Hydraulics

1. Basic hydraulics

The hydraulic system works on the principle of Pascal's law, which says that the pressure in an enclosed fluid is uniform in all directions. Pascal's law is illustrated in figure 1. The force given by fluid is given by the multiplication of pressure and the area of cross-section. As the pressure is the same in all the directions, the smaller piston feels a smaller force and a large piston feels a large force. Therefore, a large force can be generated with smaller force input by using hydraulic systems. Regardless of its function and design, every hydraulic system has a minimum number of basic components in addition to a means through which the fluid is transmitted. A basic system consists of a pump, reservoir, directional valve, check valve, pressure relieve valve, selector valve, actuator, and filter.

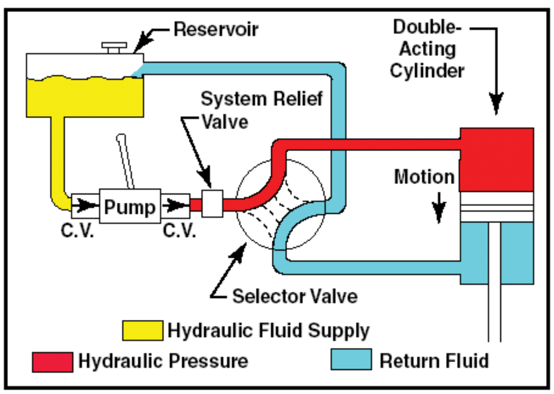


Figure 1. Basic Hydraulic system

2. Pumps

Classification of Pumps

All pumps may be classified as either positive displacement or no positive displacement. Most pumps used in hydraulic systems are positive displacement. A non-positive-displacement pump produces a continuous flow. However, because it does not provide a positive internal seal against slippage, its output varies considerably as pressure varies. Centrifugal and propeller pumps are examples of non-positive-displacement pumps. If the output port of a non-positive-displacement pump was blocked off, the pressure would rise and the output would decrease to zero. Although the pumping element would continue moving, the flow would stop because of slippage inside the pump. In a positive displacement pump, slippage is negligible compared to the pump's volumetric output flow. If the output port were plugged, pressure would increase instantaneously to the point that the pump pressure relief valve opens.

2.1. Constant-Displacement Pumps

A constant-displacement pump, regardless of pump rotations per minute, forces a fixed or unvarying quantity of fluid through the outlet port during each revolution of the pump. Constant-displacement pumps are sometimes called constant-volume or constant-delivery pumps. They deliver a fixed quantity of fluid per revolution, regardless of the pressure demands. Since the constant-delivery pump provides a fixed quantity of fluid during each revolution of the pump, the quantity of fluid delivered per minute depends upon the pump rotations per minute. When a constant-displacement pump is used for a hydraulic system in which the pressure must be kept at a constant value, a pressure regulator is required.

2.1.a.- Gear-Type Power Pump

A gear-type power pump is a constant-displacement pump. It consists of two meshed gears which revolve in a housing.

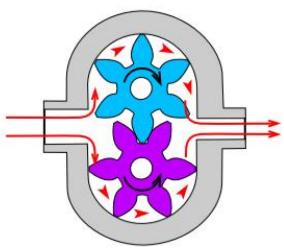


Figure 2. Gear-Type pump

2.1.b.- Gerotor Pump

A gerotor-type power pump consists essentially of a housing containing an eccentric-shaped stationary liner, an internal gear rotor with seven wide teeth of short height, a spur-driving gear with six narrow teeth, and a pump cover which contains two crescent-shaped openings.

