UNIT 4

Hydraulic Fundamentals - Pilot Operated Hydraulic System

Objectives

Upon completion of this unit, the student will:

1. Trace the oil flow from the tank to the pump, through the various hydraulic components, and back to the tank.

2. State the function of each component in the system.

3. State the system operation in the various modes.

Introduction

In this unit, students will use the basic hydraulic knowledge learned in Unit I through Unit III to explain the functions of a pilot operated implement hydraulic system.

The system components in this unit are colored dark gray, gray and yellow. The yellow represents the current position of the components in the ISO drawings and the movable parts of the components in the orthographic drawings.

The hydraulic oil colors used in this unit are:

Green	Tank oil or oil connected to the tank.
Blue	Blocked oil
Red	High pressure oil or pump oil
Red and White Stripe	High pressure oil but less than Red oil.
Orange	Pilot pressure oil

NOTES

Lesson 1: Pilot Operated Implement Hydraulic System

BASIC HYDRAULIC SYSTEMS

PILOT OPERATED IMPLEMENT HYDRAULIC SYSTEM

Introduction

The pilot operated implement hydraulic system is used on various models of mobile construction equipment. The illustrations used in this lesson are for the Caterpillar 928G Wheel Loader.

Students will identify the basic hydraulic components used in the pilot operated implement hydraulic system, state the functions of the various components and trace the hydraulic oil flow through the systems.

Objectives

Upon completion of this lesson the student will:

1. State the hydraulic principles used in the operation of the pilot operated hydraulic implement system.
2. Trace the oil flow and state the function of the components of the pilot operated hydraulic implement system.
3. Identify the basic ISO symbols of the pilot operated hydraulic implement system.

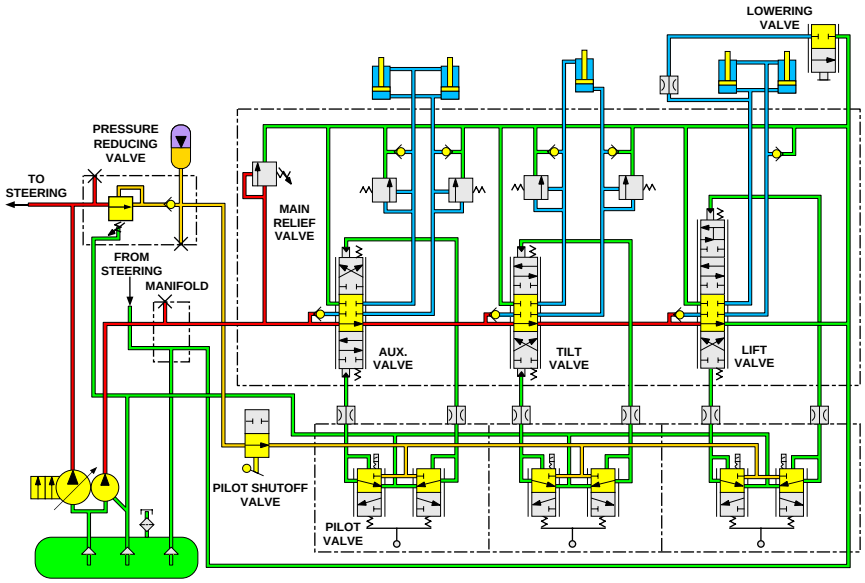

Fig. 4.1.1 Implement Hydraulic System

Implement Hydraulic System

The schematic in Figure 4.1.1 shows the implement hydraulic system with the engine running and all control levers in the HOLD position.

The gray and yellow ISO symbols represent movable components. The yellow portion of the symbol shows the current position of the component. Example, in Figure 4.1.1, the yellow center envelopes of the main control valves show that the valves are in the HOLD position.

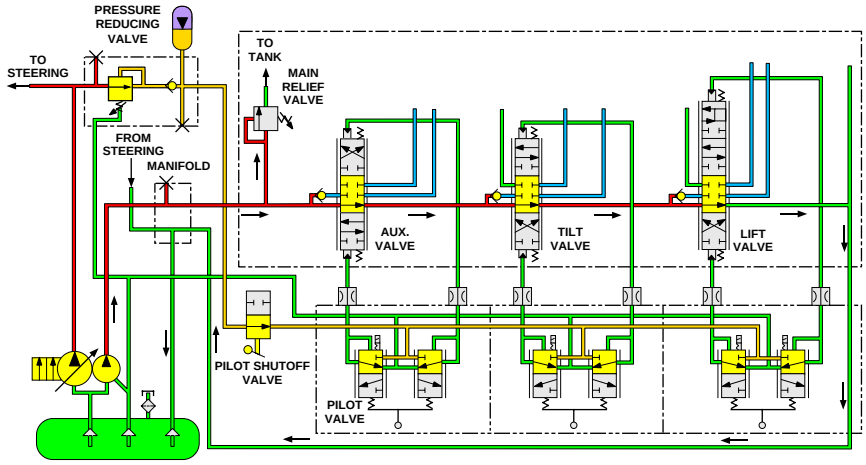

Fig. 4.1.2 Main System HOLD Position

Main System HOLD position

In the HOLD position, the main implement pump draws oil from the tank and sends supply oil flow past the test port and the main relief valve to the center envelope of the auxiliary control valve. The supply oil flows through the center of the auxiliary control valve, the center of the tilt control valve, the center of the lift control valve and returns to the tank. This type system is called an "open center" system.

Pilot System HOLD Position

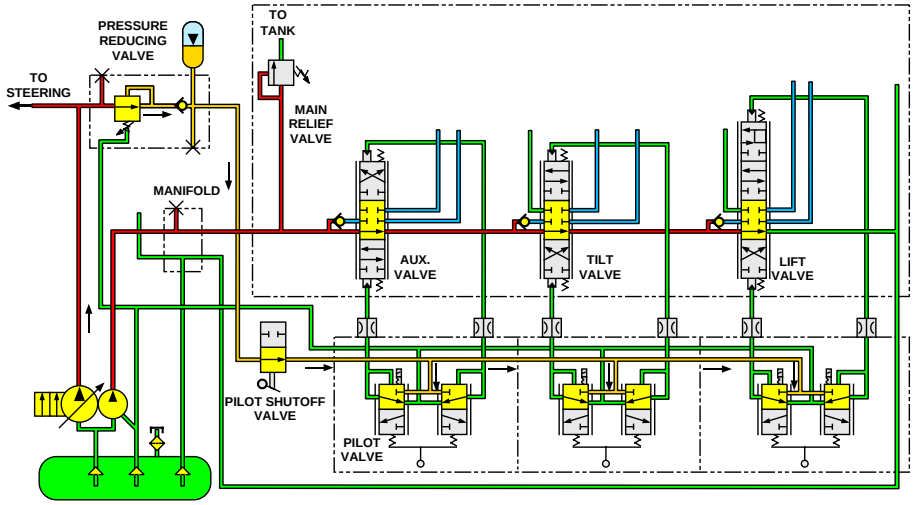

Fig. 4.1.3 Pilot System HOLD Position

In the HOLD position, the pilot and steering system pump draws oil from the tank and sends supply oil flow to the steering system supply port and the pressure reducing valve. The pressure reducing valve controls the maximum pressure in the pilot system. (The pressure reducing valve operation is explained in Unit 3, Lesson 4.) Oil flows from the pressure reducing valve, through the check valve to the accumulator and to the pilot shutoff valve.

