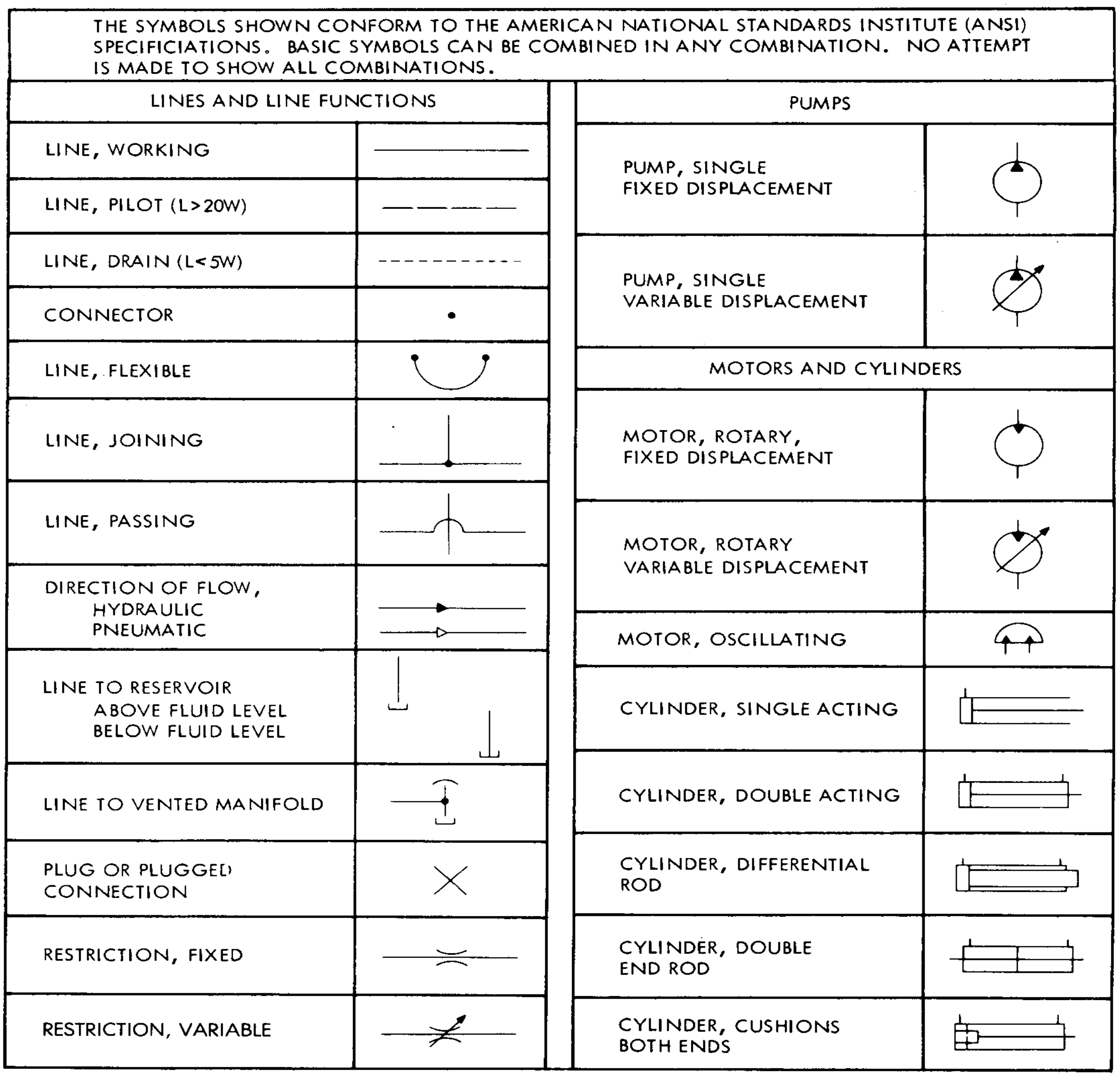
# Basic Hydraulic Circuit Design and Analysis

We are going to Discuss Basic Hydraulic Circuits. A Hydraulic Circuit is a Group of Components such as Pumps, Actuators, Control Valves, and Conductors so arranged that they will perform a Useful Task. When analyzing or Designing a Hydraulic Circuit, the following Three Important Considerations must be taken into account: Safety of Operation, Performance of desired Function, and Efficiency of Operation.

