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Sensing Methodologies in Pinch Valves

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Executive Summary
This white paper examines various types of state sensors and their functional use in pinch valves for advanced system development. Many systems today, including medical and biopharmaceutical applications, require precise control and monitoring of a variety of fluids during operation. Systems can employ several methods to control fluid. Solenoid and pneumatic pinch valves, used in conjunction with flexible tubing, offer a simple approach to non-wetted fluid control. At the most fundamental level, various types of sensors can be incorporated into pinch valves to provide feedback showing the physical, open or closed, state of the valve. This paper covers both the basics of state sensing as well as advanced applications to detect the presence of tubing.

Sensing Methodologies in Pinch Valves

Introduction

In the medical and bioprocessing markets, safety is one of the most important elements of a system. Because of this, there has been a strong trend to proactively gather feedback from individual components, monitor their state of operation, and communicate that information to the larger system. This demand for more granular feedback and tracking is not only being driven by system designers, but by regulatory agencies as well.

Pinch valves allow or prohibit the flow of fluid in many medical and biopharmaceutical applications, a mission critical safety checkpoint. Pinch valves are preferred in these industries due to their well suited interface with flexible and disposable tubing. Flexible and disposable tubing are of high importance and value when sterility and rapid tubing exchanges are required. In any system with fluid movement, it is important to have a method, such as a sensor, to detect the state and status of said fluid. These include, but are not limited to, sensors to detect pressure, flow, force, and position.

A switch or sensor integrated into a pinch valve can provide valuable feedback for a system's control loop. Specifically, position feedback can confirm that a pinch valve is in the state dictated by the control input. One key benefit of state sensing is the facilitation of closed-loop control, allowing monitoring of valve function for many important applications. Having real time data from a valve or other device allows designers to build safety systems into equipment.

Depending on the type of system and functional requirements, different types of sensors are available. This paper will discuss sensors as they apply to two-position pinch valves, while considering the following three sensor categories: Hall effect, Mechanical Snap-Action, and Optical.

Design Considerations

The selection of sensor type is dependent on various parameters including non-contact activation, power limitations, output signal requirements, operating environment, package size, and expected lifetime. In order to determine the type of sensor for the pinch valve, we must consider the system requirements. For example, the input and output of the sensor and system are important factors to know and understand. Specifically, the power required for a particular sensor to operate and the type of output the system can accept. Some systems with Programmable Logic Controllers (PLCs) accept only one type of digital output. Other systems may bypass a logic device and use a switch to power another component. Sensors may also be limited to certain voltages and current ranges.

Physical: The environment in which the sensor will be operating is an important factor. Environmental conditions typically include temperature and humidity. The operating temperature and humidity within a system will dictate the type or model of sensor that is appropriate.

Size constraints and cabling requirements are also valid concerns. Sensors typically add length to the end of a valve, so allotting room for the sensor and associated cabling is a must for any sensor option. Depending on the type of sensor, lead wires may protrude from the side or the bottom of the sensor housing. Pneumatic valves can typically come with an option for either panel or base mounting. Base mounted valves with certain sensors may require a recess or hole in the valve mounting plate.

Sensors may also need to be specified based on the types of solutions and solvents to which they will be exposed. For example, some sensor housings are constructed of polysulfone. This material will dissolve if exposed to chlorinated hydrocarbons and ketones. Therefore, certain cleaners, such as acetone and adhesives, could be destructive to the sensor housing, while isopropyl alcohol would work effectively.

Electrical: The electrical requirements of a sensor must complement the physical requirements. Sensors require different power inputs based on the required outputs. If the goal of the sensor is to power another device, it will require more power than a sensor that is designed to give a binary feedback signal. As mentioned before, PLCs may require a specified output type such as sinking or sourcing output. The type of output provided by a sensor can be configured or predetermined based on the sensor.

