber by the gear teeth. The action is simple and the gear teeth are naturally strong (Fig. 17). High-performance gear pumps (as shown in Fig. 18) are now operating with flow rates up to 150 gpm, pressures of 4000 psi, and overall efficiencies of more than 90%. The gear pump's simplicity is a great advantage, and the modern gear pump has been carefully engineered to give maximum power from minimum size. Gear pumps are available only as fixed displacement units.

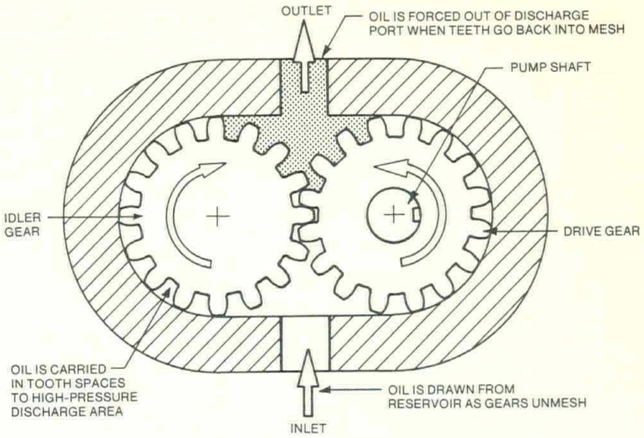

FIG. 17. Gear pump principle

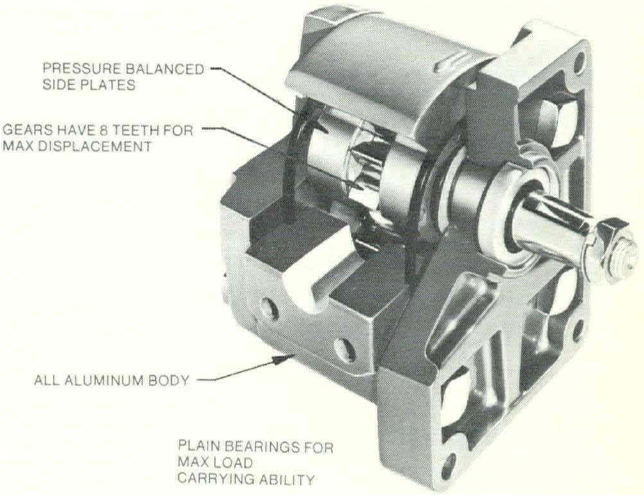

FIG. 18. Modern high-performance gear pump

6.6 Vane Pump

This is similar in construction to the vane motor. The pump shaft causes the rotor and vanes to rotate inside the cam ring and the vanes slide in and out of the rotor slots as they follow the contour of the cam ring. The pump inlet port directs the oil to regions (zones) where the vanes are retracted in their slots and are starting to extend. As the vanes extend the pumping cavity becomes larger and induces the oil to enter. This continues until the vanes reach the high point of the cam and are fully extended. Rotation continues and the vanes are forced by the cam back into the rotor slots. The pumping cavity becomes smaller and the oil is forced from the discharge ports into the circuit. Vane pumps usually have 10 or more vanes, give the smooth-est and quietest flow of the three types of pump, and they are available in both fixed and variable displacement models. Fixed displacement pumps are more common and work at pressures up to 3000 psi. In variable displacement vane pumps the bore of the cam ring is circular instead of oval and the ring is moved off center. When the cam ring is concentric with the rotor, the vanes do not slide in and out of the slots and no pumping takes place. When the cam ring is off center, the vanes are forced to reciprocate in their slots and pumping takes place. Adjusting of the cam ring position varies the stroke of the vanes and the rate of pumping. Variable displacement vane pumps are available only in smaller sizes and are used with lower operating pressures (Fig. 19, 20).

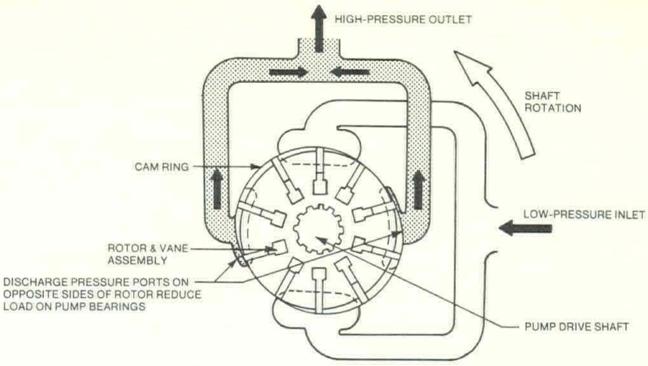

FIG. 19. Balanced vane pump principle

6.7 Piston Pump

This is the oldest form of hydraulic pump. In the 17th century a scientist named Blaise Pascal used a cylinder containing a close-fitting piston to demonstrate how force is transmitted through a liquid. The principle was adopted by manufacturers of hand-operated pumps and eventually adapted to rotating shaft pumps. This is the most suitable method of pumping fluid at high pressures because the pumping elements are simple cylindrical pistons working back and forth inside cylindrical bores. Their shape makes the pistons naturally strong and easy to seal against leakage. The piston pump is recognized as the most versatile hydraulic pump. It is suitable not only for the highest operating pressures but is available in either fixed or variable displacement models. Both fixed and variable displacement pumps are available in the same size and pressure ratings. It may well be asked why bother with gear and vane pumps if piston pumps are so superior. The only reason is that piston pumps are more complex in construction and, therefore, are more expensive than gear or vane pumps.

Piston pumps are available with radial piston or axial piston arrangements. The displacement of the axial piston arrangement can be varied more conveniently and, therefore, it is more common.

The axial piston pump is similar to the axial piston motor as shown in Fig. 21 and 22. The cylinders are parallel to and equally spaced around the shaft and form a cylinder barrel. The cylinder barrel has a piston in each bore and rotates with the shaft. Each piston follows the angled face of a swash plate as the cylinder barrel rotates. This gives the pistons the necessary reciprocating motion to act as pumps. A piston pump usually has between five and ten pistons, and at any

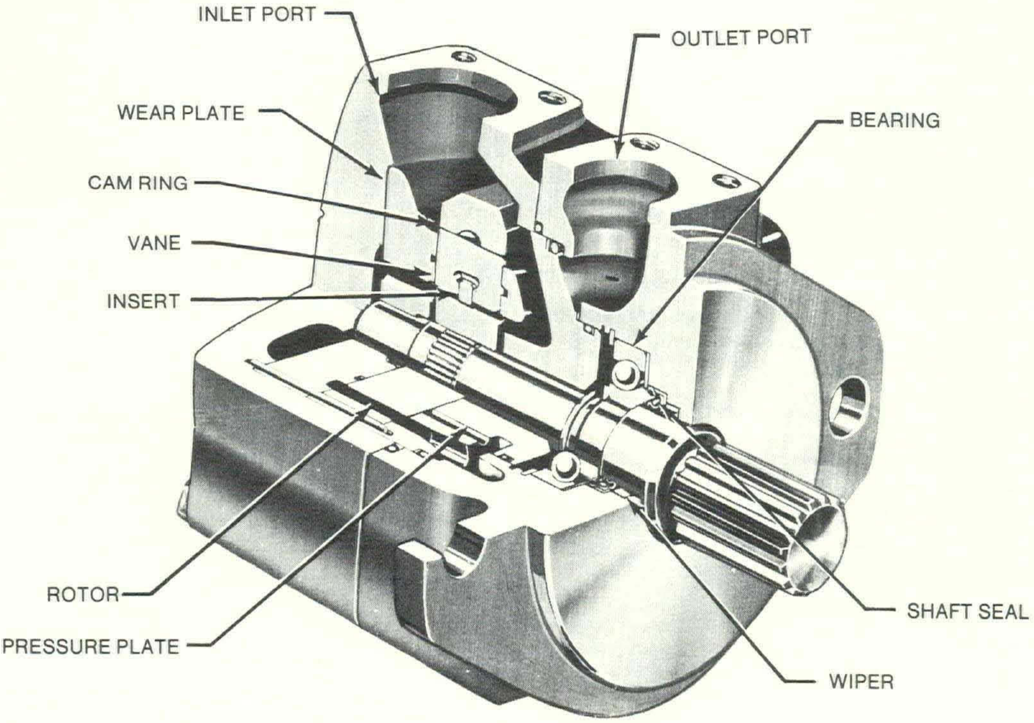

FIG. 20. Vane pump construction

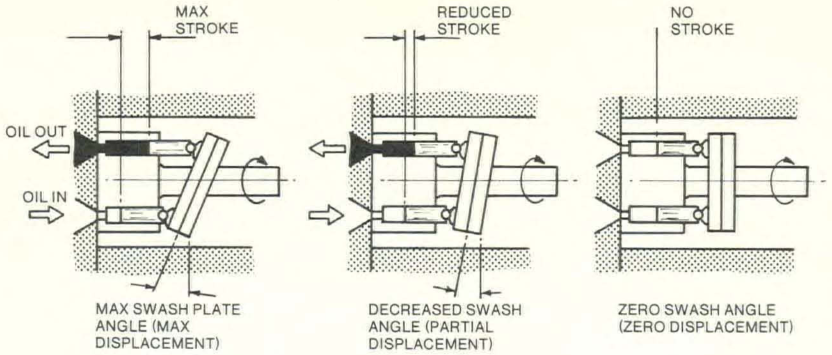

FIG. 21. How displacement of a piston pump is varied

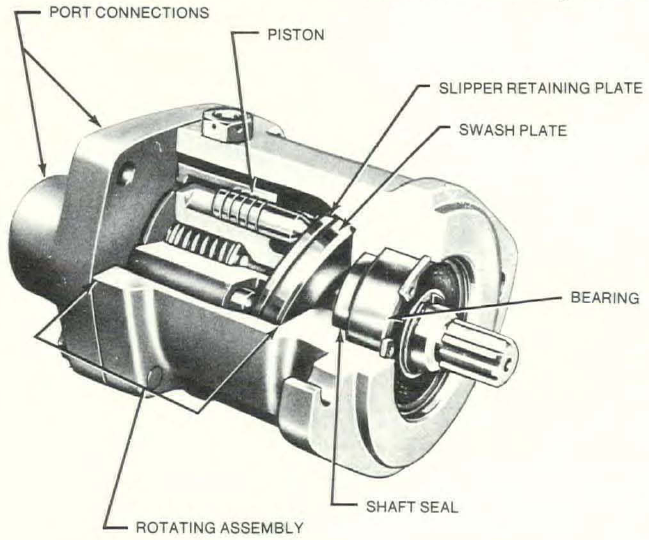

FIG. 22. Features of a modern axial piston pump

instant half are filling with oil as they are pulled out of the cylinders, and the other half are discharging oil as they are forced back into the cylinders.

