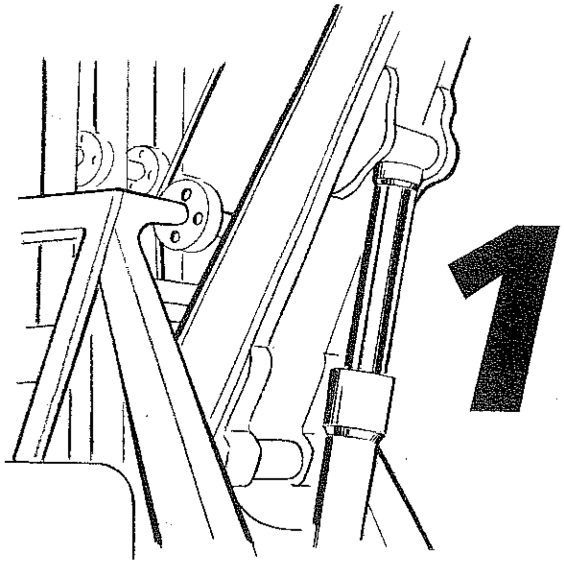
HYDRAULICS - HOW IT WORKS



BASIC PRINCIPLES OF HYDRAULICS

The basic principles of hydraulics are few and simple:

- **Liquids have no shape of their own.**
- **Liquids are practically incompressible.**
- **Liquids transmit applied pressure in all directions, and act with equal force at right angles to all surfaces.**
- **Liquids under pressure follow the path of least resistance.**
- **Pressure can be created only by a resistance to flow.**
- **Flow across an orifice results in a pressure drop that is directly proportionate to the flow and inversely proportionate to the area of the orifice opening.**
- **Hydraulic systems can provide great increases in work force.**
- **Energy put into a hydraulic system in the form of flow under pressure will result in either work or heat.**

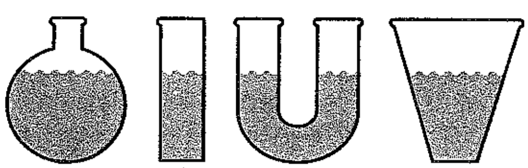


Fig. 1 - Liquids Have No Shape of Their Own

LIQUIDS HAVE NO SHAPE OF THEIR OWN. Liquids take the shape of any container (Fig. 1). Therefore fluid will flow in any direction and into a passage of any size or shape.

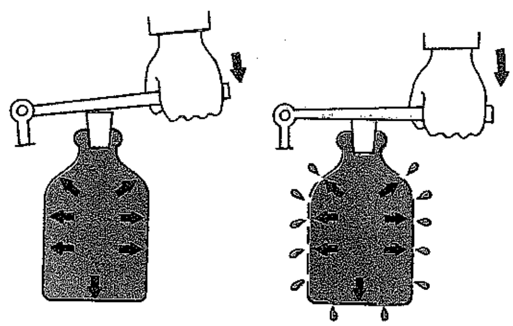


Fig. 2 - Liquids Are Practically Incompressible

LIQUIDS ARE PRACTICALLY INCOMPRESSIBLE. For safety reasons, we obviously wouldn't perform the experiment shown in Fig. 2. We will fill the container with a liquid and insert a cork. If we were then to push down on the cork with enough force, the container would bulge or break because the liquid would not compress.

NOTE: Liquids do compress slightly under pressure, but from a practical point, the amount is negligible.

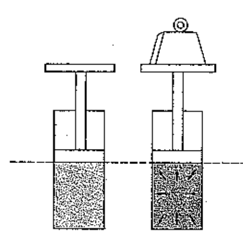


Fig. 3 - Liquids Transmit Applied Pressure Equally in All Directions

LIQUIDS TRANSMIT APPLIED PRESSURE IN ALL DIRECTIONS. The experiment in Fig. 2 shattered the glass jar and also showed how liquids transmit pressure in all directions when they are put under compression. This is very important in a hydraulic system. In Fig. 3, when a weight is added a force is applied to the liquid. The pressure is the same at every point on the cylinder and piston. The force acts at right angles to all surfaces.

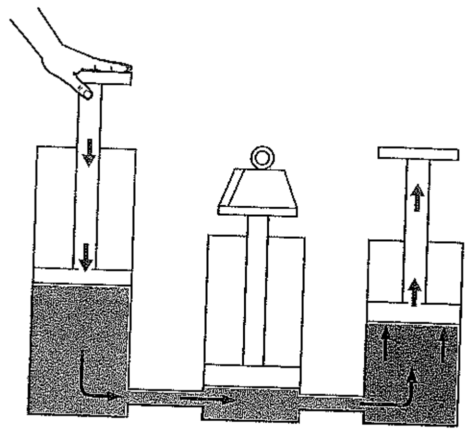


Fig. 4 - Liquids Follow the Path of Least Resistance

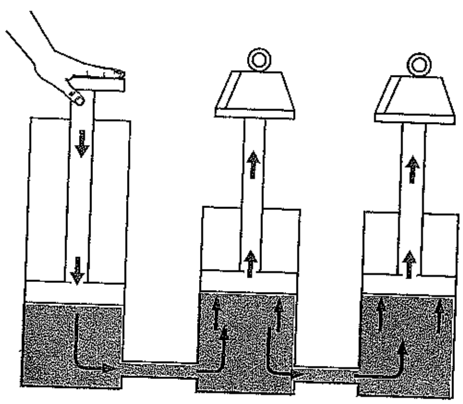


Fig. 5 - Paths of Equal Resistance

LIQUIDS UNDER PRESSURE FOLLOW THE PATH OF LEAST RESISTANCE. Refer to the three cylinders in Fig. 4. One cylinder has a weight on the piston. If a weight is applied to one of the unweighted pistons, the fluid would become pressurized and that pressure would act on the other two cylinders. The unweighted cylinder would extend while the weighted cylinder would remain stationary. The weighted cylinder would extend only after the unweighted one reached the end of its stroke.

If equal weights are added to both cylinders (Fig. 5), the pistons will rise at the same time as force is applied to the third cylinder. Both cylinders offer the same resistance to fluid flow.

PRESSURE CAN BE CREATED ONLY BY RESISTANCE TO FLOW. In Fig. 4, pressure built in the system as the piston was pushed down would be negligible as it could not exceed that necessary to raise the unweighted cylinder. When the unweighted cylinder reached the end of its stroke, the pressure would then be limited to that necessary to raise the weighted cylinder. When the second cylinder reaches the end of its stroke, the pressure is limited only by the amount of force exerted on the first cylinder.

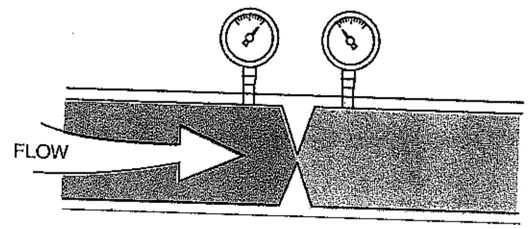


Fig. 6 - Flow Across an Orifice

FLOW ACROSS AN ORIFICE CAUSES A PRESSURE DROP

Flow across an orifice results in a pressure drop which is proportional to the square of the flow and inversely proportional to the square of the area of the orifice opening.

In Fig 6:

1. With a constant flow	1. Changing the orifice size will change the pressure drop across the orifice. *Increase opening — Decrease pressure drop* *Decrease opening — Increase pressure drop*
2. With constant inlet pressure (Variable displacement Pump)	2. Changing the orifice size will change the flow. *Increase opening — Increase flow* *Decrease opening — Decrease flow*
3. With constant inlet pressure (Variable displacement Pump)	3. Changing the outlet pressure will change flow. (It changes differential pressure) *Increased outlet pressure — Decreased flow* *Decreased outlet pressure — Increased flow*
4. With a fixed orifice size	4. Changing the inlet pressure will change the flow. *Increase pressure — Increase flow* *Decrease pressure — Decrease flow*
5. With a fixed orifice size	5. Changing the flow will change the pressure drop across the orifice. *Increased flow — Increased pressure drop* *Decreased flow — Decreased pressure drop*

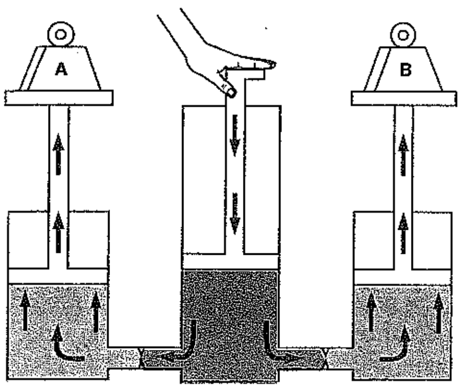


Fig. 7 - Orifices Control Flow and Pressure Drops

In Fig. 7, we will connect three cylinders. Equal sized orifices will be installed in the connecting lines. Equal weights A and B will be placed on the outside cylinders. These weights will be such that it will require 50 psi (345 kPa) in the cylinders to raise them.

On the center cylinder, we will push with a force that will create 100 psi (690 kPa) in the cylinder. The restriction of the orifices will allow the pressure to rise to100 psi (690kPa) in the center cylinder. Pressure will drop to a level necessary to lift the load (50 psi-345 kPa) as it passes through the orifices.

ENERGY PUT INTO A HYDRAULIC SYSTEM CANNOT BE DESTROYED. Energy is put into a hydraulic system in the form of fluid flow under pressure. This energy can accomplish work by moving a load with a cylinder or motor. Any oil that loses pressure without accomplishing work is turned to heat. This heat (loss of energy) can be the result of a line restriction.

In the example in Fig. 7, oil was pressurized to 100 psi (690 kPa). It required only 50 psi (345 kPa) to raise the load. Therefore, 50% of the energy created by pushing on the center cylinder went to work and 50% went to heat. This heating occurred when the oil dropped pressure as it passed through the orifices.

This type of restriction can be an essential part of the hydraulic system operation. However, it can also be undesirable when caused by hoses and lines which are too small, when fittings are restricted, when there is internal leakage in the system, or when oil is unnecessarily metered to a hydraulic function.

LIQUIDS CAN PROVIDE A GREAT INCREASE IN WORK FORCE. In Fig. 8, we have cylinders of different sizes connected with a tube. The piston in Cylinder A has an area of one square inch (6.45 cm2), but the piston in Cylinder B has an area of ten square inches (64.5 cm^2).

This time we'll place a 10-pound (45 N)(4.5 kg) weight on Cylinder B. Because the area of the piston is ten square inches (64.5 cm^2), the ten pound (45 N)(4.5 kg) weight will cause a force of one pound (4.5 N)(0.45 kg) on each square inch (6.45 cm^2) of the surface contacted by the oil. Or a pressure of one pound per square inch (1 psi.)(7 kPa).

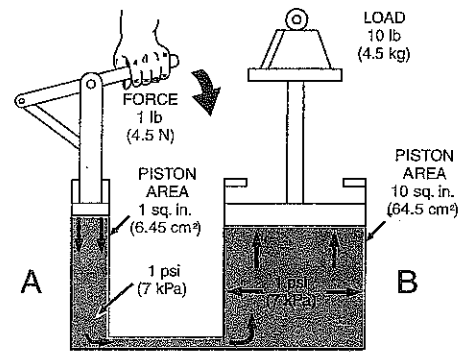


Fig. 8 - Liquids Can Provide a Great Increase in Work Force

We'll again push down on Cylinder A. It will require a force of one pound (4.5 N)(0.45 kg) to build the 1 psi (7 kPa) to move the weight up. Thus, a force of one pound (4.5N)(0.45 kg) is able to lift a10 pound (45 N)(4.5 kg) weight. It must be noted that for each inch (1 in)(2.45 cm) of travel of Piston A, Piston B will travel only 1/10 (0.1) inches (0.245 cm).

PRESSURE, AREA, DISPLACEMENT, AND FLOW

Pressure is force per unit of **Area**. U.S. customary measurement for pressure is pounds per square inch of surface area (psi). The metric unit of measurement for pressure is the Pascal (Pa.) or Newton per square meter (N/m2). The unit is often given in kilopascals (kPa) which is equal to 1000 Pascals. 1 kPa would be 1 kg acting on an area of 100 cm^2.1 psi is about 7000 Pa or 7 kPa.

NOTE: The force exerted by a piston can be determined by multiplying the piston area by the pressure applied.

Displacement is a term used for volume. It is piston area multiplied by stroke length, when referring to a cylinder (Fig. 9) or the quantity of fluid delivered in one cycle when referring to hydraulic pumps (See Chapter 4).

Two hydraulic cylinders can have the same displacement, even if they have different dimensions (Fig. 10). Displacement is usually rated in cubic inches (cu. in.) cubic centimeters (cms.), liters (l) or milliliters (mL).

Flow is the volume of fluid moved per unit of time. The flow rate for fluid flowing to the double-acting lift cylinders on a loader (Fig. 13) determines the speed the operator lifts the load. Flow is measured in gallons per minute (gpm) or liters per minute (L/min).

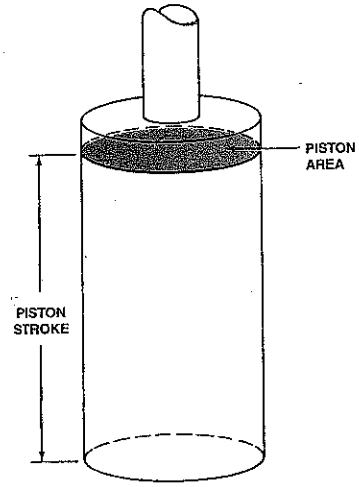


Fig. 9 - Displacement is Stroke Multiplied by Piston Area

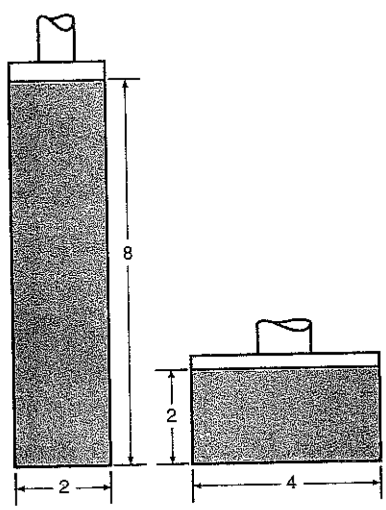


Fig. 10 - Both Cylinders Have the Same Displacement

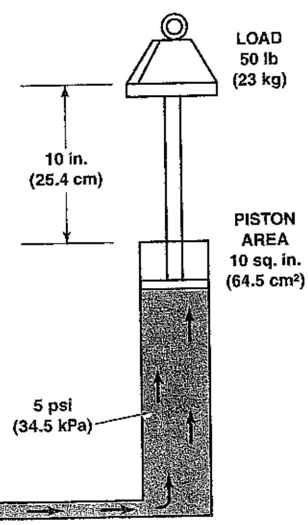


Fig. 11 - Force is Pressure Multiplied by Area
Work is Force Multiplied by Distance Traveled

FORCE, WORK, AND POWER

Force is pressure multiplied by the area to which the pressure is applied. In Fig. 11, the system is exerting 50-lb (222.5 N) of force or 5 psi times 10 square inches (34.5 kPa times 64.5 cm^2).

Work is force multiplied by distance. In Fig. 11, the piston is raising a load using 50 Lb (23 kg) over a distance of 10 inches (25.4 cm). 500 Lb-in. (56.5 N·m) of work is performed.

In some of the previous examples, force was applied, but no movement occurred. There was, therefore, no work accomplished.

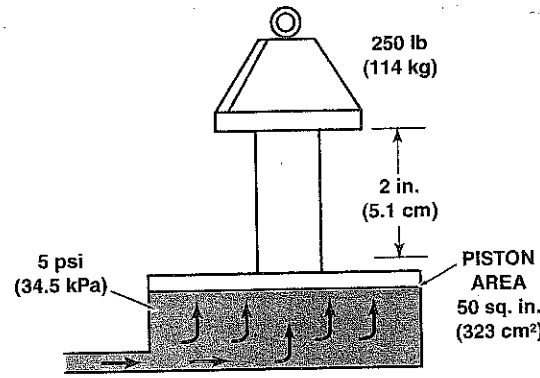


Fig. 12 - Force Increases if Cylinder Area Increases

In Fig. 12, a larger cylinder, with five times the piston area as the one shown in Fig. 11, is raising a 250-Lb (114-kg) load a distance of 2 inches (5.1 cm). With the same pressure and volume of oil input, the force will be 5 times as great, however, the work performed is equal because the load is raised only 2 in. (5.1 cm.). So 500 Lb-in. (56.5 Nm) of work is performed in both examples.

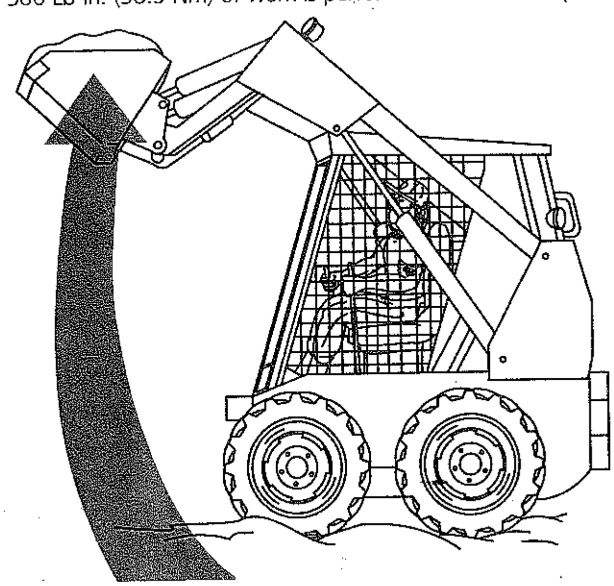


Fig. 13 - Time is a Factor

The term **power** adds the dimension of time to work. If one machine can do the same amount of work as another in less time, it has developed more power.

Power equals work per unit time.

ADDITIONAL CONCEPTS NEEDED TO UNDERSTAND A HYDRAULIC SYSTEM

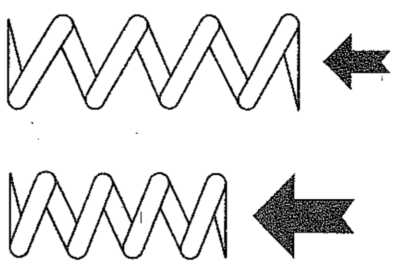


Fig. 14 - Spring Force

The Spring requires more and more force as the spring is compressed. The spring will always return to a specific length when a specific force is applied to it. These characteristics will be used in flow and pressure regulation on many of the hydraulic components covered in this manual.

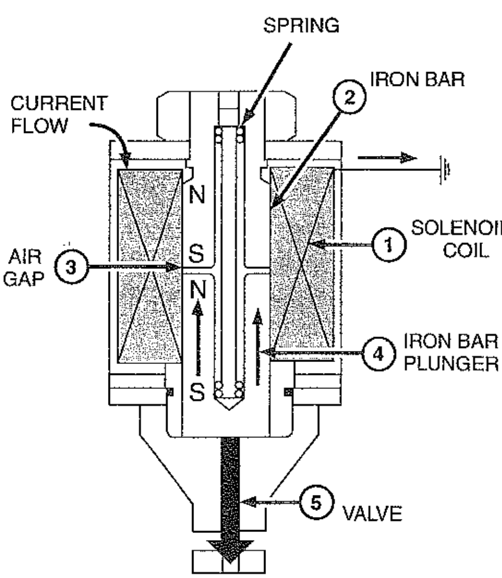


Fig. 15 - Electrical Solenoid

An Electrical Solenoid can be used to control hydraulic systems. It consists of an electrical winding (coil) and an armature (steel bar)(Fig. 15). As an electrical current is passed through the windings, it creates a magnetic field. The field magnetizes the iron bars and causes the plunger (armature) to compress the spring and move toward the stationary bar.

