5. LOGICAL ACTUATORS

5.1 INTRODUCTION

Actuators drive motions in mechanical systems. Most often this is by converting electrical energy into some form of mechanical motion.

5.2 SOLENOIDS

Solenoids are the most common actuator components. The basic principle of operation is there is a moving ferrous core (a piston) that will move inside a wire coil as shown in Figure 5.1. Normally, the piston is held outside the coil by a spring. When a voltage is applied to the coil and current flows, the coil builds up a magnetic field that attracts the piston and pulls it into the center of the coil. The piston can be used to supply a linear force. Well-known applications of these include pneumatic valves and car door openers.

Figure 5.1

A Solenoid
As mentioned before, inductive devices can create voltage spikes and may need snubbers, although most industrial applications have low enough voltage and current ratings they can be connected directly to the PLC outputs. Most industrial solenoids will be powered by 24Vdc and draw a few hundred mA.

The flow of fluids and air can be controlled with solenoid controlled valves. An example of a solenoid controlled valve is shown in Figure 5.2. The solenoid is mounted on the side. When actuated it will drive the central spool left. The top of the valve body has two ports that will be connected to a device such as a hydraulic cylinder. The bottom of the valve body has a single pressure line in the center with two exhausts to the side. In the top drawing the power flows in through the center to the right hand cylinder port. The left hand cylinder port is allowed to exit through an exhaust port. In the bottom drawing the solenoid is in a new position and the pressure is now applied to the left hand port on the top, and the right hand port can exhaust. The symbols to the left of the figure show the schematic equivalent of the actual valve positions. Valves are also available that allow the valves to be blocked when unused.

Figure 5.2
A Solenoid Controlled 5 Ported, 4 Way 2 Position Valve

The solenoid has two positions and when actuated will change the direction that fluid flows to the device. The symbols shown here are commonly used to represent this type of valve.
Valve types are listed below. In the standard terminology, the 'n-way' designates the number of connections for inlets and outlets. In some cases there are redundant ports for exhausts. The normally open/closed designation indicates the valve condition when power is off. All of the valves listed are two position valves, but three position valves are also available.

2-way normally closed - these have one inlet, and one outlet. When unenergized, the valve is closed. When energized, the valve will open, allowing flow. These are used to permit flows.

2-way normally open - these have one inlet, and one outlet. When unenergized, the valve is open, allowing flow. When energized, the valve will close. These are used to stop flows. When system power is off, flow will be allowed.

3-way normally closed - these have inlet, outlet, and exhaust ports. When unenergized, the outlet port is connected to the exhaust port. When energized, the inlet is connected to the outlet port. These are used for single acting cylinders.

3-way normally open - these have inlet, outlet and exhaust ports. When unenergized, the inlet is connected to the outlet. Energizing the valve connects the outlet to the exhaust. These are used for single acting cylinders.

3-way universal - these have three ports. One of the ports acts as an inlet or outlet, and is connected to one of the other two, when energized/unenergized. These can be used to divert flows, or select alternating sources.

4-way - these valves have four ports, two inlets and two outlets. Energizing the valve causes connection between the inlets and outlets to be reversed. These are used for double acting cylinders.

Some of the ISO symbols for valves are shown in Figure 5.3. When using the symbols in drawings the connections are shown for the unenergized state. The arrows show the flow paths in different positions. The small triangles indicate an exhaust port.
When selecting valves there are a number of details that should be considered, as listed below.

- **Pipe size**: Inlets and outlets are typically threaded to accept NPT (national pipe thread).
- **Flow rate**: The maximum flow rate is often provided for hydraulic valves.
- **Operating pressure**: A maximum operating pressure will be indicated. Some valves will also require a minimum pressure to operate.
- **Electrical**: The solenoid coil will have a fixed supply voltage (AC or DC) and current.
- **Response time**: This is the time for the valve to fully open/close. Typical times for valves range from 5ms to 150ms.
- **Enclosure**: The housing for the valve will be rated as,
  - **Type 1 or 2**: For indoor use, requires protection against splashes.
  - **Type 3**: For outdoor use, will resist some dirt and weathering.
  - **Type 3R or 3S or 4**: Water and dirt tight.
  - **Type 4X**: Water and dirt tight, corrosion resistant.