The accumulator serves as an emergency pilot oil supply when the pump is not pumping oil.

When the pilot shutoff valve is in the OFF position, the pilot oil is blocked. The pilot system will not function. When the pilot shutoff valve is in the ON position, the oil flows through the pilot shutoff valve to the auxiliary, tilt and lift pilot control valves.

When the pilot control valves are in the HOLD position, the pilot oil is blocked at the pilot control valves. This type system is a "closed center" system.

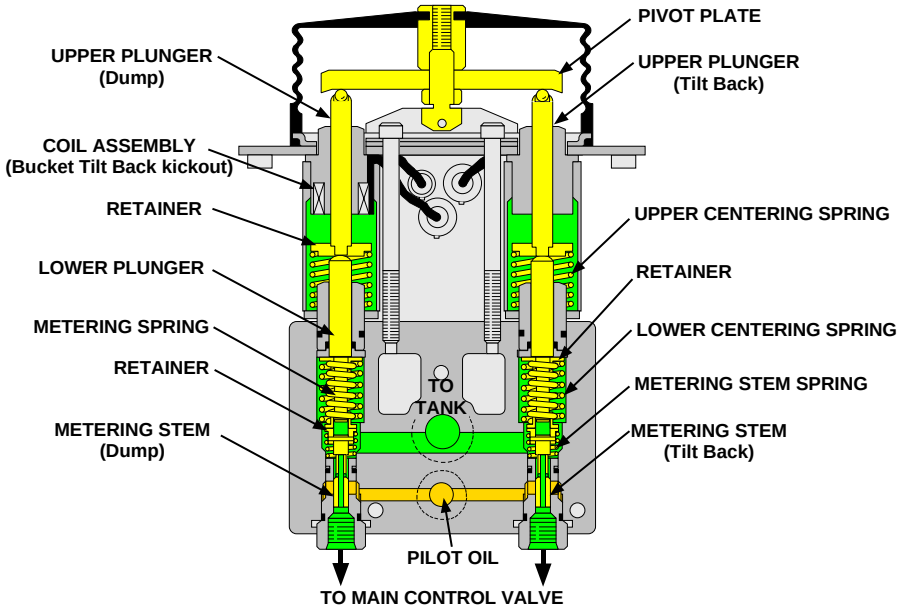

Fig. 4.1.4 Tilt Pilot Control Valve

Tilt Pilot Control Valve

Figure 4.1.4 shows the major components in the tilt pilot control valve. Except for the coil assembly at the top of the dump section (left side), the parts are the same for both sides of the valve.

With the engine running and the control lever in the HOLD position, pilot oil enters the supply port (bottom center of valve body) and is blocked by the metering stems. Any oil in the lines to the main control valve is vented to the tank port through the center of the metering stems.

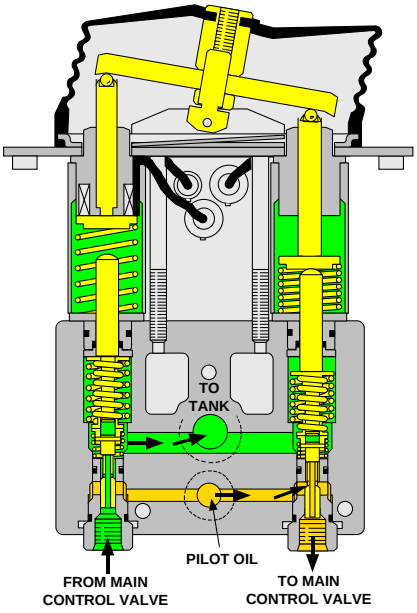

Fig. 4.1.5 TILT BACK Position

TILT BACK Position

When the operator moves the pilot control lever to the TILT BACK position, the force causes the pivot plate to move the upper plunger, the lower plunger, the metering spring, the metering stem spring retainer, the metering stem spring and the metering stem down. Oil from the pilot pump flows through the orifice and the center of the metering stem to the main control valve. Return oil from the main control valve flows through the dump metering stem port, the center of the metering stem and to the tank port.

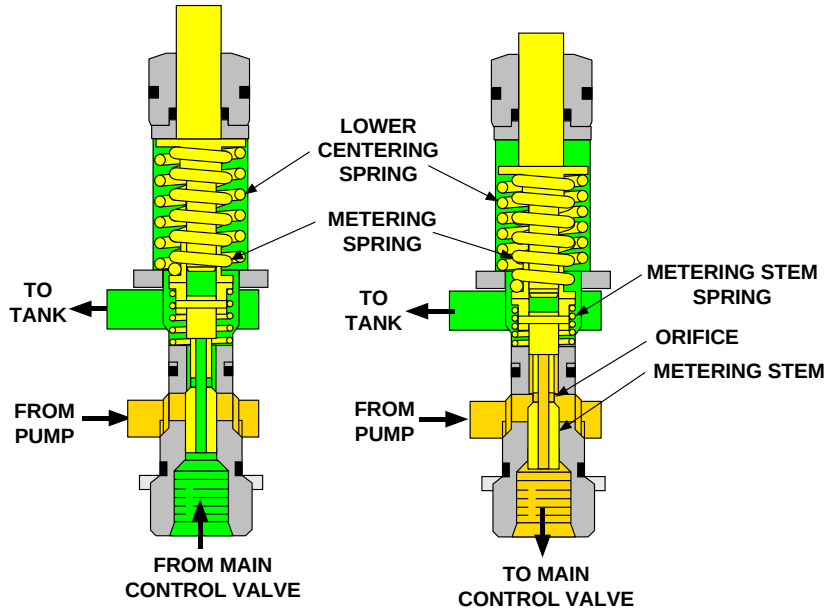

Fig. 4.1.6 Metering Spring

Metering Spring

The job of the metering stem is to allow movement of the main control valve spool in proportion to the movement of the pilot valve lever. The metering stem and metering spring function as a pressure reducing valve and control the oil pressure at the end of the main control valve spool.