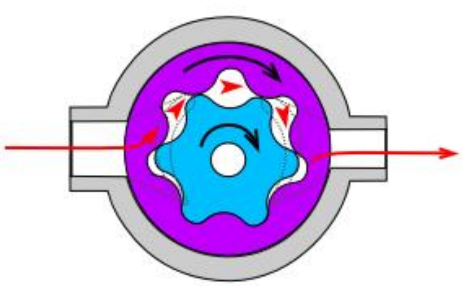


Figure 3. Gerotor-Type pump

2.1.c.- Piston Pump

Piston pumps can be constant-displacement or variable-displacement pumps. The common features of design and operation that are applicable to all piston-type hydraulic pumps - a pump drive shaft, which turns the mechanism, extending through the pump housing slightly beyond the mounting base. Torque from the driving unit is transmitted to the pump drive shaft by a drive coupling. The drive coupling is a short shaft with a set of male splines on both ends. The splines on one end engage with female splines in a driving gear; the splines on the other end engage with female splines in the pump drive shaft. Pump drive couplings are designed to serve as safety devices. The shear section of the drive coupling, located midway between the two sets of splines, is smaller in diameter than the splines. If the pump becomes unusually hard to turn or becomes jammed, this section shears, preventing damage to the pump or driving unit.

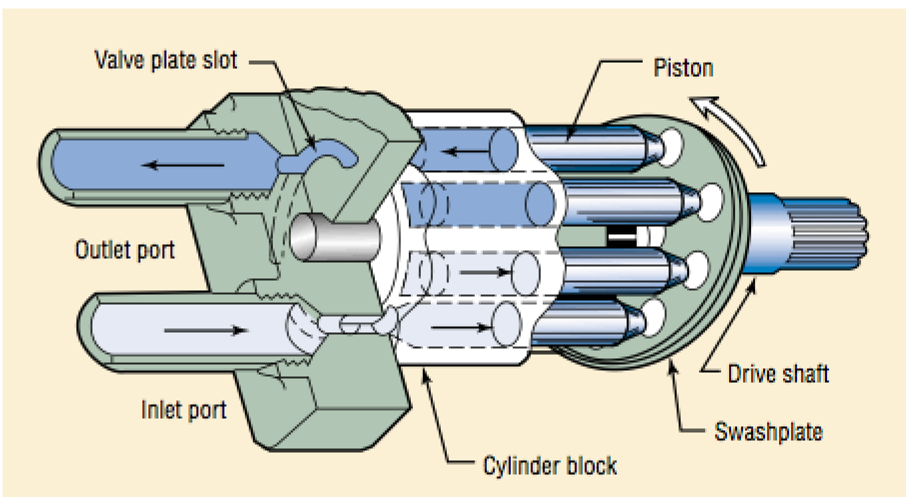


Figure 4. Piston pump

2.1.d.- Vane Pump

The vane-type power pump is also a constant-displacement pump. It consists of a housing containing four vanes (blades), a hollow steel rotor with slots for the vanes, and a coupling to turn the rotor. The rotor is positioned off-center within the sleeve. The vanes, which are mounted in the slots in the rotor, together with the rotor, divide the bore of the sleeve into four sections. As the rotor turns, each section passes one point where its volume is at a minimum and another point where its volume is at a maximum. The volume gradually increases from minimum to maximum during the first half of a revolution and gradually decreases from maximum to minimum during the second half of the revolution. As the volume of a given section increases, that section is connected to the pump inlet port through a slot in the sleeve. Since a partial vacuum is produced by the increase in the volume of the section, fluid is drawn into the section through the pump inlet port and the slot in the sleeve. As the rotor turns through the second half of the revolution and the volume of the given section is decreasing, fluid is displaced out of the section through the slot in the sleeve aligned with the outlet port, as well as out of the pump.

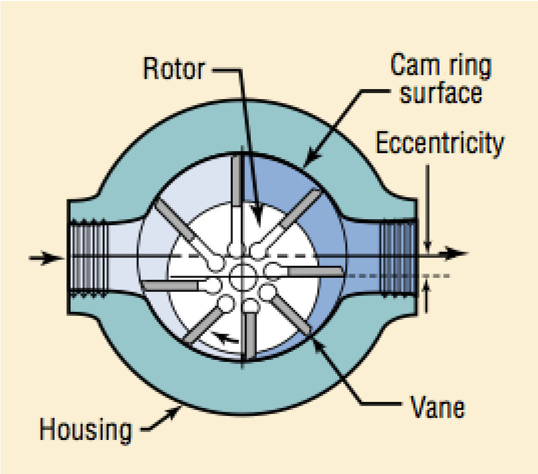


Figure 5. Vane pump

2.2 Variable-Displacement Pump

A variable-displacement pump has a fluid output that is varied in order to meet the pressure demands of the system. The pump output is changed automatically by a pump compensator within the pump. The following paragraph discusses a two-stage Vickers variable displacement pump. The first stage of the pump consists of a centrifugal pump that boosts the pressure before the fluid enters the piston pump.