Another common axial piston pump is the tilting-head type. It is arranged the same as the bent-axis motor. The cylinder barrel assembly is bent away from the axis of the drive shaft at an angle between 20 and 35°, but there is no swash plate. The cylinder barrel is driven by the drive shaft through a universal joint, but the pistons are attached to a flange on the drive shaft. The shaft and the cylinder barrel rotate together but on their different axes, and the pistons are sequentially pulled out and pushed back into their cylinders to provide the pumping action (Fig. 23, 24).

6.8 Comparison of Pumps and Motors

Although pumps and motors look alike, they perform different jobs and have important differences. The pump generates hydraulic power and the motor uses power for mechanical work.

6.8.1 Important Features of Pumps A pump circulates oil around a hydraulic circuit. To do this, it must draw oil from a reservoir at low pressure and force it into the system at higher pressure. When the pump is full, and the driving engine provides enough power, there should be no problem delivering oil from the discharge port. The major problem is getting oil into the pump. Normally the reservoir is at atmospheric pressure and this pressure provides the only force available to force oil into the inlet pipe and then the pump. Even this force is not always available and at pressures below atmospheric pressure the oil begins to vaporize, and an effect known as cavitation occurs. There are various ways to get the oil into the pump, but an inlet port as large as possible is most important. Gear and vane pumps can run for extended periods at inlet pressures below atmospheric, but piston pumps are not as suitable for these conditions. Once installed, a pump is usually required to rotate in one direction only. Pump manufacturers take advantage of this to make their products as efficient as possible and market unidirectional pumps as well as bidirectional models. In unidirectional pumps the pump shaft is suitable for either clockwise (cw) or counter clockwise (ccw) rotation but not both, and allows the manufacturer to simplify pump design as well as make it more efficient (Fig. 25).

All pumps have a small amount of internal leakage and must be drained to avoid a pressure buildup that could blow out the pump shaft seal. The easiest way to drain the oil is to allow it to run back to the pump inlet port. This avoids the need for an external drain line to return the oil to the reservoir. Unidirectional pumps only require a simple drilling from the body cavity to the inlet port.

The lowest pressure in a hydraulic circuit is at the inlet port of the pump and is often below atmospheric pressure. This means that air pressure outside the pump casing is higher than oil pressure inside and, if allowed to do so, air would enter the pump and cause the oil to foam. The pump shaft seal must, therefore, be a dual purpose component. When the shaft is stationary the seal must not allow oil to leak out, and when the shaft is rotating the seal must not only stop leakage, but also prevent air and dirt from entering the pump.

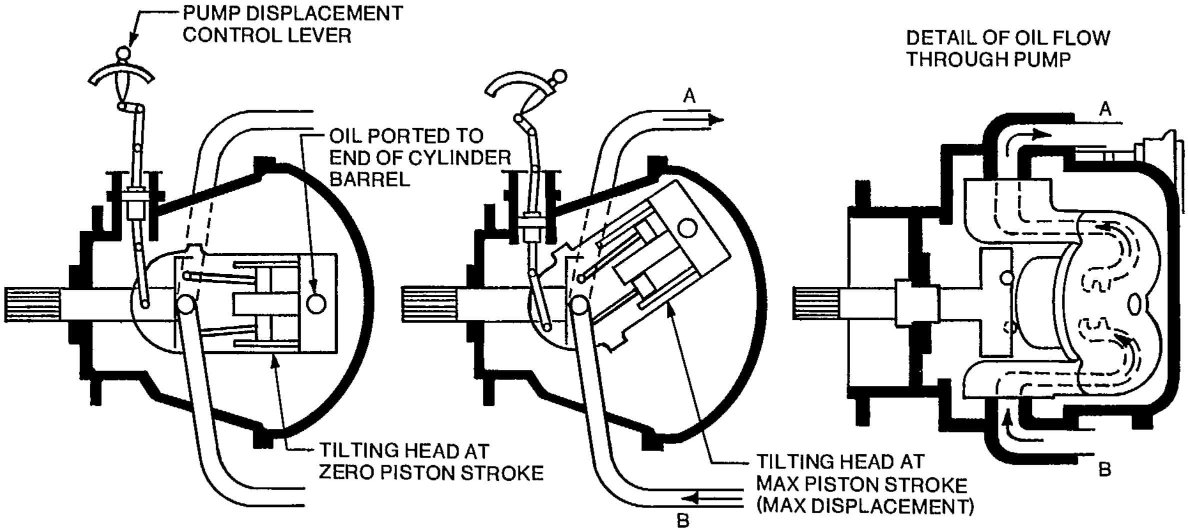

FIG. 23. Porting arrangement for a tilting-head type pump

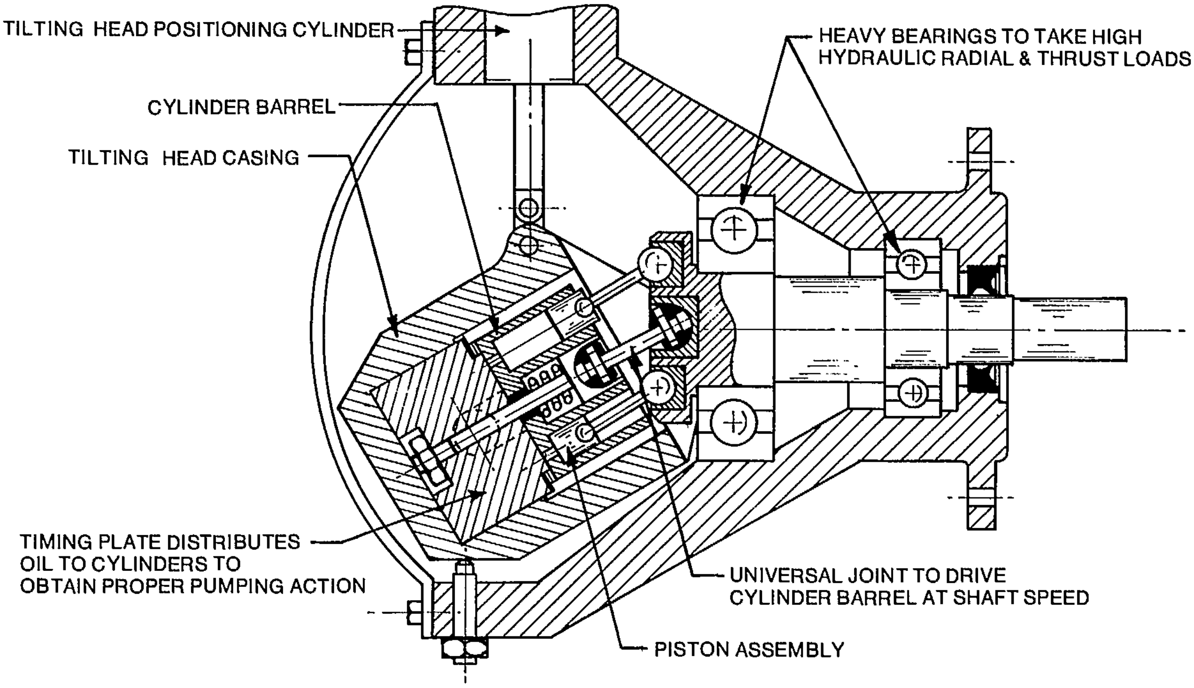

FIG. 24. Tilting-head type variable displacement piston pump construction

6.8.1.1 ***Bidirectional Pump*** This pump can be rotated in either direction and is used when the direction of rotation of the prime mover cannot be determined in advance. However, for this convenience there are penalties. Bidirectional pumps are more expensive and often less efficient than unidirectional models.

6.8.2 Important Features of Motors Unlike the pump, which depends on a lowering of pressure to induce oil to enter its inlet, oil is forced into the motor inlet port by pump pressure. When the oil has driven the shaft, the motor has only to force the oil back to the reservoir and at no point in the motor is there a suction.

Usually it must be possible for a motor shaft to rotate in either direction but, as in the bidirectional pump, this creates the problem of disposing of internal leakage. Manufacturers normally provide motors with an external drain connection. The motor casing cavity can then be connected back to the reservoir at low pressure and is not affected by the direction of the shaft rotation (Fig. 26).