When the metering stem moves down, pilot oil flows through the orifice, the center of the metering stem and out to the main control valve spool. The pilot oil is blocked at the main control valve spool causing the pilot pressure to increase. The pressure increase overcomes the main control valve spool spring and moves the main control valve spool. The main control valve spool directs the main system oil to the cylinder.

The pressure increase is also sensed against the lower end of the metering stem. When the pressure increase overcomes the applied force, the metering stem moves up and compresses the metering spring. The movement restricts pilot oil flow through the metering stem orifice. Restricting the oil flow controls the pressure at the main control valve spool. The metering spring therefore adjusts the pressure at the main control valve spool in proportion to the movement of the pilot valve lever

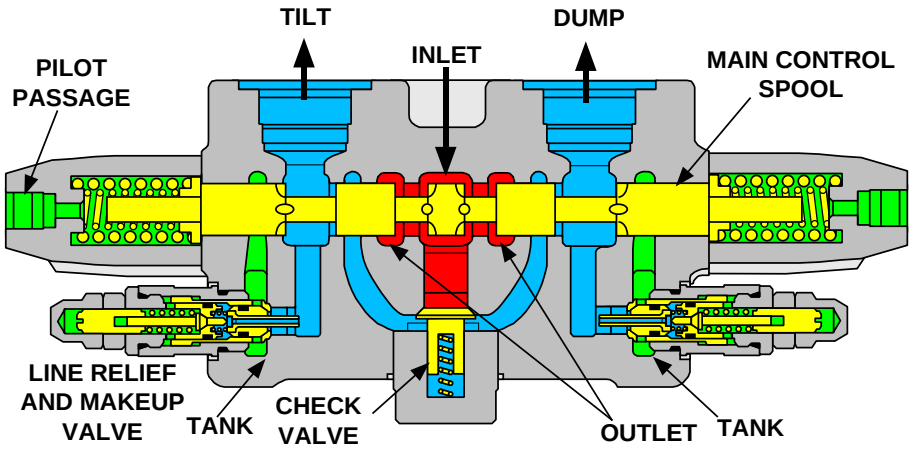

Fig. 4.1.7 Main Control Valve in HOLD Position

Control Valve in HOLD Position

Figure 4.1.7 shows a 928G main control valve in the HOLD position. The function of the valve shown is representative of the tilt valve, lift valve, auxiliary valve or the fourth function valve. The auxiliary valve contains only line relief valves in both work ports.

When in HOLD, pump supply oil enters the center passage, flows around the control spool, and through the outlet passages to the next valve . Supply oil also flows through the internal passage to the check valve. Oil flows past the check valve to the the main control spool. The main control spool blocks supply oil flow to the work ports (tilt and dump passages). The main control spool also blocks the work port oil passages from the tank oil passages.

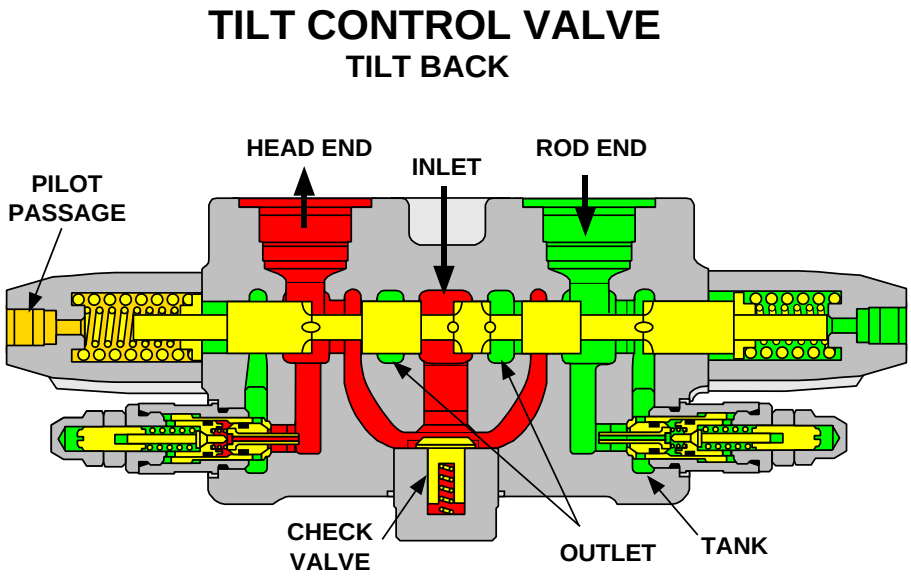

Fig. 4.1.8 TILT BACK Position

TILT BACK Position

When the operator moves the pilot control lever to the TILT position, pilot oil (orange) moves the tilt control spool to the right. The control spool blocks the oil outlet passages, opens the passage from the check valve to the tilt cylinder head end and opens the passage from the tilt cylinder rod end to the tank return. When the supply pressure is higher than the pressure in the head end of the tilt cylinder, the supply oil opens the check valve and flows past the control spool to the head end of the tilt cylinder. The return oil flows from the rod end of the tilt cylinder, past the control spool and to the tank. The bucket begins tilting back.

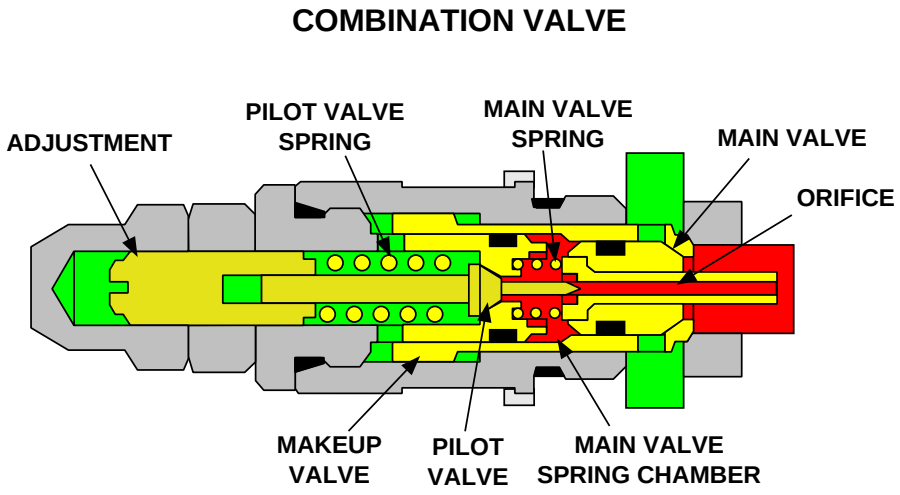

Fig. 4.1.9 Combination Line Relief and Makeup Valve

Combination Line Relief and Makeup Valve

Figure 4.1.9 shows the combination line relief and makeup valve. The line relief valve is simply a pilot operated relief valve. However, the line relief valve is not designed to handle maximum implement pump flow.

