How Sensors Are Used in Fluid Power Systems

Sensors are used as input devices in fluid power systems to indicate that a condition has been, or has not been, met. Sensors can be used to monitor pressure, flow, or position. By integrating time with position, velocity, either angular or linear, may be determined.

Digital vs. Analog Sensors

Sensors can be divided into two general groups: those that provide a digital (on or off) signal and those that provide an analog (varying voltage or amperage) signal.

Most sensors used in fluid power systems are simple switches. Switch contacts, being either open or closed, provide a digital signal. If when the switch is in its unactuated state the contacts are closed, allowing current to flow through the switch, the switch is termed a normally closed switch. If the switch contacts are open when the switch un-actuated, the switch is termed a normally open switch. However, some switches have three contacts. This type of switch may be connected so that in its un-actuated state current either does or does not flow through the switch. Variations on this type of switch include one which has six contacts, effectively providing two switches enclosed in one housing.

Switches are rated by the amount of current and voltage for which they are rated. For example, a switch may be rated to 5 amps at 240 volts. If the switch is used in a circuit in which the amperage or voltage exceeds these limits, arcing at the switch contacts is likely to occur with resultant damage to the contacts.

Analog sensors provide an analog output signal. Sometimes it is not enough to simply know that a condition, such as a specific pressure, has been met. Instead, the amount of pressure throughout a range needs to be monitored. If only two or three discrete points need to be monitored, one solution would be to have multiple pressure switches each set for a specific pressure. This solution quickly becomes expensive as there is the cost of the switches, installation hardware, and time to consider. Though a pressure transducer is generally more expensive than a pressure switch, one pressure transducer usually is less expensive than three pressure switches. If the transducer is connected to a PLC (programmable logic controller) the transducer signal will need to be connected through an A to D (analog to digital) converter. Offsetting the cost of an A to D converter is the fact that individual pressure switches each require a connection to the PLC. If you need to monitor three pressure switches three PLC inputs will be used. As the number of input and output connections on a PLC increases, so does the cost of the PLC.

Fig. 1: Pressure Transducer

In addition to electrical switches and transducers, there are sensors that do not use electricity.

Sensors Used to Monitor Pressure

In some applications pressure switches are used as a "permissive input device." For example, a process may require a given minimum pressure in order to ensure safety, an acceptable product, or both. In this case, unless that minimum pressure has been reached, the operation of the circuit is disabled. A variation on this scenario is that a minimum pressure must exist in order for the circuit to continue with its cycle. If the circuit pressure falls below the minimum pressure, the operation of the circuit is disabled to some safe condition.

In other applications, if the pressure rises beyond a given value, the operation of the circuit is disabled. A variation on this is that once the pressure rises to a given value, and the needs of the circuit have been met, for example in a pressing or forming application, action is taken to either hold at that pressure, to continue on to the next step in the operation sequence, or to end the operation.

In one pressing application in which boron nitride is pressed for use in semiconductor applications, pressure is increased in steps, with dwell times programmed in at several points along the way in the press cycle. Since there are multiple pressures that need to be monitored, and a closed loop proportional pressure reducing valve is being used to control the pressure, a pressure transducer is being used as the input device.

In some clamping applications in which a fixed displacement pump is used with an accumulator, a set of pressure switches are used to control a solenoid vented relief valve. When the pressure in the circuit falls below the minimum pressure set point, the solenoid vented relief valve is energized closed and pump flow refills the accumulator. When the high pressure set point has been reached, the solenoid vented relief valve is de-energized and the pump is vented to tank at low pressure, thereby reducing power use and heat generation while maintaining an acceptable circuit pressure.

A corollary to this example is a "start-stop" control on a reciprocating compressor. When a given air pressure has been reached in the air receiver, the compressor motor is switched off. When the pressure in the air receiver falls below the minimum set point, the compressor motor is turned on again.

Switches used to monitor pressure can be located on the compressor or power unit, or they may be located in a branch circuit. It all depends on where the pressure needs to be monitored.

Pressure gauges may also be considered to be sensors. Not all machines are automated. Though a basic pressure gauge isn't capable of generating an input to an electrically based control system, they are unquestionably useful as an input to a human operator.