The signal type of sensors should also be considered. Binary state feedback can be provided through a simple digital signal to determine the open or closed status of the valve. Analog sensors output a linear variable voltage signal that changes with valve position. Analog sensors can be read in the same manner as a digital signal, using high/low outputs to determine the valve state or utilize the linear output to detect the presence of flexible tubing.

The last major design consideration is the activation position of the sensor. Pinch valves are typically specified by one of two common configurations: Normally-Closed and Normally-Open. Sensors are typically used to detect when a valve is in the actuated position (i.e. when a Normally-Closed valve is open). While several sensor options exist on various valve models, mechanically switched sensors only change state when the valve is fully open regardless of configuration type. This is a factor that must be considered when determining the type of sensor for a valve.

Sensors, Switch Types and State Sensing Options

There are three types of sensors we have found to be most compatible with pinch valves. Each type of sensor is specified per application based on the design considerations mentioned above. The three sensor types offered are: Optical, Snap-Action, and Hall effect.

1. Optical sensors operate using a break beam system. One side of the sensor consists of an emitter and the other is a collector. An object breaks the beam between the emitter and collector, triggering the state change. Break beam systems are extremely accurate and repeatable; however, their reliability can deteriorate in environments with dust and airborne debris. Below is a list of the main features of the optical sensor:

- Low Hysteresis
- Accurate Position Sensing
- High Repeatability
- Non-Contact Actuation

2. Snap-Action switches operate through use of a tipping point mechanism. The switch opens and closes a physical circuit that transmits current from one terminal to another. Several models of Snap-Action switches can be found in the market place. A common format has three terminals and can be configured to close the circuit when the pinch valve is either open or closed based on application requirements. Mechanical Snap-Action switches can allow for the powering of other devices or simple feedback. Since these switches carry active current, they can create arching, which would be unfavorable in environments that contain volatile gases or require full wash downs. Below is a list of the main features of a Snap-Action switch:

- Long Operating Life
- Gold or Silver Contacts
- NC or NO Configuration
- Small Package

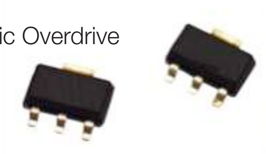
3. Hall Effect sensors function by outputting a voltage in response to changes in a magnetic field. In this case, when a pinch valve is actuated, a magnet passes over the sensor causing it to change the output voltage. Hall Effect sensors come in different packages. Common variations include Lever-Actuated versions and digital or analog Surface-Sweep versions. Hall Effect sensors have long lifetimes but are reliant on distance from and strength of the actuating magnet. If the sensor cannot detect the magnetic field generated by the magnet, it will not change states. Below are three different types of Hall Effect sensors used on pinch valves:

a. Lever-Actuated Hall Effect sensors are mechanically actuated, similar to Snap-Action switches. A rod presses on the switch lever when the valve is open to change the sensor output. The main features are listed below:

- Non-Contact Digital Output
- Reverse Voltage Protection
- Low Force Operation
- Keyed Locking Connector

b. A Surface-Sweep Hall Effect sensor is actuated by a permanent magnet passing over the surface of the sensor. Digital versions can be configured to detect either the open or closed states of the valve based on application requirements. The main features are below:

- Wide Temperature Range
- Cannot be Damaged by Magnetic Overdrive
- NC or NO Configuration
- Non-Contact Actuation



c. The analog version of the Surface-Sweep Hall Effect sensor can be used in the same manner as its digital counterpart. For more advanced applications, they can be configured to allow for displacement tube detection. Some key features of the analog sensor are below:

- NC or NO Configuration
- Linear Output
- Allows for Multi-Position Output
- Non-Contact Actuation

Displacement Tube Detection

The purpose of tube detection in a pinch valve is to allow closed-loop feedback of the presence of tubing. The ability to detect the presence of tubing offers safety and provides security, knowing the tubing is properly loaded and present within the pinch valve. There are several methods for detecting tubing, ranging from basic limit switches to more complex methods such as measuring differences in the expected magnetic field. The primary method used for tube detection on pinch valves is known as the displacement method.