Basic Pumping Operation

The motor (engine, electric motor etc.) rotates the pump drive shaft, cylinder block, and pistons via a gearbox. Pumping action is generated by piston shoes that are restrained and slide on the shoe bearing plate in the yoke assembly. Because the yoke is at an angle to the drive shaft, the rotary motion of the shaft is converted to piston reciprocating motion. As the piston begins to withdraw from the cylinder block, system inlet pressure forces fluid through a porting arrangement in the valve plate and into the cylinder bore. The piston shoes are restrained in the yoke by a piston shoe retaining plate and a shoe plate during the intake stroke.

Normal Pumping Mode

The pressure compensator is a spool valve that is held in the closed position by an adjustable spring load.

When pump outlet pressure (system pressure) exceeds the pressure setting (2,850 psi for full flow), the spool moves to admit fluid from the pump outlet against the yoke actuator piston, the pressure compensator is shown at cracking pressure; the pump outlet pressure is just high enough to move the spool to begin admitting fluid to the actuator piston.

3. Valves

Control valves control the speed and/or direction of fluid flow in the hydraulic system. Examples of flow control valves include: selector valves, check valves, sequence valves, priority valves, shuttle valves, quick disconnect valves, and hydraulic fuses.

3.a. Selector Valves

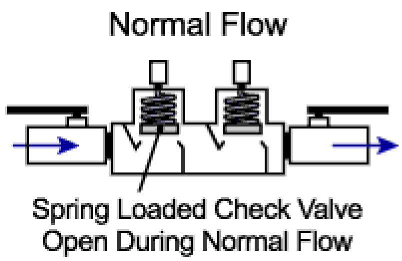
A selector valve is used to control the direction of movement of a hydraulic actuating cylinder or similar device. It provides for the simultaneous flow of hydraulic fluid both into and out of the unit. Hydraulic system pressure can be routed with the selector valve so as to operate the unit in either direction, and a corresponding return path for the fluid to the reservoir is provided. There are two main types of selector valves: open-center and closed-center. An open center valve allows a continuous flow of system hydraulic fluid through the valve, even when the selector is not in a position to actuate a unit. A closed-center selector valve blocks the flow of fluid through the valve when it is in the NEUTRAL or OFF position.

Selector valves may be poppet-type, spool-type, piston-type, rotary-type, or plug-type. Regardless, each selector valve has a unique number of ports. The number of ports is determined by the particular requirements of the system in which the valve is used. Closed-centered selector valves with four ports are most common in aircraft hydraulic systems. These are known as four-way valves. Most selector valves are mechanically controlled by a lever or electrically controlled by a solenoid or servo.

3.b.- Check Valve

Another common flow control valve in aircraft hydraulic systems is the check valve. A check valve allows fluid to flow unimpeded in one direction but prevents or restricts fluid flow in the opposite direction. A check valve may be an independent component situated in-line somewhere in the hydraulic system or it may be built into a component.

When part of a component, the check valve is said to be an integral check valve. A typical check valve consists of a spring-loaded ball and seat inside a housing. The spring compresses to allow fluid flow in the designed direction. When flow stops, the spring pushes the ball against the seat, which prevents fluid from flowing in the opposite direction through the valve. An arrow on the outside of the housing indicated the direction in which fluid flow is permitted. A check valve may also be constructed with a spring-loaded flapper or coned shape piston instead of a ball



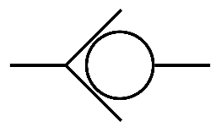


Figure 6. Check Valve   Symbol

3.c. Relief Valve

Hydraulic pressure must be regulated in order to use it to perform the desired tasks. A pressure relief valve is used to limit the amount of pressure being exerted on a confined liquid. This is necessary to prevent failure of components or rupture of hydraulic lines under excessive pressures. The pressure relief valve is, in effect, a system safety valve.