The motor starts the machine it is driving, stops it, and also keeps it moving against whatever service

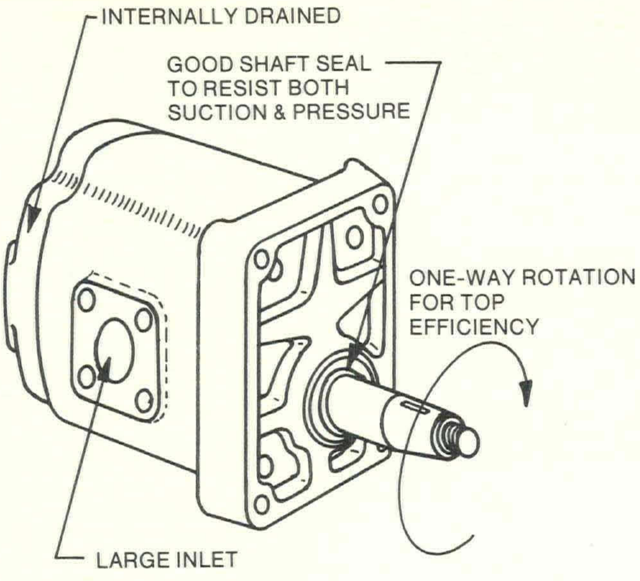

FIG. 25. Important features of pump

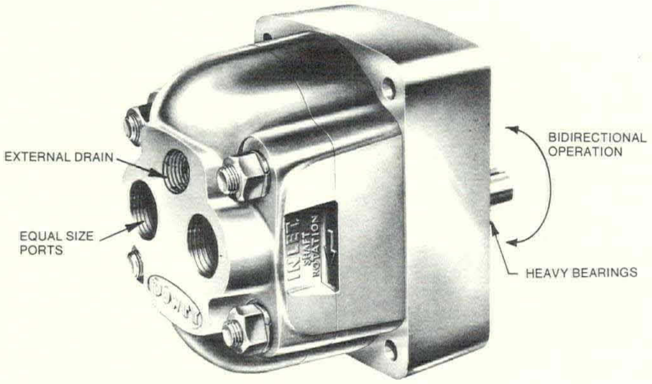

FIG. 26. Important features of motor

loads are applied. As this tends to severely load motor bearings, they are often more robust than pump bearings.

6.8.3 Motors as Pumps Under certain circumstances a pump can operate as a motor. Some units are designed for use either as a pump or motor. However, the penalty for this convenience is usually a higher price and lower efficiency.

7. ACCUMULATORS

If oil is to work it must have pressure and be able to flow, because work is the product of these two functions. A pump provides a flow of oil capable of developing pressure and an accumulator pressurizes the oil and gives it the ability to flow. In hydraulic power transmissions a pump is always required, but need not run constantly if a useful quantity of oil can be stored under pressure in a separate container. An accumulator stores energy the same way a battery stores electric energy. The accumulator can be regarded as a hydraulic battery. Although it is a constant pressure source of hydraulic energy, the accumulator contains only a limited volume of oil and has to be repeatedly charged by the pump.

7.1 Types of Accumulators

The simplest type of accumulator is a pressure vessel with an oil connection in one end, and some method of delivering oil so pressure is generated in the other end. Early accumulators looked something like a single-acting hydraulic cylinder. Oil was pumped into the cylinder and heavy weights were placed on the rod to generate pressure. Modern accumulators are closed at both ends. Oil enters at one end and compressed gas (usually nitrogen) is fed into the other end. Pressure builds up as the oil compresses the gas. A separator is used to separate the oil from the gas and prevent mixing. Usually the separator is either a piston or bladder. Both types are popular but the bladder type is less prone to contamination and leakage (Fig. 27, 28).

7.2 Accumulator Uses

There are several uses for accumulators in hydraulic systems. The most obvious use is to provide

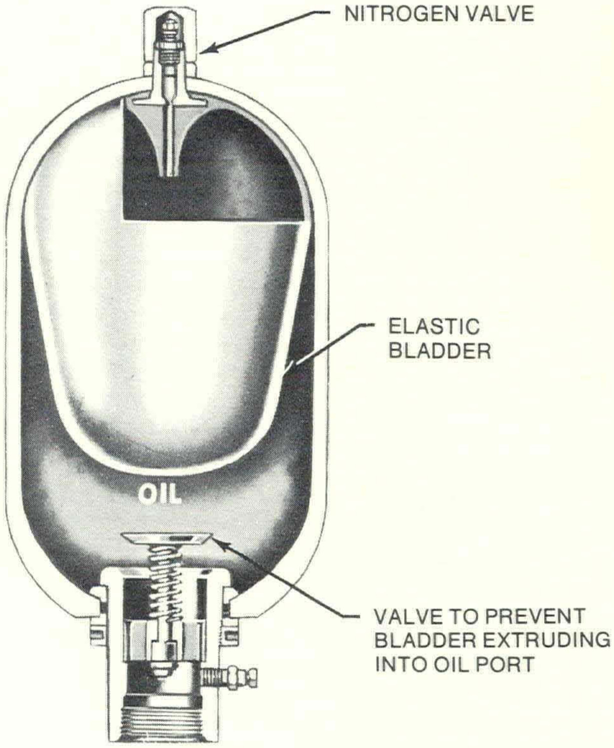

FIG. 27. Bladder-type accumulator

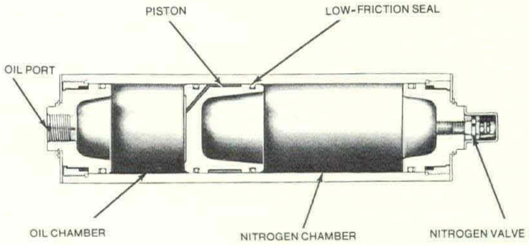

FIG. 28. Piston-type accumulator

constant oil pressure for clamping operations and thus release the pump from continuous duty. Often an accumulator stores pressurized oil for emergency use if the main hydraulic power unit fails. A useful feature of the accumulator is that it can produce virtually any flow rate required. An actuator may need a high flow rate for a short time. An accumulator can provide this flow and it is charged with oil from a small pump over a relatively long time and discharged as rapidly as needed. At the same time, some means of metering the flow as it leaves the accumulator is necessary or the actuator shaft speed will be uncontrolled. Accumulators are also used as hydraulic shock absorbers but, unless they are properly selected they also can cause shocks in a hydraulic circuit.

7.3 Accumulators Can Be Dangerous

All power-transmitting components are dangerous if improperly applied, but accumulators in particular are likely to be misapplied because of their simple shape and apparently static characteristics. An accumulator can store a large amount of energy and if this is released in an uncontrolled way it can cause injury to men and damage to equipment. When fully charged with gas and oil, the accumulator makes no sound. It remains silently in the circuit with the compressed gas acting like a large spring, ready to force out the oil whenever a demand occurs. Unfortunately, the accumulator cannot tell whether a valve has opened normally in the circuit or a pipe has broken, and it will discharge oil as soon as a line is opened for any reason. The unrestricted flow of oil from a break in a line or a disconnected joint develops very large forces that will rip pipes from their mountings. If the open line is close to the accumulator, the accumulator itself will behave like an inflated balloon released with the nozzle open. It will attempt to take off and oil will jet out of it until the accumulator is empty. Therefore, an accumulator must be securely mounted and its hydraulic connections must not fail or be disconnected while the accumulator contains pressurized oil.

8. HYDRAULIC SYSTEM CONTROLS

The motion of a machine and the force or torque it develops is controlled by action of the actuator shaft. To control the machine, the speed, direction, and force of the actuator shaft must be controlled.

8.1 Speed Control

The speed of an actuator shaft depends on the rate of flow of oil fed into it. For example, consider an actuator that receives an oil flow rate of 10 gpm and whose shaft is then driven at a certain speed. If the flow rate is doubled the shaft speed doubles, and if it is halved the shaft speed falls to half the original value. To control the speed of the actuator, the oil flow rate must be controlled.

8.2 Directional Control

A double-acting cylinder, a rotary actuator, and a motor each have two oil ports, and the direction their shafts move is controlled by the port receiving the oil flow. A single-acting cylinder has only one port and when oil is fed to it the ram extends. An external load is needed to retract the ram and the oil inside the cylinder must be returned to the reservoir.

8.3 Force Control

The force or torque an actuator shaft exerts depends on the pressure of the oil, and the actuator's maximum force or torque can be controlled by limiting the off pressure. If there is no protection against overloads, forces exerted on the machine could rise to unacceptable levels and the machine, transmission, or engine would soon break down. Mechanical transmissions limit shaft forces by means of slipping clutches and shear pins. Hydraulic transmissions control force by controlling oil pressure (Fig. 29).

8.4 Controlling Oil Flow and Pressure

The three methods used to control system flow and pressure level are pump control, valve control, or pump and valve control.

8.4.1 Pump Control The most effective but most expensive method of controlling system flow rate, direction, and pressure is to use an overcenter-type variable displacement piston pump. This type of pump can be controlled to give the desired delivery direction and pressure. The pump is driven at constant speed and the displacement is changed by control modules attached to the pump body. A change in the pump displacement changes the delivery flow rate. The control modules allow the flow rate to be set anywhere between zero and full flow. The overcenter feature allows the flow to be reversed. With the pump displacement on one side of the neutral (no-flow) position, one port is the outlet and the other is the inlet port. By reducing displacement to zero the delivery flow rate is also reduced to zero. If the pump mechanism is moved to the other side of the no-flow position it is said to be taken "over center" and the two pump ports reverse duty. The discharge port become the inlet and the inlet becomes the discharge port. Maximum displacement is the same on each side of the no-flow position and, therefore, the pump flow is fully reversible.