Displacement Tube Detection can be performed in several ways. The method we have found to be the best combination of function and simplicity utilizes an analog hall sensor to detect differences in the valve's position with tubing installed relative to the normal open or closed positions without tubing. Displacement Tube Detection is based on several factors, however three specific configuration properties are required for tube detection: *stroke, force*, and *pinch gap*. All three of these must be set properly to create a harmonious system that produces accurate, reliable tube detection while not compromising the performance of the valve.

1. **Stroke –** the total movement of the plunger from fully closed to fully open. At fully open, the plunger face meets the pole face.

2. **Force –** the force pushing the plunger against the tubing. A spring pushes the plunger towards the pinch geometry and away from the pole face.

3. **Pinch Gap –** an air gap between the two opposing pinch surfaces of the valve which allows for maximum life of the tubing while providing a reliable seal each time the valve is actuated.

Stroke and force are crucial settings on any pinch valve. These two variables must be set just right in order to have the optimal blend of sensor output with valve function. The primary goal of any pinch valve is to seal tubing; this requires force. But, if we want a functioning pinch valve, the valve must also open to start the flow; this requires stroke. Because solenoid pinch valves are actuated by a magnetic field, the magnetic forces must be able to overcome the spring forces. As stroke increases, the maximum allowable force decreases, see (Figure 1). The closer the two pole faces of the valve, the easier it is for the valve to open.

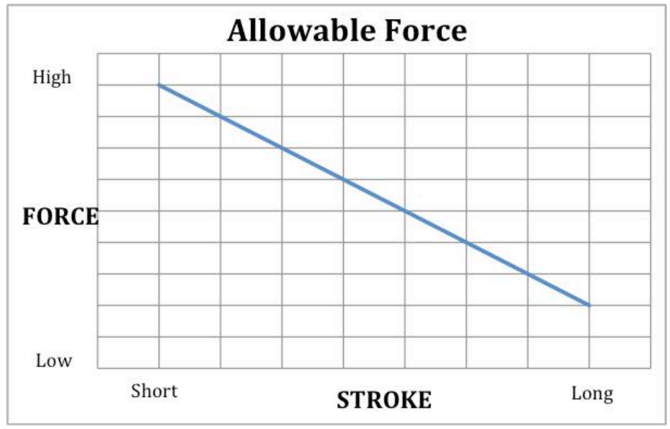


Figure 1

For tubing that is harder and requires greater force to pinch, the valve will need to be configured with a shorter stroke length so the solenoid magnetic field may overcome the increased force. A shorter stroke comes with the sacrifice of sensor output range. Analog hall sensors rely on the magnetic field produced by a permanent magnet to induce a voltage output. The less the magnetic field changes, the less voltage change we will see on the sensor output. See Figure 2 below.

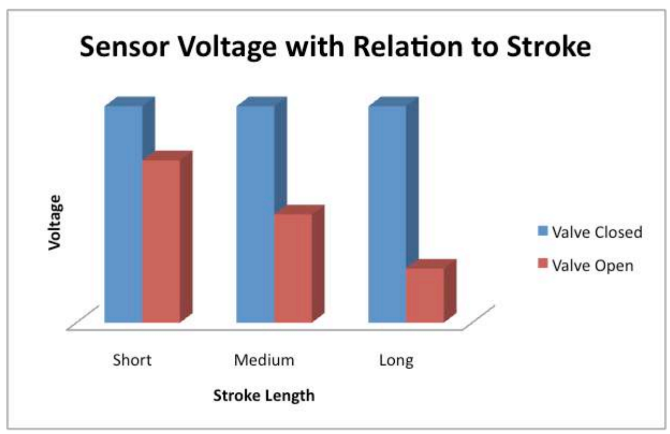


Figure 2

Once the valve has proper force and stroke, pinch gap becomes the final major consideration. For displacement tube detection, the pinch gap must be set correctly so that when the valve seals the tubing, the valve's position is offset from the closed position without tubing. See Figure 3 (on next page).