The solenoid in Fig. 16 is attached to a two position, three way valve. Full system voltage is applied to the windings. The magnetic field moves the armature against a spring force to open the valve. The valve sends oil to the circuit and blocks the return flow.

When the solenoid is deenergized, the spring will return the valve to the closed position, blocking pressure oil and dumping the circuit oil.

The strength of the magnetic field is determined by the current flowing through the windings. If a partial voltage were applied to the windings in Fig. 15, a weaker magnetic field will be developed. This would move the armature against the spring with less force, partially compressing the spring and partially opening the valve. As the voltage is increased, the stronger field will compress the spring further and open the valve further. In this way, we can have infinite positions of the valve.

The voltage to the solenoid can be controlled by an Electronic Control Unit (ECU) to provide infinite control of flows and pressures in hydraulic systems.

Reversing the current flow in the solenoid would force the armature in the opposite direction. This is used in some equipment where operation of a three-position valve is required.

HOW A HYDRAULIC SYSTEM WORKS

Let's build up a hydraulic system, piece by piece. The heart of the hydraulic system is the PUMP and the CYLINDER or MOTOR with LINES to connect them.

1. The PUMP which moves the oil (Converts linear or rotary energy into fluid energy).

2. The CYLINDER uses the moving oil to do work (Transfers the fluid energy back into a linear or rotating force to do work).

3. The LINES carry the fluid from one hydraulic component to another.

In Fig. 17, when you apply force to the lever, the hand pump forces oil into the cylinder. The pressure of this oil pushes up on the piston and lifts the weight. The pump has converted a mechanical force to hydraulic power, the line has carried it to the cylinder and the cylinder has converted the hydraulic power back to a linear force.

The load has moved up, but if the hand pressure is released, the oil would be forced back to the pump by the load.

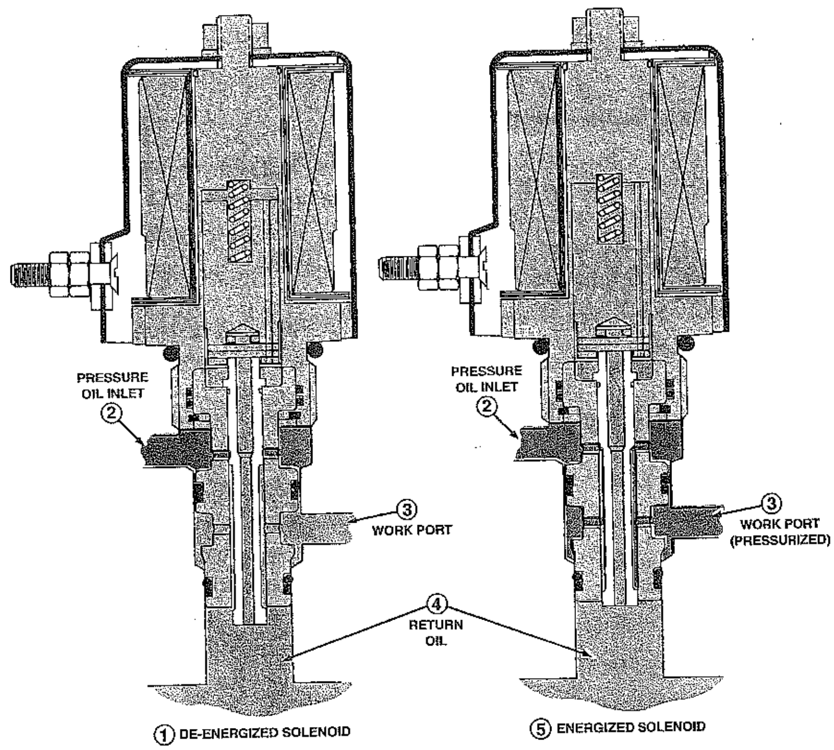


Fig. 16 - Solenoid Valve

We must therefore add a CHECK VALVE to trap the oil in the cylinder.

4. The CHECK VALVE (Fig. 18) allows fluid to pass freely into the cylinder as the fluid pushes the ball off its seat. When the flow stops the spring pushes the ball on the seat trapping the fluid in the cylinder.

So that the pump can have a supply of fluid to continue to move the load, we add a RESERVOIR.

5. The RESERVOIR is a vented container, which contains fluid to be forced by gravity or atmospheric pressure into the pump piston when retracted.

To prevent fluid from being forced back to the reservoir on the power stroke, a second check valve is installed.

Notice that the pump is smaller than the cylinder. This means that with each stroke of the pump, the piston will move only a small amount. The load lifted by the cylinder is much greater than the force applied to the pump piston.

If you want to lift the weight faster, then you must work the pump faster, increasing the volume of oil to the cylinder.

To lower the cylinder, we would need to add a line with a shutoff valve connecting the cylinder to the reservoir.

The system we have just described is a system that might be found on a hydraulic jack or a hydraulic press. To meet the hydraulic requirements in most other applications, however, we must provide a greater quantity of oil at a more consistent rate and be able to have better control of the oil movement.

To make a more usable system, let's add some new features as shown in Figs. 19 and 20.

In Fig. 19, the hand pump has been replaced with a gear-type pump. This pump will supply a continuous flow of oil. The gear pump is one of many types of pumps that transform the rotary force of a motor or engine to hydraulic energy. For more on pumps, see Chapter 4.

The cylinder has also been changed. It has two lines connected to it; one at the top and one at the bottom. The cylinder cavity is sealed above as well as below the piston. These features make this a **double-acting cylinder**.

Fluid from the bottom line supplies fluid to lift the cylinder piston. Fluid from the top line supplies fluid to push the piston back down.

The cylinder in Fig 17 is a **single-acting cylinder**. It has a hydraulic line to only one end of the cylinder and can push the load in only one direction. The only way to get the load back down is to release the oil so that the load will lower by gravity.

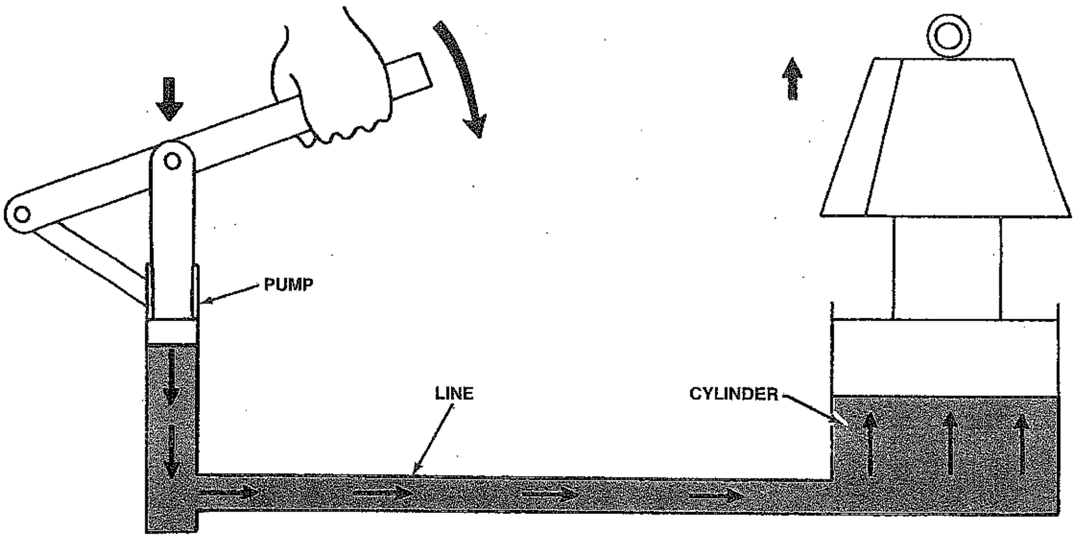


Fig. 17 - A Basic Hydraulic System

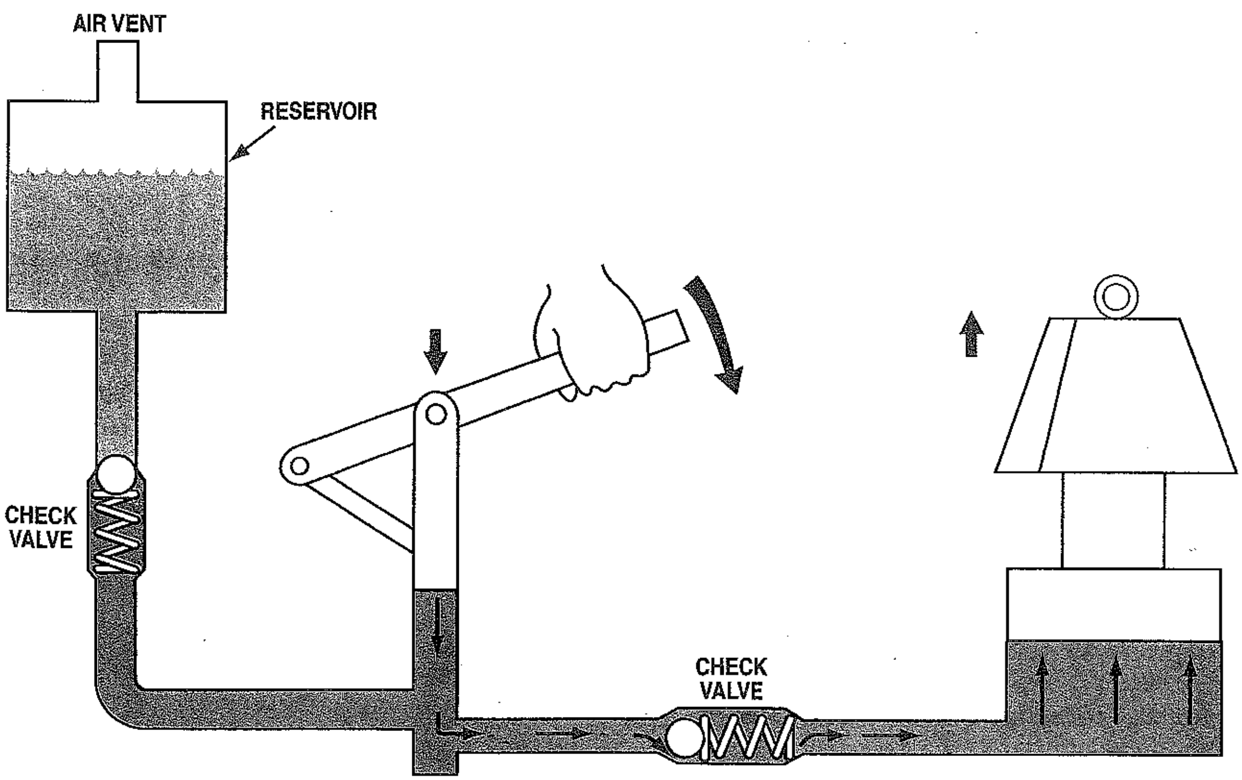


Fig. 18 - Reservoir and Check Valves Added

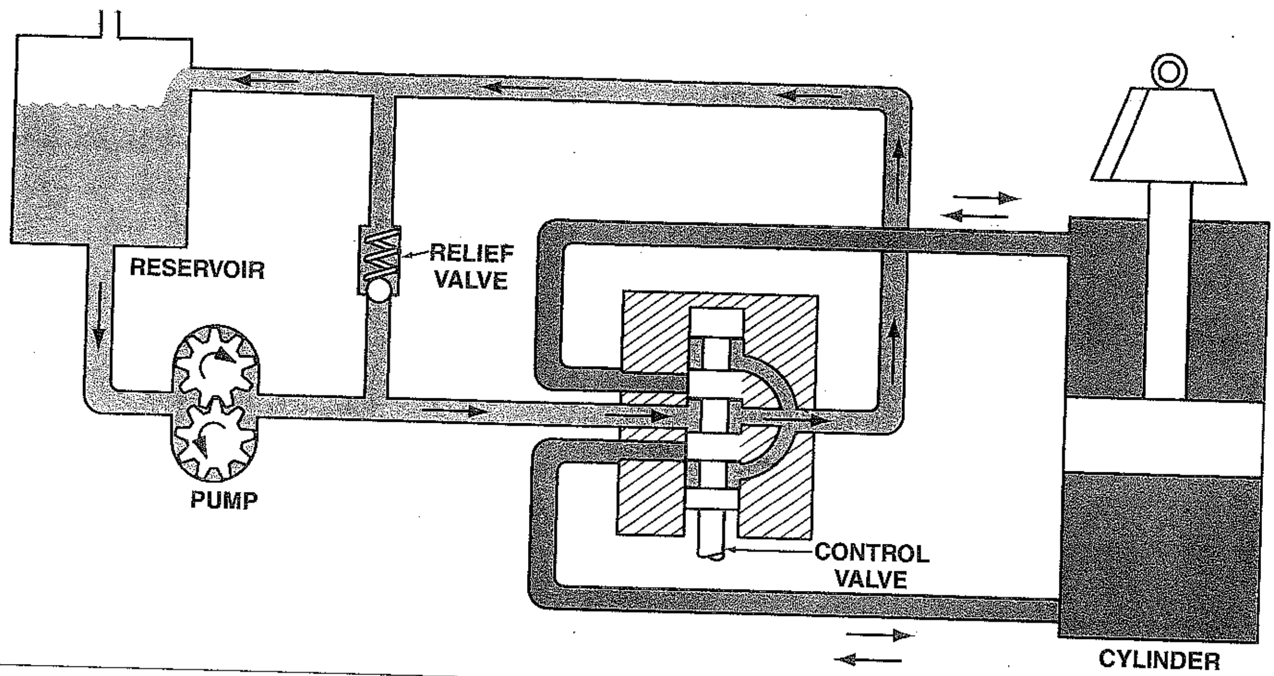


Fig. 19 - Hydraulic System with Relief Valve and Double-Acting Cylinder

To direct the pump fluid to both ends of the cylinder and to the reservoir, we need to add a CONTROL VALVE.

6. The CONTROL VALVE directs the oil. This allows the operator to control the constant supply of oil from the pump to and from the hydraulic cylinder. When the control valve is in the neutral position shown in Fig. 19, the flow of oil from the pump goes directly through the valve to a line that carries the oil back to the reservoir. At the same time, the valve has trapped oil on both sides of the hydraulic cylinder, thus preventing its movement in either direction.

When the control valve is moved down (Fig. 20), the pump oil is directed to the cavity on the bottom of the cylinder piston, pushing up on the piston and raising the weight. At the same time, the line at the top of the cylinder is connected to the return passage, thus allowing the oil forced from the topside of the piston to be returned to reservoir.

When the control valve is moved up (not shown), pump oil is directed to the top of the cylinder, lowering the piston and the weight. Oil from the bottom of the cylinder is returned to the reservoir.

When the cylinder reaches the end of its stroke, there is nowhere for the fluid from the pump to go. The pump will continue to pump fluid until something fails (hose, driveshaft, cylinder, etc.).

To limit the pressure in a hydraulic system, we will add a RELIEF VALVE.

7. The RELIEF VALVE limits the maximum pressure in the system. When the load is too great or when the cylinder bottoms, the pressure will rise. That pressure acts against the ball which is held on its seat by the spring. When the pressure is high enough to force the ball off its seat, it allows fluid to flow to the reservoir.

This completes our basic hydraulic system. We have used 7 components to do this. The modern hydraulic system will use many if not all of these.

SUMMARY

To summarize:

1. The **pump** = generates flow - converts mechanical energy to hydraulic energy.
2. The **cylinder** or **motor** = converts hydraulic energy back to mechanical energy.
3. The **lines** = carry the fluid to the hydraulic components.
4. The **check valve** = controls the flow of fluid, allowing it to go in only one direction in a line.
5. The **reservoir** = contains a reserve of fluid for the system.
6. The **control valve** = directs the flow of fluids to the proper components.
7. The **relief valve** = protects the system from high pressures.

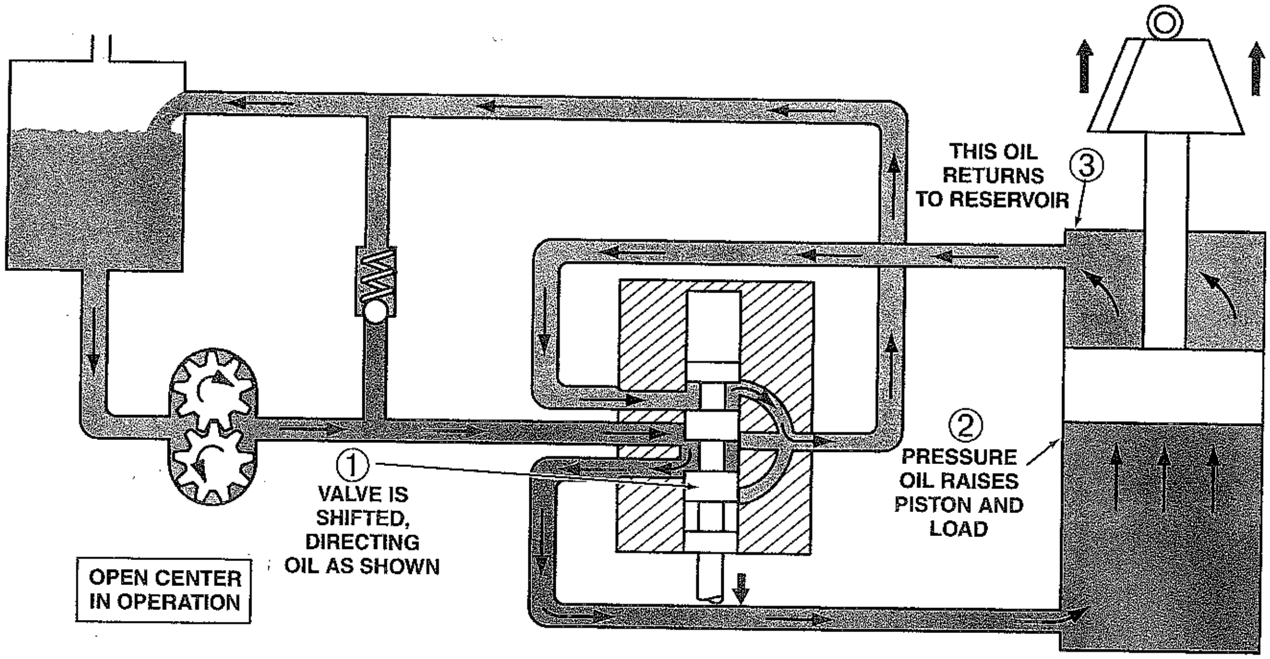


Fig. 20 - Hydraulic System in Operation

For more details on how these parts operate, go to Chapter 4 - Pumps, Chapter 5 - Valves, Chapter 6 - Cylinders, Chapter 10 - Reservoirs and Oil Coolers, and Chapter 11 - Lines and Couplers

THE PROS AND CONS OF HYDRAULICS

As you have seen in the simple hydraulic system we have just developed, the purpose is to transmit power from a source (engine or motor) to the location where this power is required for work.

To look at the advantages and disadvantages of the hydraulic system, let's compare it to the other common methods of transferring this power. These would be mechanical (shafts, gears, belts, chains, or cables) or electrical.

ADVANTAGES

1. FLEXIBILITY—The mechanical method of power transmission requires that the positions of the engine and work site remain relatively constant. With the flexibility of hydraulic lines, power can be sent to almost any location.