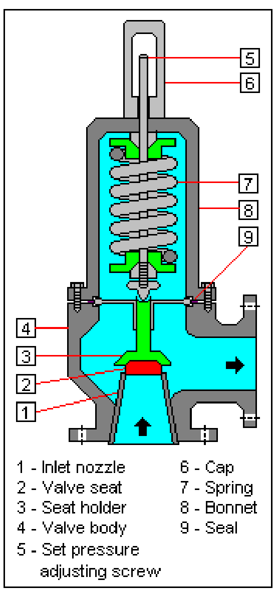


Figure 7. Relief Valve (poppet)

The design of pressure relief valves incorporates adjustable spring-loaded valves. They are installed in such a manner so as to discharge fluid from the pressure line into a reservoir return line when the pressure exceeds the predetermined maximum for which the valve is adjusted. Various makes and designs of pressure relief valves are in use, but, in general, they all employ a spring-loaded valving device operated by hydraulic pressure and spring tension. Pressure relief valves are adjusted by increasing or decreasing the tension on the spring to determine the pressure required to open the valve. They may be classified by their type of construction or their uses within the system. The most common types of valve are as follows:

1. Ball type—in pressure relief valves with a ball-type valving device, the ball rests on a contoured seat. Pressure acting on the bottom of the ball pushes it off its seat, allowing the fluid to bypass.

2. Sleeve type—in pressure relief valves with a sleeve type valving device, the ball remains stationary and a sleeve-type seat is moved up by the fluid pressure. This allows the fluid to flow between the ball and the sliding sleeve-type seat.

3. Poppet type—in pressure relief valves with a poppet type valving device, a cone-shaped poppet may have any of several design configurations; however, it is basically a cone and seat which are machined at matching angles in order to prevent leakage. As the pressure rises to its predetermined setting, the poppet is lifted off its seat, as in the ball-type device. This allows the fluid to pass through the opening created and out of the return port. An example for a poppet relief valve can be seen on figure. 7.

4. Pressure regulation

The term "pressure regulator" is applied to a device used in hydraulic systems that are pressurized by constant-delivery-type pumps. One purpose of the pressure regulator is to manage the output of the pump so as to maintain system operating pressure within a predetermined range. The other purpose is to permit the pump to turn without resistance (termed "unloading the pump") at times when the pressure in the system is within normal operating range. The pressure regulator is located in the system so that pump output can get into the system pressure circuit only by passing through the regulator.

The combination of a constant-delivery-type pump and the pressure regulator is virtually the equivalent of a compensator-controlled, variable-delivery-type pump.

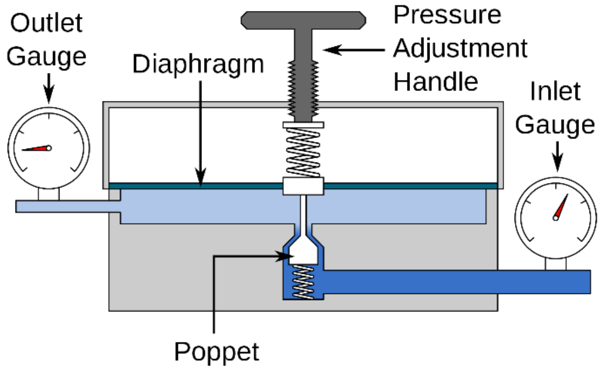


Figure 8. Pressure regulator

4.1. Pressure-Reducing Valves

Pressure-reducing valves are used in hydraulic systems where it is necessary to lower the normal system operating pressure by a specified amount. Pressure-reducing valves provide steady pressure into a system that operates at a lower pressure than the supply system. A reducing valve can normally be set for any desired downstream pressure within the design limits of the valve. Once the valve is set, the reduced pressure is maintained regardless of changes in the supply pressure (as long as the supply pressure is at least as high as the reduced pressure desired) and regardless of the system load, if the load does not exceed the designed capacity of the reducer.

5. Hydraulic Fluid

Hydraulic system liquids are used primarily to transmit and distribute forces to various units which are to be actuated. Liquids are able to do this because they are almost incompressible. Pascal's Law states that pressure applied to any part of a confined liquid is transmitted with undiminished intensity to every other part. Therefore, if a number of passages exist in a system, pressure can be distributed through all of them by means of the liquid.

