EPRI

Solenoid Valve Maintenance Guide

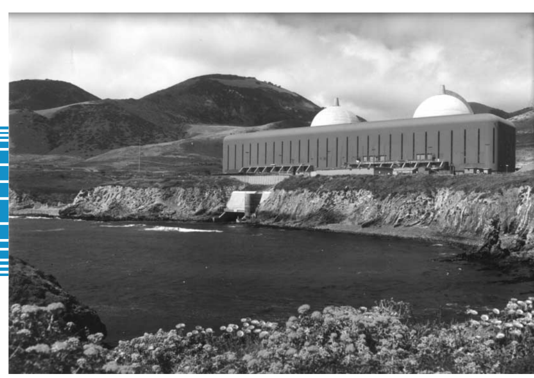
Revision of NP-7414

Technical Report

Plant Maintenance Support

Reduced Cost

Equipment Reliability



NMAC

Solenoid Valve Maintenance Guide

Revision of NP-7414

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Final Report, December 2003

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REPORT SUMMARY

Background

In 2002, EPRI NMAC conducted a survey of site representatives to determine what component maintenance guides would be most useful to plant personnel. The survey identified solenoid-operated valve (SOV) maintenance issues as fifth with respect to adding high to medium value to the plant. To address this issue, an additional survey was completed of the areas that had not been addressed by earlier EPRI documents. It was determined that only one guide had been issued (NP-7414, *Solenoid Valve Maintenance and Application Guide,* 1992) and that updating the guide to reflect current problems and practices was necessary.

Objectives

- To help power plant maintenance personnel understand the basic principles of solenoid valve design and operation
- To identify problems with solenoid valve operation and maintenance
- To discuss the effects of energized applications and life cycle
- To discuss the effects of actuator orientation on solenoid reliability
- To provide inspection and monitoring techniques
- To provide replacement recommendations for obsolete valves
- To provide PM frequencies

Approach

In order to facilitate its use by maintenance personnel, the original version of *Solenoid Valve Maintenance and Application Guide* was reorganized and edited to contain the material that is essential to carry out an effective SOV maintenance program. EPRI and industry literature, product information, and standards were reviewed to ensure that information in the guide was still accurate and applicable. Utility and industry failure databases were surveyed to determine more recent specific problems and commonly encountered failure mechanisms. Preventive maintenance tasks were reviewed for applicability. Based on these reviews, a draft was prepared and presented to the TAG for member feedback.

Results

This guide has been revised extensively to facilitate its use by power plant maintenance personnel. It provides information on the basic principles of solenoid-operated valve design and operation. It identifies problems with SOV operation and maintenance and uses that information

to provide troubleshooting and repair strategies. Finally, it provides condition monitoring techniques, periodic replacements, and a recommended preventive maintenance program for SOVs. Numerous appendices supplement the basic material.

EPRI Perspective

Solenoid-operated valve operation and maintenance, particularly those valves that are used in high-temperature environments, continue to be a challenge to reliable plant operations. This guide provides the tools that are necessary to understand the special problems of SOV maintenance and ways to effectively troubleshoot and correct these problems. It also provides steps for establishing a condition monitoring and preventive maintenance program.

Keywords

Solenoid-operated valve
SOV
Condition monitoring
Preventive maintenance
Reliability
Troubleshooting

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NMAC and the TAG were supported in this effort by

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1 INTRODUCTION

1.1 Background

In 2002, NMAC conducted a survey of site representatives to determine what component maintenance guides would be most useful to plant personnel. The survey identified solenoid valve maintenance issues as fifth with respect to adding high to medium value to the plant. To address this issue, an additional survey was completed of the areas that were not previously addressed by EPRI documents. It was determined that only one guide on solenoid valve maintenance had been issued (NP-7414, *Solenoid Valve Maintenance and Application Guide,* 1992) and that updating the guide to reflect current problems and practices was necessary.

1.2 Development

To update the 1992 guide, failure mode data since 1992 was obtained and incorporated into a revised format to facilitate the use of the guide. The format is consistent with other recent guides and has been found to be useful to a wider spectrum of readers who have maintenance responsibility for the subject equipment.

1.3 Approach

This guide was prepared using the following approach:

- Review EPRI and industry literature, product information, and standards to identify various designs, applications, and maintenance practices associated with solenoid valves that have the greatest effect on plant operations: for example, reactor vents and primary sample lines.
- Survey utility and industry failure databases to determine specific problems and commonly encountered failure mechanisms.
- Recommend condition monitoring/preventive maintenance and troubleshooting methods that will meet the task objectives.
- Review and update any related PM-basis content.

1.4 Highlighting of Key Points

Throughout this report, important information is summarized in “Key Points.” Key Points are bold-lettered boxes that succinctly restate information covered in detail in the surrounding text, making the key point easier to locate.

The primary intent of a Key Point is to emphasize information that will allow individuals to take action for the benefit of their plant. The information included in these Key Points was selected by NMAC personnel, consultants, and utility personnel who prepared and reviewed this report.

The Key Points are organized according to the three categories: O&M Costs, Technical, and Human Performance. Each category has an identifying icon, as shown below, to draw attention to it when quickly reviewing the guide.

Key O&M Cost Point

Emphasizes information that will result in reduced purchase, operating, or maintenance costs.

Key Technical Point

Targets information that will lead to improved equipment reliability.

Key Human Performance Point

Denotes information that requires personnel action or consideration in order to prevent injury or damage or to ease completion of the task.

Appendix G contains a listing of all Key Points in each category. The listing restates each Key Point and provides a reference to its location in the body of the report. By reviewing this listing, users of this guide can determine if they have taken advantage of key information that the writers of this guide believe would benefit their plants.

1.5 Glossary

Appendix A contains a glossary of terms used in this guide.

2 BASIC PRINCIPLES OF SOLENOID VALVE DESIGN AND OPERATION

2.1 Purpose

This chapter will help plant maintenance personnel understand the basic operating mechanisms of several types of solenoid valves. This overview of solenoid valve operating principles and discussion of design differences and application considerations will aid in interpreting subsequent chapters on failures, application suggestions, and maintenance recommendations.

2.2 Solenoid Valve Description

The solenoid valve or solenoid-operated valve (SOV) is simply a valve operated by a built-in actuator in the form of a solenoid. The solenoid portion of a SOV is an electromagnet comprised of a coil and a movable plunger (core). When voltage is applied, a magnetic field is produced, attracting the solenoid plunger. A spring, gravity, or some other force is used to return the plunger to its original position when voltage is removed. Figure 2-1 illustrates the major components of a normally closed two-way SOV.

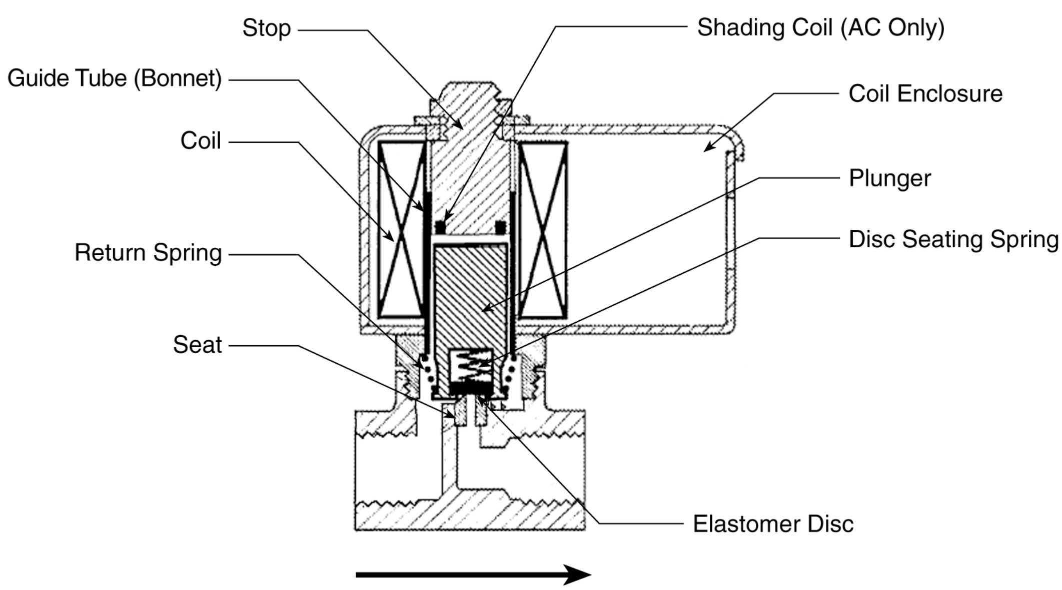

Figure 2-1
Typical Direct-Acting Normally Closed Two-Way SOV [1]

For most SOVs, the application of specified voltage to the solenoid coil causes the valve to change state (go from open to closed or vice versa). Removal of the voltage causes the valve to change back to its deenergized state. However, some SOVs are made for modulating control while others are designed to remain in their last position on loss of power. SOVs operate from either AC or DC sources of power.

The smaller air-pilot and low-pressure process valves are supplied by a number of manufacturers, including Automatic Switch Company (ASCO), Skinner, Parker, and Valcor. The two major suppliers of the larger high-pressure/temperature SOVs for nuclear power plant use in the United States are Target Rock Corporation (TRC) and Valcor Engineering (Valcor). Figures of various valve styles are presented later in this chapter.

2.3 Major Design Characteristics

A wide variety of SOV design and operating characteristics are available to suit the range of applications found in typical power plants. By selectively combining design characteristics, manufacturers can provide solenoid valves that are suited to a broad range of plant applications. Some of the more important design characteristics and a brief explanation of each are presented below. More detailed information is presented later in this chapter.

2.3.1 Operating Method

The SOV operating method is either *direct-acting* or *pilot-operated* (piloted). In direct-acting valves, all the force necessary to move the valve stem and disc is developed by the solenoid. In piloted valves, the solenoid operates a smaller internal pilot valve to control piping system operating pressure on larger pistons or diaphragms. The piston or diaphragm then opens and closes the main SOV disc.

2.3.2 Valve Porting

Valves are generally classified as two-way, three-way, or four-way, although designs with more ports exist. Most two-way valve ports are either open or closed. Three-way valves operate by connecting an intermediate port, for example, a cylinder port, to an inlet port or an outlet (exhaust) port. Four-way valves are generally described as having one inlet port, two intermediate (cylinder) ports, and either one common or two individual outlet (exhaust) ports.

2.3.3 Process Medium

The vast majority of generating station SOVs are used as air-pilots in air systems to pneumatically control larger air-operated process valves. Most of the remaining SOVs are direct in-line process valves. A few remaining valves are used in hydraulic systems to control larger pieces of equipment (for example, hydraulically operated valves).

2.3.4 Packless vs. External Solenoid

Virtually all modern SOVs are of the *packless* design, eliminating the need for an external valve stem and packing. In this design, the solenoid plunger is inside the valve's pressure boundary as shown in Figure 2-1. In other designs, the solenoid plunger is outside the pressure boundary and operates the valve stem through mechanical linkages. Unless otherwise noted, this manual refers to the packless construction.

2.3.5 Operation Modes

Most SOVs are designed for on-off applications where the valve is either opened or closed. Several manufacturers offer *modulating* valves that can be throttled based on the value of an electronic input signal.

2.3.6 Deenergized Position

Most valves are available either in *normally open* or *normally closed* constructions. This refers to the valve position when no power is applied to the SOV and is usually the convention used when identifying solenoid operation. By using a special coil option, some valves can be provided as *fail-as-is*. In this design, the valve will stay in its last position (open or closed) when power is removed.

Key Technical Point

The standard convention for identifying solenoid operation on schematics is to indicate the position of the valve when the solenoid is deenergized.

2.3.7 Seating Design

A significant number of SOVs are described as globe valves, although many do not contain a typical globe valve seating design. Other valve designs include balanced disc globe, gate, spool, and diaphragm valves.

2.3.8 Seating Material

Both hard-seated and soft-seated designs are available. A variety of different elastomers and plastics are available as seat and gasket materials. Most hard-seated process type valves use stellite as a seating material. Cobalt-free hardface trims are also available.

2.3.9 Valve Body Materials

Typical valve body materials are brass and stainless steel, although some carbon steel valves can be found.

2.3.10 Voltage

The typical voltage ratings for power plant SOVs are 120 Vac or 125 Vdc. Generally, AC valves cannot be used on DC systems and vice versa, but some styles can be used on both AC and DC. Different operating voltages are available in most models. Always refer to the equipment tag for proper voltage and voltage type. Do not rely on the model number alone.

Key Human Performance Point

Always refer to the equipment tag for proper voltage and voltage type. Do not rely on the model number alone.

2.3.11 Position Indication

Most process SOVs can be provided with position indication.

2.3.12 Coil Insulation

Coils are often offered in several operating temperature classes. Some of the coils are molded to minimize the entrance of moisture or water into the windings. Other coils must be protected from external contaminants such as moisture and water.

2.3.13 Coil Enclosures

Coil enclosures range from explosion-proof and submersible to open designs.

2.4 Principles of Operation

When an electric current is passed through a simple coil of wire, a magnetic field (also referred to a magnetic flux) is created as shown in Figure 2-2. With a constant direct current (DC), the magnetic field is constant. With an alternating current (AC), the magnitude and direction of the magnetic field vary with the AC current as shown in Figure 2-3.

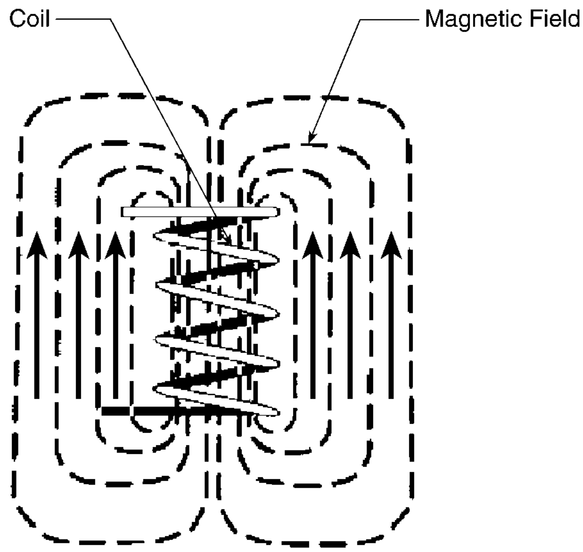

Figure 2-2
Magnetic Field Using DC Voltage

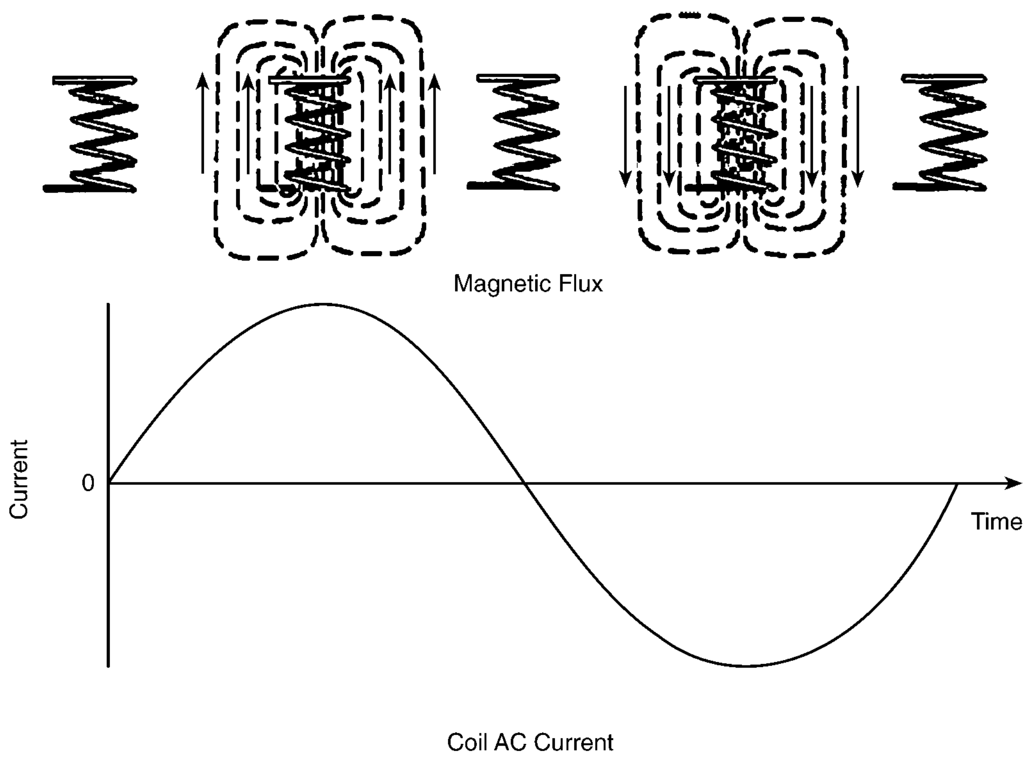

Figure 2-3
Magnetic Field and Current Using AC Voltage

Certain metallic materials, like iron, carbon steels, and 400 series stainless steels, are magnetic. When such a material (called a core) is placed around and through a coil, the magnetic field strength will increase to several thousand times the value it had without the core. If a small air gap is cut in the core, the magnetic field will be significantly reduced but will still be much greater than the field without any metallic core (compare Figures 2.4 (a) and (b)).

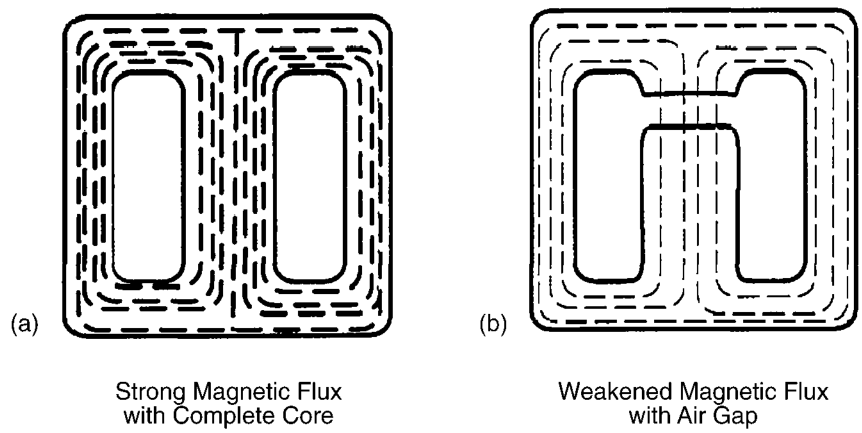

Figure 2-4
Magnetic Field in a Core With and Without an Air Gap

2.4.1 DC Solenoids

Figure 2-5 presents a simplified diagram of a spring return type DC solenoid. The main elements are the:

- Coil
- Coil leads
- Plunger
- Guide tube
- Stop
- Flux washer
- Coil housing (enclosure)
- Air gap
- Return spring
- Enclosure

The plunger, stop, coil housing, and the air gap between the plunger and the stop form the solenoid's magnetic circuit. When the solenoid is initially energized, but before any movement takes place, the magnetic circuit looks similar to the one shown in Figure 2-4(b): there is a gap in the flux. After the plunger shifts position, it "fills the gap" and resembles the magnetic circuit of Figure 2-4(a).

For maximum solenoid efficiency, materials with high magnetic permeability (giving the highest flux), like carbon steels, must be used to complete as much of the magnetic circuit as possible. Ideally, the air gap would be the only non-magnetic portion of the flux path. However, because of manufacturing tolerances/fits and design clearances (for example, some clearance must exist between the plunger and the plunger tube), the magnetic flux must also pass through other small air spaces. The plunger guide tube (often called the bonnet) must be non-magnetic; otherwise, it would let the flux bypass the air gap and the solenoid would not operate.

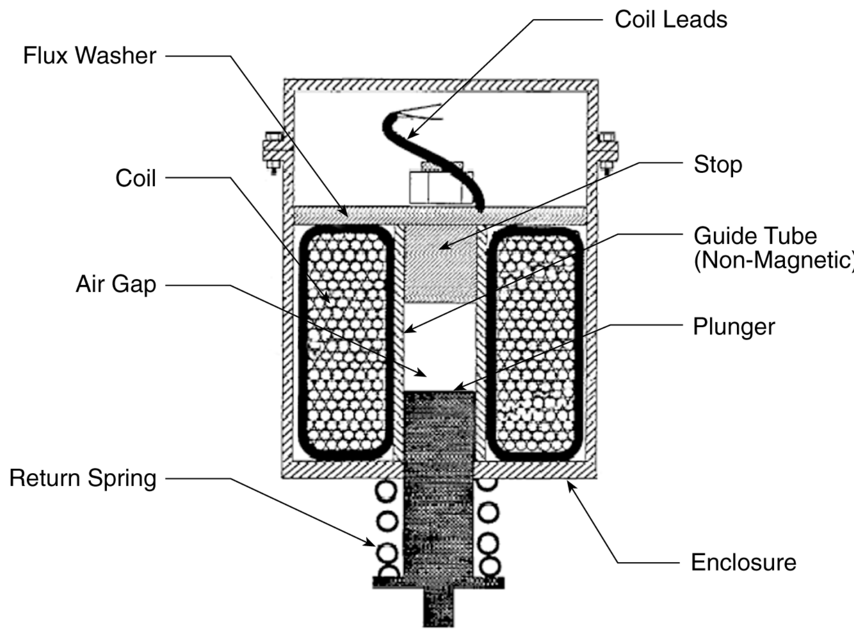

Figure 2-5
Simple Solenoid Magnetic and Spring Forces vs. Plunger Position

Key Technical Point

When a solenoid is energized, the magnetic force attracts the plunger toward the stop. The closer the plunger is to the stop, the greater the attractive force. A spring returns the plunger to the extracted position when the coil is deenergized.

When a solenoid is energized, the force created by the magnetic field attracts the plunger toward the stop. (See Appendix C for a mathematical discussion of magnetic forces.) Figure 2-6 shows a series of curves of the variation of force with both voltage and air gap distance. As the curves indicate, the magnetic force increases substantially as the plunger is drawn into the coil and reaches a maximum when the air gap is zero.

In virtually all valve solenoids, a return spring force acts on the plunger. The spring force opposes the magnetic pull and restores the plunger to its original position when the power is removed. The spring also provides a valve seating force when the valve seat is directly connected to the solenoid plunger.

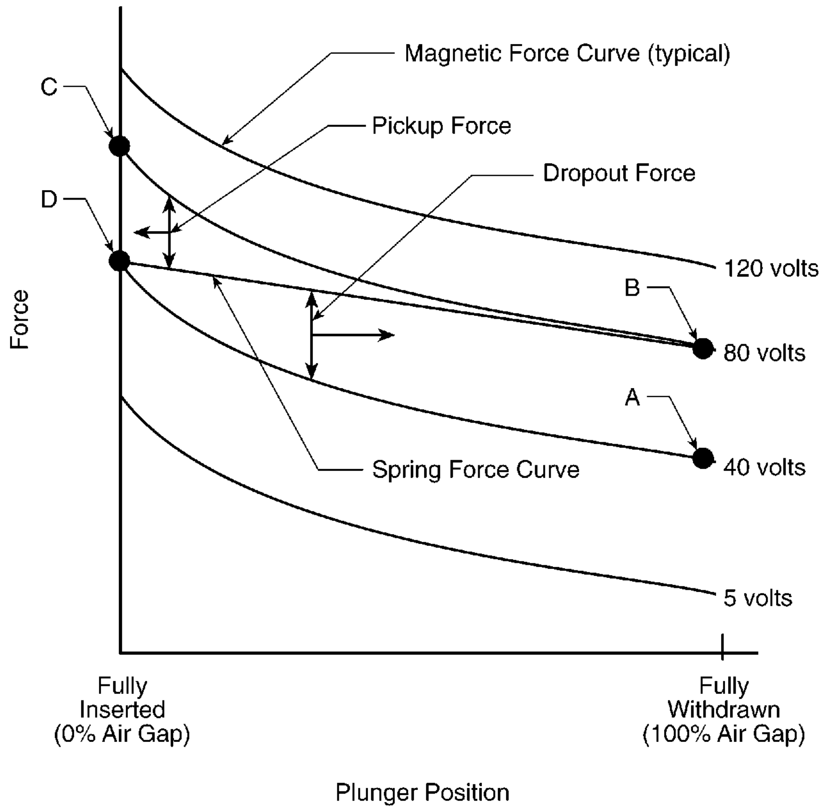

Figure 2-6
Solenoid Magnetic and Spring Forces vs. Plunger Position

Figure 2-6 also shows a typical spring force curve superimposed on the magnetic force curves. The fully withdrawn plunger position is represented by 100% air gap and the fully inserted position by 0% air gap. The spring preload (the spring force value at the 100% air gap position) must be overcome by the magnetic force in order for the plunger to move. When 40 volts are applied to the solenoid, insufficient magnetic force (point A) is created to overcome the spring force. As the voltage is slowly raised to 80 volts, point "B" is reached, and the magnetic force just equals the spring force. If the voltage is raised slightly higher, the magnetic force will exceed the spring force and the plunger will begin to insert (move to the left in the figure). This voltage is called the *pickup voltage*. Importantly, as the plunger moves to the left, the air gap decreases and the magnetic force increases faster than the spring force. This results in even greater net force on the plunger as it quickly accelerates into the coil. The process continues until the plunger strikes the stop with a loud click. For most solenoid valves, this operation occurs in 5 to 500 milliseconds and depends on both SOV design and system pressure.

As shown in Figure 2-6, the magnetic force reaches a maximum value when the plunger is fully inserted against the stop (point C). At this location, the margin between the magnetic force and the spring force has increased substantially compared to point B. If the voltage is increased, for example, to 120 volts, it simply adds to this margin. When the voltage is slowly decreased, nothing happens until forty (40) volts (point D) is reached where the spring force just equals the magnetic force. Reducing the voltage further allows the plunger to begin to withdraw. This voltage is known as the *dropout* voltage. As the plunger moves to the right, the air gap increases and the magnetic force quickly decreases. This increases the net spring force on the plunger and quickly accelerates it out of the coil until it is fully withdrawn. In other words, once the voltage goes below dropout voltage, no further decrease is necessary to cause the solenoid to deenergize. A typical pickup voltage for 120 Vdc valves is approximately 60–80 Vdc, while dropout values range from 5–20 volts. (Pickup and dropout voltages can vary substantially based on the valve's design.)

Normal operating voltages are considerably above minimum pickup voltages. Further, the voltage is zero when the valve is deenergized. As a result, considerable force margin is available to initiate plunger movement in both the opening and closing directions during normal operation and to account for problems such as friction between parts and component aging. (Some residual magnetism may always exist in both the plunger and stop materials when voltage is removed from DC solenoids. Consequently, the magnetic force may not be zero when voltage is removed.)

Valve solenoids can be broadly classified as either the "pull" or "push" type. Both operate by attracting the plunger. The difference lies in the action direction of the valve stem connected to the plunger. The two types of solenoids are depicted in Figure 2-7. The pull type solenoids are used in the vast majority of SOVs.

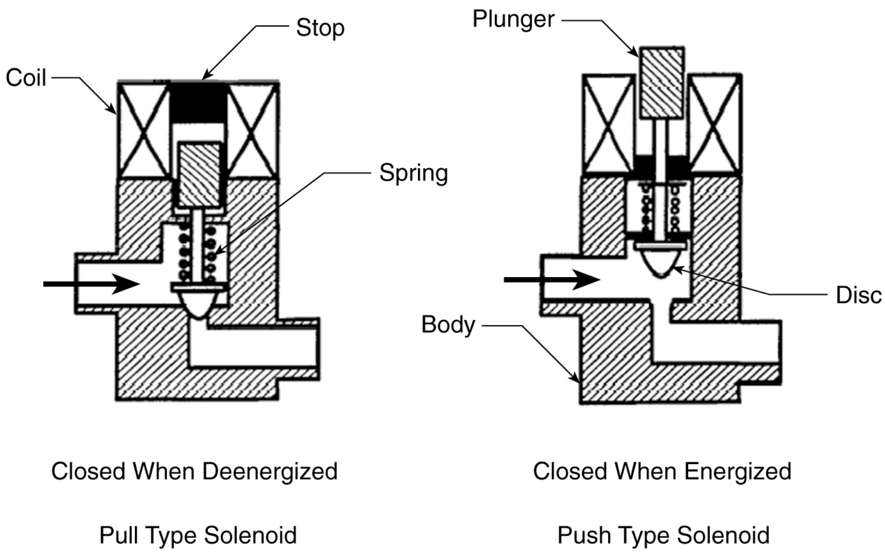

Figure 2-7
Pull and Push Type Solenoids

Direct-acting DC solenoids typically operate within 10–100 milliseconds. The operating time is related principally to two phenomena. There is a time delay as the DC current and magnetic flux exponentially increase to their steady state values. This time delay will vary based on the coil design and a characteristic called the coil's inductance (see Appendix A). In addition, there is a time delay to account for the plunger mass acceleration and the air gap travel.

Steady-state DC coil current is based simply on coil resistance (see Appendix A) and the DC supply voltage. The coil wattage and heat are similarly based on standard electrical relationships.

2.4.2 AC Solenoids

If the DC solenoid that was described previously was connected to an AC voltage source, both the magnetic field and the associated force would vary with the AC current. As shown in Figure 2-3, the magnetic field would go from zero to its maximum value and back to zero every 8.3 milliseconds (assuming 60 Hz AC voltage). However, the solenoid plunger would "chatter" loudly as the magnetic force and the spring forces alternately tried to insert and retract the plunger. This chatter would prevent the valve from maintaining its proper position and would quickly damage the plunger and stop.

Key Technical Point

SOVs can be made to operate on AC power either by using rectifiers to convert the current to DC or by shading coils to shift part of the magnetic flux.

To allow AC operation, two different design alternatives are used. The first uses solid-state rectifiers to rectify the AC input voltage to a DC coil. This is often termed a *rectified coil*. Figure 2-8 depicts the voltage, current, and flux profiles for an AC rectified coil. The relatively small changes in current and flux compared to the voltage variations are due to the large inductance of the solenoid. This inductance, acting like electrical inertia, tends to keep the current flowing without large current oscillations.

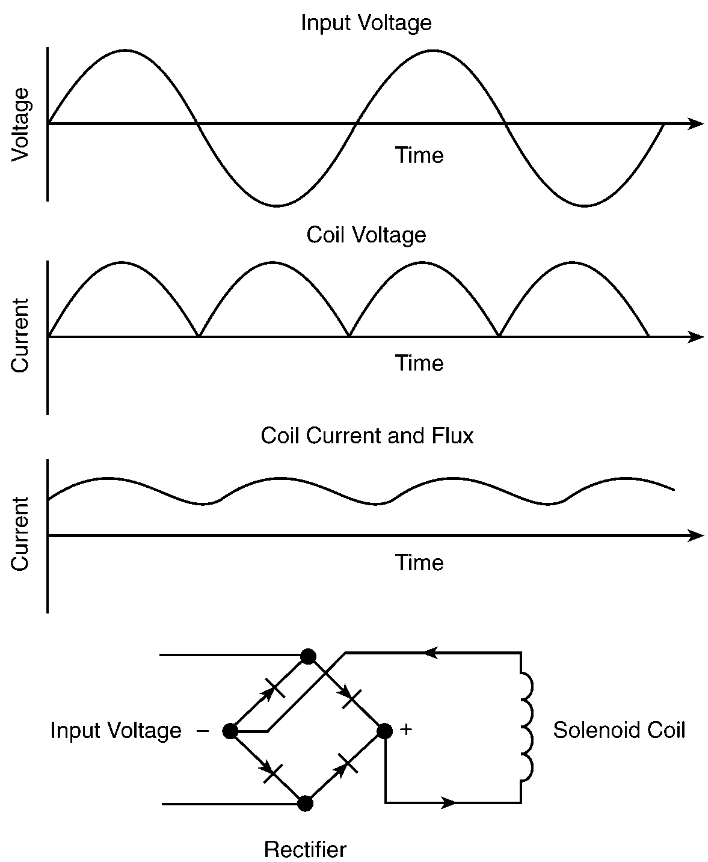

Figure 2-8
Waveforms and Power Supply Schematic for DC Coil Using AC Supply (Rectified Coil)

The second alternative is normally referred to as an *AC coil.* It incorporates a small conductive ring called a *shading coil* that is placed in the magnetic circuit. The main coil's magnetic field induces a current in the shading coil, which, in turn, creates a second magnetic field that is phase-shifted (its maximum and minimum field strength occurs at a different time) from the main coil's magnetic field. Because the main and shifted portions of the magnetic fields attract the plunger at different times, the combined magnetic force never drops below the spring force. As a result, the plunger does not chatter or vibrate, although there is a vibration or small hum. In most valve designs, the shading coil is a small copper or silver hoop inserted into the stop at the air gap (see Figure 2-1).

The operating characteristics of AC coils (those using shading coils) differ from the DC and the AC rectified coil. If the coil is energized and voltage is reduced sufficiently, the spring force begins to exceed the varying magnetic force for a small amount of time during each cycle. When this occurs, the plunger begins to chatter. As the voltage is reduced further, the chattering becomes more severe until insufficient force is available to hold the plunger near the stop and the plunger withdraws from the core. A similar but opposite action occurs when the valve voltage is slowly raised. The severe chattering makes it very difficult to define precise pickup and dropout voltages for the shaded pole AC solenoids.

The AC coil current with the plunger fully extended (often called in-rush current) is considerably greater than the value with the plunger inserted against the stop. This occurs because an AC coil has a much lower impedance (see Appendix A) when the plunger is fully withdrawn. The in-rush current for typical SOV AC coils ranges from 1.5 to 3 times the steady-state coil current.

2.4.3 Characteristic Comparisons of AC and DC SOVs

The variation of coil impedance and current with plunger position results in different force curves for AC coils and similar DC coils. (Since magnetic force is proportional to current squared, an AC coil compared to a similar DC coil will generate greater force with the plunger extended and less force with the plunger inserted.) Figure 2-9 shows the difference between the force profiles developed by similar AC and DC coils.

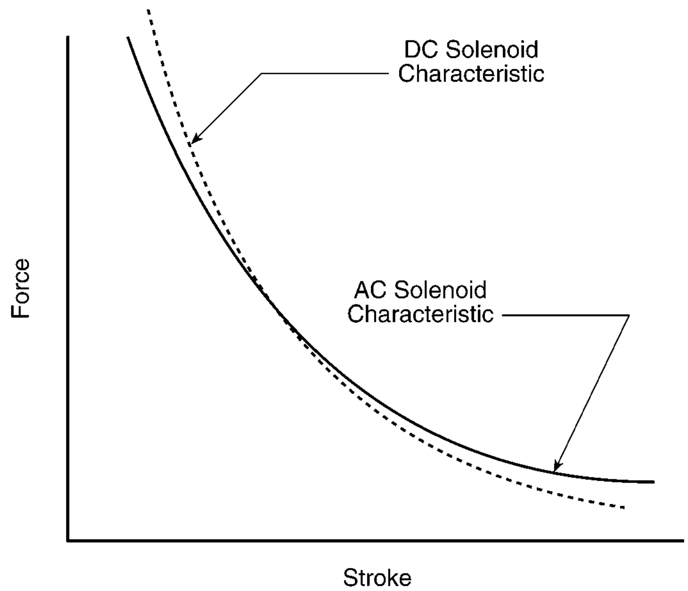

Figure 2-9
Typical AC and DC Coil Force Profiles

Another difference is that SOVs with AC coils operate faster than the same SOV with a DC coil. This occurs because the high AC in-rush current quickly generates a magnetic force, while the DC coil current increases relatively slowly. Figure 2-10 shows how AC and DC coil currents compare during energization. (For the sake of simplicity, this figure does not show the effect of counter-EMF (see Appendix A), which occurs due to plunger movement.)

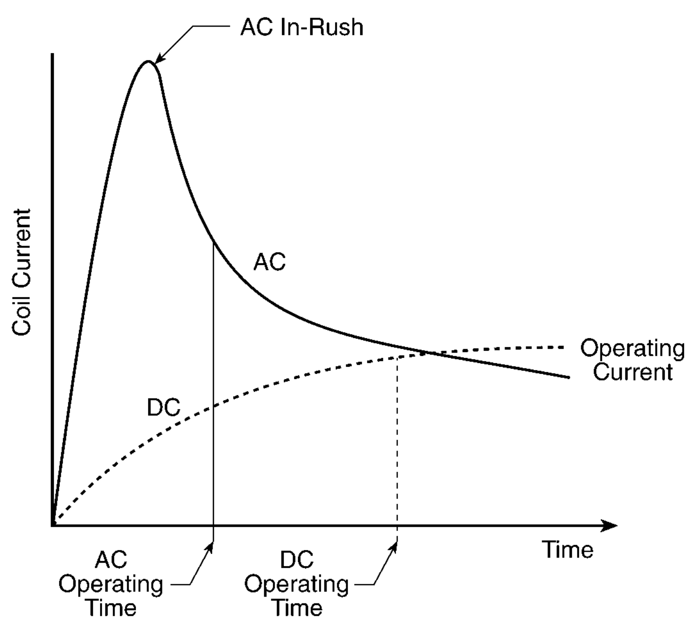

Figure 2-10
Typical AC and DC Coil Current Profiles

Because most of the AC coil's resistance to current flow is due to inductance, the AC coil's resistance must be relatively low in order to draw adequate current. For a typical air-pilot SOV, the DC coil resistance might be roughly 800 ohms. The coil's very large inductance slows its operating speed but has no effect on its normal current. A comparably sized AC coil may have a resistance of only 100 ohms and a lower impedance. AC coils tend to be wound with larger-gauge wire than DC coils.

Due to its high impedance, if the DC coil was accidentally energized with AC voltage, the SOV would likely not operate and would draw very little current. However, if the AC coil was accidentally energized with DC, the SOV would operate, draw very high currents, and would soon overheat and burn out. (For example, the AC coil with a 100-ohm resistance might be rated at only 10 watts at 120 Vac but would draw 144 watts at 120 Vdc.)

While the ratings for DC coils are typically provided in watts, AC coil data is also defined by in-rush and holding Volt-Amps (VA) data. VA ignores the phase angle between the AC voltage and current. Including the phase angle in the calculation would result in the AC wattage. VA is useful because it can be used to directly infer the current drawn by an AC device at a particular voltage. Table 2-1 provides typical AC and DC coil data for an otherwise identical valve.

Table 2-1
Coil Data for an (Example) Air-Pilot Three-Way SOV

	DC Coil	AC Coil
Watts	10.6	9.1
VA In-Rush	N/A	50
VA Holding	N/A	25

If something prevents the AC coil's plunger from fully inserting, the lower impedance will cause the valve to draw excessive current. The current will be somewhere between the in-rush and holding values depending on the relative plunger position. Since the coil's design and temperature rating are based on normal holding current, the increased current will increase coil temperature and can substantially shorten coil life. If the plunger should stick in the fully withdrawn position, the coil will quickly overheat and may burn up. In such cases, a loud hum will often be heard. (Plunger sticking has no effect on the current drawn by DC coils, since the current is based solely on the coil's resistance.)

Key Technical Point

AC SOVs that use shading coils hum excessively if the plunger is not fully inserted.

Finally, AC coil turn-to-turn shorts are more destructive than similar shorts in DC coils. When turns short in a DC coil, current, wattage, and heat increase due to a reduction in the coil's total resistance. This causes an increase in coil temperature that will shorten coil life. However, with AC coils, induced voltages in the shorted turns of AC coils produce high currents in these turns. These currents quickly cause localized heating and adjacent coil turns to short. This propagates in a cascading fashion, and coil failure quickly occurs. (The shorted turns act like the shorted secondary of a transformer.)

2.5 Direct vs. Pilot-Operated Valves

The magnetic forces developed by energizing typical valve solenoids to unseat the valve disc range from less than a pound to just under 10 pounds (44 N). (Some SOV solenoids can generate up to 40 pounds (178 N) of force.) In direct-acting valves, the solenoid force is sufficient to actuate the valve disc directly. In these valves, the valve disc and stem are directly connected to the solenoid plunger (see Figure 2-7). In many applications, based on higher pressure and flow requirements, the force developed by the solenoid is wholly inadequate to operate the disc. In these applications, line pressure, through the operation of a small internal pilot valve, is used to assist in stroking the valve. The term "pilot-operated" or "piloted" applies to these valves. This section discusses piloted and direct-acting SOVs with emphasis on the more complex piloted valves.

Key Technical Point

Direct-acting SOVs have the main disc connected to the plunger. Solenoid force alone operates the SOV.

A rough estimate of the force developed by a direct-acting solenoid to unseat a normally closed two-way valve can be made by assuming that all the magnetic force is used to counteract the seating force developed by pressure acting on the valve seat area. This assumption applies to globe type valve constructions and ignores the additional force that may be required to unseat a soft-seated valve. Similarly, if line pressure is applied over the seat, some additional spring force (used to seat the disc at low pressures and return the disc to its deenergized position) is also ignored. For example, if the seat (orifice) diameter is 9/32 inch (7.1 mm) and the maximum pressure rating is 100 psi (690 kPa), then the seating-force (lbs) (N) = [orifice area (in^2) (m^2)]* [pressure (lb/in^2) (Pa)] = 6.21 lbs (27.63 N). This force, typical of a 15–20 watt solenoid, only permits direct-acting valves to be supplied in relatively small sizes. Larger flow areas can be provided at lower pressures and smaller flow areas at higher pressures. A high-pressure, high-flow, direct-acting SOV can only be provided by making the SOV coil unacceptably large.