2. MULTIPLICATION OF FORCE—In the hydraulic system, very small forces can be used to move very large loads simply by changing cylinder sizes.

3. SIMPLICITY—The hydraulic system has fewer moving parts, fewer points of wear. And it lubricates itself.

4. COMPACTNESS—Compare the size of a small hydraulic motor with an electric motor of equal horsepower. Then imagine the size of the gears shafts and levers that would be required to create the forces which can be attained with a small hydraulic press. The hydraulic system can handle more horsepower for its size than either of the other systems.

5. ECONOMY—As the result of simplicity and compactness, cost for the amount of power transmitted is relatively low. Also, power and frictional losses are comparatively small.

6. SAFETY—There are fewer moving parts such as gears, chains, belt and electrical contacts than in other systems. Controlling overloads with relief valves is much simpler than the troublesome overload devices used on the other systems.

7. DURABILITY—With proper care and fluids, they can outlast the other systems.

DISADVANTAGES

1. EFFICIENCY—While the efficiency of the hydraulic system is much better than the electrical system, it is not as efficient as most mechanical systems of transmitting power.

2. NEED FOR CLEANLINESS—Failure to use proper cleanliness and maintenance practices can result in damage from rust, corrosion, dirt, heat and breakdown of fluids.

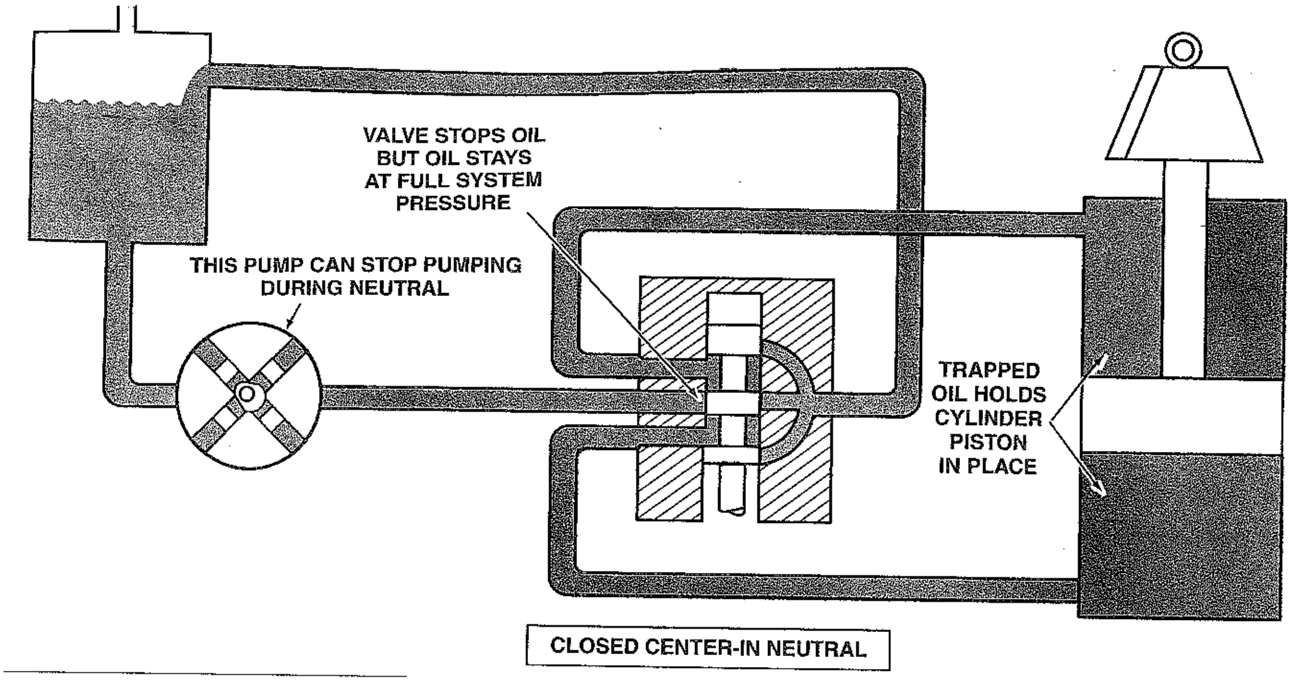


Fig. 21 – Closed-Center System in Neutral

OPEN-CENTER and CLOSED-CENTER HYDRAULIC SYSTEMS

There are many types of systems used on today's equipment. They fall into two major types determined by the type of control valves they use.

- **Open-Center Systems**
- **Closed-Center Systems**

The simple hydraulic system, which we developed earlier in this chapter (Fig. 19), is what we call an OPEN-CENTER SYSTEM. This system requires that the control valve spool be open in the center to allow pump flow to pass through the valve and return to the reservoir when the valve is in neutral. The pump we have used supplies a constant flow of oil and the oil must have a path for return to the reservoir when it is not required to operate a function.

In the CLOSED-CENTER SYSTEM, the control valve, on the other hand, blocks pump flow when the valve is in neutral. There is no passage to the reservoir while in neutral. It, therefore, requires a pump or a system that supplies oil only when needed. This can be done by using a pump that shuts itself off (takes break) when oil is not required to operate a function.

The open-center system is shown in neutral position in Fig. 19. It is shown in the operating position in Fig 20. Note that in neutral, pump oil flow is directed through the valves **open center** to the reservoir

CLOSED-CENTER SYSTEM

Let's look at a closed-center system with a variable displacement pump.

In neutral, Fig 21, the pump pumps oil until pressure rises to a predetermined level. Then a pressure-regulating valve allows the pump to shut itself off and to maintain this pressure to the valve.

When the control valve is operated as shown in Fig. 22, oil from the pump is sent to the bottom of the cylinder.

The drop in pressure caused by connecting the pump pressure line to the bottom of the cylinder causes the pump to go back to work, pumping oil to the bottom of the piston and raising the load.

When the valve was moved, the top of the piston was connected to a return line, thus allowing return oil forced from the piston to be sent to the reservoir or back to the pump.

When the valve is returned to neutral, oil is again trapped on both sides of the cylinder and the pressure passage from the pump is dead-ended. At this time, the pump again takes a break.

Moving the spool down (not shown), directs oil to the top of the piston, moving the load downward. The oil from the bottom of the piston is sent into the return line.

With the closed-center system, if the load exceeds the predetermined standby pressure or if the piston reaches the end of its stroke, the pressure build-up simply tells the pump to take a break, thus eliminating the need for relief valves to protect the system.

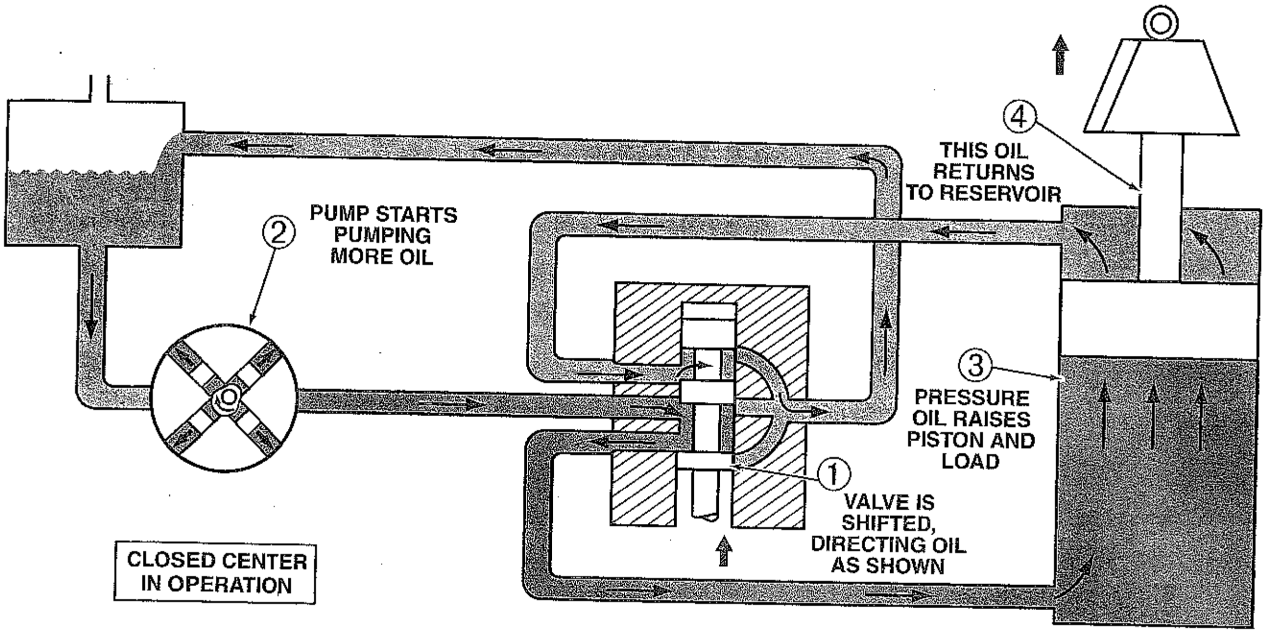


Fig. 22 - Closed-Center System in Operation - Raising a Load

We have now built the simplest of open- and closed-center systems. Most hydraulic systems, however, require their pump to operate more than one function.

Let's look at how this is done and compare the advantages and disadvantages of each system.

VARIATIONS ON OPEN- AND CLOSED-CENTER SYSTEMS

To operate several functions at once, hydraulic systems have the following connections:

OPEN-CENTER SYSTEMS

- *Fixed Displacement Pump with Open-Center Valves Connection in Series*
- *Fixed Displacement Pump with Open-Center Valves Connection in Series Parallel*
- *Fixed Displacement Pump with Flow Divider and Open-Center Valves*
- *Variable-Displacement Pump with Open-Center Valves*

CLOSED-CENTER SYSTEMS

- *Fixed Displacement Pump with Accumulator and Closed-Center Valves*
- *Fixed Displacement Pump with Priority Valve and Closed-Center Valves*
- *Pressure Sensing Variable Displacement Pump with Closed-Center Valves*
- *Load Sensing Variable Displacement Pump with Closed-Center Valves*

OPEN-CENTER SYSTEMS

Let's discuss each of these systems.

FIXED DISPLACEMENT PUMP WITH OPEN-CENTER VALVES CONNECTED IN SERIES

A multiple valve system with valves connected in series is shown in Fig 23. With all the valves in the neutral position, oil from the pump passes through each of the valves in series and returns it to the reservoir as shown by the arrows.

When a control valve is operated, incoming oil is diverted to the cylinder that the valve serves. Return oil from the cylinder is directed to the return line and on to the next valve. This system is satisfactory as long as only one valve is operated at a time. In this case, full pump flow and pressure are available to that cylinder.

However, if two or more valves are operated at the same time as in Fig. 24, all the oil goes to the first cylinder. Return oil from that cylinder is routed to the second valve. When this happens, the system pressure will be the sum of the pressures required to operate each of the activated cylinders.

In Fig. 24, if the pressure required to move the load on No. 1 cylinder is 900 psi(6205 kPa) and 1100 psi(7585kPa) is required for load on No. 2, the total system pressure would be 2000 psi (13,789 kPa). The return pressure from No. 1 cylinder would be 1100 psi (7584 kPa). Therefore, it would require 2000 psi(13,789 kPa) to overcome this pressure and supply the 900 psi (6205 kPa) required to move the No. 1 load.

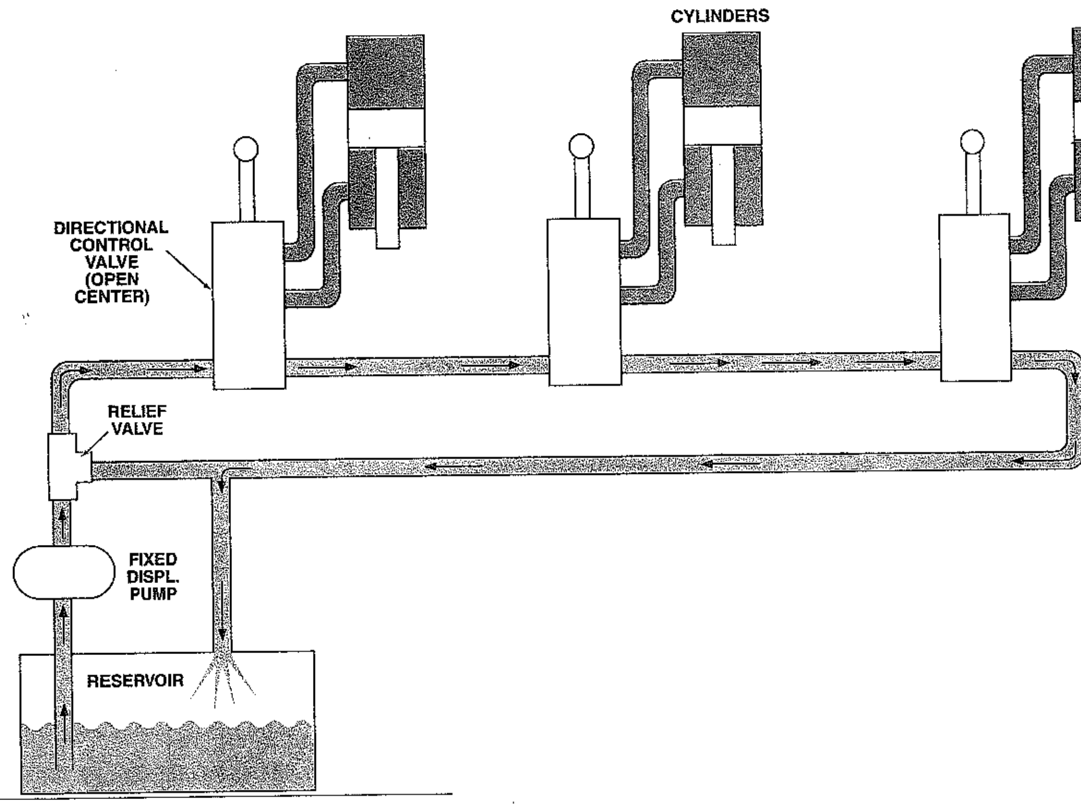


Fig. 23 - Open-Center System with Series Connection

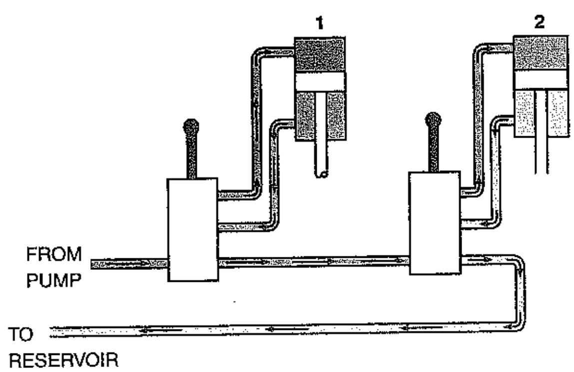


Fig. 24 - Series Valves Activated

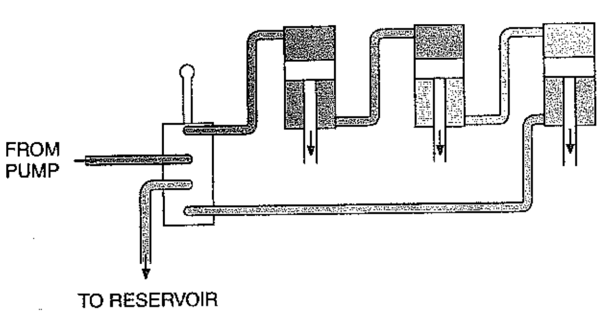


Fig. 25 - Cylinders Connected in Series

A more common application of the series hookups is shown in Fig. 25. A single valve operates several cylinders that are connected in series. Like the example used above, the system pressure is the sum of the pressures required to move each of the individual loads.

To keep the cylinders synchronized, the cylinders would bypass oil when fully extended. This would refill all cylinders in the event there was any leakage. This type of hookup is one that might be used where several functions need to be synchronized, such as raising a disc and its wing sections.

FIXED DISPLACEMENT PUMP WITH OPEN-CENTER VALVES WITH SERIES-PARALLEL CONNECTION

The system shown in Fig. 26 is the most common one used on open-center hydraulic systems. All of the valves in this system are commonly found in a single assembly. The individual valve sections are either bolted together (Stack Valve) or cast into a single housing (Unibody).

Oil from the pump is routed through the control valve in series. When all the valves are in neutral, this passage is open and allows oil to return to the reservoir. When any of the valves are activated, this passage is blocked.

There is also a parallel passage that connects to the valve inlet. This passage runs past all the valve spools and dead ends at the last section.

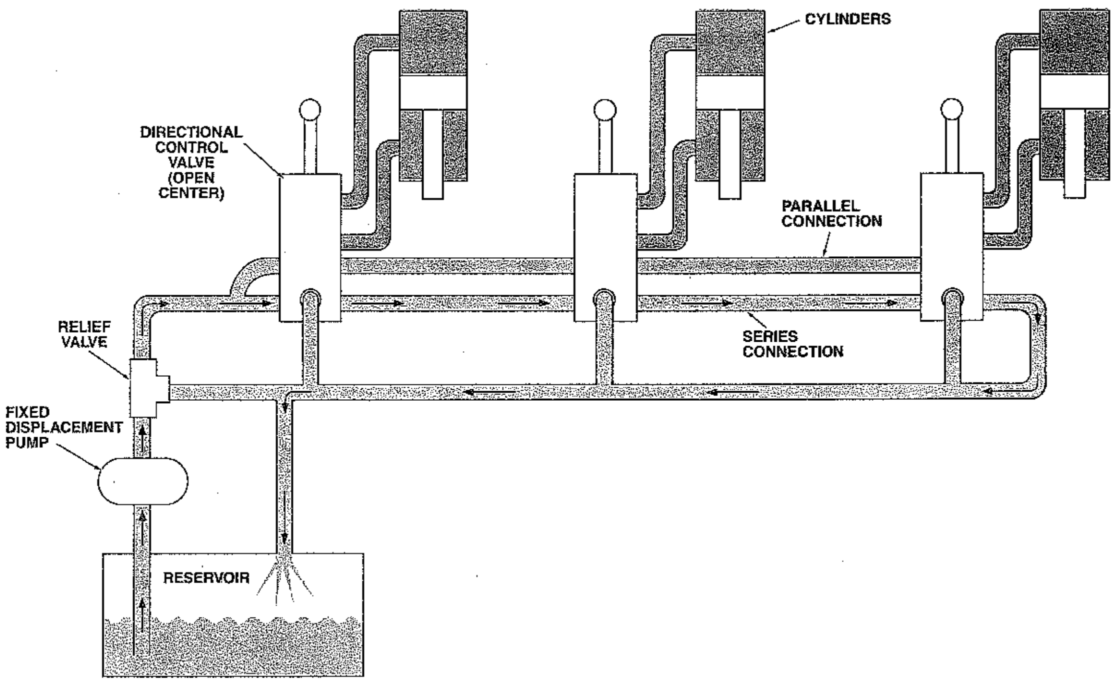


Fig. 26 - Valves with Series-Parallel Connection

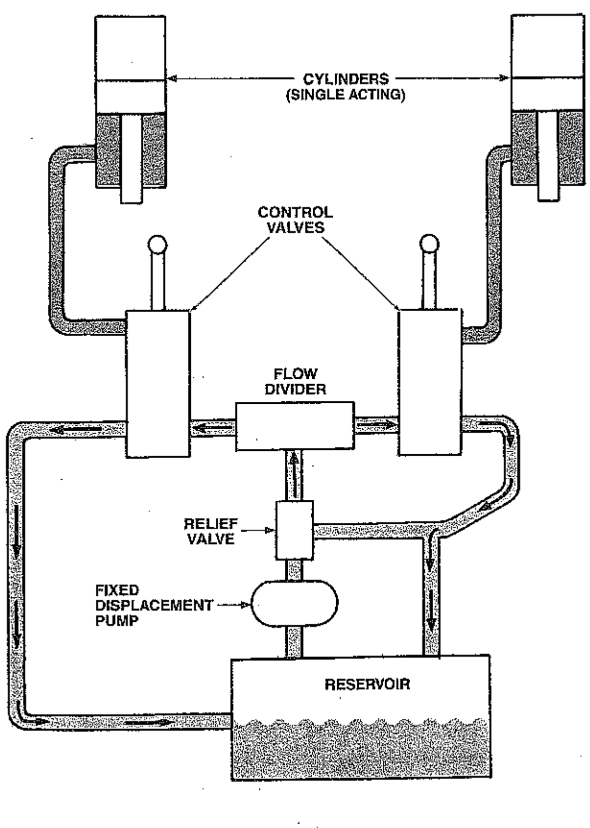


Fig. 27 - Open-Center System with Flow Divider

When any of the valves are operated, the neutral passage is blocked and the oil from the parallel passage is routed to a cylinder port of that valve. Oil in the parallel port is available equally to all of the valve spools.