It is very important for the fluid power technician or designer to have a working knowledge of components and how they operate in a circuit. Hydraulic circuits are developed through the use of graphical symbols for all components. Before hydraulic circuits can be understood, it is necessary to know these fluid power symbols.

Next table gives of Symbols that conform to the American National Standards Institute (ANSI) Specifications.

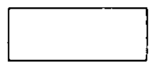
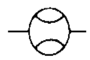
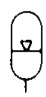
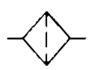
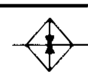
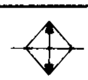
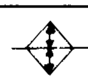
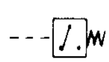


THE SYMBOLS SHOWN CONFORM TO THE AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI) SPECIFICIATIONS. BASIC SYMBOLS CAN BE COMBINED IN ANY COMBINATION. NO ATTEMPT IS MADE TO SHOW ALL COMBINATIONS.

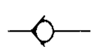
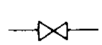
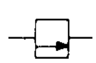
| LINES AND LINE FUNCTIONS | |
|---|---|
| LINE, WORKING | |
| LINE, PILOT (L>20W) | |
| LINE, DRAIN (L<5W) | |
| CONNECTOR | |
| LINE, FLEXIBLE | |
| LINE, JOINING | |
| LINE, PASSING | |
| DIRECTION OF FLOW, HYDRAULIC PNEUMATIC | |
| LINE TO RESERVOIR ABOVE FLUID LEVEL BELOW FLUID LEVEL | |
| LINE TO VENTED MANIFOLD | |
| PLUG OR PLUGGED CONNECTION | |
| RESTRICTION, FIXED | |
| RESTRICTION, VARIABLE | |

| PUMPS | |
|---|---|
| PUMP, SINGLE FIXED DISPLACEMENT | |
| PUMP, SINGLE VARIABLE DISPLACEMENT | |
| **MOTORS AND CYLINDERS** | |
| MOTOR, ROTARY, FIXED DISPLACEMENT | |
| MOTOR, ROTARY VARIABLE DISPLACEMENT | |
| MOTOR, OSCILLATING | |
| CYLINDER, SINGLE ACTING | |
| CYLINDER, DOUBLE ACTING | |
| CYLINDER, DIFFERENTIAL ROD | |
| CYLINDER, DOUBLE END ROD | |
| CYLINDER, CUSHIONS BOTH ENDS | |

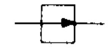
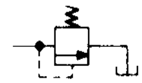
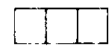
## MISCELLANEOUS UNITS

| | |
|---|---|
| DIRECTION OF ROTATION (ARROW IN FRONT OF SHAFT) |  |
| COMPONENT ENCLOSURE |  |
| RESERVOIR, VENTED |  |
| RESERVOIR, PRESSURIZED |  |
| PRESSURE GAGE |  |
| TEMPERATURE GAGE |  |
| FLOW METER (FLOW RATE) |  |
| ELECTRIC MOTOR |  |
| ACCUMULATOR, SPRING LOADED |  |
| ACCUMULATOR, GAS CHARGED |  |
| FILTER OR STRAINER |  |
| HEATER |  |
| COOLER |  |
| TEMPERATURE CONTROLLER |  |
| INTENSIFIER |  |
| PRESSURE SWITCH |  |

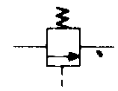
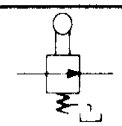
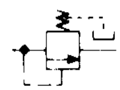
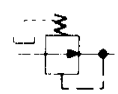
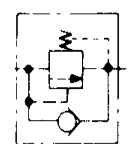
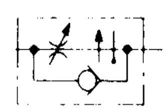
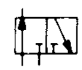
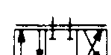
## BASIC VALVE SYMBOLS

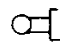
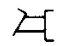
| | |
|---|---|
| CHECK VALVE |  |
| MANUAL SHUT OFF VALVE |  |
| BASIC VALVE ENVELOPE |  |
| VALVE, SINGLE FLOW PATH, NORMALLY CLOSED |  |