2.5.1 How Piloted SOVs Operate

When applications require higher flows and pressures, a piloted valve must be used. Figure 2-11 presents a simplified diagram of the fundamental operating principles of all pilot-operated valves. As illustrated in Figure 2-11, the important elements of the piloted valve are the following:

- Main disc: The main disc is constructed so that it is always exposed to three pressures: *inlet pressure* (P_{inlet}), *outlet pressure* (P_{outlet}), and *main disc chamber pressure* above the disc (P_{disc}). The piston area of the disc (the area of the disc exposed to P_{disc}) is always greater than the *seat area* (the area of the disc exposed to the outlet pressure).
- Inlet orifice: This small orifice connects the chamber above the main disc to the inlet valve port. This orifice must always be much smaller than the orifice size of the pilot valve.
- Pilot SOV: The pilot valve is small relative to the main seat area but is always larger than the inlet orifice. It is operated directly by a solenoid and is either normally open or closed. In Figure 2-11, the main disc is closed when the pilot valve is closed.

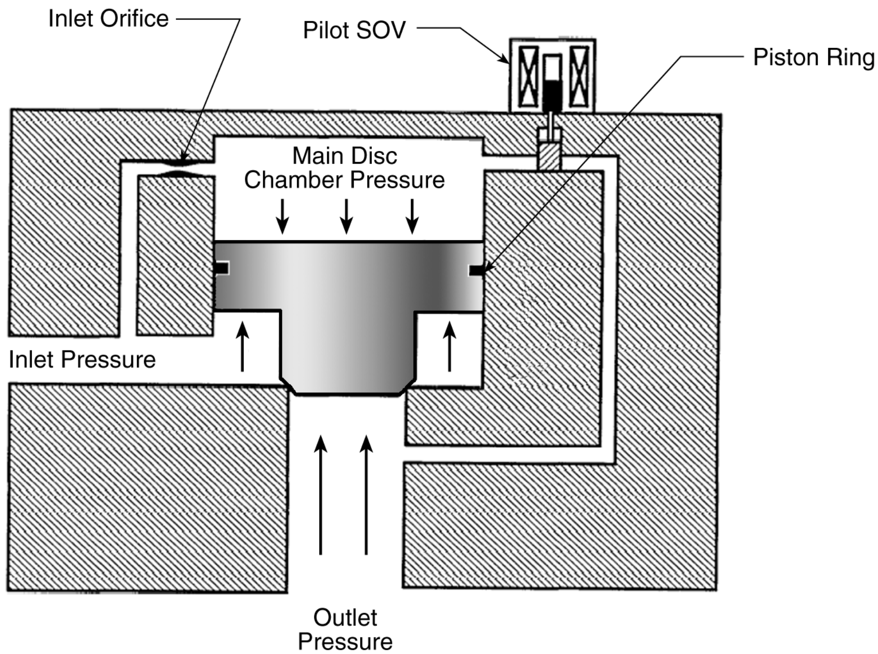

Figure 2-11
Simplified Diagram of a Piloted SOV

When the main disc and pilot valve are closed, the main disc seating force is simply the difference between the inlet pressure and outlet pressure (valve differential pressure) times the seat area. (See Appendix C for a discussion on valve hydraulic calculations for piloted valves.) This is because the force created by main disc chamber pressure (inlet pressure times piston area) is countered by the sum of inlet pressure times the piston outer annulus area plus the seating area times the outlet pressure. Since the outer annulus area forces on the top and bottom of the disc are equal, they cancel each other out. This leaves just the inlet pressure and outlet pressures acting over the seat area.

Key Technical Point

In piloted SOVs, the solenoid is too weak to directly operate the main disc. Instead, the solenoid operates an internal pilot valve. The pilot valve applies pressure to a diaphragm or piston. The pressure force then operates the main disc.

When the pilot valve is opened, the chamber pressure drops rapidly toward the outlet pressure value because the pilot valve flow area is considerably larger than the inlet orifice area. This results in the differential pressure across the seating area becoming essentially zero and the outer annulus area force (previously zero) being equal to the valve differential pressure times the outer annulus area and operating in the opening direction. The valve now opens. (See Appendix C.)

Returning the pilot valve to the closed position now isolates the chamber pressure from the outlet pressure, and it begins to re-pressurize to the inlet pressure value through the inlet orifice. This returns the valve conditions back to those described originally, and the valve closes.

Although not shown in Figure 2-11, a spring is often used to help alignment, seat the main disc, and provide operational stability. However, this spring force is generally not significant compared to the pressure forces acting on the main disc.

It is important to understand that both the seating and unseating forces are directly related to the valve differential pressure. This means that at low differential pressures, relatively little force exists to keep the disc closed and prevent seat leakage. Similarly, at low differential pressures, the force keeping the disc open may be insufficient to overcome the disc weight and closing spring force. This is reflected by the valve manufacturers' specified *minimum operating pressure differential* (MOPD). The minimum pressure differential must always be applied to the SOV, even when it is open. Low flow through the valve will minimize its differential pressure, and the valve may operate incorrectly due to insufficient operating pressure differential. This can be due to upstream or downstream flow restrictions or to too large a valve flow coefficient. For example, when three-way pilot SOVs are used to operate AOVs, upstream restrictions should not limit valve flow/pressure.

Key Technical Point

Most piloted SOVs require a minimum operating pressure differential to operate. The SOV is not designed to operate below this differential pressure.

Some piloted SOVs are designed to overcome the need for a minimum operating pressure differential. Some, termed "pilot-assisted" valves, mechanically connect the solenoid plunger, through the pilot valve, to the main disc. When the SOV differential pressure is very low, the solenoid force is sufficient to operate both the pilot valve and the main disc.

Key Technical Point

In pilot-assisted SOVs, the plunger is attached to the main disc and operates it with no differential pressure. Pilot-assisted SOVs do not have a minimum operating pressure differential.

In summary, piloted valves operate by controlling the pressure in the disc chamber. The speed at which pilot valves shift position (for example, the disc forces reverse) is directly related to the pressure in the disc chamber and the main disc area. It is also related to whether the process medium is a liquid or a gas and the difference in the flow rates through the inlet orifice and the pilot valve. The operating speed of piloted valves is much slower than direct-acting SOVs and ranges from 15 to 500 milliseconds for typical plant applications.

2.5.2 Pilot Constructions

A wide variety of pilot-operated valves are offered to suit a range of applications. Design differences in the inlet orifice, main disc, and pilot valve affect their suitability for specific applications. Typical differences in these components are listed in Table 2-2. Several of the typical constructions are discussed below.

Figure 2-12(a) illustrates a two-way SOV using a flexible diaphragm main disc. In this construction, the inlet orifice is part of the diaphragm. The seating spring shown here may exist in many of the valve designs. Several manufacturers use two such diaphragms controlled by an internal three-way pilot to produce a pilot-operated three-way valve. See, for example, Figure 2-16(b).

Most SOV process type pilot-assisted valves utilize an integral pilot-main disc design. Figure 2-12(b) illustrates a typical design. The solenoid operates the pilot disc with the pilot seat machined directly into the main valve disc. Also note the main and pilot disk link pin. Clearances between the pin and the main disc permit sufficient pilot operation to let normal pressure forces to operate the main disc. Even at zero pressure differential, however, the solenoid force through the link pin will lift the main disc. Figure 2-12(c) is a similar design that uses a primary pilot to operate a secondary pilot that operates the main disc.

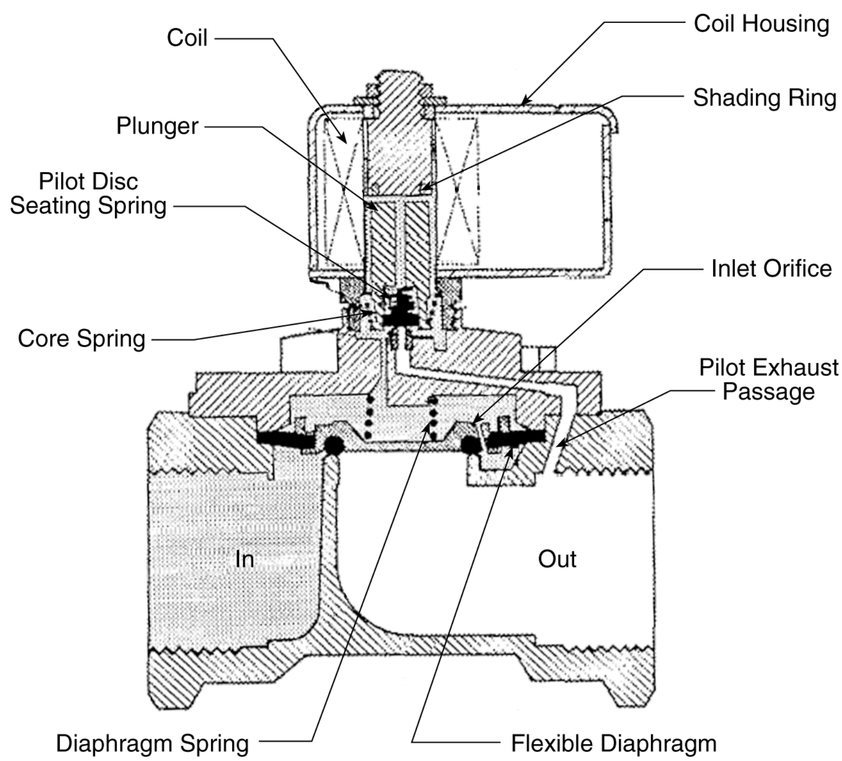

Figure 2-12 (a)
Piloted SOV Using a Flexible Diaphragm [1]

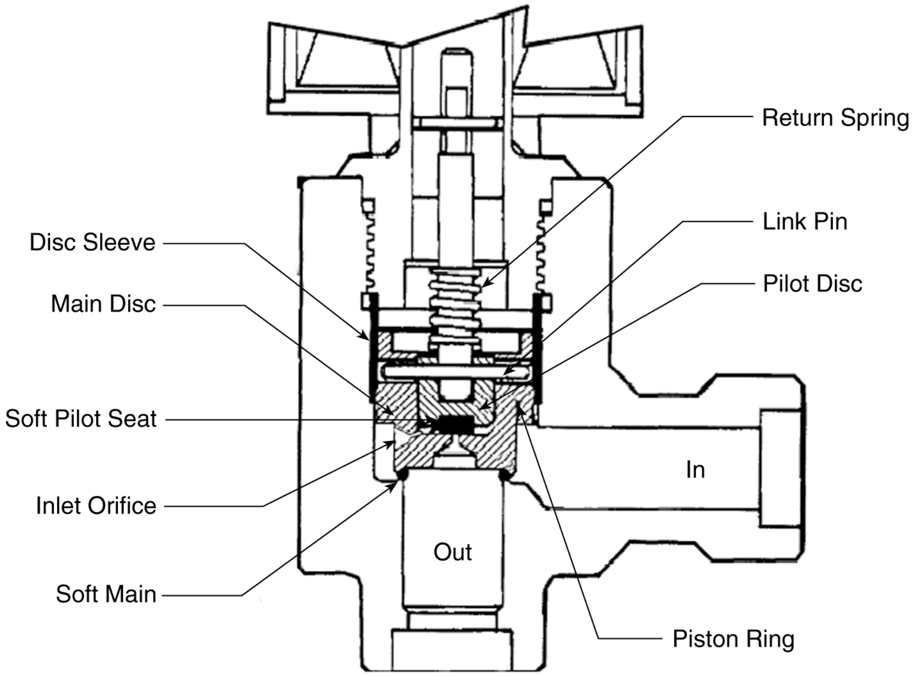

Figure 2-12(b)
Pilot-Assisted Soft-Seat Process SOV [2]

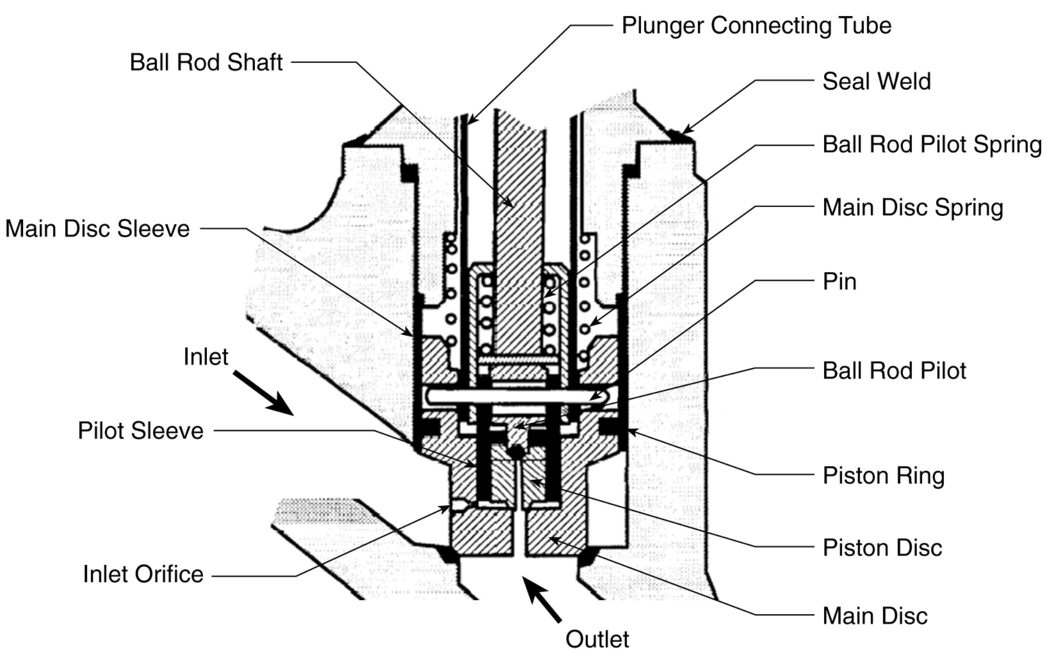

Figure 2-12(c)
Dual Pilot-Assisted Hard-Seat Process SOV [2]

Table 2-2
Piloted SOV: Important Components

Inlet Orifice	The orifice is either fabricated as an integral part of the main disc or machined into the valve body. It is sometimes equipped with a metering valve to permit flow adjustment to the disc chamber. Restricting the inlet orifice permits the valve to slowly close and prevents water hammer on incompressible fluid systems.
Pilot Valve	The most common design for process system valves is to fabricate the pilot valve seat as an integral part of the valve's main disc. In other applications, like certain power operated relief valves (PORVs), the pilot valve may be a separate SOV with connected piping to the main valve body.
Main Disc	The main disc can be designed as a disc, diaphragm, or piston. Diaphragms are often fabricated of reinforced elastomers/plastics for low-pressure applications. In certain designs, the main disc is coupled to the pilot disc to assist opening at low differential pressures. A spring is often used to assist closing on low differential pressures.

2.5.3 Burping in Piloted SOVs

When a pilot-operated valve is closed under normal conditions, the pressure in the main disc chamber generally remains equal to inlet pressure. However, some inlet pressure transients can increase inlet pressure significantly before flow through the inlet orifice balances the inlet and disc chamber pressures. If the transient is rapid enough, the inlet pressure will cause the net force on the main disc to change significantly, and the valve can spuriously open for a brief period. This condition has been observed in some pilot-operated valves and is often called "burping" (see Appendix C).

Key Technical Point

Piloted valves can open unintentionally for a fraction of a second if a rapid inlet pressure transient occurs. This phenomenon is called *burping*.

Experience and testing with typical pilot valve designs indicates that when the valve design and application permit rapid equalization of main disc chamber to inlet pressure transients, burping does not occur. (Rapid, in this sense, is some time less than the normal operating time of the pilot valve.) The characteristics of the disc chamber volume, inlet orifice size, and process fluid are critical to the rate of disc chamber pressure equalization.

When the process medium is an incompressible fluid (like water) and no gas/air is present in the disc chamber, valve burping does not occur. With incompressible fluids, very small flows will quickly equalize pressure differences between the inlet and the main disc chamber. With compressible gases (like air), burping may result when large transient pressure differences occur. Further, testing has demonstrated that the worst case for burping occurs when a portion of the main disc chamber is filled with air and the remainder of the SOV is filled with a fluid. This may also occur when the piping system is initially filled with air (for example, in a drain line), and a sudden fluid pressure transient occurs. In many fluid systems, the valve orientation (for example, stem vertical) can prevent all of the air from being purged from some portion of the disc chamber during normal operation. Both analytical models and dynamic tests have confirmed that burping is most likely to occur when there is a liquid pressure transient and the valve disc chamber is partially filled with a gas. This has prompted one manufacturer to recommend orienting piloted SOVs in fluid and steam systems with the valve stem inverted (below the horizontal) to encourage filling the full disc chamber with liquid rather than steam or air. Burping is a characteristic of piloted valves. When burping cannot be tolerated and reorientation is not an option, then direct lift type SOVs can be used. If the pressure/flow capacity of direct-acting globe valves is too limited, consider using other valve styles (for example, gate or balanced-disc globe valves).

2.6 Directional vs. Universal Valves

Most SOVs are designed to be installed with the ports connected in a specific way (that is, the valve is designed for flow in only one direction). For two-way valves, either there is an arrow on the body or the ports are labeled as INlet and OUTlet. For three-way valves used in air-pilot service, the ports are often designated as pressure, cylinder, and exhaust. Valves designed to be installed in only one way can be termed *directional* or *unidirectional*. Similarly, *universal* or *bidirectional* refers to valves designed to be installed in any direction (that is, the valve will operate with flow in either direction). Most SOVs are of the directional type. **Important operation restrictions apply to the use of directional valves.** When a manufacturer provides a particular valve style in both universal and directional models, the universal style has a lower maximum pressure rating or a lower flow capability (small orifice size). This is because the manufacturer must compromise when selecting the valve springs and the orifice size. The following paragraphs discuss why directional valves should not be subjected to reversing pressures and why most SOVs are supplied as directional rather than universal.

Key Technical Point

Most SOVs are designed for flow in only one direction. Important operational restrictions apply to the use of directional SOVs. If pressure is reversed, the SOV may spuriously open or fail to operate.

Key Technical Point

With careful design, some SOVs can permit flow in both directions. In order to have two-direction flow, these universal SOVs usually sacrifice pressure rating or flow capacity.

2.6.1 Directional Characteristics of Direct-Acting SOVs

In most directional valve styles, pressure is applied over the seat and assists in maintaining the seat in the closed position (see Figure 2-13). In these designs, only a minimal spring force, sufficient to return the plunger to the closed position, is necessary. The maximum operating pressure rating of this valve is determined by the solenoid force available to unseat the valve at maximum operating pressure differential (MOPD). If the pressure exceeds this value, the solenoid may be unable to open the valve. If the valve or system pressure is accidentally reversed and pressure is applied under the seat, then only spring force is available to seat the valve. Since the spring force is minimal, the valve will leak at only a fraction of its rated MOPD.

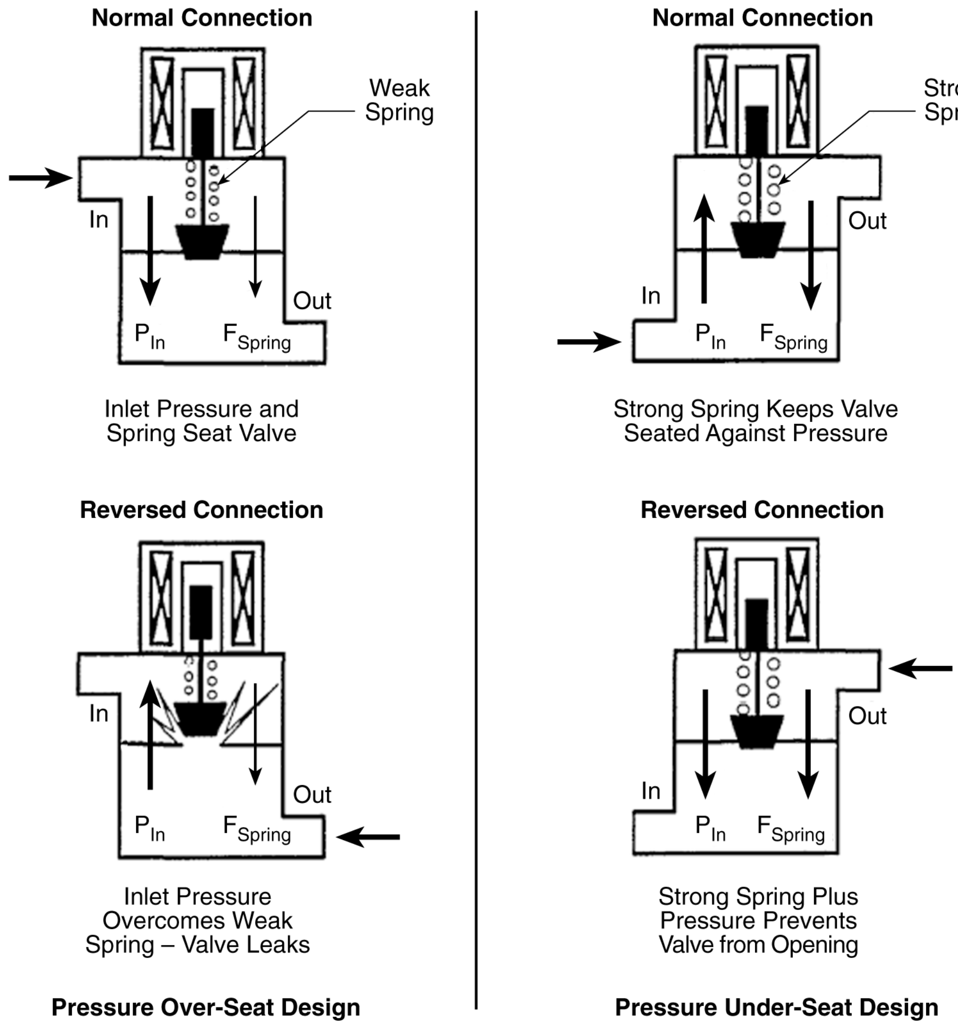

Figure 2-13
Diagrams of Reverse Pressurization Effects of Direct SOVs

In other directional SOV designs, the pressure is applied below the seat and tends to open the valve (see Figure 2-13). In these designs, a strong spring force is used to keep the valve closed when MOPD is applied. If the pressure exceeds the MOPD, the valve may leak and even open as the disc is lifted from the seat. Energizing this design will always open it fully, since the greatest solenoid force is required to open the valve when no differential pressure exists. If the valve or system pressure is accidentally reversed and pressure is applied over the seat, then both the strong spring force and system pressure combine to seat the valve. Insufficient solenoid force may be available to open the valve against both the spring force and pressure at only a fraction of the valve's MOPD. This under-seat SOV design is not typical of two-way valves but is used frequently in three-way valves as one of the two seats.

If a bi-directional (universal) style were available in the same solenoid design, then a medium spring force would be selected, and the valve orifice size might be reduced. In this way, the solenoid develops sufficient force to open the valve against both the spring and pressure when pressure is over the seat. When pressure is applied under the seat, the spring provides sufficient force to keep the valve closed. However, the MOPD or the valve's flow capacity, or both, must be lower in the universal version than in the directional construction. In addition, valve springs can vary considerably among models within a particular SOV series. Consequently, when repairing a valve, mixing the springs between two valves with different ratings will adversely affect valve performance.

Because of the reduced ratings available with the universal design, two-way SOVs are rarely universal, while three-way and other multi-ported valves are often available as universal since the valves may be used in air logic applications, and other design alternatives are available to minimize the performance reduction. (Often the coil wattage will be increased in the universal style to provide greater magnetic force.) Many air logic applications require the use of universal valves because air pressure may exist at different valve ports. When two or more directional SOVs (particularly three-way valves) are connected together to develop an "air logic," a careful review of all the combined valve positions must be made to ensure that none of the valves are subjected to reverse pressure.

Table 2-3 compares the characteristics of a typical three-way air-pilot valve style offered in normally open, normally closed, and universal constructions.

Table 2-3
Comparison of MOPDs for a Three-Way SOV (1/4 Inch NPT, 3/32 Inch Orifice)

Type	AC MOPD (psi/kPa)	DC MOPD (psi/kPa)
Normally Closed	150/1034	115/793
Normally Open	140/965	100/690
Universal	75/517	60/414

2.6.2 Directional Characteristics of Piloted SOVs

An important operating characteristic of pilot-operated valves is their strong directional characteristic. If the outlet pressure exceeds the inlet pressure, then the net disc force will cause the valve to open. Absent additional spring seating force, a piloted design functions very much like a check valve and will open when pressure reversals occur.

Key Technical Point

Most piloted SOVs exhibit strong directional characteristics.

Typical high-pressure piloted process valves will open with reverse pressures as low as 5–60 psi (34–414 kPa). Because design details affect the operation of piloted valves, all pilot designs do not function the same when reverse pressure is applied. The behavior of some three-way piloted valves becomes unpredictable if a minimum pressure differential of +10 psi (69 kPa) is not maintained. In the piloted design shown in Figure 2-12(b), the solenoid return spring assists in closing the main disc. However, this provides very little reverse pressure protection.

2.7 Valve Styles

Because SOVs are available in a broad variety of designs and configurations, it is virtually impossible to discuss all of the possible designs. However, the following is intended to illustrate the elements that are common to many of these constructions. Appendix F provides information on American National Standards Institute (ANSI) and other common SOV symbols used to represent the operating states of these valves.

2.7.1 Two-Way SOVs

Several normally closed two-way SOV designs are shown in Figures 2-1, 2-12, and 2-14. Figure 2-1 represents a typical direct-acting air-pilot valve. The spring located above the disc seat, a feature found in many designs, minimizes the impact loads on the seat that occur when the SOV closes. Figure 2-12(a) is a piloted diaphragm type valve. Figure 2-14a is a high-temperature, high-pressure, direct-acting process valve. (Figure D-3 is a similar piloted valve.) Figure 2-14(b) is an example of a piloted poppet design.

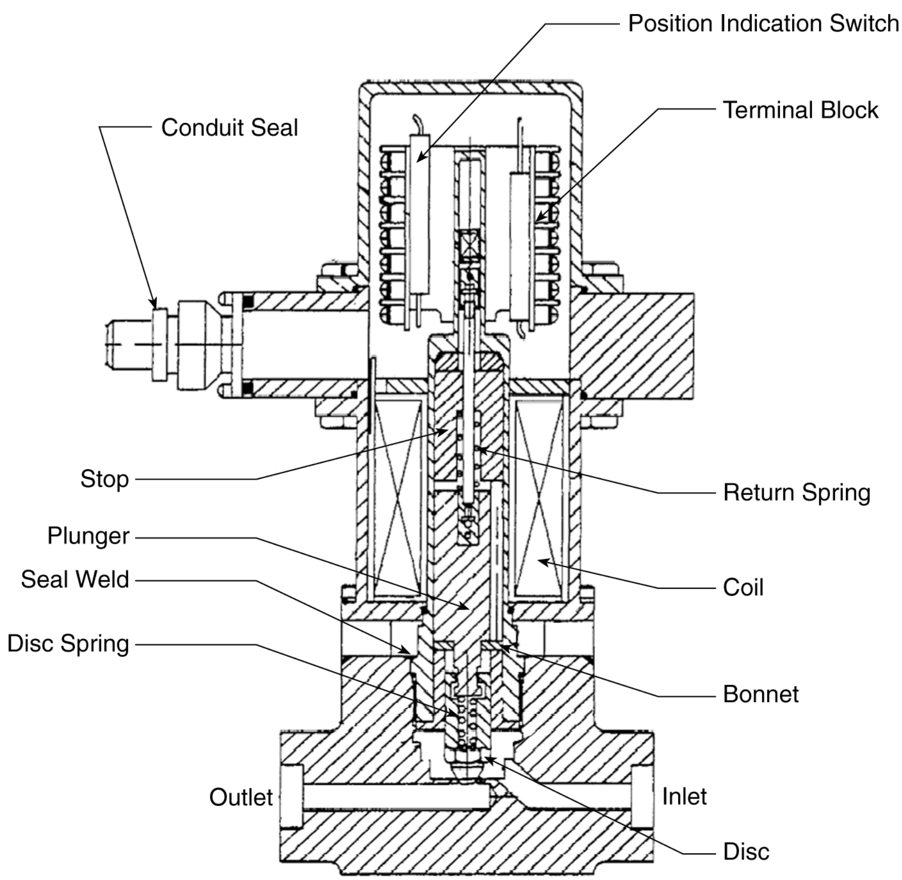

Figure 2-14 (a)
Typical Direct-Acting Two-Way SOV [3]

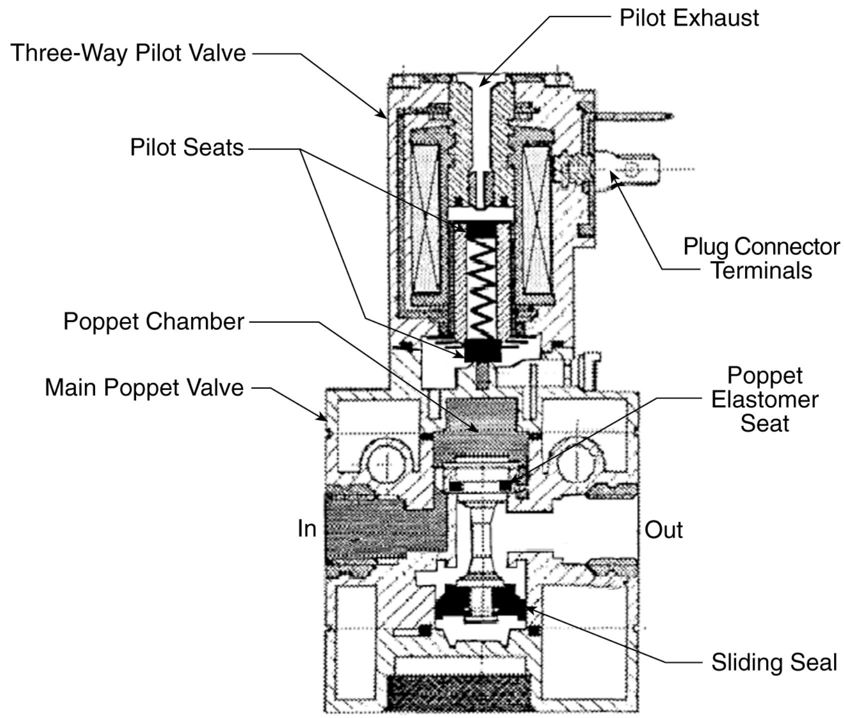

Figure 2-14 (b)
Piloted Two-Way Poppet Type SOV [4]

2.7.2 Three-Way SOVs

Figure 2-15 illustrates a variety of direct-acting three-way valves. Figure 2-15(a) is a common design containing an exhaust seat situated close to the center of the SOV coil axis. If this type of SOV is continually energized, this seat may degrade substantially faster than other seats due to the high temperatures in this location. In Figure 2-15(b), the solenoid is a hinged armature rather than the plunger type and is isolated from the process fluid. Figure 2-15(c) is a third type of direct-acting SOV. Appendix C discusses in detail the operation of another common type of three-way SOV.

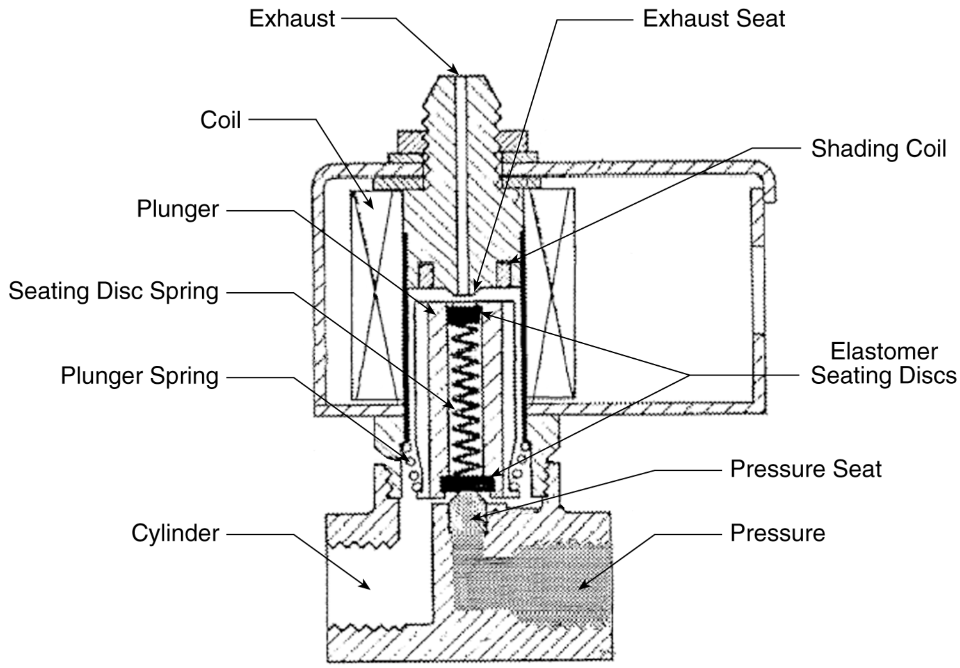

Figure 2-15 (a)
Typical Direct-Acting Three-Way Air-Pilot SOV [1]

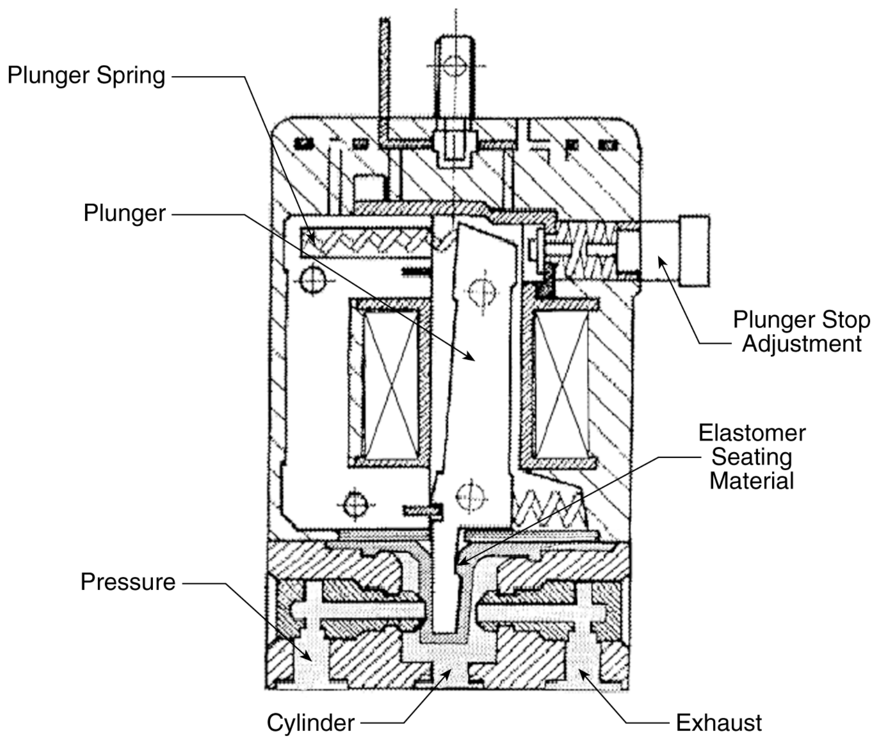

Figure 2-15 (b)
Direct-Acting Sway SOV with Hinged Plunger Isolated from Process Fluid [4]

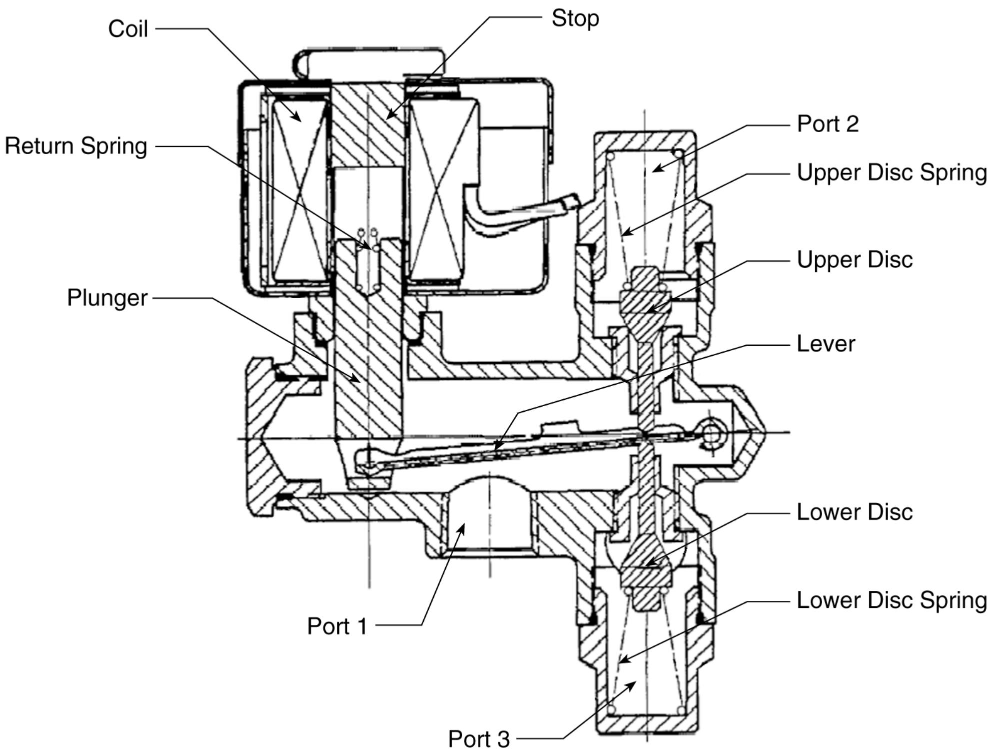

Figure 2-15 (c)
Typical Direct-Acting Three-Way SOV [5]

Figure 2-16 illustrates two types of piloted three-way valves. Figure 2-16(a) is a pilot-operated poppet valve. The SOV shown in Figure 2-16(b) uses two diaphragms to achieve three-way operation.

Three-Way Piloted Poppet

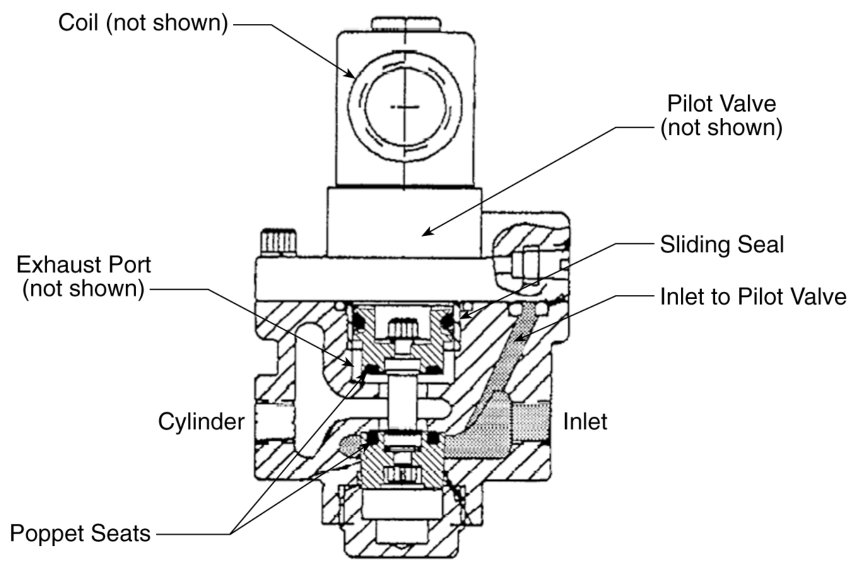

Figure 2-16 (a)
Piloted Three-Way Poppet Type SOV [6]

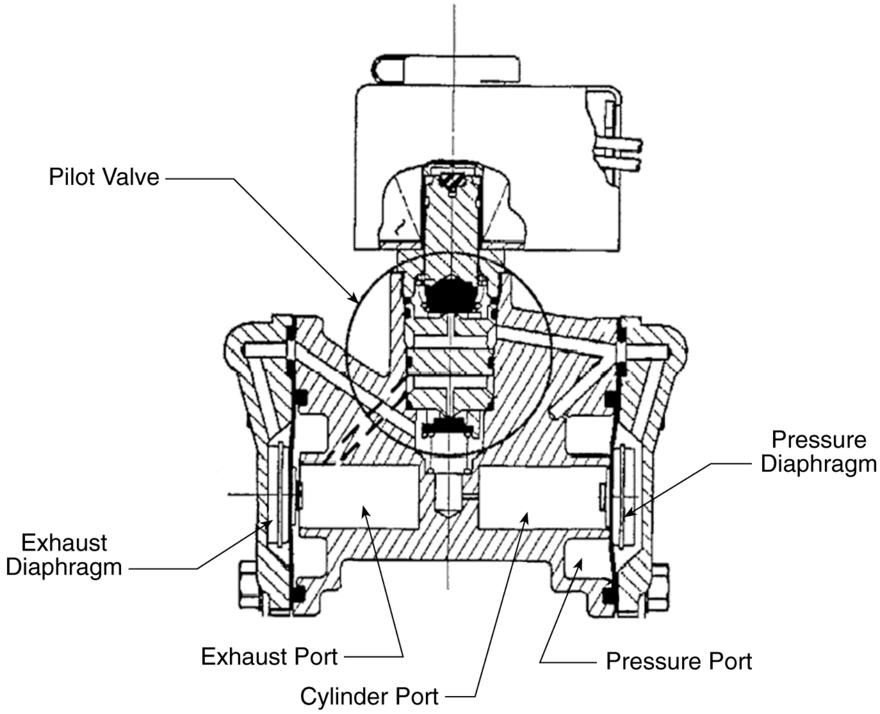

Figure 2-16 (b)
Piloted Three-Way SOV with Two Diaphragms [5]

2.7.3 Four-Way SOVs

Figure 2-17 depicts several of the many four-way valve designs. Figure 2-17(a) shows a valve with two coils operating two three-way poppets. Figure 2-17(b) is a piloted piston type design using U-cups as sliding seals. Figure 2-17(c) is a piloted spool type design. Most four-way and other multi-port valves use either a spool or a poppet type construction.