### 5.4 CYLINDERS

A cylinder uses pressurized fluid or air to create a linear force/motion as shown in Figure 5.4. In the figure, a fluid is pumped into one side of the cylinder under pressure, causing that side of the cylinder to expand, and advancing the piston. The fluid on the other side of the piston must be allowed to escape freely — if the incompressible fluid was trapped, the cylinder could not advance. The force the cylinder can exert is proportional to the cross sectional area of the cylinder.
Figure 5.4
A Cross Section of a Hydraulic Cylinder

Single acting cylinders apply force when extending and typically use a spring to retract the cylinder. Double acting cylinders apply force in both directions.

For Force:

\[
F = \frac{P A}{\text{advancing}}
\]

\[
F = \frac{P A}{\text{retracting}}
\]

where,

\[P\] = the pressure of the hydraulic fluid

\[A\] = the area of the piston

\[F\] = the force available from the piston rod

\[F\] = Fluid pumped in at pressure

\[F\] = Fluid flows out at low pressure

\[F\] = Fluid pumped in at pressure

\[F\] = Fluid flows out at low pressure
Magnetic cylinders are often used that have a magnet on the piston head. When it moves to the limits of motion, reed switches will detect it.

5.5 HYDRAULICS

Hydraulics use incompressible fluids to supply very large forces at slower speeds and limited ranges of motion. If the fluid flow rate is kept low enough, many of the effects predicted by Bernoulli's equation can be avoided. The system uses hydraulic fluid (normally an oil) pressurized by a pump and passed through hoses and valves to drive cylinders. At the heart of the system is a pump that will give pressures up to hundreds or thousands of psi. These are delivered to a cylinder that converts it to a linear force and displacement.
Hydraulic systems normally contain the following components:

1. Hydraulic Fluid
2. An Oil Reservoir
3. A Pump to Move Oil, and Apply Pressure
4. Pressure Lines
5. Control Valves - to regulate fluid flow
6. Piston and Cylinder - to actuate external mechanisms

The hydraulic fluid is often a noncorrosive oil chosen so that it lubricates the components. This is normally stored in a reservoir as shown in Figure 5.6. Fluid is drawn from the reservoir to a pump where it is pressurized. This is normally a geared pump so that it may deliver fluid at a high pressure at a constant flow rate. A flow regulator is normally placed at the high pressure outlet from the pump. If fluid is not flowing in other parts of the system this will allow fluid to recirculate back to the reservoir to reduce wear on the pump. The high pressure fluid is delivered to solenoid controlled valves that can switch fluid flow on or off. From the valves fluid will be delivered to the hydraulics at high pressure, or exhausted back to the reservoir.
Hydraulic systems can be very effective for high power applications, but the use of fluids, and high pressures can make this method awkward, messy, and noisy for other applications.

5.6 PNEUMATICS

Pneumatic systems are very common, and have much in common with hydraulic systems with a few key differences. The reservoir is eliminated as there is no need to collect and store the air between uses in the system. Also because air is a gas it is compressible and regulators are not needed to recirculate flow. But, the compressibility also means that the systems are not as stiff or strong. Pneumatic systems respond very quickly, and are commonly used for low force applications in many locations on the factory floor.

Some basic characteristics of pneumatic systems are,

- stroke from a few millimeters to meters in length (longer strokes have more springiness)
- the actuators will give a bit - they are springy
- pressures are typically up to 85psi above normal atmosphere
- the weight of cylinders can be quite low
- additional equipment is required for a pressurized air supply- linear and rotatory actuators are available.
- dampers can be used to cushion impact at ends of cylinder travel.

When designing pneumatic systems care must be taken to verify the operating location. In particular the elevation above sea level will result in a dramatically different air pressure. For example, at sea level the air pressure is about 14.7 psi, but at a height of 7,800 ft (Mexico City) the air pressure is 11.1 psi. Other operating environments, such as in submersibles, the air pressure might be higher than at sea level.