5.1. Viscosity

One of the most important properties of any hydraulic fluid is its viscosity. Viscosity is the internal resistance to flow. A liquid such as gasoline that has a low viscosity flows easily, while a liquid such as tar that has a high viscosity, flows slowly.

Viscosity increases as temperature decreases. A satisfactory liquid for a given hydraulic system must have enough body to act as a good seal for pumps, valves, and pistons, but it must not be so thick that it offers resistance to flow, thereby leading to power loss and higher operating temperatures. These factors add to the load and to excessive wear of parts. A fluid that is too thin also leads to the rapid wear of moving parts or of parts that have heavy loads. The instruments used to measure the viscosity of a liquid are known as viscometers or viscosimeters, and several types of them are in use today.

The Saybolt viscometer measures the time required, in seconds, for 60 milliliters of the tested fluid at 100 °F to pass through a standard orifice. The time measured is used to express the fluid's viscosity, in Saybolt universal seconds or Saybolt FUROL seconds.

5.2. Chemical Stability

Chemical stability is another property that is exceedingly important in selecting a hydraulic liquid. It is the liquid's ability to resist oxidation and deterioration for long periods. All liquids tend to undergo unfavorable chemical changes under severe operating conditions. Liquids may break down if exposed to air, water, salt, or other impurities, especially if they are in constant motion or subject to heat. Some metals, such as zinc, lead, brass, and copper, have an undesirable chemical reaction with certain liquids. These chemical processes result in the formation of sludge, gums, and carbon or other deposits that clog openings, causing valves and pistons to stick or leak and providing poor lubrication to moving parts. As soon as small amounts of sludge or other deposits are formed, the rate of formation generally increases more rapidly. As they are formed, certain changes in the physical and chemical properties of the liquid take place. The liquid usually becomes darker in color and higher in viscosity, with acids being formed.

Flash Point

The flash point is the temperature at which a liquid gives off vapor in sufficient quantities to ignite momentarily or "flash" when a flame is applied. A high flash point is desirable for hydraulic liquids because it indicates good resistance to combustion and a low degree of evaporation at normal temperatures.

Fire Point

The fire point is the temperature at which a substance gives off vapor in sufficient quantities to ignite and continue to burn when exposed to a spark or flame. Like a flash point, a high fire point is required for desirable hydraulic liquids.

5.3. Types of Hydraulic Fluids

To assure proper system operation and to avoid damage to nonmetallic components of the hydraulic system, the correct fluid must be used. When adding fluid to a system, use the type specified in the aircraft manufacturer's maintenance manual or on the instruction plate affixed to the reservoir or unit being serviced.

The three main categories of hydraulic fluids are:

1. Minerals

2. Polyalphaolefins

3. Phosphate Esters

When servicing a hydraulic system, the technician must be certain to use the correct category of replacement fluid.

Hydraulic fluids are not necessarily compatible. For example, contamination of the fire-resistant fluid MIL-H-83282 with MIL-H-5606 may render the MIL-H-83282 as not fire-resistant. Today, type IV and V fluids are used. Two distinct classes of type IV fluids exist based on their density: class I fluids are low density and class II fluids are standard density. The class I fluids provide weight savings advantages versus class II. In addition to the type IV fluids that are currently in use, type V fluids are being developed in response to industry demands for a more thermally stable fluid at higher operating temperatures. Type V fluids will be more resistant to hydrolytic and oxidative degradation at high temperatures than the type IV fluids.

6. Filters

A filter is a screening or straining device used to clean the hydraulic fluid, preventing foreign particles and contaminating substances from remaining within the system. If such objectionable materials were not removed, the entire hydraulic system of the aircraft could fail through the breakdown or malfunctioning of a single unit of the system. The hydraulic fluid holds tiny particles of metal in suspension that are deposited during the normal wear of selector valves, pumps, and other system components. Such minute particles of metal may damage the units and parts through which they pass if they are not properly removed by a filter. Since tolerances within the hydraulic system components are quite small, it is apparent that the reliability and efficiency of the entire system depend on such adequate filtering.