The oil in the cylinder is connected through lines to the right end of the combination valve. The oil flows through the main valve orifice to the main valve spring chamber. The oil pressure at the front (right) of the valve is the same as the oil pressure in the spring chamber. The oil pressure in the main valve spring chamber plus the force of the spring keeps the valve closed.

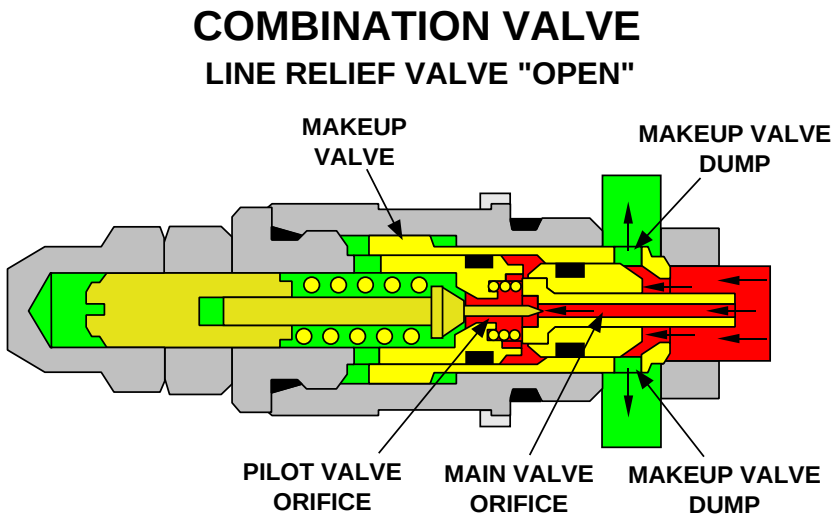

Fig. 4.1.10 Line Relief in RELIEF Position

Line Relief in RELIEF Position

In Figure 4.1.10, the line relief is shown in the RELIEF position. When the oil pressure overcomes the setting of the pilot valve, the pilot valve moves to the left against the spring. The high pressure oil in the main valve spring chamber flows through the pilot valve orifice to the pilot valve spring chamber drain passage. The pressure in the main valve spring chamber decreases. The higher pressure oil at the right side of the main valve moves the main valve to the left. The high pressure oil flows past the main valve, through the makeup valve dump openings to the tank.

The makeup valve does not move when the line relief valve opens.

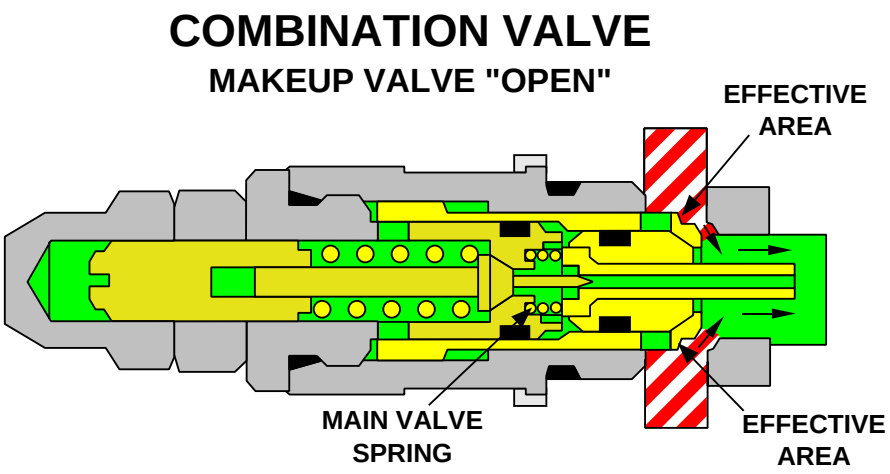

Fig. 4.1.11 MAKEUP Position

MAKEUP Position

Figure 4.1.11 shows the combination line relief and makeup valve in the MAKEUP position. The tank pressure is sensed on the effective area of the combination valve at all times. When the oil pressure in the cylinder, the connecting line and the relief valve spring chamber decreases to 13.78 kPa (2 psi) less than the oil pressure in the tank, the tank pressure moves the makeup valve and the main valve to the left against the main valve spring. The tank oil flows through the newly opened passage to the connecting line and cylinder.

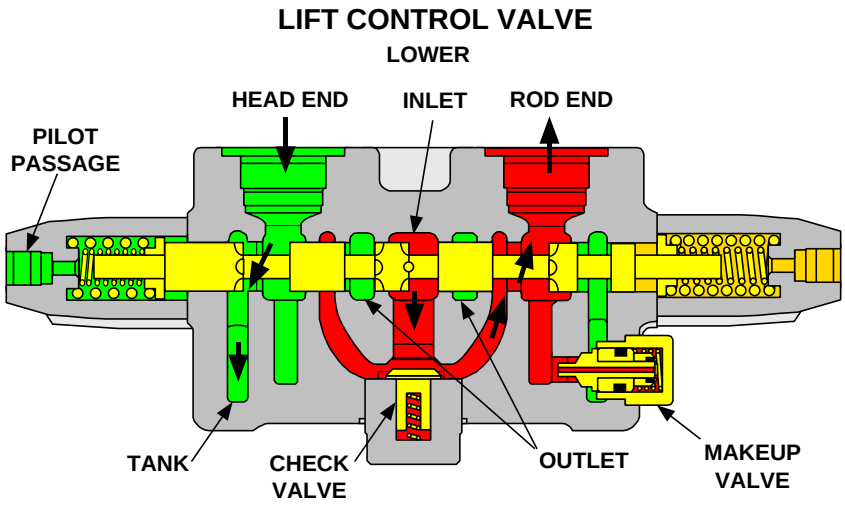

Fig. 4.1.12 Lift Control Valve in LOWER Position

Lift Control Valve in LOWER Position

Figure 4.1.12 shows the lift control valve in the LOWER position.

When the operator moves the lift/lower pilot control lever to the LOWER position, pilot oil (orange) moves the lift control spool to the left. The control valve spool blocks the oil outlet passages, opens the passage from the check valve to the lift cylinder rod end and opens the passage from the lift cylinder head end to the tank return. When the supply pressure is higher than the pressure in the rod end of the tilt cylinder, the supply oil opens the check valve and flows past the control spool to the rod end of the lift cylinder. The return oil flows from the head end of the lift cylinder, past the control spool and to the tank. The bucket begins to lower.