Maximum pump pressure is controlled by a pressure limiting module (pressure compensator) attached to the pump. When the pump is delivering oil at pressures less than the compensator setting, the device has no effect on pump flow rate. When system pressure begins to exceed the setting, the pressure compensator

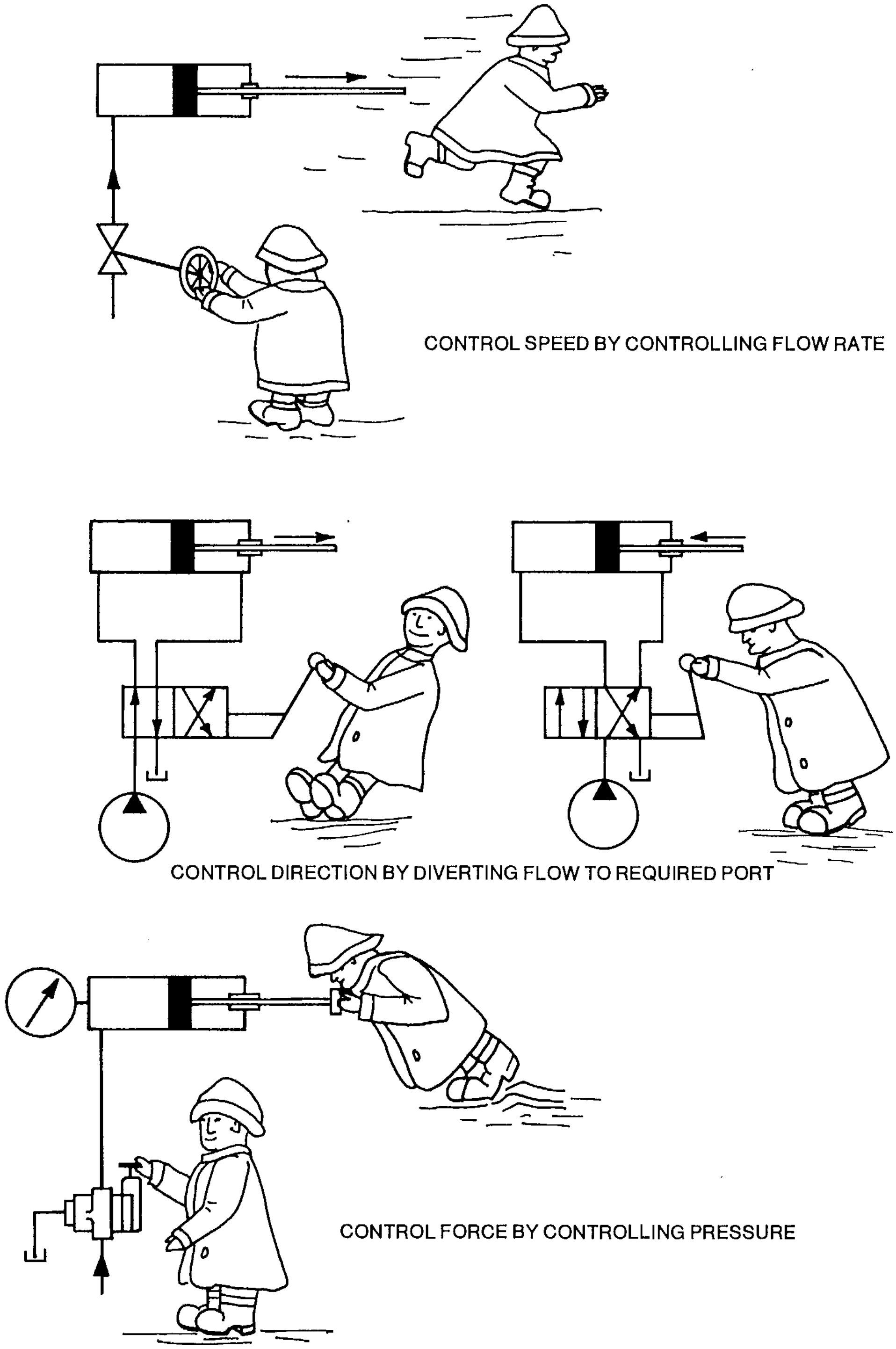

FIG. 29. Methods of controlling hydraulic transmissions

reduces pump displacement (to zero if necessary), and this keeps oil pressure and actuator force from becoming dangerously high. When the load is removed and pump pressure drops, the pressure compensator allows the flow rate to increase. The advantage of pump control is that, although the system control devices are built directly into the pump, operating signals can be sent from a remote location. Pump control is also the most efficient method to control hydraulic power — that is, it wastes the least power. However, the axial-piston pump is the only pump suitable for this purpose and it is also the most expensive. Consequently pump control is usually employed only for high-power and continuously running transmissions or where great accuracy of control is required.

8.4.2 Valve Control This method of controlling a hydraulic system separates the controls from the pump.

A simple fixed displacement pump supplies a constant flow rate, and individual control units (valves) regulate oil pressure and flow to the actuator. An advantage of valve control is that an economical pump supplies the required circuit flow and the separate valves can be positioned in the most convenient locations. A valve controlled system is not as efficient as a pump controlled system, but is usually much less expensive and more flexible in application. Therefore, it is more widely used.

8.4.3 Pump and Valve Control Control achieved by a combination of a variable displacement pump and certain control valves permits the use of a simpler and less expensive pump than is needed for pure pump control. In this type of control the variable displacement pump usually contains only a pressure compensator control module to limit pump pressure, and the control valves are used to control system flow. A pump and valve control arrangement is generally more efficient than pure valve control, but the pump is more complex than a fixed displacement pump, and makes the system more expensive. This arrangement may be useful if a transmission runs continuously, but usually the pure valve control method is simpler, more economical, and completely satisfactory for fishing boat duty.

8.5 Hydraulic Power Transmission Control Valves

These components do not generate oil power or use power for mechanical work. Control valves regulate oil power supplied to the actuator, but in doing so they use some power themselves. The power used by the control valves is lost and does not reach the actuator, so it is necessary for the valves to operate as efficiently as possible. Control valves must work at high pressure yet operate safely, with little effort, and must have rugged bodies of high-strength iron, steel, or aluminum. Their working parts are hardened steel, and clearances between mating surfaces are extremely small. Valves are either poppet type or spool type. Poppet valves are normally closed and the poppet is positively held against a seat to ensure good sealing characteristics. This type of valve is especially suitable for load-holding jobs and pressure controls. A spool-type valve consists of a cylindrical, grooved bar that slides inside a close-fitting bore. It does not have the positive shutoff feature of the poppet valve because of the clearance necessary between the spool and bore. However, it controls flow much better and is often used for this purpose. Spool valves are also used to control pressure and are available in normally open as well as normally closed patterns. Hydraulic valves are loosely classified as either pressure control valves or flow control valves (Fig. 30, 31).

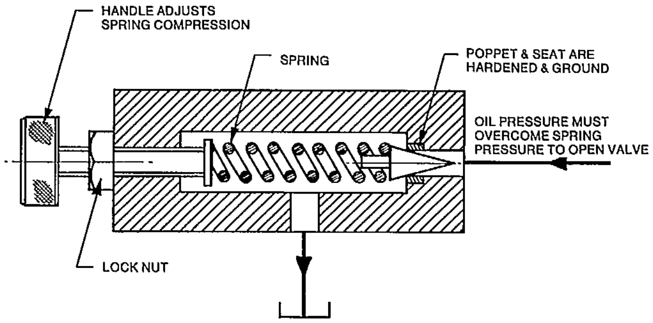

FIG. 30. Operation of a normally closed, poppet-type, pressure control valve

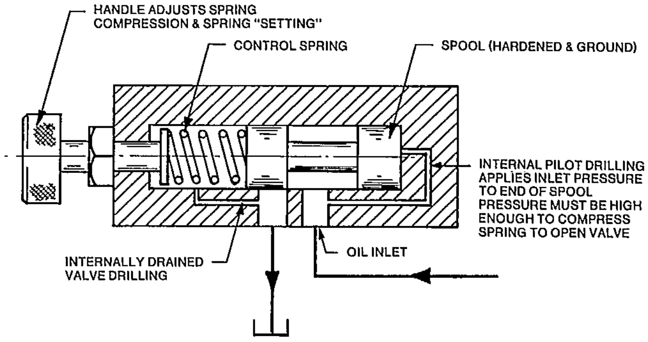

FIG. 31. Operation of a normally closed, spool-type, direct-acting relief valve

8.5.1 Pressure Control Valves These valves prevent system oil pressure from rising above the maximum level allowed in any part of the circuit. They are actuated by a pressure signal and either open or close in response to that signal. There are several types of pressure control valves and all but one are normally closed. The main differences lie in the source of the operating pressure signal and the method of dealing with internal leakage.