Filters may be located within the reservoir, in the pressure line, in the return line, or in any other location that the designer of the system decides that they are needed in order to safeguard the hydraulic system against impurities. Modern design often uses a filter module that contains several filters and other components. There are many models and styles of filters.

The element may be a micron, porous metal, or magnetic. The micron element is made of a specially-treated paper and is normally thrown away when removed. The porous metal and magnetic filter elements are designed to be cleaned by various methods and replaced in the system.

6.1. Micron-Type Filters
A typical micron-type filter assembly utilizes an element made of specially-treated paper which is formed in vertical convolutions (wrinkles). An internal spring holds the elements in shape. The micron element is designed to prevent the passage of solids greater than 10 microns (0.000394 inch) in size. In the event that the filter element becomes clogged, the spring-loaded relief valve in the filter head bypasses the fluid after a differential pressure of 50 psi has been built up. Hydraulic fluid enters the filter through the inlet port in the filter body and flows around the element inside the bowl. Filtering takes place as the fluid passes through the element into the hollow core, leaving the foreign material on the outside of the element.

6.2. Maintenance of Filters
The maintenance of filters is relatively easy; it mainly involves cleaning the filter and element or cleaning the filter and replacing the element. Filters using the micron-type element should have the element replaced periodically according to application instructions. Since reservoir filters are of the micron type, they must also be periodically changed or cleaned. For filters using other than the micron-type element, cleaning the filter and element is usually all that is necessary.

6.3 Filter Differential Pressure Indicators
The extent to which a filter element is loaded can be determined by measuring the drop in hydraulic pressure across the element under rated flow conditions. This drop, or differential pressure, provides a convenient means of monitoring the condition of installed filter elements and is the operating principle used in the differential pressure or loaded-filter indicators found on many filter assemblies. Differential pressure-indicating devices have many configurations, including electrical switches, continuous reading visual indicators (gauges), and visual indicators with memories. Visual indicators with memory usually take the form of magnetic or mechanically-latched buttons/pins which extend when the differential pressure exceeds that allowed for a serviceable element. When this increased pressure reaches a specific value, inlet pressure forces the spring-loaded magnetic piston downward, breaking the magnetic attachment between the indicator button and the magnetic piston.

7. Piping

7.1. Fluid conductors

The fluid conductors are the parts of the system that are used to transport fluids to all the different components of the hydraulic circuit. Between these conductors are included: hydraulic hoses, pipes, and steel pipes. This section will help to understand the benefits of different drivers and where they can be used better in a hydraulic system.

The transmission of power from one place to another is a key element in the design and the performance of the system. This is defined as fluid conduction. The fluid conductors are the different types of conduction lines which transport hydraulic fluid between the components. The three main types of Pipes that are used in hydraulic systems are steel pipes (pipes), steel tubes, and flexible hoses. To determine the pressure of driver's work, you must first determine the pressure burst percentage and it must be divided by a safety factor of 4.

7.1.1. Hoses

Hydraulic hoses are used in applications in which the lines of Driving should be flexed or bent. By taking into account the use of hoses, first you should check the system pressure, the pulses of pressure, speed, fluid compatibility, and the environmental conditions. The manufacture of hoses has been standardized by the society of engineers in the automotive industry under the SAE I standard 5-17. This is known as the R series. For example, 100R2, 100R4. This denomination describes the cover, the manufacturer, the pressure rating, and the application.

Hoses generally receive a pressure rating with a factor of 4 to 1 security. The different types and amounts of reinforcement contribute to the Pressure ratings specific to the hose. The reinforcement can be a natural or synthetic fiber or a metallic wire. The reinforcement can be braided or a spiral connection. The hose sizes that are required depend on the volume and speed of the fluid flow. Unlike what happens with tubes and pipes, the sizes of the hoses are designated by D.I. or internal diameter. The sizes are designated in sixteenths of an inch, using a wording and a numerical equivalent for the numerator of the fraction.

7.1.2 Tubes

Steel pipes are usually the preferred drivers from the standard point of view of performance and cost. However, they are often difficult to mount, since it is necessary to apply welding to provide maximum protection against leaks. They also require expensive flushing to ensure that the system is free of contaminants when starting up. The pipeline is specified according to its nominal external diameter, but the capacity of actual flow is determined by the internal area. For example, the program 40 drops, 80, and 160 and Extra Double have the same external diameter, D.E., and can be screwed in the same pipeline matrix. The difference is in the internal diameter, D.I. The pipeline of the program 40 is standard and has the thinnest wall of all, with greater flow area but a lower pressure rating.