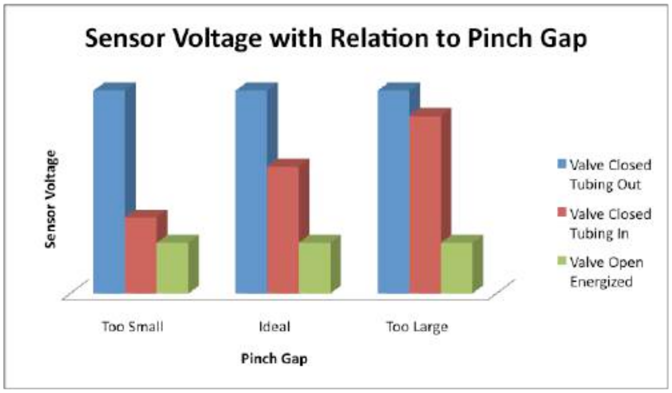


Figure 3

Figure 3 outlines three scenarios for the pinch gap as compared to the tubing: too small, too large, and ideal. The primary purpose of the pinch gap is to lengthen tubing life by minimizing stresses and preventing crushing of the tubing. When the two walls of a flexible tube come together, the tubing ceases the flow of media. However, for displacement tube detection to work properly, the tubing must be compressed beyond the minimum requirement. Displacement tube detection typically requires an over-pinch, where the tubing is compressed to more than just a seal, to achieve the proper variations in sensor voltage output that will maximize reliability.

Creating a gap that will maximize reliability varies with tubing material and size. As mentioned above and outlined in Figure 3, a pinch gap that is configured too small (with the tubing installed and valve closed on the tubing) may cause the sensor output voltage to be so close to the valve open voltage reading that it will be difficult to distinguish between the two readings. The opposite effect occurs with a large pinch gap. With the valve closed on the tubing, the sensor voltage reading may be so close to the valve closed, tube out voltage reading that it will be difficult to distinguishing between the two readings. The ideal pinch gap will balance both of the previously listed scenarios.

Maximum separation between closed-tube-out, closed-tube-in, and open voltages, allows designers to configure their system for discrete feedback positions and will provide the best balance of tubing life and sensor reliability.

Conclusion

Sensing technologies are routinely employed in a wide variety of applications and markets. Today's fluidic systems use many different sensors to monitor fluids in a safe and controlled manner. As discussed here, medical and biopharmaceutical applications are increasingly utilizing position feedback and tube detection in conjunction with non-wetted pinch valves and disposable cassettes and tubing. When determining feedback for overall system design one must consider power constraints, signal output/type, materials, layout, and accuracy of the required feedback. Feedback systems may come in several forms including Hall Effect, Snap-Action, and Optical devices. These can then be divided into digital or analog output; digital output provides the basic open/closed feedback, and analog output allows for tube detection.

Many types of sensors are readily available and can be used for several variations of state detection. Each has their own features and benefits depending on overall system requirements, performance features, and cost. When sensing methods offer more than singular state function, they can provide additional feedback, safety, and monitoring that ensure optimum system operation.

About Acro and Bimba

Acro Associates is a leading innovator in pinch valves and fluid control componentry for medical, bioprocessing and industrial applications. As a wholly-owned subsidiary of Bimba Manufacturing, a global leader in actuation technologies, Acro is a part of a family of brands that includes Mead, MFD, Pneumadyne and TRD. Together, they provide industry-leading actuator based pneumatic, hydraulic, electric and automation solutions worldwide. Acro is based in Concord, CA and Bimba is headquartered in University Park, IL. For more information, visit acroassociates.com or bimba.com.