8.5.1.1 ***Operating Principle of Pressure Control Valves*** Pressure control valves balance oil pressure against the force of a coil spring. The spring is held inside the valve housing and, in the case of a spool valve, pushes against one end of the spool or, in the case of a poppet valve, holds the poppet on its seat. Oil pressure acts on the other end of the spool or poppet. When the pressure is sufficiently high to overcome the spring force the spool moves axially or the poppet lifts, and oil flow starts or stops. If oil pressure acts directly against the spring the valve is called a direct acting valve. With larger sizes, the spring needed to actuate the valve directly becomes large, and a power-assist feature is often used to keep the valve small. This also improves the quality of the control achieved.

8.5.1.2 ***Relief Valve*** This valve keeps system pressure from exceeding a safe level. It is usually placed next to the pump discharge port where the highest pressures are most likely to occur, but can be used to

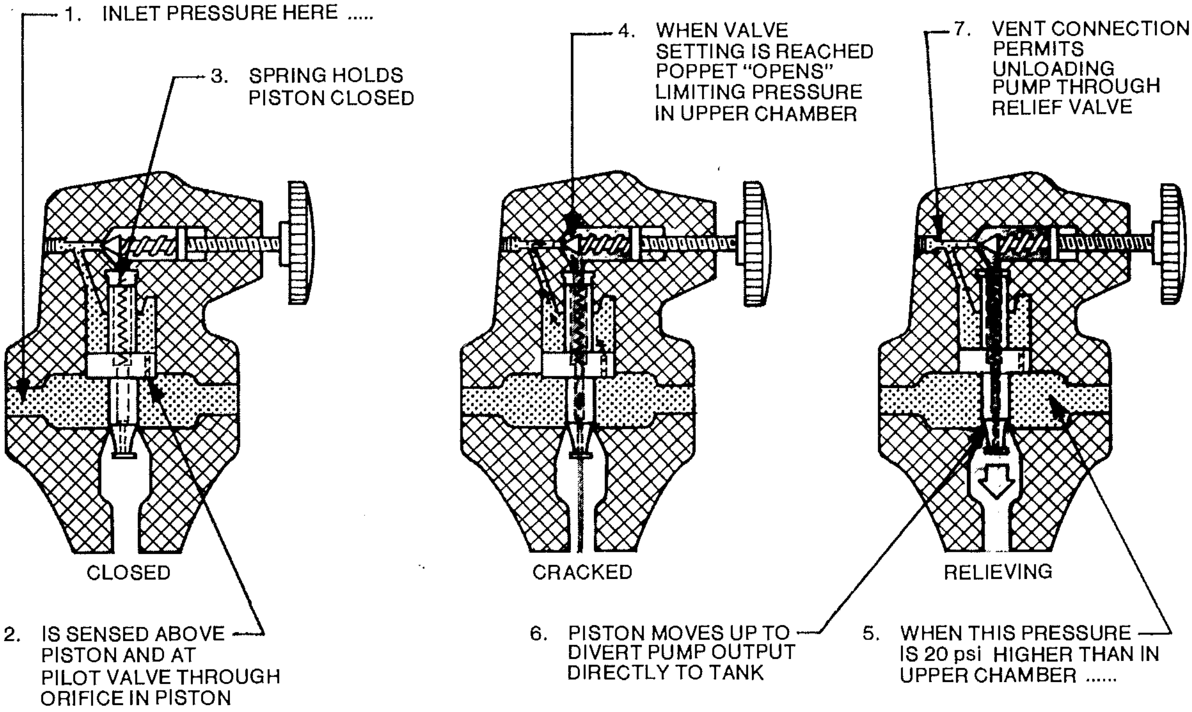

FIG. 32. Pilot-operated relief valve — principle of operation

prevent excessive pressure developing anywhere in the circuit (Fig. 32).

The relief valve is a normally closed valve, which means that it is always closed unless it is open to permit oil to escape from the system. It opens in response to a pressure signal inside the inlet port and is known as an internally piloted valve. When inlet pressure reaches the valve setting, the valve opens and bypasses oil directly back to the reservoir. Circuit pressure stays at the level determined by the valve setting until the load is removed, then the valve closes and stops bypassing the oil. As the outlet flow from the relief valve is taken directly back to the reservoir, the internal leakage flow is usually drained into the valve outlet port, that is, an internal-drain arrangement. This means that any pressure that develops in the relief valve discharge line is also felt in the drain line and can alter the valve setting. To avoid this, the discharge line must be large enough to ensure that a pressure does not develop and it must return the oil directly to the reservoir.

8.5.1.3 ***Unloading Valve*** This is also a normally closed, internally drained valve. It is almost the same as a relief valve and differs only because the operating (pilot) pressure is sensed at a point in the circuit away from the valve. Therefore, it is called an externally piloted valve. The unloading valve is mounted in the discharge line next to the pump and, like the relief valve, it stays closed until pilot pressure reaches the valve setting. The valve usually acts exactly like a relief valve if the pump is the only pressure source in the circuit. If there are two pumps, a remote pressure signal taken from a point of higher pressure can fully open (unload) the valve and allow all the pump flow to return to the reservoir at low pressure. This return flow to reservoir will continue until the external pressure signal is removed. There is a type of unloading valve that unloads a single pump circuit, but it is more complex than the usual unloading valve and is employed mainly in accumulator circuits. Its operation is such that when the pump pressure reaches the valve setting the valve simply resets to a lower pressure. Sensing that the pressure is now too high the valve opens fully and allows the pump to run unloaded until the remote pressure signal falls to the reset level, then the valve closes. Both types of unloading valve are internally drained and any pressure in their discharge ports affects the valve settings. Therefore, the line to the reservoir in both cases must be short in length and large in diameter (Fig. 33).

8.5.1.4 ***Sequence Valve*** When some machines are operating, certain motions must take place in sequence. For example, latches that keep a deck hatch closed have to be withdrawn before the hatch can open. A pressure control arranged as a sequence valve is often used to keep these motions in proper order. The sequence valve is a normally closed valve. It shuts off part of the circuit until another pressure condition is complete. In this example, oil is directed first to the latch actuators and, when the latches are completely

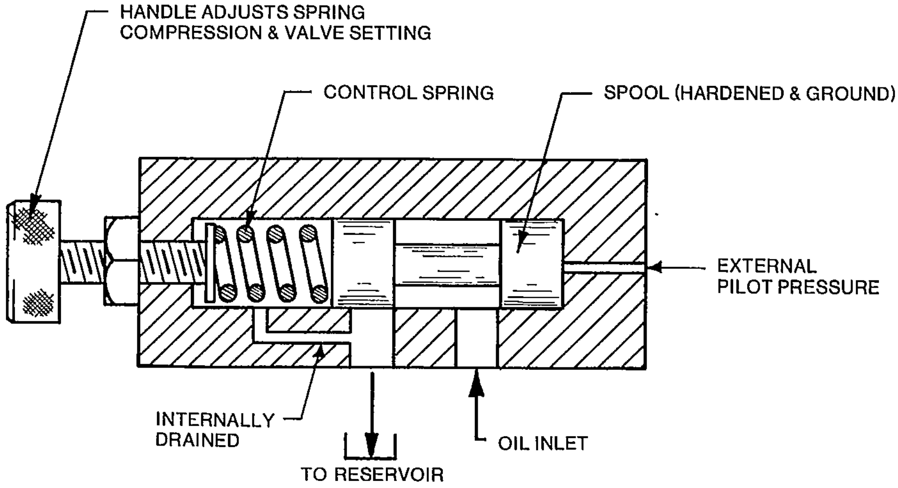

FIG. 33. Spool-type unloading valve

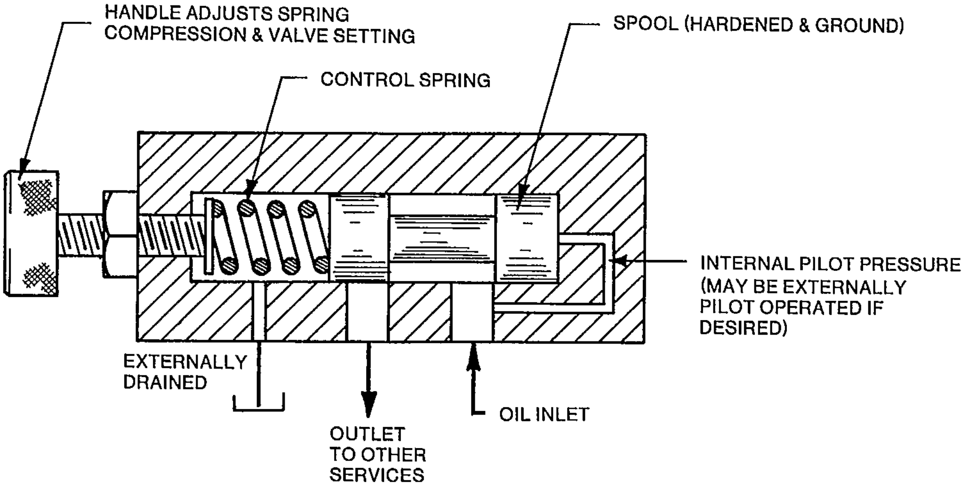

FIG. 34. Spool-type sequence valve

withdrawn, pressure rises and opens the sequence valve. This allows oil to pass through and operate the hatch actuator. The discharge port of the sequence valve must withstand the pressure needed to operate the hatch. The internal leakage flow cannot be discharged into the sequence valve itself, as in relief and unloading valves. In the sequence valve, internal leakage must be drained to a reservoir through a separate drain line and the valve is said to be externally drained. The pilot pressure signal can be obtained from the inlet port of the valve or from a remote location, and the sequence valve is said to be either internally or externally piloted. Often this type of pressure control valve is fitted on the outlet line of an actuator to help stop its movement, or prevent the load from running away. In this application it is called a brake valve or counterbalanced valve. To be suitable for flow in both directions, an actuator can be obtained with a built-in check valve that allows unrestricted oil flow in the reverse direction (Fig. 34).