Some symbols for pneumatic systems are shown in Figure 5.7. The flow control valve is used to restrict the flow, typically to slow motions. The shuttle valve allows flow in one direction, but blocks it in the other. The receiver tank allows pressurized air to be accumulated. The dryer and filter help remove dust and moisture from the air, prolonging the life of the valves and cylinders.
Motors are common actuators, but for logical control applications their properties are not that important. Typically logical control of motors consists of switching low current motors directly with a PLC, or for more powerful motors using a relay or motor starter. Motors will be discussed in greater detail in the chapter on continuous actuators.
5.1 COMPUTERS
- More complex devices contain computers and digital logic.
- To interface to these we use TTL logic, 0V=false, 5V=true.
- TTL outputs cards supply power and don't need a separate power supply.
- Sensitive to electrical noise.

5.9 OTHERS
There are many other types of actuators including those on the brief list below.
- Heaters - Often controlled with a relay and turned on and off to maintain a temperature within a range.
- Lights - Used on almost all machines to indicate the machine state and provide feedback to the operator. Most lights are low current and are connected directly to the PLC.
- Sirens/Horns - Useful for unattended or dangerous machines to make conditions well known. These can often be connected directly to the PLC.

5.10 SUMMARY
- Solenoids can be used to convert an electric current to a limited linear motion.
- Hydraulics and pneumatics use cylinders to convert fluid and gas flows to limited linear motions.
- Solenoid valves can be used to redirect fluid and gas flows.
- Pneumatics provides smaller forces at higher speeds, but is not stiff.
- Hydraulics provides large forces and is rigid, but at lower speeds.
- Many other types of actuators can be used.
1. A piston is to be designed to exert an actuation force of 120 lbs on its extension stroke. The inside diameter of the cylinder is 2.0" and the ram diameter is 0.375". What shop air pressure will be required to provide this actuation force? Use a safety factor of 1.3.

\[ A = \pi r^2 = 3.14159 \text{in}^2 \]
\[ P = FS\left(\frac{F}{A}\right) = 1.3 \left(\frac{120}{3.14159}\right) = 49.7 \text{psi} \]

Note, if the cylinder were retracting we would need to subtract the rod area from the piston area. Note: this air pressure is much higher than normally found in a shop, so it would not be practical, and a redesign would be needed.

2. Draw a simple hydraulic system that will advance and retract a cylinder using PLC outputs. Sketches should include details from the PLC output card to the hydraulic cylinder.

3. Develop an electrical ladder diagram and pneumatic diagram for a PLC controlled system. The system includes the components listed below. The system should include all required safety and wiring considerations.

- a 3 phase 50 HP motor
- 1 NPN sensor
- 1 NO push button
- 1 NC limit switch
- 1 indicator light
- a doubly acting pneumatic cylinder
3. ASSIGNMENT PROBLEMS

1. Draw a schematic symbol for a solenoid controlled pneumatic valve and explain how the valve operates.

2. We are to connect a PLC to detect boxes moving down an assembly line and divert larger boxes. The line is 12 inches wide and slanted so the boxes fall to one side as they travel by. One sensor will be mounted on the lower side of the conveyor to detect when a box is present. A second sensor will be mounted on the upper side of the conveyor to determine when a larger box is present. If the box is present, an output to a pneumatic solenoid will be actuated to divert the box. Your job is to select a PLC, sensors, and solenoid valve. Details are expected with a ladder wiring diagram. (Note: take advantage of manufacturers web sites.)

3. A PLC based system has 3 proximity sensors, a start button, and an E-stop as inputs. The system controls a pneumatic system with a solenoid controlled valve. It also controls a robot with a TTL output. Develop a complete wiring diagram including all safety elements.

4. A system contains a pneumatic cylinder with two inductive proximity sensors that will detect when the cylinder is fully advanced or retracted. The cylinder is controlled by a solenoid controlled valve. Draw electrical and pneumatic schematics for a system.

5. Draw an electrical ladder wiring diagram for a PLC controlled system that contains 2 PNP sensors, a NO pushbutton, a NC limit switch, a contactor controlled AC motor and an indicator light. Include all safety circuitry.