## BASIC VALVE SYMBOLS (CONT.)

| | |
|---|---|
| VALVE, SINGLE FLOW PATH, NORMALLY OPEN |  |
| VALVE, MAXIMUM PRESSURE (RELIEF) |  |
| BASIC VALVE SYMBOL, MULTIPLE FLOW PATHS |  |
| FLOW PATHS BLOCKED IN CENTER POSITION |  |
| MULTIPLE FLOW PATHS (ARROW SHOWS FLOW DIRECTION) |  |

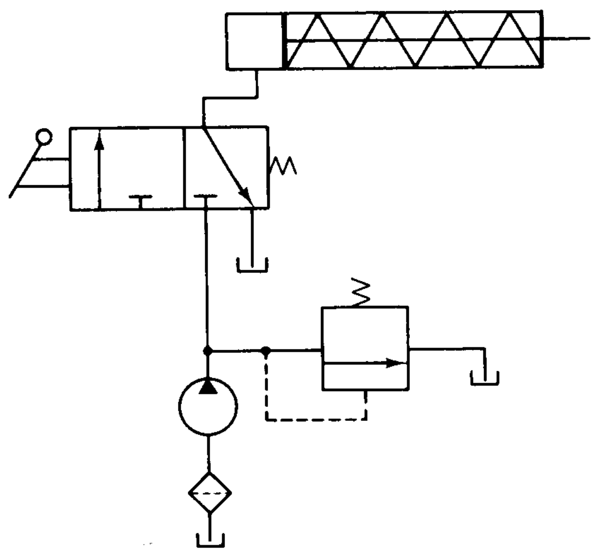
## VALVE EXAMPLES

| | |
|---|---|
| UNLOADING VALVE, INTERNAL DRAIN, REMOTELY OPERATED |  |
| DECELERATION VALVE, NORMALLY OPEN |  |
| SEQUENCE VALVE, DIRECTLY OPERATED, EXTERNALLY DRAINED |  |
| PRESSURE REDUCING VALVE |  |
| COUNTER BALANCE VALVE WITH INTEGRAL CHECK |  |
| TEMPERATURE AND PRESSURE COMPENSATED FLOW CONTROL WITH INTEGRAL CHECK |  |
| DIRECTIONAL VALVE, TWO POSITION, THREE CONNECTION |  |
| DIRECTIONAL VALVE, THREE POSITION, FOUR CONNECTION |  |
| VALVE, INFINITE POSITIONING (INDICATED BY HORIZONTAL BARS) |  |

| METHODS OF OPERATION | | | METHODS OF OPERATION | |
|---|---|---|---|---|
| PRESSURE COMPENSATOR |  | | LEVER |  |
| DETENT |  | | PILOT PRESSURE |  |
| MANUAL |  | | SOLENOID |  |
| MECHANICAL |  | | SOLENOID CONTROLLED, PILOT PRESSURE OPERATED |  |
| PEDAL OR TREADLE |  | | SPRING |  |
| PUSH BUTTON |  | | SERVO |  |

## 2. CONTROL OF A SINGLE-ACTING HYDRAULIC CYLINDER

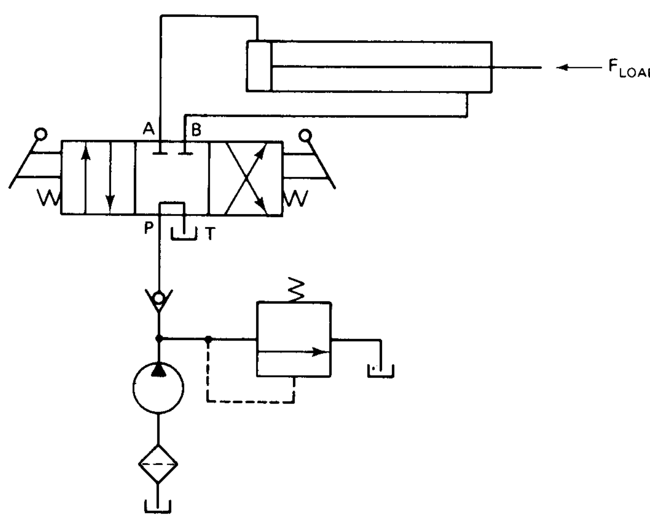
A Two-Position, Three-Way, Manually Actuated, Spring Offset Directional Control Valve (DCV) can be Used to Control the operation of a single-Acting Cylinder. In the spring offset mode, full pump flow goes to the Tank via the Pressure Relief Valve. The spring in the rod end of the cylinder Retracts the Piston as oil from the blank end drains back to the Tank. When the valve is manually actuated into its Left Envelope, flow Path Configuration, Pump Flow Extends the Cylinder. At Full Extension, pump flow goes through the Relief Valve. Deactivation of the DCV allows the Cylinder to Retract as The DCV Shifts into its Spring Offset Mode.



