PDHonline Course M543 (3 PDH)

An Engineer's Primer on Actuators

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Introduction

This course provides an overview of 4 basic types of actuators. It emphasizes the maintenance and reliability considerations for each actuator type. The course focuses on actuators used in industrial and municipal plants to operate devices like valves, gates, and conveyors. It gives readers enough information that they can understand the advantages and disadvantages of each type of actuator, and the circumstances under which one type is likely to be the better - or only - fit for an application.

Actuators vary a lot in size. On the small size, a solenoid valve with 1" ports may open to provide seal water to a pump. On the large size, huge hydraulic actuators are used to operate stamping presses. But the principles of operation among various types of actuators are quite similar.

A Note for Readers

Actuators perform one of two functions. The first is to operate a device such as a valve in order to regulate a control loop. This course refers to such devices as final control elements, and actuators may be automatically operated, manually operated, or manually operated at some times and automatically operated at others. Final control elements are usually operated through a control system. The second function provided by actuators is to apply a force or torque for applications like lifting, turning, or forming parts.

Actuators are widely used in automatic control systems. But the reader won't need to know much about that subject to take this course. The definitions below, mostly from the field of automatic controls, will help the reader understand the course.

Some Definitions

Actuator: A pneumatic, hydraulic, or electrically powered device that supplies force (or torque) and motion to open or close a valve (or another powered device).

Black Box: A device used for control purposes in which the end user doesn't need to be concerned about how it works internally. A black box can accept one or more input signals and generate one or more output signals. For this course, control systems or individual controllers can be assumed to be black boxes.

Controller: A device that operates automatically to regulate a controlled variable.

Direct Acting Controller: A controller in which the value of the output signal increases as the value of the input (measured variable) increases.

Double Acting Actuator: An actuator that has fluid pressure (compressed air or liquid) applied to both sides of its movable surface.

Error: The difference between the measured variable (e.g., a temperature) of a control loop, and the control loop's set point.

Fail Closed: A type of actuator that causes its actuated device to automatically move to a closed position if power or fluid pressure to operate the device is lost.
Fail In Place: An actuator characteristic that causes it to remain in its last position on loss of either power or the control signal. Sometimes also referred to as Lock In Place.
Fail Opened: A type of actuator that causes its actuated device to automatically move to an opened position if power or fluid pressure to operate the device is lost.
Final Control Element: A device, such as control valve, that directly controls the manipulated variable of a control loop.
Limit Switch: A switch with a contact that opens or closes when a final control element or other device reaches an end position.
Load: An object to be moved. Also, a force or torque that must be applied by an actuator to move an object.
Modulating Control (also called Throttling Control): A type of control action in which the position of an actuated device varies between fully closed and fully opened positions.
Normally Closed: A device that will be closed when no power or pressure is applied to it.
Normally Open: A device that will be open when no power or pressure is applied to it.
NPT: National Pipe Thread. In the United States, the NPT standard sets the taper angle and numbers of threads per inch to be used for mating parts of a given size.
OEM: Original Equipment Manufacturer.
Output Signal: The signal sent by a control system or controller to an actuator.
Pilot Valve: A small valve which is operated to control another valve, or reposition an actuator.
Reverse Acting Controller: A controller in which the value of the output signal decreases as the value of the input (measured variable) increases.
Servo (or Servomechanism): An automatic feedback device in which mechanical position is controlled.
Single Acting Actuator: A type of actuator that has fluid pressure (compressed air or liquid) applied to only one of its movable surfaces.
Static Pressure: The pressure of a fluid relative to atmospheric pressure. Static pressure can be less than atmospheric pressure.
Stem: A rod or spindle used to help operate a valve or other actuator.
Torque Switch: A switch that opens to stop a motor when its torque exceeds a value that could damage the motor due to high current.

Final Control Elements

Before discussing different types of actuators, it's worthwhile to review some different types of final control elements, or activated devices.

Valves

As mentioned before, valves are the most common type of final control element. There are many types of valves. This section covers some basics. It begins with some terms.

Valve Terminology

Direct Actuator: A diaphragm actuator in which the actuator stem extends with increasing diaphragm pressure.

Disc: A valve trim element used to modulate the flow rate with either linear or rotary motion. Can also be referred to as a valve plug or closure member.

Packing: A part of the valve assembly used to seal against leakage around the valve disc or stem.

Plug: A term frequently used to refer to the closure member. For some valve types, a plug and disc are the same.

Positioner: A position controller (servomechanism) that is mechanically connected to a moving part of a final control element or its actuator and that automatically adjusts its output to the actuator to maintain a desired position in proportion to the input signal.

Reverse Actuator: A diaphragm actuator in which the actuator stem retracts with increasing diaphragm pressure.

Seat: The area of contact between the closure member and its mating surface that establishes valve shut-off.

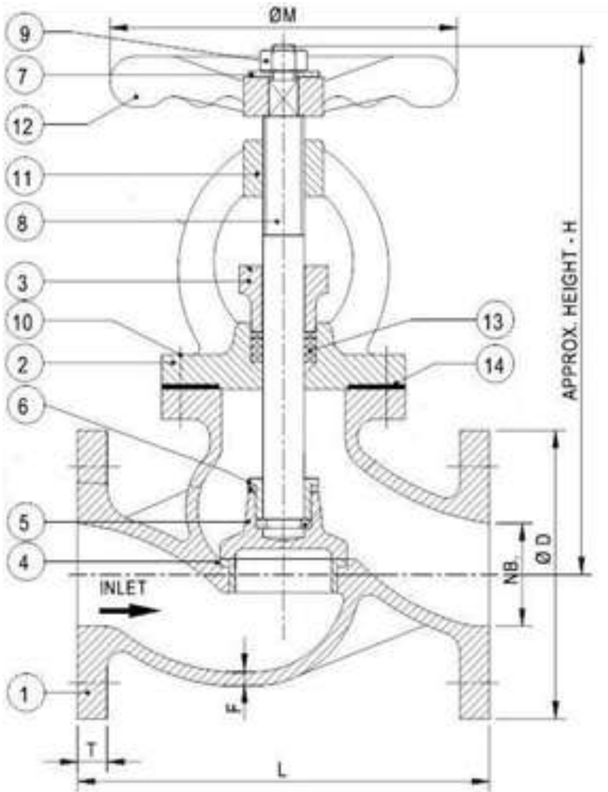
Trim: The internal components of a valve that modulate the flow of the controlled fluid.

Yoke: The structure that rigidly connects the actuator power unit to the valve.

Most valves are have 2 ports, or ends. Most valves operated through control systems are control valves, also known as throttling valves. The positions of control valves are changed to adjust the flow of a fluid through the valve. One example is a control valve which adjusts cooling water flow to a heat exchanger, to maintain the temperature of fluid leaving the heat exchanger as near as possible to a set point. If the flow rate of heated fluid into a heat exchanger increases while the coolant temperature remains unchanged, the valve's controller will cause the actuator to open the valve further to provide additional cooling. If the outlet temperature dropped below the set point, the valve's controller would reduce the valve's opening somewhat.

Linear Valves

Most valves have a stem that moves with a straight-line motion. Such valves can be referred to as linear valves. Figure 1 shows a cross section through a valve. The valve is attached to process piping through bolts at its flanges. When the valve is fully closed, its disc rests against the valve's seat. The stem (called the spindle in this figure) moves through a gland where packing is installed. The packing prevents (or limits) the escape of fluid from the valve to its surroundings. The bonnet surrounds the gland and gland packing. The valve's stem extends through the bonnet.



SR. NO.	DESCRIPTION
1	VALVE BODY
2	BONNET
3	GLAND
4	VALVE SEAT
5	VALVE DISC
6	VALVE DISC NUT
7	WASHER
8	VALVE SPINDLE
9	NUT FOR HANDWHEEL
10	BONNET STUDS
11	SPINDLE NUT
12	HANDWHEEL
13	GLAND PACKING
14	GASKET

Figure 1

Figure 1 shows a valve with flanges for bolted connections, but many valves, especially small ones, have threaded or soldered end connections.

A fluid's pressure is reduced as it passes through a valve. Yet, significant forces operate on the disc, seat and stem of many valves. Fluid pressures inside valves often exceed 100 psi, and in some applications they exceed 1000 PSI. A valve must be strong enough to handle the forces acting on it. It also must be constructed to handle the heat of the fluid, and resist any corrosive and degrading effects of the fluid (especially for chemicals and solutions.)

A valve's actuator must be powerful enough to open and close the valve. And it should be able to maintain a steady position even when pressure upstream or downstream of the valve changes.

Many valves require maintenance from time-to-time. This is especially true for valve packing - doing so helps limit leakage. Sometimes the disc will wear enough that a tight shutoff cannot be obtained - or the valve's actuator and control system will not be able to control a process well. In such cases, the disc may need to be replaced. The seats of some valves also wear, and for some valves, worn seats can also be replaced. This is especially likely if material gets trapped between the disc and seat. Sometimes wear is so extensive that the valve itself must be replaced.

Three types of widely used linear valves are globe valves, gate valves, and needle valves.

Rotating Valves

Some valves are opened by rotating a movable part from a fully closed to fully open position. These valves still have a stem, but the stem turns like a shaft. Ball valves, butterfly valves and plug valves are three types of rotating valves. Each of these valve types has its own unique characteristics. And each type of valve is often the best type to use in certain applications.

Some valves only need to be fully opened or fully closed. This course refers to such valves as shutoff valves. Gate valves are often used as shutoff valves.

Shutoff valves may or may not have powered actuators. Whether a shutoff valve needs one depends upon circumstances. Most valves that are only closed to isolate a tank that is usually in service don't need an actuator.

Many valves that have an actuator also have a handwheel, and a lever that allows the actuator to be detached from the stem. When the lever is moved to a different position, the actuator is no longer mechanically coupled to the valve stem, but the user will be able to open and close the valve using a handwheel. This is often useful if the actuator isn't working for some reason. Valves without a powered actuator may have a protrusion or recess for use of a wrench or air tool instead of a handwheel.

Dampers

Dampers are another common type of final control element. The most common type of damper has parallel surfaces called louvers of identical size that operate together. Louvers are usually linked together mechanically. An actuator is used to either directly or indirectly move a louver’s common linkage. Some dampers have matching sets of opposable blades. See Figure 2A for a photo of a damper with parallel louvers.

A butterfly damper has a disc that rotates (usually 90 degrees) between fully closed and fully opened positions. Such dampers are often used for air or gas flow control. This type of damper is used in round ducts. See Figure 2B on page 10.

The most common use for dampers is in HVAC (Heating, Ventilation and Air Conditioning) applications. In building HVAC systems, dampers are used to modulate air flow; to admit outdoor air (makeup air) into the building; to exhaust air; and to direct air flow into certain areas.

Dampers are also used to control air flow into boilers and furnaces, and within compartments of boilers and furnaces. Some of these dampers are quite large in size, and require powerful actuators. These dampers usually have parallel louvers.

Dampers are not subject to high pressures. However, many are susceptible to operational problems due to buildup of dust and dirt anywhere movable parts exist. If the buildup gets bad enough, the damper's actuator will have difficulty moving the louvers. Some dampers allow a compressed air source to be hooked up to prevent dust and dirt from getting into some bearings.

Figure 2A – Damper with Parallel Louvers

Other Final Control Elements

Actuators also operate devices such as gates, conveyors, ship rudders and aircraft control surfaces. In such applications, there are usually linkages and/or gears, or a gearbox, between the actuator and the operated device.

Figure 2B – Butterfly Damper

Actuator Types

The four basic types of actuators are:

- Solenoid Valves
- Electric Motor actuators
- Pneumatic actuators
- Hydraulic actuators

I. Solenoid Valves

This course is about actuators, but a solenoid valve, alone of the 4 types of actuators, is both an actuator and final control element. But they are only useful as actuators for low flow applications like turning seal water on and off for pumps. Solenoid valves are also widely used as pilot valves with pneumatic and hydraulic actuators.