When two or more valves are operated, the cylinder, which requires the least pressure, will move first and then the one requiring the next highest pressure.

In operation, the operator can meter the oil to the functions so that they will all move at the same time.

This valve can also be used on a closed-center system by blocking the neutral (series connection) passage.

FIXED DISPLACEMENT PUMP WITH FLOW DIVIDER AND OPEN-CENTER VALVES

Fig. 27 shows a flow divider used with an open-center system. The proportional flow divider splits the pump output flow and sends it proportionally to two different circuits. The percentage is designed into the valve and the flow will always go to each valve in those proportions regardless of the activity of the other valve. Those proportions can be 50%-50%, 25%-75%, etc.

In this type of system, the pump will always have to pump all the oil against the highest pressure needed in either circuit. If we had a 25%-75% divider and the "25%" circuit was operated and required 1500 psi (10,500 kPa), the pump would have to pump all the oil against that pressure even though only 25% is needed. The other 75% of the oil would lose it's pressure as it went through the flow valve. Because this pressure loss did not accomplish work, 75% of the energy put into pumping the oil would go into heat and only 25% into work.

A priority type flow divider can also be used in this system. This valve directs a specific flow of oil to the primary circuit before any is allowed to go to the secondary circuit. In some cases, the secondary circuit is simply a return to reservoir.

This system is used primarily where pump output varies greatly because of engine speeds and a constant flow of oil is required for the function, i.e. automotive power steering.

The same inefficiencies exist as described in the proportional dividers. For this reason, they are used primarily on functions that are not cycled frequently.

VARIABLE DISPLACEMENT PUMP WITH OPEN-CENTER VALVES

These systems are being used on machines like excavators on which the total engine output is used through the hydraulic system.

This system uses a variable displacement pump, which does not go completely out of stroke. Because there is always some oil being pumped, it is connected to a multiple section series-parallel open-center valve.

In Fig. 28, we show a typical system using a bent-axis axial piston pump and a multiple section series-parallel open-center valve. The valve spools are often operated hydraulically by pilot controllers.

When no valve is operated, the pump is held in the minimum flow position. Oil flows through the valves neutral passage and back to the reservoir. When any valve is operated, the controller allows the pump to increase its output. It then determines how much oil the hydraulic system needs and regulates the pump output flow to satisfy the requirements of the system. To control the flow, the controller receives the following signals:

1. Valve inlet pressure.

2. The highest work port pressure in the valve.

3. Reservoir return flow from the neutral passage of the valve.

4. The position of the valve spools (senses the highest Pilot Controller operating pressure).

Some systems may also sense engine speed and the output of a second hydraulic system.

Most systems use pressure lines to send the sensing pressures to the pump controller, however, some use electronic sensors and send signals to an Electronic Control Unit (ECU). The ECU

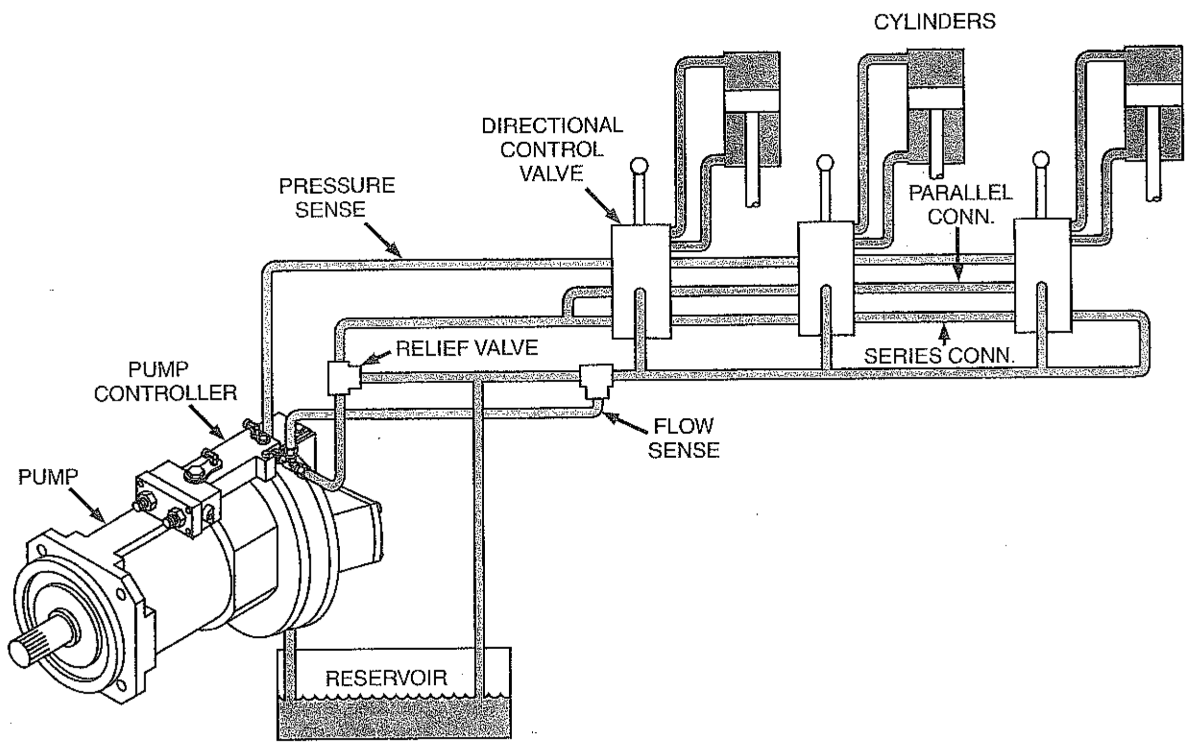


Fig. 28 - Variable Displacement Pump - Open-Center Valve

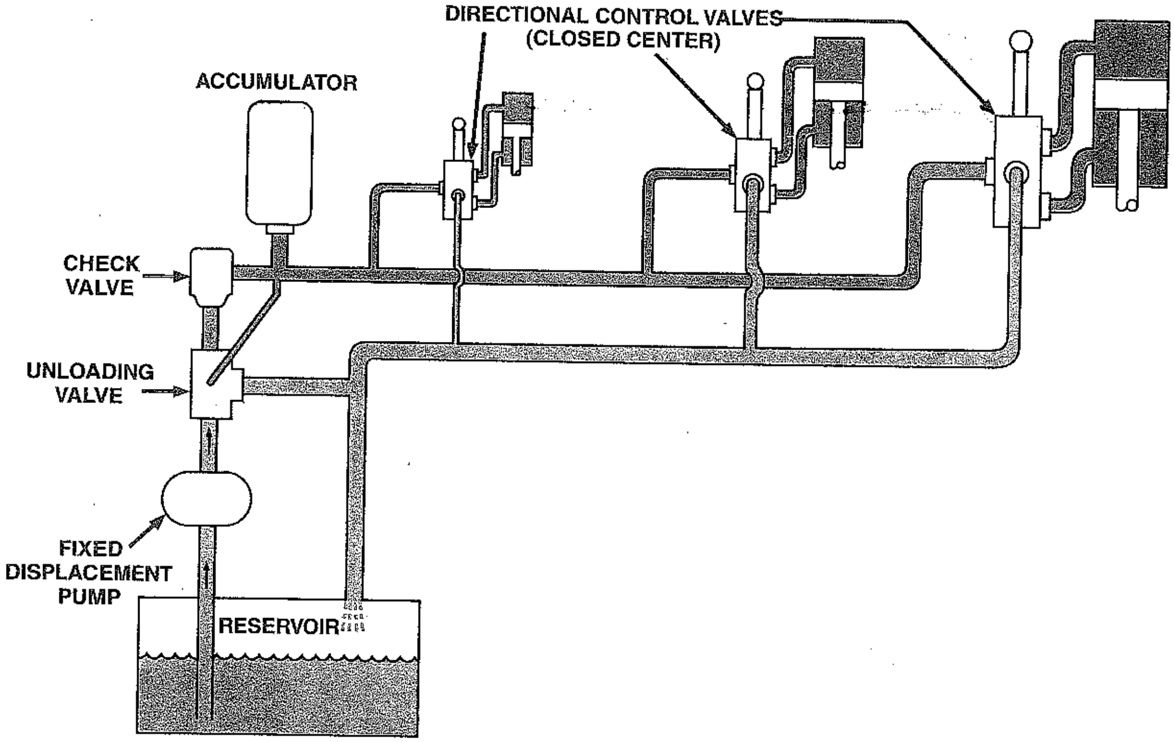


Fig. 29 - Closed-Center System with Fixed Displacement Pump and Accumulator

controls a variable electric solenoid that in turn operates a valve controlling the pump output.

These systems often have a load-limiting feature. On machines, such as excavators and backhoes, it is desirable to use the largest possible pump so that maximum production can be obtained at normal operating pressures.

With this high flow, the engine can be overloaded when full pressure and full flow are required. The load limiting valve senses the system operating pressure and slightly limits the pump output flow as maximum pressure is reached so the engine is not overloaded.

CLOSED-CENTER SYSTEMS

CLOSED-CENTER SYSTEM WITH FIXED DISPLACEMENT PUMP AND ACCUMULATOR

This system is shown in Fig. 29. A small fixed displacement pump charges an accumulator. When the accumulator is charged to full pressure, an unloading valve diverts the pump flow back to the reservoir. The check valve traps pressure oil in the accumulator circuit.

When a control valve is operated, the accumulator discharges its oil and actuates the cylinder. As pressure in the accumulator begins to drop, pump flow is again directed by the unloading valve to recharge the accumulator.

This system, using a small capacity pump, is effective only when operating oil is needed for short periods of time. Typical uses for this system would be for brakes, differential locks, rockshafts, etc. It is not practical when a steady flow of oil is needed.

FIXED DISPLACEMENT PUMP WITH PRIORITY VALVE AND CLOSED-CENTER VALVE

This system is shown in Fig. 30. The output of the fixed displacement pump is directed to a priority valve. The priority valve divides that flow to a primary circuit, which has a closed-center valve and a secondary circuit, which has an open-center valve.

In our example, the priority valve restricts oil flow to the open-center loader circuit to maintain specific pressures in the closed-center steering circuit. Oil not needed for steering is allowed to go to the secondary circuit(s).

A sensing line connected to the primary (steering) valve work port(s) will let the priority valve know what pressure is needed to move the primary load. The priority valve will restrict secondary flow enough to always maintain a higher pressure to the primary valve than it takes to move the load.

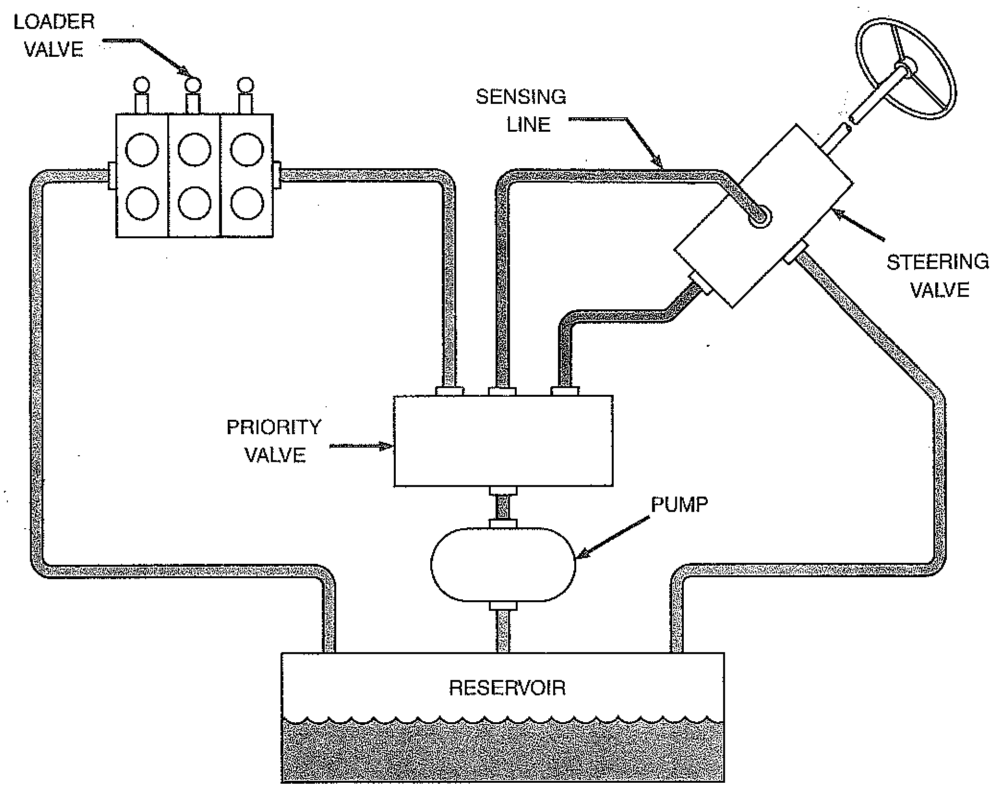


Fig. 30 - Fixed Displacement Pump with Priority Valve and Closed-Center Valve

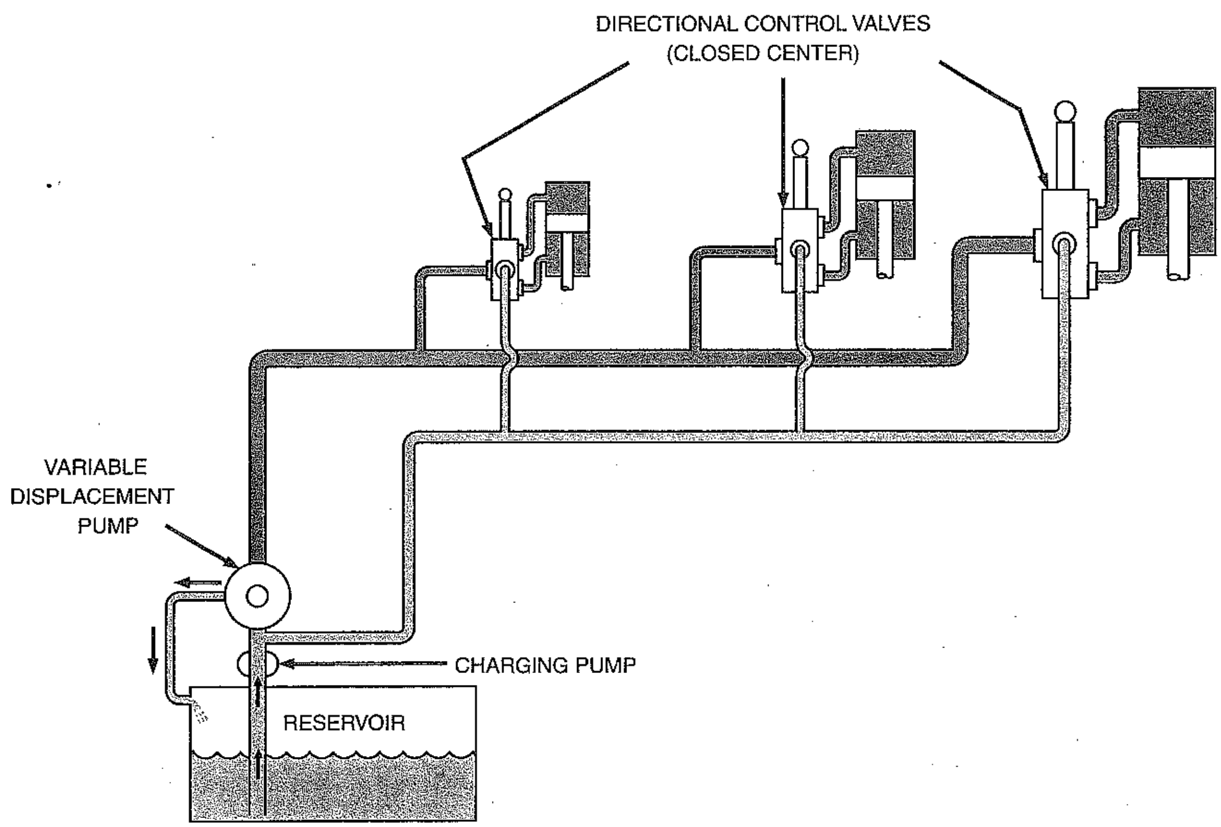


Fig. 31 - Pressure Compensated Variable Displacement Pump with Closed-Center Valves

In our example, with the steering in neutral, the sensing pressure would be 0.0. A spring in the priority valve is adjusted to maintain a standby pressure to the steering. For our example, we'll use a standby pressure of 100-psi (700 kPa).

When the steering valve is activated, the valve working pressure will be directed, by the sensing line, to the spring area of the priority valve. The priority spool will now have to move against this working pressure, plus the spring force, before oil will go to the loader circuit. This means that the valve will always maintain a pressure to the steering valve which is 100 psi (700 kPa) greater than the pressure required to steer the wheels.

When the loader is being used, the priority valve will reduce the higher pressure to maintain the proper pressure to the steering (See Chapter 5 for valve operation).

PRESSURE SENSING VARIABLE DISPLACEMENT PUMP WITH CLOSED-CENTER VALVES

This system is shown in Fig. 31. The variable displacement pump supplies oil to the valves that are closed, or "Blocked" in the neutral position. The pump will pump oil until the system pressure reaches "Standby" which is the pressure at which the pump shuts itself off. This is the maximum pressure that occurs in the system and could be compared to the relief valve setting of the open-center systems. In this system, the pump senses its outlet pressure and always tries to maintain that pressure ("Standby").

When a valve is actuated, flow will begin. This will cause a drop in system pressure. The pump senses this drop and goes into "Stroke", pumping enough oil to try to maintain standby pressure. That flow will satisfy the needs of the machine function. Return oil from the cylinder is directed by the valve to the return line, which carries the oil to the reservoir, or to the inlet of the pump.

When the valve is returned to the neutral position or the cylinder reaches the end of its travel, pressure builds to standby and the pump stops pumping.

When the pressure required to move the load exceeds standby, the pump will go out of stroke and maintain that pressure on the cylinder.

Because the pump may be mounted above or away from the reservoir, it is often necessary to use a charge pump to supply oil to the hydraulic pump. Fig. 31 shows a charge pump supplying reservoir oil to the main pump. The charge pump has much less capacity than the variable displacement pump so return flow from the valves is returned to the main pump inlet. The charge pump, therefore, needs only to supply the system with makeup oil. On machines, however, this oil is usually used to operate a hydraulically engaged transmission or reversor, supply cooler oil flow and to pressure lubricate transmissions.