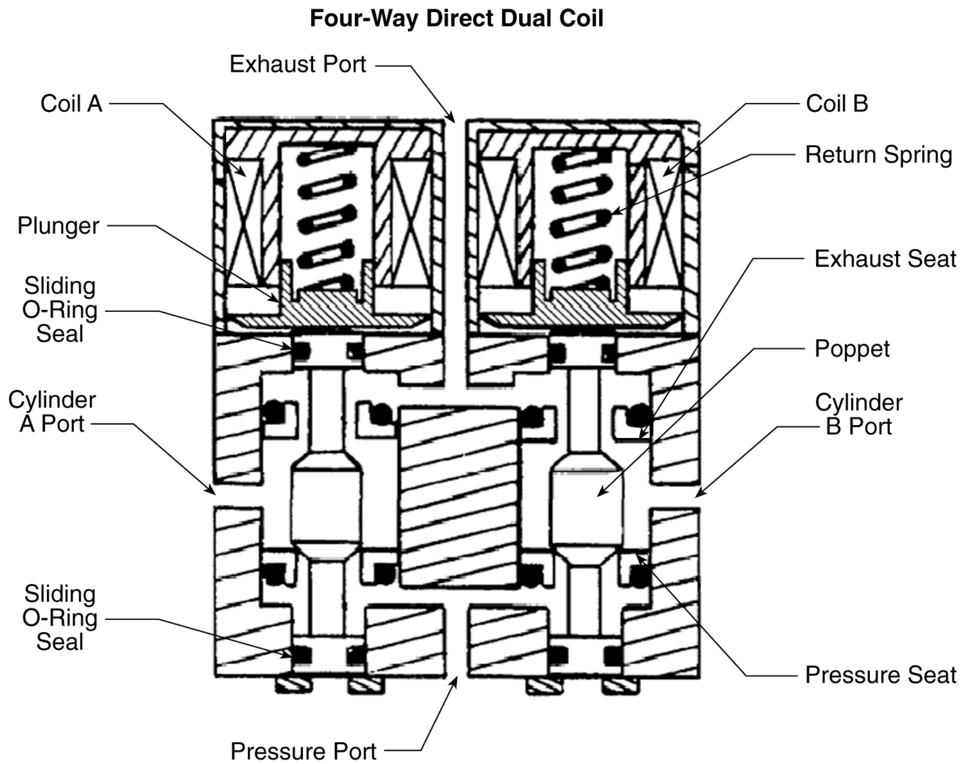

Figure 2-17 (a)
Four-Way SOV Using Two Solenoids [7]

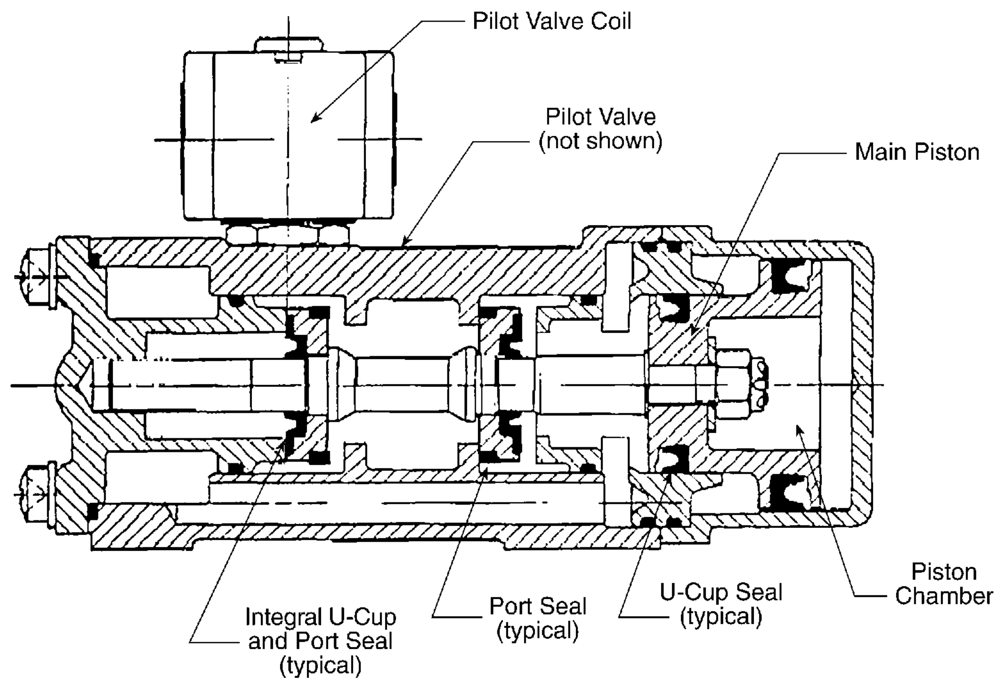

Figure 2-17 (b)
Piloted Four-Way SOV [5]

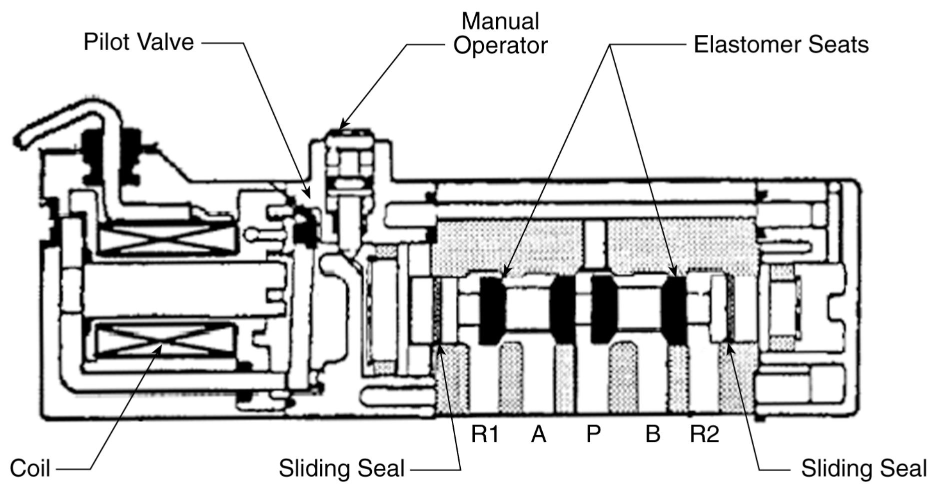

Figure 2-17 (c)
Piloted Spool Type Four-Way SOV [1]

2.7.4 Balanced-Disc SOVs

SOVs can also be provided in balanced disc type constructions. In these designs, the objective is to balance the pressure forces acting on the disc in both the open and closed positions. This generally requires one or more sliding seals to withstand maximum rated pressure.

A globe type balanced disc design is shown in Figure 2-18. (The poppet valves shown in Figures 2-17(a) and 2-17(c) are also considered balance type valves.) As shown in this figure, pressure in the area above the disc is maintained at outlet pressure by an adequately sized port in the disc. The area above the disc is precisely sized to equalize the forces acting above and below the disc. With balanced forces acting on the disc, higher flow capacity can be achieved without requiring a pilot-operated valve. The characteristics of this design also permit balanced disc SOVs to be designed as universal valves.

In balanced designs, the disc sealing ring or piston must withstand full system pressure when the valve is closed. This can contribute to leakage in this design. Because of machining tolerances/variations and other considerations, some balanced disc designs cannot balance forces at large pressure differentials. Finally, the sliding seals can be prone to sticking.

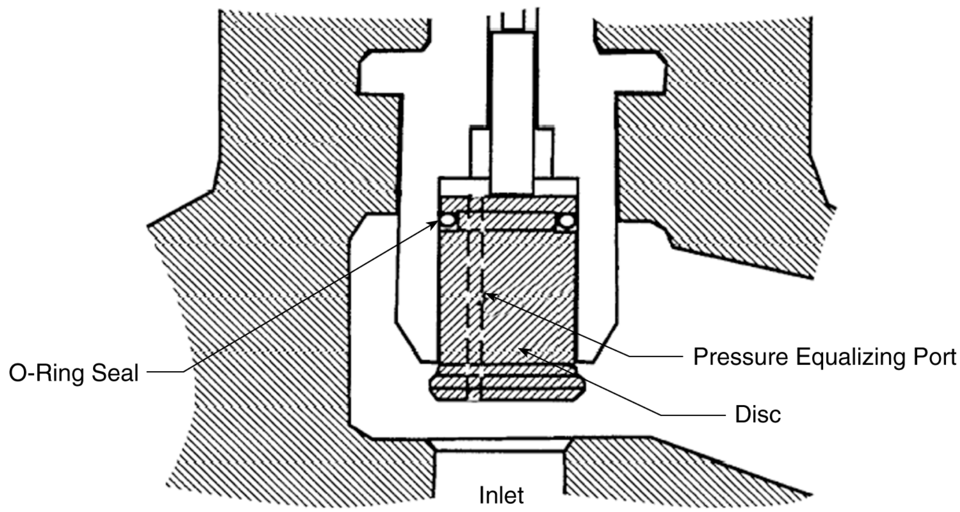

Figure 2-18
A Balanced-Disc SOV

2.7.5 Gate Type SOVs

Gate type valves (often called sliding seal SOVs) are available from some manufacturers. Several utilities have found gate type SOVs well-suited to applications where problems were experienced (principally, internal leakage) with globe type valves. These types of valves can better handle contaminated fluids due to the wiping action each time the gate opens/closes. Although gate valves are normally considered bidirectional, there may be a significant difference in the forward and reverse pressure MOPD. One example of a gate type SOV design is shown in Figure 2-19.

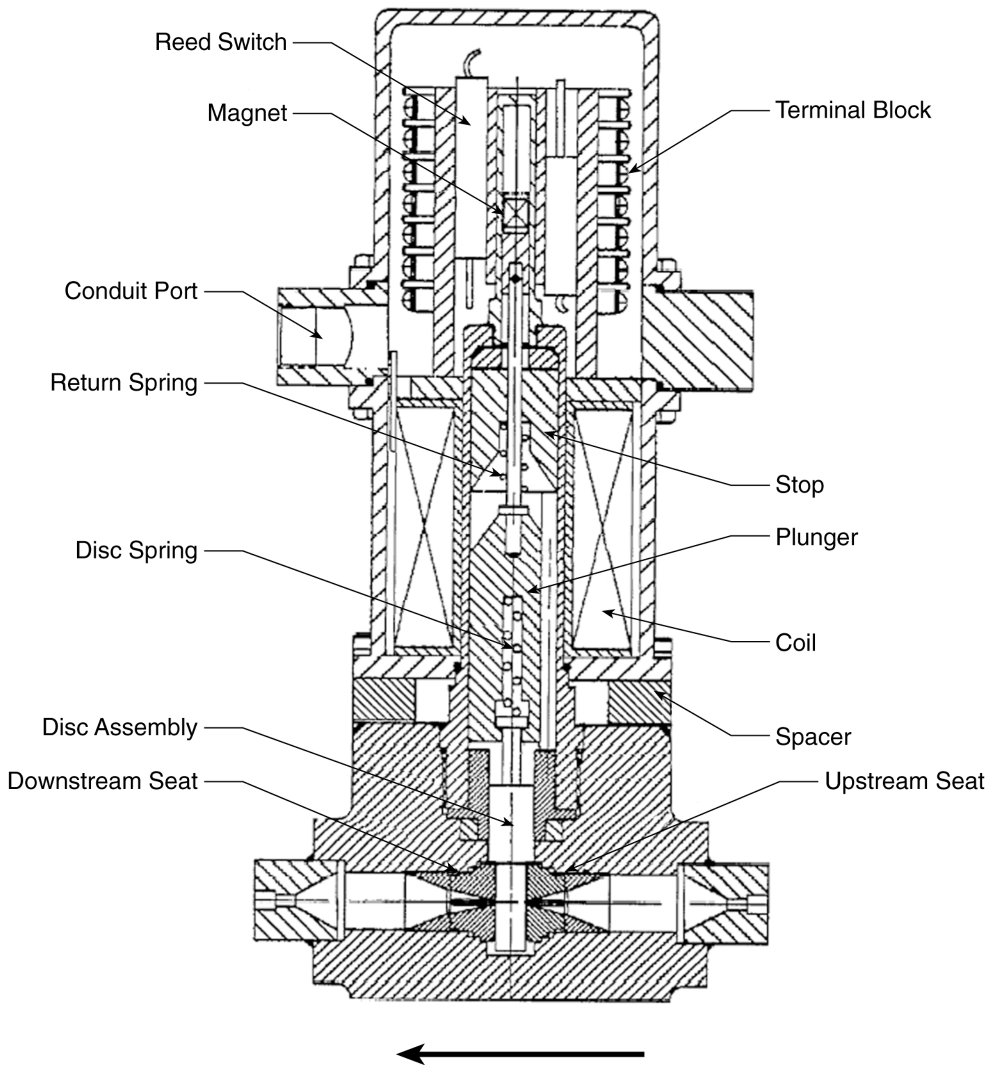

Figure 2-19
Gate Type SOV Construction [3]

2.7.6 Other SOV Designs

A variety of other SOV designs exist but may have limited application in power plants. Two common valve types are the balanced poppet and spool designs. Like the balanced disc, both of these designs use sliding seals to balance pressurization forces and to minimize solenoid size and force requirements. These sliding seals can be susceptible to sticking. Finally, in some SOV designs, a flexible diaphragm is used to isolate the process fluid from the plunger and other solenoid parts. This design modification is still considered packless but offers the advantage of isolating the plunger areas from process-borne contaminants.

2.7.7 Normally Open vs. Normally Closed SOVs

The terms normally open (NO) and normally closed (NC) are best applied only to two-way valves, although they are also used to describe operation of the inlet port for certain types of three-way valves. The terms refer to valve position when power is removed from the solenoid. The inlet port of a normally closed valve is closed when power is removed from the solenoid and is connected to the outlet port when power is applied. Normally open valves work in reverse.

Because solenoids only function by attracting the plunger to the coil, normally open and normally closed valves can differ in design and construction. Virtually all normally closed valves are constructed with pull plungers, while normally open valves can be constructed with either push or pull type plungers. Figure 2-7 schematically depicts direct operating normally closed and normally open SOVs.

2.8 Seat Design

Valves are often classified as hard-seated or soft-seated. Hard seating indicates the use of metal-to-metal seating. Soft seating refers to the use of an elastomer or plastic type material at the seating surfaces. (The valve seat is defined as the fixed, pressure-containing portion of a valve, which comes in contact with a movable closure (generally called the disc or plug). However, either the closure or the seat may be the soft material.) For seat tightness, the objective is to block off or minimize leakage paths across the seating surface. This requires either compressive stresses at the mating surface sufficient to plastically deform the seat material, thereby closing the leakage paths, or an excellent finish between the seat surfaces. Tapered seats with small differential angles are typically used to achieve the required plastic deformation.

Soft seating achieves tight shutoff at much lower seating forces. It is easier to deform the softer material to close the surface leakage paths. The following factors should be considered when a soft-seat material is selected:

- Fluid compatibility, including chemical reaction and swelling
- Loss of hardness, permeability, and degradation
- Hardness, tensile, and compressive strength
- Compression set and extrusion under load
- Thermal resistance
- Radiation resistance
- Abrasion resistance
- Wear resistance
- Mechanical cycling

Hard seats should be used in high-temperature applications or where the tight shutoff provided by soft seats is not needed. Hard seats are preferred in these applications, since soft seats can wear out or become contaminated with prolonged use. Hard seats are more susceptible to excessive leakage when the process system contains particulate contamination that can lodge in or damage the seat area. Soft-seat designs are generally not suitable to applications with process temperatures over 350°F (177˚C) because of rapid thermal degradation of the seal elastomer.

Key Technical Point

Hard seats are preferred where tight shutoff is not necessary. Soft seats are limited to temperatures below 350°F. Soft seats are better able to tolerate particulate contaminants.

2.9 Operating Temperatures and SOV Life

When coils are energized, they generate heat. This heat must be dissipated to limit both the coil and valve temperature. This heat results in temperature increases in the coil and surrounding valve components until temperatures are reached where the heat dissipated to the environment through convection (both natural and forced) and conduction balances the coil heating. The heat generated by DC coils (including coils with rectifiers for AC service) is result of the coil resistance to current flow and is proportional to the product of the current squared times the resistance (sometimes called the "I-squared R" loss). In AC coils, heat is also generated by the current circulated in the shading ring and by the magnetic circuit current losses that are characteristic to all the magnetic path materials. As previously noted in Section 2.4.2, if obstructions prevent the AC solenoid plunger from contacting the solenoid stop, higher currents will occur.

Typical coil heat rise values vary based on manufacturer, valve size, and overall design. The data provided by one manufacturer of air-pilot SOVs suggests that typical coil hot spot temperatures can range from 115° to 175°C (239° to 347°F) for 25°C (77°F) ambient conditions. Since AC coils for a particular valve size tend to have lower wattage ratings, the AC coils might be expected to run slightly cooler. However, there are a number of exceptions, since AC coil temperature is a complex function of both electrical and physical variables.

For typical plant ambient temperatures (60–100°F (15–38°C)), it can be assumed that coil heat rise is independent of ambient conditions. At higher ambient temperatures, the coil heat rise value will decrease slightly. In DC solenoids, this decrease in heat rise occurs because of the increase in coil wire resistance at higher temperatures.

In fact, average coil temperatures are often calculated based on the measured changes in coil resistance in the energized and deenergized state. The formula for the change in copper wire resistance with temperature is:

$$R_{hot}/R_{cold} = (T_{hot} + K)/(T_{cold} + K)$$

Where R (resistance) is in ohms, T (temperature) is in °C, and K = 234.5°C for copper and 225°C for aluminum.

For all SOVs, as coil resistance increases at higher temperatures (assuming constant supply voltage), coil heating due to resistance decreases (power = V^2/R). This is the case for DC valves, but for AC valves, the magnetic circuit current losses dominate the heat-rise process and vary with temperature but at a different rate than coil resistance. Experience indicates that, in general, ambient temperature changes have a greater effect on the heat rise of AC coils than on similar DC coils.

Solenoid force is roughly proportional to the square of current (I^2). Since temperature causes coil resistance to increase and, therefore, current to decrease ($I = V/R$), less force is generated at higher coil temperatures. Therefore, a solenoid will generate less force if it has been continuously energized than if it has not been energized and the coil is at ambient temperature. In addition, solenoids will generate less force at higher ambient temperatures. Generally, SOV maximum operating pressure ratings are based on the SOV's ability to cycle the valve at its **maximum** published ambient temperature at **minimum** specified voltage after the coil reaches its energized steady-state temperature.

Key Technical Point

DC SOV coils generate less force at higher temperatures (for example, when they get hot) because the higher coil resistance reduces coil current.

Heat is transmitted away from the coil by both the coil enclosure and the valve body, although the majority of the heat dissipation is through the enclosure. The operating temperature of the coil and other valve components can be significantly affected by heat transfer from the valve and coil enclosure to their surroundings. During recent research tests, it was found that coil heat rise values for typical air-pilot SOVs were effectively cut in half when air at relatively low velocities was circulated around the valves. This air circulation increased the heat transfer from the coil enclosure and the valve body and, thus, reduced the internal operating temperatures. Conversely, SOV coils can quickly overheat and fail when they are accidentally insulated; heat-traced; or located in areas near high-temperature equipment/piping, steam leaks, or where other factors restrict heat dissipation from the valve.

The thermal life of insulating materials, plastics, and elastomers is inversely related to their operating temperature (that is, the higher the temperature, the shorter the material life). A rule of thumb, known as the "10°C rule," suggests that a material's life is doubled for each 10°C (18°F) decrease in operating temperature. Conversely, the life is halved for each 10°C (18°F) increase. More accurate modeling of thermal life using other models (for example, the Arrhenius degradation model) indicates that the temperature effect may be even more pronounced than predicted by the 10°C rule. A more appropriate temperature rule for doubling/halving might use 7°–8°C (12°–15°F) instead of 10°C.

Manufacturers provide varying recommendations on how to address the effect of process heating on solenoid coil temperatures. Most specify a maximum process temperature, which is limited by either the valve materials or the temperature limits of the standard coil supplied with the SOV. One manufacturer of air-pilot valves suggests that high process temperatures need only be considered if they exceed 180°F. For temperatures over 180°F, the manufacturer recommends adding one-half the difference between the process temperature and 180°F to determine the added heat rise at the coil. (This recommendation is likely based on experience that the valve tends dissipate much of the heat from the hot process before it reaches the solenoid coil.) This approximation may not apply when the valve is insulated or heat-traced. Manufacturers of in-line process type SOVs (for example, Target Rock, Valcor, etc.) often perform tests to determine the effect of process temperatures on the coil and other valve components.

Key Technical Point

Energized coils have a shorter life because their materials degrade at higher temperatures. Coil material life is halved for every 7°–8°C (12°–15°F) increase in coil temperature.

2.10 Voltage Variations and Performance Effects

In general, commercial SOVs are rated to operate continuously at the specified limiting conditions (that is, maximum operating temperature and pressure) at a 15% undervoltage. The maximum continuous voltage is typically listed as the rated voltage, for example, 120 Vac, although manufacturers will generally indicate that the valve is capable of intermittent operation at +10% of the nominal voltage. Since both AC and DC power plant voltages tend to be higher than the nominal rating for most commercial valves, plant SOVs are often operated above their specified operating voltage limits. For SOVs that are continuously energized, this results in increased operating temperatures and shortens SOV life.

SOV coil operating temperatures can also vary based on operating voltage. For DC valves, temperature rise is proportional to voltage squared divided by resistance (V^2/R). Increasing coil voltage from 100% to 110% would increase the heat rise by 121%, not by 110%. The actual coil wattage and heat rise increase are less, since a coil resistance increases slightly at the higher operating temperature and offsets some of the increase due to the higher voltages. Experience indicates that AC solenoid continuous operating temperatures are generally more sensitive than DC solenoids to voltage variations.

Voltage variations become significant for DC valves because plant DC systems, although specified at 125 Vdc, generally operate at a floating voltage between 132 and 135 Vdc. During battery equalization, this voltage may increase to 140 Vdc and higher. Most standard commercial SOVs are rated for 120 Vdc with a voltage range of 102–126 Vdc. For these devices, operation at 132 Vdc is outside their specified voltage range. Operation for prolonged periods at these higher voltages will cause coil overheating and premature coil or other component failures due to higher operating temperatures. One manufacturer estimates that operation at 132 Vdc, instead of 125 Vdc, increased coil temperatures approximately 14.5°F (8°C). While this may appear to be a modest increase, it can effectively reduce the coil life by more than half (remember the 10°C rule). Manufacturers who are familiar with power plant DC systems generally offer special coils (typically rated at 125 Vdc) that are designed to operate continuously in the voltage range of 90–140 Vdc.

Key Technical Point

Plant DC systems operate at roughly 132 Vdc. This is higher than the rating of most commercial DC SOVs (120–125 Vdc). The higher voltage can shorten coil life because of higher operating temperatures. Some SOVs are not capable of prolonged operation at 132 Vdc and will prematurely fail.

2.11 Position Indication

Position indication is often provided as an option on most process SOVs. However, position indication typically is not available for the small air-pilot type SOVs.

Key Technical Point

Position indication is often provided by magnetically operated reed switches. The permanent magnet is inside the valve bonnet. It is connected to and moves with the solenoid plunger.

Valve position indication designs can be categorized based on whether the SOV is a packless or a non-packless design. In the packless design, a rod attached to the plunger is connected to a permanent magnet located in a non-magnetic extension tube. The extension tube either is attached to the valve body or is an extension of the plunger guide tube. Since the tube forms part of the valve's pressure boundary, the internal magnet and rod are wetted by the process fluid.

External to the tube, magnetically sensitive reed switches respond to changes in the permanent magnet's position. These electrical switches are designed to operate when a magnetic field greater than a certain intensity exists at the switch. Figure 2-20 illustrates the design of the position indication assembly on one valve type.

When the valve is energized, the solenoid plunger and the attached permanent magnet move, changing the location of the magnet's field. Although this movement may be relatively small (for example, 1/4–1/2 inch (6.4–12.7 mm)), the sensitive reed switches are positioned so that the small change in the magnetic field intensity causes the switches to operate.

Generally, at least two reed switches are provided. One indicates that the valve is fully open, and the other indicates that the valve is closed. The two switches are positioned such that one switch is actuated because it is near the magnet when the valve is deenergized. When the valve is energized the magnet moves away from the switch, the magnetic field decreases at the switch location, and the switch deactivates. The other switch operates in reverse, with the magnet moving toward the switch when the valve is energized. Figure 2-20 shows the location of the switches and the relative magnet movement between the energized and deenergized positions.

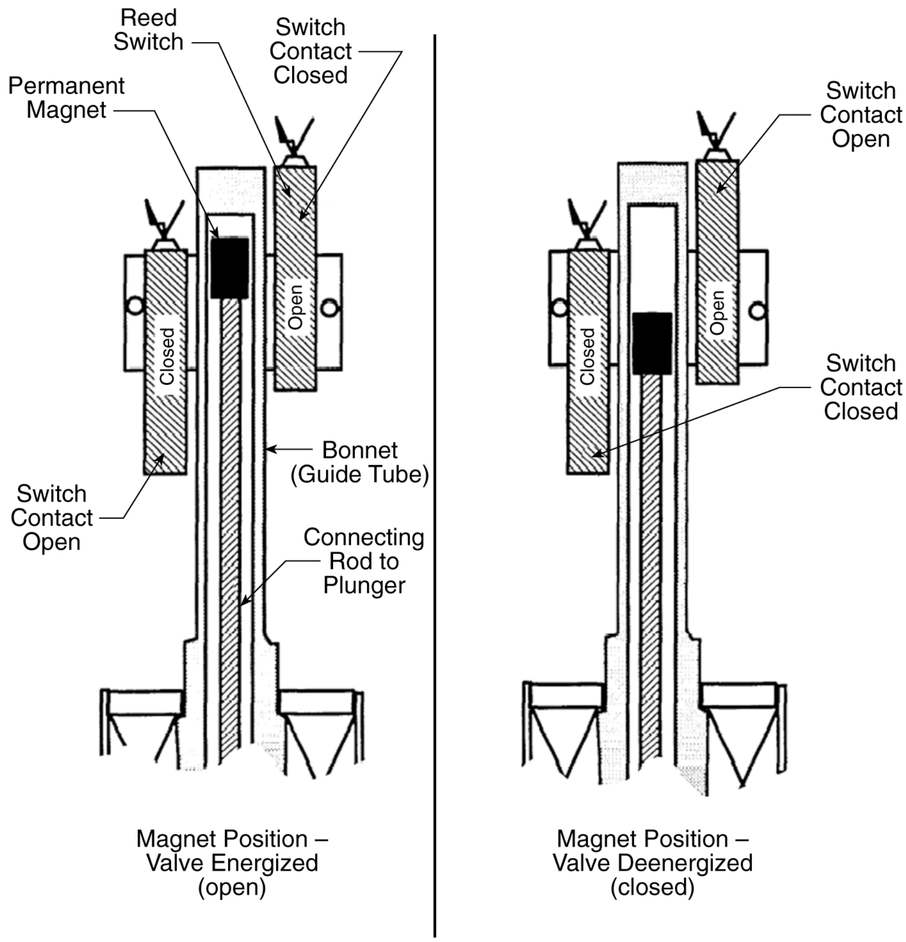

Figure 2-20
Permanent Magnet - Reed Switch Position Indication [2]

Operation in many reed switch designs is complicated by the fact that the stray magnetic fields that are produced when the SOV coil is energized can affect switch operation. (Virtually all the coil's magnetic field is contained in the ferrous materials (for example, core, enclosure, and flux washers) that comprise the magnetic circuit. The remaining "stray" magnetic field can exist near the reed switches.) This is particularly true when the coil is powered by DC or rectified AC voltage. In these designs, the coil's magnetic field will either add or subtract from the permanent magnet's field depending on the polarity of the coil connections. Because the reed switches are sensitive to magnetic field changes, even removing or replacing the valve coil enclosure can modify the field and affect the switch operating points. Similarly, the switches will not operate properly if the magnet's field strength changes. For example, high temperatures or strong impacts are known to slightly demagnetize some permanent magnet materials.

One modification to this position indication design uses inductive pickups instead of reed switches. The pickups combined with remote electronics sense the position of the magnet and provide contact output signals.

The position indication design for non-packless valves generally uses external limit switches similar to those that are used in conventional valve applications. Because SOV solenoids do not create the thrust forces produced by most air actuators, these limit switches are generally of the microswitch type and do not require substantial forces to change position.

2.12 Reduced Voltage Operation

SOV coils historically have been sized to create sufficient force to attract the plunger when initially energized. As discussed in Section 2.4.2, when the plunger is in contact with the solenoid stop, the solenoid force is substantially greater than the force required to keep the valve in the energized position (Figure 2-6, Point C). If coil voltage and, thus, coil current could be reduced after the valve actuated, sufficient force would still exist to hold the plunger in the energized position, and less heating would occur. With lower operating temperatures, both valve coil and elastomer life would be extended.

Key Technical Point

Special SOV designs can reduce the voltage to the coil after the valve is energized. Reducing the voltage lowers valve temperatures and prolongs elastomer and coil life.

Some specialized SOV designs require large initial coil forces (for example, requiring 5–50 amps). These coils would be prohibitively large if they were designed to continuously operate at these current levels. Consequently, voltage reduction is necessary after the SOV cycles.

To address these two situations, manufacturers have developed a variety of methods to reduce valve power requirements once the SOV has fully shifted to the energized position. These methods can be grouped into two categories: dual winding coils and power reduction modules.

2.12.1 Dual Winding Coils

Dual winding coils consist of two windings. One winding (the high-resistance winding) is made of very fine-gauge wire. The other winding is fabricated of a heavier-gauge wire. When the valve is energized, both windings are connected in parallel and both produce complementary magnetic fields. However, the majority of the magnetic field is produced by the low-resistance heavy-gauge winding because it has the highest current. After the valve shifts position, and with a suitable time delay (for example, 20 milliseconds–5 seconds), a relay interrupts power to the heavy-gauge winding. The reduced magnetic flux produced by the higher-resistance, low power winding is sufficient to maintain the valve in the energized position. In the dual winding coil design, the holding current can range from 5–30% of the pickup (in-rush) current.

2.12.2 Power Reduction Modules

In the power reduction module design, a single coil winding is connected to a solid-state or relay logic control circuit that reduces the voltage to the valve coil. After some predetermined time delay, the relay logic circuit places a voltage dropping power resistor in series with the valve coil, which reduces the voltage available at the coil. As a result, the SOV current, magnetic field, and heat rise are also reduced. In the solid-state design, an electronic circuit is used to control the voltage or current provided to the coil.

The solid-state circuit can offer certain other advantages. First, some electronic modules can compensate for wide supply voltage variations. Rather than the standard +10% voltage range, electronic designs can maintain adequate coil voltage with power supply swings as large as a factor of 10 (for example, 24–240 volts). The modules can also overcome another important drawback of the other two designs. In both the dual coil and relay designs, if the valve fails to cycle fully during the initial time period or if voltage to the coil is accidentally reduced or interrupted, then the SOV may drop out. However, insufficient power is available to reopen the valve. (These designs typically reset only when the input voltage to the module or relay falls below some design value that may be lower than the valve dropout voltage.) In some electronic designs, full voltage is periodically applied (for example, every few seconds) to ensure that the SOV is maintained in the energized position.

The relay type and some electronic modules are generally designed to be remotely mounted from the valve. Some manufacturers have built the electronic circuitry directly into the valve coil or coil housing.

2.13 “Fail-As-Is” Designs

In most valve designs, the SOV returns immediately to its deenergized state on loss of power to the valve coil. However, a variety of SOV applications require the valve to fail as is (in the position it was in at loss of power) on loss of power. In other applications, the valve operating temperature can be significantly reduced if voltage can be removed from the coil after the valve is energized. Several manufacturers offer a *fail-as-is* option on selected SOV designs. Generally, these options use one or more coils in combination with permanent magnets to maintain sufficient magnetic flux to hold the valve in the energized position when power is removed. One typical design is shown in Figure 2-21 and is described below. In the following discussion, *Latch* refers to the valve with the plunger in the energized position and *Release* refers to the plunger position in the deenergized position.

Key Technical Point

A typical “fail-as-is” design uses permanent magnets and two coils. Fail-as-is designs can be used to reduce energized valve operating temperatures.

The coil design shown in Figure 2-21 uses two coils and a permanent magnet. The magnetic flux from the permanent magnet has two flux paths (labeled “upper flux path” and “lower flux path”). Assume that the valve is in the Release position and the coils are deenergized. In this position, the upper flux path presents a greater resistance than the lower path to the permanent magnet’s magnetic flux because of the air gap in the upper flux path. Consequently, most of the permanent magnet's flux exists in the lower path and holds the plunger in the Release position. If the upper coil is energized, the plunger will operate as in standard valves. However, the upper coil must produce a greater initial force to overcome the holding force of the lower magnetic circuit.

When the upper coil is energized, no air gap exists in the upper flux path. The air gap now exists in the lower flux path. As a result, the permanent magnet's flux is directed around the upper path rather than the lower flux path. If the coil is deenergized, the upper path flux from the permanent magnet is sufficient to hold the plunger in this position. Remember that just like the dual coil and power reduction module designs, a relatively small magnetic field can generate sufficient force to keep the plunger in this Latched position. To release the plunger, the lower coil is momentarily energized. The lower coil field attracts the plunger with sufficient force to overcome the force generated by the permanent magnet upper flux path, and the valve changes position.

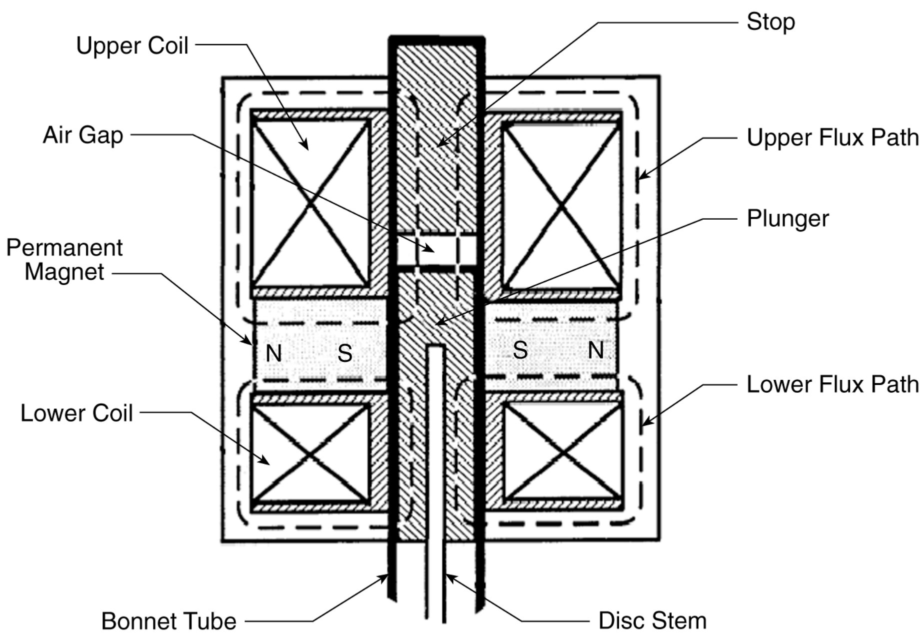

Figure 2-21
Typical Latching Coil SOV Design

2.14 Modulating Valves

Modulating valves must be able to position the valve disc(s) at intermediate (partially open) positions in response to varying input signals. Although several different concepts may be used to produce a modulating SOV design, the one described here is used by several manufacturers of the process SOVs found in generating stations.

As described earlier, when a standard SOV is energized and the plunger begins to move toward the solenoid stop, the net opening force on the plunger increases rapidly as the solenoid air gap decreases. This causes the plunger to transfer quickly to the energized position. In order for a SOV to function as a modulating valve, some method must be devised to balance the forces acting on the plunger at all intermediate plunger positions. One approach could be to simply reduce the coil pull by decreasing voltage to the coil. Although the coil voltage and force can easily be reduced to a level where both the coil and spring forces exactly balance at some intermediate plunger position, this condition is highly unstable. Figure 2-22(a) illustrates this situation when 80 volts to a coil exactly balances the spring force at mid-position "A." Unfortunately, if the plunger moves slightly closer to the stop (to the left), a net positive force is created and quickly accelerates the plunger to the stop. (The same situation would occur if the voltage was slightly increased, since the plunger would be slightly left of the balance point at the higher voltage.) Conversely, if the plunger moves slightly to the right, the net force is negative, and the plunger quickly accelerates to the fully extended position. Thus, it is essentially impossible for the plunger to be maintained at position "A" simply by reducing coil voltage. In other words, the plunger position is unstable.

Key Technical Point

By using stiffer return springs, position feedback, and electronic controls, SOVs can be designed as modulating valves.

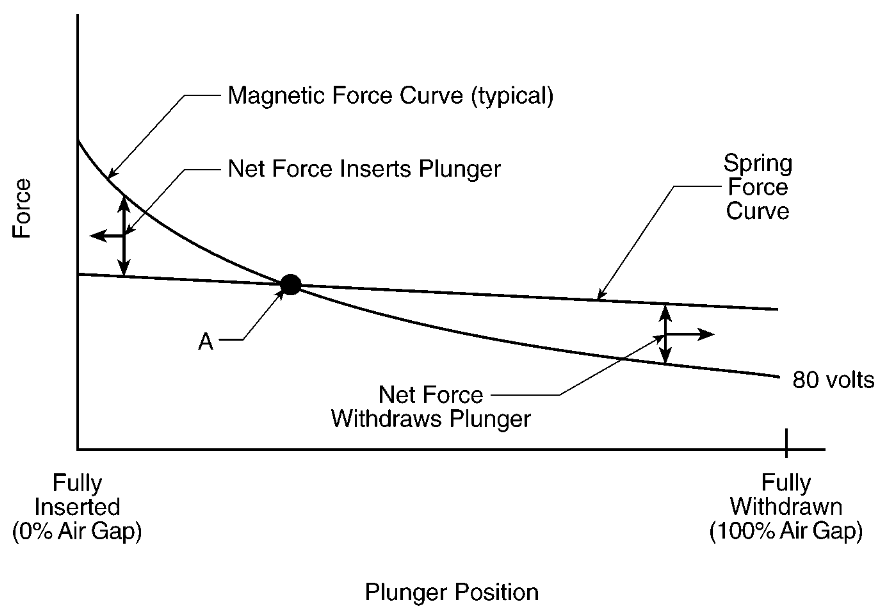

Figure 2-22 (a)
Modulating SOV Magnetic Force and Spring Curves (Small Spring Constant)

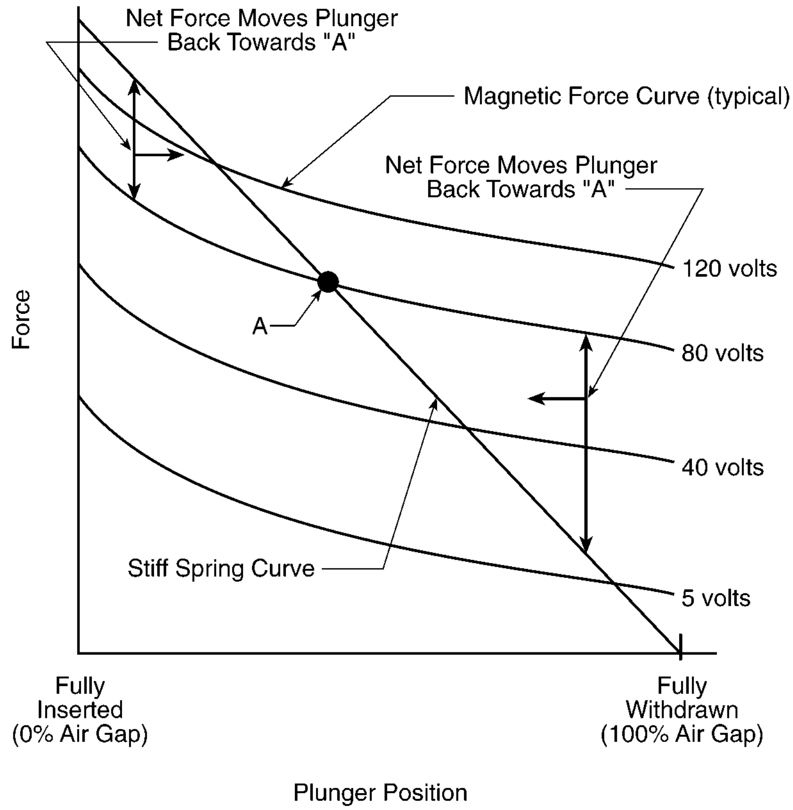

Figure 2-22 (b)
Modulating SOV Magnetic Force and Spring Curves (Large Spring Constant)

By significantly increasing the spring constant, a stable condition can be developed. Figure 2-22(b) illustrates this case. (Remember that the slope of the spring line is equal to the spring constant (k) since, for springs, $F = -k * L$, where L is the length of displacement from the unloaded spring length.) Here, slight plunger movement to the left results in a spring force that is greater than the coil force. The net negative force restores the plunger to position A. Similarly, if the plunger moves slightly to the right, the coil force is greater than the spring force, and the plunger moves back toward position A. Figure 2-22(b) also shows that, for each intermediate plunger position, a unique voltage exists that maintains the plunger in a specific position. Further, the plunger can be made stable and very responsive to changing position demands by incorporating a high-gain closed-loop electronic position control system into the valve design. This "electronic positioner" functions very much like pneumatic positioners on AOVs.