Most solenoid valves are simple devices. Each has a coil of wire that focuses the magnetic field of an electric current inside the coil. The magnetic field acts on a magnetized material to cause a straight-line movement of a valve attached to the internal magnetized piece. Typical solenoid valves (like the one shown below) have only two positions, usually fully open or fully closed.

Choices for end connections - or port connections - vary. Many have internally-threaded screwed end connections. In the U.S., these end connections are usually per the NPT standard. With these types of solenoid valves, often there will be an intermediate fitting between each end connection and process pipe. That is particularly true when copper pipe is used. Other constructions allow for pipe to be soldered to the valve ends.

2-port solenoid valves are the most common type. Another widely-used type is the 3-port valve. These valves are sometimes used with pneumatic actuators. Three other frequently used types are 4-port, 5-port, and 6-port valves. They're often used with pneumatically or hydraulically powered cylinders. Some applications of multi-port solenoid valves are covered in more depth later in this course.

Most – but not all – 2-way solenoid valves are Normally Closed, that is, their ports are opened to flow only when the coil is energized.

Some solenoid valves use two solenoid coils on opposite ends. Often, such valves have a neutral center position which the valve will be in when the neither coil is energized.

Some solenoid valves have built-in mechanical or magnetic detents, or latches. With these types of valves, only a momentary current is applied to move the valve from one position to another. The detent(s) will maintain the valve in a latched position until power is applied to one of its coils to change its position. Solenoid valves with mechanical detents are used in some pneumatic and hydraulic power applications. Solenoid valves with one or more magnetic detents will be held in a fixed position by an internal magnet(s). A momentary current to one of the solenoids will either move the valve to or from a fixed position. Detented solenoid valves are useful in applications requiring that something be held in one position without power. Figure 3 below shows a how a mechanically detented solenoid valve is repositioned.

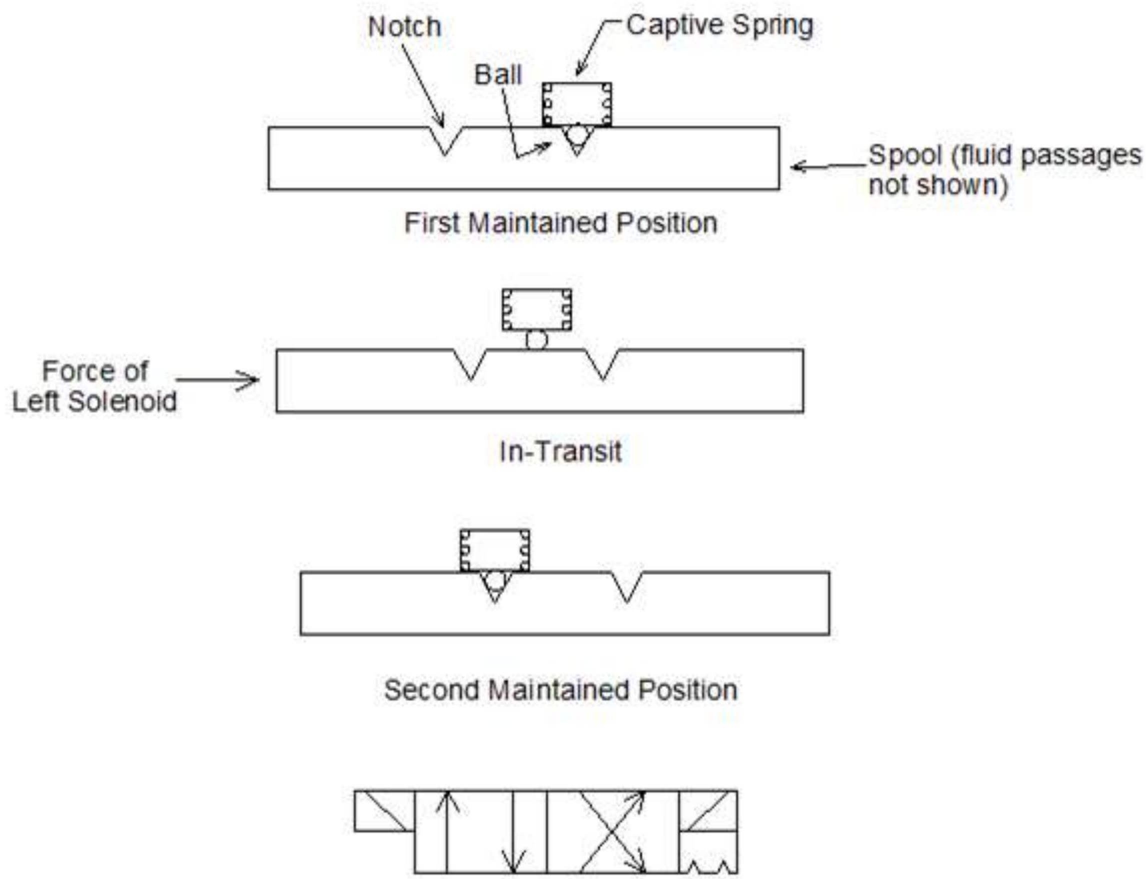


FIG. 3 - TWO-POSITION, SOLENOID OPERATED, DETENTED, 4-WAY DIRECTIONAL VALVE

Solenoid valves are usually operated using single-phase 120 VAC or 24 VDC power carried over 2 or 3 wires, with no other electrical devices.

Solenoid valves must be suited for the application. Each must be selected so its body and moving parts won't be chemically attacked by the fluid passing through it.

Advantages of Solenoid Valves

- Simplicity.
- Power consumption is low.

- They are inexpensive.
- They are easy to replace.

Disadvantages and Limitations of Solenoid Valves

- The maximum size available for solenoid valves is rarely more than 2-1/2". They can only be used where flow requirements are low.
- The pressure drop across solenoid valves can be considerable for liquids. Sometimes that rules out their use.
- Solenoid valves sometimes fail to work properly when particles get between the seat and disc. This can happen if pressure downstream of the valve exceeds upstream pressure due to an abnormal process condition.
- Few solenoid valves are available with limit switches. So, there is no direct means to detect if one is working properly. In cases where a solenoid valve is used in a process and the user wants to know if it is working, another device like a pressure switch will be needed to indirectly confirm that it's OK by detecting its effect on the process.
- Galvanic corrosion will occur over years when a metallic solenoid valve and the pipe it connects to have electrochemical potential differences. If possible, it's best that solenoid valve and pipe be made of the same material. Threaded seal tape can help deter this if NPT or screwed fittings are used.

II. Electric Motor Actuators

Electric Motor Actuators are self-contained units used to operate a final control element or load.

Electric motor actuators are sometimes supplied with the device they will be used to control, such as a valve, as one combined unit. The OEM providing the actuated device or equipment will usually buy the actuator from a manufacturer. The OEM will select an actuator with appropriate characteristics such as Horsepower (HP), attach the actuator to the final control element at its factory, and supply actuator and element as a single unit. The motor actuator will have parts such as shafts, gears, couplings and linkages that can do one of several things:

- Convert the rotation of the motor's shaft to a straight-line movement of a final control element or load through a gearbox, or a mix of gears and linkages.
- Convert the rotation of the motor's shaft to a lower speed through a gearbox for the final control element or operated device.
- Position the vanes of a damper through a connecting linkage between the motor and damper. Sometimes more than one linkage is used.

Gears in actuators are usually made of high strength, wear-resistant steels for durability. They're usually enclosed and not readily accessible. Planetary gears are one type of gear used in electric actuators when the axes of the motor and the final control element are parallel. Worm and bevel gears are commonly used in motor actuators when the axes of rotation are 90 degrees apart, which is often the case.

Electric actuators for some applications use very little power. For example, building HVAC systems typically have small single-phase 120 VAC motors that open or close dampers.

But most electric actuators use 3-phase 480 VAC motors. (See photo on the next page.) Such motors can readily apply the needed torque. 3-phase motors are the natural choice for applications in which the direction of travel must be reversed - which is the norm. This is easily done by reversing 2 of the 3 phase connections inside the motor actuator's compartment.

Electric motor actuators have many of the same components, such as a starter and an overload with motor cutoff contacts, that Motor Control Center compartments have for loads like pumps.

Most motor actuators have external controls such as Open, Close and Stop push buttons, and a Local-Off-Remote switch. Indicating lights are also standard features. Some also have built-in LCD screens which allow setup by the installer. Often noncontact devices are used to set up the valve.

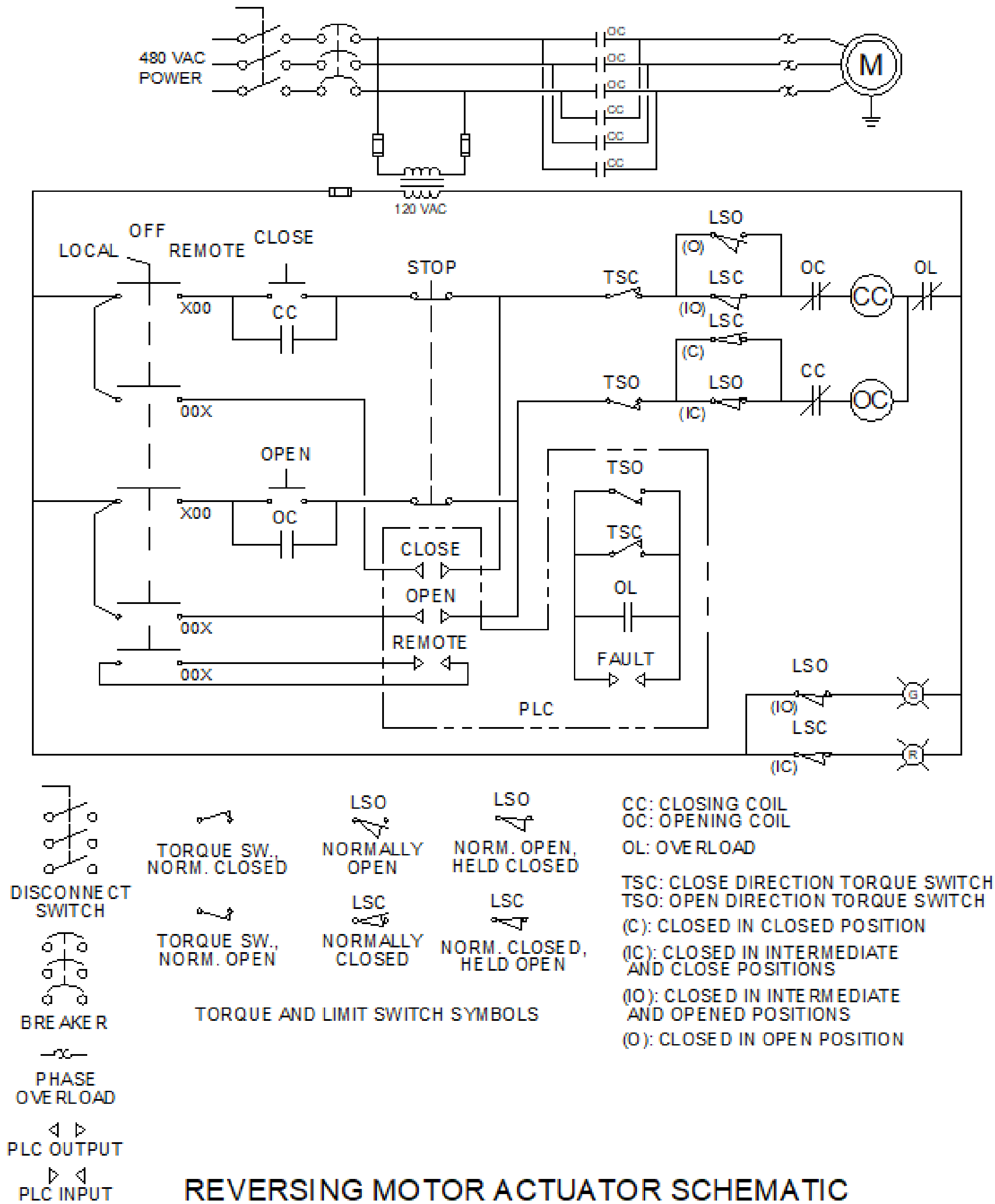
The typical electric motor actuator will have some or all of these features:

- Limit switches that can be used by an external PLC (Programmable Logic Controller), DCS (Distributed Control System), or remote control panel to detect when the valve is at an end position. Alternately, in the case of modulating valve, it usually includes a position feedback signal.
- A torque switch with an auxiliary contact that signals the PLC if the motor has been overloaded.
- A contact that signals if the motor is set for Remote Control, so it can be operated by a remote controller.