8.5.1.5 ***Pressure-Reducing Valve*** Sometimes the pressure in part of a circuit must be held below the main system pressure. For instance, it might be convenient to use a 2000 psi oil supply to operate a winch brake cylinder that is designed to accept only 1000 psi. A pressure-reducing valve can be used to reduce the 2000 psi pressure to a usable level. A pressure-reducing valve is a normally open valve and is the only normally open pressure control valve. It stays fully open until the outlet pressure reaches the valve setting, then it closes and prevents outlet pressure rising above the valve setting. The outlet and inlet ports are pressurized, and internal leakage flow must be drained to a reservoir through a separate line. That is, it is externally drained like the sequence valve (Fig. 35).

8.5.2 Flow-Control Valves To fully control the movement of an actuator, both the oil flow rate and the direction of flow must be regulated. However, if the actuator is a hydraulic motor that rotates in only one direction, flow-rate (speed) control is all that is needed. If the actuator is a double-acting cylinder then

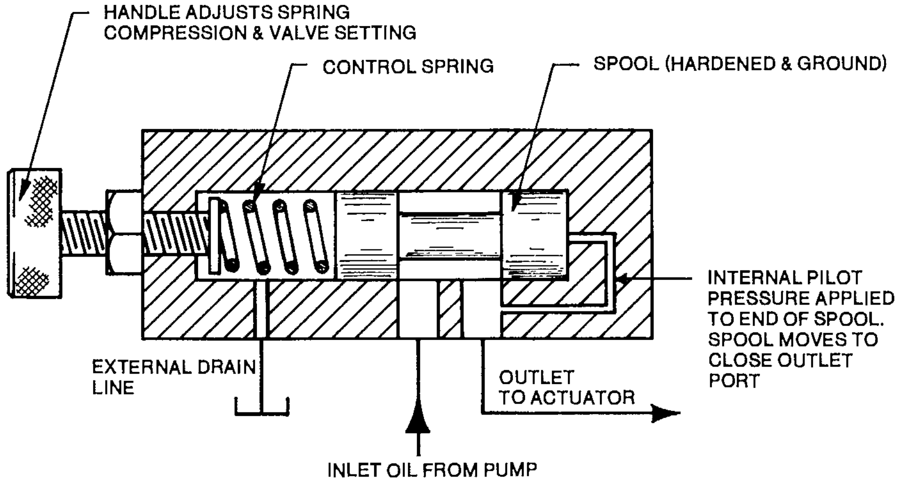

FIG. 35. Normally open (pressure-reducing valve) pressure control valve

an oil direction control valve is required so the piston rod can be made to reciprocate, and speed control may not be necessary. Not every actuator needs both oil flow rate and direction controls, and manufacturers, therefore, produce valves that control one but not the other. Oil flow-rate control valves are called flow-control valves and oil flow direction control valves are directional valves.

8.5.2.1 ***Flow-Rate Control Valves*** These devices regulate the size of an orifice through which oil flows to or from an actuator. Flow-rate control valves can be pressure compensated or not pressure compensated. The flow-rate control valve that is not pressure compensated is more commonly known as the needle valve. This valve is simple and inexpensive, but it has certain limitations. The pressure compensated flow-control valve is often used when these limitations are to be avoided.

8.5.2.1.1 *Needle valve* A plug valve is the simplest device for controlling the flow rate of oil delivered to an actuator. This type of valve gives good control of flow rate if three conditions exist: (1) the valve plug is shaped to regulate the valve orifice so that its size changes slowly and evenly as the plug is adjusted; (2) the supply pressure is constant; (3) the downstream pressure, often called the load pressure, is also constant. A cone-shaped plug inserted in the valve orifice determines the free area remaining for the flow of oil. When the valve stem is screwed in or out the orifice size is adjusted gradually. If the conical plug is long and slender it begins to look like a needle and this makes the orifice size easy to control. The name "needle valve" applies to any of this general type valve that controls flow rate. Needle valves give good control of flow rate if the other two conditions noted above are obtained. The flow rate of water from a household faucet can easily be regulated because the upstream and downstream pressures in the pipe are constant. Water pressure is held at about 50 psi and the outlet discharges into the sink at atmospheric pressure. In hydraulic systems, flow rate and not pressure is usually held constant. A constant pressure is created upstream of the valve by closing it until the pressure reaches the relief valve setting. When the relief valve opens liquid escapes and prevents pressure from rising above the set point of the relief valve. A constant supply pressure condition is thus achieved.

The downstream pressure depends completely on the actuator load. If the load is steady, the downstream pressure is constant and good flow-rate control is obtained with the needle valve. If the load changes, the valve has to be adjusted to maintain the same flow rate and in many applications this simple valve provides satisfactory control of actuator speed. A disadvantage of the needle valve is that it creates a serious obstruction in the pipeline and, as previously noted, where oil is forced through a small hole there is a large pressure drop and heat is generated (Fig. 36). Therefore, this type of control tends to be inefficient.

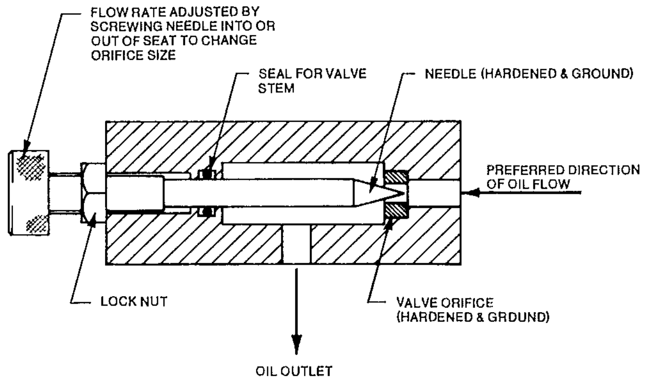

FIG. 36. Needle valve

8.5.2.1.2 *Pressure compensated flow-control valves* To obtain good flow control with a needle valve the pressures upstream and downstream from the valve must be held constant. If the load pressure, i.e. downstream pressure, is 1000 psi and the upstream pressure 1500 psi and both are steady, flow through the valve orifice is also steady. Pressure drop across the valve is 500 psi (1500 – 1000 psi = 500 psi). Suppose the downstream pressure goes up by 200 psi (to 1200 psi) and by an alteration of the relief valve setting the upstream pressure is quickly adjusted to 1700 psi. The upstream and downstream pressures have changed but the valve still has a 500 psi pressure drop (i.e. 1700 – 1200 = 500 psi) and the flow rate does not change. What is really important is the pressure drop across the valve itself. It does not matter whether the upstream pressure is 1500 psi and downstream pressure is 1000 psi or they are 2500 psi and 2000 psi as long as the difference remains the same. The pressure compensated flow-control valve is designed to give a constant flow rate of oil and is not affected by changes in the system load. This is accomplished by a device with an orifice that is equivalent to a needle valve together with a pressure drop sensing mechanism (PDSM). The PDSM is a simple device that works continually while the valve is in operation to keep the pressure drop at the control orifice at about 100 psi. Flow rate through the valve can be easily adjusted by manually opening or closing the orifice a certain amount. The PDSM regulates any changes in system pressure and keeps the selected flow rate constant. A flow-control valve designed with two ports (inlet and outlet) works by throttling the oil flow through the valve. Increases in inlet pressure spill the unwanted flow rate over a relief valve to the reservoir. Because it restricts flow, this valve is called a restrictive flow control. If the valve is designed with three ports (inlet and two outlets) the oil entering the valve is divided into two streams. One is the priority or regulated flow, the other the excess or bypass flow that usually returns to the reservoir. In many flow-control valves this bypass flow can supply other parts of the circuit. The three-port valve is generally called a bypass flow control. (Fig. 37).

8.5.2.2 ***Directional Control Valves*** A positive displacement pump delivers flow whenever the shaft rotates. With the pump directly coupled to an engine, oil begins to flow when the engine starts. Directional control valves prevent oil flow reaching the actuator until it is needed. A directional control valve is really a hydraulic switch, because it receives oil from the pump and directs it either to the reservoir or the actuator. Although some types of directional control valves are operated by a rotary movement of a handle, the most popular is the spool type. It is economical to produce, the spool slides back and forth inside a close-fitting bore, and it can be operated by several different methods.