## 3. CONTROL OF A DOUBLE-ACTING HYDRAULIC CYLINDER

The operation is described as follows:

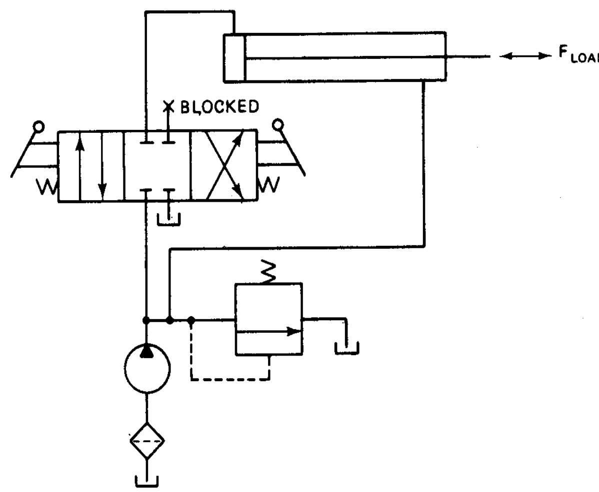
1. When the four-way valve is in its spring-centered position (tandem design), the cylinder is hydraulically locked. Also the pump is unloaded back to the tank at essentially atmospheric pressure.
2. When the four-way valve is actuated into the flow path configuration of the left envelope, the cylinder is extended against its load force, $F_{load}$, as oil flows from port P through port A. Also, oil in the rod end of the cylinder is free to flow back to the tank via the four-way



valve from port B through port T. Note that the cylinder could not extend if this oil were not allowed to leave the rod end of the cylinder.

3. When the four-way valve is deactivated, the spring-centered envelope prevails, and the cylinder is once again hydraulically locked.
4. When the four-way valve is actuated into the right envelope configuration, the cylinder retracts as oil flows from port P through port B. Oil in the blank end is returned to the tank via the flow path from port A to port T.
5. At the ends of the stroke, there is no system demand for oil. Thus, the pump flow goes through the relief valve at its pressure-level setting unless the four-way valve is deactivated. In any event, the system is protected from any cylinder overloads.
6. The check valve prevents the load (if it becomes excessive) from retracting the cylinder while it is being extended using the left envelope flow path configuration.

## 4. Regenerative Cylinder Circuit




It is used to speed up the extending speed of a double-acting hydraulic cylinder. Notice that the pipelines to both ends of the hydraulic cylinder are connected in parallel and that one of the ports of the four-way valve is blocked. The operation of the cylinder during the retraction stroke is the same as that of a regular double-acting cylinder. Fluid flows through the DCV via the right envelope during retraction. In this mode, fluid from the pump bypasses the DCV and enters the rod end of the cylinder. Fluid in the blank end drains back to the tank through the DCV as the cylinder retracts. When the DCV is shifted into its left envelope configuration, the cylinder extends. The speed of extension is greater than that for a regular double-acting cylinder because flow from the rod end ($Q_R$) regenerates with the pump flow ($Q_p$) to provide a total flow rate ($Q_r$), which is greater than the pump flow rate to the blank end of the cylinder.