A few manufacturers of pneumatic components, including Parker-Hannifin (www.parker.com), Legris (www.legris.com), Dynamco (www.dynamco.com), and Clippard Instrument Laboratory, Inc. (www.clippard.com), have sensors that operate on air pressure. Depending on the actual sensor, the presence, or lack of presence, of air pressure is indicated. Other sensors use air pressure to sense the presence of an object. Air is bled through an orifice. If the outlet of the orifice is unobstructed a given back pressure exists. If the outlet becomes obstructed by the presence of an object, there is a resultant change in the backpressure, which is sensed, creating an output.

Sensors Used to Monitor Flow

As with pressure, the monitoring of flow falls into three categories: Is there a minimum amount of flow? Is there too much flow? Exactly how much flow do we have?

If all one needs to know is if there is or isn't enough flow, a simple flow switch should suffice. A typical flow switch consists of a paddle shaped surface which is connected to a support that operates the contacts of a switch. The switch may be built around a plug type of support that is designed to screw into a pipe tee or cross, or the switch may include a housing which is teed into a flow line. Most commonly available flow switches are relatively low pressure components that are typically used in the process industry. As a consequence, their pressure rating is often too low to be used in a hydraulic circuit. A solution to this problem is to use a flow meter that includes a switch.

Hedland (www.hedland.com) and Lake Monitors (www.lakemonitors.com) are the two prominent manufacturers of these flow meters. Both companies offer flow meters for use in pneumatic and hydraulic systems. These flow meters can be equipped with a switch, or switches, that open or close when a given flow rate is achieved or exceeded. These switches will provide a digital output. Sometimes that actual flow rate needs to be monitored. To satisfy these applications, a position transducer is fitted to the switch. The position of the cone shuttle inside the meter is monitored. The displacement of the shuttle is typically output as a 4-20 mA, a 0-5 vdc, or a 0-10 vdc proportional analog signal.

In a turbine style flow meter, the speed of the turbine can be measured yielding a proportional analog signal.

A third type of flow meter is the gear type flow meter which is similar in construction to a spur (external) gear pump. A transducer is used to sense the motion of the gear teeth. This information is processed by electronics which are part of the flow meter and an analog output signal is generated.

Flow meters can be located in the main supply or return line of a system or they may be located in a branch circuit.

Sensors Used to Monitor Position or Velocity

Sensors are used for position sensing in a wide variety of applications. Two typical applications on hydraulic power units are oil level monitoring and pump inlet monitoring.

It is preferable for a hydraulic pump to have a flooded inlet. This achieved by using either an L-shaped or an overhead reservoir. In order to facilitate replacement of the pump without the need to drain the reservoir, it is common practice to install a ball valve in the pump inlet line. However, if someone forgets to open the ball valve before starting the pump, cavitation will result and the pump will fail catastrophically. An easy method of preventing the motor from being started if the inlet ball valve is closed is to install a limit switch on the ball valve. The input from the switch can be connected so as to prevent the motor from being started when the ball valve is not fully open.

It doesn't matter whether the prime mover is an electric motor or a diesel engine. The limit switch can be wired in a way that will prevent the starting circuit from operating if the limit switch contacts are not closed. One way to achieve this is to wire the limit switch, or a relay controlled by the limit switch, in series in the starting circuit. If a PLC is being used to control the machine a line in the program can require that the contacts of the limit switch be closed as a condition of that rung of the ladder logic being completed. The limit switch would be located in series with any other input elements on that rung. This would ensure that the ball valve is open before the motor can start. Also, unless some sort of latching circuit is included in the run circuit, if someone were to close the ball valve during operation of the system, the motor would shut down, preventing cavitation induced damage to the pump.

A similar arrangement could be used in a pneumatic system. The air generation portion of the system may be isolated from the air distribution system by a ball valve. Operation of machinery connected to the air distribution system could be prevented if the ball valve has not been opened, allowing flow into the distribution system.