The positioner requires precise information on valve position. Analog position information is provided by replacing the reed switch and permanent magnet position system with a linear variable differential transformer (LVDT). The LVDT is simply an electric transformer whose secondary (output) voltage varies based on the position of the movable transformer core.

Although this modulating valve will work in direct-acting SOV designs, modulating pilot-assisted SOVs are needed for high-pressure, high-flow applications. In pilot-assisted valves, the main disc must precisely follow the position of the pilot disc for the valve to function properly. Since the forces acting on the main disc are controlled by the pressure in the disc chamber, modulating this pressure is the obvious method of controlling main disc position.

The pressure modulating method must insure stability and generate the proper restoring forces when the main disc is slightly out of position. One very effective method of accomplishing this main disc control is inherent in pilot SOV designs in which the SOV pilot disc seat is machined directly into the main disc (see, for example, Figure 2-12(c)). We have already shown that this is the typical design for many on-off pilot-operated process SOVs.

Consider what happens when the pilot disc moves in this design. As the pilot disc rises, it vents pressure from the main disc chamber, and the main disc will begin to rise. However, as soon as the main disc rises, the pilot opening begins to close, pressure increases in the main disc chamber, and the main disc movement stops or may even reverse direction. As a result, the main disc will simply follow the pilot disc as the pilot changes position. If the main disc gets too close to the pilot, chamber pressure will increase and push it away. If it gets too far away, chamber pressure will decrease and pull it toward the pilot. In essence, the pilot and main disc function in a very similar manner to self-contained air regulators. In these regulators, small pressure changes acting on the diaphragm quickly reposition the regulator needle valve to restore the set pressure. Because the stability of this modulating pilot SOV design is related to the type of process fluid or gas and operating conditions, very precise pilot, main disc, and valve designs are necessary. Several manufacturers have successfully produced such modulating pilot SOV designs.

2.15 Materials of Construction

2.15.1 Valve Bodies

Brass is the most common valve body material for air-pilot SOVs and the smaller process valves. Bronze may be found on certain larger-size valves. Stainless steel is used on virtually all other SOVs. However, neither brass nor bronze is acceptable ASME Section III material or recommended for certain hydraulic fluids, for example, Fyrquel®, since acids and corrosion byproducts that occur in the fluid attack these materials. Stainless steel is used on virtually all SOVs when brass is not acceptable, which usually makes it the material of choice for safety-related applications. Valve bodies can be machined from bar stock, forged, or investment-cast depending on the size, material, and design requirements.

2.15.2 Plunger Material and Construction

Solenoid plungers can be made of any magnetic material, but since the plunger in most SOVs is wetted by the process fluid, carbon steel is not used. Instead, plungers are typically fabricated of 400 series (magnetic) stainless steels (for example, 430F or 430FR). Because these stainless steels are not as corrosion-resistant as the 300 series stainless steels, some manufacturers offer a magnetic plunger with 300 series cladding or chrome plating.

Solenoid plungers are fabricated in a variety of shapes based on the design characteristics of the valve. Different shapes of the “pole faces” of the plunger and stop affect the solenoid’s force-position curve. Generally, flat-face designs are used for short strokes or where a maximum holding force is required. The conical face construction is used for longer strokes and lower holding forces.

> **Key Technical Point**
>
> Plungers are typically made of 400 series (magnetic) stainless steels, which are not as corrosion-resistant as the 300 series. Therefore, the plunger may need to be cladded or plated with a material corrosion-resistant to the fluid environment.

Residual magnetism is the magnetism in a material that remains when the coil is deenergized. When the plunger and stop pole faces are in intimate contact, the residual magnetism can prevent the plunger from retracting after the coil is deenergized or may result in significantly lower dropout voltage. To minimize residual magnetism concerns, many manufacturers design DC solenoids in ways that prevent intimate contact between the plunger and stop pole face. (In AC solenoids with shading rings, intimate pole face contact is desirable in order to maximize the solenoid's inductance and, consequently, minimize holding current. Residual magnetism is not a concern.) The methods vary, including the use of a non-magnetic shim attached to the plunger pole face, or pins, snap rings, special machining, or design clearances. Only a small clearance (for example, 0.010 inch (0.25 mm)) is necessary to minimize the effects of residual magnetism. As discussed in Section 2.4.2, in AC valves using shading coils, the plunger must be in intimate contact with the stop/bonnet in order to minimize hum and holding current.

> **Key Technical Point**
>
> Plungers in DC valves are designed to minimize the effects of residual magnetism that can prevent the plunger from retracting. Plungers in AC valves must be in intimate contact with the core/bonnet in order to minimize hum and holding current.

In most SOV designs, the plunger and the air gap are wetted by the process fluid. When the solenoid is energized, the fluid in this cavity must be easily displaced by the plunger. Otherwise, the plunger stroke time will be limited by a "dash potting" effect of the fluid. This could become significant for viscous fluids. Rather than increase the clearances between the plunger and its guide tube, most manufacturers machine one or more grooves in the plunger to facilitate exhausting the fluid for the plunger cavity.

The plunger guide tube must be fabricated of a non-magnetic material. Generally, 300 series stainless steel is used as the plunger guide tube material.

> **Key Technical Point**
>
> The plunger guide tube or bonnet must be fabricated of a non-magnetic material for the solenoid to attract the plunger.

2.15.3 Return Springs

Like plungers, the return springs are generally wetted by the process fluid. As a result, the springs must be corrosion resistant and, because they are under stress, must resist stress corrosion cracking. Common spring materials are 302 stainless, Inconel®, Elgiloy®, and precipitation-hardened stainless steels (for example, 17-7PH and 18-8PH). Generally, the return springs provide some preload force to assist seating the valve seats. Manufacturers typically try to minimize the value of the spring rate constant except for the modulating type SOV designs.

2.15.4 Coil Material and Construction

Solenoid coils consist of a bobbin, insulated magnet wire, pigtail extension leads, pigtail-to-wire connections, insulating cloth/tape, and a coil varnish or encapsulant. Some coils, instead of extension leads, have spade or lug terminals that permit field cable termination directly to the coil. (Because continuously energized coils may become extremely hot, standard 90°C (194˚F) rated cable is generally inadequate for termination directly to the terminals of coils that are energized for extended periods.) Coils are rated by insulation class. The most common coil classes are A, B, F, H, and C. Based on IEEE, NEMA, and UL criteria, each insulation class has a specified temperature rating. The operating temperature ratings for the common coil classes are presented in Table 2-4. Each of the coil materials, and often completely fabricated coils, are tested to verify long-term performance at the specified insulating class temperature limits. (Long-term performance is typically considered to be in excess of 20,000–60,000 hours under controlled laboratory test conditions.) Ambient temperatures and coil heat rise temperatures are generally added to estimate coil operating temperatures. Published limits for air-pilot valves generally assume a maximum ambient temperature of 25°C (77°F).

Table 2-4
Temperature Limits for Insulating Classes

Class	Temperature Rating
A	105°C (221°F)
B	130°C (266°F)
F	155°C (311°F)
H	180°C (356°F)
C	220°C (428°F)

Key O&M Cost Point

Coils are supplied with different temperature ratings. Higher temperature ratings provide extra operating margin and life.

The insulation class rating is the maximum permissible operating temperature that the coil can reach and still provide acceptable performance and reasonably long life. The coil temperature results from a combination of ambient temperature, the heat rise due to energizing the coil, and any additional heating due to high process fluid temperatures. Coils are often provided by manufacturers with higher ratings than required by the SOV design. This margin is used to provide longer coil thermal life or to tolerate increased coil temperatures due to higher ambient/process temperatures or higher operating voltages.

Figure 2-23 illustrates how coils can be supplied. Coils 1, 2, 5, and 8 represent coils (based on wattage requirements and other design considerations) operating at their specified maximum operating temperatures when the ambient temperature is 25°C (77°F). Higher ambient/process temperatures or coil voltage would result in these coils exceeding their rated temperature limits. Coil 3 is essentially identical to coil 1 except that it is fabricated of higher temperature materials: in this case, Class F materials. Similarly, coil 6 is identical to coil 1 except that it is fabricated of

Class H materials. Since both coils 3 and 6 have higher temperature ratings, the available thermal margin can be used to extend coil thermal life or to compensate for higher coil temperatures due to high ambient/process temperatures or increased voltages.

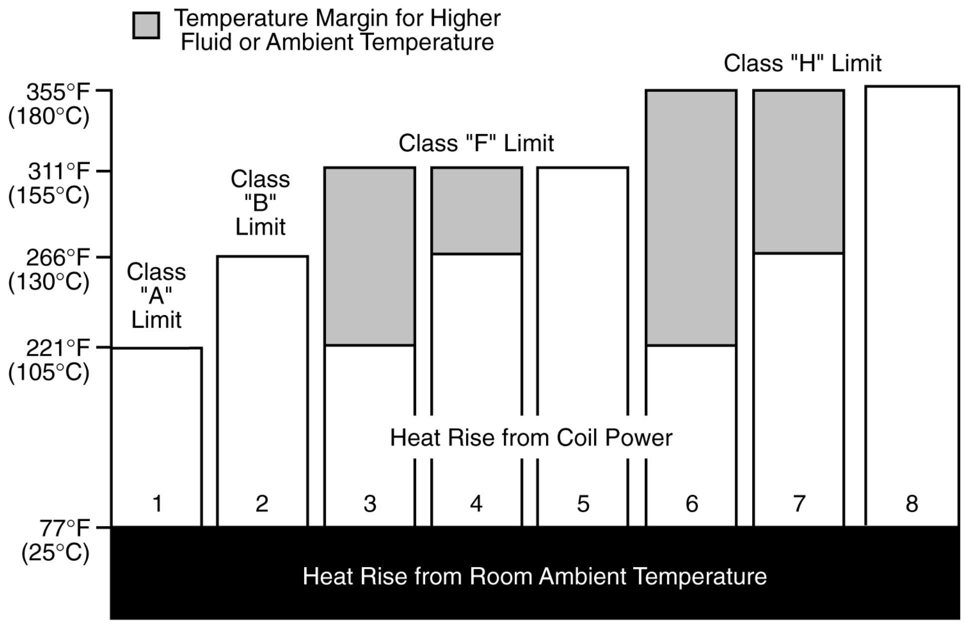

Figure 2-23
Example SOV Coil Classes and Heat Rise Values

Coils are provided in both molded and non-molded constructions. The non-molded designs typically utilize an insulating cloth/tape on the outside of the coil windings. Concentrically wound coils often contain similar cloth/tape insulation after each winding layer. After the coil is wound, the magnet wire is soldered to the coil leads, the connection is insulated, and the fabricated assembly is dipped into a varnish bath and then baked. The varnish tends to fill voids in the coil, helps with the heat dissipation, and provides additional strength and structural integrity. The varnish type (non-molded) coils can be fabricated with materials that are suitable for any of the insulation classes. The non-molded coils are generally considered moisture-resistant but are not intended for wet or extreme moisture conditions.

Molded coils are typically random wound coils that are completely encapsulated in a high-temperature resin (typically epoxy or polyester). The molding is intended to provide a homogeneous moisture-resistant boundary that enables the coil to be used under conditions of high humidity and extreme weather. Many manufacturers indicate that the encapsulant is also resistant to caustic solutions, fungus, and other conditions that are potentially degrading to insulating materials.

Key Technical Point

Molded coils are more resistant to moisture, water, and external contaminants than varnished coils.

Manufacturers also offer coils that are totally potted inside the coil enclosure. The potting, generally a flexible silicone-based material, provides additional moisture and vibration protection. Obviously, potting a coil's enclosure can affect its heat transfer capabilities and may significantly change the operating temperature of the coil. Depending on the potting compound used, coil temperatures might increase or decrease. Potting of enclosures should not be performed in the field without first consulting the SOV manufacturer.

2.15.5 Plastics and Elastomers

A wide variety of plastic and elastomers may be used as SOV molded parts, as gaskets/seals, and to serve as the seat seal material. The following information summarizes some of the more popular materials. Table 2-5 tabulates thermal and radiation limits for these compounds.

Buna-N: Buna-N is the most widely used SOV seal elastomeric material. Properly termed *nitrite rubber*, it is also called NBR. The main advantages of the nitrite rubbers are low cost, good oil and abrasion (wear) resistance, and good low-temperature and swell characteristics. They have a greater resistance than neoprene to oils, fuels, and solvents. Inherently, they do not possess good resistance to ozone, sunlight, or weather, but this can be improved through compounding. Buna-N does not have exceptional heat resistance. Standard Buna-N has a maximum operating temperature of 250°F (121˚C). It will harden at high temperatures. Some SOV manufacturers only recommend Buna-N in the range of -10° (-23°C) to 180°F (82°C). Buna-N is considered radiation resistant up to 100 million rads (1 million grays [Gy]).

Neoprene: Neoprene's dynamic properties are very similar to those of natural rubber, but its chemical resistance is superior to natural rubber's. At its maximum operating temperature of 200°F (93˚C), Neoprene maintains good physical properties and relatively long-term resistance to heat degradation. Unlike other elastomers, Neoprene does not soften or melt when heated to high temperatures. Most elastomers are resistant to deterioration from exposure to either petroleum lubricants or oxidizing agents. Neoprene is unusual because it has limited resistance to both. Neoprene is considered radiation resistant to 100–200 million rads (1–2 million Gy).

Ethylene propylene: Ethylene propylene rubber is often called EPR. Variations in the chemistry of the base rubber are called ethylene-propylene-dien-monomer (EPDM) and ethylene-propylene-terpolymer (EPT). The EPRs are extremely resistant to attack from oxygen, ozone, and weather. EPR has an excellent operating temperature range extending from -70°F (-57°C) to 300°F (149°C) in most applications. With compounding, temperature limits can be extended to 400°F (204°C) and higher. Since the EPRs are hydrocarbon based, they are not resistant to petroleum-based oils: they will swell, become soft, and deteriorate. Particular care should be used to keep petroleum-based lubricants away from EPRs. Several manufacturers do not recommend EPRs for use in air systems containing oil. EPR is considered resistant to radiation of 100–200 million rads (1–2 million Gy).

Viton: Viton, like other fluorocarbon elastomers, has exceptional resistance to oil, chemicals, and elevated temperatures. It possesses excellent compression recovery and thermal resistance. At high temperatures, Viton retains its physical properties better than any other elastomer. The standard temperature range for Viton is -15°F (-26°C) to 400°F (204°C). Unfortunately, Viton is only considered resistant to radiation of 10–20 million rads (100,000–200,000 Gy).

Silicone: As a group, silicones have poor tensile strength, tear resistance, and abrasion strength. However, special compounds have exceptional heat and compression set resistance. With special compounding, silicones can cover low- and high-temperature applications from -65°F (-54˚C) to 450°F (232°C) and higher. Silicone is considered resistant to radiation up to 50 million rads (500,000 Gy), although some silicone seals have been tested to 200 million rads (2 million Gy).

Teflon: Teflon, a fluorocarbon, is available as a solid material or combined with fillers. Teflon will withstand chemical attack from almost any fluid. Its temperature range extends from -300°F (149°C) to 350°F (177°C). Because it is not easily fabricated into parts and is known to have cold flow characteristics, its valve applications are limited. Teflon is extremely sensitive to radiation and is only considered resistant to radiation up to 10 thousand rads (100 Gy).

Urethane: Urethane is widely used where high strength, toughness, and abrasive resistance are required. Its temperature range, -10°F to 160°F is less than that of Buna-N. Urethane rubber is a unique material that can be made very hard (Shore A of 95) and still remain highly elastic (elongation to break of 400%). Urethanes are also considered highly resistant to radiation up to 100 million rads (1 million Gy).

Nylon: Nylon (a polyamide) is not generally used as a seal material. However, when combined with fillers, this thermoplastic can be molded into strong parts. Nylon is used to fabricate internal SOV parts and, in some low-cost designs, as a body or enclosure material. Nylons are also considered resistant to radiation up to 10 million rads (100,000 Gy).

Polyimides: Polyimides (not to be confused with polyamides) are a very thermally and radiation-stable material used in some applications as a seat material. Polyimides are generally too hard to be used as O-rings. Vespel (by DuPont) is the trade name of one such polyimide. Polyimides are stable to temperatures in excess of 400°F (204°C). Polyimide radiation resistance is excellent, with no significant damage when exposed to radiation in excess of 500 million rads (5 million Gy). Polyimides have been noted to be sensitive to cracking due to the combined effects of high humidity, temperature, and bending stress when used as a wire insulation (for example, Kapton by DuPont).

Table 2-5
Properties of Plastics and Elastomers Found in SOVs

Material Name	Petroleum Resistance	Temperature Limit ˚F (˚C)	Radiation Limit in Mrads (Mgrays)
Buna-N	Good	180 (82)	100 (1)
Neoprene	Fair	200 (93)	100–200 (1–2)
Ethylene Propylene	Poor	300 (149)	100–200 (1–2)
Viton	Excellent	400 (204)	10–20 (0.1–0.2)
Silicone	Good	450 (232)	50–200 (0.5–2)
Teflon	Excellent	350 (177)	0.010 (0.0001)
Urethane	Good	160 (71)	100 (1)
Nylon	Good	160–250 (71–121)	10 (0.1)
Polyimides	Excellent	400+ (204+)	500 (5)

2.15.6 Solenoid Enclosures

SOV enclosures can vary considerably, with many non-safety-related valves supplied in general-purpose enclosures. However, water- and dust-tight enclosures (for example, NEMA 4) are preferred since they provide coil protection from splashing, seeping, falling, or hose-directed water and external condensation. Open type enclosures (NEMA 1) provide little environmental protection for the coil or other components inside the enclosure. Certain applications (for example, diesel oil transfer pump areas) may require explosion-proof enclosures, but this enclosure type is also found on many environmentally qualified (EQ) SOVs. In many EQ applications, enclosure sealing is critical to proper SOV operation during accidents. In some cases, special gaskets and conduit seals are required. Figure 2-14(a) shows an EQ SOV with a special conduit seal.

Key O&M Cost Point

At a minimum, use water- and dust-tight enclosures (NEMA 4). EQ applications may require special enclosures and seals.

3
SOV TROUBLESHOOTING AND REPAIR

3.1 Purpose

Section 3 provides a basis for the initial steps in troubleshooting problems of SOV operation. It also provides methods for performing repairs after the root cause has been identified. This section is based on SOV problems that have been identified through a review of INPO Operational Experience events. The complete analysis is shown in Appendix B. The maintenance-related topics that are discussed are important to the proper operation and maintenance of SOVs. Section 3.2 addresses SOV troubleshooting; Sections 3.3–3.16 discuss specific technical issues and provide recommendations.

3.2 Troubleshooting

Troubleshooting is the systematic approach to data collection, failure analysis, and a test/measurement plan that results in high confidence that the complete cause of system/equipment degradation has been corrected and that the system/equipment has been restored to normal operation.

The formal process for troubleshooting has been documented in EPRI's *System and Equipment Troubleshooting Guide* [14]. The process is divided into two main parts: a preliminary evaluation and the formal process of troubleshooting. The discussion of the preliminary evaluation describes the following:

1. Identifying the issue.
2. Defining the problem.
3. Determining and validating operating conditions.
4. Comparing to previous conditions to determine if symptoms adversely affect system/component performance or reliability. If this last step is confirmed, then detailed troubleshooting begins.

Detailed troubleshooting consists of the following:

1. Performing system walkdown and collecting additional system/component data.
2. Identifying failure modes and system effects.

3. Developing and implementing a troubleshooting plan.

4. Determining if results identify the cause(s) of the problem and, if so, performing the corrective actions; otherwise, collect additional data.

5. Determining if the corrective actions restore performance and, if so, confirming if the root cause is discovered, and document; otherwise, collect additional data.

This section of the guide supports steps 2, 3, and parts of steps 4 and 5. Troubleshooting of the following four failure modes, as identified in Appendix B, is discussed:

- Shift failure
- Stroke time
- Spurious shift
- Leakage

Initial troubleshooting should begin with careful observations of several symptoms that can be seen, smelled, or heard. These observations are listed below and should be an integral part of initial SOV troubleshooting. The value of many of these observations is directly related to the experience of the technician. Experience or training can be beneficial, particularly when trying to distinguish normal coil hum from more severe hum or chattering. Similarly, experience with proper and improper SOV operating sounds can help to pinpoint problems without further disassembly or testing.

Initial SOV troubleshooting observations:

- Visually inspect the condition of the valve for signs of obvious damage; loose electrical or piping connections; and possible leakage, including any obvious water, moisture, or chemical deposits.
- Verify that the valve is correctly installed with respect to fluid direction.
- The odor of burned coil insulation is very distinctive. This odor can be detected before the coil enclosure is opened and will become much stronger afterward.
- Visually examine the condition of the components inside the coil enclosure for signs of electrical arcs, physical damage, cracking, or other signs of high temperature and aging.
- Verify that the connections to the valve are correct and in accordance with the electrical schematic. Examine and gently pull on the leads and wires to see if all electrical connections are secure.
- Observe the inside of the enclosure for signs of water intrusion and damage. Rust and water rings are obvious signs of moisture intrusion.
- If the SOV uses an AC coil (with a shading ring) and is energized, listen for the characteristic hum. Excessively loud hum or chattering are indicators of potential electrical or mechanical problems.
- Cycle the SOV and listen for its characteristic clicks.

Key Human Performance Point

When troubleshooting SOVs, ensure that station safety and equipment tagging procedures are carefully followed.

3.3 Shift Failures/Stroke Time Failures

Shift and stroke time failures are related in that a shift failure is simply an infinite stroke time failure. They were analyzed separately to ensure that other mechanisms were not involved; no additional mechanisms were identified. Therefore, troubleshooting of shift and stroke time failures is identical.

3.3.1 Shift/Stroke Time Failure When Energized

Failures to shift from the deenergized to the energized position are not uncommon and can be due to a variety of mechanisms.

Failure Mechanisms

- Electrical problem
  - Coil remains deenergized due to loss of circuit voltage, shorted or open circuited wires or connections, defective control switches, or incorrect wiring
  - Coil is burned up or otherwise open
- Binding internals
  - Presence of foreign material: debris, elastomer particles, or corrosion
  - Lubricant deterioration or wrong lubricant
- Inadequate differential pressure (pilot valves only)

Troubleshooting

The following are some suggested troubleshooting steps:

1. Ensure that voltage is at the coil. Measure voltage at the coil leads.

2. If adequate voltage exists, attempt to measure coil current. (The manufacturer’s literature should be referenced for the proper current value.) Alternatively, place a screwdriver at the top of the bonnet to determine if any magnetism exists. (Use of the magnetic check should be limited to smaller size valves.) If inadequate current or magnetism exists, deenergize the circuit and measure coil resistance. Verify the value against published manufacturer’s literature.

3. Listen for the characteristic SOV click when the valve is energized and deenergized.
   a. If a coil click is heard but the valve fails to operate, verify proper piping, solenoid direction, and system alignment.
   b. For piloted valves, if a coil click is heard, ensure that adequate differential pressure is applied to the valve. Reestablish circuit voltage and attempt to cycle the valve several times.
   c. Listen for the SOV clicks in both the energized and deenergized directions. This attempt at cycling, however, may cause the valve to temporarily function.
4. When mechanical problems are suspected, it may be useful to mechanically agitate (lightly tap) the SOV and repeat the previous steps. This may result in the valve functioning. If the valve functions, then it may help to understand the results of disassembly and to determine the final root cause. It other words, functioning brought about by mechanical agitation should not be considered the repair.
5. If these attempts are unsuccessful, the valve should be disassembled and repaired or replaced. If the valve is replaced, disassemble the failed SOV to determine the failure cause, or retain the SOV for subsequent failure evaluation.

If the valve begins to function properly during troubleshooting, a careful evaluation, including disassembly and inspection, should be performed before it is returned to service permanently. Section 3.10 further discusses several important issues related to continued use of these “unstuck” valves.

3.3.2 Shift/Stroke Time Failure When Deenergized

Shift and stroke time failure when deenergized are not as common as when energized.

Failure Mechanisms

- Coil remains energized due to shorted wires or connections, defective control switches, or incorrect wiring
- Binding internals
  – Presence of foreign material: debris, elastomer particles, or corrosion
  – Lubricant deterioration or wrong lubricant
- Inadequate differential pressure (pilot valves only)

Troubleshooting

The following are some suggested troubleshooting steps:

1. Ensure that the coil has been deenergized. Verify that voltage has been removed at the coil leads. Trip the associated circuit breaker or remove the circuit fuses to ensure that voltage is removed.

2. Verify proper piping, valve direction, and system alignment.

3. For piloted valves, ensure that adequate differential pressure is applied to the valve.

4. Reestablish circuit voltage and attempt to cycle the valve several times. Listen for the SOV clicks in both the energized and deenergized directions. This attempt at cycling may cause the valve to temporarily function.

5. When mechanical problems are suspected, it may be useful to mechanically agitate (lightly tap) the SOV and repeat the previous steps. This may result in the valve functioning. If the valve functions, then it may help to understand the results of disassembly and to determine the final root cause. It other words, functioning brought about by mechanical agitation should not be considered the repair.

6. If these attempts are unsuccessful, the valve should be disassembled and repaired or replaced. If the valve is replaced, disassemble the failed SOV to determine the failure cause, or retain the SOV for subsequent failure evaluation.

If the valve temporarily functions properly during troubleshooting, a careful evaluation, including disassembly and inspection, should be performed before it is returned to service permanently. Section 3.10 further discusses issues related to continued use of these unstuck valves.

3.4 Seat Leakage

Failure Mechanisms

- Presence of foreign material (debris)
  - On seat
  - Blocking disc movement
- Worn/damaged seats
- Binding caused by
  - Elastomer failure
  - Lubricant failure
- Damaged internals

Troubleshooting

The following are some suggested leakage troubleshooting steps:

1. Cycling the valve several times may help to flush debris from internal SOV areas. Blowing down the system through the SOV or back-flushing can also help to clear internal debris.

2. If the leakage does not stop after flushing, initiate disassembly/repair or replacement. If the valve is replaced, disassemble the leaking SOV to determine the failure cause, or retain the SOV for subsequent failure evaluation.

3. If the leakage terminates after the flush/blowdown, establish follow-on corrective actions. The debris may be an isolated particle (for example, weld spatter), or other debris may still be upstream or inside the valve. The debris could also be part of damaged internal equipment. For some soft-seated valves, the debris may be damaged seat material.

4. Review prior maintenance on this and similar system valves. Determine if other corrective actions are appropriate. Refer to the discussion in Section 3.10 on stuck valves for additional alternatives.

Air that continually exhausts from the exhaust port of three-way and four-way air-pilot valves generally indicates a SOV problem. However, the same type of SOV leakage can occur when a piston type actuator downstream of the SOV is leaking air around the piston seal. Before repairing or replacing the SOV, check the actuator for piston seal leakage.

Debris in three-way and four-way air-pilot SOVs can originate from either the air piping or the actuator. When debris problems persistently occur on a particular valve and not on others, the actuator may be the source of the debris. Actuator disassembly and inspection may be necessary. Alternatively, air filters can be placed on both the inlet air and actuator air lines.

3.5 Position Indication

Failure Mechanisms

- Switch not adjusted properly (calibration)
- Switch malfunction
- Weak magnet
- Coil polarity incorrect

Troubleshooting

It is initially difficult to differentiate between some stuck/binding valve problems and position indication problems. Although the valve may sound like it is properly stroking, internal damage or debris may be preventing it from achieving full travel. The following are some suggested position indication troubleshooting steps.

1. If redundant reed switches (for example, two open position switches) exist on the SOV, compare their contact status. If both switches are in the same state, the problem is probably not a defective switch but drift, magnet damage, or a stroke problem.
2. If the switch is failing to close, place a strong magnet next to the switch contact location. Try this with each of the magnet's poles next to the switch. The switch is probably not defective if it can be operated by the magnet.
3. If the indication problem is occurring when the coil is energized, check the polarity of the coil wiring and verify that it conforms to the manufacturer's drawings.
4. Readjust the problem reed switch in accordance with the manufacturer's instructions. Note the dimensional adjustment that is necessary to correct the problem. Additional information is provided in Section 3.6. Alternatively, a stroke measurement could be taken to verify that no internal valve problems are preventing a full valve stroke.
5. If the switch cannot be adjusted, either a different sensitivity switch can be used or the coil polarity can be reversed. Alternatively, replace it with another switch and adjust accordingly.
6. If the problem is not corrected, consider performing a plunger stroke measurement to verify proper SOV stroke. At the same time, check the permanent magnet's strength with a known operable switch.

3.6 Hard-Seated Valve Repairs

When hard-seated SOVs leak, the leakage can be corrected by several means. This includes replacing the discs and/or seats, re-forming and lapping the existing seats or discs, or replacing the entire SOV. Typical field repair to these seats is discussed below.

The most prevalent type of SOV seating design is the angled seat. This seat is found in most globe valves. There are a number of gate type SOVs; however, due to the high-precision finish needed in a gate valve seat, field refinishing of the disc/seat is not recommended. Usually, gate type SOVs or their disc/seats are replaced when they are found to have leaks.

3.6.1 Globe SOV Angled Seats

Angle type seats are the typical seating design on hard-seated globe SOVs. In this seat design, the disc is cut at a slightly sharper angle than the body seat. The difference in the disc and body seat angles causes sealing to occur where the disc and seat intersect. This sealing area occurs in the valve body at the intersection of the seat angle and the seat bore diameter (see Figure 3-1).

Some SOV designs use disc and seat angles that differ by only a single degree, while others rely on larger differences, like 10°.

When the seat and disc angle differences are relatively small (for example, one degree), then the seating surface tends to be much wider than if the angle difference is larger (see Figure 3-1). With only one degree of angular difference, the width of the sealing area tends to range from 1/64 to 1/32 inch (0.38 to 0.76 mm) or more. When the angle difference is 10°, the seal can almost be considered a "knife edge" since the width of the seal is very small.

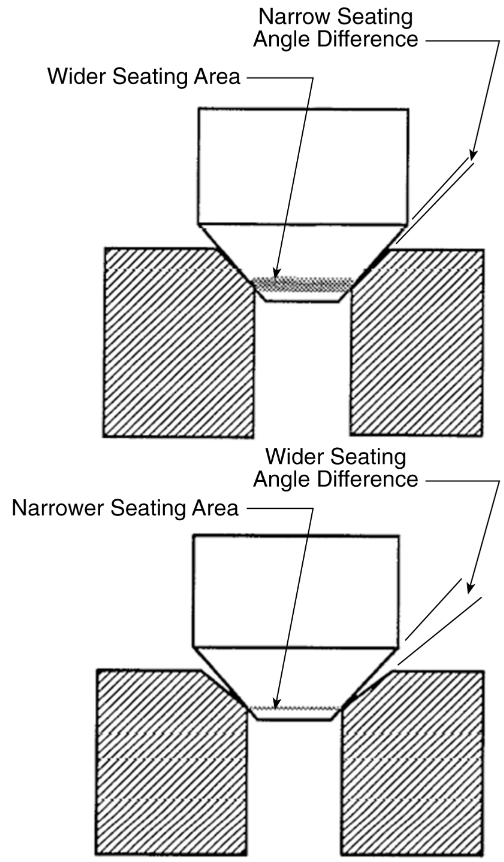

Figure 3-1
Different Angled Globe Seats

This difference in seating design affects the way the disc and seat are repaired and lapped together. Typical repair techniques for Target Rock piloted SOVs and Valcor V526 piloted SOVs will be discussed. Note that this information is provided for illustration purposes. It may vary from the information applicable to installed valves. It does not supersede the manufacturer instructions provided with specific valves unless approved by the manufacturer. Since the Target Rock valves contain a small differential angle (for example, 0.5°–1.5°) and the Valcor valves use a larger differential angle (approximately 10°), this information only illustrates typical differences in seat repair methods.

Refinishing and lapping valve seats is an art that can vary considerably from one valve type to another. Do not attempt to repair a critical valve without prior training or experience.

Key Human Performance Point

Do not attempt to repair a critical SOV seat without prior training or experience. Closely observing others who are skilled in refinishing a particular valve style as well as training and practice are essential to properly refinishing SOV seats.

Tradeoffs must be considered when deciding whether to replace the complete valve, replace only the discs, or rework the existing parts. As a rule of thumb, pilot and main discs represent roughly 15% to 30% of the valve's replacement cost. Machining or grinding existing discs/seats requires skilled personnel and the proper equipment. If an existing valve must be removed from the system to perform repairs, it may be preferable to replace rather than to repair the valve. The difference between the valve replacement cost and the cost to repair may be insignificant when compared to the total cost of removal, repair, replacement, and system testing. Finally, when existing personnel are not skilled in refinishing a particular SOV style, it may be preferable to contract with others (like the manufacturer) who are skilled in SOV repairs.

Virtually all manufacturers supply tool kits containing the proper guides and lapping tools. If a utility fabricates lapping tools and guides, their surface finishes, seat angles, and total indicated runout (TIR) must be within the tolerances specified for the seat and disc surfaces. Manufacturers will often provide tool drawings.

In non-SOV valves, bluing is often used to determine the seat condition. However, bluing may not helpful when examining narrow SOV globe valve seats. SOV seats that appear acceptable by bluing can easily fail leak tests. However, wire drawing and significant damage can be observed visually.

3.6.2 Target Rock Seat Repair (Small Differential Angle)

Examine the disc and seat areas of the body, main disc, pilot disc, and ball rod for evidence of erosion, corrosion, wire drawing, or other damage. The pilot and ball rod seating areas are very small and are best examined under magnification. Significant leakage is usually evidenced by seat/disc erosion, staining, or wire drawing. Since sealing occurs at the edge of the seat, scratches or damage to the bore will prevent proper sealing. Carefully examine the seat bore area immediately below the seat. If there is evidence of damage at the sealing edge, the bore must be resurfaced using a bore lap, or the body must be replaced.

In cases of minor leakage, visual examination may not identify a problem. For minor leakage, the existing main disc and seat can be cleaned up by very lightly lapping them together using extra-fine (1800 and 8000 grit) diamond grit lapping compounds. The disc-to-seat lapping technique is discussed further below. Of course, the disc and seat should be thoroughly cleaned prior to lapping.

If more significant damage is evident, the main seat should be re-formed (through grinding or lapping) or recut and the main disc skim cut or replaced. Many main seat repairs have been successfully performed by simply re-forming the seat through lapping. This should begin with the heavier grit lapping compounds (for example, 180 to 320) and continue until the existing seal band is removed. More significant seat damage generally requires the valve to be cut out and the main seat recut on a lathe. Only the smallest amount of material that is necessary to properly re-form the seat should be removed. Main seat grinding generally is not done in the field. When the main seat is cut, care must be taken to ensure that the valve is properly centered, since runout typically is limited to 0.001 inch (0.025 mm) total indicated runout (TIR).

Damage to the main seat bore is repaired using special lapping tools with a slight taper (for example, 2–3°). The coarser lapping compounds should be used initially, and final lapping should use a 400 grit. Refinishing the bore area at the seat and lapping the seat angle should permit a sharp concentric seal to be formed. More significant damage may require replacing the valve body.

Whenever the main seat is refinished, the main disc should be skim-cut or replaced. The disc must be carefully centered in the lathe, since its runout is also limited to 0.001 inch (0.025 mm) TIR. (This TIR measurement should be taken on the piston diameter.) Only the smallest amount of material that is necessary to resurface the disc should be removed.

Machining or grinding should be as fine as possible with no spiral tool marks. A minimum 32 μin. Ra (0.81μm) finish is specified for the disc and seat surfaces prior to lapping.

Rough to fine main seat lapping should be successively performed with 180, 240, 320, 400, and 600 grit compounds to initially finish the seat after machining. If the seat is machined well, it may be possible to begin with the 400 grit compound. Extra-fine finishing should be done using 1800 and 8000 diamond grit compounds. When finished, the seat should be highly polished with a sharp, clean edge.

Once the main seat is fully lapped, the main disc must be lapped into the seat. This operation is critical to proper sealing. Lapping of the main disc to the seat should result in a narrow band seating area. Generally, the seating area width should range from 1/32 to 1/16 inch (0.8 to 1.6 mm). If the seat is too narrow, foreign material or small scratches can cause leakage. If the seat is too wide, then the decreased seating stress will cause leakage. (As the seating area increases, the seating force per unit area decreases.) Main-disc-to-seat lapping should be done with the extra-fine diamond grit compounds. The procedure outlined below has been used with success.

Target Rock disc-to-seat lapping technique:

1. Clean the seating area of prior lapping compounds.

2. Lap the disc-seat area using a few (for example, 3) dots of the 1800 grit compound. Apply no pressure, using only the weight of the disc, and lap for a few minutes (for example, 2). Clean the seat and disc of the lapping compound.

3. Lap the disc-seat area using a few (for example, 3) drops of the 8000 grit compound. Apply no pressure, using only the weight of the disc, and lap for a few minutes. Clean the seat and disc of the lapping.

4. Repeat the previous step, except only clean the disc after the lapping. The compound that remains on the seat will be used in the next lapping operation.

5. Apply additional lapping oil but no additional compound. Apply no pressure, using only the weight of the disc, and lap for a few minutes. Only clean the disc after lapping. The compound that remains on the seat will be used in the next lapping operation.

6. Repeat step 5 two additional times. Apply additional lapping oil but no additional compound.

Good Practices

The pilot seat on the main disc should be relapped if repair of the main seating surface occurs. Pilot seat lapping should be performed using extra-fine diamond grit compounds. The main disc generally should be replaced if there is more extensive damage to its pilot seat, since it is difficult to machine the small seat area. The pilot disc should be replaced and not skim cut if there is any evidence of damage.

The ball rod seat on the pilot disc should be relapped if repair of the main or pilot seats is performed. Lapping should be performed with the extra-fine diamond grit compounds. The pilot disc should be replaced if there is more extensive damage to its ball rod seat. The ball rod should be replaced if there is any evidence of surface damage or if the ball does not rotate freely. Neither the pilot disc nor the ball rod should be lapped into their seats.

3.6.3 Valcor Globe Valves (Large Differential Angle)

Because of its 10° differential seating angle, the seat width on the Valcor V526 series is narrower than in the Target Rock design. The seating surfaces on the body, main disc, and pilot discs should be examined under magnification for evidence of erosion, corrosion, wiredrawing, or other damage. Seat damage generally will appear as a scratch across the narrow seal "footprint" on the main or pilot discs. Since sealing occurs at the edge of the seat, scratches or damage to the bore will prevent proper sealing. Carefully examine the seat bore. If there is evidence of damage at the seating edge that cannot be removed by cutting the seat, the bore must be resurfaced or the body replaced. Body or pilot seat damage will appear as scratches or nicks at the seat edge.

Repair of the body seat, per Valcor, requires machining, but minor seat damage can also be repaired by lapping with course, fine, and extra-fine lapping compounds. Similar precautions to those discussed in Section 3.5.2 should be followed. Damage to the main seat bore can be repaired using special lapping tools.

Machining of the main disc is necessary when damage to the seating area is evident. Per Valcor, the main disc need not be skim-cut whenever the main seat is reworked. Valcor specifies an 8 µin. Ra (0.2 µm) machined finish for both the main disc and main seat.

The main seat should be lapped after machining. Lapping is initially done with an 80° lapping tool. Lapping at 80° should continue with progressively finer compounds, finishing with an extra-fine 6 micron (0.15µm) diamond grit polishing compound. The objective of this initial lapping is to obtain a sharp clean edge at the corner of the seat. Next, perform a very light finish lap using a 78°–79° tool and 9 micron (0.23 µm) diamond grit with minimal pressure. During this light lap, the objective is simply to "break the edge" of the sharp seat.

Finally, the disc should be lapped into the seat once, very lightly, with a dot of extra-fine (6 micron/0.15 µm) diamond grit polishing compound, to create a small sealing line on the disc assembly.

As a good practice, the pilot seat on the main disc can be relapped if main seat repair occurs. Pilot seat lapping should be performed using extra-fine diamond grit compounds and an 80° lapping tool. The main disc should be replaced if there is more extensive damage to its pilot seat, since machining of the small seat may be difficult. The pilot disc should be replaced but may be skim cut if there is any evidence of damage. The pilot disc **should not** be lapped into the pilot seat.

3.7 Seal Welds (Body-to-Bonnet Joint)

Care in cutting and rewelding the body-to-bonnet seal welds minimizes the potential for leaks. Because the bonnet threads into the valve body, the seal welds need not provide structural strength. Also, care in weld removal and rewelding can significantly increase the number of repairs that may be made before the valve body must be replaced. Manufacturers indicate that approximately five repairs can be made reasonably without replacing the valve body. Virtually all manufacturers of SOVs using seal welds supply seal weld cutters. In cases where special weld preparation is required, the seal weld cutters also perform the weld preparation. If utilities are frequently repairing a number of process SOVs, procurement of a seal weld cutter may be very cost effective.

The seal welds should not be large welds (1/16–3/32 inch or 1.6–2.4 mm). Larger welds make future seal weld cutting more difficult, decrease the number of times repairs can be made without replacing the SOV body, and can potentially damage the valve internals by applying too much heat to the bonnet assembly. Welder training on dummy valves using small weld rods (1/16 inch or 1.6 mm) can also help to prevent excessive weld size.