An electrical schematic diagram of a motor actuator is shown in Figure 4 below. When the Local-Off-Remote (L-O-R) mode switch is set to Local, the actuator will, for example, typically open from a closed position until the fully opened position is reached, and the open position limit switch (LSO) is reached and stops the motor. It could be stopped before reaching the end position if the motor drew excessive current and the torque switch (TSO) stopped the motor; if the motor Overload protector operated; or if the operator pressed the Stop push button before the motor reached fully opened state.

Activation of the Close push button from the open (or an intermediate) position would normally power the final control element to the fully closed position.

Figure 4 also illustrates how the actuator can be remotely operated to close or open the final control element when its mode switch is set to Remote (REM). In this case the remote controller is a PLC.



REVERSING MOTOR ACTUATOR SCHEMATIC

FIGURE 4

Electric motor actuators are most often used for devices that are either fully opened or fully closed, like gates and shutoff valves. However, they are also available for modulating devices for loop control applications where the final control element's position is varied between fully closed and fully opened. Modulating electric motor actuators almost always use a microprocessor controller.

Valves and other devices are often located at heights, or in locations where the actuator, with its mode switch (Local-Off-Remote, typically) and operator control push buttons and knobs (Open, Close, Stop, for example) are inaccessible. There are two solutions to this problem. In the first, the operator controls and indications are removed from the actuator, and placed in a Remote Control Station (RCS) that's located in an accessible place. Control wiring runs between the actuator and RCS. In the second solution, the RCS has a set of controls and indicators that duplicate most of the actuator's controls and indications. If the Local-Off-Remote switch at the actuator is set to Remote, an operator will be able to control the actuator from the RCS, if the RCS's mode switch is set to Local. If the mode switches at both the actuator and RCS are set to Remote, the actuator will be operated through an external control system or controller.

When a final control element and motor actuator are coupled together, the motor can usually be mechanically disengaged from the final control element so it can be manually positioned with a handwheel. This allows operation of the element when power is lost.

Electric motor actuators use an oil or grease for lubrication. The manufacturer may recommend that the oil or grease be replaced periodically. Users should follow such instructions. The actuator may also have one or more seals. For longevity, seals should be replaced at the recommended interval.

Electric motor actuators are sometimes used to open and close heavy gates that must move up or down several feet or more. In such cases, the actuators are often coupled to the gate by a long stem with grooves that spiral around the stem. Such gate stems should be periodically relubricated per the manufacturer's instructions to remain in good condition. In some applications, users enclose the stem in a transparent tube, and cap the tube so rain won't affect the stem.

Advantages of Using Electric Motors for Actuators

- A properly selected motor actuator offers great reliability.
- They are often cost-competitive, and are now widely used where pneumatic actuators were used in the past.
- They are easy for end users to install, because it's simple to install conduits and run wiring from a power source and remote controller to the actuator.
- They are quite compact.
- They are quite simple. Accessory equipment and systems required for pneumatic and hydraulic actuators are not needed.

- Power consumption is low.
- Maintenance is rarely needed.
- Accurate position control is possible.
- In many cases users will need to monitor the end positions or the actual position of the final control element anyway, so use of electric actuators makes sense. Likewise, feedback for high torque or fault condition may be needed. It's easy to install both power and signal cables.

Disadvantages and Considerations of Using Electric Motor Actuators

- Power is limited. Electric actuators have to be large to be powerful.
- They tend to be slow for large final control elements and loads.
- Motor actuators that are suitable for classified environments where there is an explosion potential are expensive. Usually an explosion-proof enclosure will be needed.
- In event of power loss, a valve or damper will not automatically revert to a safe position.
- Some manufacturers offer users the choice of having the motor in-line or at a 90 degree angle to the final control element. One orientation might be more advantageous than the other.
- It's sometimes a judgment call whether to use electrical or pneumatic actuators for some applications.

III. Pneumatic Actuators

Pneumatic actuators work by applying compressed air to one or more movable surfaces. Like electric motor actuators, pneumatic actuators are also used to operate valves and dampers. They are also useful in some manufacturing applications. Most pneumatic actuators use a few standard components which are easy for technicians to maintain. They rely on a compressed air system, the next topic.

Typical Components of a Compressed Air System

A Compressed Air System will usually include one or more Air Compressors; a Receiver Tank; one or more Dryers; Filters; compressed air piping and fittings; and sometimes oil lubricators.

The number of air compressors needed in a plant or a facility will depend upon the end user's requirements. A power plant with many pneumatic actuators may have four large air compressors, each of which discharge to a common receiver tank. Air compressors of varying capacities and nominal discharge pressures are available from many manufacturers. Compressors with reciprocating engines are one common type. Axialflow compressors with multiple stages of blades rotating on a shaft are also widely used. Intercoolers, or coolers between stages of a compressor, are a feature of many multistage compressors. An aftercooler is normally used when the air compressor provides air to air-operated actuators. Aftercoolers help remove moisture from air, and are usually built-in. Most compressor motors use 3-phase 480 VAC power, but many small capacity air compressor motors run on 120 or 208 VAC single-phase power.

Air compressors which raise air pressure to the 100 to 200 PSI range are common.

Receiver tanks store compressed air. They are useful for two reasons. First, once a receiver tank is filled with compressed air of desired pressure, the compressor(s) need only be operated when they are needed. Second, receiver tanks provide compressed air for a limited period if no compressors can operate. The receiver tank will usually be fitted with one or two pressure switches that start and stop the compressor(s) to maintain air pressure in the tank within a range. Such tanks are also usually fitted with another pressure switch to provide an alarm in case of abnormally low pressure.

Air dryers are widely used in compressed air systems, too. They are essential in many plants, because water droplets in air lines can freeze in cold weather, making equipment inoperable. The risk of freezing water droplets is greater in cold climates. A typical air dryer is located after a compressor. One common type has two vessels of hygroscopic, or water absorbing granules. When one vessel is in service, absorbing water vapor in air, the other is regenerated. Regeneration in this type of dryer can be done by a few different methods. During regeneration, water vapor is removed in the regenerating vessel, restoring it to useful state in time. These dryers operate at a fixed period. Halfway through the period, the roles of the vessels are swapped.

Air filters in compressed air systems trap contaminants that might otherwise impair devices that use compressed air. A small water drain valve is a common accessory with many air filters. Most air filters can be cleaned. But the compressed air line should be isolated before cleaning.

Pressure regulators are another widely used, and usually essential component. Pressure regulators are typically located at the pneumatically-operated device. They reduce compressed air pressure to the required level. Most have a handle or nut which can be turned to adjust outlet pressure. Regulators typically are provided either with a gauge to display regulated pressure, or have a plugged port where a gauge can be connected. Pressure regulators subdivide between force-balance and self-operated pressure regulators. Power to operate a self-operated regulator is provided by the compressed air itself. Self-operated pressure regulators are good at maintaining a steady pressure even when supply air pressure varies.

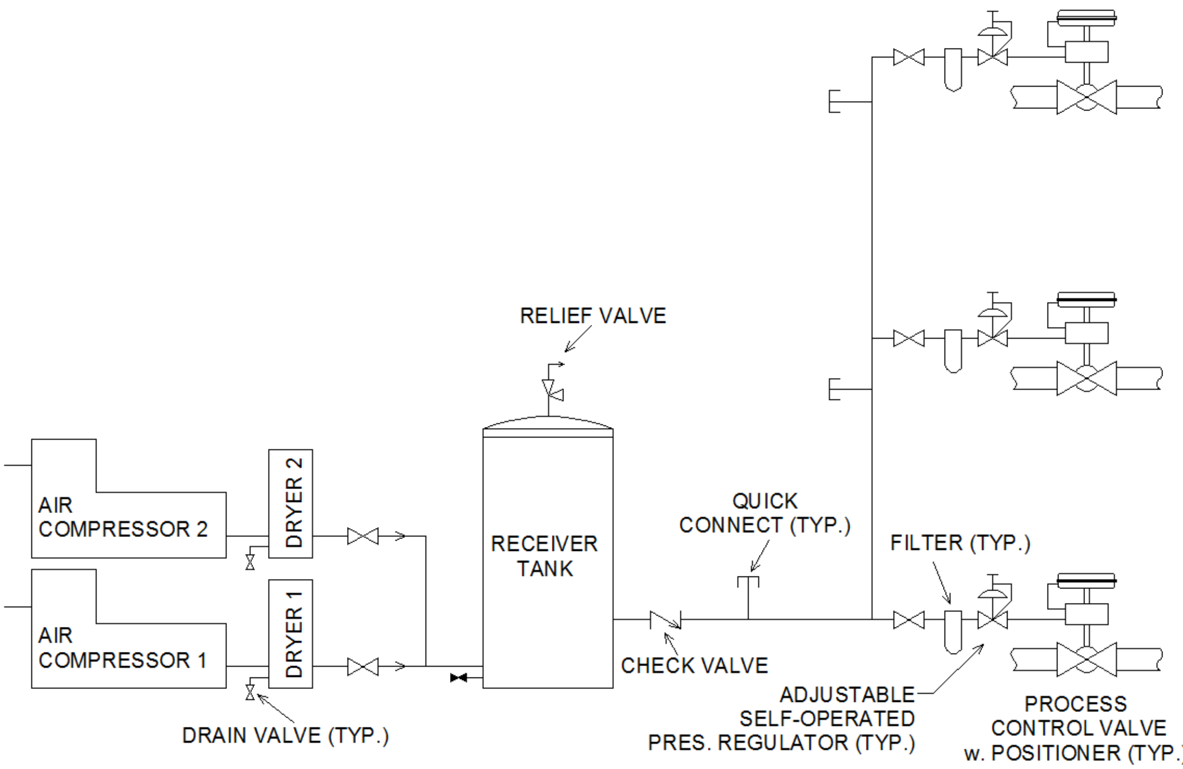


FIGURE 5 - EXAMPLE PNEUMATIC SYSTEM

Tubing (or pipes), fittings, and isolation valves are also part of a compressed air delivery system. Most tubing is either copper or stainless steel. Unlike copper, stainless steel is rigid, but copper is not appropriate for all environments. Fittings which connect tubes together, or tubing to end devices, usually has either tapered NPT end connections, or one of several different types of quick-disconnect or compression fittings. Sometimes copper compressed air lines are soldered together at unions. Quick-disconnect and compression fittings are widely used because they can be easily disconnected and reconnected. Each device which uses compressed air piping, such as a positioner (page 23) should include an isolation valve so compressed air pipes and tubes can be closed off for maintenance.

Sliding-Stem Valve Actuators

Most pneumatically operated valves are sliding stem valves, that is, they have stems which move vertically without rotation.