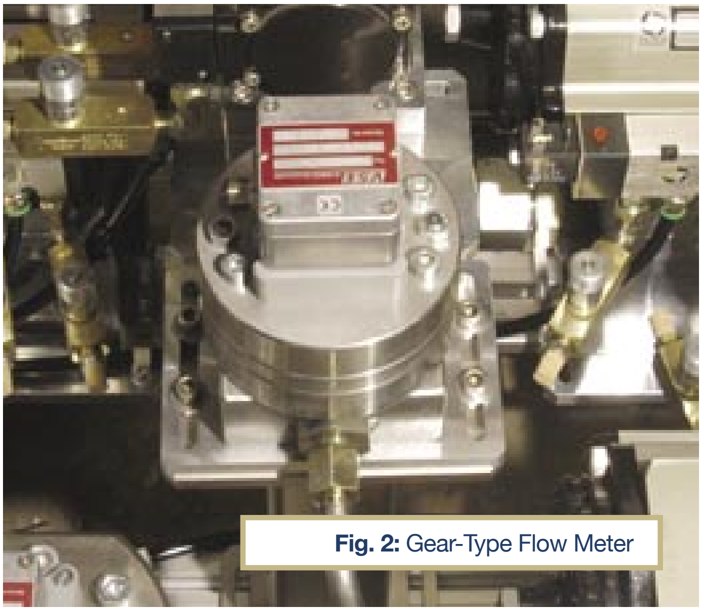

Fig. 2: Gear-Type Flow Meter

Though almost every pump manufacturer cautions against the use of suction strainers, some users insist on inlet filtration. If the inlet strainer or filter becomes clogged pump cavitation will result. Some, though not all, suction strainers and filters have bypass check valves, which of course, may or may not fail. The usual way to monitor the inlet condition of the pump is to use a vacuum switch. One should consult the pump manufacturer's data regarding the acceptable inlet pressure. This inlet pressure may be stated in inches of mercury (in-Hg), negative gauge pressure, or in absolute pressure. Installation of a vacuum gauge near the switch will aid in setting the switch. While technically a vacuum switch is a pressure switch, it is being discussed here because it fits the topic of pump inlet monitoring.

A second type of position switch commonly installed on hydraulic power units is an oil level switch. Sometimes two level switches are used. One switch warns of low fluid level while the second switch, located to indicate an even lower fluid level, can be used to shut down the prime mover before the fluid level uncovers the inlet line.

A note here on ways of connecting a level switch is in order. One line of reasoning would be that if the fluid level falls below an acceptable level, the switch contacts will close and an alarm input will occur. However, if a wire breaks somewhere or a connection comes loose, the switch will close when the fluid level falls unacceptably, but the input signal will not be received by the monitoring device, whether that is a simple indicator light or a PLC. By wiring the level switch so that when the fluid level is acceptable, current will flow through the switch when the fluid level is at or above the float of the switch. If either the fluid level falls, a wire breaks, or a termination becomes disconnected, electrical current flow will cease and the input signal that everything is "okay" will be interrupted.

Temperature switches are a third type of switch used on hydraulic powers. Though not a position sensing switch, a discussion of temperature switches fits well here. As with fluid level switches, a system may include either one or two temperature switches. If two switches are installed on the power unit the one with a lower set point can indicate that a high temperature has been reached. At this point an alarm can be turned on, or a cooling system can be switched on. If an oil-to-air heat exchanger is installed, the fan motor can be activated. If an oil-to-water heat exchanger is being used, then the input from the temperature switch can be used to actuate a solenoid operated water control valve that will allow the flow of cooling water to the heat exchanger. The second temperature switch would be set at a higher temperature and could send an input to the control system to shut down the power unit.

Fig. 3: Vacuum Switch & Vacuum Gauge

Filters are commonly located on power units. It is rare to not include a bypass switch on a filter to indicate that the filter element must be changed. Some of these switches are position monitoring switches that sense the position of the bypass check valve, if the housing is equipped with a bypass check. For non-bypassing pressure line housings, and typically for return line filters, a pressure switch, or pressure differential switch, is used to indicate the differential pressure across the filter element has reached a given value.