3.8 Plunger Stroke Information

Accurately determining the total plunger stroke after valve repair is an important way to verify the adequacy of the repair and reassembly. In addition, during troubleshooting, it is often very helpful to know the plunger stroke value. Comparing the measured stroke value against the manufacturer-specified value can help isolate SOV problems. For example, if the plunger is traveling the proper distance but the SOV remains closed, the problem is quite likely a severed main disc pin. Similarly, if the stroke is less than specified, it may indicate internal binding. Measuring strokes can also help determine if leakage problems are due to either debris restricting valve seating or seat damage.

Measuring plunger travel is very difficult for values without position indication. (Plunger travel could be measured and the internals examined using radiography, but this is rarely used.) There is a convenient and simple method available for valves, however, using permanent magnets for position indication. Figure 3-2 shows a simple stroke measuring tool, which can be purchased or fabricated. The tool fits over the portion of the bonnet assembly that contains the position indication's permanent magnet. The tool contains a vernier adjustment, distance scale, and a pinned and balanced indicator needle. The permanent magnet attracts the indicator, which accurately locates the magnet's pole. When the valve is energized, the magnet's position changes. By readjusting the indicator, the magnet's center can again be located. The difference in the two scale readings is the total plunger stroke.

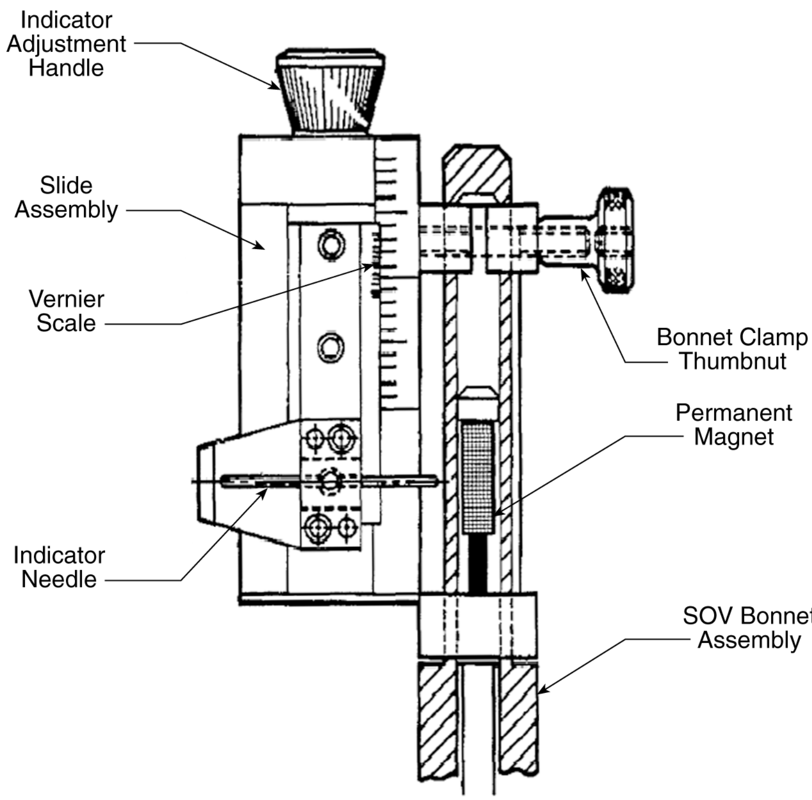

Figure 3-2
Plunger Stroke Measuring Tool [2]

Another very simple method of verifying general plunger movement is to place a paperclip or other small carbon steel object on the bonnet where the clip is attracted and held in place by the permanent magnet. When the SOV cycles, the paperclip will follow the movement of the permanent magnet.

Key O&M Cost Point

Stroke measurements can help during troubleshooting and verify the adequacy of valve repairs. Measuring stroke generally requires a special tool. Strokes cannot be easily measured on SOVs without position indication.

3.9 Position Indication Adjustment

Maintaining reliable operation of the reed switch position indication system has been a recurring problem for many utilities. Position indication problems can be due to misadjustment, binding internals, defective reed switches, loss of the permanent magnet's magnetism, or "drift" due to a combination of these and other causes. For example, some manufacturers have provided heavy-cast steel coil enclosures that must be removed to set the reed switches. Unfortunately, when the cast cover is replaced, it changes the distribution of the magnetic field, and switches that operated properly during adjustment may now be out of adjustment due to the magnetic influence of the cover. It has even been suggested that other iron or steel in close proximity to the SOV can affect the setting of the reed switches.

3.9.1 Problems

The most frustrating problems occur when the position indication appears to work initially but fails shortly after the valve is placed in service. After the valve is in service, high temperatures and differential heating due to coil energization and process temperatures can cause minor changes to the relative position of the reed switch and the magnet. The high temperature may also affect the strength and location of the magnetic field. These combined effects can cause switch settings to drift.

Manufacturers have addressed some of these field problems by modifying switch adjustment procedures and redesigning the reed switch holders. The redesigned holders are intended to make setting switches easier even in difficult plant locations. One manufacturer now offers a vernier reed switch adjustment that should significantly simplify switch adjustments, as shown in Figure 3-3. A second design improvement has been the replacement of cast steel/iron SOV covers with non-magnetic stainless steel enclosures. Several manufacturers also offer different sensitivity reed switches to help address the switch-setting problem.

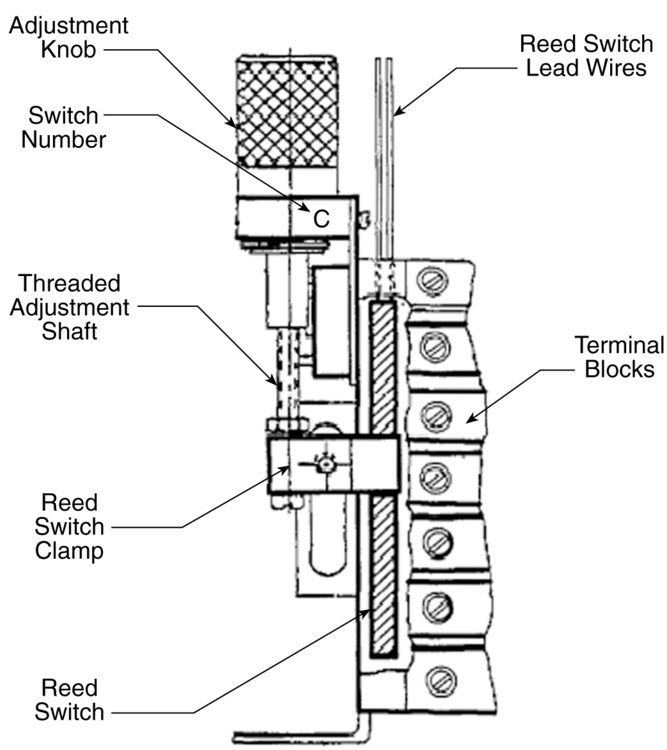

Figure 3-3
Reed Switch Vernier Adjustment Design [3]

These design changes will help to minimize indication problems if they are incorporated into new valves or retrofit onto old valves. Position indication reliability, however, is still heavily dependent on properly adjusting the switches. The following information is intended to provide some helpful advice on switch adjustments.

Key Technical Point

Careful reed switch adjustment is critical to continued reliable position indication.

3.9.2 Reed Switch Basics

Before discussing reed switch adjustment, some basics about reed switches should be reviewed. A normally open magnetic reed switch is simply a switch whose contact closes when a certain strength magnetic field is moved near the switch and opens as the magnetic field becomes weaker. By moving the magnetic field toward and then away from the switch, the contacts can be made to first close and then open. If a magnet is slowly brought closer to the reed switch, a distance “X” (between the magnet and switch) is reached where the switch just operates (see Figure 3-4). The switch remains closed as the magnet is brought closer. If the magnet is then withdrawn, a distance “Y” is reached where the switch will just open. The switch will remain open if the magnet is withdrawn further. The “Y” distance is always greater than “X.” In other words, once the magnet gets within “X,” the switch will close and will remain closed until the magnet is withdrawn to “Y” or beyond. This dead area between the closed and open points is termed *switch deadband* or *hysteresis*.

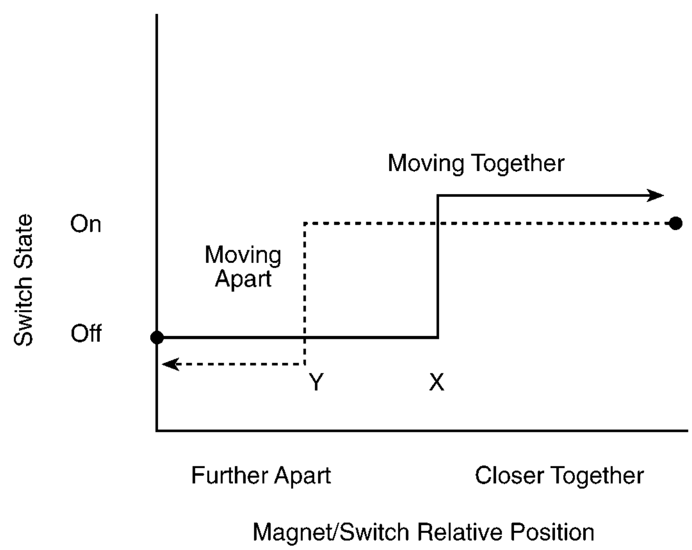

Figure 3-4
Reed Switch Contact Development

Deadband

The deadband distance is based on a variety of factors, including switch design and the radial distance from the magnet to the switch. The closer the radial distance between the switch and magnet, the greater the deadband. The switch deadband for typical SOV reed switches mounted in position on the bonnet is roughly 1/16 inch (1.6 mm). (This value does not consider coil magnetic field influences.) Reed switches can be made with different sensitivities. A lower-sensitivity switch requires a stronger magnetic field (also called greater ampere-turns) to close the switch. Lower sensitivity switches generally have a smaller deadband than higher-sensitivity switches. (Since the switch sensitivity and deadband are related to the contact gap inside the switch, dropping or rough handling can affect both the switch's sensitivity and deadband.)

The reed switch that is closed when the coil is deenergized (typically, the closed position switch) only sees the permanent magnet's field when it is closed. When the coil is energized, the magnet moves away from the closed switch, and the magnetic field strength at the switch decreases. When the coil is energized, however, a stray magnetic field from the coil also exists near the switches. If the coil and the magnet fields are in the same direction, then total magnetic force at the switch may not decrease sufficiently for the switch to open. If the coil and magnet fields are in opposite directions, then total magnetic force at the switch will be much lower. (A similar but opposite effect exists for the switch that is closed when the valve is energized (typically, the open switch).)

When the coil and permanent magnet fields are in opposite directions, the reed switches exhibit greater sensitivity and smaller deadband. As a result, better switch performance is achieved when the coil is wired to the proper polarity. It is important to install and maintain proper coil polarity for proper switch adjustment and stability. Recommendations on ways to ensure correct coil polarity are provided in Section 3.7.

Key Technical Point

Proper coil polarity is critical to adjusting reed switches.

3.9.3 Adjusting Reed Switches

When adjusting reed switches, it is important to adjust the open switches when the valve is open and the closed switches when the valve is closed. The valve is closed when the coil is deenergized in normally closed valves. The valve is open when the coil is deenergized in normally open valves.

Key Technical Point

Adjust the open switches when the valve is open and the closed switches when the valve is closed.

During adjustment, switches should initially be open and then slowly be brought closer to the magnet until the switch closes. The switches should be advanced toward the magnet from the opposite direction from the magnet's travel when the SOV changes state. After the switch actuates, it should be advanced an additional 1/32 to 1/16 inch (0.8 to 1.6 mm) before being secured in place. The amount of this additional advancement should be based on the SOV manufacturer's recommendations, but some amount of advancement should always be used.

Enrichment

The additional movement that is discussed above is intended to provide margin ensuring that the switch will continue to close when operating conditions (for example, higher temperatures, stray magnetic fields, weakening of the permanent magnet, or even replacing a cast iron cover) can alter the actuation point slightly. This final adjustment is often called *enrichment*. Properly enriching the reed switch position is critical to minimizing position indication drift problems.

Be careful when enriching and do not assume that if a little is good, more is better. If you enrich too much, the switch may fail to reopen when the SOV changes state. When the switch is enriched too much, the switch may always be too close to the magnet (that is, it never get beyond its reset point "Y"). Even if the switch opens properly when the indication is adjusted, it may be so close to its deadband point that changes in operating conditions may cause it to drift. In other words, some margin must be provided for both the switch's pickup (close) and dropout (open) points. Ideally, the final position should be in the middle of the deadband between points "X" and "Y." When manufacturers recommend an amount of enrichment, it should have been carefully selected to provide balanced operating margin in both switch-operating directions.

Effect of Enclosures

A cast iron or ferrous enclosure placed over the switches after adjustment may cause drift. If the drift is small and the switches are properly adjusted, misoperation should not occur. If unacceptable drift does occur, using a non-ferrous (300 stainless steel) cover is the preferred corrective action. Another approach is to use a standard cover with selectively drilled small holes or slots that permit access to the switch adjustments. After calibration, this "calibration cover" would be replaced with the standard cover.

Effect of Voltage

One manufacturer's instructions indicate that the operating points of the switch are affected by voltage level, voltage type (that is, AC or DC), the leg of the power source being opened, and the load being carried by the switch. It also suggests that stray fields can affect switch actuation. The impact of these conditions on switch operation suggests that switches will be most reliable when they are adjusted in the field. However, experience suggests that these conditions may be secondary to cast iron cover and high-temperature effects.

Indicating Lights vs. Ohmmeter

The literature from one manufacturer suggests a preference for using indicating lights rather than ohmmeters to monitor the reed switch contacts. This preference apparently stems from the possibility of false ohmmeter indication when the switch is about to change position. Evidently, the indicating light will flicker in this intermediate state, but the ohmmeter might signify either an open or closed condition.

Solving Sensitivity or Deadband Problems

Often, switches cannot be properly adjusted because of sensitivity or deadband problems. Some manufacturers offer switches with high, medium, and low sensitivity. If a switch remains closed and cannot be opened, then a lower-sensitivity (higher ampere-turns) switch should be used. If the switch remains open, then a higher-sensitivity (lower ampere-turns) switch is necessary.

The sensitivity of most reed switches will vary as the switch is rotated. (For example, Target Rock requires that the side of the position switch with the black mark or part number must face the bonnet tube. This ensures the greatest reed switch sensitivity.) Some manufacturers purposely offset the reed switch inside its protective tube. When the switch is rotated, the reed switch moves radially away from the magnet, and its sensitivity and deadband will change. Figure 3-4 (Section 3.9.2) illustrates how the reed switch can be offset inside its housing.

Position indication problems can be associated with the switches, a loss of the permanent magnet's field strength, or improper operation of the valve internals (for example, plunger binding or sticking). If plunger travel is less than specified, the permanent magnet may not have sufficient movement to overcome the reed switch deadband. In this case, it would be impossible to adjust the switches.

Switch Problems

Faulty reed switches can be tested by bringing a magnet (a spare position indication permanent magnet is excellent for this purpose) in close proximity to the switch while verifying switch operation with an ohmmeter or indicating lamp.

Permanent Magnet Problems

During troubleshooting, if at least one of the reed switches is operating properly when the SOV is cycled, then the permanent magnet's strength should be acceptable. However, adequate permanent magnet strength can be verified by sliding a reed switch (that is known to be operable) up and down on the side of the bonnet and observing switch operation with an ohmmeter or lamp. SOV manufacturers and operating experience indicate that permanent magnet problems are rare. However, the magnet's strength can be affected by sharp impact (for example, dropping the magnet onto a hard surface). Since replacement of defective magnets requires valve disassembly, some SOV manufacturers offer devices that can reestablish the permanent magnet's field without disassembling the valve.

Reed switches should be installed symmetrically around the bonnet as shown in Figure 3-5. The symmetrical arrangement helps to develop a radially uniform magnetic field.

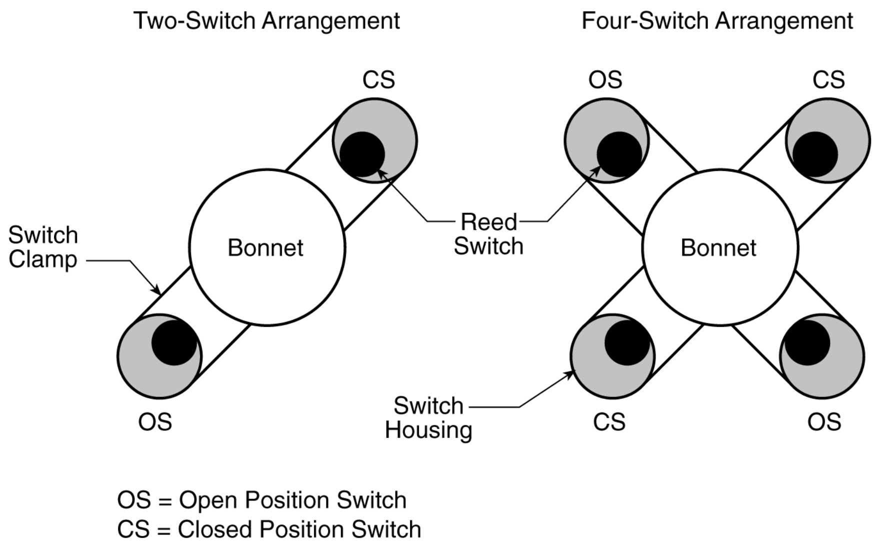

Figure 3-5
Place Reed Switches Symmetrically Around the Bonnet

Most applications require only two reed switches (one open-position switch and one closed-position switch). It has been suggested that when switch-setting problems are encountered, a good idea might be to install four switches. With four switches, there is a better chance that at least two can be made to operate properly; however, if problems are encountered while setting any of the switches, the others might be operating marginally. These other switches are likely candidates for switch drift problems.

Key Technical Point

When adjusting reed switches:

- Carefully follow manufacturer guidance.
- Adjust each set of switches when the valve is in the proper position.
- Set closed switches when the SOV is deenergized and open switches when the SOV is energized.
- Move the switches into the magnet's influence, and monitor switch closure.
- Enrich the switch setting by advancing it some additional distance (see manufacturer's recommendation).
- Replace the cover prior to final switch testing.
- Test proper operation by cycling the valve at least three to six times.

3.10 Coils

3.10.1 Coil Problems

The adage "replacing the coil may not solve the real problem" is true for AC coils, since any valve sticking or internal damage that prevents the plunger from traveling fully can cause excessive AC coil currents and overheating. However, for DC coils and rectified coils, internal valve failures should not result in coil damage.

Environmental stress can also cause coil damage, particularly high ambient temperatures, water, condensation, or very high humidity inside the coil enclosure. Finally, continuous energization, particularly at high ambient temperatures, can substantially shorten coil life.

As a rule of thumb, if the coil is **not** continuously energized, its failure is likely due to internal SOV problems (AC only), water/condensate damage, or excessive temperatures.

Key Technical Point

Coil failures are often caused by other problems. Coils will burn up when AC valves cannot fully open (hum excessively). Water/moisture in the coil enclosure can damage non-molded coils. High temperatures, generally due to continuous energization and high local temperatures, can thermally degrade coils.

3.10.2 Swapping AC and DC Coils

There have been numerous instances in which incorrect SOVs or SOV replacement coils have been installed during maintenance. This generally involves valves that can be supplied in either AC or DC versions. Some manufacturers even use the same SOV model number for both AC and DC versions. As discussed in Section 2, SOVs with AC coils (the type that use shading rings and not rectifiers) have a much lower coil resistance than DC coils with the same voltage rating (for example, 120 volts). In fact, the AC coil's resistance may be only 10% of a similarly sized DC coil's resistance.

When a DC coil is accidentally used in an AC application, the SOV generally will not operate or will barely operate because of inadequate coil magnetic force. However, if an AC coil is used in DC applications, the coil will continuously draw a current greater than the in-rush current in an AC application. As a result, the DC SOV with the AC coil will operate when energized. However, the excessive coil current will soon cause coil overheating, and the coil will quickly burn up. The excessive heat may also damage other valve internal parts.

Key Technical Point

AC coils can work in DC applications but will overheat and burn up after being energized for a relatively short time.

Two methods are recommended to minimize this problem. The first involves verifying that the valve nameplate properly specifies the correct voltage. This includes both value (for example, 120 volts) and type (for example, AC or DC) during installation. The second method requires measuring and comparing the replacement coil's resistance to the known resistance value of the correct coil. Because AC and DC coil resistances vary considerably, this is a simple and convenient way of preventing the wrong coil from being installed. When replacing coils, reliance should be placed on part number verification and a coil resistance check. Requiring that the SOV nameplate data (or coil part number) and coil resistance be recorded on an installation data sheet will also help to ensure that the data is collected and verified.

Key Technical Point

Make sure that the replacement coil has the correct part number. Check the coil resistance, and compare it to specified values. AC coils have about 1/10 the resistance of similar DC coils. Requiring that the SOV nameplate data (or coil part number) and coil resistance be recorded on an installation data sheet helps to ensure that the data is collected and verified.

3.10.3 Coil Polarity

Any SOV will correctly cycle when the coil lead polarities are reversed, since the coil produces the same magnetic pull with current flow in either direction. However, experience has shown that reversing the coil leads can significantly affect the performance and sensitivity of position-indicating reed switches (see discussion in Section 3.9). Normally, when the coil's magnetic polarity opposes the permanent magnet's polarity, the leads are properly connected. Coil polarity always refers to the coil leads. For DC circuits, the leads are connected to the incoming power source (+) and (-) connections. For AC circuits, the leads are connected to the (+) and (-) rectifier terminals. (This refers to valves using rectified coils for AC applications.)

Determining Polarity

One method for determining polarity involves first measuring the actuation point of the reed switches closest to the coil with the coil energized in one direction and then again with the coil polarity reversed. (Since the closed position switches are closest to the coil, they are most affected by the coil's magnetic field.) The correct coil polarity is the one that causes the closed position reed switch to actuate at a point closer to the permanent magnet (that is, the actuation point is further up the bonnet).

Another method is employed when replacing a coil. If the closed reed switches do not properly operate, then either reverse the polarity of the coil leads or replace the switches with lower-sensitivity (higher ampere-turn) reed switches. This method assumes that the coil leads were properly wired at the factory, and polarity was properly observed during installation.

An alternative to either of these cumbersome methods is to ensure that the coil leads are properly marked before installing the coil and then verify that the leads are properly connected to either the field wires or the rectifier terminals. A simple coil polarity test involves energizing the coil (ideally, not installed on the valve) at full or reduced voltage and placing a compass near the top center of the coil. If the compass NORTH-seeking pole points toward the top of the coil, then the polarity is correct. If the compass NORTH-seeking pole points away from the top of the coil, then the polarity is reversed. Coil lead polarity should be verified and correctly marked based on the test. This simple test can minimize testing and adjustment problems after the coils are installed.

Do not bring the compass further into the coil's magnetic field than necessary to verify polarity. It might be possible for strong coils to remagnetize a cheaply made compass if the magnetic field is too strong. It is important for the compass to be placed near the top, and not the bottom, of the coil. If the test is performed on the bottom, the test results will be reversed.

Key O&M Cost Point

A simple coil polarity test can be done, using a compass, prior to mounting the coil on the SOV.

3.11 Lubricants

SOV lubricants are principally used to facilitate assembly or to reduce the friction of the internal moving parts. It is important to carefully evaluate deviations from manufacturer-recommended lubricants because similar lubricants can have significantly different effects. Excessive lubrication has been known to promote SOV failures by retaining process-borne debris, migrating to critical valve areas, or both.

Lubrication as an assembly aid generally applies to O-rings or similar types of elastomer seals. The most common O-ring lubricants are silicone based. However, silicone lubricants should not be used on silicone O-rings. The silicone lubricant interacts with the silicone O-ring material and causes it to deteriorate and swell. Similarly, fluorinated silicone fluids and greases should not be used with fluorosilicone O-rings. In addition, several manufacturers do not recommend the use of silicone lubricants on fluorosilicones. As a rule of thumb, do not use lubrication fluids or greases with a base compound similar to the O-ring material (for example, silicone grease with a silicone O-ring). It is also possible for silicone lubricants to cause shrinkage of low-temperature nitrites.

Key Technical Point

Do not use silicone fluids or grease to lubricate silicone O-rings.

Table 3-1 lists generally recommended lubricants for common seal materials. However, avoid making changes from the manufacturer's recommended lubricants without first consulting the manufacturer.

Ethylene propylene-based compounds (EPRs) are not compatible with petroleum-based and some synthetic lubricants. Petroleum products cause EPRs to soften and swell. Importantly, none of the recommended O-ring lubricants are petroleum-based products. Normally, petroleum-based lubricants should not be used on O-rings unless they are specifically recommended by the manufacturer. If the recommended lubricants are not available and compatibility with other lubricants has not been determined, the safest course of action is to use water as an assembly aid lubricant. Nitrile (Buna-N) and Neoprene are exceptions, since these materials are generally resistant to petroleum degradation. However, low nitrite content Buna-N is more susceptible to petroleum attack.

Key Technical Point

To be safe, do not use petroleum-based lubricants except if required by the manufacturer. NEVER use petroleum-based lubricants with ethylene propylene-based compounds.

Table 3-1
Generally Recommended O-Ring Lubricants

O-Ring Material	Recommended Lubricant
Group A	Group A
Silicone	Fluorinated oil (Krytox) or water
Fluorosilicone	
	Group B
Group B	Silicone-based fluid/grease
Fluoroelastomers (that is, Viton)	
Natural rubber	
Neoprene	
Nitrile (Buna-N)	
Ethylene propylene	
Urethane	
Butyl	

The lubricants that are recommended by SOV manufacturers for internal metal parts in most process SOVs are generally dry type lubricants containing either graphite or molybdenum disulfide. Do not use grease type lubricants where dry types are specified. Generally, either graphite- or molybdenum disulfide-based products are considered acceptable. If in doubt, check with the manufacturer.

Lubrication of sliding seals is necessary to minimize sliding friction and the possibility of sticking seals. These seals exist on balanced plug, spool, and piloted piston type SOVs. The seals are generally O-rings, but U-cups, T-rings, and other seals can be used. Many of these dry type lubricants contain a carrier (for example, isopropyl alcohol) that quickly evaporates after application.

Overlubrication can be almost as harmful as no lubrication. The following guidelines can assist in determining the proper amount of lubricant. Do not apply more lubricant if the valve is sticking or malfunctioning after assembly. The problem is not the lubrication.

Key Human Performance Point

Overlubrication can be almost as harmful as no lubrication. Sticking is rarely caused by inadequate lubrication. Do not overlubricate to solve the problem.

General Lubrication Guidelines

- Static seals: Lubricant is only necessary to aid in assembly. When applying lubricant to static seals, a very thin film is all that is needed. You should not even see the lubricant on the surface except for the polish it gives to the O-ring. Remember, in some cases, a little water is an adequate lubricant. Use this to judge how much lubricant to apply.
- Sliding seals: Sliding seals require more lubricant than static seals, but not much more. Rather than a film, sliding seals require a thin coating.
- Dry lubricants: Sufficient lubricant should be applied to give a dull-gray finish to the surface after the carrier has evaporated.

3.12 Pipe-Sealing Compounds

The misapplication of thread tapes and other piping thread sealants can also cause excess material to become lodged in critical areas inside SOVs. This problem occurs most frequently on air-pilot SOVs.

As discussed above, the excess application of sealing compounds can place foreign materials inside SOVs. Particular care must be exercised with SOV applications because of the relatively small clearances and openings in the valve and the low solenoid forces. In order to keep the compound out of the piping system, only apply it to the male threads of fittings. Generally, do not apply the compound to the first two or three threads of the fitting.

Key Human Performance Point

Do not apply adhesives or sealing compounds to the first two or three threads of a fitting.

3.13 Air Filtration

Air filtration is really a problem only for those SOVs that function as air pilot valves: for example, those that control air to another device such as an AOV. Air filtration is a problem when there is no local air filter and foreign material migrates from the instrument air system. The ISA *Quality Standard for Instrument Air* [3] requires that instrument air have a maximum particulate size of 40 microns (40 micrometers). This is not at variance with most SOV manufacturer specifications; it appears that the quality of the instrument air system is a problem. Therefore, this guide recommends that particulate air quality no greater than 40 microns be supplied to the SOV. However, other equipment, such as positioners, may specify lower values. This may require installation of local filters, and for critical applications, this is recommended.

3.14 Unstuck Valves

There are a variety of opinions about the continued use, without disassembly and repair, of SOVs that exhibit sticking or misoperation. The valves that function after repeated cycling attempts, after light tapping on the SOV, or after some time period are of primary concern. Subsequent failures of some of these valves often occur within a relatively short time (six months), while others apparently do not experience further problems. These mixed results can be traced to a lack of root cause determination of the failures. If the sticking is due to process contamination/debris becoming lodged in the valve seat or plunger area, then clearing the debris from the valve by repeated cycling attempts, blowing down the system, or backflushing can resolve the immediate concern. Of course, there may be additional contamination/debris ready to cause the valve to stick again.

Sticking can be due to prolonged SOV inactivity, particularly if the valve is in a system that contains debris or is a soft-seated or balanced disc design. (Over time, soft seats can flow into the valve orifice and stick. Balanced-disc SOVs use a sliding seal O-ring that is subject to sticking.) The valve can "loosen up" after repeated cycling attempts or a sharp tap and then function normally for some additional period of time. Periodically cycling the valve may be sufficient to remedy the problem. However, if the valve once again remains in one position for an extended period, the sticking may reoccur.

Other more significant problems can cause a valve to stick. Soft seats can deteriorate with age, break off in chunks or pieces, and clog the valve. Sticking can also be caused by wear, fretting, galling, or misalignment of internal SOV parts. Sometimes repeated SOV cycling or troubleshooting can marginally improve this damage for a short period. However, it is likely to reoccur. Finally, process contaminants or debris may cause internal parts to adhere to each other. This sticking may be corrected temporarily by tapping the valve but can quickly reappear if the valve remains in one position. Utility laboratory tests of one air-pilot valve design confirmed that sticking reappeared for most valves after being energized for two days to two weeks.

Key O&M Cost Point

When a previously stuck SOV is not operating properly, the safest action is repair or replacement of the SOV. Other actions may be appropriate, however, based on function, safety significance, and other available failure information. Without repair or other corrective action, unreliable SOV operation can be expected.

Unfortunately, without disassembling the valve and determining the likely cause, sticking may reappear. This uncertainty may or may not be acceptable based on the application and its safety or power production significance. The most conservative course of action is to repair or replace the valve after it sticks, but a variety of other maintenance alternatives are possible. The following options are available when a valve is known to stick but now is operating:

- Replace
- Disassemble, inspect, and repair
- Blowdown or backflush process system and valve

- Increase inspection/surveillance frequency
- Conditionally accept and replace/repair as soon as is practical
- Evaluate using conditioning monitoring techniques
- Use maintenance history to evaluate cause, and respond accordingly

Selecting the appropriate options, singly or in combination, should be based on a variety of factors including operating history, safety or power production significance, availability of parts or new valves, application limitations, and equipment/personnel capabilities. The following should be considered:

- Replacement is the most obvious option. However, if process system contamination is the root cause, simply replacing the valve will not solve the problem. A new valve is less likely to stick than an existing valve that has been degraded by contamination.
- Condition monitoring techniques generally are not available to determine the root cause without disassembly.
- Maintenance history information on this and similar valves can be used to assess the likely cause. (In this context “similar” means both valve and application (for example, process SOVs in the Service Water System or SOVs in the instrument air system).) Unfortunately, this information may not be readily available. Information from other plants or applications can be acquired through the manufacturer, EPIX, or similar sources.
- Conditional acceptance and subsequent repair/replacement combined with some of the other measures, such as increased surveillance and a maintenance history review, may be the best alternative if immediate replacement/repair is not feasible.
- The only causes that may justify not repairing or replacing the SOVs when they appear to be sticking are those due to lack of periodic cycling or minor particulate debris. However, some basis for concluding that these are the actual sticking causes must be available. In most cases of particulate debris, inspection and cleaning is warranted.
- If increased surveillance prevents recurrence and surveillance is reduced, sticking may reoccur if lack of periodic cycling is the root cause.

3.15 Rebuilding with Proper Parts

When SOVs are rebuilt, particularly the small air-pilot SOVs, ensure that the correct spares are used. The small air pilot valves are often supplied in a variety of sizes, voltages, and pressure ratings within a particular valve style. While the valves may appear identical, the internal parts vary within the style from one model number to another. Although many of these parts appear interchangeable, small design differences can exist. For example, the springs in most valves vary depending on the construction (for example, normally open, normally closed, or universal), coil type (AC or DC), the internal orifice size, and the maximum pressure rating. If the springs from another “similar” valve or parts kit are used, unpredictable operation may result. If the incorrect springs or other parts are used during a repair, the valve may work initially, but small changes in operating conditions, such as pressure, temperature, or prolonged energization, can cause it to fail prematurely.

Key Human Performance Point

Within a particular SOV style, parts may look similar but actually differ among model numbers. This can be especially true with the springs in air-pilot valves.

For special process type SOVs, instruction manuals and drawings generally provide specific part number information. Unfortunately, for the air pilot valves and the smaller, commercial, in-line SOVs, this information is not readily available from the nameplate, drawings, or instruction sheets. In these cases, manufacturers or distributors must be contacted to identify repair kit and replacement coil numbers. These part kit numbers are based on the SOV model number and coil voltage, including AC or DC designation. In some cases, SOV serial numbers can also be used to order kits.

Discussions with several of the manufacturers indicate that most repair kits do not contain information that uniquely identifies which specific SOV models use the kit. At best, the kit may identify the model series but not the full model number of the installed valve. Complicating matters further is the fact that two valves with exactly the same model number but with different coils (that is, one uses an AC coil and the other a DC coil) can have different repair kit numbers. Finally, except for coils, individual parts are so small that identification numbers cannot be imprinted on them.

Key O&M Cost Point

Cross-references between repair kit numbers and valve model numbers may not be supplied in SOV manuals. Even valves with identical model numbers, but supplied in AC and DC versions, can have different part kits. Verify the proper kit numbers using documents or discussions with distributors or manufacturers.

Except in cases when the parts clearly do not fit, it may be difficult for maintenance technicians to verify that the correct repair kits have been provided to them. The general recommendations provided below can be used to minimize part replacement problems.

Strategies to Minimize the Use of Wrong Parts

- If parts are marked with numbers, verify that the replacement part has the same identifying number as the part being replaced.
- Compare replacement parts to those being replaced and note differences that may suggest that the wrong part might have been supplied.
- Measure the resistance of replacement coils and compare to the expected value. (See additional discussion under Section 3.7.2.)
- Develop a maintenance aid that specifies the repair kit and coil referenced to SOV model numbers and coil voltages for installed SOVs. Even more detail can be provided if repair part numbers are cross-referenced to specific SOV plant identification numbers.
- Specify the repair kit and coil numbers in repair procedures. Record the repair kit and replacement coil numbers on maintenance data sheets.

3.16 Post-Maintenance Testing

EPRI Report NP-7213, *Postmaintenance Testing: A Reference Guide* [2] provides program and technical guidance on post-maintenance testing (PMT). As discussed in that report, the level of PMT must be commensurate with the maintenance being performed. Further, PMT should be performed to:

- Verify that the original deficiency has been corrected, and
- Verify that the equipment performs its intended functions based on design criteria.

The PMT guide categorizes testing into the following four levels:

- **Maintenance tests** that demonstrate that the original problems are corrected and that no new problems (as a result of the maintenance) exist. This can include inspections and tests of internal components.
- **Run/operational tests** that demonstrate that normal operation has been maintained.
- **Functional tests** that demonstrate that the equipment is completely capable of performing its design functions.
- **Special tests** that do not fit into the previous categories. These tests might include integrated equipment or system tests, condition monitoring or baseline tests, and predictive maintenance tests.

Although these testing categories are appropriate, Table 3-2 classifies PMT based on typical SOV maintenance categories and discusses the types of tests appropriate to each.

Table 3-2
Maintenance Activity Groups

SOV replacement generally involves replacement of the entire SOV.
Coil replacement or removal does not involve components inside the pressure boundary. Coil removal may involve disturbing other components such as position switches.
Position indication repair includes calibration or replacement. This category is limited to those components outside the valve's pressure boundary.
Pressure boundary disassembly does not include disassembly, repair, or replacement of internal parts.
Internal repairs include disassembly of any internals and repair or replacement of defective parts.
Miscellaneous electrical components include repair, inspection, or replacement of electrical components within the coil enclosure.
Tightening of fittings also includes gaskets or other pressure boundary closures.
Upstream repairs of the piping system or components.
External electrical repairs include component or interconnecting wires/cable repairs and adjustments or replacements when the components are electrically connected to the SOV coil or position-indication circuitry.

When SOV maintenance is performed, the tasks fall into one or more of these repair groups. Tasks in more than one group are often necessary, even though they may not be directly related to the original need for maintenance. For example, reed switches generally must be removed, replaced, and recalibrated when a coil is replaced. Further, if a valve is removed from the piping system to perform internal seat repairs, repair activities will fall into most of these groups.

General PMT inspection/test categories that are appropriate for SOVs are identified in Table 3-3. Within each category, the methods can vary substantially based on the valve's design, repair scope, and application requirements. The PMT inspections/tests that are selected after a particular repair should be based on the repair activities' effect on valve operability and the original reason for the maintenance action. Possible effects on valve operability can be identified by considering what could reasonably go wrong with the valve if any of the maintenance actions were incorrectly performed. For example, a leakage test or hydrotest is unnecessary for most valves when a coil is replaced. Since coil replacement does not involve the valve internals or pressure boundary, even using the wrong coil should not affect leakage or pressure boundary integrity. PMT must demonstrate that the repair was effective. For example, after coil replacement, a cycle test is appropriate. Obviously, after seat repairs, an internal leakage test should be performed. In general, a cycle test should be performed after each repair. Section 4 discusses, in detail, the potential use of condition monitoring and diagnostic tests for SOVs.

Key O&M Cost Point

PMT inspections/tests should be based on the possible effects of the repair activities on SOV performance and the original reason for the maintenance action.

Table 3-4, utilizing the maintenance groups in Table 3-2 and the maintenance/inspection categories in Table 3-3, suggests appropriate PMT inspections/tests based on the type of maintenance performed. The maintenance/test abbreviations used in Table 3-4 are identified in brackets in Table 3-3.

Table 3-3
SOV Post-Maintenance Inspection/Test Categories

Valve cycling by energizing and deenergizing the SOV several times and observing proper operation. Generally, the SOV is not pressurized during the testing. [**VC**]
Plunger stroke distance measurement [**PSM**]
External leakage inspections using soap solutions or other appropriate methods. [**EL**]
Valve cycling, pressurized, by energizing and deenergizing the SOV at rated or system pressure several times and observing proper operation. [**VCP**]
Position indication verification by valve cycling. [**PIV**]
Coil electrical tests, including coil resistance, current, and high potential or insulation resistance (meggar) tests. (High potential tests are generally not performed, since they are often considered to be cumulatively destructive tests.) [**CET**]
Hydrotesting per system and piping criteria. [**HT**]
Internal leakage, including local leak rate testing. [**IL**]
Flow monitoring/measurements [**FM**]
General inspections [**GI**]
Condition monitoring/diagnostic tests [**CMD**]

Table 3-4
Suggested Post-Maintenance Tests

Maintenance Task Group	PMT Category Codes
SOV Replacement	VCP, EL, IL, HT, PIV
Coil Replacement	CET, VC
Position Indication Repair	PIV
Pressure Boundary Disassembly	VCP, HT, EL
Internal Repairs	VCP, EL, IL, HT, PIV
Miscellaneous Electrical Components	CET, VC, PIV
Tightening of Fittings	VC, EL
Upstream Repairs	VC, FM, IL
External Electrical	VC, PIV

3.17 Other SOV Maintenance Considerations

3.17.1 Orientation

The valve's orientation (for example, mounting position) should be in accordance with manufacturer recommendations and limitations. The operation of some SOVs can be seriously affected by orientation. For these valves, proper orientation is an important installation requirement. For example, some SOVs use gravity to assist in operating the plunger. These valves are typically mounted with the coil axis vertical and pointing up. When SOVs are qualified (either seismically or environmentally), there may be orientation requirements associated with the qualification.

Key Technical Point

In general, the best SOV operating position is with the coil and plunger upright and vertical. If the SOV is qualified, this position must be verified in order to ensure operability.

3.17.2 Port Connections and Flow Direction

SOVs are typically designed for flow in one direction only. Many valves have a flow arrow on the body or identification markings for the ports (for example, INlet and OUTlet). For three-way and four-way valves, these markings often describe the port's typical connection (for example, PRESSure, CYLinder, and EXHaust).

Unfortunately, some three-way and four-way valve bodies are used in a variety of models and have ambiguous markings like “A,” “B,” and “C.” Therefore, always refer to the manufacturer's instruction manuals or catalogs to determine the proper connections for these ports. Appendix F explains the standard ANSI symbols and typical manufacturer SOV sketches that are often used to indicate the proper connections of SOV ports.

4
CONDITION MONITORING AND PREVENTIVE MAINTENANCE

4.1 Purpose

This section complements the troubleshooting and repair information in Section 3. Section 4's initial sections address SOV diagnostic techniques, periodic parts replacement, and general inspection methods. Based on this and the information in Section 3, general SOV maintenance recommendations are provided in Section 4.7.

4.2 Equipment Failures and Condition Monitoring/Preventive Maintenance

The failure rate of mechanical components, including SOVs, is often described by the classical "bathtub" curve shown in Figure 4-1. The curve is broken down into three regions: *infant mortality, normal failure rate,* and *wearout.* In the infant mortality portion of the curve, equipment experience higher rates of failure because of defects in manufacturing, application, installation, or operation. After these defects, if any, are corrected, components typically experience relatively trouble-free operation during the normal failure rate portion of the curve. At some point, the equipment begins to experience an increasing failure rate as the old equipment simply wears out. This is termed the *wearout* portion of the curve.