LOAD SENSING VARIABLE DISPLACEMENT PUMP WITH CLOSED-CENTER VALVES

This system shown in Fig. 32 has all of the advantages of the pressure sensing system. It has a standby pressure setting that limits the maximum pressure of the system. In addition, it has a second stroke control valve that controls the operating pressure at slightly more than required to move the load.

The spring area of this low-pressure valve is connected to the control valve with a sensing line. The sensing passage of the control valve, through check valves, senses the highest workport pressure.

When there is no hydraulic function operated, there is no sensing pressure in the spring area of the low-pressure stroke control valve. The pump will maintain a pressure established by the spring force. For our example, we'll use 300 psi (2070 kPa) for this low standby pressure. There is no flow at this time and a pressure of 300-psi (2070 kPa) is maintained at the closed control valve.

When a valve(s) is operated, the pressure in the sensing passage and line will be that of the highest pressure needed to lift the load(s). This pressure is fed to the spring side of the low stroke control valve.

In order to destroke the pump, pressure will have to overcome the spring force (300-psi)(2070 kPa) plus the pilot working pressure. The pump will maintain a pump flow which is adequate to keep the pump outlet pressure 300 psi (2070 kPa) higher than the highest pressure needed to lift the load.

For example, if valves were activated, one to a load requiring 1500 psi (10,340 kPa), the other 1200 psi (8275 kPa). The sensing line and spring area of the low pressure stroke control valve would read 1500 psi (10,340 kPa). The pump would then go into stroke and maintain enough flow to keep the pump outlet pressure at 1800 psi (12,410 kPa)

The high-pressure stroke control valve functions only when the system pressure reaches the maximum pressure established for the system.

When this system is used on machines, such as backhoes, which use full engine power through the hydraulic system, the pump can be equipped with a load-limiting valve. This allows the use of a large pump to supply plenty of oil for normal operating pressures. When high pressures are required, the load limiter reduces the maximum pump flow so that the engine is not overloaded. This feature was also described in the "Variable Displacement Pump with Open-Center Valves".

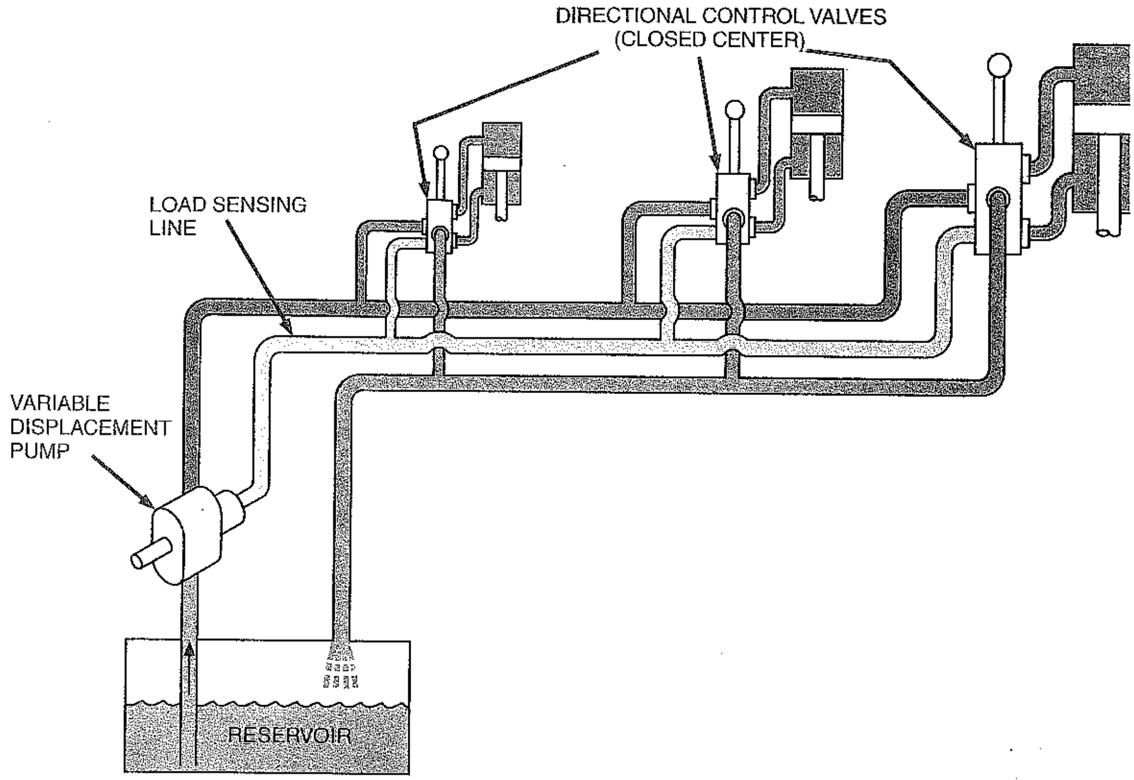


Fig. 32 - Load Sensing Variable Displacement Pump with Closed-Center Valves

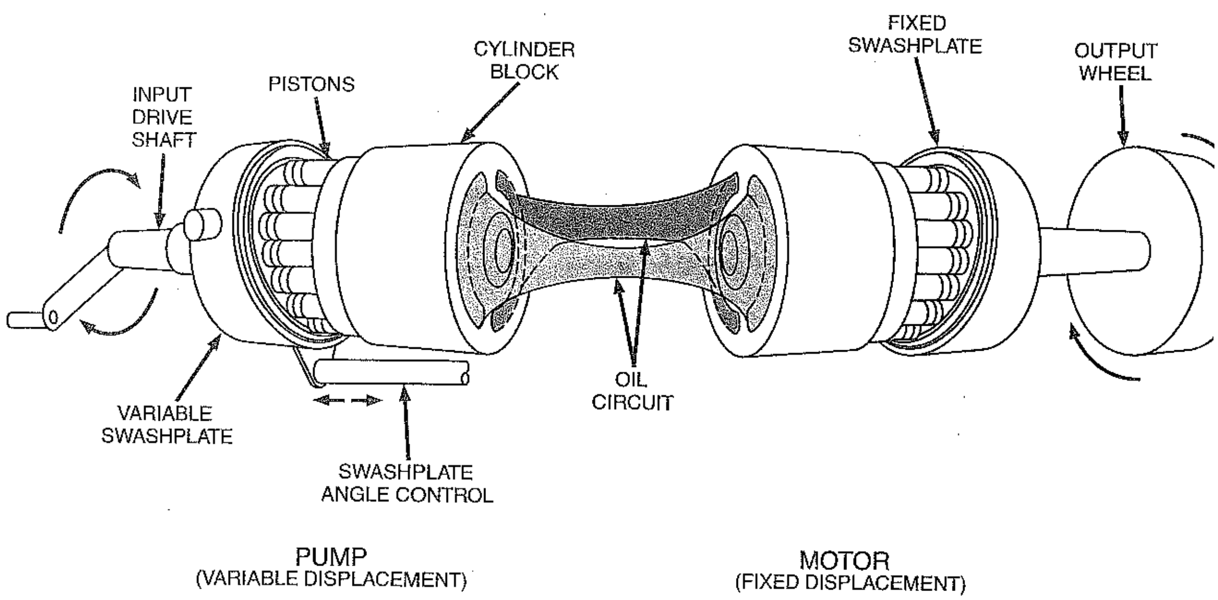


Fig. 33 - Closed Loop System

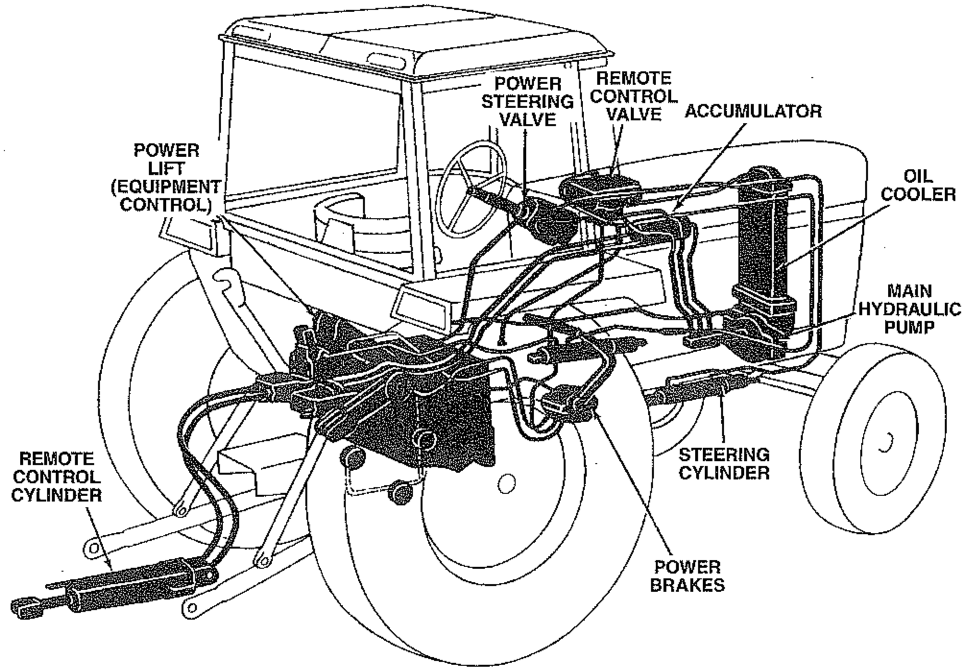


Fig. 34 - A Modern Tractor with Hydraulic System

SOME ADVANTAGES OF CLOSED-CENTER SYSTEMS

1. There is no requirement for relief valves in a basic closed-center system because the pump simply shuts itself off when standby pressure is reached. This prevents heat build-up in systems where relief pressure is frequently reached.

2. The size of lines, valves, and cylinders can be tailored to the flow requirements of each function. Components in the open-center system must be sized to accept the total output flow of the pump.

3. By using a larger pump, reserve flow is available to insure full hydraulic speed at low engine rpm with no loss of efficiency because the pump supplies only the oil required by the function(s) being operated.

4. On functions such as brakes and differential locks that require force but very little or no flow, this system is very efficient. By holding the valve open, standby pressure is constantly applied to the piston with no loss of efficiency because the pump has returned to standby. To accomplish this in an open-center system, pressure could be maintained only by pumping oil past a relief valve.

We saw earlier that the open-center system is the simplest and least expensive for hydraulic systems that have only a few functions or where the entire pump output can be used in any of the valves. But today's machines need more versatile hydraulic systems as more functions with varying demands for each function are added.

To meet those varying demands, the open-center system requires the use of flow dividers to proportion the oil flow. The use of these inefficient flow dividers results in reduced useable power and creates heat build-up in the system.

The trend has been to use the closed-center systems to better meet the needs of today's varying flow applications.

CLOSED LOOP SYSTEMS

The closed loop system shown in Fig 33 uses no valves to direct the high-pressure oil. A pump and a motor are connected together by hoses, lines or passages.

In this illustration, a variable displacement pump is used with a fixed displacement motor. This means that pump flow can vary from zero, when the swashplate has no angle, to maximum capacity when the swash plate is fully tilted. A swashplate angle control operates the swashplate. The operation of the pumps and motors are covered in Chapters 4 & 7 respectively.

The pump can be equipped with a reversible swashplate that means it can be tilted in either direction. When the swashplate is reversed, oil flow is reversed. The return passage becomes the pressure passage and the pressure passage becomes the return passage. The direction of the motor is reversed.

This system can use any combination of fixed, variable and reversible pumps with fixed or variable displacement motors.

THE USES OF HYDRAULICS

Hydraulics are used at many points on a single machine. The tractor in Fig. 34 uses hydraulics to steer, brake, control mounted equipment, and supply oil for remote operation of tools. A single hydraulic system serves to power all these functions.

Let's briefly discuss the major uses of hydraulics.

HYDRAULIC STEERING SYSTEMS

Three major types of steering are used for today's machines:

1. MANUAL STEERING
2. POWER STEERING
   a. Hydraulic steering with mechanical drag link
   b. Hydrostatic steering
   c. Metering pump steering
3. HYDRAULIC ASSIST STEERING

1. **MANUAL STEERING** - The steering wheel is linked directly to the turning wheels and the operator does all the work of steering. No hydraulics are used—only mechanical effort.

2. **POWER STEERING** - These systems are divided into three major categories.

A. HYDRAULIC STEERING WITH MECHANICAL DRAG LINK

Fig. 35 illustrates hydraulic steering with a mechanical drag link. We are showing it with the open-center spool valve, however, it is equally adaptable to the closed-center system. A rotary valve could also be used on either open or closed-center systems. A rotary valve could be mechanically connected to the wheel linkage (This would not contain the follow-up motor described in Fig. 37). A poppet valve could also be used with a closed-center system.

Operation is shown during a right turn. In the right turn, the operator turns the steering wheel as shown. Because of the resistance in turning the front wheels, the shaft is forced up out of the worm nut. This shifts the spool valve and the steering shaft up, which directs oil to the cylinder at the front wheels. This cylinder rotates a rack and pinion device that turns the front wheels. Oil from the other side of the steering cylinder is returned through the spool valve to the reservoir as shown.

As long as the steering wheel is turned, oil will continue to move the wheels. As soon as the steering wheel motion is stopped, the hydraulic pressure will turn the wheels slightly further to the right, moving the steering linkage forward and pulling the valve back to the neutral position.

When turning to the left, the valve spool is pulled down as the shaft is threaded into the worm nut. This sends oil to the other side of the steering cylinder turning the wheels to the left.

B. HYDROSTATIC STEERING

Hydrostatic steering has no mechanical connection between the steering valve and the steering cylinders. Basically the operation is the same as that just described except that we have a hydraulic "drag link" instead of a mechanical one.

Fig. 36 shows a hydrostatic steering system used with a poppet valve on a closed-center hydraulic system. Operation is shown during a right turn.

When the operator turns the steering wheel to the right, the steering shaft, which is threaded through the steering valve piston, attempts to pull this piston upward. Because oil is trapped in the circuit at this time, the shaft instead moves the collar downward, rotating the pivot lever and opening a pressure and a return valve.

When the valves open, pressure oil enters the steering valve cylinder, forcing the piston upward. This pushes the oil out of the valve cylinder and into the right-hand steering cylinder, turning the front wheels to the right.

As the wheels turn, oil is forced out of the left-hand steering cylinder and returns through the open return valve to the reservoir or pump. This will continue as long as the operator turns the wheel.

When the operator stops turning the steering wheel, the steering shaft is moved upward by the steering valve cylinder, pulling the collar upward and centering the pivot lever, thus closing the valves.

For simplicity, a second pivot lever and a second set of pressure and return valves are not shown.

During the left turn, the steering wheel shaft moves upward as the steering wheel is turned. This moves the collar up tc open the second set of valves. Oil is sent directly to the left steering cylinder. Oil from the right cylinder will go to the top of the valve piston, moving the piston, shaft and pivot lever down to neutralize the valves. Oil from the bottom of the steering piston is forced through the open return valve back to the reservoir or pump.

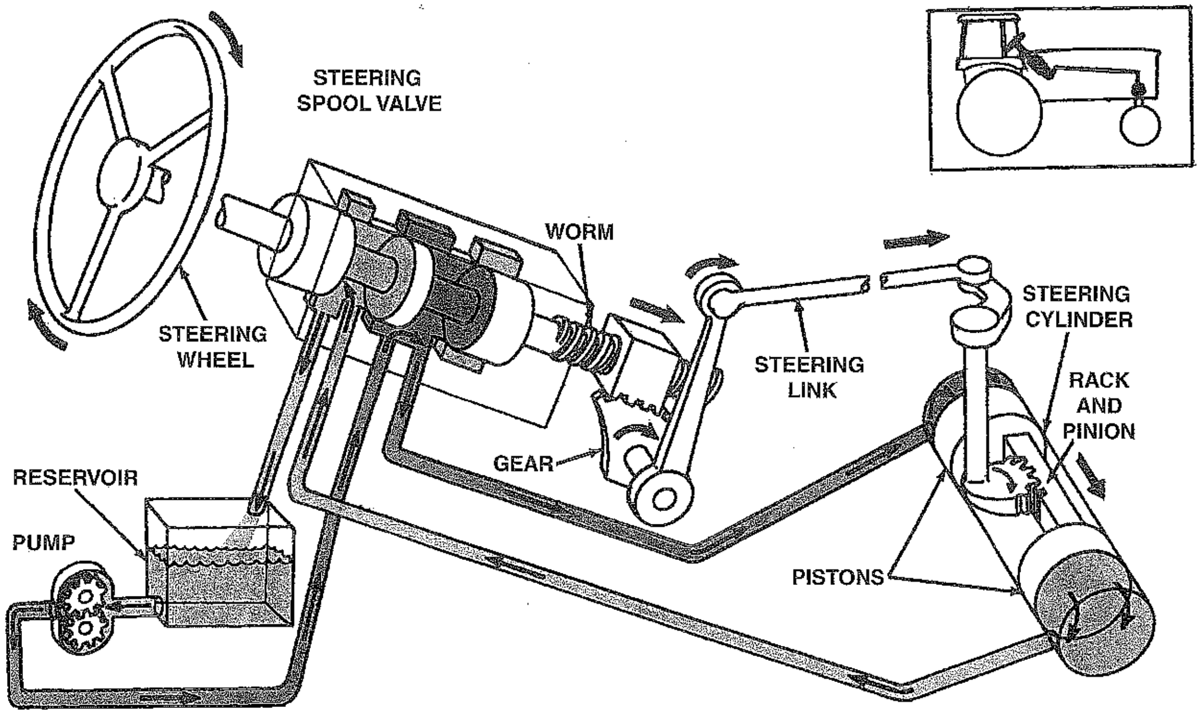


Fig. 35 - Hydraulic Steering with Mechanical Drag Link (Right turn)

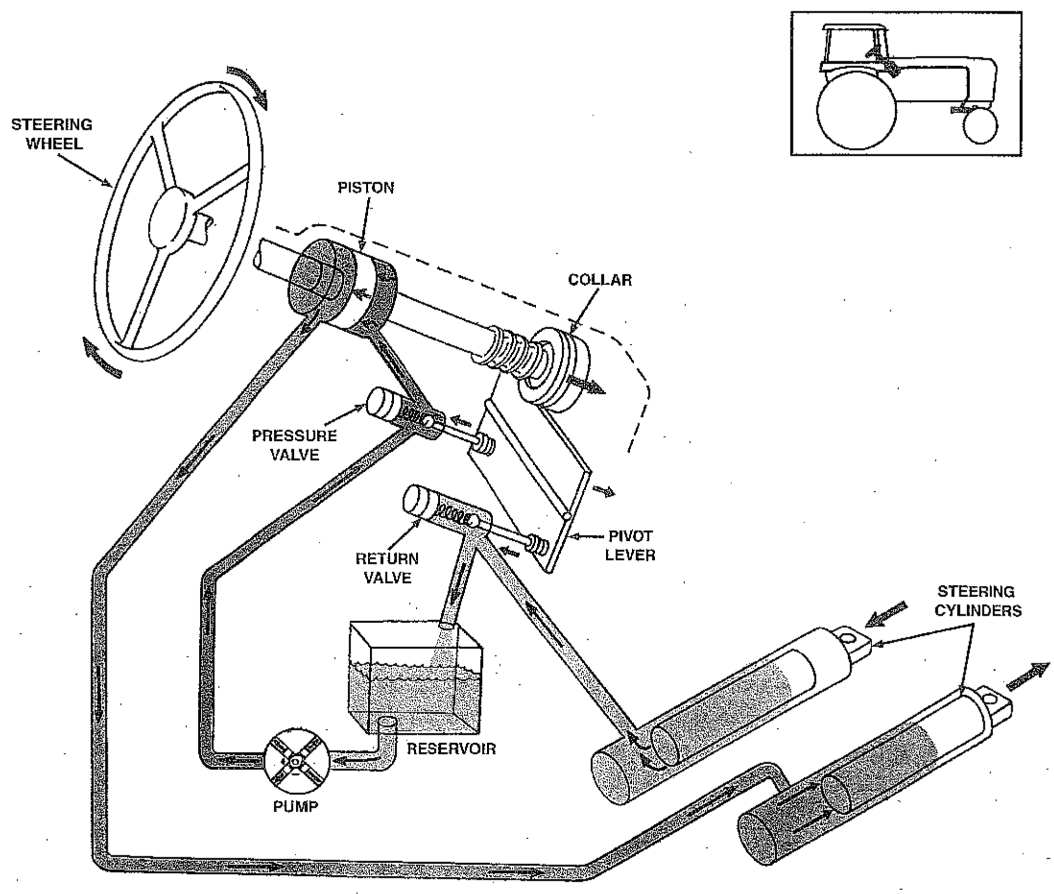


Fig. 36 - Poppet Type Hydrostatic Steering (Right Turn)

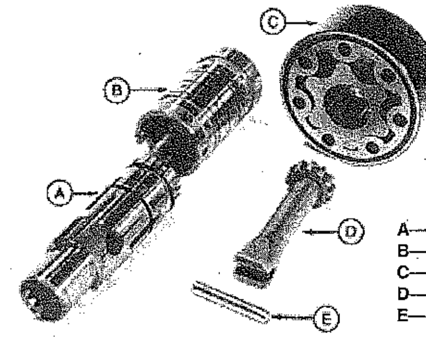


Fig. 37 - Hydrostatic Steering with Rotary Valve

The trapped oil and the follow-up piston in the steering valve provides the hydraulic drag link connection between the steering valve and the wheels. When the steering wheel has turned to the full right, the piston is at the top, the right turn cylinder is fully extended and the wheels are in the full turn position.