8. Sealing

Seals are used to prevent fluid from passing a certain point, and to keep air and dirt out of the system in which they are used. The increased use of hydraulics and pneumatics in the systems has created a need for packings and gaskets of varying characteristics and designs to meet the many variations of operating speeds and temperatures to which they are subjected. No one style or type of seal is satisfactory for all installations. Some of the reasons for this are:

- The pressure at which the system operates.
- The type of fluid used in the system.
- The metal finish and the clearance between adjacent parts.
- The type of motion (rotary or reciprocating), if any.

Seals are divided into three main classes: packings, gaskets, and wipers. A seal may consist of more than one component, such as an O-ring and a backup ring, or possibly an O-ring and two backup rings. Hydraulic seals used internally on a sliding or moving assembly are normally called “packings”.

Hydraulic seals used between nonmoving fittings and bosses are normally called gaskets.

8.1. V-Ring Packings

V-ring packings (AN6225) are one-way seals and are always installed with the open end of the V facing the pressure. V-ring packings must have a male and female adapter to hold them in the proper position after installation. It is also necessary to torque the seal retainer to the value specified by the manufacturer of the component being serviced, or the seal may not provide satisfactory service.

8.2. U-Ring

U-ring packings (AN6226) and U-cup packings are used in brake assemblies and brake master cylinders. The U-ring and U-cup seal pressure in only one direction; therefore, the lip of the packings must face toward the pressure. U-ring packings are primarily low-pressure packings to be used with pressures of less than 1,000 psi.

8.3. O-Rings

Most packings and gaskets used in aircraft are manufactured in the form of O-rings. An O-ring is circular in shape, and its cross-section is small in relation to its diameter. The cross-section is truly round and has been molded and trimmed to extremely close tolerances. The O-ring packing seals effectively in both directions. This sealing is achieved by distorting its elastic compound. Advances in design have made new O-ring composition necessary to meet changing conditions. Hydraulic O-rings were originally established under Air Force-Navy (AN) specification numbers 6227, 6230, and 6290 for use in fluid at operating temperatures ranging from –65 °F to +160 °F. When new designs raised operating temperatures to a possible +275 °F, more compounds were developed and perfected. Recently, newer compounds were developed under Military Standard (MS) specifications which offered improved low-temperature performance without sacrificing high-temperature performance. These superior materials were adopted in the MS28775 O-ring, which is replacing AN6227 and AN6230 O-rings, and the MS28778 O-ring, which is replacing the AN6290 O-ring. These O-rings are now standard for systems where the operating temperatures may vary from –65 °F to +275 °F.

O-Ring Color Coding

Manufacturers provide color coding on some O-rings, but this is not a reliable nor complete means of identification. The color coding system does not identify sizes, but only system fluid or vapor compatibility and, in some cases, the manufacturer.

Color codes on O-rings that are compatible with MIL-H-5606 fluid always contain blue, but may also contain red or other colors too. Packings and gaskets suitable for use with Skydrol® fluid are always coded with a green stripe, but may also have a blue, grey, red, green, or yellow dot as a part of their color code. Color codes on O-rings that are compatible with hydrocarbon fluid always contain red, but never contain blue. A colored stripe around the circumference indicates that the O-ring is a boss gasket seal.

8.4. Backup Rings

Backup rings (MS28782) made of Teflon™ do not deteriorate with age, are unaffected by any system fluid or vapor, and can tolerate temperature extremes in excess of those encountered in high-pressure hydraulic systems. Their dash numbers indicate not only their size but also relate directly to the dash number of the O-ring for which they are dimensionally suited.

8.5. Gaskets

Gaskets are used as static (stationary) seals between two flat surfaces. Some of the more common gasket materials are asbestos, copper, cork, and rubber. Asbestos sheeting is used wherever a heat-resistant gasket is needed. It is used extensively for exhaust system gaskets. Most asbestos exhaust gaskets have a thin sheet of copper edging which prolongs their life.