There are various types of pneumatic actuators for such valves, but the most common type is for an air-to-open, fail-closed regulating valve. This type of actuator is "single-acting". (See Figure 6 on page 22.) Notice the actuator's rod is coupled to the valve's stem. Important parts include the yoke, positioner, positioner feedback linkage, casing, diaphragm, upper chamber, lower chamber, and spring. The yoke supports the positioner and actuator. The casing is a rigid enclosure for the diaphragm, and has upper and lower chambers. The diaphragm is a flexible surface between the upper and lower chambers, and it's coupled to a rod with rigid components. Gaskets prevent air leakage from the chambers to the atmosphere. A spring holds the valve closed when no or minimal air pressure is applied to the lower chamber. This will happen when a 0% output signal is sent by a PLC, DCS, or other controller to the positioner. The valve is opened by increasing the air pressure to the lower chamber through the positioner. The valve will be fully opened when the output signal is 100%.

The force exerted by a single-acting pneumatic actuator's diaphragm in pounds equals the product of the air pressure in PSI and the moveable area of the diaphragm in square inches. This area will increase in proportion to the square of the diameter of this moveable area (neglecting the rod's area.) As operation of the valve compresses a spring, the force exerted on the stem must counter the spring's force. It must also handle whatever forces act on the stem due to movement of the disc in the fluid stream, and resistance of stem movement through the packing.

Pneumatic actuators should be selected to operate the final control element. This is usually the work of specialists.

Pneumatic actuators typically have one or more springs to force the valve to a safe position in event of loss of compressed air.

The force exerted by a pneumatic actuator can be increased just by enlarging the diameter of the movable surface area of the diaphragm. This is an advantage for pneumatic actuators. This is also true for hydraulic actuators.

Positioners

Positioners deserve closer examination. A positioner will have, at a minimum, a control signal input, air supply port, output port, and an I/P converter. A pressure regulator to reduce compressed air pressure to a positioner is normally used. An air filter is often placed between the air supply tubing and the regulator's inlet.

The most widely-used control signal type applied to positioners by a remote controller is the 4-20 milliampere (mA) signal. Usually 4 mA will correspond to 0% output, and 20 mA to 100% output, and signals in an intermediate range will cause a proportional output signal. For example, a 16 mA input signal to positioner will cause a 75% output demand signal to pneumatic output signal. Positioners for pneumatic actuators might apply a pressure varying from 6 to 30 PSI to the diaphragm between fully closed and fully open positions.[l]

A positioner includes one or more position feedback linkages so the valve's stem position is monitored by the positioner, which verifies that the position demand signal applied to the valve is achieved. A cam inside the positioner is often used to linearize a rotary motion to achieve a good actual position measurement. Commonly, a separate

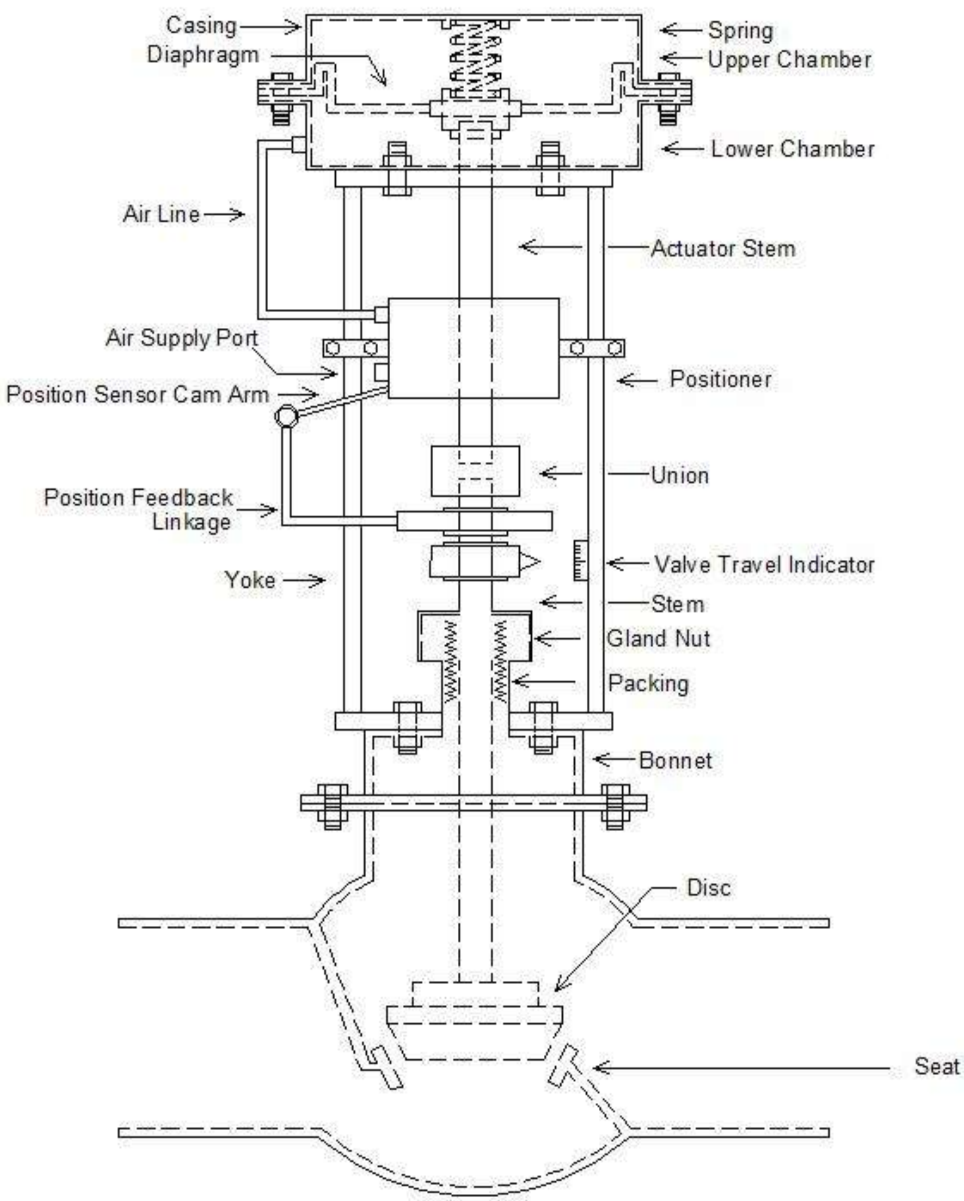


FIGURE 6
Globe Valve with Pneumatic Actuator and some hidden views

4-20 mA signal representative of the valve's position is generated by the positioner, and sent to a remote controller, e.g., a DCS.

Present-day positioners are usually configured either with built-in push buttons, or a Bluetooth-type remote controller, both using an interactive screen.

Valve Flow Nonlinearity

Flow through most valves is not linear with flow. A 30% valve opening will not usually lead to 30% of rated flow, nor will a 70% opening usually result in 70% of rated flow. In one type of valve, when the valve is 25% open, flow through the valve will be about 50% of maximum flow, assuming pressure upstream and downstream of the valve remain steady. For the same valve under the same conditions, when the valve is 75% open, flow will be about 87% maximum flow. This makes it difficult to get good flow control from a valve, and also makes it hard to control a process. Valve manufacturers have paid a lot of attention to this problem. A common way to make flow more linear in a valve is to use a disc or plug which is formed in a way to reduce flow non-linearity. Usually other benefits like noise reduction result when this is done. In the past, positioners with "characterizable" cams were often used to reduce flow non-linearity, but that approach is no longer widely used.

An air-to-close, fail-open valve is similar to an air-to-open, fail-closed valve. The main differences are that the positioner applies air to the upper rather than the lower chamber; and the spring forces the valve open when no (or minimal) air pressure is applied to the upper chamber.

Fail-open valves are often used in applications with a safety requirement. For example, many heat exchangers that condense steam have a cooling water connection with a regulating valve. If cooling water is lost, the steam won't condense to water, and equipment may be damaged. Fail-open cooling water supply valves provide safety, because if the positioner fails, or the valve's diaphragm leaks, adequate cooling water will still be provided.

Rotary Actuators

Some final control elements rotate, like butterfly dampers. An image of a rotating actuator follows. A movable surface with internal seals inside the actuator rotates due to a difference in pressure across the movable surface, and turns a shaft with a protruding square stub. The shaft for the final control element or load must be attached to a part with a mating square key recess.

	The quarter-turn rotary actuator shown to the left is by Kinetrol Ltd. Compressed air tubes are connected to the actuator. The underside of this actuator has a square key. It is mated to the shaft of a final control element with a matching square key recess. This actuator has an internal vane which rotates due to difference in air pressure. Instead of a vane, many rotary actuators use an internal cylinder to operate a rack-and-pinion gear train, which rotates the final control element.

Pneumatic Actuators and Solenoid Valves

Solenoid valves are often used with both single-acting and double-acting actuators. Figures 7A and 7B show how a 3-way solenoid valve is used to vent a single-acting valve by providing an escape path for air between actuator and positioner. And Figures 8A and 8B on page 26 show how a single coil 4-way solenoid valve is used to control a double-acting cylinder.

Fail In Place Action

Sometimes a pneumatic actuator needs to fail in its last position if power to operate it is lost, or if the control signal abruptly drops to 0%. So most OEMs in the business offer a Fail In Place option for pneumatic actuators. Details on Fail In Place action are beyond the scope of this course.

Direct and Reverse Actuators

A direct actuator was previously defined as "A diaphragm actuator in which the actuator stem extends with increasing diaphragm pressure." And a reverse actuator was defined as "A diaphragm actuator in which the actuator stem retracts with increasing diaphragm pressure." A design engineer or specification developer needs to be clear about the difference, so an incorrect actuator isn't selected.[ii] Don't confuse direct and reverse actuators with direct acting *control* and reverse acting *control*. (definitions, page 5.) The latter two relate to how a controller responds to an *error* signal.

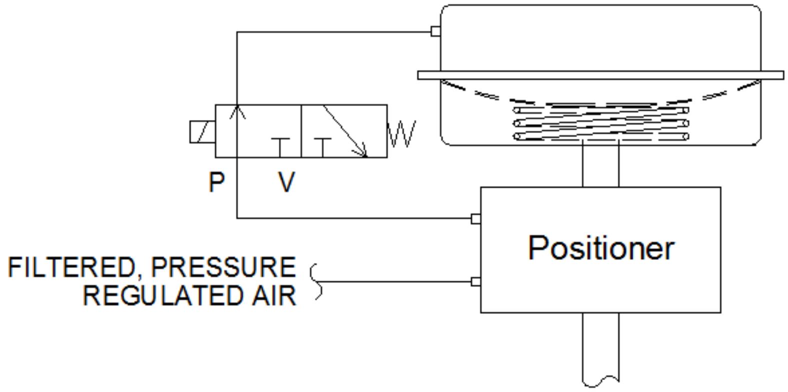


FIG. 7A - SOLENOID ENERGIZED, ACTUATOR CONTROLLING FAIL-TO-OPEN VALVE

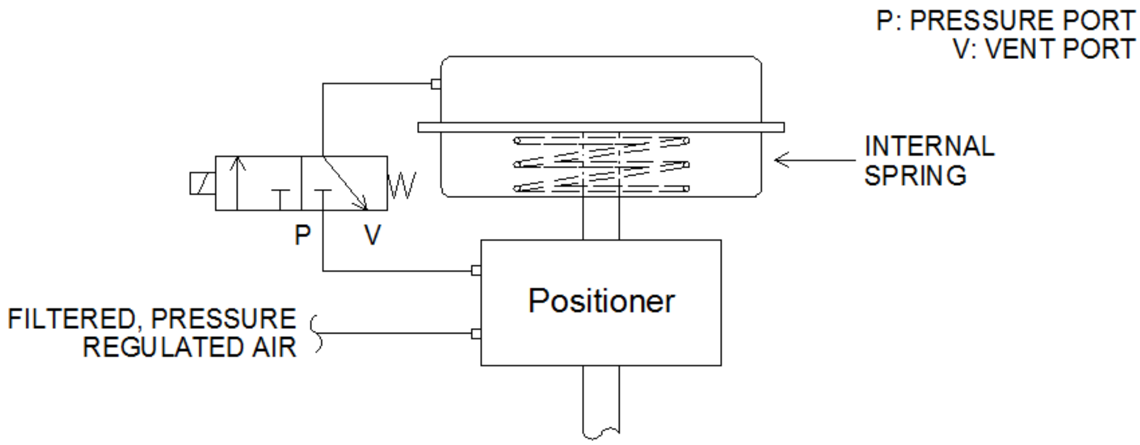


FIG. 7B - SOLENOID DEENERGIZED, ACTUATOR VENTING, VALVE FAILING TO SAFE POSITION

Air Cylinders

Sometimes air cylinders are used to operate valves, dampers, and other devices. Air cylinders have ports on both ends, a piston with a seal on its perimeter, and a rod. The rod extends through one end of the cylinder to the operated device. A seal at the rod end of the cylinder limits air escape. Air cylinders can be either single-acting or double-acting. For single-acting air cylinders, air pressure to move the device is applied only to one side of the piston. For double-acting air cylinders, it can be applied to either or both sides. Figures 8A and 8B show a double-acting cylinder. Modulating air cylinders are usually operated through a positioner.

