Department of Energy
Fundamentals Handbook

INSTRUMENTATION AND CONTROL
Module 5
Position Indicators

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REFERENCES

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TERMINAL OBJECTIVE

1.0 Given a position indicating instrument, **RELATE** the associated fundamental principles, including possible failure modes, to that instrument.

ENABLING OBJECTIVES

1.1 **DESCRIBE** the synchro position indicators to include the basic construction and theory of operation.

1.2 **DESCRIBE** the following switch position indicators to include basic construction and theory of operation.
a. Limit switches
b. Reed switches

1.3 **DESCRIBE** the following variable output position indicators to include basic construction and theory of operation.
a. Potentiometer
b. Linear variable differential transformers (LVDT)

1.4 Given a diagram of a position indicator, **STATE** the purpose of the following components:
a. Detection device
b. Indicator and control circuits

1.5 **STATE** the two environmental concerns that can affect the accuracy and reliabiltity of position indication equipment.

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SYNCHRO EQUIPMENT

Position indicating instrumentation is used in DOE nuclear facilities to provide remote indication of equipment positions including control rods and major valves.

EO 1.1 DESCRIBE the synchro position indicators to include the basic construction and theory of operation.

Position indicating instrumentation is used in nuclear facilities to provide remote indication of control rod position with respect to the fully inserted position, and remote indication of the open or shut condition of important valves. This remote indication is necessary for the monitoring of vital components located within inaccessible or remote areas. Remote position indication can be used at any DOE facility, not only nuclear facilities, where valve position indication is required for safety.

Synchro Equipment

Remote indication or control may be obtained by the use of self-synchronizing motors, called synchro equipment. Synchro equipment consists of synchro units which electrically govern or follow the position of a mechanical indicator or device. An electrical synchro has two distinct advantages over mechanical indicators: (1) greater accuracy, and (2) simpler routing of remote indication.

There are five basic types of synchros which are designated according to their function. The basic types are: transmitters, differential transmitters, receivers, differential receivers, and control transformers. Figure 1 illustrates schematic diagrams used to show external connections and the relative positions of synchro windings. If the power required to operate a device is higher than the power available from a synchro, power amplification is required. Servomechanism is a term which refers to a variety of power-amplifiers. These devices are incorporated into synchro systems for automatic control rod positioning in some reactor facilities.

The transmitter, or synchro generator, consists of a rotor with a single winding and a stator with three windings placed 120 degrees apart. When the mechanical device moves, the mechanically attached rotor moves. The rotor induces a voltage in each of the stator windings based on the rotor's angular position. Since the rotor is attached to the mechanical device, the induced voltage represents the position of the attached mechanical device. The voltage produced by each of the windings is utilized to control the receiving synchro position.