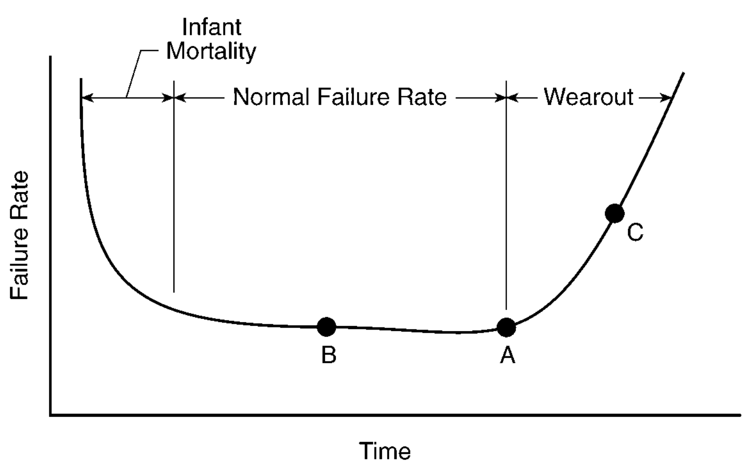

Figure 4-1
Bathtub Failure Rate Curve

The beginning of the wearout phase will vary based on equipment design and use. Examples of SOV wearout conditions are brittle and leaking soft seats, wiredrawn hard seats, cracked diaphragms, thermally degraded coil insulation, and excessive accumulations of process-borne debris.

One objective of maintenance is to repair or replace equipment before it experiences the increasing failures associated with the wearout portion of the bathtub curve. The challenge comes in determining the right time to repair or replace the equipment. Point “A” in Figure 4-1 depicts the ideal time to rebuild or replace. If the action is performed at point “B” instead, then replacement occurs too frequently. This can be wasteful of resources and costly, although, generally, it is appropriate to be somewhat conservative when selecting repair times. Too-frequent repairs can affect short-term reliability, since with each replacement, the possibility of infant mortality is introduced. Alternatively, replacement/repair at point “C” compromises performance because the equipment is operating well beyond its useful life, and the possibility of failure increases.

Two general methods are available to help to identify when equipment is in the region near point A and then to initiate timely refurbishment/replacement. The first, called *predictive maintenance* or *condition monitoring,* attempts to determine if the equipment condition is indicative of the condition near point A. The decision to repair or replace is based on comparing the value of the measured condition to some predetermined minimum acceptable value. Alternatively, the value can be trended over time and the repair initiated when the trend suggests that the wearout phase is occurring.

The second method involves simply defining a calendar (for example, 5 years) or operating time (for example, 10,000 hours of operation) when the equipment will be refurbished or replaced. This calendar or operating time is selected based on experience, SOV design, and the severity of the application. No *in situ* measurements are performed. The SOV is simply rebuilt or replaced at the selected time.

These two techniques can be illustrated by considering the replacement of automotive tires. Condition monitoring would involve periodically measuring the tread thickness and replacing the tire whenever a minimum amount of tread remains. Operating time replacement would be replacing the tires every 50,000 miles.

Condition monitoring is preferred because it requires repair actions only when they are necessary. Since a variety of factors, including road condition, tire pressure, and driving style, affect tire wear, replacement of tires based on operating time is a very imprecise method of determining when the tire should be replaced. Like tires, SOVs and other plant equipment will degrade at different rates depending on a variety of application factors. Without prior operating experience for a specific set of conditions, the replacement interval must conservatively bound the worst set of assumed conditions.

Key O&M Cost Point

Preventive maintenance based on calendar time is imprecise, since a variety of factors affect degradation and wear. Without operating experience, replacement intervals must conservatively bound the worst set of assumed conditions.

4.3 SOV Condition-Monitoring Techniques

The following tests are recommended for inclusion into SOV corrective or preventive work practices. When properly applied, they can help to determine the general condition of the SOV. None of these methods has been established as a proven SOV condition-monitoring technique by itself. Rather, they are suggested as standard maintenance tests and should be used collectively as resources allow.

4.3.1 Coil Electrical Tests

The most common type of coil insulation test is the insulation resistance (IR) test. Coil IR tests are an excellent method of quickly determining the general condition of SOV coils. Coil IR tests should be performed whenever valves are rebuilt. Coil IR measurements should also be considered during troubleshooting and corrective maintenance. This test determines the general condition of the insulating system by measuring the resistance between the system and ground at voltages (for example, 500 Vdc) that are generally higher than the operating voltage of SOVs. The results are sensitive to winding temperature and are often corrected to a common reference temperature. Insulation resistance tests can help to identify when a winding has been degraded by prolonged temperature and humidity degradation. As a result, it is a good practice to measure winding insulation resistance whenever major valve repairs are performed. Care must be exercised to isolate rectifiers/diodes during the test, or damage may result.

Key O&M Cost Point

Coil insulation resistance (IR) tests are an excellent method of determining the general condition of SOV coils. Coil IR tests should be performed whenever valves are rebuilt. They should also be used during troubleshooting and corrective maintenance.

4.3.2 Coil Pickup and Dropout Voltage Tests

When utilities repair valves, the SOVs are generally cycled at normal voltage to determine if they are operating properly. Because of the margin designed into SOVs, internal problems may exist, but the valve plunger will appear to cycle properly at rated voltage. Rather than cycle the valve at normal voltage (for example, apply 125 Vdc and then remove all voltage), manufacturers often perform more refined tests (pickup and dropout voltage tests) to determine if the valve is performing properly.

SOVs, depending on their design, generally pick up, that is, go from the deenergized to the energized position, at 50–75% of rated voltage. Dropout voltages similarly vary. Valves with 125 Vdc coils typically drop out (that is, go from the energized to the deenergized position) at voltages ranging from 5–40 volts. If, after repair, a valve requires 90% of rated voltage to pick up, this suggests a possible problem with the valve internals, the coil, or the magnetic circuit. Similarly, should the valve drop out at a lower-than-anticipated dropout voltage, internal binding or sticking may be the cause.

Key O&M Cost Point

Pickup and dropout cycle tests are preferred to normal voltage valve cycling, since they provide a better gauge of valve condition.

A better test of the valve's condition and the adequacy of repairs is to test the valve at minimum specified pickup voltage. Generally, the SOV should be at rated pressure during this test because of the additional magnetic force that is required to overcome the pressure seating force (in some SOV designs, pressure may aid in unseating the SOV). When performing these tests, the valve should be cycled and the data recorded several times to ensure reproducible operation. The average of the readings is then recorded.

It also may be possible to periodically trend pickup or dropout voltage for problem valves. When pickup voltage values increase over time, it suggests that additional force is being required to unseat the valve. Dropout voltage can similarly be tested, although variations may not be as significant. If contaminants are suspected of holding the plunger in the energized position, the dropout voltage test may be used to identify the potential for this type of sticking failure. In addition to trending the data for an individual valve, data comparisons can also be made among valves with similar model numbers.

These tests may be difficult to perform or interpret on AC coil SOVs because of the chattering that occurs just prior to the valve changing state. More reproducible information could be developed if the valve is energized with a DC current to produce an equivalent magnetic flux. This must be performed carefully, however, since energizing the AC valve at the same voltage from a DC source can cause valve damage. AC coil valves might only require 10% of rated voltage when operated from a DC supply to produce the same magnetic flux. Information must be requested from the manufacturer on the DC voltage/current that is necessary to produce the equivalent operating and holding ampere-turns for these AC coil valves.

(As an approximation, DC normal operating voltage is roughly equal to [in-rush VA] * [coil resistance]/[rated AC voltage]. Minimum pickup voltage would be some percentage of this value. The equivalent DC voltage should be applied only momentarily to the AC coil. The test circuit should be designed to minimize voltage spikes when the coil is deenergized.)

Alternatively, the AC voltage could be applied in gradual steps. If it is possible to collect the pickup and dropout operating speeds, they also may be useful in analysis. Changes in these values with time can also suggest coil degradation, excessive wear or binding of internal parts, onset on sticking or debris buildup and, therefore, can corroborate conclusions that are gathered from the changes in voltage.

4.3.3 Temperature Measurements

The use of infrared thermography, measurements of coil resistance, or other temperature measurement methods can be used to determine valve component temperatures. (See C.4.5 for calculations.) EPRI NP-6973, *Infrared Thermography Guide* [2], provides condition-monitoring information.

Excessive coil temperatures could indicate coil degradation or, for AC valves, the existence of internal binding or debris accumulation. Higher-than-anticipated temperatures may suggest that more frequent replacement of coils may be necessary. (Recall the 10°C rule.)

4.3.4 AC Coil Operating and In-Rush Current Measurements

For AC valves, variations in normal operating current may indicate internal binding or debris accumulation. The current changes would result because internal debris would prevent intimate contact between the plunger and the stop. (See Section 2.4.2 for additional discussion of AC type coils.) Similarly, measurement of current in-rush changes could provide information on the wear/binding of the internals when the coil is energized and deenergized.

4.3.5 Internal Leakage Measurements

After any internal repairs, it is advisable to perform a seat leakage test. The test method and arrangement will vary based on a number of factors, including whether the valve was removed from the piping system in order to perform the repairs.

In applications with either critical SOV internal leakage requirements or known leakage problems, trending of the leakage data may be one method of estimating when seat repairs will be required. However, seat leakage tests are not generally trended.

4.3.6 Flow Tests

Like leakage measurements, flow tests should be performed after SOV internal repairs or disassembly. The flow test helps to ensure that the internals are properly assembled, the valve is operational, and there are no internal obstructions in the flow path.

If air-pilot valves are repaired, bench testing can easily be performed. One method of verifying the adequacy of the air-pilot SOV repairs and flow capability is to measure SOV flow and differential pressure. This information can then be translated into an equivalent flow coefficient (C_v) and verified against published manufacturer data. Values that are similar to the published data should be considered acceptable. Figure 4-2 is a sketch of a typical SOV flow test arrangement.

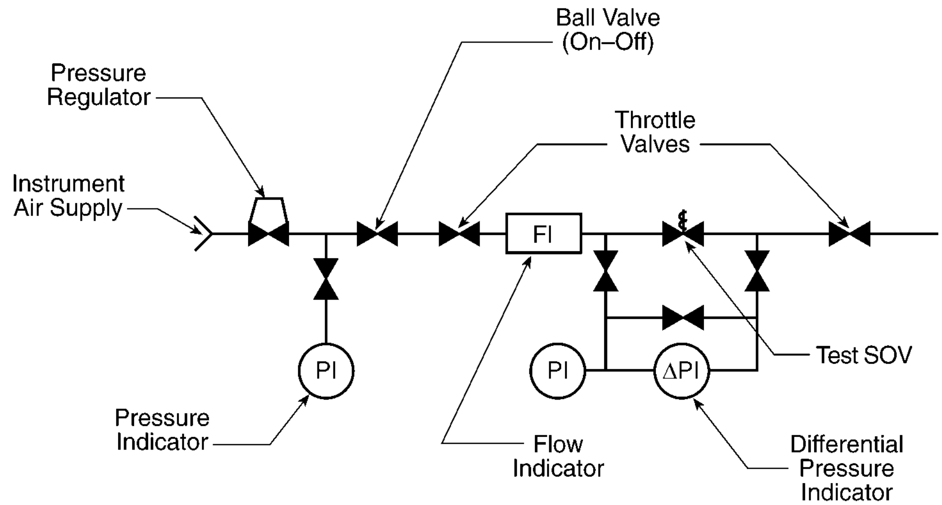

Figure 4-2
Sketch of an Air SOV Flow Test Arrangement

4.4 Periodic Replacement of Limited-Life Components

In addition to parts replacement during corrective maintenance, periodic replacement of age-sensitive parts and rebuilding of selective SOVs are often performed to maintain long-term SOV performance. The two major SOV component classes that may benefit from periodic replacement are the SOV coil and the elastomeric components (for example, seats, diaphragms, and seals).

Minimum periodic SOV or part replacement intervals may be required by special technical or licensing commitments. Environmental qualification, per 10CFR50.49, is the best example of a program requiring such replacements. The periodic rebuilding of BWR scram SOVs is another example of an established SOV refurbishment frequency. When SOVs are not controlled by these programs, periodic replacement intervals can be determined using manufacturer recommendations, rules of thumb, and operating experience. Since general recommendations are, by their very nature, imprecise, the best method of establishing refurbishment/replacement intervals is operating experience with the same or similar applications.

Key O&M Cost Point

One of the most important factors for selecting periodic replacement frequencies is operating experience.

The importance of operating experience is related to the lack of proven SOV condition-monitoring or diagnostic techniques. Without condition-monitoring methods, SOV periodic maintenance is generally based on calendar time. Unfortunately, since application conditions vary widely, the uncertainty about the actual SOV condition can be significant. Under these circumstances, the best method of determining the level and extent of in-service deterioration is prior operating and maintenance experience in similar applications.

4.4.1 Coils

When SOV coils are properly protected from humidity damage and are not continuously energized, they can have an indefinite life. When subjected to continuous energization, particularly at high ambient temperatures, their life is reduced considerably. As a rough rule of thumb, coil insulating systems can be expected to remain functional at their insulation class rated temperature for 4 to 10 years. (At their operating temperature, insulating systems typically have lifetimes ranging from 30,000 to 60,000 hours and greater.) Conservatively, their thermal life should double for every 15–20°F (8–10°C) decrease in temperature. Coils should not be used continuously above their rated temperature because of rapid deterioration and failure.

Key O&M Cost Point

Coil life generally ranges from 4 to 10 years when continuously operated at the insulation's rated temperature.

If SOVs or materials are controlled by the EQ program, then the EQ qualified life for the material in that application can be considered to be a very conservative estimate of the coil's life in similar applications that are not controlled by the EQ program. In a recent test, air-pilot SOV coils were successfully tested for time intervals six times longer than the previous established service interval based on the SOV's environmental qualification test.

4.4.2 Elastomers

The service time limits for elastomers are more difficult to establish, because they vary with the material, the part design, and the elastomer's function. In general, manufacturer recommendations should be followed when establishing initial intervals. The effects of contaminants and debris are application-specific and cannot be predicted. Assuming an otherwise ideal application, temperature does have a significant effect on elastomer life.

If similar SOVs are controlled by the EQ program, then the EQ qualified life for the material in that application can be considered to be a very conservative estimate of the elastomer's life. For elastomers wetted by the process fluid and in SOVs that are normally open with fluid flow, the elastomer temperature should be similar to the process temperature. When air-pilot SOVs are energized for prolonged periods, the seat and seal temperatures can increase roughly 45–90°F (25–50°C) above ambient temperatures.

Table 2-5 presented general upper temperature limits for several types of elastomers. When they are operated near their upper service-temperature limit, elastomers should be usable for a few years. Long-term performance (5–10 years and longer) is achieved when the elastomers are operated at temperatures well below these service limits.

When SOVs are periodically removed from service for repair or replacement, the elastomers should be examined and their condition documented. Generally, an elastomer will continue to be serviceable if it remains flexible and shows little evidence of swelling, cracking, compression set, or shrinkage. Since elastomers are supplied in a wide range of hardness values, comparisons should be made to new parts to gauge the amount of deterioration that has occurred. This information can then be used to modify part replacement and valve refurbishment intervals.

Key O&M Cost Point

Examine the condition of elastomers when valves are disassembled. Compare the condition to that of new components. Adjust service intervals to keep the elastomers flexible.

4.5 Periodic Valve Cycling

With the possible exception of high-pressure, high-temperature applications, manufacturers collectively agree that periodically cycling SOVs is one of the best SOV preventive maintenance techniques. One air-pilot SOV manufacturer's instruction manual for commercial SOVs recommends monthly cycling.

The potential for SOV sticking varies widely among valve styles. For example, SOVs with elastomer sliding seals appear to be more susceptible to sticking than direct-acting SOVs with globe type seats. Application factors such as process medium, contamination, debris, temperature, and coil voltage can all affect a valve's susceptibility to sticking. In many commercial/industrial applications (for example, pneumatic control SOVs on metal stamping machines), sticking often occurs when the SOVs are idle for only a few days. In power plant applications, it appears that SOVs on air systems are more prone to sticking than those in other plant applications.

Because of the variety of factors that affect SOVs, there cannot be one recommended cycling frequency. The most relevant factor for selecting a cycle frequency is operating experience. Other important factors are operating temperatures, valve design, and the level and types of process contamination. As a general rule of thumb, air system SOVs should be cycled quarterly. Longer intervals are readily justified when operating experience indicates no prior operating or sticking problems. If SOV sticking is observed and the root cause cannot be readily determined, the test interval should be shortened.

Key O&M Cost Point

One of the best SOV preventive maintenance techniques is periodic valve cycling. No one cycle frequency can be recommended; the most important factor for selecting a cycle frequency is operating experience.

4.6 General Inspections

Several simple inspection techniques can be used by both the operating and maintenance staff to assess the general condition of SOVs. These techniques are easily performed and even can be integrated into roving inspection schedules. None of them require any equipment; however, they do require training and familiarity with both normal and abnormal SOV characteristics. Suggested techniques are asking:

- Is there physical damage to the SOV, its piping system, or the associated field cable and conduit?
- Are the SOV, piping, and conduits properly mounted and supported?

- Are the SOV wiring and terminations properly connected?
- Is there evidence of external leakage (for example, water marks, chemical deposits, etc.) from the SOV?
- Are there odors that suggest electrical overheating (burn up of the coil or other electrical components)?
- Is a loud buzzing sound coming from the SOV?
- Does it sound like the valve is leaking or stuck?
- Place a finger over the exhaust port (for air-pilot SOVs). Does it appear that the valve is leaking air? (An inexpensive sight-glass type flowmeter could be used to more accurately determine the leakage.)

4.7 Recommended Maintenance

A recommended PM program may be found in the EPRI report *Preventive Maintenance Basis – Volume 7: Solenoid Operated Valves* [4]. The following information provides additional considerations when establishing a PM program.

Reference [4] requires that the criticality of each SOV be established. In addition, many safety-related valves presently have maintenance requirements that are defined based on prior licensing or technical commitments (for example, EQ). These requirements should form the minimum recommended maintenance for these valves. For other safety-related and important-to-power-production valves, credible failure modes affecting either safety or power production may not exist. For example, a closed, deenergized SOV's only safety function may be to remain in that state. For this valve, periodic maintenance may be unnecessary, and replacement at failure may be the appropriate maintenance strategy.

For other valves, some type of periodic maintenance or replacement may be warranted. For valves that are required to change state (open-to-closed or closed-to-open) and maintain a minimum seat leakage, periodic maintenance is an appropriate strategy to maintain/improve performance and reliability. The following discussion recognizes that some SOVs will fall into this category and provides general recommendations on the timing of maintenance activities.

The principal factors that affect SOV life and performance in most power plant applications are discussed below. These factors can be used to qualitatively establish maintenance frequencies. When a factor suggests more rapid deterioration, the valve should be periodically maintained more frequently. By using these factors, a comparison can be made between otherwise different applications.

4.7.1 Process Contaminants (Level and Type)

When **high** levels of process contamination exist, valves should be disassembled and cleaned frequently. The frequency should be based on the condition that is found during disassembly. An initial frequency of once per refueling outage is reasonable. With **moderate** contamination levels, maintenance should be based on the performance of the valve and its prior failure history. At **low** levels, no contamination-related maintenance need be performed.

4.7.2 Electrical Condition (Energized or Deenergized)

Normally, energized valves experience thermal-degradation-related failures of coils and elastomers. Many valve designs can experience significant degradation after being energized for 5 to 10 years. Unless other data or performance history information is available, periodic replacement at 5 to 10 year intervals should be considered. The interval should be adjusted based on ambient and process temperature conditions and the type of elastomers used.

4.7.3 Process Fluid Temperature

High process temperatures for SOVs that are normally open during plant operation can contribute to elastomer and coil degradation. The predominant effect is on the valve elastomers. Maintenance intervals should be based on expected elastomer temperature and published temperature limits. See Section 4.7.6 for further guidance.

4.7.4 Ambient Temperature

High ambient temperatures contribute to elastomer and coil degradation. As previously discussed, materials degrade roughly twice as fast for each 12–15°F increase in temperature. This approximation can be used to vary maintenance intervals based on ambient temperature, published material limits, and operating experience.

Alternatively, ambient temperatures can be categorized as *normal* (<100°F (38°C)); *moderate* (100°F (38°C) to 135°F (57°C)); and *high* (135°F (57°C) to 160°F (70°C)). Valves in the moderate ambient temperature range should be refurbished roughly two to three times as often as valves in normal ambient temperatures. Similarly, valves in the high temperature category should be refurbished roughly four times as often as valves in normal ambient temperatures.

4.7.5 Valve Position

All seats are subject to flow-induced damage and erosion when the valve is normally open during plant operation. Degradation becomes worse with the existence of process contaminants. Valves that are normally open and experiencing process flow should be rebuilt more frequently that valves that are normally closed.

Normally closed high-pressure, high-temperature process valves can experience greater seat degradation when they are periodically cycled. Valves that are cycled may require periodic seat repair to maintain them within allowable seat leakage limits.

4.7.6 Elastomer Type

Elastomers with higher temperature limits generally require less-frequent replacement than those with lower limits. However, some higher-temperature materials may be more sensitive to abrasion-type damage (for example, silicone) or radiation (for example, Viton). The lower-temperature materials, such as Buna-N, should require more frequent maintenance, especially in higher-temperature applications or when the SOV coil is continuously energized. Refer to Section 2.15.5 and Table 2-5 for additional information.

4.7.7 Valve/Seat Design

The need for periodic maintenance that is based on differences in seat design should rely primarily on operating experience.

5
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5.1 References

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5.2 Figure Sources

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4. Burkert Contromatic, Inc.
5. ASCO
6. Automatic Valve Co.
7. Keane Controls Corp.
8. Dresser Industries
9. Crosby Valve

A GLOSSARY

Aging—The effects of time or use on the physical characteristics of a component.

Air-Operated Valve (AOV)—A valve operated by a pneumatic actuator. The actuator is typically either a piston type or a diaphragm type.

Air-Pilot SOV—An SOV that controls the air supply to another device, such as an AOV, that, in turn, controls the process fluid.

Bubbletight—A condition when no detectable leakage occurs after a specified time using a soap bubble solution or observing gas released as bubbles in a water container.

Blowby—Leakage from the exhaust port of 3- and four-way valves generally due to internal obstructions preventing the SOV from fully shifting.

C_v Factor—This refers to the flow capacity of the valve. The C_v is defined as the quantity of water at 60°F, in gallons per minute, that will flow through the valve with a one-PSI pressure drop.

Coil, Rectified—A coil assembly that permits AC voltage to be applied to a DC design coil through the use of rectifiers.

Coil, AC—A coil assembly that minimizes the effect of the coil's fluctuating electromagnetic field by the use of a shading coil or shading ring.

Coil Class Rating—An Underwriter Laboratory designation that defines the maximum internal coil temperature that the coil materials can tolerate with a reasonable service life.

Coil Yoke—A magnetic steel shroud around a coil that is used in the magnetic circuit of an SOV when the coil enclosure's magnetic properties are inadequate to carry the magnetic flux produced by the coil.

Continuous Duty—A rating given to an SOV that can be energized continuously without overheating. SOVs that operate continuously for 30 minutes or more should be rated for continuous duty.

Counter-Electromotive Force or Counter-EMF—A property of an inductive circuit (coil) in which a change in the current flowing through the coil induces a voltage in the coil that is counter to the voltage causing the current, and, therefore, it is this induced voltage that resists the change in current.

Disc—An internal valve part that, when seated, prevents flow through an internal passageway or orifice.

Duty Cycle—The longest time that a valve is energized, followed by the shortest time that it is deenergized. Expressed in percent as ((on-time/total time) x 100).

Elastomers—Soft synthetic or natural rubber-like materials used in O-rings, gaskets, and as the seating material in soft-seated valves.

Electromotive Force (EMF)—The force that causes current to flow in a circuit. Commonly called voltage.

Enclosure, Drip-Proof—A NEMA enclosure classification (type 2) designed for use indoors to protect enclosed equipment against falling non-corrosive liquids and dirt. Drip-proof enclosures do not protect against hose-directed water or rain.

Enclosure, Watertight/Dust-Tight—A NEMA enclosure classification (type 4) designed for use indoors or outdoors to protect the enclosed equipment against splashing water, water seepage, falling or hose-directed water, and severe external condensation.

Enclosure, Explosion-Proof—A NEMA enclosure classification (type 7) designed to be used in hazardous locations as defined by the National Electric Code. These enclosures are able to withstand internal explosions while preventing ignition of atmospheric gases.

Environmental Qualification (EQ)—A term that is generally used to refer to qualification data demonstrating that a device will operate as required under nuclear accident conditions associated with loss of coolant accidents (LOCA) and other types of pipe breaks. These hypothesized accidents cause high-pressure, high-temperature steam, water/chemical spray, and radiation conditions within certain plant areas. The most severe environmental conditions generally occur inside primary containment structures. Devices, like SOVs, are generally qualified (EQed) only for a specified installed life called the *qualified life*.

Equipment Qualification—The accumulated testing experience and analysis data, including environmental and seismic qualification data, that demonstrates that a device will operate as required under normal, abnormal, and nuclear accident conditions. This term is often confused with "Environmental Qualification."

Failure Mode—The way that a component fails (for example, excessive leakage). Different failure mechanisms and failure causes may produce the same failure mode.

Failure Mechanism—The physical, chemical, mechanical, or other processes (for example, insulation embrittlement coupled with moisture intrusion) that result in failure. Different failure causes may produce the same failure mechanism.

Failure Cause—The reason for the failure. Failure causes can be related to human errors, defects, service stresses, and wearout.

Flux Washer or Plate—A magnetic steel washer or plate used in the magnetic circuit of an SOV to help to carry the magnetic flux from the enclosure to the bonnet or plunger tube assembly.

Heat Rise—The difference between the stabilized temperatures of the SOV coil when energized and deenergized in a constant ambient temperature environment. As current flows through the coil, heat is generated. The coil temperature rises until the coil enclosure dissipates heat as fast as it is generated, and steady state temperatures are achieved.

Impedance—The sum of the resistance and reactance for a circuit that contains a coil or capacitance. The unit of measure is ohms.

Inductance—A circuit or component, such as a coil, in which a change in current causes an electromotive force to be induced within the circuit. The unit of measure is henrys.

Insert—An elastomeric or plastic material used in the plunger assembly or in other internal SOV parts to seal an orifice.

Intermittent Duty Coil—An SOV coil that is not designed for continuous duty but that will perform satisfactorily for a specified duty cycle.

Leakage, External—The leakage from the internal part of the SOV to atmosphere.

Leakage, Internal—The leakage between the internal sealed ports of an SOV in either the energized or deenergized position. Leakage rate is normally described in cc (cubic centimeters) or bubbles per minute.

LLRT—An abbreviation for local leak rate testing. LLRTs are often performed at containment design pressure that may be significantly below rated system operating pressure. Air is often the test media for LLRTs.

LVDT—An abbreviation for linear variable differential transformer. LVDTs are electrical transformers whose output voltage varies based on the position of a moveable core.

Manual Override—A mechanical device that permits manual opening of normally closed valves or manual closing of normally open valves.

Magnetic—In this guide, metallic parts fabricated of materials with a high magnetic permeability (ferromagnetic). Carbon steels and ferritic stainless steels are magnetic. Copper, aluminum, and austenitic stainless steels are not magnetic.

Maximum Operating Pressure Differential (MOPD)—The maximum pressure difference in PSI between the inlet port and the outlet port at which an SOV will operate. Exceeding this pressure may cause the valve to open spuriously or could prevent opening, depending on the SOV design.

Minimum Operating Pressure Differential—The minimum pressure difference in PSI between the inlet port and the outlet port required for proper SOV operation. For three-way valves, the pressure difference may be referenced to the inlet and exhaust ports. Minimum operating pressure differential applies only to piloted SOVs.

Motor-Operated Valve (MOV)—A valve operated by an electric motor actuator that is controlled by valve position and actuator torque information.

Orifice—A controlling internal SOV circular passageway that is the point of sealing when the valve is closed. The orifice size is one of the determining factors affecting the flow capacity (C_v) of the SOV.

Port—An opening or passageway in the valve body whose flow is controlled by operation of the SOV.

Port, Inlet—A port that provides flow from the source of the fluid. This port is also termed the *pressure port*.

Port, Outlet—A port where the fluid leaves the valve. This term generally refers to two-way SOVs.

Port, Cylinder—A port that provides fluid passage to or from an actuator. This term generally refers to three-way and four-way SOVs.

Port, Exhaust—A port that generally provides fluid passage to the atmosphere. This term generally refers to three-way and four-way SOVs.

Port, Normally Closed—The port that is closed to fluid flow when the valve is deenergized.

Port, Normally Open—The port that is open to fluid flow when the valve is deenergized.

Postmaintenance Testing (PMT)—Any appropriate combination of inspections, checks, and testing that is performed following maintenance to verify that a particular piece of equipment or system performs its intended function based on its design criteria and to verify that the original deficiency has been corrected.

Process Fluid or Media—The fluid or gas controlled by the SOV.

Process SOV—An SOV that directly controls the process fluid or media. Compare with the air-pilot SOV.

Qualified Life—The installed period of time that an item of qualified equipment can be used. At the end of the qualified life, the component must be refurbished or replaced.

Reactance—The product of 2π times the AC frequency times the inductance. The unit of measure is ohms, the same as resistance. Reactance is the reason why AC coils have greater overall resistance (called impedance) to the flow of current.

Rectifiers—Solid-state electronic devices that convert AC input power to DC power to operate a DC coil. They are also called diodes or diode rectifiers.

Resistance—The property of a metal to resist the flow of electron current, resulting in a voltage drop and generation of heat. The unit of measure is ohms, the same as reactance.

Response Time—The length of time that is required for an SOV to move from the fully closed to the fully open position, or vice versa, when the valve is energized or deenergized.

Safety-Related—A designation assigned to nuclear power plant systems, structures, or components whose operation is relied upon to provide safe plant operation during normal, abnormal, and accident conditions.

Shading Coil—A small conductive ring or loop, generally fabricated of copper or silver, that shifts a portion of an AC coil's magnetic flux and prevents humming or chatter of the solenoid plunger.

Solenoid-Operated Valve (SOV)—A valve that uses an electromagnetic coil to move a plunger and valve stem to control flow of fluid through the valve.

Solenoid-Operated Valve, Direct-Acting—An SOV where the pull (or push) of the solenoid opens the valve port directly by operating the plunger, valve stem, and seat disc. Since these valves depend solely on the solenoid power for operation, internal orifice size is limited by the operating pressure.

Solenoid-Operated Valve, Piloted—An SOV where the solenoid operated plunger and stem are connected to a pilot seat disc and not the main port disc. Pressure that is directed through the pilot orifice is the source of force, operating through a piston or diaphragm, that operates the main valve disc.

Solenoid-Operated Valve, Pilot-Assisted—An SOV that is similar in design to a piloted SOV except with a mechanical linkage between the pilot valve stem and the main disc. This linkage allows operation of the main disc when little or no pressure drop exists across the valve.

Solenoid-Operated Valve, Two-Way—An SOV that controls media flow between two ports (inlet and outlet).

Solenoid-Operated Valve, Three-Way—An SOV with three ports that controls media flow among ports. Generally, one port is closed and the other two ports are interconnected when the SOV is deenergized. When the SOV is energized, a different port is closed and the remaining ports are interconnected.

Solenoid-Operated Valve, Four-Way—An SOV with four ports that controls media flow among ports. Generally, two pairs of ports are interconnected when the SOV is deenergized. When it is energized, two different pairs of ports are interconnected. Generally, none of the ports are closed when the valve is energized or deenergized.

Voltage, Dropout—The highest voltage applied to the SOV coil that will cause the valve to change from its energized to its deenergized position. This value varies based on process pressure and coil temperature.

Voltage, Pickup—The lowest voltage applied to the SOV coil that will cause the valve to change from its deenergized to its energized position. This value varies based on process pressure and coil temperature. For typical SOVs, this value can range from 40% to 85% of rated voltage.

Voltage, Rated—The manufacturer’s published (catalog) normal coil operating voltage.

Water Hammer—The pressure surge that is transmitted through a fluid system when flow is abruptly reduced.

Wire Drawn—Localized erosion damage of a hard-seated valve surface. The seat damage resembles a cut made by a sharp *wire drawn* over the seat.

B
OPERATIONAL EXPERIENCE

B.1 Introduction

As discussed in Section 3, INPO Operational Experience events were reviewed to determine what issues caused reportable challenges SOV operation. The sources of this information included Operational Experience reports and U.S. NRC Notices and Licensee Event Reports. Of 299 events reviewed, 70 were identified that contained meaningful information for analysis. Table B-1 is a summary of these operating events.

B.2 Solenoid-Operated Valve Problems and Causes

The following definitions were used when classifying the data.

Failure mode – The SOV function that was prevented by the failure.

Failure mechanism – The physical, chemical, mechanical, or electrical process that prevented the SOV from accomplishing its function.

Failure cause – The reason or root cause for the failure, related to human errors, defects, service stresses, and/or wearout.

B.2.1 Failure Modes

The following failure modes were identified. Figure B-1 shows their percentage distribution.

Leak – Valve seats did not prevent operating fluid isolation.

Shift failure – Valve did not complete stroke.

Spurious shift – Valve changed position without a signal.

Stroke time – Valve stroked but did not meet time requirements.

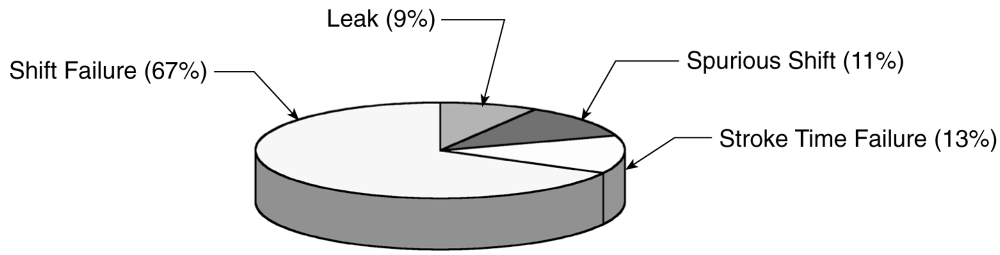

Figure B-1
Solenoid-Operated Valve Failure Modes

B.2.2 Failure Mechanisms

The following failure mechanisms were identified. Figure B-2 shows their percentage distribution.

Differential pressure requirement not met – The manufacturer's required minimum operating differential pressure or maximum differential pressure was not present.

Elastomer failure – There is hardening or decomposition of the elastomer.

Electrical failure – The coil insulation is degraded, there is coil physical damage or poor or inadequate solder joints, or the coil is open.

Foreign material – Material is determined to be from an external source.

Lubricant failure – The lubricant is degraded or the wrong lubricant is present.

Other – A one-time occurrence of a failure mechanism.

Unknown – Insufficient information is available.

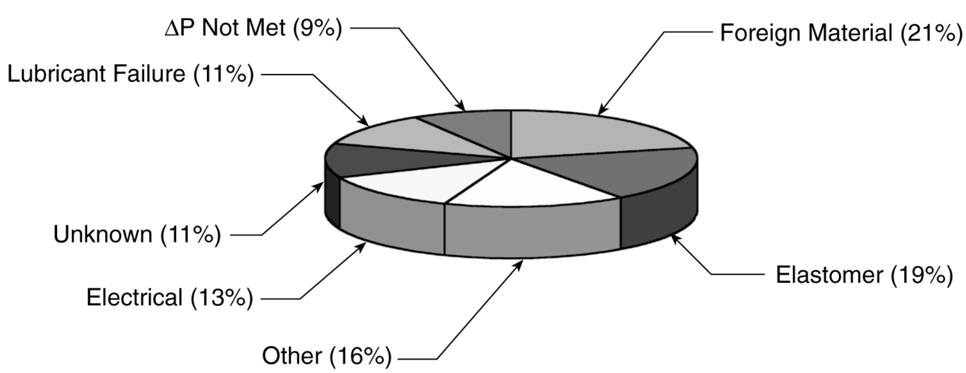

Figure B-2
Solenoid-Operated Valve Failure Mechanisms

B.2.3 Failure Cause

The following failure causes were identified. Figure B-3 shows their percentage distribution.

Aging – This is an end-of-life failure.

Air filter – The air filter is clogged, or the improper filter size is in use.

Heat – The temperature is elevated because of continuously energized coil.

Lubricant interaction – The lubricant has deteriorated, or the improper lubricant is present.

Maintenance/manufacturing/design – Errors in maintenance, manufacturing, or design (including design changes that change the type of SOV) have occurred.

Other – A one-time occurrence of a mechanism.

Unknown – Insufficient information is available.

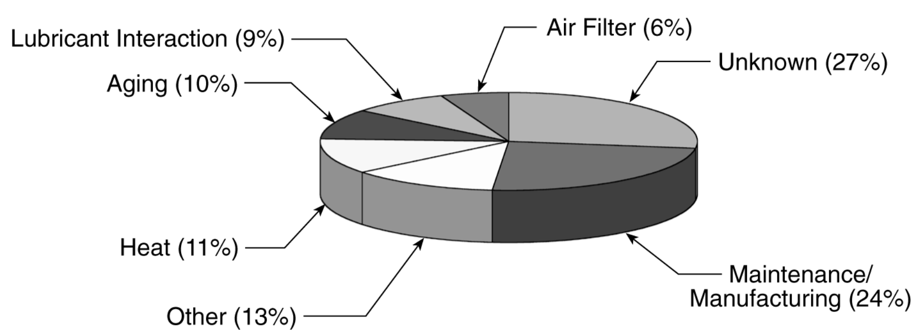

Figure B-3
Solenoid-Operated Valve Failure Causes

B.3 Failure Mechanisms for Each Failure Mode

Failure mechanisms were identified for each failure mode in order to provide a better understanding of the reason that the physical, chemical, mechanical, or electrical process prevented the SOV from accomplishing its function. Figures B-4, B-5, and B-6 provide this insight.

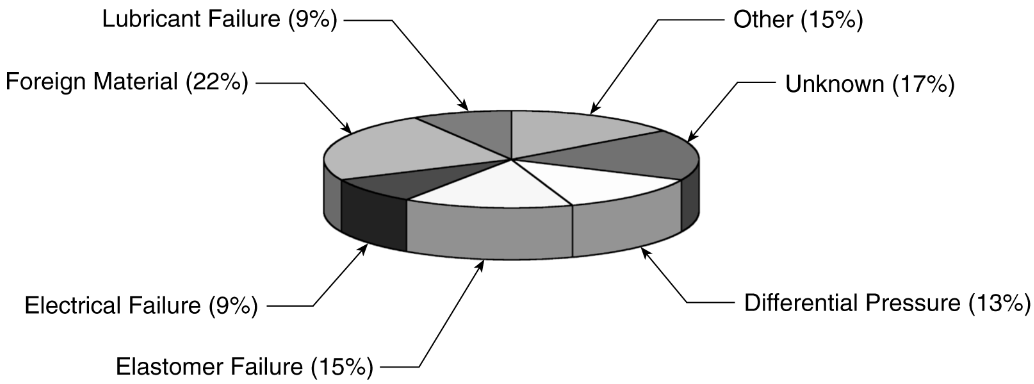

Figure B-4
Failure Mechanisms for Shift Failure

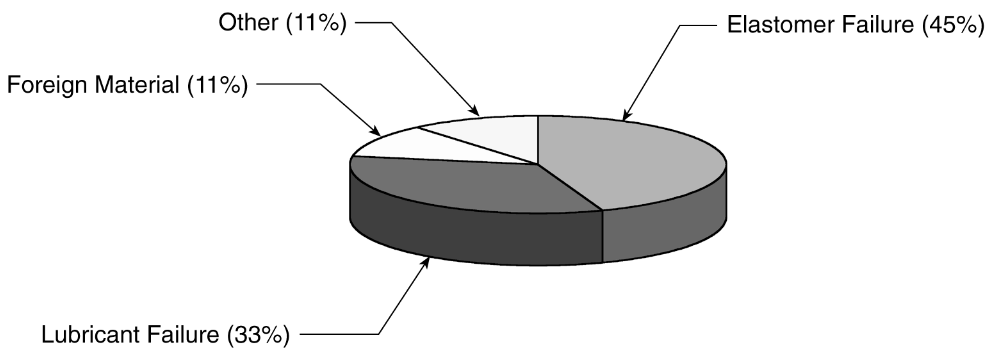

Figure B-5
Failure Mechanisms for Stroke Time Failure

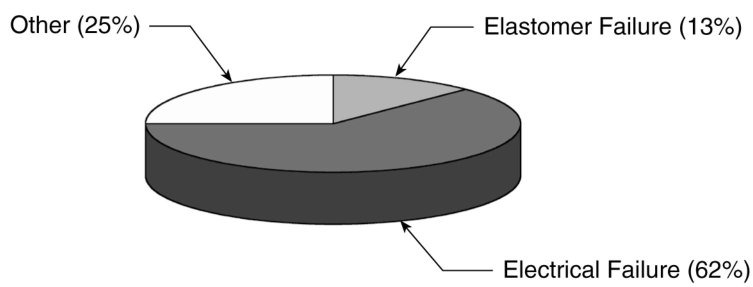

Figure B-6
Failure Mechanisms for Spurious Shift

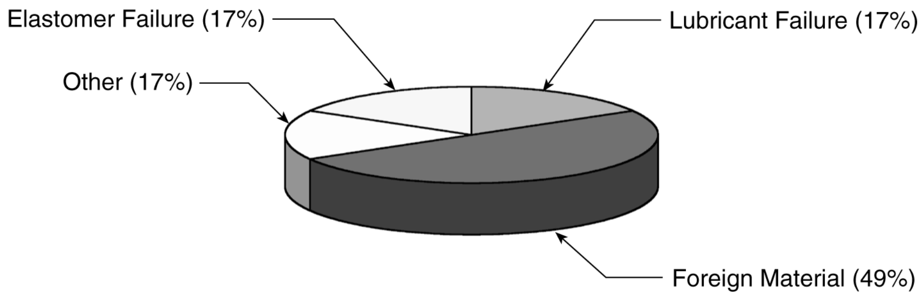

Figure B-7
Failure Mechanisms for Leak

B.4 Table of Events

Table B-1 of event summaries follows. Events are from Operational Experience (OE), Operating Plant Experience Code (OPEC), or Significant Operating Experience Report (SOER) and EPIX databases.