Air cylinders are stronger and heavier than valve diaphragms.

When used with a double-acting cylinder, a positioner applies air at different pressures to opposite sides of the cylinder's piston simultaneously. The net force applied by the cylinder will equal the difference in force on opposite sides of the piston, minus spring pressure (if a spring is present) plus small frictional losses at the piston and rod seals.

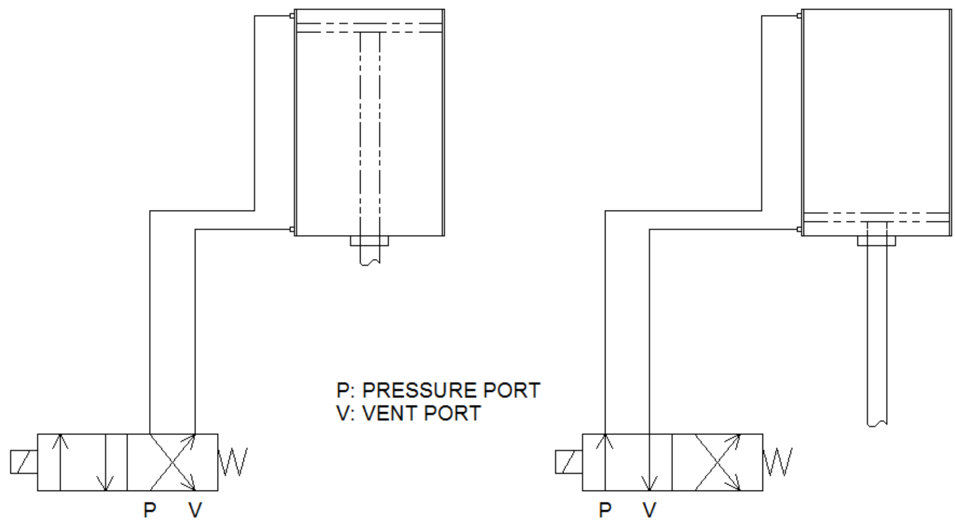


FIG. 8A - CYLINDER OPENED AND PRESSURIZED,SOLENOID VALVE ENERGIZED

FIG. 8B - CYLINDER CLOSED AND VENTING, SOLENOID VALVE DEENERGIZED

Positioners that direct compressed air to both sides of a cylinder usually include a proportioning valve that moves in a straight line to apply compressed air at different or equal pressures to the cylinders. By applying somewhat different air pressures to both sides of a cylinder's piston, stability of the final control element is improved. Small changes in the position of a final control element are easily achieved with a double-acting cylinder. This is helpful when process variations, such as changes in the pressure of fluid before or after a valve, are present.

Air cylinders are used in some applications where an activated device is only fully open or fully closed. In such applications, air pressure is applied to one side of the piston (such as to open a damper) at one time, and only to the other side at another time (such as to close a damper.) Typically this is done using a 4-port, 2-position, spring-return solenoid valve.

Some Maintenance Considerations

Maintenance for valves and pneumatic system components like filters has already been discussed. For pneumatic actuators, the primary failure risks are leakage due to a torn diaphragm, or at poorly joined fittings. Spring wear can also degrade a valve's ability to shut off tightly, and reduce actuator controllability.

Other Considerations for the Application of Pneumatic Power

- If it's necessary to send a 4-20 mA control signal to the device or transmit the actuator's position to a PLC, and the actuator is in a classified environment, proper use of interposing intrinsic safety barriers will eliminate potential hazard.
- Safety devices may be needed for personnel protection. Where hazards exist, warning signs should be used.
- It's usually necessary to depressurize piping and/or de-energize energy storage devices to do maintenance on pneumatic actuators.
- Each actuator needs to be sized so it's suitable for the application.
- The actuator materials should be proper for the environment.
- Many different sizes of compressors are available in the market. Likewise, receiver tanks can be different sizes in situations where the compressor will cycle on and off.

Advantages of Pneumatic Power

- Provides more power than electric actuators.
- Usually the best choice for a site with many modulating valves.
- Fast to medium-fast response time. They are faster than most electric motor actuators.
- In many plants, compressed air is essential in many plants. It is needed for uses like providing power to air tools or transporting granular substances. Compressed air is also used in many manufacturing apps. In such cases, using pneumatic actuators in process applications makes a lot of sense.
- Generally the safest type of power. Well-suited for most uses in classified environments. Lower explosion risk.

Disadvantages of Pneumatic Power

- Air compressors and dryers use enough power that pneumatic power may not always be the most economical choice.
- Air compressors are noisy. They should be located in an area where people are not usually present. Warning signs informing personnel to use hearing protection are needed in areas where compressors are located.
- Maintenance of compressors, dryers, and actuators will be necessary from time to time.
- Air filters at actuators should be cleaned periodically, and it's easy for technicians to overlook that.
- Leaks can occur at compressed air fittings.

IV. Hydraulic Actuators

Hydraulic actuators are devices which use a liquid under pressure, a hydraulic fluid, to operate equipment. The liquid is usually an oil which is fire resistant and stable over a wide range of temperatures. Hydraulically powered devices and systems vary from very simple ones to others that are complex. This course aims to demystify the subject by providing diagrams that show how they work. It's easy to be puzzled by hydraulically powered equipment because often hydraulic devices are hidden and/or have hidden features; or component parts are relatively far from each other; or both factors. Many of the diagrams presented show equipment or features that are not readily apparent.

Common Principles of Hydraulic Power Systems

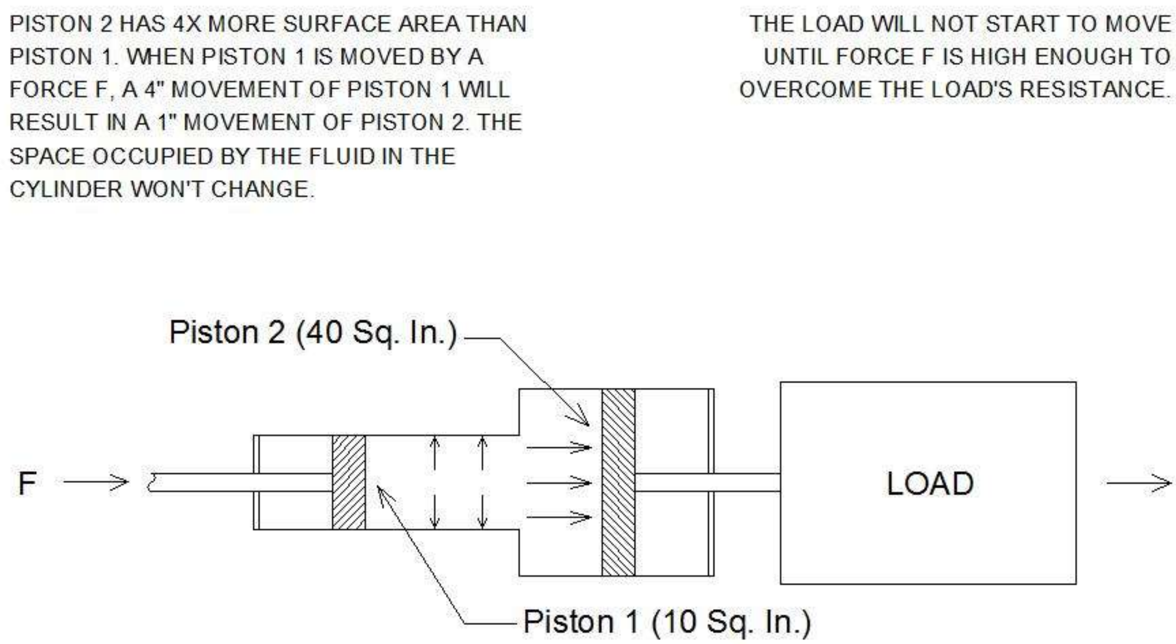
All hydraulically operated devices and systems do one of two things: move a fluid within a space with two or more movable surfaces, like in a hydraulic jack; or confine it inside a system where hydraulic fluid is pumped so it can do useful work. They rely on a basic fact about liquids: the volume occupied by trapped hydraulic fluid cannot change because it is incompressible. (See Figure 9 on next page.) Pressure can be exerted manually, like with a person's foot against a brake pedal in a car's mechanical braking system; by a pump; or by a stored energy device with a movable surface.

Hydraulic Power Systems

Over time engineers have created many ingenious hydraulic devices, and ways to use hydraulic power. Often they are the only choice for applications requiring a lot of power. The design and application of hydraulic systems is the work of specialists.

Hydraulic actuators can provide more power than any other type of actuator. They also can provide a faster response than any other type of actuator if that criterion is essential[1]. Many hydraulic actuators are also surprisingly compact. Where used, hydraulic actuators and essential components like pumps and fluid tanks are often part of a "turnkey" system - a system supplied as a unit by an OEM that stands alone by itself, such as an Electrohydraulic Actuator (see page 37).

[1] To provide a fast response, it must be possible to run the pump in an idle mode at low power, recirculating fluid without powering a load.



Sectional View Through Part of a Hydraulic Actuator

FIGURE 9

Hydraulic actuators rely on a system of components (See Fig. 10 on next page). Each system requires a fluid tank, a pump, connecting piping, and more. The pump delivers pressurized hydraulic oil to the actuator(s), and oil is returned to the tank through one or more return lines. In stationary applications, the pump is normally run by an electric motor. A pump can be submerged in a tank; mounted in the fluid tank but above the operating fluid level; or atop the tank. When a pump's inlet line is submerged, is it called a flooded suction pump. Pumps located above the fluid are referred to as elevated pumps. (Note: Portable equipment that uses hydraulic actuators, such as power lifts, usually use an engine to run the pump.)