When in full left position the piston is at the bottom and the left turn cylinder is fully extended.

Anywhere the steering wheel is stopped in its rotation, the wheels will be in a corresponding position. This is called "Position Responsive Steering".

Manual steering is accomplished when the collar is bottomed in the housing. Turning the steering wheel further moves the piston up or down pressurizing the oil and sending it to the right or left steering cylinders.

Fig. 37 shows the components of a rotary steering valve. The steering wheel is connected to the valve spool with a splined shaft. The inner gear of the gerotor assembly is connected to the valve sleeve by the shaft and pin.

When the steering wheel is turned, the valve spool is turned inside the valve sleeve. Trapped oil in the gerotor assembly prevents the sleeve from turning. This aligns passages to send pressure oil to the gerotor and oil returning from the gerotor to a work port connected to the steering cylinder. It also connects the return passage from the steering cylinders to the reservoir return.

As the gerotor turns it also turns the sleeve trying to catch up to the spool to neutralize the valve. This causes steering as long as the steering wheel is turned and stops when the desired steering position is reached.

The pin goes through a hole in the sleeve and a slot in the valve spool. The slot allows only about 8 degrees of rotation between the valve and sleeve. When no hydraulic power is available, turning the steering wheel turns the valve, sl and the gerotor. The gerotor acts as a pump, pressurizin and sending it to the right or left steering cylinders, thus viding manual steering capability.

This valve can be designed to be used in an open-cente closed-center system. It can also be equipped with a sen line to be used on a flow or load sensing system.

C. METERING PUMP POWER STEERING

Metering pump power steering consists of four asseml (Fig. 38):

- **metering pump**
- **steering valve**
- **steering motor**
- **feedback cylinders**

As with hydrostatic steering, there are no mechanical nections between the steering valve and the wheels b turned. However, the metering pump steering also h hydrostatic connection between the steering wheel and valve, which also ties in to a follow-up system independer the working pressure.

Note: Indications of directions refer to those as seen from operator's seat. Side A and side B will help identify direc of movement in the steering valve housing.

Fig. 38 shows the metering pump power steering opera during a right turn. When the operator turns the wheel tc right, the gears in the metering pump direct oil in the trap oil circuit to the steering valve housing and to the left en the feedback piston.

This oil (under some pressure) moves the steering v toward side B. The movement of the steering valve opens pressure oil circuit to the left end of the steering piston from the right end of the piston flows back to the stee valve oil gallery and to the reservoir.

Oil from the right end of the feedback piston cylinder is fo out, by piston movement, and returns through the stee valve housing to the metering pump. This movement of steering and feedback pistons from left to right causes the s dle to rotate clockwise and turn the front wheels to the ri

When the operator stops turning the steering wheel, the g in the metering pump stop directing oil to the steering v Circuit pressure, from the right end of the feedback pisto the steering valve, (caused by movement of the feedback ton) acts against the side B of the steering valve. The v

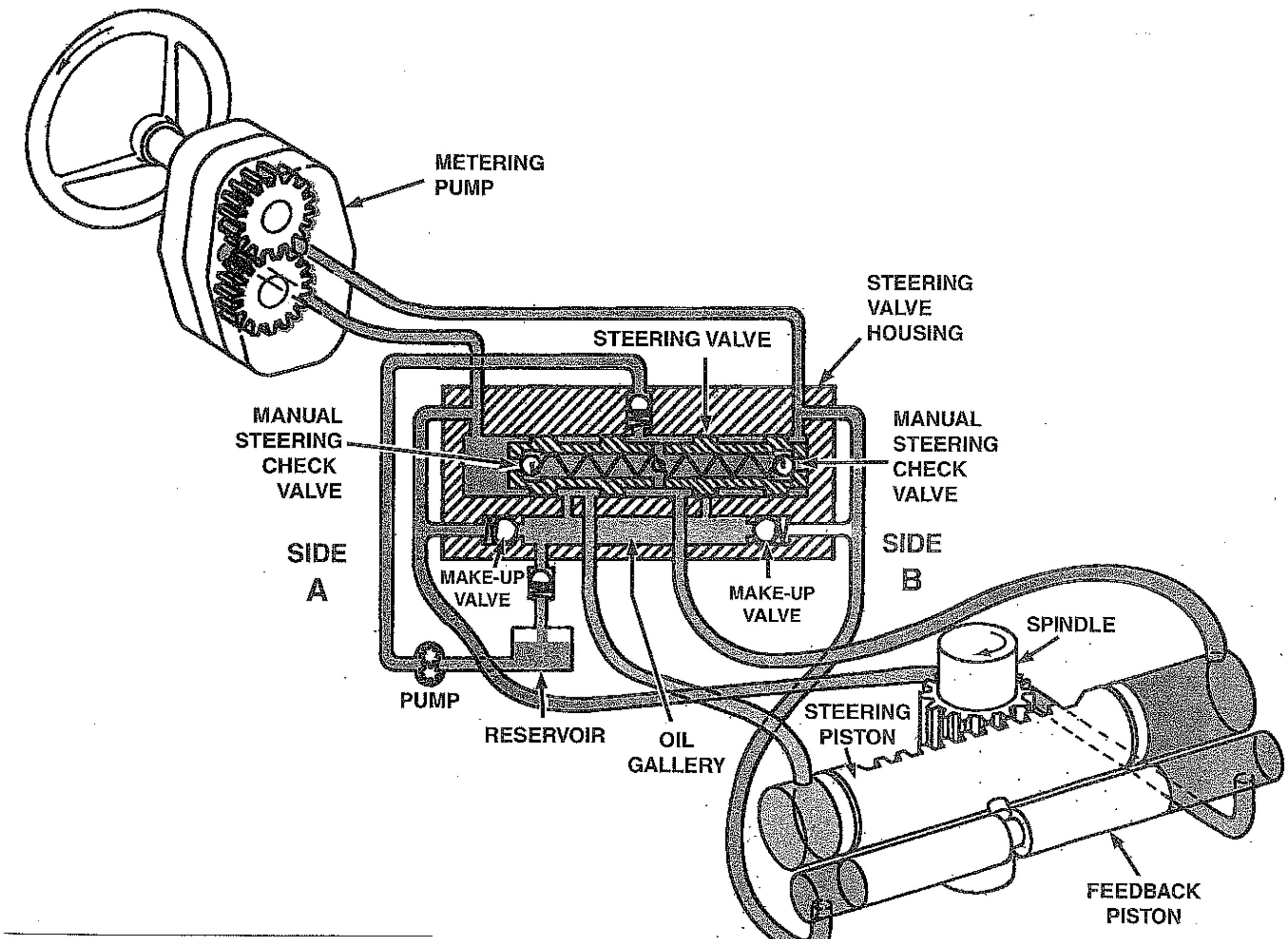


Fig. 38 - Metering Pump Steering (Right Turn)

moves toward side A, closing the pressure oil passage from the main hydraulic pump, and stops the turning movement. The valve becomes centered and traps oil in passages to both sides of the steering piston. The trapped oil holds the wheels in position until the operator again turns the steering wheel.

If oil is lost from the control circuit, pressure in the control circuit drops. The reduced pressure allows oil in the return circuit to unseat the make-up valve, filling the control circuit.

On articulated tractors, hydraulic cylinders that control steering replace the steering and feedback pistons.

Manual Turn with Metering Pump Steering

When there is no inlet pressure oil to the steering valve housing, the machine may be steered manually. Without pressure oil, the inlet check valve is seated preventing oil in the steering system from entering the hydraulic system pressure circuit.

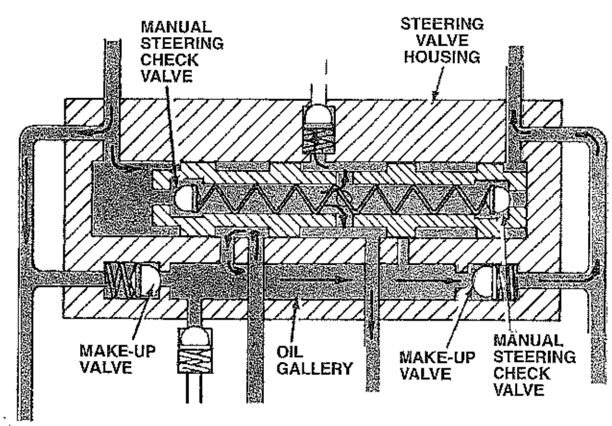


Fig. 39 - Metering Pump Steering (Manual Turn)

When the operator turns the wheel to the right (Fig. 39), oil in the trapped oil circuit is again directed to side A of the steering valve and the left end of the feedback piston. Enough pressure is exerted on side A of the steering valve to unseat the manual steering check valve in the hollow steering valve.

Oil then passes through the steering valve to the left end of the steering piston. The force of the oil on the feedback piston and steering piston moves both pistons to the right, turning the steering spindle clockwise, and turning the front wheels to the right.

Oil from the right end of the feedback piston cylinder returns through the steering valve housing to the metering pump.

Oil from the right end of the steering piston opens the make-up valve on side B and joins with oil returning from the feedback piston cylinder. This insures a recirculating oil supply in the steering circuit.

When not turning, oil is trapped in the circuits and holds the wheels in position.

3. Hydraulic Assist Steering

In hydraulic assist steering systems, steering force is an amplification of the force used by the operator. It is used where the operator must maintain a high degree of feel, such as in crawler steering. In these systems, the amount of pressure built up in the system is in direct proportion to the effort used by the operator.

Fig. 40 is a hydraulic assist system used on a crawler tractor. It is an open-center system that has a flowdivider to divide the pump flow evenly to the two valves. In neutral (lower valve), the oil enters the piston area and then goes through the open piston seat and out to return.

When the steering lever or pedal are operated, the st valve is pulled forward restricting oil flow at the pistoı This will cause pressure to build behind the piston mo forward to put a force on the steering control arm. Witł restriction, the pressure will rise and more force exerted control arm.

The land on the steering valve is slightly larger than the This means that whatever pressure is built behind the will have a negative force on the steering valve. The op will have to overcome that force. The higher the pressur higher the operator effort. So, while the force on the c arm is considerably more than the effort of the operatc in direct proportion to it.

If hydraulic power is lost, the valve bottoms on the pistoı and there is a mechanical linkage to the control arm.

Protection Against Failure of Power Steering

If hydraulic steering is lost in steering with a mechanical link, the solid link takes over and the operator can still the machine mechanically, but with more effort.

The same protection is also provided in most hydro power steering. This is done by pressurizing trapped oil i steering valve and using the steering valve piston, the ge or metering pump to build pressure and direct it to the s ing cylinders.

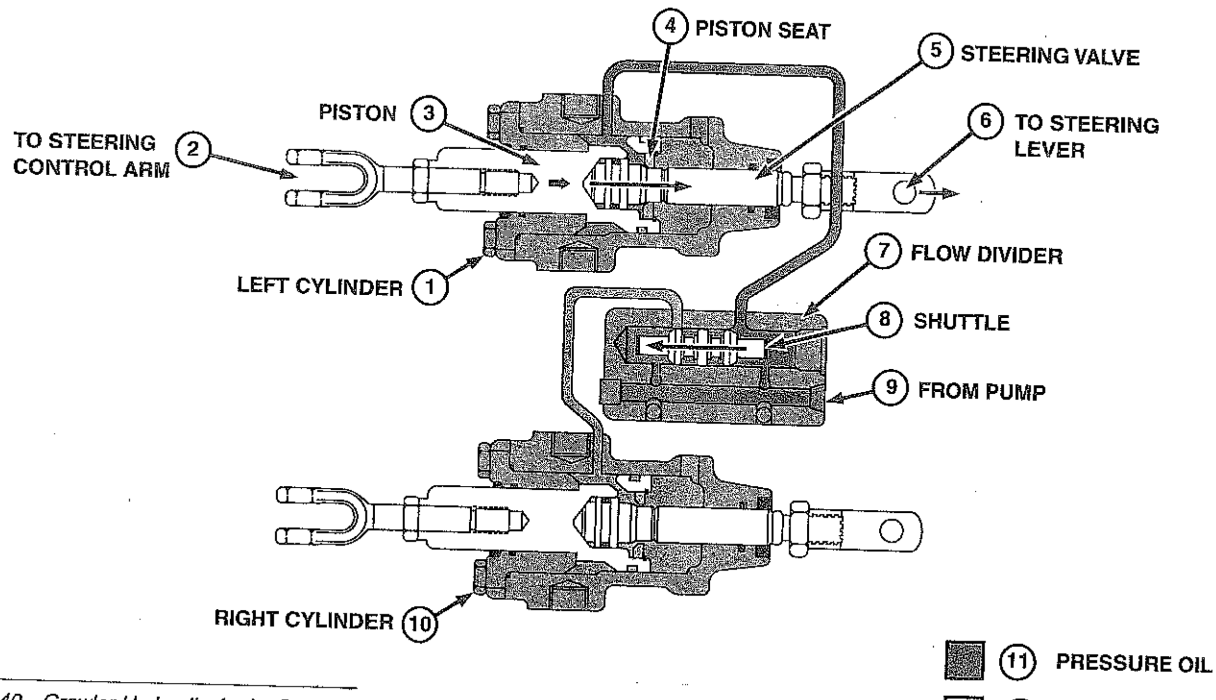


Fig. 40 - Crawler Hydraulic Assist Steering

HYDRAULIC AND POWER BRAKE SYSTEMS

Three major types of brakes are used to turn or stop farm and industrial machines:

1. Manual brakes

2. Hydraulic brakes

3. Power brakes

1. MANUAL BRAKES. When the operator applies the brakes, a mechanical linkage connects the lever or pedal to linkage which forces friction surfaces against a drum or disc to slow or stop a vehicle.

2. HYDRAULIC BRAKES. When the operator applies the brakes, a column of trapped oil is forced through a tube to a cylinder. The cylinder then forces the friction surfaces against a drum or disc. The force exerted on the lever or pedal generates all pressure in the system.

3. POWER BRAKES. When operator applies the brakes, he/she simply directs pressure oil to the brake cylinder to slow or stop the vehicle.

On some machines, two types of brakes may be used. For example, the power brakes for stopping may be backed up by a manual brake for parking. They may or may not use the same braking mechanism.

Most modern machines have parking brakes that are spring engaged and require hydraulic power to disengage them. In this case, pressurized oil is directed to the park brake to keep it disengaged while operating. To engage the brake, a valve is closed not allowing pressurized oil to reach the brake piston. In case of engine or hydraulic failure, the springs will automatically engage the brake.