Table B-1
Operating Events

Date	Event (See Paragraph B.1)	Event Description
4/8/91	OE4602 - Solenoid Valve Failure due to Oil Degradation	Valve failed the stroke time requirement. If stroked frequently, the valve would meet the requirement. In-line air-oilers were installed between the SOV and AOV. During AOV exhaust through SOV, oil entered the SOV, which was normally energized. Over time, heating caused the oil to become gummy. Stroking cleared the gummy material after one stroke. Oilers were removed. The AOV is greased regularly.
4/18/91	OE4572 - Failure of Solenoid Valve Coil Resulting in Closure of Main Steam Isolation Valve	An MSIV closed with the handswitch still aligned for the valve to be open. One of the two solenoid valves (ASCO NPL8321A6V), which supply air to the MSIV, had failed by changing position and venting the MSIV operator cylinder. An earlier, similar event had occurred that was caused by the SOV, but the valve had been discarded before analysis. The failure was caused by an open circuit in the solenoid coil. The cause of the open circuit has been preliminarily determined to be some type of corrosion or mechanical damage of the copper magnet wire approximately one inch from the wire to the lead connection. The solenoid valve was replaced and power ascension was resumed.

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
6/30/91	OE4716 - ASCO Solenoid Valve Failures	SOV (L206832 RVF ASCO) failed to shift position. The root cause for the sticking of the SOV was an abundance of lubricant that had gelled, causing the solenoid core to adhere to the top of the core casing in its energized position. The cause for the sticking of the SOV is most likely a combination of lubricant gelling and foreign matter. (Both are possible causes, and both were present.) A lubricant identified as a polymethyl siloxane (consistent with Dow Corning 550 or one of the Neolube products) was found on the solenoid core assemblies.
11/9/91	IN 91-83 - Solenoid-Operated Valve Failures Resulted in Turbine Overspeed	During routine turbine testing at 100% power, an oil pressure perturbation occurred in the auto-stop trip system. This caused the interface valve to open and thereby depressurized the EHC fluid. Both the turbine and the reactor tripped and all turbine stop valves closed. However, the emergency trip solenoid valve failed to open. This allowed for repressurization of the auto-stop trip system, opening the turbine stop valves, thus admitting steam to the turbine. Since the output breakers had opened, the turbine oversped. The overspeed protection controller SOVs failed to open. The turbine reached 160% rated speed, causing severe damage to the turbine. The proximate cause of the event was the failure of the emergency trip solenoid valve and both overspeed protection controller solenoid valves to open when energized. The specific failure mechanisms of the Parker-Hannifin SOVs are yet to be determined, but preliminary analysis indicated that the pilot valve assembly in each solenoid unit was mechanically bound sufficiently to prevent movement. Other previous failures of these valves in the industry have also been attributed to mechanical binding, corrosion, and worn or pinched elastomeric parts.
1/16/92	OE5118 - Aging of Solenoid Valve Disables Diesel Trip Capability	A failed seating surface within SV-5, a solenoid valve in the diesel's control air system, defeated its trip function. The failed solenoid valve allowed the engine's throttle control cylinder to remain pressurized with a trip signal present. The failure, due to aging, of a rubber seating surface of the solenoid valve defeated its trip function from the control room and also locally, with the electric trip push button.

**Table B-1 (cont.)
Operating Events**

Date	Event (See Paragraph B.1)	Event Description
2/21/92	OE5229 - Failure on Main Turbine Overspeed Protection Solenoid	During outage tests to verify the proper operation of main turbine protection solenoid valves (in response to an earlier turbine overspeed event, one of the two overspeed trip solenoid valves (OPC 20-1) in the EHC system failed to perform its safety function. When the solenoid and valve assembly were inspected, one of the wires to the solenoid was found to be partially severed. The cause of the severed wire is unknown. The plant is incorporating the special test of main turbine protection EHC overspeed trip solenoid valves into a regularly scheduled surveillance test.
8/5/92	OE5663 - Reactor Trip due to an Equipment Failure	The reactor trip was due to a steam generator LO-LO actuation, when the feedwater regulating valve moved to its closed position upon loss of power to the controlling safety solenoid. These were DC solenoids configured for AC operation. The blocking diode failed. The cause is unknown. Blocking diodes were removed from remaining valves, since DC power was used. The rectifier circuit remained to provide surge protection.
1/1/93	IN 94-06 - Potential Failure of Long-Term Emergency Nitrogen Supply for the Automatic Depressurization System Valves	During a review of components that form the pressure boundary of a safety-grade nitrogen supply system, it was found that parts of the SOVs used in the drywell coolers were made of Buna-N. Since the temperatures post-LOCA would cause the Buna-N to fail, the nitrogen supply would leak and would not be able to perform its safety function. The problem was caused by the inadequate design of modifications that were made in 1985 to upgrade the ADS pneumatic supply.
3/29/93	OE5973 - Potential for Solenoid Operated Valves Installed in Safety-Related Applications to be Over Pressurized, Rendering Them Unable to Perform Their Safety Function	It was determined that, as a result of certain failures, the potential existed for solenoid-operated valves (SOVs) installed in safety-related applications to be over pressurized, rendering them unable to perform their safety function (from GL 91-15 review). The pneumatic supply systems to the susceptible SOVs utilized non-safety-related pressure-regulating valves (PRVs) and/or relief valves (RVs) to maintain the operating pressure below the SOVs' maximum operating pressure differential. To resolve the identified concerns, several SOVs have been replaced with those rated for higher pressure, and modifications are being made to the nitrogen supply system.

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
8/3/93	OE6375 - Reactor Scram due to Main Steam Isolation Valve (MSIV)	Scram occurred during surveillance on a main steam line radiation monitor. The main steam isolation valves received an isolation signal on high steam flow when an inboard MSIV went closed. The inboard MSIV shut because of a half-isolation signal that was received from the surveillance procedure while a half-isolation signal was "mechanically" present on the remaining solenoid for the MSIV. This "mechanical" isolation signal was caused by a wrong-size stem being installed during rebuild during the previous refueling outage. Inadequate post-modification testing failed to detect the problem. Although instructions existed to install the entire rebuild kit (including the square 29 mm stem), the craft inadvertently installed a hexagonal 26 mm stem in the solenoid. Additionally, training for the craft on building these type valves is performed on a single solenoid type valve instead of the dual type application in the MSIVs. Recommendations were to revise or ensure that the mockup for the dual solenoid type valves is used. Due to the distinct difference between the single and dual solenoid valves, this practice severely hampers the craft in troubleshooting these valves. Post-modification testing requirements for other selected dual solenoid valves included individual testing of solenoids and revision of the training program for craft on these valves to include more specific information on the dual solenoid type of valves.
8/25/93	LER 387-93-009-00 - Unplanned ESF Actuation Primary Containment Isolation Valve Closure	The CIV failed safe due to the associated SOV going to the deenergized position. Indications of elevated temperatures in the solenoid coil area were observed as well as a failed solder joint between a wire lead and an electrical connection post on the coil. This solenoid had been installed just five days prior to the event. Analysis concluded that the solenoid coil wire insulation had failed, resulting in the turns of the coil wire shorting together. The SOV was replaced.
12/31/93	NPRDS Failure Report - Main Steam MSR Intercept Valve Operator Solenoid Pilot Valve	Maintenance identified a blown fuse in the electro-hydraulic control panel. Maintenance installed a strip chart to identify the cause and replaced the fuse. The fuse blew again. The cause was traced back to a burned-up solenoid coil on the fast-acting closing solenoid valve (piece-part) of the moisture separator reheater intercept valve operator. The cause of the burned-out solenoid coil on the intercept fast-acting solenoid valve may have been the end of the coil's life. In the future, this type of solenoid valve will be replaced with a new type supplied by a different vendor.

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
1/19/94	OE6409 - Failure of Emergency Containment Cooler Component Cooling Water Discharge Solenoid-Operated Valves	Three control valve failures were caused by failure of the solenoids (ASCO model NPL8342B2E). Specifically, the solenoids failed to reposition when deenergized. These valves were replaced on 8/93 and were factory-lubricated with Nyogel lubricant. The cause of the failure was degradation of the lubricant that increased friction between the disc and the seat. Corrective action indicates that this was considered to be a solenoid temperature related problem. The corrective action is to change the solenoid from deenergize-to-actuate to energize-to-actuate. (Safety analysis indicated that operator action would be allowed.) ASCO issued a Part 21 report 7/7/94.
3/26/94	OE6564 - Control Rod Scram Time Testing Failure (Follow up to OE 6540) BWR-6	The most probable cause of the SLOW scram time testing at GGNS was found to be Neolube 100 contamination in the pilot valve internals of the scram solenoid valve top head assemblies. Significant contamination occurred, and all SLOW rods that were examined had contamination of the solenoid valve internals. During the last refueling outage (10/93), the scram solenoid valves were rebuilt in the field using preassembled top head assemblies and then reinstalled. In the past, scram solenoid valves have been rebuilt in the shop. Several days later, they were installed, the air supply restored, and the valves functionally tested. The source of the contamination was not determined.
3/26/94	LER 397-94005 - Control Rod Fails to Scram due to Scram Solenoid Pilot Valve Elastomer Degradation	One control rod failed to insert during scram time testing due to aging degradation of the diaphragms' elastomer in the scram solenoid pilot valves. The diaphragms had been in service for just under four years and had hardened and cracked. The recommended service life for the Buna-N diaphragms is three to four years, and the degraded diaphragms were scheduled for replacement during the next refueling outage.
3/26/94	IN 94-71 - Degradation of SCRAM Solenoid Pilot Valve Pressure and Exhaust Diaphragms	Two plants noted longer rod insertion times. One of the plants exceeded the technical specification. Both plants identified SOV diaphragm deterioration as the reason. The ASCO HV-90-405 SCRAM solenoid pilot valve diaphragms were made of Buna-N. Due to heat, the diaphragms hardened and cracked. There was also a residue (composition unknown) that was found indicating that a contaminant may have contributed to the failures. In particular, the physical location and pressure conditions at the exhaust diaphragm of one of the SOVs were identified by the IN as particularly harsh.

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
1/12/95	OE7266 - Solenoid Valve Springs Found to Have Insufficient Spring Force	Testing performed by the Target Rock Corporation revealed that valve springs used in some solenoid valves did not exert the specified force. The springs had an average force of 3.5 lbs instead of the specified 5.25 lbs. An evaluation of actual valve performance identified the lowest spring force as 1.9 lbs. Engineering analysis concluded that the solenoid valves containing spring with insufficient spring force would still perform all design functions.
2/18/95	IN 95-53 - Failures of Main Steam Isolation Valves as a Result of Sticking Solenoid Pilot Valves	The main steam isolation valves failed to close because of sticking solenoid pilot valves. It was determined that the ASCO 8323 solenoid valves had failed to operate because the core and the plug nut had stuck together. The root cause of the sticking of the two pieces appeared to be the presence of a lubricant (Nyogel 775A) and a thread sealant (Loctite PST 580 or Neolube 100), which had formed an adhesive film between the core and the plug nut. An NRC vendor inspection at ASCO was conducted (on March 13–14, 1995). An NOV was issued. ASCO investigated and responded to the NOV that the Nyogel lubricant deteriorization was not from heat but possibly from volatiles from uncured thread sealant or ester oils possibly used.
5/12/95	SIL 591 - Delayed Scram Solenoid Pilot Valve Operation	GE issued SIL 591 to advise owners of GE BWRs of slow scram times that were observed during routine scram time surveillance testing. The two plants that have observed slower-than-normal 10% insertion times are both BWR/6 plants using a “T-Type” scram solenoid pilot valve for each control rod drive hydraulic control unit. The pilot assembly uses two discs: a lower pilot disc on the B side and a core disc on the A side. Investigation determined that the delay in the 10% scram insertion time was caused by a delay in the lower pilot disc moving off its seat, delaying the venting of air pressure from the scram valve air operators. The investigation identified three likely contributors: 1. A variation in the specific properties of the lower pilot valve disc. This could account for an increase in the 10% insertion time of 150 to 200 milliseconds. 2. Contamination of internal valve components with thread sealant. This contributor has been shown to cause a delay, in combination with factor 1 above, of up to 200 milliseconds, which would be sufficient to cause the delays of greater than 300 milliseconds. 3. Contamination of some internal valve components with a cleaning solution residue. GE and the valve manufacturer have developed an improved specification and manufactured parts that will limit the likelihood of disc bonding that could lead to delayed scram times.

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
5/12/95	Failure Report 112 - Solenoid Valve 20-1/OPC Failed to Trip the Turbine	During performance of ICP54-69, solenoid valve 20-1/OPC failed to trip the turbine the first time. This solenoid operated normally thereafter (Parker Hannifin Corp R6V2DFHV54X2252 70). The cause of this failure is unknown. To correct this failure, the solenoid valve was replaced and retested.
6/10/95	NPRDS Failure Report	The valve would not close upon demand from the control room. This valve is normally held open by a pressurized air actuator, which requires a normally energized solenoid valve. Troubleshooting found that when the solenoid valve was deenergized to close the valve, the valve remained in the open position with the power removed. The suspected cause of the solenoid valve failure was the combination of high ambient temperature, infrequent cycling while being energized, and the intrusion of foreign material into the solenoid valve body and stem, which caused binding in the solenoid valve. Relocating the solenoid valve from the harsh environment was a plant priority for the next extended outage.
9/6/95	OE7459 - Incorrect Solenoid Valve Seat Results in Unit Trip	Diablo Canyon Power Plant Unit 1 tripped when the backup main turbine trip valve suffered a solenoid valve pilot seat failure, and the valve failed to open. The valve seat material was specified to be Teflon; however, it was actually pressure-cast urethane. The vendor substituted urethane without notifying distributors or users. Industry experience has shown that urethane may fail when exposed to oil systems. The urethane seat appears to have failed due to chemical incompatibility. SV-171 was replaced with a solenoid valve with a PTFE seat.
10/4/95	INPO Significant Event - Reactor Building Ventilation Dampers Fail to Close because of Sticking Air Pilot Solenoid Valves	Isolation dampers failed to close. Failure was caused by sticking air pilot solenoid valves. The dampers closed when the solenoid valves were lightly tapped. The solenoid valves (ASCO Model No. X-206-832-3RF-15385) contained a black residue at the core-plug nut interface that caused the solenoid core to stick to the plug nut. The high operating temperature of the normally energized solenoid and the low air differential pressure (less than 25 psig (172 kPa)) contributed to the sticking problem. These valves were part of a set that was replaced earlier because of heat-accelerated lubrication deteriorization concerns. They did not contain lubricant but failed after 18 months. No cause for the black residue was specified. A new-model solenoid will be used. The ASCO catalog lists no minimum operating pressure differential.

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
12/8/95	IN 96-07 - Slow Five Percent Scram Insertion Times Caused by Viton Diaphragms in Scram Solenoid Pilot Valves	Two plants noted longer rod insertion times. Both plants identified adherence of the Viton diaphragm to the brass valve seat as the problem. The Viton diaphragms were installed as a design change in the SSPVs (GE PN 107E6022P001) that were supplied by ASCO in response to problems with Buna-N rubber diaphragms becoming brittle and cracking, which was seen at some BWRs in the early 1990s. Most of the American BWR-2, BWR-3, BWR-4, and some BWR-5 plants have replaced the Buna-N diaphragms with Viton in the past year or so. Some BWR-5 and all BWR-6 plants use a different model (T-type) of scram solenoid pilot valve that does not appear to be susceptible to this problem.
12/18/95	LER 254-95009	The valve was not mounted vertically as required by the manufacturer. The valve was reoriented.
2/2/96	LER 324-96001 - Degraded Buna-N Diaphragms in Scram Solenoid Pilot Valves Cause Slow Control Rod Scram Insertion	After a manual scram to begin a refueling outage, analysis determined that the average control rod insertion time for the first 5% of travel exceeded the technical specification limit (0.358 seconds). The slow insertion times were attributed to degraded Buna-N diaphragms in the scram solenoid pilot valves. The use of Loctite PST-580 thread sealant may have been a contributor to the Buna-N degradation. The south bank hydraulic control unit scram solenoid pilot valves were installed in 1993. Loctite PST-580 thread sealant was used on 20 of the 21 south bank scram solenoid pilot valves that had slow insertion for the first 5% of travel. Scram solenoid pilot valve assemblies were replaced with new assemblies with Viton pressure inlet diaphragms and Buna-N exhaust diaphragms.
9/6/96	LER 423-96031 - Design Review Identifies 48 Safety-Related Solenoid-Operated Valves Susceptible to Potential Failure Caused by High Pressure Differentials	Engineering personnel conducting design reviews in accordance with NRC Generic Letter 91-15 concluded that 48 safety-related control valves were susceptible to the potential application of full instrument air system pressure and could exceed the maximum operating pressure differential rating identified in NUREG 1275, Volume 6.

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
11/8/96	OE8203 - Single Control Rod Scram During Plant Startup	During testing, a single control rod scrammed. An expected half-scram existed on the A scram solenoid pilot valve (SSPV). During troubleshooting, the B SSPV was energized repeatedly. In a single instance, it was noted that the solenoid did not produce the expected audible click when energized. This meant that the valve had been in the scram position (vented) and was the apparent cause for the scram. Bench testing of the valve confirmed that the "B" solenoid core assembly intermittently stuck in the deenergized (scram) position in the solenoid base subassembly (SBSA). The "B" solenoid base subassembly was inadequately crimped.
1/24/97	OE8523 - Turbine Could Not be Manually Tripped with Main Control Room Trip Push Buttons	Two events occurred where attempts to manually trip the main turbine from the main control room with the turbine trip push buttons were unsuccessful. In both events, the turbine was successfully tripped locally with the manual trip lever. The cause of both events was found to be the lack of turbine protective trip block testing. The root cause of the second event was improper adjustment of the remote trip plunger clearance on the Auto Stop Trip master solenoid on the protection control block. Procedures will be revised to require functional testing of the alternate trip solenoid (1/2-LO-SOV-AST2) prior to each startup using the turbine trip test lever. Testing of the protective trip block will be performed at power on a six-month frequency. The test will include only activation of the Auto Stop Trip master solenoid (1/2-LO-SOV-AST1) using the main control room trip push buttons while placing the turbine trip lever in "test."
2/5/97	NPRDS Failure Report - ASCO Solenoid Valve Degradation Over Time (Model #8344C37)	While reviewing completed work orders, it was noted that there have been three failures of air operator solenoids on the condensate booster pump recirculation valves. All failures were due to "sticking" of the solenoid. The root cause of these failures was found to be degradation of the Buna-N materials in the subject solenoid valves combined with the filter regulator design, which restricted supply air flow and hampered the "air-assisted" movement of the solenoid. The design that was used for the air supply line was a standard arrangement and did not take into account the unique characteristics of the subject solenoid that requires air flow assistance for optimum valve operation. To address these failures, the solenoids will be replaced with a design that uses Viton rather than Buna-N. This will increase the life of the elastomer parts within the solenoid valves. In addition, the regulators will be removed from the air supply to improve the air-assisted movement of the valves.

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
2/7/97	Failure Report 2 - SOV Failed to Operate	During the trip test of the main steam turbine hydraulic control unloader valve, the valve (a Parker Hannifin Corp R6V2DHV50X2252) failed to operate. The failure was attributed to particulate in the valve. The valve was replaced. The failed SOV was sent to Parker Hannifin corporation for failure determination and refurbishment. P-H recommends replacement of the existing spool type valve with a poppet type solenoid valve. This replacement will be evaluated.
3/6/97	SIL 607 - T-Type Scram Solenoid Pilot Valve Inadvertent Scram	SIL issued to discuss a single rod scram that occurred at a BWR in November 1996. The single rod scram occurred during turbine valve surveillance testing when a half-scram signal was applied to the reactor protection system as part of the test. The GE analysis of the event determined that the cause of the single rod scram was an incorrect tolerance in the scram solenoid pilot valve that caused the B-side core assembly to wedge in the deenergized state, even when the solenoid was energized. Consequently, when the half-scram signal was applied to the A side, the control rod received a full scram signal. GE performed an inspection of the scram solenoid pilot valve and determined that the solenoid base subassembly core tube had a crimp that was not the correct size. No other anomalies could be identified.
7/2/97	Failure Report 41 - Solenoid Failure	The Turbine Emergency Trip Solenoid-Operated Valve (20/ET) (Parker Hannifin MRFN16MX0834) failed to fully close after actuation. Four attempts were required to actuate it during turbine trip testing. The SOV sticking was due to possible debris buildup. The Parker Hannifin drawing directs that no painting is allowed on valve-to-pilot block surface. The subject valve assembly was found to have been painted on both the failed valve and in the latest-received refurbished valve.
9/26/97	Failure Report 51 - Minimum Pressure Problem	SOVs (ASCO NPK8344A74E) were replaced after being identified as being potentially at the end of life. After one month, one of the replacements failed. It was determined that differential pressure was too low for reliable operation. A modification was performed to install a different SOV. The 8344 minimum operating pressure differential is 10 psi (69 kPa).

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
12/24/97	OE8781 - Leakage of Air Solenoid Valve and Partial Loss of Component Cooling Water	The station identified a leaking air solenoid valve (ASCO8344). The solenoid valve was in the energized position, supplying air to the associated AOV. The failed solenoid valve was supplied by approximately 90 psig instrument air and had operated properly for over 8 years. ASCO stated that 8344 solenoid valves had experienced blowby when used in applications of less than 125 psi (861 kPa). The station observed that slight hardening of grease in the solenoid valve and hardening of the bushings had occurred. The low-pressure and grease degradation were considered factors that contributed to the SOV failure. The station replaced the solenoid with a three-way pilot operated solenoid valve.
2/6/98	Failure Report 180 - ASCO Solenoid Valve Degradation Over Time (Model #8344C37)	These valves would not change position when deenergized. The Buna-N internals on these solenoid valves were experiencing degradation over time. Vendor documentation indicated that the valves have a shelf life of 3–5 years. The solenoids that were removed from the plant were fabricated in 1989 and removed in 1998 (9 years of use). The Buna-N materials had hardened and, in some cases, had obtained a compression set, resulting in squared-off edges that no longer provided an adequate seal.
3/24/98	Failure Report 42 - Emergency Makeup to Charging Pump Suction Would Not Stroke	LCV-115B failed to close on demand (stuck open). The solenoid valve (ASCO 8320) is constantly venting. When the vent port was covered, the AOV moves. When uncovered, the AOV stops. No cause of the failure was identified by the investigation. The SOV was replaced.
6/3/98	Plant Incident Report (non-LER) 34334 - Steam Generator Feedwater Pump Trip Solenoid Failure	The steam generator feedwater pump trip solenoid failed to provide the proper response during surveillance testing of the SSPS. The trip solenoid failed due to an open coil. No further investigation was performed to determined the root cause of the open coil. The failed solenoid was replaced.

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
7/8/98	LER 410-98018 - MSIV Failed to Close When Tested because of Faulty Solenoid Valve	Station personnel discovered that the A inboard main steam isolation valve would not fast-close. They determined that the solenoid valve that needs to reposition to release air and allow the main steam isolation valve (MSIV) to fast-close had failed. The continuously energized solenoid had a degraded EPDM seal inside the solenoid. Laboratory results confirmed that the failure was caused by EPDM seal material in the plug-nut area breaking down because of exposure to temperature in excess of 250°F (121°C). While station personnel were aware of this problem, it was assumed that all remaining solenoid operated valves with EPDM would be used up during the 1992 refueling outage; however, the solenoid operated valve that failed was installed in 1996.
7/30/98	Failure Report 159 - HPCI Remote Turbine Trip	The HPCI turbine stop valve could not be remotely tripped closed from the control room. Troubleshooting revealed a loose solder connection within the turbine trip solenoid valve. This loose connection had intermittent continuity, which would result in the turbine trip solenoid valve failing to actuate. Continuity and integrity of the remainder of the turbine trip 125 VDC control logic was verified to be satisfactory. The loose solder connection on the turbine trip solenoid valve was repaired, and the ability to remotely trip the HPCI turbine from the control room was demonstrated three times.

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
9/19/98	Failure Report 112	Operators observed the demand for 2FDW-316 at 50% when SG level was ~25 inches (64 cm). At this time, demand should have been 100%. Work Order 98086342-01 was issued. Inspection and Enforcement (I&E) crews found that 2FDW-316 was not auto operable due to a leaking solenoid; however, 2FDW-316 would operate in manual. This solenoid valve is a Valcor V70900-65. This investigation found a sliver of plastic-like material stuck to the valve seat. This material was approximately 1/16 inch (0.8 mm) long by 1/32 inch (1.6 mm) wide and about 0.002 inch (0.05 mm) thick. The material had apparently traveled to the valve seat in the air stream through the valve. With the foreign material stuck to the SOV seat, the auto signal control air was allowed to bleed back into the manual regulator and not build sufficient air pressure to provide control functions to 2FDW-316. Further attempts to determine the origin or type of material found in the SV seat were unsuccessful. The "B" port is connected to the control port of the positioner. The "C" port is connected to control air. The "A" port is connected to a manual air regulator located in the control room to provide manual control. Normally, control air is ported through the SOV from port "C" to port "B." With the valve in manual, control air is ported through the SOV from port "A" to port "B." With the foreign material stuck to the SOV seat, the auto signal control air was allowed to bleed back into the manual regulator.
9/20/98	OE9371 - Three Solenoid-Operated Containment Isolation Valves Failed to Shut due to Foreign Material on Solenoid Core	Three solenoid-operated containment isolation valves failed to shut when signaled from the control room. A gray deposit was observed in the top of the core spring assembly and on internal portions of the base subassembly of one of the SOVs (IA-909). No contaminants were found during the internal inspection of the SOV body. A black deposit was found on the upper and lower valve disk stems. Similar deposits were found on a second SOV (RC-606). The grayish deposits on both IA-909 and RC-606 were examined using an infrared spectrometer and were found to closely follow the test plot of a silicon compound similar to a compound used by the solenoid manufacturer in the assembly of solenoid valves. Station personnel concluded that the most probable cause for failure of the subject solenoid valves was the accumulation of silicon gel from fabrication on the top of the core and subassembly housing, causing the valves to stick in the energized position. This phenomenon will manifest when the silicon is exposed to a high temperature for extended periods without stroking of the solenoid.

**Table B-1 (cont.)
Operating Events**

Date	Event (See Paragraph B.1)	Event Description
11/19/98	OE9590 - Failure of a Turbine Master Trip Solenoid Valve	The master trip solenoid valve (MTSV) appeared to be sticking during operator testing. The spool piece was not traveling the required distance to produce the required trip. A combination of a swelled rubber stopper and EHC fluid within the solenoid portion of the valve spool piece prevented full travel of the spool piece. The rubber material was not compatible with the EHC fluid. The rubber stopper was replaced and the position indicator was removed to allow any EHC leakage into this area to drain. A stopper of correct material is to be supplied.
12/4/98	Failure Report 323 - Maintenance Rule Functional Failure Report	The SOV failed to change position completely when deenergized. The SOV vented instrument air, resulting in insufficient pressure to the associated AOV. ASCO HB8320G-1 experienced failure due to either a stuck plunger or a seat leak. The MWR comments did not include enough information for a failure determination. The SOV was in service 4692 days.
12/11/98	LER 423-98045 - Spurious Main Steam Isolation Valve Closure Results in Automatic Scram	The A MSIV went fully closed during partial-stroke testing, resulting in scram. Failure was attributed to a faulty solenoid valve that did not fully open during the partial stroke test. A circumferential 270° through-wall crack was discovered on the solenoid's main piston. The crack reduced the ability to adequately vent the inside of the piston, which prevented the actuator from opening the valve. Metallurgical examination attributed the crack to stress corrosion cracking (SCC). Several other valves exhibited surface indications on their main pistons; however, solenoid operation was not affected. The SCC originated in surface pits on the inside of the main piston. The pitting was attributed to an uncontrolled lay-up environment during an extended plant shutdown. The station replaced all solenoid valve actuators with a material that is less susceptible to stress corrosion cracking and upgraded the valve actuators to provide additional force. The new solenoid pistons are made from a 17% chromium alloy and are heat-treated for pitting resistance.
1/11/99	Failure Report 240 - During CPI-Trip-Test-5.50, SOV-5501S2 Did Not Actuate	During the trip-test 5.50, the solenoid valve (Parker Hannifin MRFN16MX0834) did not actuate when the test switch went to test. This was tested about six times before system engineering suggested agitation of the valve while in test. This worked. The subject valve failed to open due to metal shavings in the primary spool and small debris in the pilot spool. A trouble report (TR) has been written to replace the valve before the test is completed.

**Table B-1 (cont.)
Operating Events**

Date	Event (See Paragraph B.1)	Event Description
3/6/99	OE10368 - Overflow from Condensate Backwash Receiving Tank due to Solenoid Failure	During the restoration of the 2A condensate demineralizer following backwashing, the station had an overflow occur of approximately 25,000 gallons of condensate water to the condensate pit due to a failed dual coil solenoid valve. The cause of the event was a leak from the diaphragm of the dual coil solenoid valve that resulted in the loss of air on the closing actuator on the valve operator. This resulted in the valve going fully open. This event was discussed with Graver Technology (the OEM.) They concurred that the drain valve opening is the only way that they knew of to lose this much water (3500 GPM) from the system. They also stated that the dual coil valve arrangement has caused failures at other plants, like the one the station described.
3/13/99	OE9870 - Repetitive Failures of Solenoid Valve	The CO_2 header was not charged with CO_2 when 1USVCO005 was manually placed to the open position. The duplicate test steps for division 2 were successful. The failure of these Skinner solenoid valves was attributed to the material (Buna-N) that was manufactured recently for the plunger seals not being compatible with the heat of continuously energized coil. An older Skinner equivalent model solenoid was installed.
7/15/99	OE10475 - Saltwater Cooling Pump Discharge Valve Solenoid Operator Venting Continuously	The valve was found venting air to the atmosphere continuously. The shuttle inside the solenoid valve was stuck midway between the open and closed position, so that the supply air was vented directly to the exhaust port. Accumulation of dirt in the air regulator/filter and wear particles/debris in the ASCO solenoid valve's piston was the root cause. Restriction at the output port was considered to be a contributing factor to the failure. All air regulator/filters installed in safety-related and important-to-safety air-operated valves were replaced.
7/15/99	OE10475 - Saltwater Cooling Pump Discharge Valve Solenoid Operator Venting Continuously	The discharge valve solenoid operator (ASCO solenoid valve model NP8344A71E) was found blowing air out the port with the valve open. Inspection found a minor amount of foreign debris such as iron and aluminum oxide particles inside the solenoid valve and no grease at the sliding surfaces. Inspection of the supply air filter found small particles embedded in the 40-micron cellulose filter. The solenoid valve 0.436 ID exhaust port was connected to 0.215 ID tubing. The cause was the accumulation of dirt in the air regulator/filter and wear particles/debris in the ASCO solenoid valve's piston. Restriction at the outlet port was considered to be a contributing factor to the failure. The exhaust piping and air filters were replaced.

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
11/23/99	Failure Report 163 - SOV Installed Backward	After removing the SOV for repairs, the SOV was installed backward and the associated valve would not stroke. The SOV was an ASCO EHFT8320G172. After talking with the individuals involved, it was established that this failure most likely occurred when the SOV was disassembled for repairs. It was removed from the operator and returned. This SOV easily could have been installed backward since its ports were not labeled. In the future, any piece of equipment that is disassembled shall be labeled appropriately to insure proper reassembly. The 8320 is a three-way SOV. It has numbered ports instead of ports designated P, E, and A.
12/1/99	Failure Report 242 - During Performance of SP 2849 Liquid Pass Sampling Unable to Change Position of V-7 2-S-490 Solenoid-Operated Valve	During the performance of a test of the liquid post-accident sampling system (PASS), personnel were unable to change the position of sampling valve V-7 (2-S-490), solenoid-operated valve (Circle Seal Controls SV-43-2-s-2NC-B-4-4). Operation of the valve is necessary to maintain the ability to remotely obtain a representative sample of the reactor coolant via PASS.
2/27/00	Failure Report 434 - Master Trip Solenoid Failed to Trip	Turbine master trip solenoid A test P/B is depressed in the control room, and the red status light is supposed to go out if the solenoid is working correctly. It was tested several times for durations of up to 5 seconds, and the light never extinguished. The solenoid (GE 119C9168P0003) appeared to be sticking. The reason for sticking was not reported.
6/10/00	Failure Report 344 - SOV Failed to Close During Surveillance Test	While testing the SOV (Target Rock 76HH-008) during a surveillance test, it failed to close when required to. Troubleshooting was performed on the valve failing to close. The plant believes that the failure was probably the result of process-transported debris. The valve hung open during the initial event but closed once bumped. Either the obstruction has been repositioned within the valve internals, or it has been flushed from the valve. It is reasonable to assume that the debris has been flushed from the valve because of the repeated successful strokes performed during troubleshooting and subsequent surveillance tests.

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
6/20/00	OE11167 - Spurious Closure of Main Feedwater Isolation Valve Results in Low Steam Generator Level and a Manual Reactor Scram	The A MFIV spuriously closed. The MFIV failed to close because of a diode failure that caused a short across one of two parallel solenoid valves that keep the valve open against nitrogen pressure. When the diode failed, it caused a control power fuse to blow, and this deenergized both solenoid valves. The vendor (Automatic Valve Company) was not aware of similar diode failures. The vendor also reported that the solenoid valves were originally qualified without the diode but that a separate evaluation was performed when the diode was added. The station replaced the failed solenoid with a like replacement, after performing a bench test to break in the new coil.
10/23/00	OE11545 - Main Steam Isolation Valves Did Not Operate due to Clear Tape Covering Ports on the Bottom of the Valves' New Electric Solenoid Manifold Assembly Blocks	The C inboard main steam isolation valve would not operate when an attempt was made to stroke it during the preventive maintenance (PM) process. Personnel discovered that clear tape was covering the ports on the bottom of the block. The industry is being notified of this event because it resulted from clear tape not being removed from a component before it was installed. Such tape can be difficult to detect, especially when it is not expected to be present. This is most relevant for plants that are currently in refueling outages and performing similar preventive maintenance on similar MSIVs using solenoid manifolds received from vendor labs following EQ testing. The vendor lab applied the clear tape for foreign material exclusion purposes.
10/30/00	Failure Report 699 - Secondary Containment Damper Valve Did Not Stroke due to Apparent SOV Failure	The SOV pilot valve apparently did not stroke to allow the damper to close. The SOV is an ASCO model 206-832-3U & 3F. There is a strong likelihood that the failures of the AOV stroke times are a result of the SOVs sticking. This is based on industry research and what has been observed in the SOVs that have been sent to PECO labs for analysis. There is conflicting research on how this mechanism works and what causes it. There is some thought that the lubricant used during manufacture is the problem and some thought that the thread sealant is the cause. Until the evaluation of the SOVs was performed, it was assumed that any thread sealant that entered the SOVs was the result of the work practices at the time that the SOVs were installed. Testing of the SOVs has identified that the manufacturer, ASCO, also uses the same type of sealant during the assembly of the SOV. The thread sealant that the manufacturer uses was found in the uncured state even after nine years (these SOVs were received in 1990).

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
1/28/01	OE12548 - Manufacturing Lubricant Causes Turbine Control Solenoid Failure (Also see OE 9996 and OE 11506)	The main turbine master trip solenoid valve (Vickers) did not trip during the performance of routine miscellaneous EHC and turbine trip checks. Mechanical agitation of the solenoid was unsuccessful in freeing the stuck solenoid spool piece from its unported energized position. Inspection of the failed component revealed that the most probable failure mechanism was coil slug binding. A lubricant applied during the manufacturing process had formed a sticky residue along the slug guide tube after approximately 6 years of in-service operation. Earlier styles of Vicker coils were shipped with a rust inhibitor that later caused binding problems. A complete replacement of the coil and valve was performed. In newer solenoid designs, the clearances were opened to minimize the spool sticking to the lands.
5/1/01	OE12774 - Solenoid Valve Fails to Open because of Thermal Pressurization	On two occasions in May 2001, during extended emergency diesel generator operation for testing, the solenoid valve associated with automatic makeup to the fuel oil day tank failed to open. The cause was thermal pressurization of a portion of the fuel line greater than the capability of the solenoid valve to open against. A lift-check valve was installed in series with the solenoid valve. During the time between makeup cycles to the day tank, the cooler oil from the underground tank heated up sufficiently to significantly pressurize the section of piping between these valves. The problem was intermittent because ambient temperature was a factor. The solenoid valve had performed satisfactorily on four previous 24-hour runs. The solenoid that was associated with the two other site emergency diesel generators were of a newer design and capable of opening against significantly higher pressure; however, they were susceptible to the same phenomenon. Design changes were made, removing the solenoid valves from the system.
5/9/01	Failure Report 437 - Containment Integrity Valves Failed to Close On Demand (Stuck Open)	During the restoration of plant systems, flow could not be isolated during testing. The plant believed that the root cause of the failure to close was magnetite fouling of the valve internals (Valcor Eng Corp model V526-5683-5). No matches in the INPO database were found.

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
6/1/01	OE12385 - Drywell Sump Drain Valve Isolation Solenoid Sluggish Operation	A drywell floor drain sump isolation valve solenoid exhibited intermittent sluggish operation. After replacement of the solenoid valve, intermittent sluggish operation was identified again approximately one week later. A new solenoid from a different date/lot code was installed, and no further problems have been experienced. Sluggish operation was a result of higher-than-expected friction forces acting on the solenoid valve piston. A large contributor to this friction was determined to be the lubricant used on the elastomer U-cup that is at the end of the piston shaft.
9/5/01	OE14118 - Functional Failure of an Instrument Air Compressor Solenoid-Operated Unloader Valve	ASCO 8316G16: During a capacity check of the standby instrument air compressor 1A (IA-P-1A), the compressor, which should have loaded to approximately 100 psig, would only load to 20 psig. The solenoid operated unloader valve was inspected and found to be sticking. The valve seat vertical diaphragm surfaces were coated with sticky residue and some erosion of the elastomer. The supplier confirmed that the solenoid could stick if the solenoid were to sit idle for long periods of time. All of the standby compressors sit idle for months. Following installation of a new solenoid unloader valve, the compressor operated normally. Since the last failure was 8 years ago, PM was established to replace the valve every 5 years.
9/22/01	Plant Failure Report 492 - Containment Isolation Valve Failed	Containment isolation valve (Target Rock 76HH-008) 2JSGAUV1134 failed in its closed position. The plant had installed a high-temperature coil (HTC) on this valve on July 22, 1996. At the time of the failure, the HTC had been in service for 66 months. The electricians determined that the control power fuse was blown and suspected that this condition had been caused by a failed coil. This was a normally energized coil. The plant believed this was an end-of-life failure for this coil and was satisfied with the 5+ years of service in this particular location (previously, the standard coil in this application would fail in approximately one year).
1/18/02	Failure Report 667 - Feedwater Valve Did Not Stroke On One Train	The SOV (ASCO 206-832-3VF) did not change positions. This was attributed to aging/wear. The SOV was in service 5312 days.

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
1/25/02	NRC EVENT #38651 - Part 21 report valves were leaking in the energized position. The valve was being used in the normally closed mode at an inlet pressure of 74 psig. Other valves at the station are exhibiting the same problem.	At the valve vendor (Automatic Valve), it was found that at inlet pressures of 74 and 125 psig (861 kPa), the valve did not reset after the solenoid was deenergized. It did not reset until the inlet pressure was reduced to approximately 40 psig (276 kPa). When tested in the normally open mode (pressure to port 1), there was leakage at exhaust port 3 when the solenoid was energized, but the valve immediately reset at its maximum rated inlet pressure of 125 psig when the solenoid was deenergized. It was determined that the top seat was 0.020 inch below the top surface of the plunger or 0.007 inch below the maximum design standard of 0.013. With the top seat 0.020 inch below the top surface of the plunger, the top seal was touching the top orifice but was not compressing the internal spring and, hence, not creating a good seal. Consequently, there was severe leakage out of exhaust port 3, which is 0.125 inch (3.2 mm) in diameter. This severe leakage created a pressure differential across the top of the plunger and, thus, a force tending to hold the plunger in place. This force could not be overcome by the external spring until the inlet pressure was reduced to approximately 40 psig.
2/9/02	OE13294 - Manual Reactor Trip In Response to Main Feedwater Regulating Valve Failure	The feedwater regulating valve failed closed, isolating feedwater to the steam generator. This required a manual reactor trip in anticipation of the steam generator low water level trip. The fuse for the lead feedwater isolation circuitry failed. The coil resistance for the solenoid valve (ASCO) was approximately 12% of the expected resistance for a good coil.
6/5/02	Failure Report 515 - Valves Do Not Respond to Open Demand From the Control Room Handswitch	Steam trap containment isolation valves (Target Rock Corp model 76H–008) did not respond to open demand from the control room handswitch. This was discovered during restoration from testing. Old internal parts were inspected. No visible damage abnormal wear or galling was noted. However, the parts were coated with magnetite/oxide. The magnetite buildup on the parts is expected for these valves in this application. Given the tight design allowances and tolerances, excessive magnetite buildup or debris could cause binding between sliding parts and prevent the valve from opening.