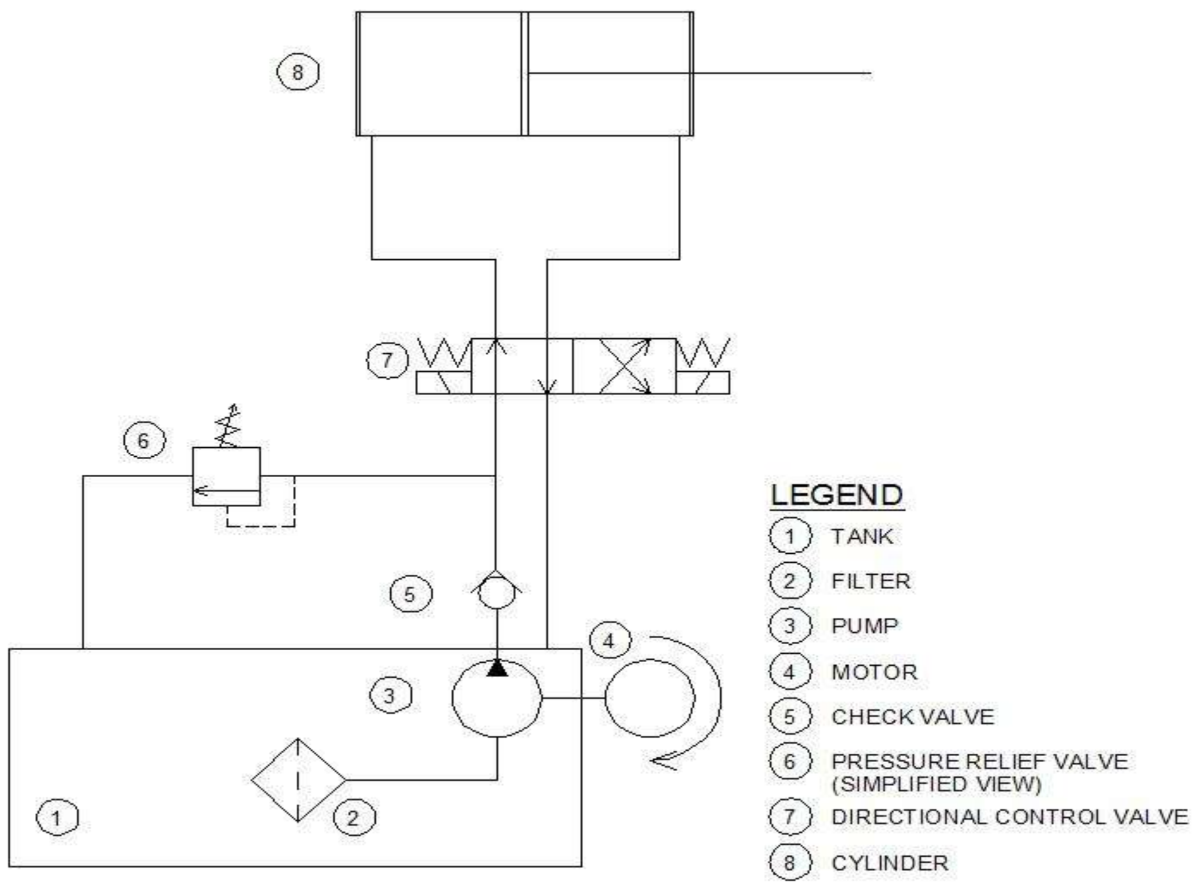


FIGURE 10 - A SIMPLE HYDRAULIC SYSTEM

Figure 16 in the Appendix shows a diagram of a more complex hydraulic system for operation of a heavy load like a large gate. It is preceded by a description of operation.

Many hydraulic devices and systems need a way to remove air bubbles that may enter the fluid and impair proper operation. They often come with a bleed screw[2] or bleed valve that is cracked open when being filled with fluid to allow air to escape.

Many commonly-used hydraulic pumps discharge fluid at hundreds or even thousands of PSI. However, the discharge flow rate of many hydraulic pumps is fairly low. Many

[2] Most cars have a bleed screw near each wheel for use whenever brake fluid is replaced.

hydraulic actuators do not require a high fluid flow rate for an acceptable speed of operation. The power needed by a hydraulic pump is proportional to the product of the discharge pressure and flow rate. Powerful motors are not needed for all hydraulic pumps.

Most hydraulic systems include a filter. A filter helps prevent dirt and particles from affecting the pump, actuators and other components.

For simplicity, this course will assume use of only one pump and one filter.

Submerged pumps are less susceptible to the destructive phenomenon of cavitation than elevated pumps. Cavitation occurs as tiny bubbles in the fluid stream collapse. It happens when the static pressure of a fluid drops too low as it is pulled into a pump. It often causes significant damage. Over time it can ruin a pump.

A typical tank will also have a fill connection, a fluid drain connection, a fluid level indicator, and a breather cap. Air passing through a breather cap equalizes tank fluid surface pressure with atmospheric pressure. The filter may have a differential pressure (D.P.) gauge, a high filter D.P. alarm switch, or both. If an alarm is received indicating high pressure drop across a hydraulic system's filter, maintenance should be notified.

Operation of hydraulic equipment generates heat. It's often necessary to cool hydraulic fluid, so hydraulic systems often include a cooler. Coolers are normally mounted on the fluid return side of a hydraulic power system. Some hydraulic equipment suppliers provide a high temperature alarm for the cooler outlet.

Hydraulic Pumps

Hydraulic fluid is usually pumped by positive displacement pumps. This type of pump continually confines fluid into one or more chambers, then expels it as it runs. Several types are frequently used in hydraulic power systems. Figures 11A and 11B show views of two common types of these pumps.

Hydraulic piping and equipment are typically subject to high pressures, and sometimes also shocks. So, many hydraulic systems include one or more spring-operated pressure relief valves to prevent system overpressure. Each pressure relief valve is connected to a return line that carries fluid back to the tank.

Another commonly used component is the check valve. Conventional check valves in hydraulic systems allow fluid to flow only in one direction, so backflow is prevented. A notable exception is the pilot-operated check valve. A “normally closed” pilot-operated check valve allows fluid to flow through it in a forward direction when inlet fluid pressure exceeds the setting of an internal spring. However, when a remote pressure, or "pilot pressure", is applied to the valve, fluid flows backwards from the outlet to inlet port. Both types are widely used. See Figure 15 in the Appendix for diagrams showing how both types of check valves work.

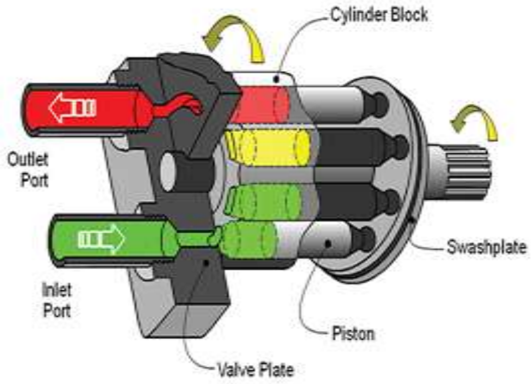


Figure 11A
Piston Pump

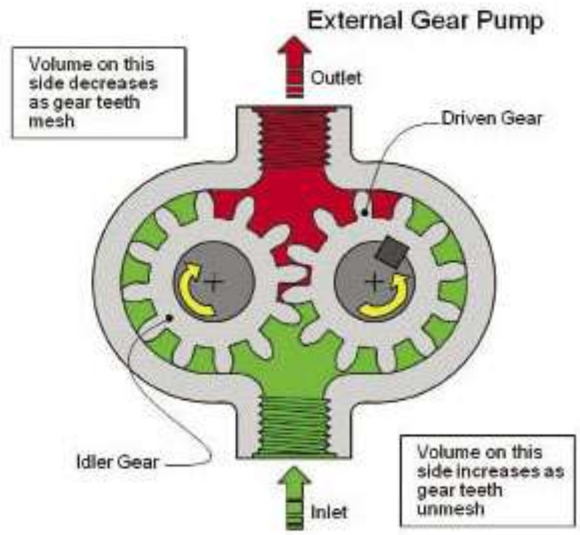


Figure 11B
External Gear Pump (a.k.a. Gerotor)

Piping (or tubing) and fittings used in hydraulic systems are similar to what's used in compressed air systems. However, steel and stainless steel piping is used more often in hydraulic systems than compressed air systems. Both are stronger than the copper tubing used so widely in pneumatic systems. Another difference is that flexible hose is often used with hydraulic equipment. That's because many hydraulic actuators have parts that move.

Accumulators are sometimes used in hydraulic systems. An accumulator is an energy storage device which is connected to hydraulic piping. Accumulators provide two important functions: they store energy, which can be used to provide extra fluid for operation of actuators; and they absorb some of the shocks that can occur during operation of equipment. Several different types of accumulators are widely used. One type has a diaphragm and sealed chamber with pressurized nitrogen. Often pressure switches are used in hydraulic systems to turn a pump on and off, so accumulator pressure remains in a certain range.

Hydraulic Cylinders

Most hydraulic actuators are cylinders. Hydraulic cylinders are similar to pneumatic cylinders. They can also be either single-acting or double-acting. Hydraulic cylinders have a piston that moves due to the difference in fluid pressure across the piston. The pressure difference must of course be high enough to overcome the forces acting on the final control element to move the load. Cylinders have built-in piston seals. In most (but not all) cylinders, a single rod protrudes through only one end of the cylinder. The rod end of a cylinder also has a seal to prevent leakage of hydraulic oil where the rod penetrates the cylinder. The rod moves through a removable rod gland bushing which guides and supports the rod. The opposite end of a cylinder is called the cap end. Sometimes two identical cylinders are used to move a load.

Single-acting cylinders either have one or two fluid ports. Cylinders with two ports are far more common. Some cylinders have an internal spring to force the cylinder back to closed position when there is no fluid pressure.

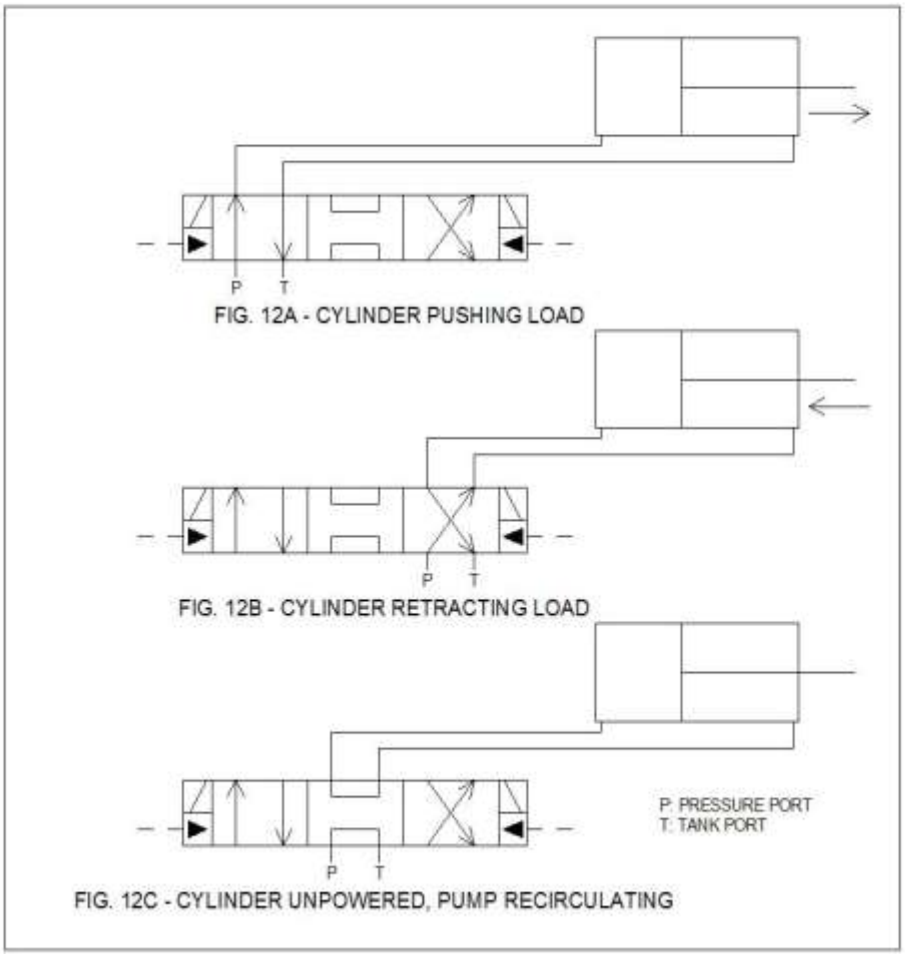
Most single-acting hydraulic actuators have a return line to carry hydraulic fluid back to the tank for each actuator. That way, fluid leaking through the cylinder's seals is recovered. In double-acting cylinders, fluid will return to the tank from either side of the cylinder, depending on its direction of operation. In some double-acting cylinders, piston rod end seals also have a return line connected to a port, so any fluid leaking past the seal is also returned to the tank.