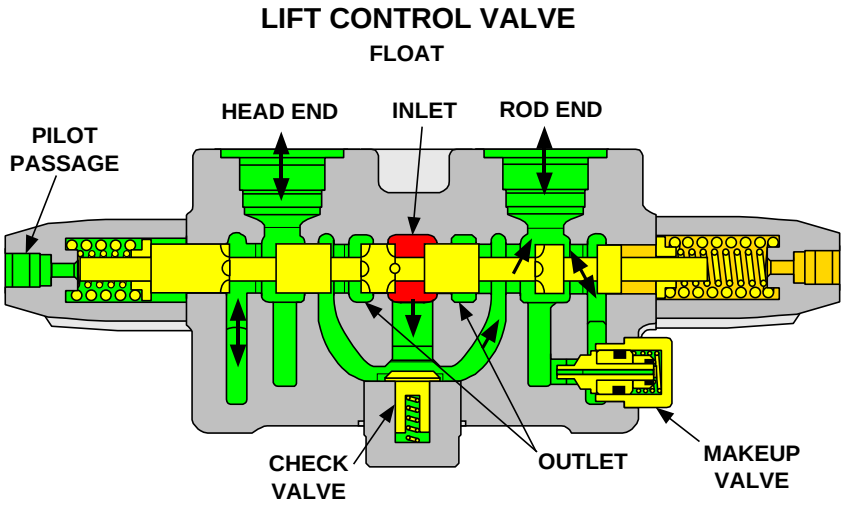

Fig. 4.1.13 Lift Control Valve in FLOAT Position

Lift Control Valve in FLOAT Position

Figure 4.1.13 shows the lift control valve in the FLOAT position.

When the operator moves the lift/lower pilot control lever to the FLOAT position, pilot oil (orange) moves the lift control spool completely to the left. The control spool opens the passage from the check valve to the left side outlet and opens the passage from the lift cylinder head end to the tank return. The control spool also connects the lift cylinder rod end to the tank return. When the pump and both ends of the lift cylinder are connected to the tank, the lift cylinder cannot be hydraulically raised of lowered.

When the machine is moved and the lift/lower control is in the FLOAT position, the implement follows the curvature of the ground.

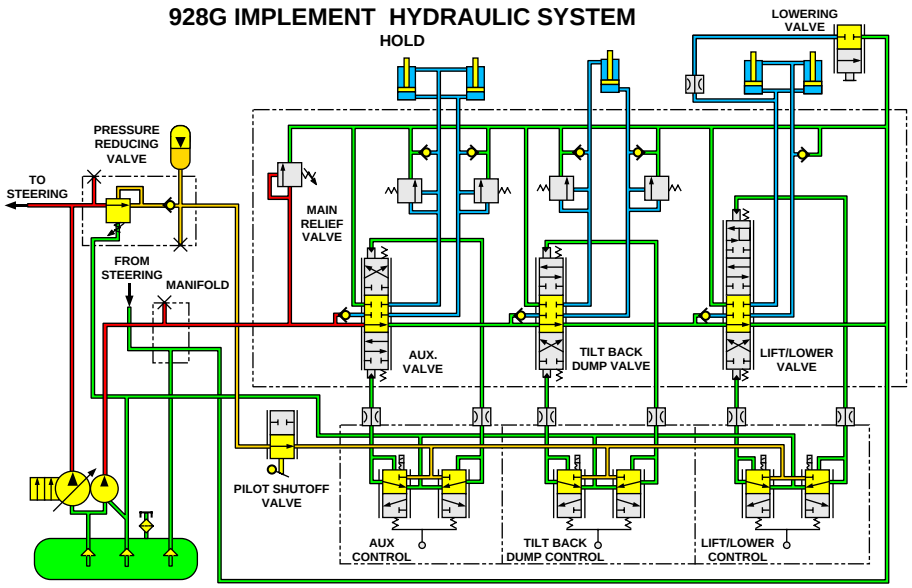

Fig. 4.1.14

In the HOLD position, the oil from the steering and pilot pump flows to the steering system supply port and the pressure reducing valve. The pressure reducing valve controls the maximum pressure in the pilot system. (The pressure reducing valve operation is explained in Unit 3, chapter 4.) Oil flows from the pressure reducing valve, through the check valve to the accumulator and to the pilot shutoff valve.

The accumulator serves as an emergency pilot oil supply when the pump is off.

When the pilot shutoff valve is in the OFF position, the pilot oil is blocked. The pilot system will not function. When the pilot shutoff valve is in the ON position, the oil flows through the pilot shutoff valve to the auxiliary, tilt back/dump and lift/lower pilot control valves. When the pilot control valves are in the HOLD position, the pilot oil is blocked at the pilot control valves. This type system is called a "closed center" system.

Oil from the main implement pump flows past the test port and the main relief valve to the main control valve.

The implement pump oil flows through the center of the auxiliary valve spool, the center of the tilt back/dump valve spool, the center of the lift/lower valve spool and returns to the tank. This type system is called an "open center" system.

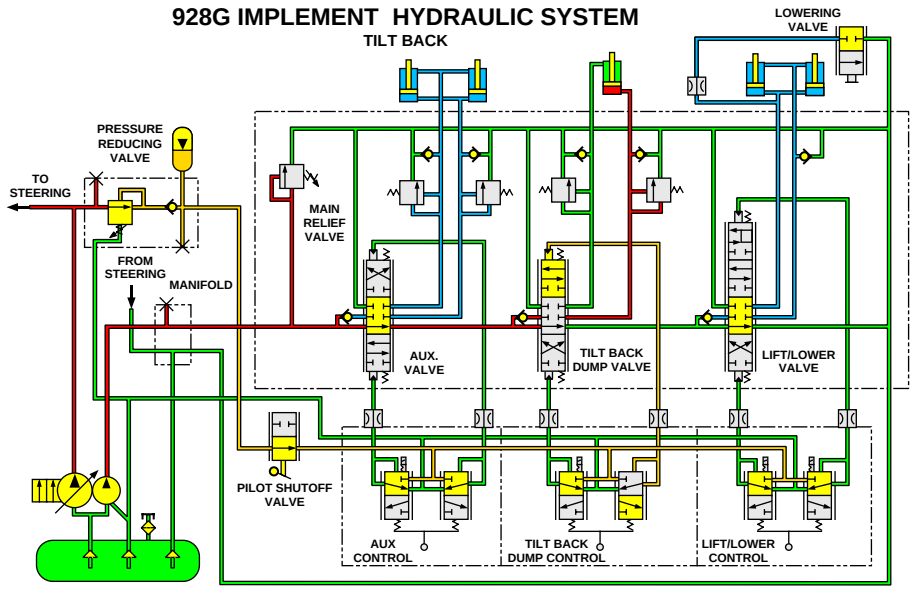

Fig. 4.1.15

This schematic shows the flow through the hydraulic system with the tilt back/dump control lever in the TILT BACK position.