Limit switches and inductive proximity switches are widely used on machines to indicate the presence, or lack of the presence, of an object. The object can range from a machine member, to the part being processed on the machine, to a foreign object, such as someone's body part.

Limit switches are actuated my mechanical action. "Something" actually contacts a movable part of the switch, which in turn, opens or closes movable switch contacts. Inductive proximity switches sense the presence of metal as it passes near the switch. The range of distance and the mass of the metal required to actuate the switch varies with the sensitivity of the switch. Inductive proximity switches are solid state electronic devices that do not have moving parts which can wear out and break. Optical switches are yet another type of position sensing switch. Often, guards are installed on machinery. The guard must be closed, actuating a position sensing switch, before the machine cycle can continue.

Light curtains and ultrasonic sensors are also used in machine guarding applications. Since these devices can be used as input devices to permit, or to stop, all or part of a machine cycle, they too may be considered to be sensors used in fluid power systems.

Fig. 4: Oil Level Switch & 2 Oil Temp. Switches installed on a Hydraulic Unit

Position sensing switches are often installed to sense the end of the stroke of a cylinder. When the cylinder must be decelerated before the end of the stroke a limit switch or proximity switch can be used to determine that it is time to actuate the deceleration circuit. The same scheme is used for applications which require a slow starting speed. After an initial point of travel is reached the valving for the slow speed is deactuated and high speed is attained. Sometimes switches are installed on the structure of the machine. Other times, the cylinder may be fitted with switches.

Hall Effect switches are actuated by the presence of magnetic flux. Reed switches have two small contacts that are connected when a sufficient magnetic flux deforms the contacts, bringing them into contact with each other, allowing electrical current to flow through the switch. Non-contact solid state switches that actuate in the presence of magnetic flux are also available. Hall Effect switches are widely used on pneumatic actuators that are constructed using aluminum or non-magnetic stainless steel. A magnet is attached to the cylinder piston, or to a vane in a rotary actuator. The Hall Effect switch becomes actuated when the magnetic flux is present.

Sometimes several positions need to be sensed. As mentioned in the section on pressure monitoring, it may be less expensive to use some sort of input device that will allow monitoring of the entire range of positions through which the actuator will travel. Closed loop position and/or velocity control requires the sensing of the actuator or machine member though the entire range of possible positions. Two types of linear transducers are available for this purpose. One an LVDT (linear variable displacement transducer) is essentially a linear potentiometer. In most cases, the potentiometer wiper is attached to the movable part being monitored. One drawback to an LVDT is that, as is the case with any potentiometer, wear between the wiper and the main wire of the potentiometer happens over time. This wear can create an inaccurate output value and eventually, the potentiometer can fail.

In magnetostrictive transducers, such as those manufactured by Temposonics (www.temposonics.com) and Balluff (www.balluff.com), the movable target consists of a magnet that is attached to the moving part being monitored. The magnet does not come in direct mechanical contact with the linear component of the transducer, so wear is not a factor over time. An excellent description of magnetostrictive technology may be found at: http://www.technology.mtslinearsensors.com/namedPageViewer.php?keyword=magnet

Yet another method of sensing position uses a glass scale upon which very fine lines are printed. An optical sensor counts the lines as the scale moves in relationship to the sensor. Glass scale transducers have been uses successfully on machine tools for many years and can offer resolution to the ten thousandth of an inch.

On closed loop proportional valves, linear transducers can be used to sense the position of valve spools or poppets. This information is used by the valve's amplifier to increase the performance of the valve

Rotary encoders, which are used to measure angular displacement rather than linear displacement, often use the glass scales as discussed in the last paragraph. A typical rotary encode might have 1800 lines printed on a circular glass scale. Light is directed through the glass scale. As the lines break the path of the light an optical sensor detects the passing of the printed lines. An electronic package processes this information and provides an analog output of the angular displacement of the encoder shaft.

Closed loop electro-pneumatic and electro-hydraulic systems incorporate linear transducers or rotary encoders to sense the position of the actuator. If velocity needs to be measured, then the change in position vs. time will be calculated resulting in a linear or angular velocity value.