Directional Control Valves

Directional Control Valves are valves with internal fluid passages that connect different input and outlet ports as the valve is repositioned. The positions of these valves are changed by one or more solenoids; by pilot-operated solenoid valves (discussed on next page); or other means like manual push buttons or levers. The solenoid valves previously mentioned with pneumatic actuators are directional control valves, although that term wasn't used. Many directional control valves are returned to a de-energized position by a spring.

Figures 12A and 12B (see next page) show how an actuator is moved in opposite directions depending on how the spool of a directional control valve is positioned. Different passages are opened and closed at different times depending on the valve's position. Each land of the spool has annular or piston-like surfaces. When the spool is centered, as shown in Figure 12C, fluid will be directed back to the tank if the pump is running. The spool within this directional control valve is a Tandem Center Spool.

The directional control valve of Figures 12A to 12C does not use electric solenoids on its ends for repositioning. Instead, it uses pilot-operated solenoid valves[3], and these figures show symbols for pilot-operated solenoid valves. Solenoids are often not powerful enough to overcome the force of hydraulic fluid pressure acting on a spool within a directional control valve. In such cases, pilot-operated solenoid valves are used. When a pilot-operated solenoid valve opens, pressurized fluid passes through it and acts against one of the lands within the valve spool. The reader may be confused, however, because the 3 figures don't distinctly show a fluid supply line to each such valve.



Directional control valves are often mounted either close to one or more hydraulic actuators, or at the actuator.

[3] Don't confuse a pilot-operated solenoid valves with (previously mentioned) pilot-operated check valves.

Modulating Hydraulic Actuators

Modulating hydraulic actuators allow the position of a final control element or load to be adjusted between closed and open positions.

There are many uses for modulating hydraulic actuators. One example is a steam turbine's governor valve at an electric power plant. A governor valve changes its opening so steam flow is controlled to meet changes in load demand while also maintaining the generator output frequency at 60 Hertz.

The photo above shows a hydraulic power unit. Its pump provides power to a scraper (not shown) with a back-and-forth motion that cleans a large screen. Its elevated pump pumps pressurized fluid to two equally-sized actuators on opposite sides of the scraper's actuators. It includes a cooler, and a filter atop the tank.

Servos

Modulating hydraulic actuators rely on a servo to apply hydraulic fluid at different pressures to opposite sides of hydraulic actuator. Sometimes they are also called servo valves or servomechanisms. They are similar to proportioning valves mentioned previously for positioners. A controller causes a servo to move to a particular position through a small motor, based either on an operator's input, or automatically. In automatic control mode, the controller acts as a black box, sending a position demand signal to the servo.

One type of servo is shown in Figure 13. At mid-position, the jet pipe is directing equal fluid pressure to both sides of the spool. When the armature/flapper is shifted to the left, the jet pipe applies higher fluid pressure to the left side of the spool than the right. This causes the cylinder to move to the right. The opposite happens when the armature/ flapper is moved to the right from the center position. A slight change in position of a servo often causes a significant change in pressure difference between its output ports.

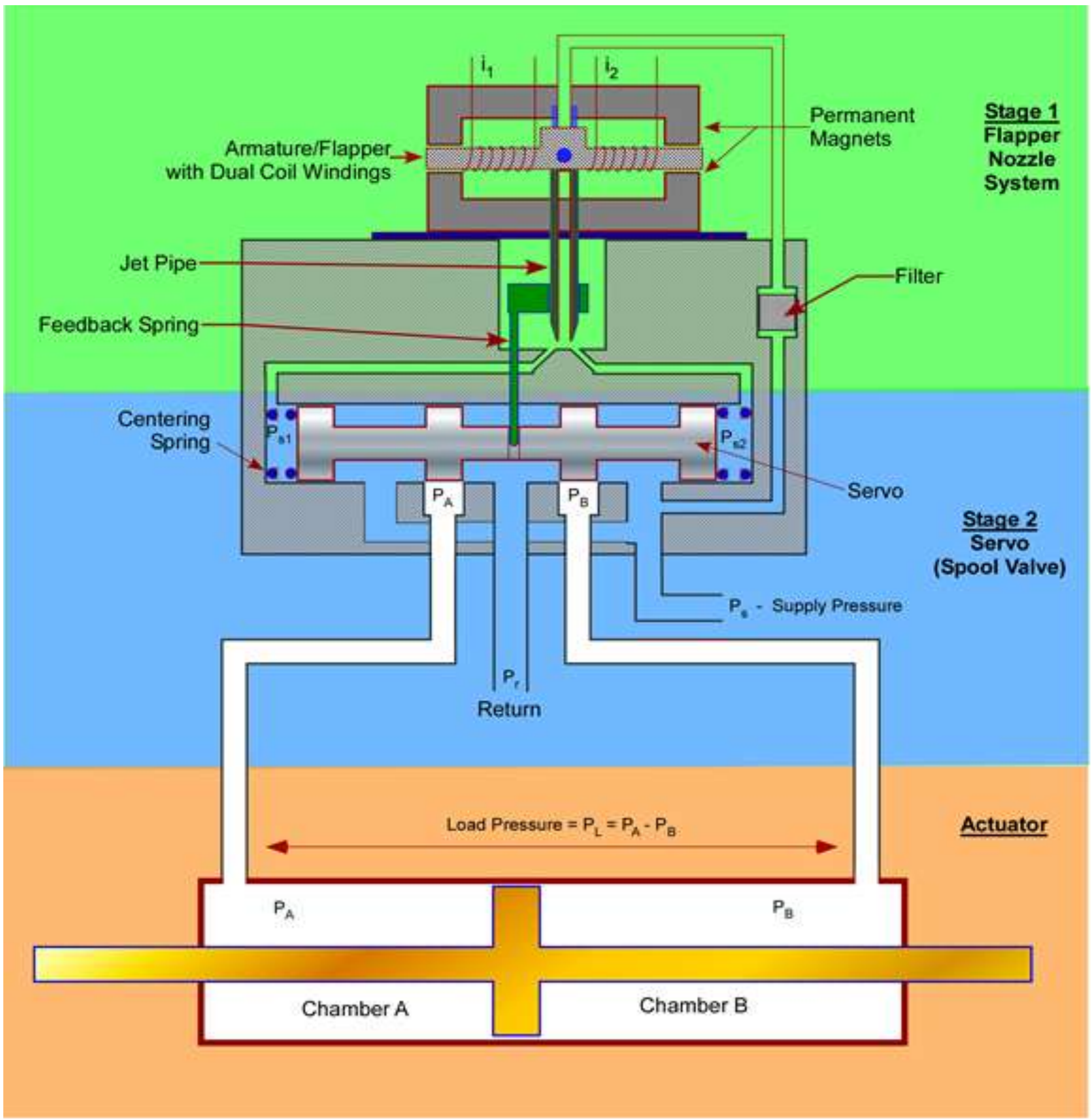


Figure 13

Servos are carefully manufactured to tight tolerances. The performance of a servo will be affected if it is worn or degraded by abrasive particles or corrosive fluid contaminants.

Hydraulic Motors

Hydraulic motors are used to rotate an axle or a gear which moves a load. This happens because within a hydraulic motor, fluid pressure decreases between the inlet and outlet ports as one form of mechanical energy is converted to another. Most can rotate in either direction. Like hydraulic pumps, there is an assortment of different types of hydraulic motors.

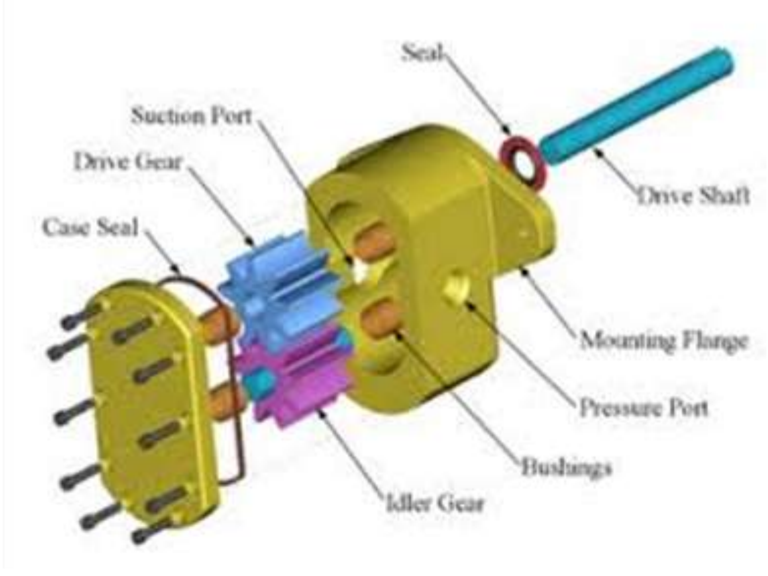


Figure 14

Figure 14 provides a detailed view of one type of hydraulic motor. This type is similar to the external gear type of hydraulic pump, except it is a power consuming device. Like hydraulic cylinders, hydraulic motors can be controlled with a servo and controller.

Hydraulic motors, like hydraulic cylinders, can provide a lot of power without using very much space. They provide a compact means to rotate shafts and axles that carry a high load. For example, to operate a long conveyor carrying a heavy load, a hydraulic motor is often a better choice than an electric motor. An electric motor and a gear train would have to be powerful and large to rotate a shaft that moves a large load. In such applications, the hydraulic motor sometimes is an attractive alternative. They are also used for operating some large dampers.

Electrohydraulic Actuators

So far this course has discussed individual components used in hydraulic systems. And in most hydraulic systems, the individual components are separated from each other and connected by pipes. But many OEMs provide actuators as a complete system, with all the individual components of a conventional system including, but not limited to, a pump, cylinder, fluid tank, piping, solenoid valve(s), relief valve(s), and sometimes an accumulator and/or servo. These actuators as complete standalone units are often referred to Electrohydraulic Actuators. An electrohydraulic actuator used only for an open-closed cylinder doesn't need a servo.

Some Electrohydraulic Actuators rotate loads and final control elements, and use a hydraulic motor or a device like a hydraulic motor.

And some OEMs offer simplified Electrohydraulic Actuators that only require the end user to connect hydraulic fluid supply and return lines, and wire up the actuator to an external controller. In such cases, an external hydraulic system pumps fluid from a tank, filters the fluid, and cools it if necessary.

Fail In Place Action

Hydraulic actuators frequently need to remain in their last position in event of loss of operating power. This is often essential for safety reasons, like when an actuator is suspending a large load. As for pneumatic actuators, Fail In Place, also known as Lock In Place, is often an option for hydraulic actuators. Details on how Fail In Place action can be achieved are beyond the scope of this course.

Manual Operation of a Hydraulic Actuator

Another option offered by some OEMs allows a hydraulic actuator to be opened or closed using a hand pump if the pump fails. Sometimes this is a worthwhile feature.

Other Considerations of Using Hydraulic Power for Actuators

- Safety devices are often essential for personnel protection. In such cases, warning signs are needed.
- It will be necessary to depressurize piping or de-energize energy storage devices to do maintenance on hydraulic equipment.
- Hydraulic fluid leaks can be dangerous, because fluid pressures are often high, and leaks can be difficult to see. A pressure gauge located near each actuator can help pinpoint leaks.
- A key aspect of hydraulic system maintenance is replacing failed parts with the correct parts. But it's easy to use the wrong parts. That's because differences between many parts, such as filters, fittings and valve spools are quite minor.

Engineers should take the trouble to obtain the proper spare parts if end user personnel will be doing maintenance.

- Water vapor in atmospheric air will condense in hydraulic fluid over time. This can eventually cause rusting. Periodic fluid replacement will increase equipment longevity.
- Because hydraulic systems are often complex, and sometimes require specialized tools, many organizations subcontract maintenance and service on them to an outside firm. Some end users have standing agreements with an OEM or subcontractor to provide service.
- The proper hydraulic fluid must be used or there will be harmful consequences.