**Cylinder Extending Speed**

The equation for the extending speed can be obtained as follows: The total flow rate entering the blank end of the cylinder equals the pump flow rate plus the regenerative flow rate coming from the rod end of the cylinder: $Q_T = Q_P + Q_R$ $\qquad Q_P = Q_T - Q_R$

We know that the total flow rate equals the piston area multiplied by the extending speed of the piston ($Vp_{ext}$). Similarly, the regenerative flow rate equals the difference of the piston and rod areas ($A_p — A_r$) multiplied by the extending speed of the piston. Substituting these two relationships into the preceding equation yields $Q_p = A_p V_{pext} - (A_p - A_r) V_{pext}$

Solving for the extending speed of the piston, we have: $V_{pext} = Q_p/A_r$

From the previous equation, we see that the extending speed equals the pump flow divided by the area of the rod. Thus, a small rod area (which produces a large regenerative flow) provides a large extending speed. In fact the extending speed can be greater than the retracting speed if the rod area is made small enough.

**Ratio of Extending and Retracting Speeds**

Let's find the ratio of extending and retracting speeds to determine under what conditions the extending and retracting speeds are equal. We know that the retracting speed ($V_{pret}$) equals the pump flow divided by the difference of the piston and rod areas: $V_{pret} = Q_p / (A_p - A_r)$

Dividing two equations, we have $$\frac{Vp_{ext}}{Vp_{ret}} = \frac{Qp/Ar}{Qp/(Ap - Ar)} = \frac{Ap - Ar}{Ar}$$

$$\frac{Vp_{ext}}{Vp_{ret}} = \frac{Ap}{Ar} - 1$$

From the previous equation, we see that when the piston area equals two times the rod area, the extension and retraction speeds are equal. In general, the greater the ratio of piston area to rod area, the greater the ratio of extending speed to retracting speed.

**Load-Carrying Capacity During Extension**

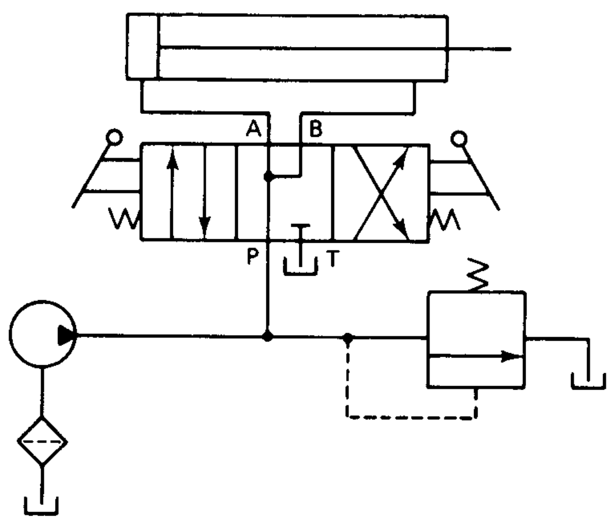
It should be kept in mind that the load-carrying capacity of a regenerative cylinder during extension is less than that obtained from a regular double-acting cylinder. The load-carrying capacity ($F_{load}$) for a regenerative cylinder equals the pressure times the piston rod area rather than the pressure times piston area. This is due to the same system pressure acting on both sides of the piston during the extending stroke of the regenerative cylinder. This is in accordance with Pascal's law. $F_{load} = P A_r$

Thus, we are not obtaining more power from the regenerative cylinder because the extending speed is increased at the expense of load-carrying capacity.

**Drilling Machine Application**

A four-way valve has a spring-centered design with a closed tank port and a pressure port opens to outlet ports A and B. The application is for a drilling machine, where the following operations take place:

1. The spring-centered position gives rapid spindle advance (extension).
2. The left envelope mode gives slow feed (extension) when the drill starts to cut into the workpiece.
3. The right envelope mode retracts the piston.




Why does the spring-centered position give rapid extension of the cylinder (drill spindle)? The reason is simple. Oil, from the rod end, regenerates with the pump flow going to the blank end. This effectively increases pump flow to the blank end of the cylinder during the spring-centered mode of operation. Once again we have a regenerative cylinder. It should be noted that the cylinder used in a regenerative circuit is actually a regular double-acting cylinder. What makes it a regenerative cylinder is the way it is hooked up in the circuit. The blank and rod ends are connected in parallel during the extending stroke of a regenerative cylinder. The retraction mode is the same as a regular double-acting cylinder.