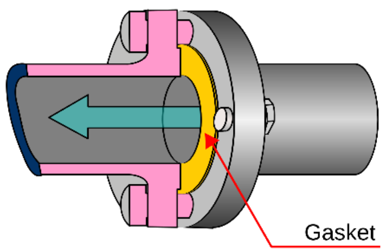


Figure 9. Gasket

8.6. Seal Materials

Most seals are made from synthetic materials that are compatible with the hydraulic fluid used. Seals used for the MIL-H-5606 hydraulic fluid are not compatible with Skydrol® and servicing the hydraulic system with the wrong fluid could result in leaks and system malfunctions. Seals for systems that use MIl-H-5606 are made of neoprene or Buna-N. Seals for Skydrol® are made from butyl rubber or ethylene-propylene elastomers.

9. Hydraulic Actuators

An actuating cylinder transforms energy in the form of fluid pressure into mechanical force, or action, to perform work.

It is used to impart powered linear motion to some movable objects or mechanisms. A typical actuating cylinder consists of a cylinder housing, one or more pistons and piston rods, and some seals. The cylinder housing contains a polished bore in which the piston operates, and one or more ports through which fluid enters and leaves the bore. The piston and rod form an assembly. The piston moves forward and backward within the cylinder bore, and an attached piston rod moves into and out of the cylinder housing through an opening in one end of the cylinder housing.

Seals are used to prevent leakage between the piston and the cylinder bore and between the piston rod and the end of the cylinder. Both the cylinder housing and the piston rod have provisions for mounting and for attachment to an object or mechanism that is to be moved by the actuating cylinder. Actuating cylinders are of two major types: single action and double action. The single-action (single port) actuating cylinder is capable of producing powered movement in one direction only. On the other hand, the double-action (two ports) actuating cylinder is capable of producing powered movement in two directions.

9.1. Linear Actuators

A single-action actuating cylinder is illustrated in *Figure 10.* Fluid under pressure enters the port at the left and pushes against the face of the piston, forcing the piston to the right. As the piston moves, air is forced out of the spring chamber through the vent hole, compressing the spring. When pressure on the fluid is released to the point where it exerts less force than is present in the compressed spring, the spring pushes the piston toward the left. As the piston moves to the left, fluid is forced out of the fluid port. At the same time, the moving piston pulls air into the spring chamber through the vent hole. A three-way control valve is normally used for controlling the operation of a single-action actuating cylinder.

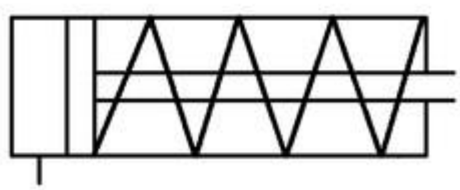


Figure 10. Single-acting cylinder with spring return

A double-action (two ports) actuating cylinder is illustrated in *Figure 11.* The operation of a double-action actuating cylinder is usually controlled by a four-way selector valve. The operation of that mechanism is discussed below.

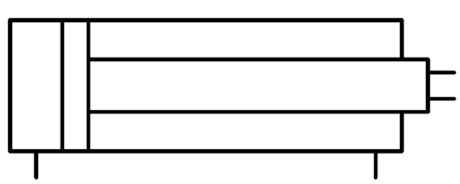


Figure 11. Double-acting cylinder

When the selector valve is placed in the ON or EXTEND position*,* fluid is admitted under pressure to the left-hand chamber of the actuating cylinder. This results in the piston being forced toward the right. As the piston moves toward the right, it pushes return fluid out of the right-hand chamber and through the selector valve to the reservoir. When the selector valve is placed in its RETRACT position, as illustrated, fluid pressure enters the right chamber, forcing the piston toward the left. As the piston moves toward the left, it pushes return fluid out of the left chamber and through the selector valve to the reservoir. Besides having the ability to move a load into position, a double-acting cylinder also has the ability to hold a load in position. This capability exists because when the selector valve which is used to control operation of the actuating cylinder is placed in the "off" position, fluid is trapped in the chambers on both sides of the actuating cylinder piston. Internal locking actuators also are used in some applications too.