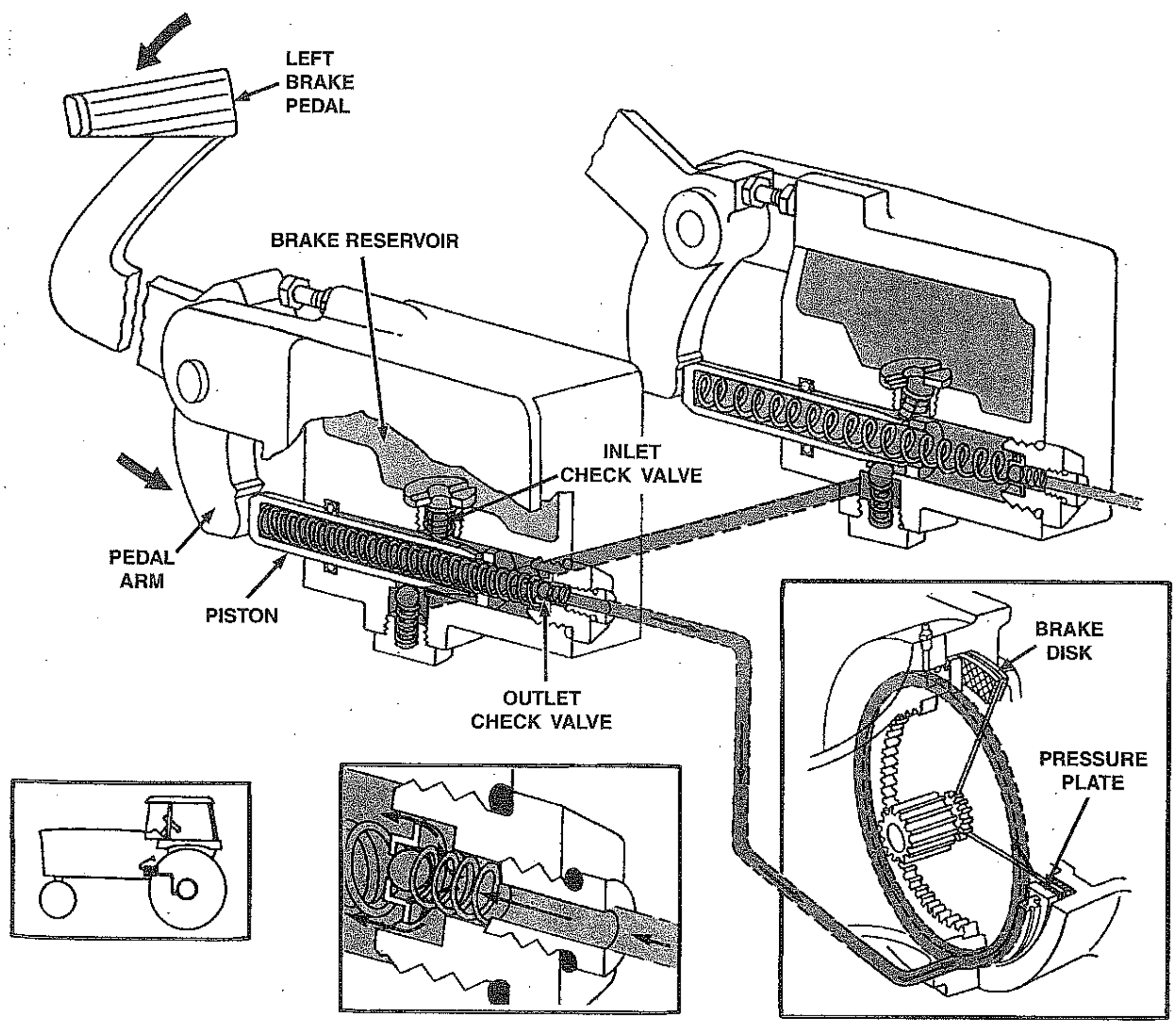


Fig. 41 - Hydraulic Brakes (Left Turn)

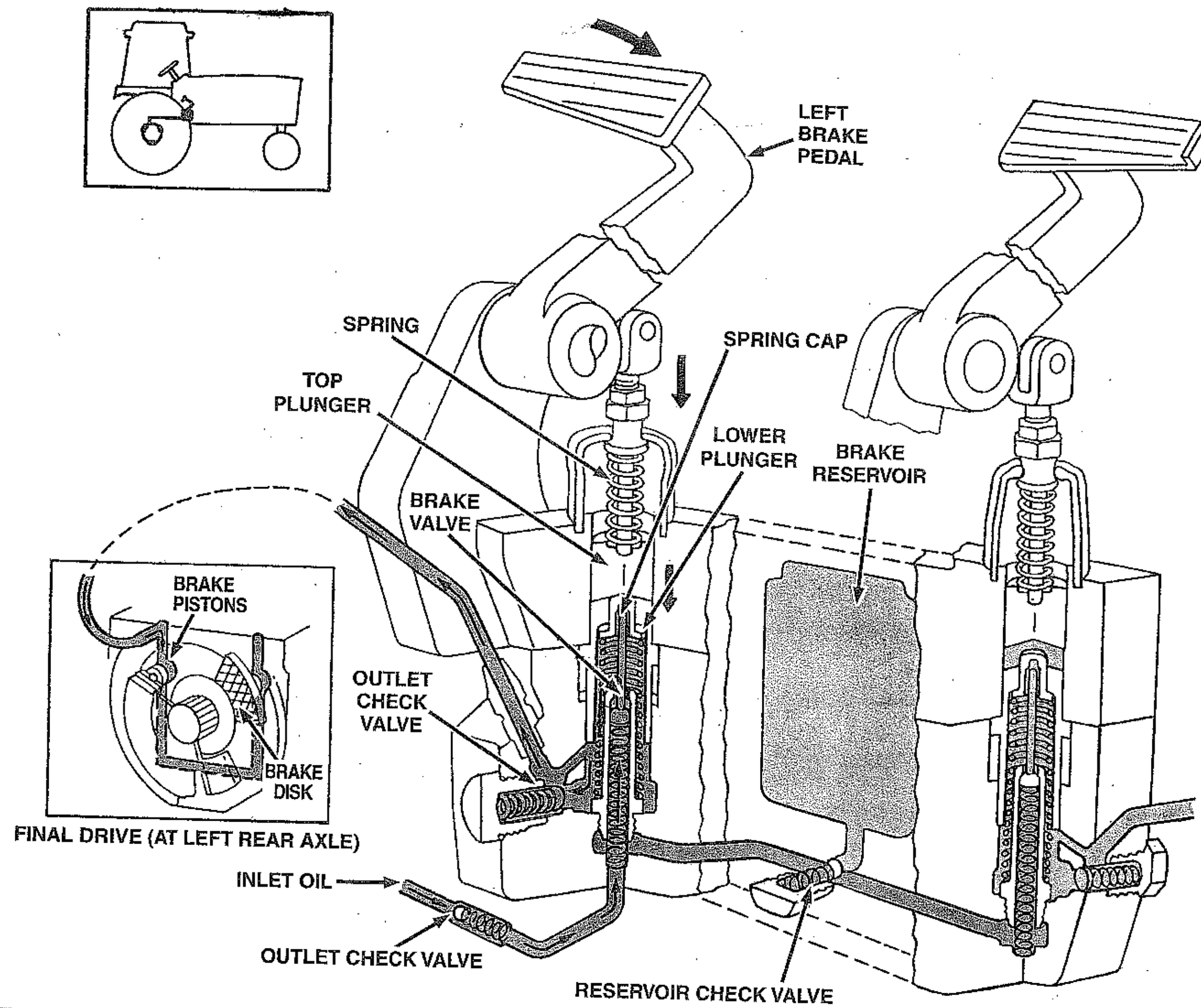


Fig. 42 - Power Brakes (Left Turn)

On most two-wheel drive tractors, brakes are located on each rear axle or wheel. For turning, the operator presses down the pedal for the left or right wheel. For stopping, he presses down on both pedals at once.

On four-wheel drive machines, a single brake mechanism controls the whole unit.

Let's discuss the operation of hydraulic and power brakes in more detail.

HYDRAULIC BRAKES

Fig. 41 shows hydraulic brakes on a typical tractor. Operation is shown during a left turn.

For a sharp left turn, the operator presses down the left brake pedal. This rotates the pedal arm against the brake piston as shown and moves it to the rear. The piston closes the inlet check valve from the reservoir, trapping oil in the cylinder. As the piston moves farther, it forces the trapped oil out of the cylinder, unseating the outlet check valve.

The oil is pushed through a pipe to the final drive at the left rear axle, where it applies force against the brake pressure plate (see inset). This presses the revolving brake disk against the side of a fixed plate, braking the left axle and wheel.

When the brake pedal is released, the force against the brake disk is relieved. The outlet check valve and retainer (inset, Fig. 41), may meter oil returning from the axle unit. Spring force pushes the piston to the front again. This opens the reservoir check valve allowing more oil to enter the cylinder as needed for the next braking.

When both brake pedals are pressed down at once, oil is sent by both brake valves to both final drives.

To assure equal oil pressure on both sides, equalizing valves under each brake piston are opened, connecting the two brake cylinders. Note in Fig. 41 that when the left pedal was

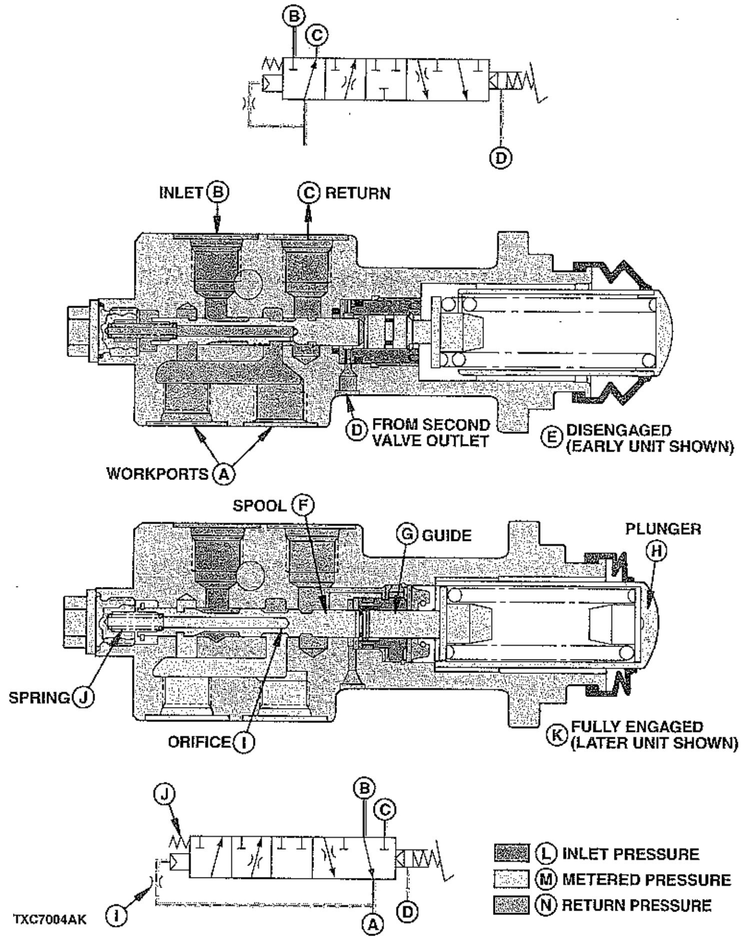


Fig. 43 - Spool Type Power Brake Valve

pushed, that pressurized oil was available at the equalizing valve for the right side. If the right valve is moved just a little bit, it will open the equalizing valve and allow pressurized oil to act on the right brake with the same force as the left. This is particularly important for higher speed roading operations.

These brakes are not affected by engine or hydraulic failure. Oil may be supplied to the brake reservoirs from the tractor hydraulic system, however, many need to be checked and filled periodically.

POWER BRAKES

"Power" brakes mean that oil from a hydraulic source does the braking of the machine. Power brake valves do have an operator "feel" built into them so the brakes can be applied smoothly. The valve is designed so that the more foot pedal force the operator applies, the more pressure will be sent to the brake pistons thus making it possible to control the amount of braking.

Fig. 42 shows poppet type power brakes with a closed-center hydraulic system. The left brake is being operated.

When the operator presses down on the left brake pedal it puts spring pressure against the top plunger. The top plunger pushes the spring cap into the lower plunger, blocking return oil flow to the reservoir.

The guide pushes a rod linkage down to open the brake valve. Inlet oil under pressure now rushes in through the open valve, forces the outlet check valve open, and flows on to the final drive at the left rear axle (see inset).

Here the oil forces the brake pistons and pressure plates to press the revolving brake disk against a fixed plate which is connected to the final drive shaft. This brakes the left axle and wheel.

When pressure builds in the brake cavity it will push the spring cap and top plunger up against the spring. When the hydraulic force equals the spring force, the valve will close. The amount of pressure built in the brakes therefore will depend on how much force is applied to the top spring by the operator. The brake pressure will be in direct proportion to the pedal force applied.

When the brake pedal is released, the brake valve is closed again by its spring, and inlet oil is shut off. This relieves pressure on the brake disk at the axle, and braking stops as some oil flows back to the brake valve area. This oil flows through the spring cap into the brake reservoir.

To insure equal braking on two wheel drive machines when both brake pedals are pressed down at once, equalizing valves (not shown) are opened, connecting the two brake valves.

In case of engine or hydraulic failure, the brakes will operate as hydraulic brakes rather than power brakes. When the pedal is depressed the top plunger makes contact with the lower plunger. The lower plunger becomes the piston for hydraulic brakes and forces oil out to operate the brakes. Inlet and reservoir check valves keep oil trapped in the circuit for continued operation.

On some large machines, the valve is also backed up with an accumulator which holds enough "charge" of pressurized oil in reserve to insure several power brake applications after power is lost.

Fig. 43 shows one type of a spool type power brake valve. It is shown in the neutral and engaged positions. When in neutral the inlet oil is trapped (closed-center system) and the line to the brakes connected to the return.

Note: Return lines on brakes are always returned to the reservoir and not to the pump to insure that pump charge pressure does not keep the brakes engaged.

When the brake pedal is depressed, the plunger is pushed against the spring. The spring in turn pushes the valve spool. As the spool moves, it first closes the return passage, then opens the high pressure passage allowing oil to go to the brake piston(s).

Oil is also directed to the end of the spool causing it to push back against the pedal spring. When pressure in the brake line can overcome the spring, the valve will close maintaining that pressure to the brakes. The pressure to the brakes is therefore determined by how hard the operator pushes on the pedal. This gives complete control of the degree or "feel" of braking.

When the pedal effort is removed, the valve returns to neutral, shutting off the high-pressure oil and allowing the oil in the brakes to return to the reservoir.

Because this valve has no hydraulic brake capability, it is backed up with an accumulator which stores enough oil under pressure for several emergency brake applications.

HYDRAULIC POWER LIFT (ROCKSHAFT) FOR REAR-MOUNTED EQUIPMENT

On modern tractors, there are many uses for rear mounted equipment. On some equipment, it is necessary to have precise control of implement depth with the use of the control lever. On others, such as plows or rear blades, it is desirable to have the equipment respond to the load or draft that the implement is putting on the tractor. In other applications, it is desirable to use a combination of the two. There are therefore three modes of operation:

1. **Depth Control**
2. **Draft Control**
3. **Draft and Depth Control**

DEPTH CONTROL

In Fig. 44, the operator has selected the depth position on the selector lever. This puts the valve linkage in line with the rockshaft cam. It will take a signal only from the cam. Any movement of the draft linkage will not move the valve link.

When the operator moves the lever to the raised position, the linkage rotates the valve lever to open the pressure valve. Oil is directed to the piston that raises the rockshaft. As the rockshaft rotates, the cam rotates also. The valve link rotates clockwise and closes the valve when the rockshaft reaches the position called for by the control lever position.

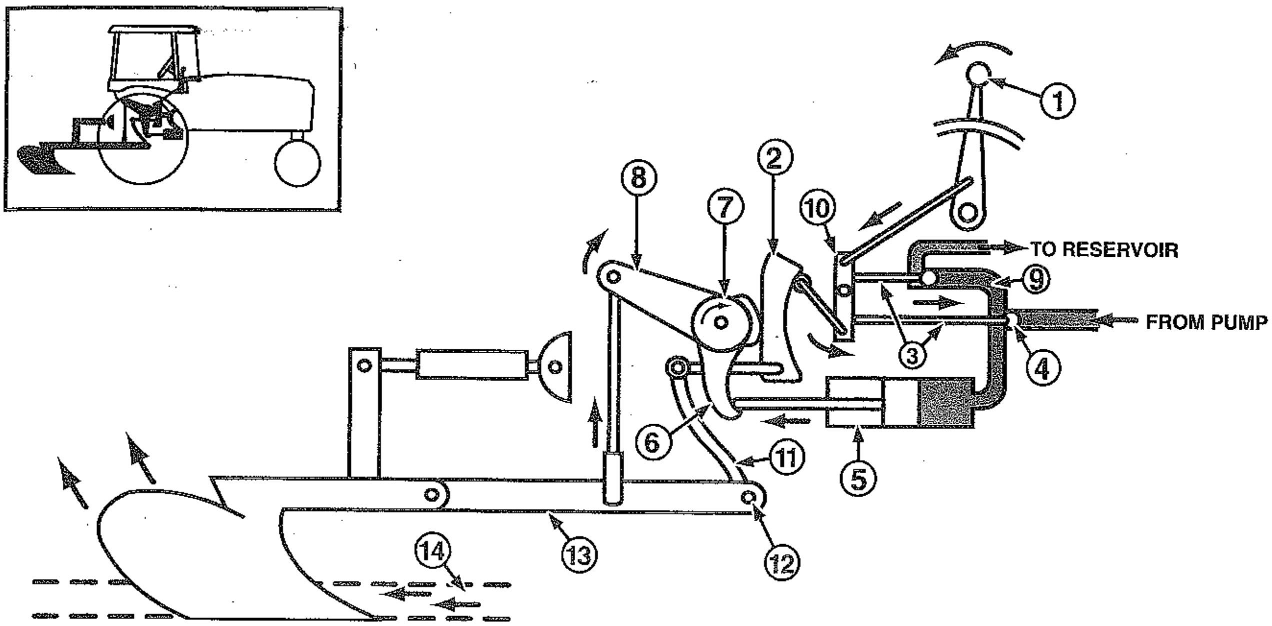
When the control lever is moved to the lower position, the valve lever rotates clockwise opening the return valve allowing oil in the rockshaft piston to return to the reservoir. As the rockshaft and cam lower, the cam follower and link will rotate the valve linkage until it closes the return valve.

In the depth position, every position of the control lever has a corresponding position of the rockshaft. This provides excellent control of rockshaft depth by the operator.

DRAFT CONTROL

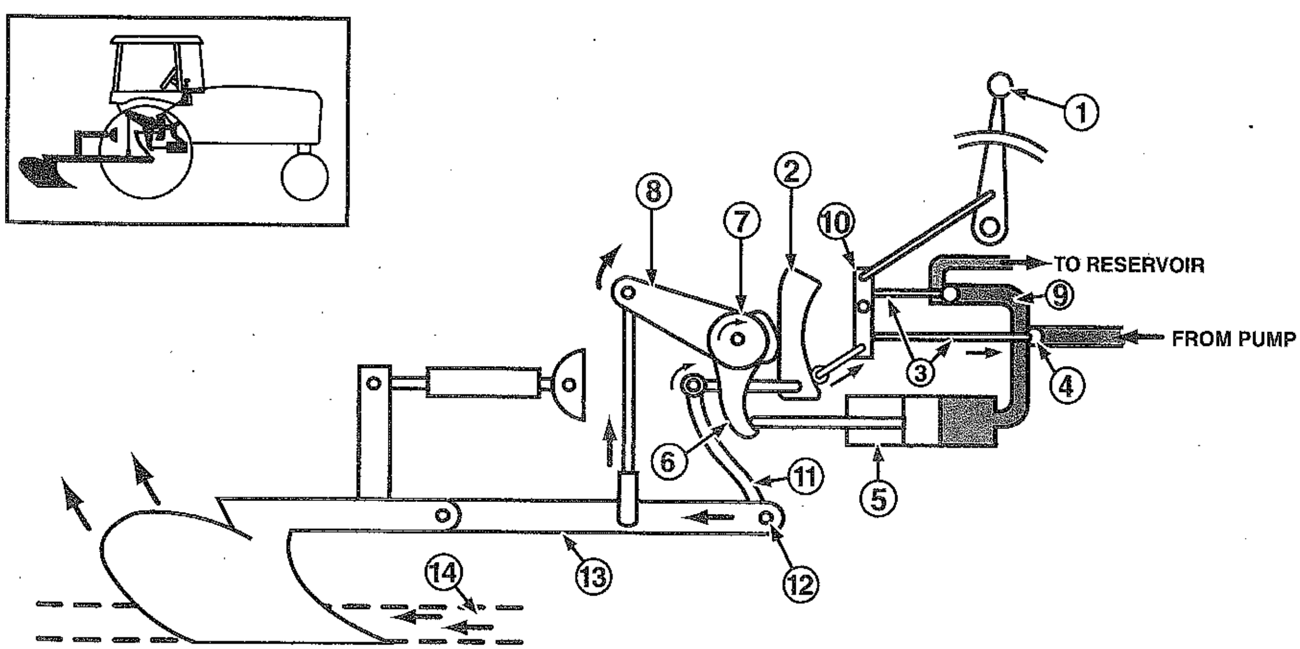
Fig. 45 shows the rockshaft linkage moved to the Draft position. The follow-up linkage has been moved to the bottom of the cam follower. In this position, the valve linkage will receive a signal from the draft linkage but none from the rockshaft cam.

When the control lever is at the top, the pressure valve will be held open, holding the rockshaft in the full raised position.