When the operator moves the tilt back/dump control lever to the TILT BACK position, pilot oil flows past the tilt back/dump pilot control valve to the end of the tilt back/dump valve spool in the main implement control valve. Pilot oil moves the tilt back/dump valve spool to the TILT BACK position. Oil from the opposite end of the tilt back/dump valve spool flows past the tilt back/dump pilot control valve to the tank.

Movement of the tilt back/dump valve spool to the TILT BACK position blocks the flow of implement pump oil to the tank and directs implement pump oil to the head end of the tilt cylinder. Oil in the rod end of the tilt cylinder is forced back past the tilt back/dump valve spool to the tank.

The orifices in the pilot oil lines between the tilt back/dump pilot control valve and the tilt back/dump valve spool causes a restriction to the flow of pilot oil and provides better operator control of the tilt back/dump valve spool.

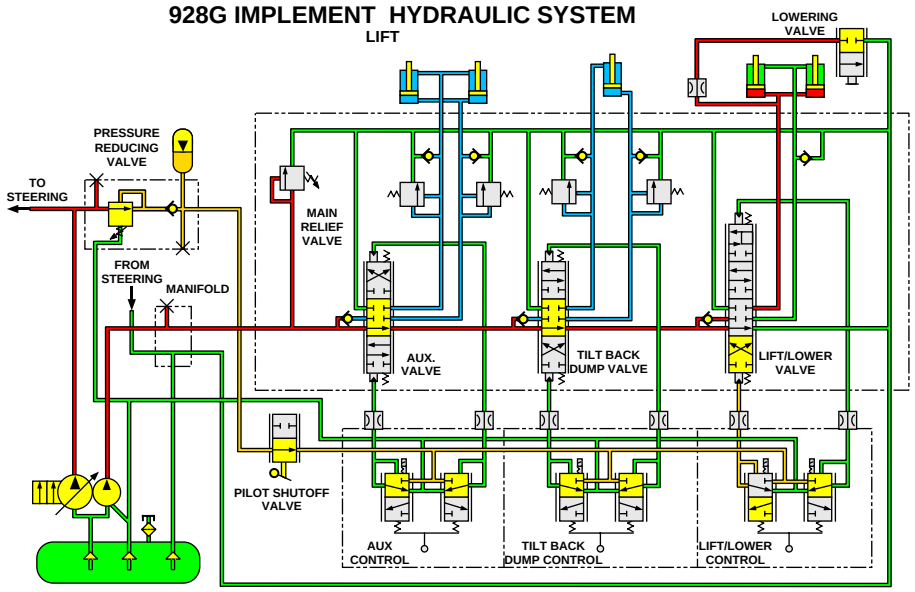

Fig. 4.1.16

Shown in this schematic are the conditions in the implement hydraulic system with the lift/lower control lever in the LIFT position.

When the operator moves the lift/lower control lever to the LIFT position, pilot oil flows past the lift/lower pilot control valve to the end of the lift/lower valve spool in the main implement control valve. Pilot oil moves the lift/lower valve spool to the LIFT position. Oil from the opposite end of the lift/lower valve spool flows past the lift/lower pilot control valve to the tank.

Movement of the lift/lower valve spool to the LIFT position blocks the flow of supply oil to the tank. Supply oil is directed to the head ends of the lift cylinders. Oil in the rod ends of the cylinders is forced past the lift/lower valve spool to the tank.

The orifices in the pilot oil lines between the lift/lower pilot control valve and the lift/lower valve spool causes a restriction to the flow of pilot oil and provides better operator control of the lift/lower valve spool.

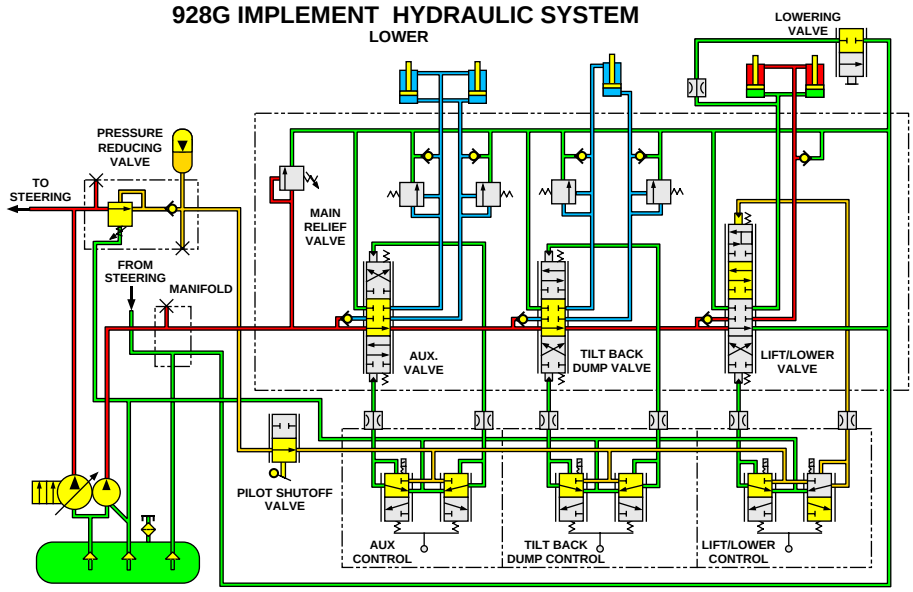

Fig. 4.1.17

Shown in this schematic are the conditions in the implement hydraulic system with the lift/lower control lever in the LOWER position.

When the operator moves the lift/lower control lever to the LOWER position, pilot oil flows past the lift/lower pilot control valve to the end of the lift/lower valve spool in the main implement control valve. Pilot oil moves the lift/lower valve spool to the LOWER position. Oil from the opposite end of the lift/lower valve spool flows past the lift/lower pilot control valve to the tank.

Movement of the lift/lower valve spool to the LOWER position blocks the flow of supply oil to the tank. Supply oil is directed to the rod ends of the lift cylinders. Oil in the head ends of the cylinders is forced past the lift/lower valve spool to the tank.

The orifices in the pilot oil lines between the lift/lower pilot control valve and the lift/lower valve spool causes a restriction to the flow of pilot oil and provides better operator control of the lift/lower valve spool.