Table B-1 (cont.)
Operating Events

Date	Event (See Paragraph B.1)	Event Description
11/19/02	OE15432 - Lockout Valve “Sticking” in Locked-Out Position Following Mechanical Overspeed Trip Test	Following performance of the mechanical overspeed trip test on the main turbine, the lockout valve took approximately 14 minutes to reset. With the lockout valve in the locked-out position, turbine overspeed protection was reduced from 3 levels of defense to 2 levels of defense. Solenoid valves that are subjected to EHC fluid can become “sticky” over time. This is due to EHC fluid quality and a varnish-type buildup that develops internal to the solenoid valve and prevents the spool piece from moving freely inside the valve body. This problem has been successfully solved using a PM program. A program was set up for this valve.
11/19/02	Failure Report 230 - Secondary Containment Isolation Damper Failure to Close	An inboard isolation damper failed to close. The solenoid (ASCO 8320), which was in service 2514 days, failed to shift. Inspection of the failed solenoid valve revealed a black substance that had accumulated on the interface of the core and plug. This substance is consistent with the substance found in the 2-64-13 solenoid valve when it failed. The substance is believed to have caused the plug and core to stick in a fixed position so that when the coil is deenergized, the FSV failed to change states and the air was not vented from the damper operator. The source of the substance was not determined in this report. A plan was established for replacement of components, preventive maintenance procedures, or revision of tasks.
2/11/03	OE15652/15935 - The No. 3 Turbine Stop Valve Failed to Close During Quarterly Valve Testing	The solenoid valve that should pass air to the test cylinder to position the pilot valve would not allow the passage of air when the solenoid was energized. The root cause of the solenoid valve failure was a foreign substance that was found between the sleeve assembly and the plunger assembly of the solenoid valve, causing it to bind. The valve had recently been installed but had been in stores for approximately 10 years. The solenoid valve was replaced with a new one from stock, and the turbine stop valve was successfully tested.

C
DESCRIPTION OF TYPICAL SOV OPERATION

C.1 Interaction

The following information is provided to assist readers in understanding the operating principles and components of two valve styles that are frequently found in nuclear power plant applications. The first is a direct-acting three-way SOV that is typically used to control AOVs. The second is a double-piloted valve type that is widely used in high-temperature, high-pressure process applications.

C.2 Typical Three-Way Air SOV

Figure C-1 is an exploded view of one of the more widely applied three-way direct-acting SOV designs. This type of valve is widely used to control air-to-diaphragm type pneumatic valve actuators. Importantly, the operating mechanism of this direct-acting valve is virtually identical to the pilot valve portion of other three-way and four-way piloted valves that are provided by several manufacturers. The following discussion also provides insight into the directional characteristics of this type of SOV.

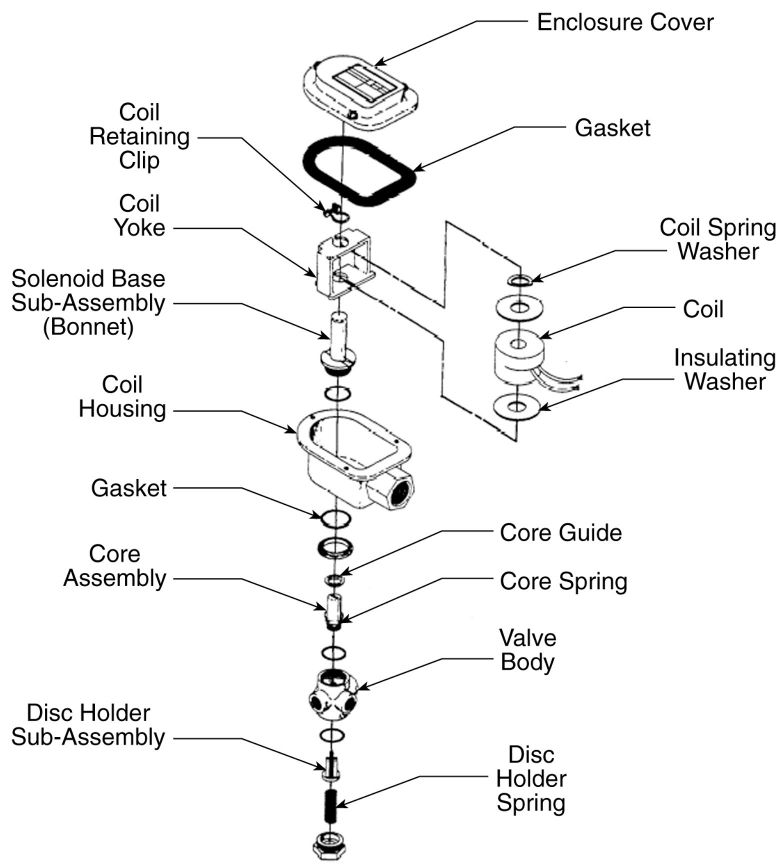

Figure C-1
Expanded View of Three-Way Direct-Acting SOV [5]

The SOV is supplied with soft seats, which can be provided in a variety of materials. The most common are Buna-N, Viton, and EPDM. The valve is available in both DC and AC versions. The AC version uses a shading coil.

Figure C-2 schematically depicts the operation of the active valve components. The core assembly, containing an integral soft seat material, is pulled vertically when the SOV coil is energized. The core spring is attached to the core assembly. The core spring opposes the SOV coil's magnetic pull. The disc holder subassembly (DHS), often called a milk stool due to its shape, contains an integral soft-seat material. The DHS spring applies continual upward force to the DHS, causing it to follow the movements of the core assembly.

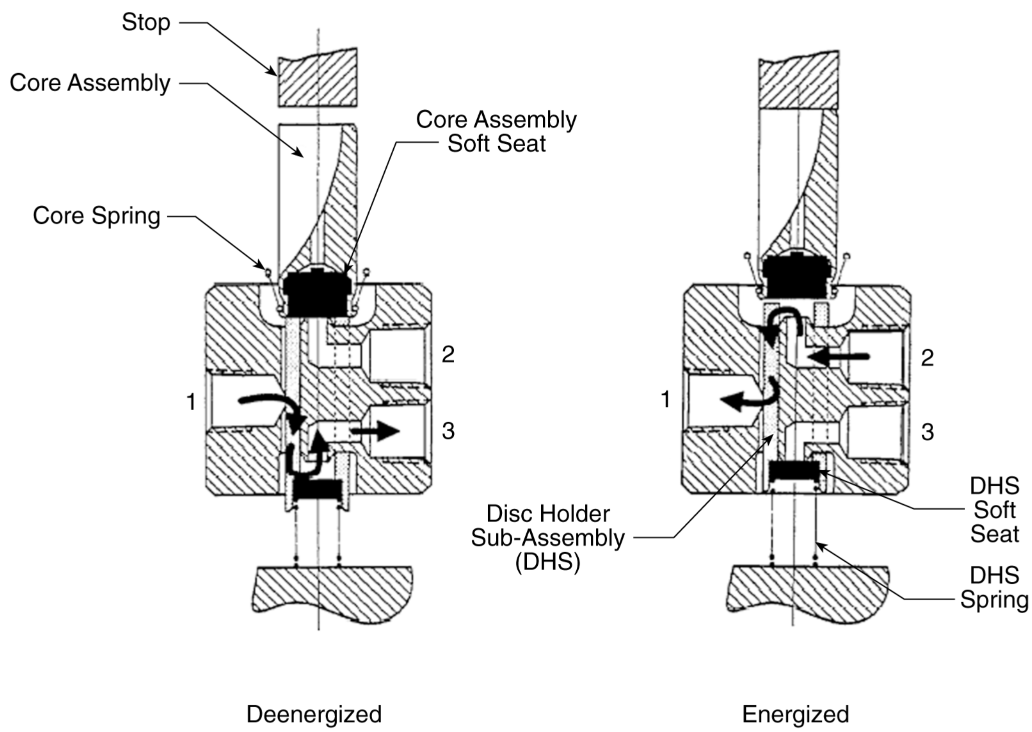

Figure C-2
Three-Way SOV Operating Schematic [5]

In the deenergized position, since the core spring force is stronger than the DHS spring force, the core assembly is seated and the DHS is unseated. This interconnects ports 1 and 3 through the DHS seat (lower) orifice. In this position, the net core assembly seating force is the difference between the core spring and DHS spring forces plus the pressure acting on the core assembly (upper) seat.

When the coil is energized, the magnetic attractive force causes the core assembly to be drawn up into the coil and unseats the core assembly. Unopposed by the core assembly spring, the DHS is seated due to the force that is exerted by the DHS spring. This interconnects ports 1 and 2 through the core assembly seat orifice. The core assembly travels roughly 0.060 inch between the energized and deenergized positions. In the energized state, a small gap exists between the DHS and the core assembly. This assures that all of the disc holder spring force is used to seat the DHS. It also permits the core assembly to build up a little momentum, helping to unseat the DHS when the valve is deenergized.

When the valve is energized, increasing pressure at port 1 assists in the seating of the DHS. The net spring force must be sufficient to overcome this seating force, or the valve will not shift position when deenergized. In the energized position, increasing pressure at port 3 will try to unseat the DHS. The unseating force must be less than the DHS spring force, or the DHS will be unseated and the valve will leak.

In the deenergized position, increasing the pressure at port 2 tries to unseat the core assembly. The unseating force must be less than the opposing net spring force, or the core assembly will be unseated and the valve will leak. Increasing pressure at port 1 in the deenergized position assists the seating of the core assembly. In this case, sufficient magnetic force must be exerted on the core assembly to overcome both this and the net spring force. Excessive pressure can prevent the valve from shifting to the energized position.

This SOV design is available in several orifice sizes in normally open, normally closed, and universal constructions. Design changes in the core spring, disc holder spring, and coil result in the range of MOPD and orifice sizes provided.

In the *normally closed* construction, supply pressure is applied at port 2. The normally closed configuration requires a strong core spring and a weak disc holder spring. For the normally closed construction, the disc holder spring needs to exert only a minimum amount of force to close the DHS port in the energized condition. (Remember that when energized, the pressure at port 1 is greater than the pressure at port 3 and therefore helps to close the DHS port.) The core spring must be strong enough to both unseat the DHS and close against the pressure at port.

In the *normally open* construction, supply pressure is supplied at port 3. This configuration requires a much stronger disc holder spring and a core spring that is slightly stronger than the disc holder spring. For the normally opened construction, the disc holder spring needs to exert sufficient force in the energized condition to keep the DHS port closed against the higher pressure at port 3. The core spring must be strong enough to unseat the DHS but needs only a minimum amount of additional force to close the core assembly port.

In the *universal* construction, since pressure may be applied at either ports 2 or 3, the disc holder spring must be strong and the core spring must be much stronger. The core spring must overcome both the disc holder spring and possible unseating pressure at port 2. Because stronger spring forces are required in the universal construction, the MOPD is significantly reduced.

C.3 Pilot-Operated Process SOVs

Figure C-3 is a high-pressure, high-temperature piloted process SOV. Figure 2-12(c) is a close-up of the valve seat design. The valve can be supplied in normally open and normally closed constructions. The normally closed design described here is the most popular. The valve is available with a stellite hard seat or silicone soft seats. The valve can be provided in both DC and AC versions. The AC version uses a rectified coil with a rectifier located in the switch housing.

Uniquely, this valve employs a dual pilot and dual plunger design. The primary pilot (ball rod pilot) is located coaxially with the secondary pilot and the main disc. The ball rod pilot is seated on the secondary pilot. The ball rod pilot is operated directly by the plunger.

The secondary pilot (pilot disc) is operated mechanically by the movable core (the second plunger). The pilot disc is located coaxially with, and is seated on, the main disc.

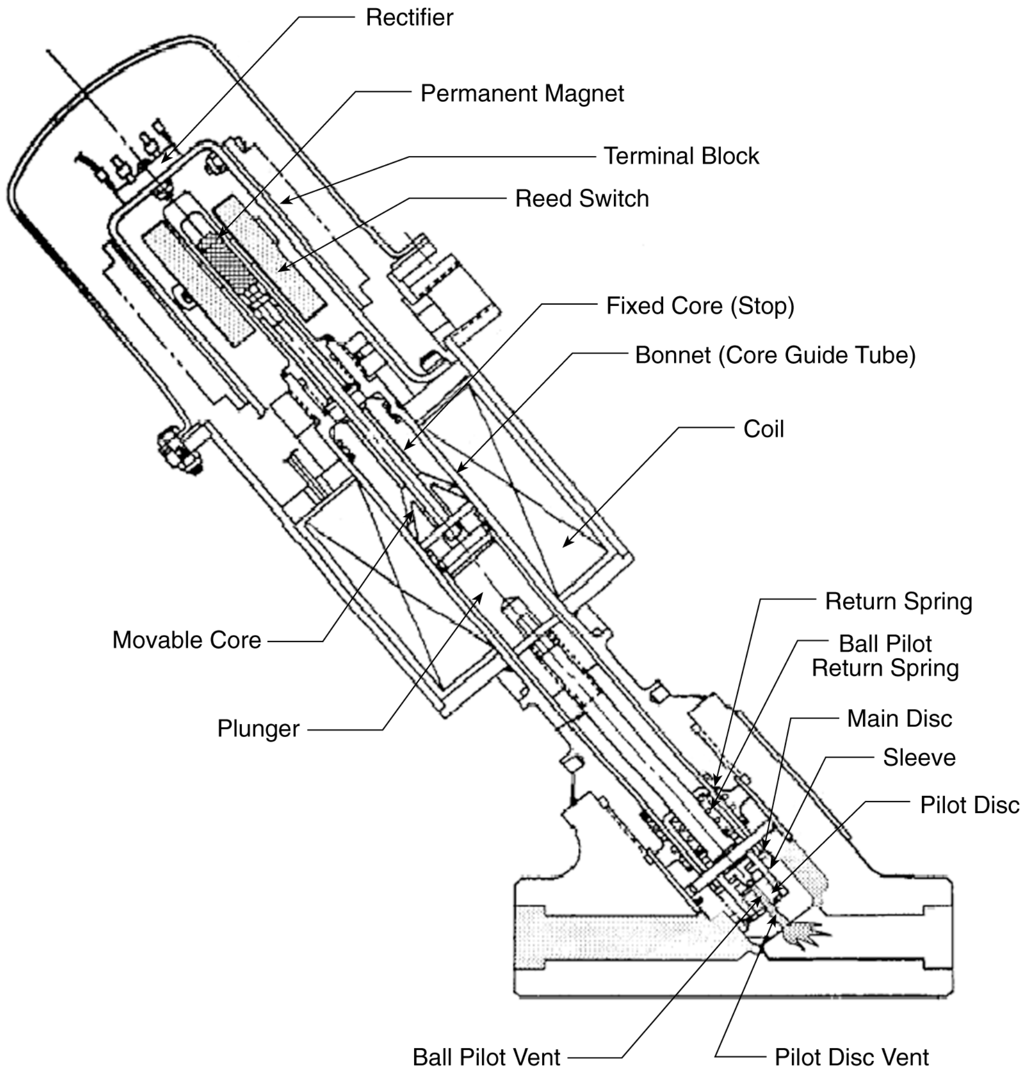

Figure C-3
Piloted Normally Closed Two-Way Process SOV [2]

The main disc is attached to the movable core connecting tube by a pin that fits loosely into an oversized hole in the main disc. The pin also passes through a larger hole in the ball rod shaft.

A main disc seal ring isolates the disc chamber from inlet pressure. The inlet orifice is located in the wall of the main disc.

The general operation of the valve is different from the valves described in Section 2.2. When the coil is energized, the plunger is attracted to the movable core assembly, and the ball rod pilot opens. As pressure is vented above the pilot disc, it also opens and further decreases the pressure above the main disc. When the pressure above the main disc decreases sufficiently, the main disc opens fully, and the movable core is drawn against the stop.

In the absence of supply pressure, when the coil is energized, the plunger is attracted to the movable core assembly, similar to the manner described above. However, no differential pressure is available to cause the pilot or main discs to open. In this case, the movable core is magnetically attracted to the stop. Since the main disc is attached to the movable core, the main disc opens.

The valve contains an integral magnetically operated position indication system that is located in the switch housing. The position system magnet is connected by a stem to the movable core. Section 2.9 describes in detail the operation of this type of position indication system.

C.4 Miscellaneous SOV Calculations

C.4.1 Magnetic Force

The general equation for the magnetic force attracting the plunger to the stop is:

$$F = \frac{(NI)^2}{A(R_o + \frac{x}{A})^2}$$

Where N = the number of wire turns, I = the coil current, A = the cross section area of the plunger, and x = the length of the air gap. In this expression, Ro is the reluctance of the non-air gap portion of the magnetic circuit. According to this equation, the magnetic force attracting the plunger varies inversely with the square of the air gap distance.

For DC coils, the current (I) is related to voltage (V) and the coil's resistance (R) by I = V/R. In other words:

$$Fm = \frac{(\frac{NV}{R})^2}{A(R_o + \frac{x}{A})^2}$$

C.4.2 Valve Spring Force

A spring's force can be represented by the following expression:

$$F = -(K_o + xk)$$

Where Ko is the spring preload force when the plunger is fully withdrawn, k is the spring constant, and x is the air gap distance. The negative sign indicates that the spring force acts in the opposite direction of the magnetic force. In a few applications, there is no spring, and the weight of the plunger is used to draw the plunger out of the coil when the valve is deenergized.

C.4.3 Valve Hydraulic Forces (See Figure 2-11)

Main Disc Open/Pilot Valve Closed

If the main disc and the pilot valve are closed, the main disc forces are as follows:

Assume $A_{disc} = A_{inlet} + A_{outlet}$.

Then, each of the forces on the main disc is simply the applied pressure times the area exposed to the pressure, or:

$$F_{disc} = P_{disc} * A_{disc}$$

$$F_{outlet} = P_{outlet} * A_{outlet}$$

$$F_{inlet} = P_{inlet} * A_{inlet} = P_{inlet} * (A_{disc} - A_{outlet})$$

Observe that the inlet and outlet forces oppose the disc force and are trying to unseat the main disc. If positive force seats the valve, then the sum of the seating forces is:

$$F_{seating} = F_{disc} - (F_{inlet} + F_{outlet})$$

$$= (P_{disc} * A_{disc}) - [(P_{inlet} * (A_{disc} - A_{outlet})) + (P_{outlet} * A_{outlet})]$$

$$= A_{disc} * (P_{disc} - P_{inlet}) + A_{outlet} * (P_{inlet} - P_{outlet})$$

This general equation always describes the forces applied to the main disc. When the pilot valve is closed, $P_{disc} = P_{inlet}$, and the equation reduces to:

$$F_{closed} = A_{outlet} * (P_{inlet} - P_{outlet})$$

Pilot Valve Open

When the pilot valve is open:

Assume that disc and outlet pressures are equal, and the force equation becomes:

$$F_{open} = A_{disc} * (P_{outlet} - P_{inlet}) + A_{outlet} * (P_{inlet} - P_{outlet})$$

$$= -(A_{disc} - A_{outlet}) * (P_{inlet} - P_{outlet})$$

Since A_{disc} is always greater than A_{outlet} and P_{inlet} is always greater than P_{outlet}, a negative force is created, lifting the main disc. Additional insight is provided by remembering that $A_{disc} = A_{inlet} + A_{outlet}$. Then, the equation reduces to:

$$F_{open} = A_{inlet} * (P_{inlet} - P_{outlet})$$

Burping

Insight into burping can be provided by rearranging the force equation, assuming that the net seating force is zero (the point when the disc just begins to change position), assuming that $P_{outlet} = 0$, and re-labeling the inlet pressure to $P_{inlet\text{-}transient}$. Then

$$P_{inlet\text{-}transient}/P_{disc} = A_{disc}/(A_{disc} - A_{outlet})$$

This equation indicates that the point when the disc forces just balance is related to the main disc and seat areas and the ratio of the inlet pressure to disc chamber pressure. As the disc area becomes large relative to the seat area, the transient inlet pressure that is necessary to cause possible disc movement (burping) decreases.

C.4.4 Electrical Calculations

Electrical Relationships (DC coils)

I = V/R
P = V*I
P = Voltage²/Resistance

Where I = Current (amps)
V = Voltage (volts)
R = Resistance (ohms)
P = Power (watts)

C.4.5 Coil Resistance-to-Temperature Rise Calculations

The generalized equation for converting coil resistance to temperature (°C) is:

$R_h = R_c\ (T_h + K)/(T_c + K)$ or $T_h = (R_h/R_c \times (T_c + K))-K$

Where T_h and T_c are the hot and cold coil temperatures in °C, R_h and R_c are the hot and cold coil resistances in ohms, and K = 234.5 for copper and 225 for aluminum.

D
SOV FAILURE REPORTING CHECKLIST

SOV FAILURE REPORTING CHECKLIST

SOV ID (TAG #):______________________ MANUFACTURER:______________________

MODEL NO.:_________________________ SERIAL NO.:___________________________

OPERATING CONDITIONS:

COIL TYPE: [ ]AC [ ] DC

[ ] NORMALLY ENERGIZED [ ] NORMALLY DEENERGIZED

[ ] FREQUENTLY CYCLED REPETITIONS PER HOUR:___________

PROCESS FLUID: [ ] AIR [ ] WATER [ ] OTHER

PRESSURE: MAX.________ MIN.____________

AMBIENT TEMPERATURE:_________

VALVE PURPOSE/FUNCTION:

____

____

____

VALVE PROBLEM:

[ ] NOT OPENING [ ] NOT CLOSING

[ ] SEAT LEAKAGE WHILE: >>>>> [ ] ENERGIZED OR [ ] DEENERGIZED

[ ] EXTERNAL LEAKAGE [ ] NOT SHIFTING

[ ] EXCESSIVE WEAR [ ] COIL BURNOUT

[ ] SOLENOID NOISE [ ] CHATTERING ON CLOSE

[ ] DIAPHRAGM RUPTURE [ ] WATER HAMMER

[ ] OTHER (SPECIFY):___________________________

ADDITIONAL DATA:

IN-SERVICE TIME (DAYS, WEEKS, ETC.) _______________

IS THIS A RECURRING PROBLEM? [ ] YES [ ] NO

HOW MANY OTHER VALVES OF THIS TYPE?___________

SIMILAR PROBLEM WITH THESE OTHER VALVES? [ ] YES [ ] NO

REMARKS:

____

____

____

E
SOV SPECIFICATION CHECKLIST

SOLENOID VALVE SPECIFICATION CHECKLIST

1. Type: [ ] 2-way [ ] 3-way [ ] 4-way [ ] Other _______________

   Design (globe, gate, etc) _______ Seat: [ ] Hard [ ] Soft

2. Actuation: [ ] Open/Close [ ] Modulating [ ] Direct [ ] Pilot

   Deenergized Position: [ ] Open [ ] Closed [ ] Other _________

   Failure Position: [ ] Open [ ] Closed [ ] As Is

3. Line Size:______in. Schedule ________

4. Port Connections: [ ] Socket-Welded [ ] Butt-Welded [ ] Threaded (NPT)

5. Fluid Composition: _______________________________________

6. Pressure: Design______ psig Max. Operating ________psig

   Normal Operating ____ psig Max. ΔP at shutoff ______psid

   Allowable ΔP @ max. flow ____psid Min. Operating ΔP ______psid (pilot)

7. Fluid Temperature: Design _____ Maximum _____Normal _____Minimum_____

8. Ambient Temperature: Maximum _____ Normal _____ Minimum ______

9. Flow Rate: Sizing _____ Maximum ______Minimum (valve open) ______

10. Allowable Leakage: ________ @ ΔP from ___________ to ____________

11. Codes: [ ] ASME III Class _____ [ ] ANSI Pressure Class ________

12. Qualification: [ ] Seismic: Category _____ [ ] Active [ ] Passive

    [ ] Environmental: Category _______ [ ] Active [ ] Passive

    Radiation Dose _____________

    [ ] Inside Containment [ ] Outside Containment

13. Operating Voltage: [ ] DC _____ [ ] AC ____ Normal _____ Maximum _____

14. Duty Cycle: [ ] Energized Continuously [ ] Energized Intermittently

    Maximum “On” Time ____________

15. Materials: Body _______________ Seat ____________ Seals _______________

16. Miscellaneous: Stem Orientation ________________

F
DESCRIPTION OF SOV DRAWING SYMBOLS

F.1 Introduction

Since a large number of SOVs are used in fluid power applications, the ANSI graphic symbols for fluid power diagrams are found in many SOV catalogs. Often, other symbols are also used to depict the confusing interconnections of SOV ports.

F.2 Building Blocks

Figure F-1 illustrates the building blocks of the ANSI symbols. The symbols are composed of two principal elements: *actuation* symbols and *porting* symbols. Commonly used actuation symbols are shown on the upper-left side of Figure F-1, and the porting symbols are on the right side. The three most important actuation symbols are the pilot, the solenoid, and the spring.

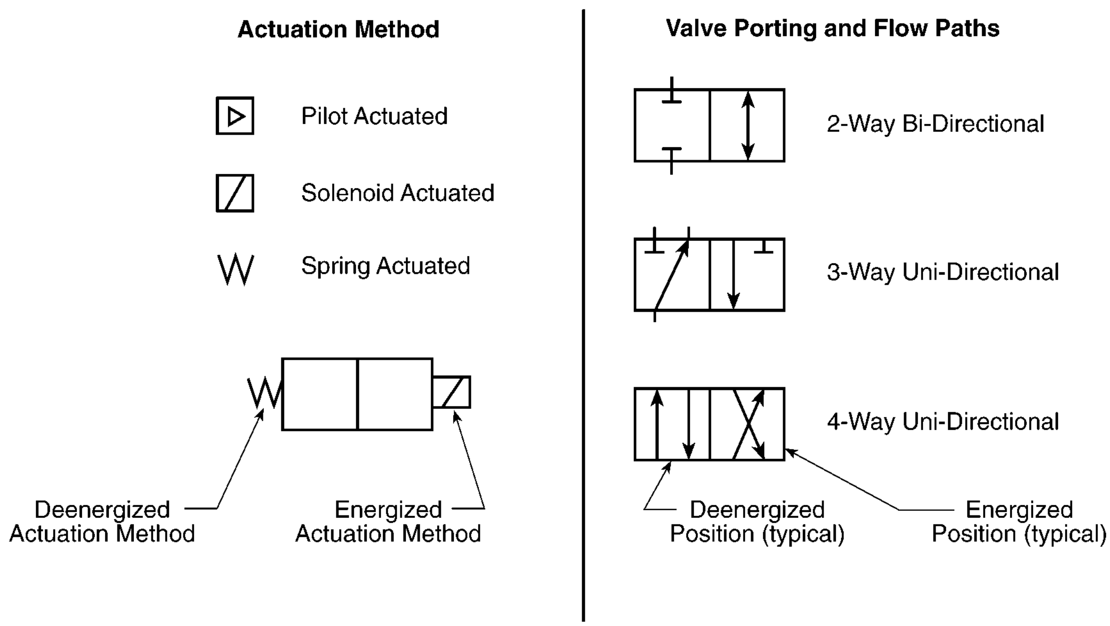

Figure F-1
Building Blocks of the ANSI SOV Symbols

F.3 Porting

To define porting, two squares are placed side by side. Inside the squares are flow symbols and arrows showing how the ports are interconnected. One square represents the port arrangements with the SOV in one state (for example, energized), while the other square represents the opposite state (for example, deenergized).

F.4 Actuation

The porting and actuation symbols are combined in the following way: actuation symbols are placed adjacent to each of the port squares. The actuation symbol represents the method that is used to transfer the SOV to that particular state. Typically, the left square represents the deenergized state and the right square represents the energized state. For example, a direct-acting SOV with unspecified port connections is shown on the lower left half of Figure F-1. The solenoid symbol on the right means that the port arrangement in this square exists in the energized state. The spring symbol on the left indicates that a spring returns the SOV to the deenergized state. Therefore, the port arrangement in the left square represents connections in the deenergized state.

F.5 Common Port Arrangements

The right side of Figure F-1 shows three common port arrangements for two-way, three-way, and four-way valves. If these porting arrangements were used in the lower left figure, they would represent two-way, three-way, and four-way direct-acting SOVs. The port symbols are self-explanatory. The two-way valve has a double-headed flow arrow. This double-headed arrow indicates that the valve is designed for flow in either direction (it is a universal construction). The three-way and four-way valves are both unidirectional, since the arrows point only in one direction.

F.6 Examples

Figure F-2 shows several complete ANSI symbols and other simple SOV sketches that represent the same flow conditions. Notice that, in the ANSI symbols, the port designations generally are shown once on the left-side square.

The middle ANSI symbol (for the three-way piloted no-return spring SOV) has no spring symbol and two pilot symbols. This does not mean that the SOV has two pilots. Rather, the valve uses a pilot combined with a solenoid to transfer the valve to the energized state, while the pilot alone returns the valve to the deenergized state. This type of piloted valve will usually have a minimum operation pressure differential requirement. The piloted four-way valve uses a spring to return the valve to the deenergized position. Unfortunately, this does not mean that the valve requires no minimum differential pressure.

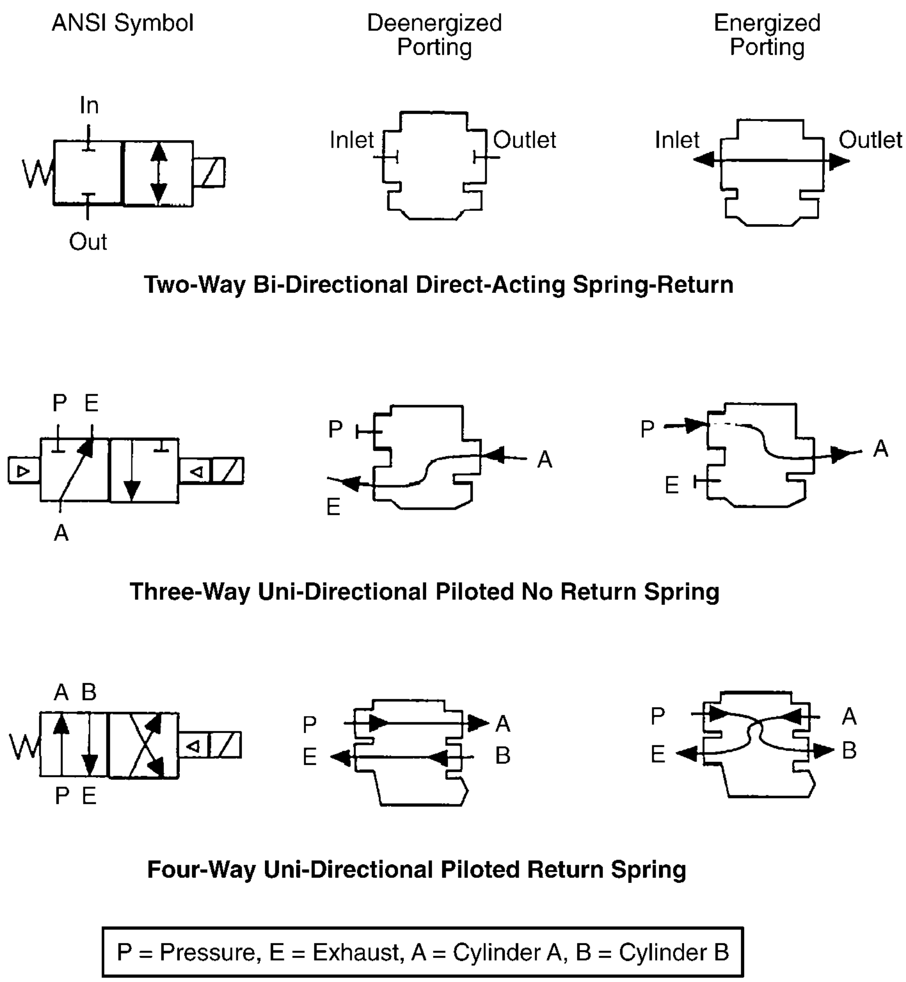

Figure F-2
Several Commonly Found ANSI and Other SOV Symbols

G
LISTING OF KEY INFORMATION

The following list provides the location of Key Point information in this report.

Key O&M Cost Point

Emphasizes information that will result in reduced purchase, operating, or maintenance costs.

Section	Page	Key Point
2.15.4	2-45	Coils are supplied with different temperature ratings. Higher temperature ratings provide extra operating margin and life.
2.15.6	2-49	At a minimum, use water- and dust-tight enclosures (NEMA 4). EQ applications may require special enclosures and seals.
3.8	3-13	Stroke measurements can help during troubleshooting and verify the adequacy of valve repairs. Measuring stroke generally requires a special tool. Strokes cannot be easily measured on SOVs without position indication.
3.10.3	3-22	A simple coil polarity test can be done, using a compass, prior to mounting the coil on the SOV.
3.14	3-25	When a previously stuck SOV is not operating properly, the safest action is repair or replacement of the SOV. Other actions may be appropriate, however, based on function, safety significance, and other available failure information. Without repair or other corrective action, unreliable SOV operation can be expected.
3.15	3-27	Cross-references between repair kit numbers and valve model numbers may not be supplied in SOV manuals. Even valves with identical model numbers, but supplied in AC and DC versions, can have different part kits. Verify the proper kit numbers using documents or discussions with distributors or manufacturers.
3.16	3-29	PMT inspections/tests should be based on the possible effects of the repair activities on SOV performance and the original reason for the maintenance action.
4.2	4-3	Preventive maintenance based on calendar time is imprecise, since a variety of factors affect degradation and wear. Without operating experience, replacement intervals must conservatively bind the worst set of assumed conditions.
4.3.1	4-3	Coil insulation resistance (IR) tests are an excellent method of determining the general condition of SOV coils. Coil IR tests should be performed whenever valves are rebuilt. They should also be used during troubleshooting and corrective maintenance.

Section	Page	Key Point
4.3.2	4-4	Pickup and dropout cycle tests are preferred to normal voltage valve cycling, since they provide a better gauge of valve condition.
4.4	4-6	One of the most important factors for selecting periodic replacement frequencies is operating experience.
4.4.1	4-7	Coil life generally ranges from 4 to 10 years when continuously operated at the insulation's rated temperature.
4.4.2	4-8	Examine the condition of elastomers when valves are disassembled. Compare the condition to that of new components. Adjust service intervals to keep the elastomers flexible.
4.5	4-8	One of the best SOV preventive maintenance techniques is periodic valve cycling. No one cycle frequency can be recommended; the most important factor for selecting a cycle frequency is operating experience.

Key Technical Point

Targets information that will lead to improved equipment reliability.

Section	Page	Key Point
2.3.6	2-3	The standard convention for identifying solenoid operation on schematics is to indicate the position of the valve when the solenoid is deenergized.
2.4.1	2-7	When a solenoid is energized, the magnetic force attracts the plunger toward the stop. The closer the plunger is to the stop, the greater the attractive force. A spring returns the plunger to the extracted position when the coil is deenergized.
2.4.2	2-10	SOVs can be made to operate on AC power either by using rectifiers to convert the current to DC or by shading coils to shift part of the magnetic flux.
2.4.3	2-13	AC SOVs that use shading coils hum excessively if the plunger is not fully inserted.
2.5	2-14	Direct-acting SOVs have the main disc connected to the plunger. Solenoid force alone operates the SOV.
2.5.1	2-15	In piloted SOVs, the solenoid is too weak to directly operate the main disc. Instead, the solenoid operates an internal pilot valve. The pilot valve applies pressure to a diaphragm or piston. The pressure force then operates the main disc.
2.5.1	2-16	Most piloted SOVs require a minimum operating pressure differential to operate. The SOV is not designed to operate below this differential pressure.
2.5.1	2-16	In pilot-assisted SOVs, the plunger is attached to the main disc and operates it with no differential pressure. Pilot-assisted SOVs do not have a minimum operating pressure differential.
2.5.3	2-19	Piloted valves can open unintentionally for a fraction of a second if a rapid inlet pressure transient occurs. This phenomenon is called *burping*.

Section	Page	Key Point
2.6	2-20	Most SOVs are designed for flow in only one direction. Important operational restrictions apply to the use of directional SOVs. If pressure is reversed, the SOV may spuriously open or fail to operate.
2.6	2-20	With careful design, some SOVs can permit flow in both directions. In order to have two-direction flow, these universal SOVs usually sacrifice pressure rating or flow capacity.
2.6.2	2-22	Most piloted SOVs exhibit strong directional characteristics.
2.8	2-33	Hard seats are preferred where tight shutoff is not necessary. Soft seats are limited to temperatures below 350°F. Soft seats are better able to tolerate particulate contaminants.
2.9	2-34	DC SOV coils generate less force at higher temperatures (for example, when they get hot) because the higher coil resistance reduces coil current.
2.9	2-35	Energized coils have a shorter life because their materials degrade at higher temperatures. Coil material life is halved for every 7°–8°C (12°–15°F) increase in coil temperature.
2.10	2-36	Plant DC systems operate at roughly 132 Vdc. This is higher than the rating of most commercial DC SOVs (120–125 Vdc). The higher voltage can shorten coil life because of higher operating temperatures. Some SOVs are not capable of prolonged operation at 132 Vdc and will prematurely fail.
2.11	2-36	Position indication is often provided by magnetically operated reed switches. The permanent magnet is inside the valve bonnet. It is connected to and moves with the solenoid plunger.
2.12	2-38	Special SOV designs can reduce the voltage to the coil after the valve is energized. Reducing the voltage lowers valve temperatures and prolongs elastomer and coil life.
2.13	2-39	A typical “fail-as-is” design uses permanent magnets and two coils. Fail-as-is designs can be used to reduce energized valve operating temperatures.
2.14	2-41	By using stiffer return springs, position feedback, and electronic controls, SOVs can be designed as modulating valves.
2.15.2	2-44	Plungers are typically made of 400 series (magnetic) stainless steels, which are not as corrosion-resistant as the 300 series. Therefore, the plunger may need to be cladded or plated with a material corrosion-resistant to the fluid environment.
2.15.2	2-44	Plungers in DC valves are designed to minimize the effects of residual magnetism that can prevent the plunger from retracting. Plungers in AC valves must be in intimate contact with the core/bonnet in order to minimize hum and holding current.
2.15.2	2-44	The plunger guide tube or bonnet must be fabricated of a non-magnetic material for the solenoid to attract the plunger.
2.15.4	2-46	Molded coils are more resistant to moisture, water, and external contaminants than varnished coils.
3.9.1	3-15	Careful reed switch adjustment is critical to continued reliable position indication.
3.9.2	3-16	Proper coil polarity is critical to adjusting reed switches.

Section	Page	Key Point
3.9.3	3-16	Adjust the open switches when the valve is open and the closed switches when the valve is closed.
3.9.3	3-19	When adjusting reed switches: • Carefully follow manufacturer guidance. • Adjust each set of switches when the valve is in the proper position. • Set closed switches when the SOV is deenergized and open switches when the SOV is energized. • Move the switches into the magnet's influence, and monitor switch closure. • Enrich the switch setting by advancing it some additional distance (see manufacturer's recommendation). • Replace the cover prior to final switch testing. • Test proper operation by cycling the valve at least three to six times.
3.10.1	3-20	Coil failures are often caused by other problems. Coils will burn up when AC valves cannot fully open (hum excessively). Water/moisture in the coil enclosure can damage non-molded coils. High temperatures, generally due to continuous energization and high local temperatures, can thermally degrade coils.
3.10.2	3-20	AC coils can work in DC applications but will overheat and burn up after being energized for a relatively short time.
3.10.2	3-21	Make sure that the replacement coil has the correct part number. Check the coil resistance, and compare it to specified values. AC coils have about 1/10 the resistance of similar DC coils. Requiring that the SOV nameplate data (or coil part number) and coil resistance be recorded on an installation data sheet helps to ensure that the data is collected and verified.
3.11	3-22	Do not use silicone fluids or grease to lubricate silicone O-rings.
3.11	3-23	To be safe, do not use petroleum-based lubricants except if required by the manufacturer. NEVER use petroleum-based lubricants with ethylene propylene-based compounds.
3.17.1	3-31	In general, the best SOV operating position is with the coil and plunger upright and vertical. If the SOV is qualified, this position must be verified in order to ensure operability.

Key Human Performance Point

Denotes information that requires personnel action or consideration in order to prevent injury or damage or to ease completion of the task.

Section	Page	Key Point
2.3.10	2-4	Always refer to the equipment tag for proper voltage and voltage type. Do not rely on the model number alone.
3.2	3-3	When troubleshooting SOVs, ensure that station safety and equipment tagging procedures are carefully followed.
3.6.1	3-9	Do not attempt to repair a critical SOV seat without prior training or experience. Closely observing others who are skilled in refinishing a particular valve style as well as training and practice are essential to properly refinishing SOV seats.
3.11	3-24	Overlubrication can be almost as harmful as no lubrication. Sticking is rarely caused by inadequate lubrication. Do not overlubricate to solve the problem.
3.12	3-24	Do not apply adhesives or sealing compounds to the first two or three threads of a fitting.
3.14	3-27	Within a particular SOV style, parts may look similar but actually differ among model numbers. This can be especially true with the springs in air-pilot valves.

Program:
Nuclear Power

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