A group of non-electrical position sensors are mechanically actuated limit valves. Many pneumatic systems make great use of 3/2 valves which are actuated by rollers, one-way trip cams, "whiskers," and other mechanical operators. These limit valves are used for a number of applications such as sensing the end points of stroke, intermediate stroke points, and part presence. The

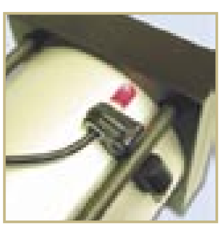

Fig. 5:
Proximity Switch Mounted on a Pneumatic Cylinder

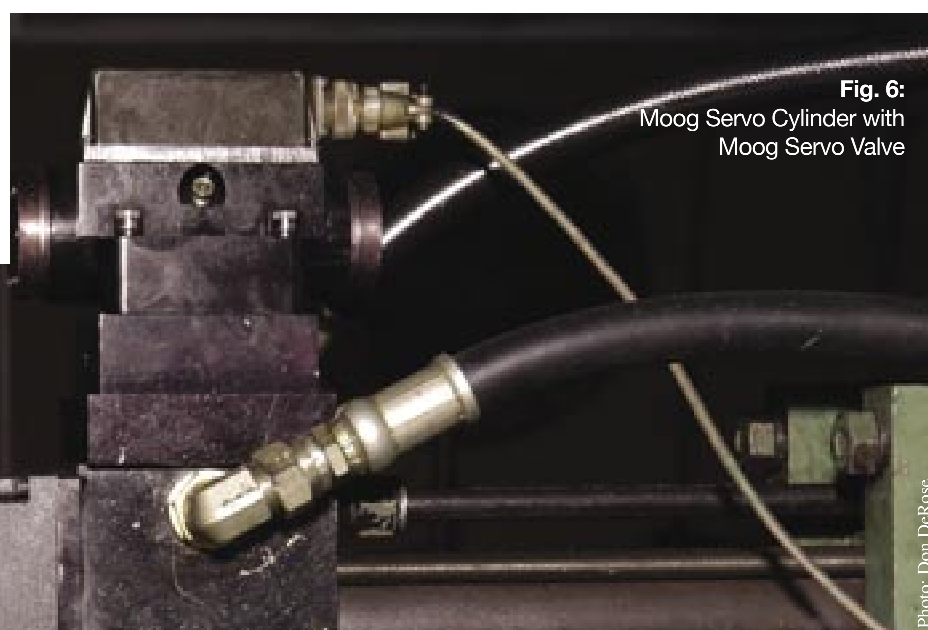

Fig. 6:
Moog Servo Cylinder with Moog Servo Valve

Photo: Don DeRose

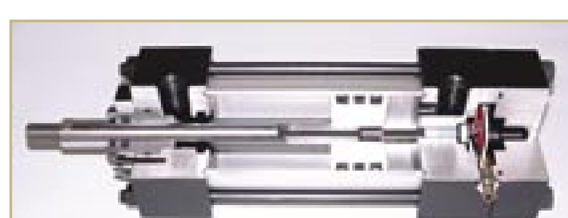

Fig. 7: (right)
A Pneumatic Cylinder Cutaway showing a Glass Scale Transducer

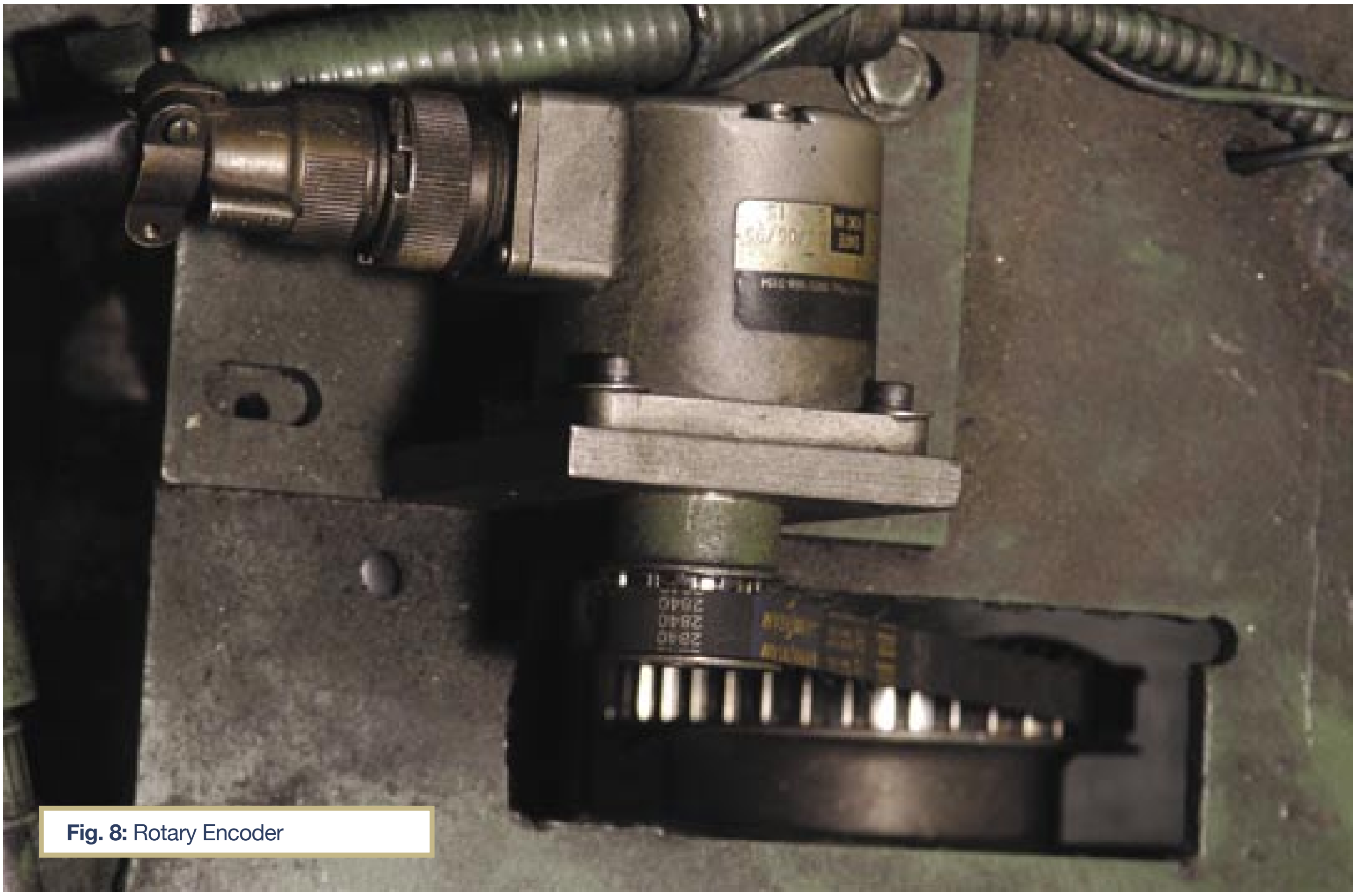

Fig. 8: Rotary Encoder

creative use of these limit valves allows a designer to design and assemble a complete motion control system without the need to resort to the use of any electrical devices. In applications where one or two axes require higher forces than pneumatics can offer, pneumatic limit valves can be used to control pneumatically pilot operated hydraulic valves.

Though not encountered very often in this day of PLC controlled machines, a few manufacturers, such as Parker-Hannifin, continue to offer 2/2 limit valves in their product lines. These valves can be placed in parallel with a flow control valve to provide a slow start (acceleration) or a decel (deceleration) actuator circuit. Eaton and Bosch-Rexroth continue to manufacture pressure compensated flow control valves with integral cam operated 2/2 valves for speed control for accel and decel circuits.

In Summation

The addition of sensors to a fluid power system provides for the monitoring of critical conditions, such as whether or not sufficient pressure is present or if fluid temperature has risen too high. Sensing the position of actuators provides verification that a condition has been met, or has not been met, providing input to the control sequence logic of the machine. The use of well chosen and placed sensors can enhance the reliability, safety, and efficiency of a fluid power system.