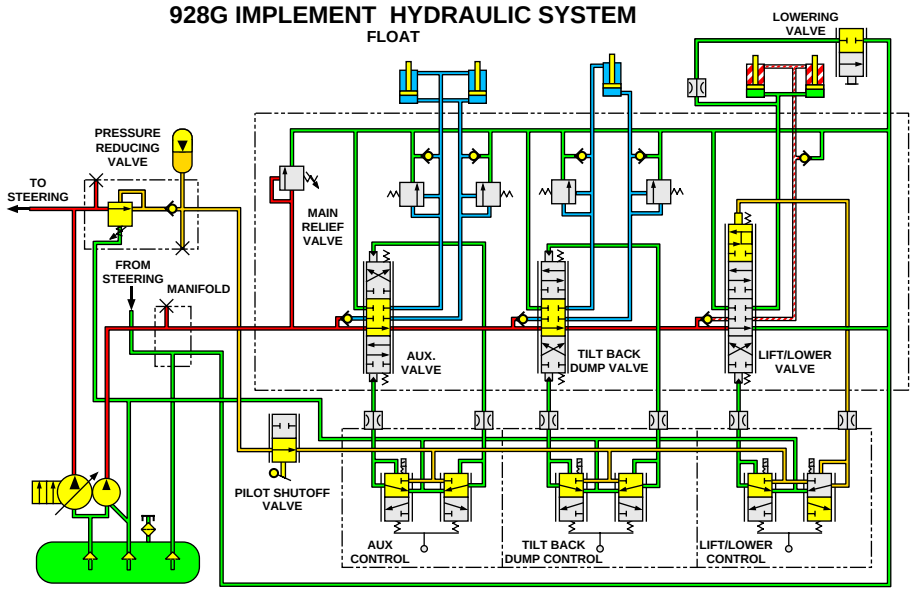

Fig. 4.1.18

In this schematic, the lift/lower control lever has been moved to the FLOAT position.

When the operator moves the lift/lower control lever to the FLOAT position, pilot oil flows past the lift/lower pilot control valve to the end of the lift/lower valve spool in the main implement control valve. Pilot oil moves the lift/lower valve spool to the FLOAT position. Oil from the opposite end of the lift/lower valve spool flows past the lift/lower pilot control valve to the tank.

Movement of the lift/lower valve spool to the FLOAT position blocks the flow of supply oil to the tank. Supply oil is directed to the rod ends of the lift cylinders and to the tank. Oil in the head ends of the cylinders flows past the lift/lower valve spool to the tank.

When the machine is moved and the implement is in "float." The bucket will follow the curvature of the ground. The slight pressure in the rod ends of the lift/lower cylinders will not force the bucket into the ground.

NOTES

GLOSSARY OF TERMS

Accumulator – A container which stores fluids under pressure as a source of hydraulic power. It may also be used as a shock absorber.

Actuator - A device which converts hydraulic power into mechanical force and motion. (Examples: hydraulic cylinders and motors.)

Bleed – The process by which air is removed from a hydraulic system.

Bypass – A secondary passage for fluid flow.

Cavitation – A phenomenon which occurs when the pressure point in a hydraulic system is lowered below the vapor pressure of the oil in the system. This allows bubbles of oil vapor to form in the oil. If this occurs at the pump inlet, the quick pressure rise inside the pump forces these bubbles to collapse violently. This can cause erosion of metal parts, noise and vibration.

Circuit – A series of component parts connected to each other by fluid lines or passages. Usually part of a "system."

Closed Center System – A hydraulic system in which the control valves are closed during neutral, stopping oil flow. Flow in this system is varied, but pressure remains constant.

Controller – A microprocessor that controls electro-hydraulic valve functions.

Cooler (Oil) – A heat exchanger which removes heat from a fluid. (See "Heat Exchanger.")

Coupler – A device to connect two hoses or lines, or to connect hoses to valve receptacles.

Cushion – A device, sometimes built into a cylinder, which restricts outlet flow and thereby slows down the piston.

Cycle – A single complete operation of a component which begins and ends in a neutral position.

Cylinder – A device for converting fluid power into linear or circular motion. An "actuator."

> **Double-Acting Cylinder** – A cylinder in which fluid force can be applied to the movable element in either direction.
>
> **Single Action Cylinder** – A cylinder is which fluid force can be applied to the movable element in only one direction.

Displacement – The volume of oil displaced by one complete stroke or revolution (of a pump, motor, or cylinder).

Drift – Motion of a cylinder or motor due to internal leakage past components in the hydraulic system.

Energy – Three types of energy are available in modern hydraulics (of the normal hydrostatic type):

Potential Energy – Pressure energy. The static energy of oil which is standing but is pressurized and ready to do work. Example: oil in a loaded accumulator.

Heat Energy – Friction or resistance to flow. (An energy loss in terms of output.) Example: friction between moving oil and the confines of lines or passages produces heat energy.

Kinetic Energy – The energy of the moving liquid. Varies with the velocity (speed) of the liquid.

Filter (OIL) – A device which removes solids from a fluid.

Flow Meter – A testing device which gauges either flow rate, total flow, or both.

Flow Rate – The volume of fluid passing a point in a given time.

Fluid Power – Energy transmitted and controlled through use of a pressurized fluid. Force – A push or pull acting upon a body. In a hydraulic cylinder, it is the product of the pressure on the fluid, multiplied by the effective area of the cylinder piston. It is measured in pounds or tons.

Friction – The resistance to fluid flow in a hydraulic system. (An energy loss in terms of power output.)

Heat Exchanger – A device which transfers heat through a conducting wall from one fluid to another. (See "Cooler, (Oil)".)

Horsepower – The work produced per unit of time.

Hose – A flexible line.

Hydraulics – The engineering science of liquid pressure and flow. (In this manual, our main interest is in oil hydraulics as applied to produce work in linear and rotary planes.

Hydrodynamics – The engineering science of the energy of liquid pressure and flow.

Hydrostatics – The engineering science of the energy of liquids in equlibrium. (All the systems covered in this manual operate on the hydrostatic principle.)

Inert Gas – A non-explosive gas.

Line – A tube, pipe, or hose for conducting a fluid.

Manifold – A fluid conductor which provides many ports.

Motor (Hydraulic) – A device for converting fluid energy into mechanical force and motion – usually rotary motion. Basic design types include gear, vane, and piston units.

Open Center System – A hydraulic system in which the control valves are open to continuous oil flow, even in neutral. Pressure in this system is varied, but flow remains constant.

Orifice – A restricted passage in a hydraulic circuit. Usually a small drilled hole to limit flow or to create a pressure differential in a circuit.