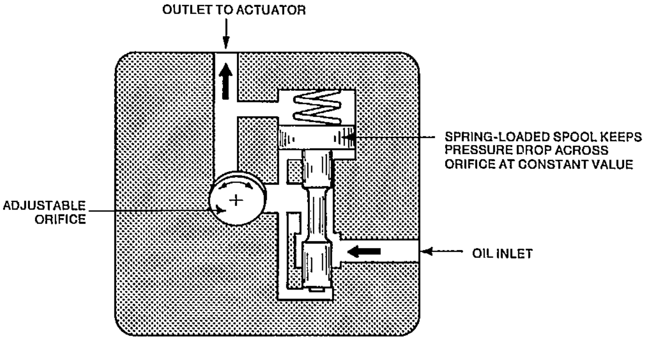

Fig. 37. Pressure compensated flow control valve — restrictive type

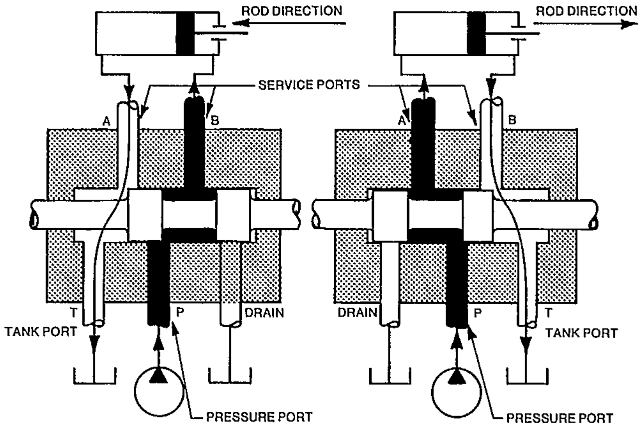

Fig. 38. Operation of spool-type, four-way directional control valve

8.5.2.2.1 *Four-way valve* The four-way valve is the most popular model of directional control. It is called four-way not because the valve diverts the flow in any of four different directions, but because it has four ports. One port (pressure port, P) always receives oil from the pump. Another port (tank port, T) is connected to the reservoir and usually carries low-pressure oil, but sometimes it carries high-pressure oil, so the tank port of a directional control valve must be suitable for maximum system pressure. The other two ports (service ports) are connected to the actuator.

A four-way valve controls the movement of a double-acting cylinder, a rotary actuator, or a bidirectional hydraulic motor. With the spool valve set in one position, shown in Fig. 38, oil from the pump enters the pressure port and is directed to one of the two service ports (usually identified as A and B or C1 and C2) and from there to an actuator port. Movement of the actuator shaft forces oil from its other port and back into the second service port of the valve. The valve directs this flow to the T port and back to the reservoir. When the spool moves to the other end of its travel, the connections inside the valve are reversed.

For example, if port P connects to port A then port B connects to port T. When the valve spool moves to the opposite end of its travel, P connects to B, and A connects to T. Pressure is changed only at the service ports, and the P and T ports remain with their pressures unchanged.

8.5.2.2.2 *Two-position, three-position, and four-position valves* The valve described in the above Section is a two-position valve because the spool is positively positioned at each end of its travel. A three-position valve is one in which the spool, or other method of switching flow, is stopped and positioned half way between the two extremes of travel. The two-position and three-position four-way valves are widely used, but four-position valves are also available.

8.5.2.2.3 *Advantage of a three-position valve* The three-position valve has a center position midway between the two extremes of valve movement. The two end positions provide flow to the actuator in either of two directions and the center position prevents any flow from reaching the actuator. In the center position the four ports of the valve, P, A, B, and T, are interconnected in various ways to stop flow to the actuator or to give special circuit effects. The most common patterns of port interconnections at the center position are as follows:

1) All ports blocked. This is the closed-center pattern.

2) All ports connected together. This is the open-center pattern.

3) Both service ports blocked and P port connected to T port. This is the tandem-center pattern.

4) The P port blocked, but A, B, and T ports connected together. This is the motor-center pattern.

There are several other possible arrangements and the choice of valve center pattern depend on the type of circuit (Fig. 39).

8.5.2.2.4 *Four-position valve* This valve provides the choice of two center positions. A four-position valve provides: (1) two positions for directing flow to the actuator (one for each of the two flow directions), (2) a tandem-center position where the service ports are blocked and P is connected to T, and (3) the extra center position where all ports are interconnected so that a free-wheeling or free-fall condition of the actuator may be obtained. However, the difficulty of securing the spool positively in the intended one of the two center positions usually limits its use to manual operation.

8.5.2.2.5 *Methods of holding valve in selected position* Valves may be held in selected positions by:

1) *Detents* Although the simplest way to hold a valve in a selected position is to depend on the friction in the operating linkage and seals, a more reliable method is to use detents. A detent is a notch cut in the valve spindle. A spring-loaded ball pressed into

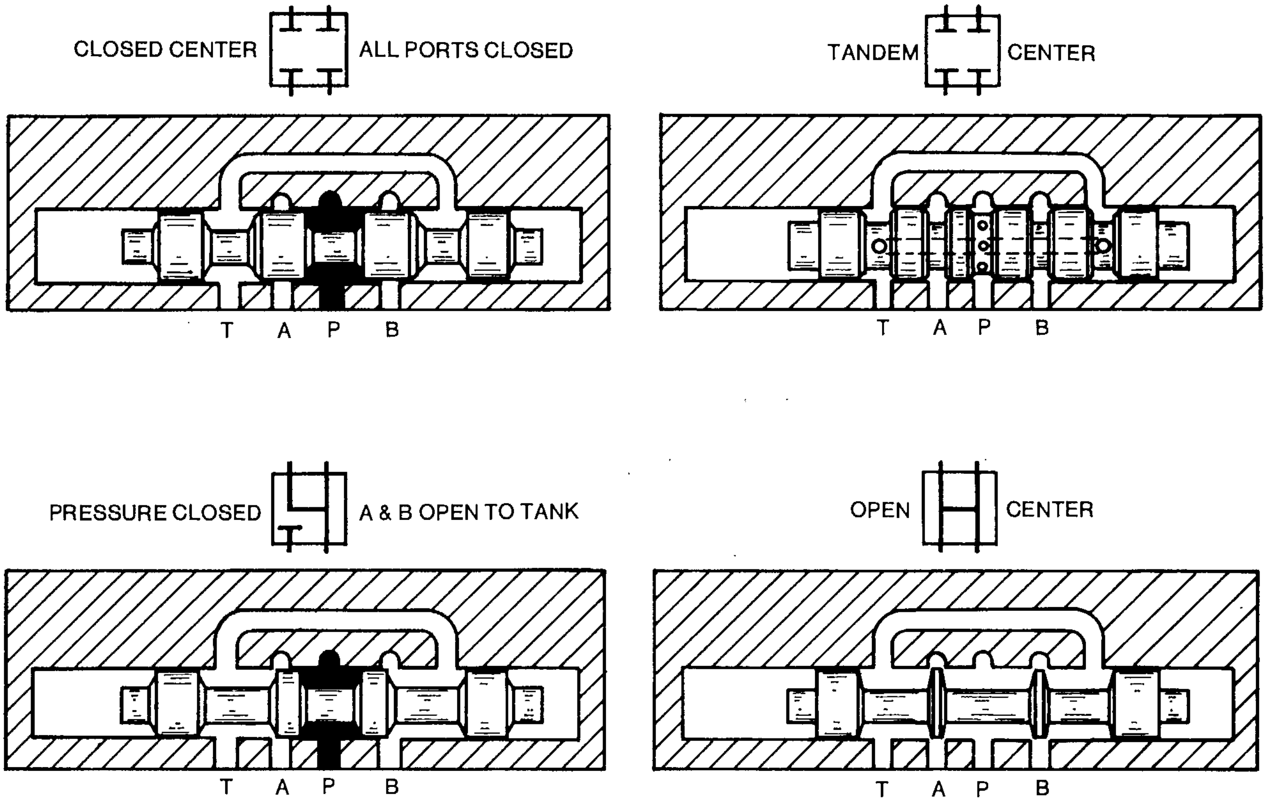

FIG. 39. Four popular types of spool for directional control valves

the notch holds the valve in the selected position. This gives a more positive means of positioning the valve and is suitable for the two-, three-, or four-position valves.

2) *Springs* are suitable for positioning two- and three-position valves. If the springs are arranged to hold the valve halfway between the two extremes of travel it is called a spring-centered valve. The valve can be moved in either direction but when released it always returns to the center position. This arrangement of springs is used only for three-position valves.

Often a single spring is used to position a valve at one end of its range of travel. The valve then has a spring-offset arrangement. It has no center position and is only used in two-position valves. The valve may be moved to the other end of its travel but when released will return to the original spring-offset position.

8.5.2.2.6 *Valve operators* The spool, or other means of controlling the direction of flow of oil through the valve, must be moved by a mechanism. Often a hand-operated lever is sufficient and, in some cases, is the only practical method. For example, four-position and rotary action valves are readily available with lever operated arrangements. Two- and three-position spool valves can also be operated by a lever but in addition they can be operated by the plungers of simple air or hydraulic cylinders and electrical solenoids. The solenoid can be regarded as an electrical cylinder whose plunger is actuated when electrical power is applied to the coil. The straight-line motion of these plungers is ideal for operating a spool-type directional control valve. As the valves become larger and capable of handling larger flows, the forces required to operate them also increase. To overcome this difficulty, two stage valve arrangements (sometimes called piggyback valves) are used. The main valve handles the flow delivered to the actuator and is in turn controlled by hydraulic pressure delivered to either end of the main valve spool to force it to the intended control position. The flow rate required to move the main valve spool is small and can be controlled by a small valve, usually operated by an electrical solenoid (Fig. 40, 41).

8.5.2.2.7 *Directional control valves as flow-rate controls* A directional valve actuated by a hand-operated lever is often used to control oil flow rate as well as direction. The operator can see what the machine is doing, and can adjust the lever to alter the size of the orifice inside the valve, and thereby regulate the oil flow rate to the actuator. Remotely controlled directional valves are not suitable for flow-rate control because they can be set only in two or three definite positions. Remote control of flow rate requires more complex equipment called servo controls.