Advantages of Using Hydraulic Power for Actuators

- Good if not essential in applications requiring substantial power.
- Fast responding if a pump is idling with no load.
- Compact.
- As with pneumatic actuators, each actuator needs to be sized so it's suitable for the application. This usually is the concern of an OEM, not an end user.

Disadvantages of Using Hydraulic Power for Actuators

- Good maintenance practices are essential if the user wants hydraulically operated equipment to last. This is easy to overlook unless a maintenance schedule is set up.
- Hydraulic equipment is quite susceptible to problems when any particles are present. Failure to clean or replace dirty filters can result in poor performance of expensive assets.
- Maintenance personnel are often not very familiar with hydraulic equipment.
- Hydraulic systems are relatively energy-inefficient due mostly to heat generated because of friction, and fluid cooling requirements.
- Tend to be expensive.
- Can be loud.

V. Actuator Communications and Control Options

Digital Communications Protocols

This course has discussed the use of 4-20 mA signals from and to control systems & controllers. The 4-20 mA signal remains the most frequently used signal type, but use of purely digital communications has been growing in recent decades. Two widely-used digital protocols are HART and Foundation Fieldbus H1. Communication signals for both protocols can be carried on the same twisted-pair wiring used for 4-20 mA signals. A HART signal can be superimposed on a 4-20 mA circuit. Modbus and Profibus PA are two other widely-used protocols. And some manufacturers have their own proprietary protocols. When signals to and from actuators are purely digital, usually more specialized cables are used. Actuators which use purely digital communications are typically part of a network. Digital communications protocols are widely used with actuators of all types.

Wireless Communications and Control

Another growing trend in the field of controls is wireless communications and controls. Some actuators are located far from the control system. In such cases, wireless radio communications between control system and remote actuators may be a good option. Currently the most prevalent method of long-distance communications involves use of fiber optic cables with converter devices. But wireless control with some actuators may be the best choice in some new installations. Of course, site-specific factors like power availability are also important in such decisions.

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APPENDIX

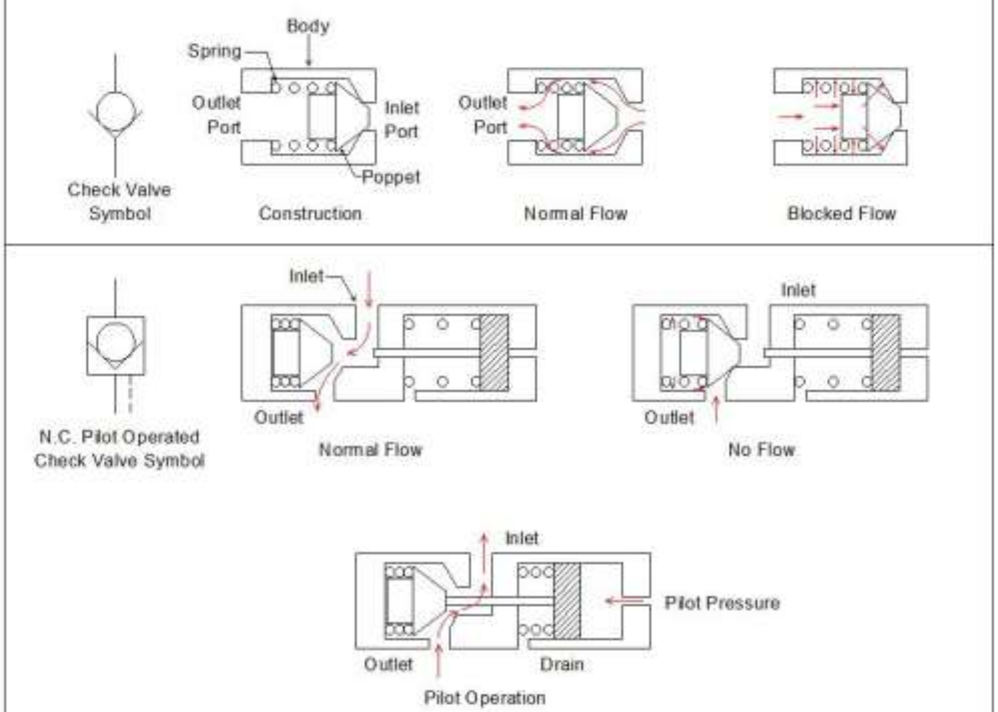

FIGURE 15
Check Valves and Normally-Closed (N.C.) Pilot Operated Check Valves

Description of an Open-Closed Hydraulic Circuit

Figure 16 (next page) is a diagram of a hydraulic system which operates a double-acting cylinder to drive it either fully open (rod moves up) or fully closed (rod moves down). The cylinder might be used to raise a gate. The pump pumps oil from a vented tank through a filter to an "open center" type directional control valve. Fluid returns to the tank regardless of the position of the directional valve when the pump is running. Fluid returning to tank passes through a cooler.

At start of operation, the cylinder is retracted to fully closed position, and the directional valve is centered. First, the directional valve is shifted to the right, then the pump is started. Pressure rises rapidly, and the pressure relief valve opens to prevent shock. But fluid pressure is high enough to extend the rod and move the load. The operator can change the speed at which the load is raised is opened by adjusting flow control valve A. (The degree of flow control valve B's opening also affects this speed.) If pressure on check valve C's inlet surges up, it will open, and some fluid will bypass the needle valve, but normally check valve C limits the pressure which can be applied to the cylinder's rod end. As the cylinder is extending, return flow to tank passes through needle valve B, but is blocked from passing through check valve D. During this opening sequence, check valve F is held open because pilot pressure at check valve E is high enough to open valve F and allow reverse flow through it (to the tank). Flow through pilot-operated check valve E is in a forward direction.

Once the cylinder is fully extended (as detected by a limit switch), the pump will stop, and the directional valve will be deenergized, and spring-returned to center position. With the pump off and pressure reduced, check valves E and F will close. There will be no reverse flow through either valve because pilot pressures are too low to open either valve and allow backward flow. The load can be maintained in this position because fluid is trapped and can't flow back to the tank.

To return the load to fully closed position, the directional valve is shifted to the left, then the pump is started. The lowering sequence is very similar to the raising sequence.

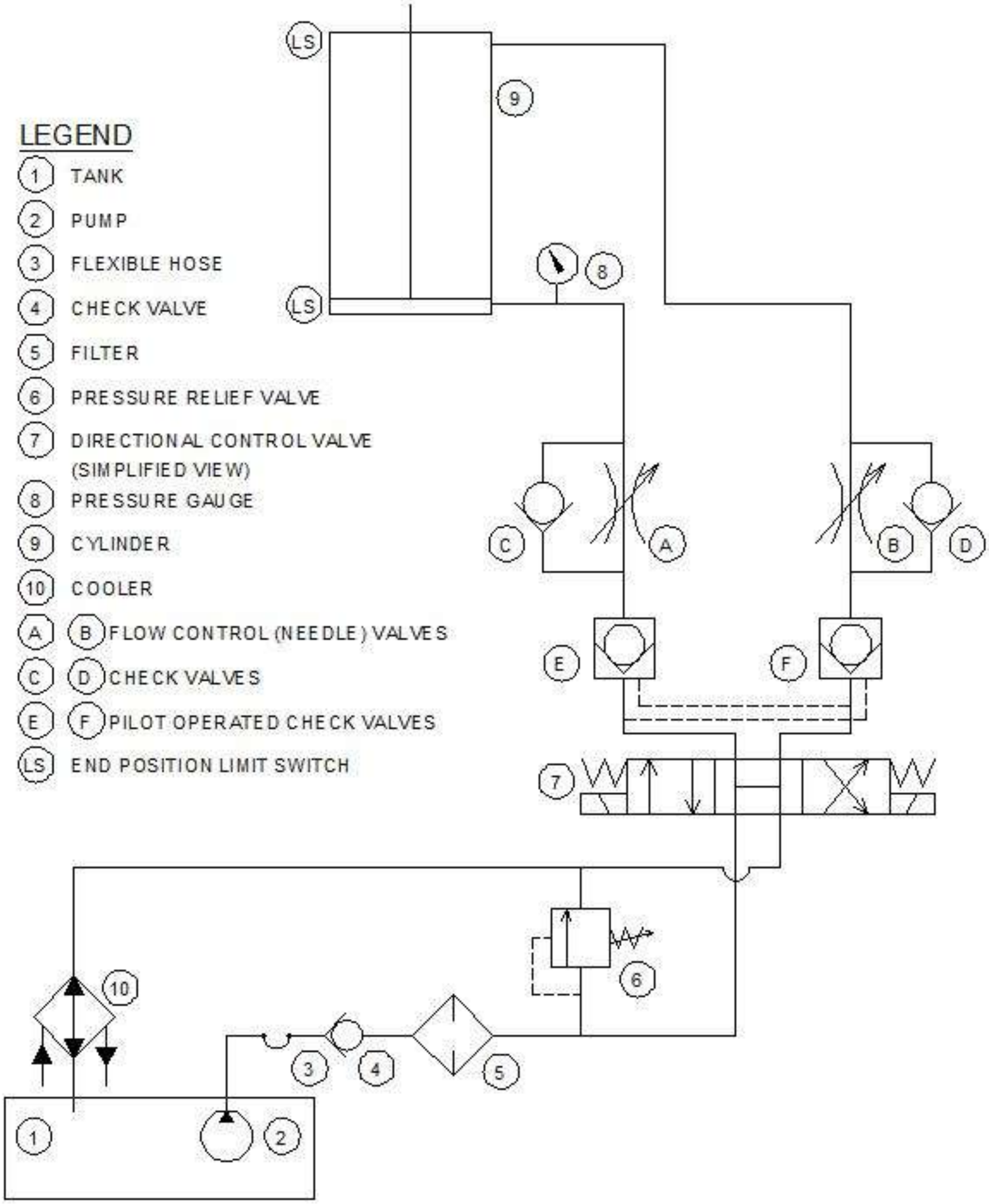

FIGURE 16
Hydraulic System for Open-Closed Cylinder

ENDNOTES

[i] The first type of commonly used process control system used pneumatic controllers. These controllers operated solely on compressed air, and performed many of the same functions that present day control systems do, like calculating proportional and integral (a.k.a. reset) control signals for valve positioners. Control signals were sent through compressed air tubing. A typical pneumatic controller would output a 3-15 PSI control signal to a valve positioner. But pneumatic control systems had many disadvantages. Beginning in the 1960s, analog electronic control systems with components like transistors started to replace pneumatic control systems. In the 1970s, microprocessor-based control systems came to the marketplace. They were more reliable and easily configured than analog electronic control systems, and replaced the latter systems in time. The DCSs, PLCs, and single-loop controllers offered nowadays by many suppliers remain microprocessor-based.

[ii] In most industrial, municipal and manufacturing applications, the discs or plugs of linear valves are mounted above the seat. In HVAC applications, a valve's plug can be either above or below the seat. This is true regardless of whether the valve is normally closed (N.C.) or normally open (N.O.). Honeywell, a leading North American manufacturer of HVAC control systems, has a different way of designating valve control actions. They are summarized as follows:

a. A direct acting actuator is used with a N.C. valve with plug below seat to apply force downwards to retract the valve stem, move the plug off the disc, and open the valve.
b. A direct acting actuator is used with a N.O. valve with plug above seat to apply force downwards to retract the valve stem, move the plug towards the seat, and close the valve.
c. A reverse acting actuator is used with a N.C. valve with plug above seat to apply force upwards to extend the valve stem, move the plug off the disc, and open the valve.
d. A reverse acting actuator is used with a N.O. valve with plug below seat to apply force to extend the valve stem, move the plug towards the seat, and close the valve.