1. Control Lever
2. Cam Follower
3. Operating Rods
4. Pressure Valve Ball
5. Piston
6. Shaft Arm
7. Rockshaft
8. Lift Arm
9. Return Valve Ball
10. Valve Lever
11. Load Control Arm
12. Load Sensing Shaft
13. Draft Link
14. Plow Furrow

Fig. 44 - Raising an Implement in Depth Control



1. Control Lever
2. Cam Follower
3. Operating Rods
4. Pressure Valve Ball
5. Piston
6. Shaft Arm
7. Rockshaft
8. Lift Arm
9. Return Valve Ball
10. Valve Lever
11. Load Control Arm
12. Load Sensing Shaft
13. Draft Link
14. Plow Furrow

Fig. 45 - Rockshaft Operating in Draft Control

When the control lever is lowered, the valve link will rotate clockwise opening the return valve to lower the rockshaft. The rockshaft will continue to lower until the draft of the implement is enough to flex a load-sensing bar or spring and move the linkage. As the linkage is moved, it will rotate the valve shaft counterclockwise closing the return valve.

For our example, we'll attach a plow to the rockshaft in Fig. 45. If the draft increased, it would need to be raised in order to maintain an even load on the tractor. The increased draft would further flex the torsion bar. The linkage would move the valve linkage to open the pressure valve and raise the plow. When it had raised enough to reach the normal draft load, the linkage would move to close the valve.

When the draft reduced, the linkage would move to lower the plow until normal draft was achieved.

In draft control, the position of the control lever sets a certain draft load. The plow will be raised and lowered automatically to maintain that draft load.

DRAFT AND DEPTH CONTROL

The draft and depth control is a combination of the two positions. The operator moves the draft and depth selector lever so that the valve linkage will contact the cam follower in one of several intermediate positions. It is usually at mid point. In this position, the linkage receives a signal from both the rockshaft and the draft linkage.

This gives the operator good control of the implement depth and the automatic load control will move the implement up and down a little even though it does not maintain a constant draft load. This is the position most used in plowing.

HYDRAULIC SENSING ROCKSHAFT

The hydraulic load sensing system in Fig. 46 consists of a load control valve (1) and a sensing cylinder (2). The load control selector (3) is in a position at the top of the cam follower (4) to allow maximum load sensing. The rod end of the sensing cylinder piston (5) is attached to one draft arm (6). A shaft connects the two draft arms. The draft links (7) are attached to the draft arms.

As the plow enters hard ground (8), the soil resistance increases the draft load on the draft arms. The draft force is transmitted to the sensing cylinder (2) by the draft arms and pulls the sensing cylinder piston and valve (9) rearward. More oil then flows into the sensing cylinder through a variable orifice (10), causing sensing pressure on the front of the load control valve (l) to increase.

The increase in sensing pressure results in rearward movement of the load control valve (1), cam follower (4), and valve operating link (12) which causes the valve operating cam (13) to rotate clockwise. Note that an orifice (11) allows some oil to escape from the front of the load control valve. This results in a variable pressure on the valve depending on the amount of oil that enters through the variable orifice (10).

The clockwise rotation of the valve operating cam causes the pressure valve (14) to open and direct pressure oil through the throttle valve (15) to the backside of the rockshaft piston (16).

The throttle valve controls the speed of oil flow to and from the rockshaft piston. The piston moves forward and causes the rockshaft (22) to rotate, lifting the draft links (7) and raising the plow. The check ball (21) prevents return oil from the front of the rockshaft piston from entering the return valve housing (19).

When the plow passes the hard ground, the draft force on the sensing cylinder decreases. The sensing cylinder piston (5) and valve (9) move forward permitting less oil to flow through the variable orifice, decreasing sensing pressure at the front of the load control valve. The spring in the load control valve housing (17) pushes the valve forward.

The spring (18) causes the valve-operating cam to rotate counterclockwise and forces the cam follower (4) forward, along with the load control valve. The pressure valve (14) closes and, if necessary, the return valve (19) opens to lower the plow.

When the pressure and relief valves are closed, oil trapped at the rear of the rockshaft may expand if the oil temperature rises. The thermal relief valve (20) senses thermal expansion of hydraulic oil in the system and opens if the expansion is too great.

ELECTRONICALLY CONTROLLED ROCKSHAFT

Fig. 47 shows a tractor with two external cylinders that raise or lower the three-point hitch and thus the implement.

Hydraulic pump (D) transfers pressurized oil via the inlet priority valve to rockshaft valve (F), which controls the rockshaft cylinders.

The rockshaft cylinders act on draft links (H), enabling implements to be raised or lowered. The rockshaft assembly is controlled electronically.

Electronic control box (B) receives signals from the operation unit (A) and also from draft sensor (G) or position sensor (C). These values are coordinated in electronic control box (B) before being passed on to stepper motor (E). The stepper motor opens the raising or lowering valve in the rockshaft valve assembly by means of a cam.

When operating in depth control, the signal received from the operation unit (A) is coordinated with the actual value from position sensor (C).

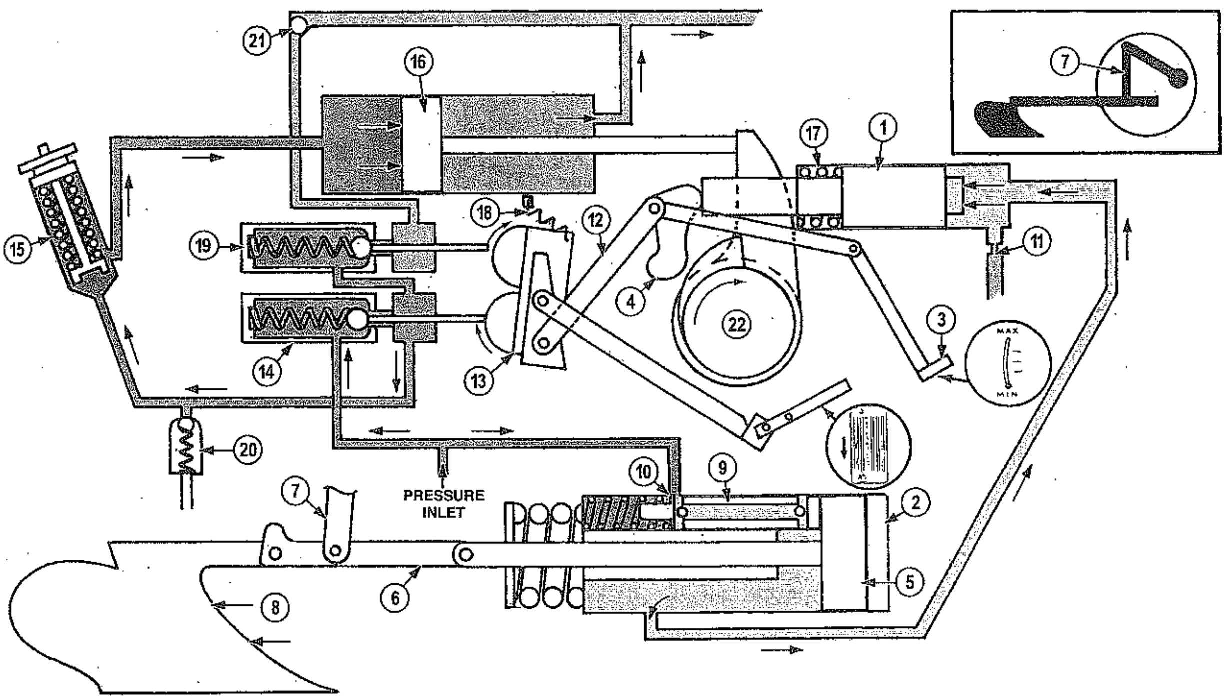


Fig. 46 - Hydraulic Sensing Rockshaft

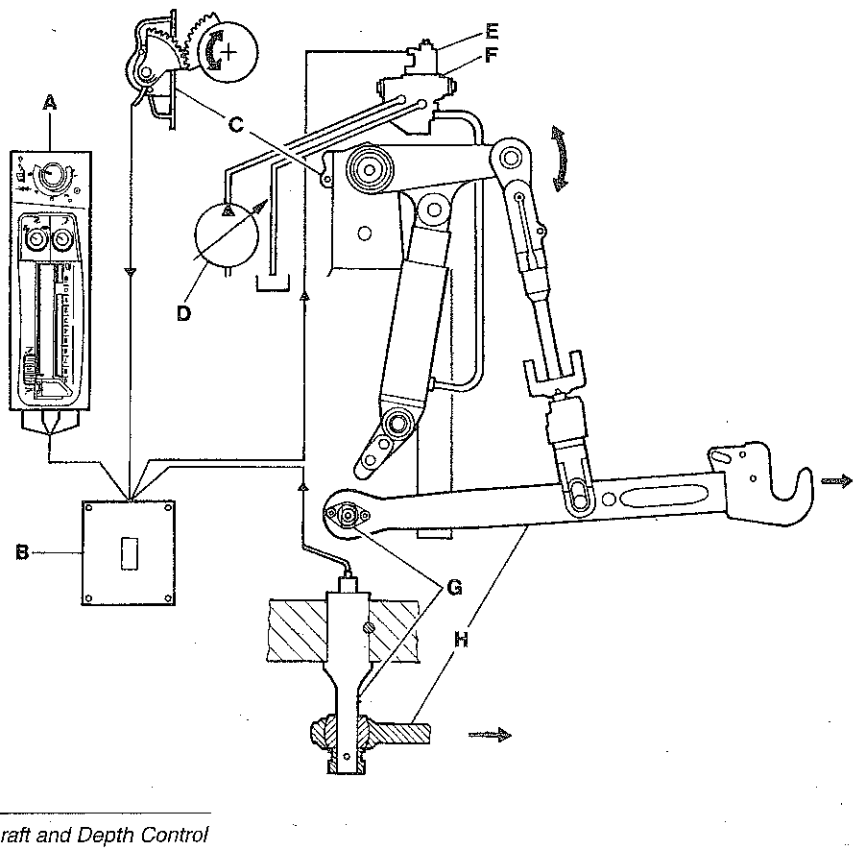


Fig. 47 Electronic Controlled Draft and Depth Control

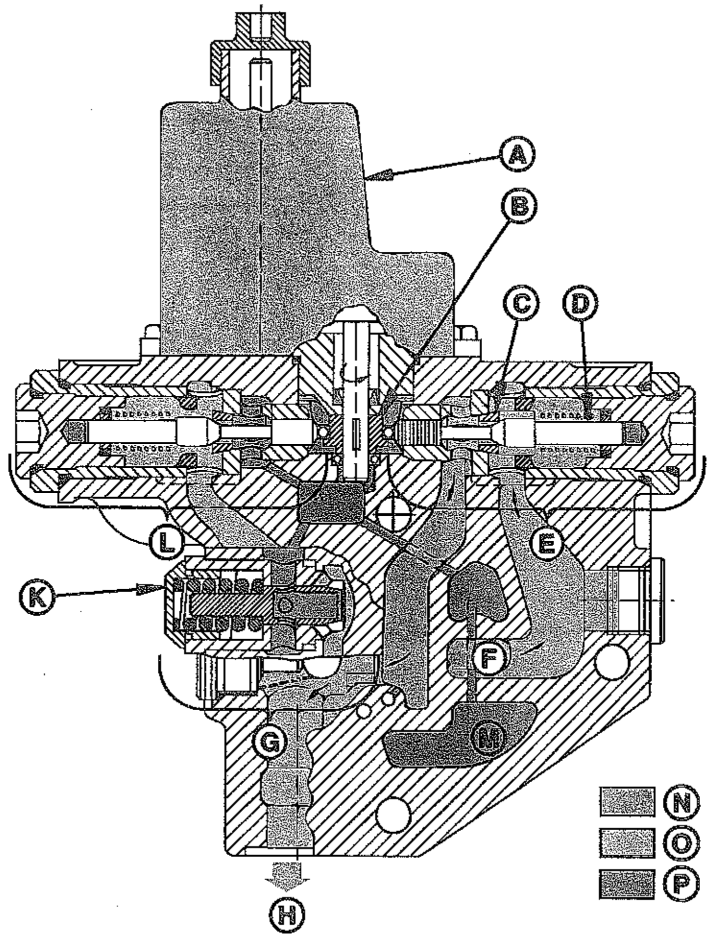


Fig. 48 - Rockshaft Valve - Electronic Control

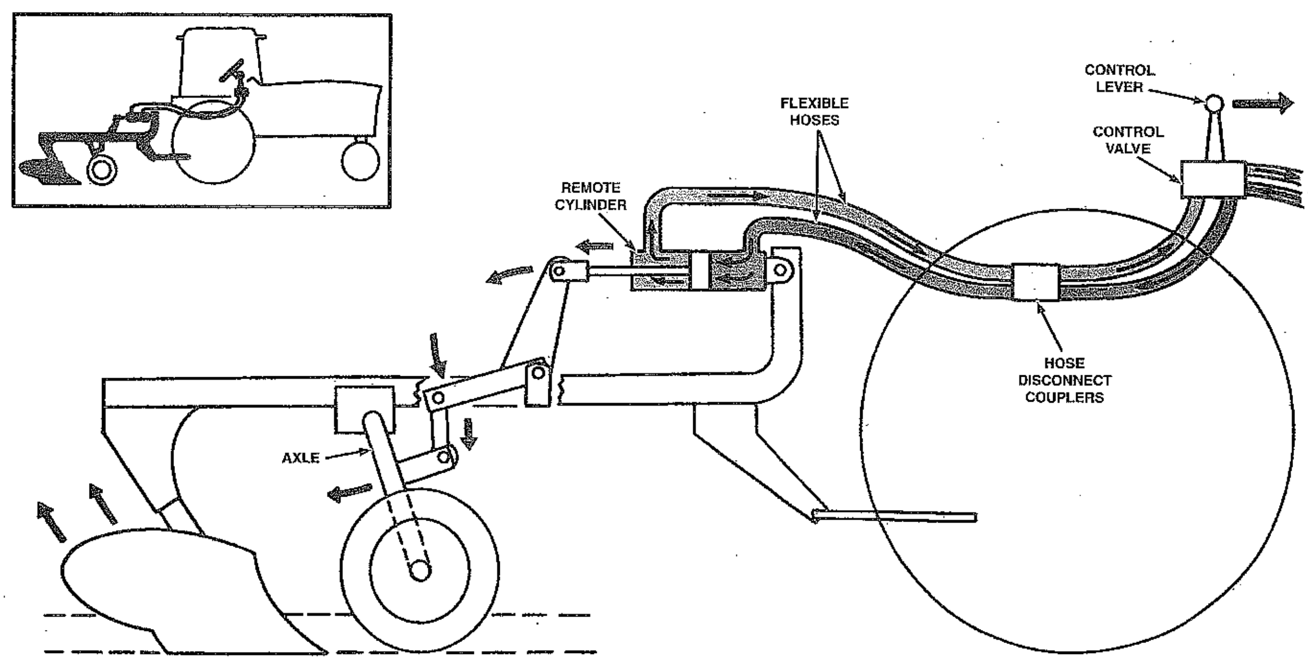


Fig. 49 - Remote Control Hydraulics

When operating in draft control, the signal from the operation unit (A) is coordinated with the actual load value at draft sensor (G).

The rockshaft valve (Fig. 48) has the raising and lowering valves (E) and (L), check valve (G), surge relief valve (K) and stepper motor (A). It is shown raising.

During the lifting process, stepper motor (A) receives a signal and rotates cam (B), which raises valve spool (D) from the seat (C) of raising valve (E). High-pressure oil (N) can now flow through check valve (G) to the two rockshaft cylinders.

During the lowering process, lowering valve (L) is opened by the cam and the oil flows out of the rockshaft cylinders by the weight of the implement.

When the rockshaft valve is in its neutral position, check valve (G) traps the hydraulic oil in the rockshaft cylinders and prevents the lift arms from lowering when the engine is shut off.

Surge relief valve (K) reduces pressure peaks caused when transporting heavy implements.

Pilot-pressure oil (O) gives a signal to a load sensing hydraulic pump.

REMOTE CONTROL OF EQUIPMENT

Tractors may operate equipment that is not mounted, but is pulled or pushed. To control this equipment with hydraulics, a remote actuator such as a cylinder or a motor is needed. It is separate from the tractor and connected by flexible hoses.

Let's take the case of a plow again, this time, one that is pulled behind the tractor (Fig. 49). The operator wants to raise it so he moves the control lever to the front as shown. This actuates the control valve that sends pressure oil to the front of the remote cylinder. As this oil pushes the piston to the rear, the cylinder rod extends. Oil from the other side of the cylinder is forced out and returns through the valve to the reservoir. As the cylinder extends it pivots linkage to raise the plow.

Note- See Chapter 5 for details of Valves and Chapter 6 for cylinders

DIAGNOSIS AND TESTING OF HYDRAULIC SYSTEMS

In the final chapter of this manual, we will once again return to complete hydraulic systems for diagnosis and testing. But because the most important tool in troubleshooting is knowledge of the system, we must look at the various working parts in more detail.

The following chapters will do that. We will then use our knowledge of "how the system works" to find out "why the system fails" and "how to remedy" these failures. Chapter 15 is titled "Diagnosis and Testing of Hydraulic Systems."

HYDRAULIC FACTS

Here are some key facts that will help you understand hydraulics:

1. There are two basic types of hydraulics:
   a) Hydrodynamics is the use of fluids at high speeds that impact another member to supply power (kinetic energy). It is the weight and speed of the oil that is harnessed.
      Example: a torque converter.
   b) Hydrostatics is where fluids are forced through tubes at relatively low speeds but at higher pressures to transfer power (hydraulic energy) from the power source (pump) to the work (cylinder or motor). Example: most hydraulic systems. It is the only type covered in this manual.
2. Hydraulic power is generated from mechanical power. Example: A hydraulic pump driven by an engine crankshaft.
3. Output is achieved by converting hydraulic power back to mechanical energy. Example: A cylinder that raises a heavy plow.
4. Hydraulic energy is neither created nor destroyed, only converted to another form. All energy put into a hydraulic system must come out either as work (gain) or as heat (loss).
5. Flow through an orifice or restriction causes a pressure drop.
6. When a moving liquid is restricted, heat is created and there is a loss of potential energy (pressure) for doing work.

   Example: A tube or hose that is too small or is restricted. Orifices and relief valves are also restrictions but they are purposely designed into systems.
7. Oil takes the course of least resistance.
8. Oil is pushed into a pump by atmospheric pressure, not drawn into it.
9. A pump does not pump pressure; it creates flow. Pressure is caused by resistance to flow.
10. Two hydraulic systems may produce the same power output, one at high pressure and low flow, the other at low pressure and high flow.

11. A basic hydraulic system must include four components: a reservoir to store the oil, a pump to push the oil through the system, valves to control oil pressure and flow, and a cylinder (or motor) to convert the fluid movement into work.

12. Compare the two major hydraulic systems:

    Open-Center System = Valves used have an open passage when in the neutral position to allow oil to pass from the valve inlet to the outlet and back to the reservoir.

    Closed-Center System = Valves used have all paths for the oil blocked when in the neutral position. There is no oil flow through the valve. This requires that the system be able to supply oil only when needed.

TEST YOURSELF

QUESTIONS

1. (True or False) "A pump creates pressure?"

2. Oil flow through an orifice causes pressure beyond the orifice to:

   a. rise

   b. drop

3. How do you determine the force exerted by a piston?

4. What four components are needed to complete a very basic hydraulic system?

5. (True or False) "Hydraulic pumps convert hydraulic power to mechanical power?"

6. (Fill in the blank.) "Speed is a factor in determining ________."

   a. displacement

   b. work

   c. power

7. (Fill in the blank.) "To determine if a system is an open-center or closed-center system you must look at ________."

   a. the pump

   b. the control valve

   c. both the pump and valve

8. Describe the difference in the control valve during neutral in an open-center system, as compared to a closed-center system.

9. Is fluid pushed into a pump or drawn into it?

10. In what system do both the flow and pressure vary?