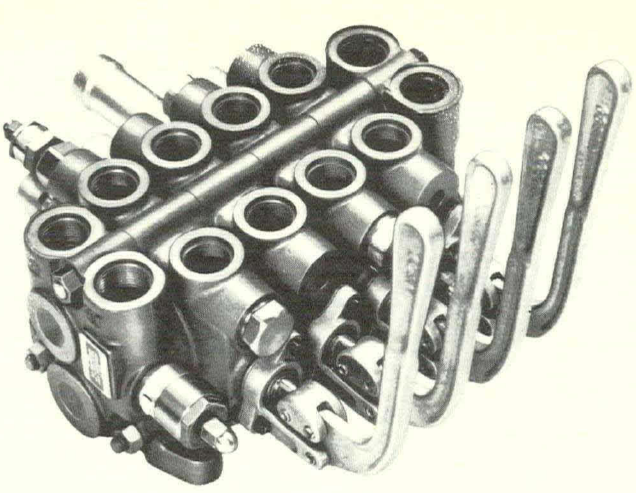

FIG. 40. Banked four-way valves — manually operated

8.5.2.2.8 *Three-way valve* When a hydraulic actuator is a single-acting cylinder or a motor with a shaft that rotates only in one direction, a four-way control valve may not be necessary. The single-acting cylinder has one oil port, and a single service port on the directional control valve is all that is needed. A unidirectional motor only has to be switched on and off, and it, too, can be controlled by a valve with only one service port. A directional control valve with three ports is called a three-way valve. It has a pressure port, one service port, and a tank port, or alternatively a pressure port and two service ports. In the first case it controls a single-acting cylinder, and in the latter case, where it is called a diverter valve, it can be used to control a unidirectional motor or direct pump flow into either one of two circuits. If the three ports of the three-way valve have the same pressure rating the valve may be used for either purpose. If one port is the tank port, the pressure capacity of the tank port must be checked before the valve is used as a diverter. Three-way valves are generally simpler in construction and not as versatile in application as the four-way valve. Often it is convenient to convert a four-way valve to a three-way valve by simply blocking one service port or connecting it to a reservoir.

8.5.2.2.9 *Check valve* The simple two-port poppet valve is classed as a directional control because it allows oil to flow through freely in one direction but prevents flow in the reverse direction. It is a unidirectional flow control and often called a nonreturn valve, and where it has a spring to hold the poppet on its seat is called a check valve. In early types of check valve a steel ball was used as the poppet and was held on the seat by a light spring. Modern, high-performance check valves have specially designed poppets to permit high flow with low pressure drop and give smooth, quiet operation. The check valve cracking pressure is the pressure that must build up in the inlet of the valve to just lift the poppet off its seat against the spring, and allow only a trickle of oil to flow

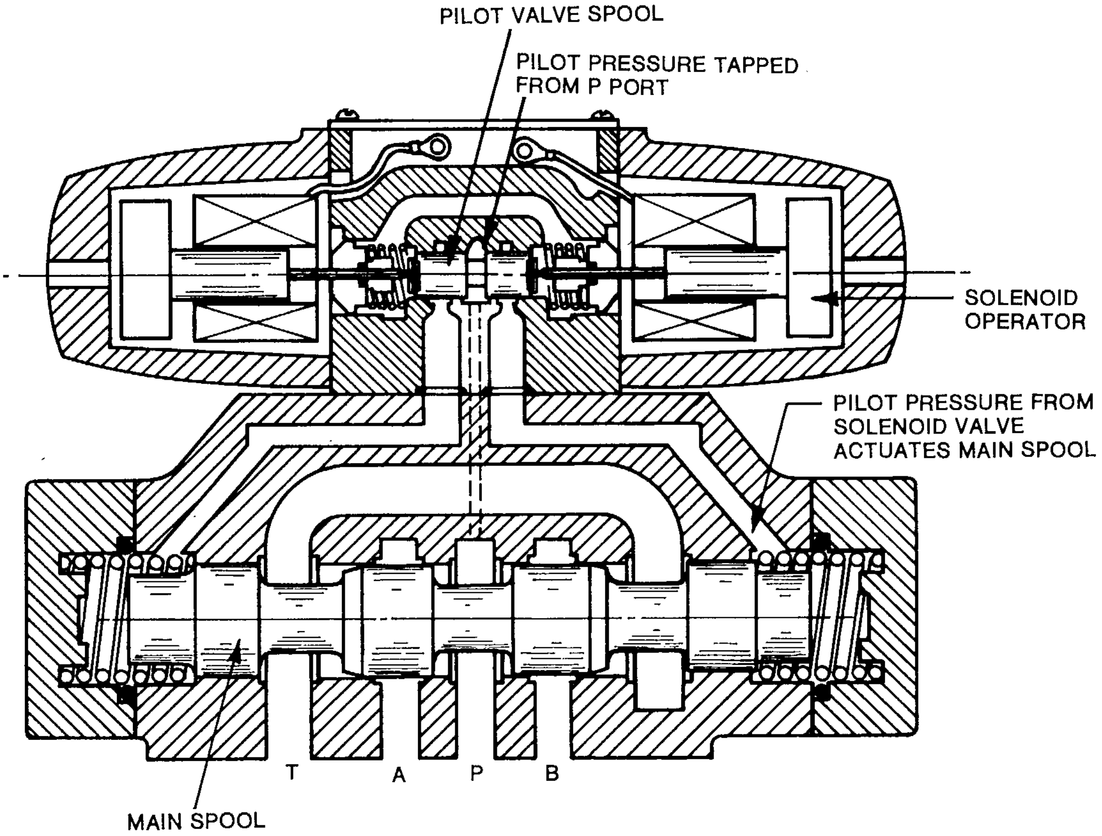

FIG. 41. Solenoid actuated, pilot-operated, four-way valve

through. As flow rate through the valve increases, the poppet is pushed back and compresses the spring. This requires more force, therefore, the pressure must rise above the cracking pressure to permit the additional flow. The check valve can also be regarded as a pressure control valve as it prevents flow until a certain pressure is reached. Check valves are available with cracking pressures from less than 1 psi to 75 psi and the higher the cracking pressure, the more the valve acts like a direct acting relief valve and it is often used for that purpose. The check valve (poppet valve) has a good sealing characteristic and is, therefore, useful as a lock valve. Such a valve is essential if a hydraulic cylinder must support a load for long periods of time, but when the valve is used for load holding, the hydraulic cylinder seals must also be leakproof to ensure the load will not lower (Fig. 42).

8.5.2.2.10 *Pilot-operated check valve* Oil flows through a standard check valve in one direction only. The pilot-operated check valve is a standard check valve with a small built-in hydraulic cylinder called a pilot cylinder. The piston rod of this pilot cylinder is arranged to push against the underside of the poppet. The area of the pilot cylinder piston is several times larger than the poppet. If a lower pressure from another part of the circuit is delivered to the pilot cylinder the piston lifts the poppet off its seat and allows oil to flow back through the valve. The pilot-operated check valve is useful but must be applied carefully. Remember, it is a two-position valve, is either open or closed, and will not control flow rate (Fig. 43).

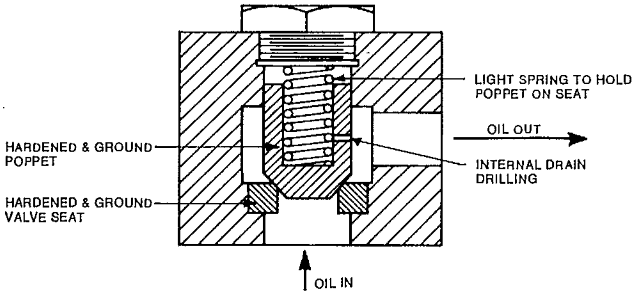

FIG. 42. Check valve

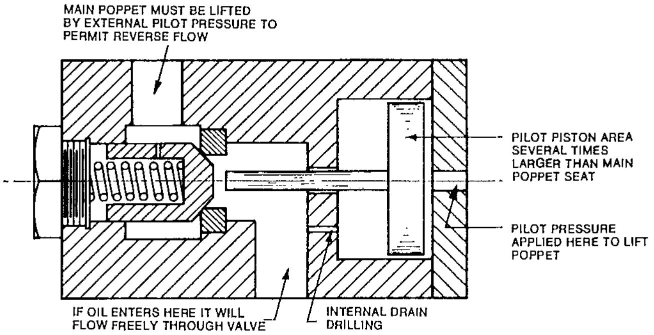

FIG. 43. Pilot-operated check valve

8.5.2.2.11 *Hydraulic control valve combinations* Pressure controls and flow controls discussed in this Booklet are the fundamental valves that control the oil in a hydraulic circuit. However, it is sometimes convenient to combine two or more types of valves in one housing. For example, a four-way valve may contain a built-in relief valve. A pressure control valve allows flow in one direction only, and a check valve is often included in the same housing to allow the oil to flow freely in the reverse direction. Other off-the-shelf combinations exist and several valves may be mounted on (or in) a manifold. A manifold is a block of metal, usually cast iron or aluminum, containing drilled passages that replace the pipes which normally connect the valves together. This permits the valve assembly to be compact and at the same time the amount of interconnecting piping is reduced.

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	Part II.	Principles of Hydraulic Power Transmission
Booklet 2		Power Transmission Components
Booklet 3		Oil-Conditioning Components
Booklet 4	Part I.	Hydraulic Power Transmission Standards and Symbols
	Part II.	System Design
Booklet 5		Installation of Hydraulic Power Transmission Systems
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