O-ring – A static and or dynamic seal for curved or circular mating surfaces.

Pipe – A line whose outside diameter is standardized for threading.

Piston – A cylindrical part which moves or reciprocates in a cylinder and transmits or receives motion to do work.

Port – The open end of a fluid passage. May be within or at the surface of a component.

Pour Point – The lowest temperature at which a fluid will flow under specific conditions.

Pressure – Force of a fluid per unit area, usually expressed in pounds per square inch (psi), kilopascals (kPa) or BAR (bar).

Back Pressure – The pressure encountered on the return side of a system.

Breakout Pressure – The minimum pressure which starts moving an actuator.

Cracking Pressure – The pressure at which a relief valve, etc., begins to open and pass fluid.

Differential Pressure – The difference in pressure between any two points in a system or a component. (Also called a "pressure drop.")

Full-flow Pressure – The pressure at which a valve is wide open and passes its full flow.

Operating Pressure – The pressure at which a system is normally operated.

Pilot Pressure – Auxiliary pressure used to actuate or control a component.

Rated Pressure – The operating pressure which is recommended for a component or a system by the manufacturer.

Static Pressure – The pressure in a fluid at rest. (A form of "potential energy.")

Suction Pressure – The absolute pressure of the fluid at the inlet side of the pump.

Surge Pressure – The pressure changes caused in a circuit from a rapidly accelerated column of oil. The "surge" includes the span of these changes, from low to high.

System Pressure – The pressure which overcomes the total resistances in a system. It includes all losses as well as useful work.

Working Pressure – The pressure which overcomes the resistance of the working device.

Pulsation – Repeated small fluctuation of pressure within a circuit.

Pump – A device which converts mechanical force into hydraulic fluid power. Basic design types are gear, vane, and piston pumps.

Fixed Displacement Pump – A pump in which the output per cycle cannot be varied.

Variable Displacement Pump – A pump in which the output per cycle can be varied.

Regenerative Circuit – A circuit in which pressure fluid discharged from a component is returned to the system to reduce flow input requirements. Often used to speed up the action of a cylinder by directing discharged oil from the rod end to the piston end.

Remote – A hydraulic function such as a cylinder which is separate from its supply source. Usually connected to the source by flexible hoses.

Reservoir – A container for keeping a supply of working fluid in a hydraulic system.

Restriction – A reduced cross-sectional area in a line or passage which normally causes a pressure drop. (Examples: pinched lines or clogged passages, or an orifice designed into a system.)

Solenoid – An electro-magnetic device which positions a hydraulic valve.

Snubber – (See "cushion").

Starvation – A lack of oil in vital area of a system. Often caused by plugged filters, etc.

Strainer – A coarse filter.

Stroke – The length of travel of a piston in a cylinder. (Sometimes used to denote the changing of the displacement of a variable displacement pump.)

Surge – A momentary rise of pressure in a hydraulic circuit.

Symbols, Schematic – Used as a short-hand representation on drawings to represent hydraulic system components.

System – One or more series of component parts connected to each other. Often made up of two or more "circuits".

Thermal Expansion – Expansion of the fluid volume due to heat.

Torque – The turning effort of a hydraulic motor or rotary cylinder. Usually given in inch-pounds (in-lbs), foot-pounds (ft-lbs) or Newton Meter (N.M.).

Tube – A line whose size is its outside diameter.

Valve – A device which controls either pressure or fluid, directions of fluid flow, or rate of flow.

Bypass Flow Regulator Valve – A valve which regulates the flow to a circuit at a constant volume, dumping excess oil.

Check Valve – A valve which permits flow in only one direction.

Closed Center Valve – A valve in which inlet and outlet ports are closed in the neutral position, stopping flow from pump through the valve.

Directional Control Valve – A valve which directs oil through selected passages. (Usually a spool or rotary valve design.)

Electro-Hydraulic Valve – A valve that is opened and closed by a solenoid.

Flow Control Valve – A valve which controls the rate of flow. (Sometimes called a "volume control valve.")

Needle Valve – A valve with an adjustable tapered point which regulates the rate of flow.

Open Center Valve – A valve in which the inlet and outlet ports are open in the neutral position, allowing a continuous flow of oil from the pump.

Pilot Valve – A valve used to operate another valve or control.

Pilot Operated Valve – A valve which is actuated by a pilot valve.

Poppet Valve – A valve design in which the seating element pops open to obtain free flow in one direction and immediately reseats when flow reverses.

Pressure Control Valve – A valve whose primary function is to control pressure. (Includes relief valves, pressure reducing or sequencing valves, and unloading valves.)

Pressure Reducing Valves – A pressure control valve which limits outlet pressure.

Pressure Sequence Valve – A pressure control valve which directs flow in a preset sequence.

Relief Valve – A valve which limits the pressure in a system, usually by releasing excess oil.

Rotary Directional Valve – A valve designed in a cylindrical shape. When the valve is turned, it opens and closes drilled passages to direct oil.

Selector Valve – A valve which selects one or two or more circuits in which to direct oil.

Shuttle Valve – A connecting valve which selects one of two or more circuits because of flow or pressure changes in these circuits.

Shutoff Valve – A valve which operates fully open or fully closed.

Spool Directional Valve – A valve designed as a spool which slides in a bore, opening and closing passages. Two-, Three-, Four-, or Six-Way Valve – A valve have 2, 3, 4, or 6 ports for direction of oil flow.

Volume Control Valve – A valve which controls the rate of flow. Includes flow control valves, flow divider valves, and bypass flow regulators.

Valve Stack – A series of control valves in a stack with common end plates and a common oil inlet and outlet.

Velocity – The distance which a fluid travels per unit time. Usually given as feet per second or meters per second.

Vent – An air breathing device in a fluid reservoir.

Viscosity – The measure of resistance of a fluid to flow.

Volume – The amount of fluid flow per unit time. Usually given as gallons per minute (gpm) or liters per minute (lpm).

ABBREVIATIONS

ANSI – American National Standards Institute

ASAE – American Society of Agricultural Engineers (sets standards for many hydraulic components for agricultural use)

°F – degrees Fahrenheit (of temperature)

ft-lbs. – foot-pounds (of torque or turning effort)

gpm – gallons per minute (of fluid flow)

hp – horsepower

I.D. – inside diameter (as of a hose or tube)

ISO – International Standards Organization

kPa – Kilopascals (of pressure)

LPM – Liters per minute (of fluid flow)

O.D. – outside diameter (as of a hose or tube)

psi – pounds per square inch (of pressure)

rpm – revolutions per minute

SAE – Society of Automotive Engineers (sets standards for many hydraulic components)