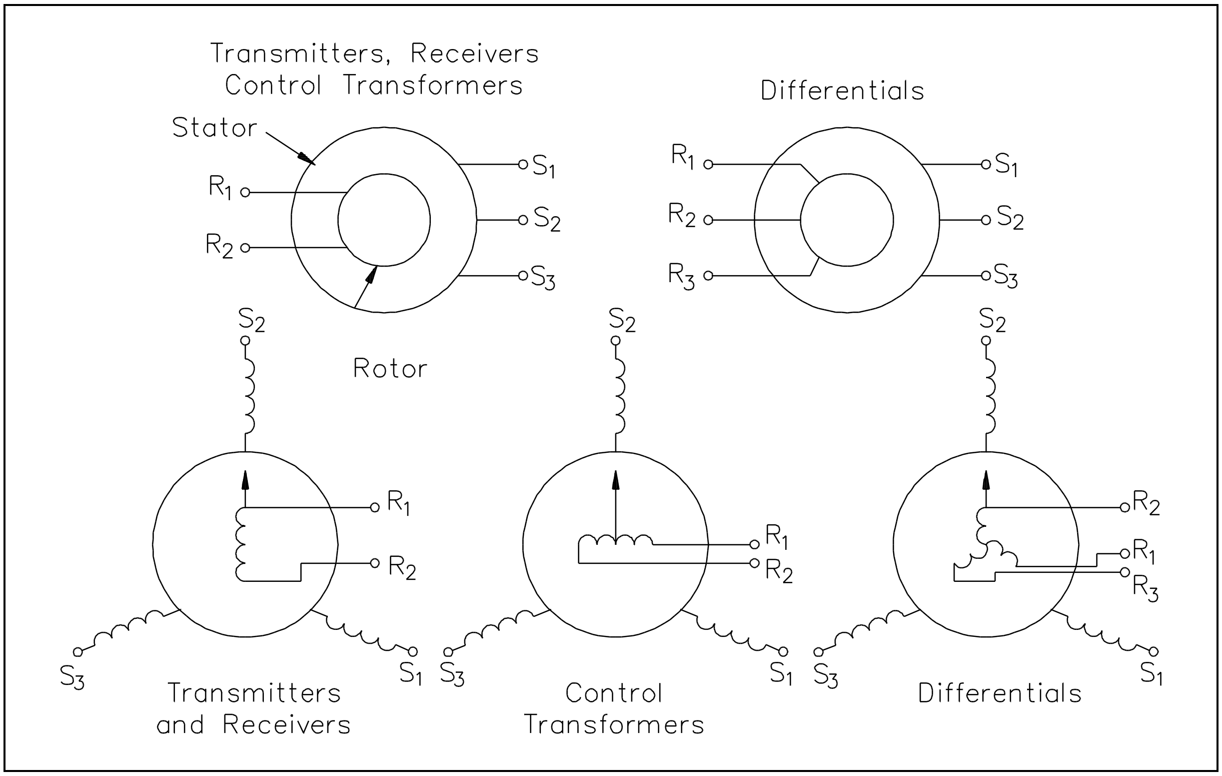

Figure 1 Synchro Schematics

The receiver, or synchro motor, is electrically similar to the synchro generator. The synchro receiver uses the voltage generated by each of the synchro generator windings to position the receiver rotor. Since the transmitter and receiver are electrically similar, the angular position of the receiver rotor corresponds to that of the synchro transmitter rotor. The receiver differs mechanically from the transmitter in that it incorporates a damping device to prevent hunting. Hunting refers to the overshoot and undershoot that occur as the receiving device tries to match the sending device. Without the damping device, the receiver would go past the desired point slightly, then return past the desired point slightly in the other direction. This would continue, by smaller amounts each time, until the receiver came to rest at the desired position. The damper prevents hunting by feeding some of the signal back, thus slowing down the approach to the desired point.

Differential synchros are used with transmitter and receiver synchros to insert a second signal. The angular positions of the transmitter and the differential synchros are compared, and the difference or sum is transmitted to the receiver. This setup can be used to provide a feedback signal to slow the response time of the receiver, thus providing a smooth receiver motion.

Control transformer synchros are used when only a voltage indication of angular position is desired. It is similar in construction to an ordinary synchro except that the rotor windings are used only to generate a voltage which is known as an error voltage. The rotor windings of a control transformer synchro are wound with many turns of fine wire to produce a high impedance. Since the rotor is not fed excitation voltage, the current drawn by the stator windings would be high if they were the same as an ordinary synchro; therefore, they are also wound with many turns of fine wire to prevent excessive current.

During normal operation, the output of a control transformer synchro is nearly zero (nulled) when its angular position is the same as that of the transmitter.

A simple synchro system, consisting of one synchro transmitter (or generator) connected to one synchro receiver (or motor), is shown in Figure 2.

Figure 2 Simple Synchro System

When the transmitter's shaft is turned, the synchro receiver's shaft turns such that its "electrical position" is the same as the transmitter's. What this means is that when the transmitter is turned to electrical zero, the synchro receiver also turns to zero. If the transmitter is disconnected from the synchro receiver and then reconnected, its shaft will turn to correspond to the position of the transmitter shaft.

Summary

Synchro equipment is summarized below.

Synchro Equipment Summary

- A basic synchro system consists of a transmitter (synchro generator) and receiver (synchro motor).
- When the transmitter's shaft is turned, the synchro motor's shaft turns such that its "electrical position" is the same as the transmitter's.

SWITCHES

Mechanical limit switches and reed switches provide valve open and shut indications. They also are used to determine the physical position of equipment.

EO 1.2 DESCRIBE the following switch position indicators to include basic construction and theory of operation.
a. Limit switches
b. Reed switches

Limit Switches

A limit switch is a mechanical device which can be used to determine the physical position of equipment. For example, an extension on a valve shaft mechanically trips a limit switch as it moves from open to shut or shut to open. The limit switch gives ON/OFF output that corresponds to valve position. Normally, limit switches are used to provide full open or full shut indications as illustrated in Figure 3.

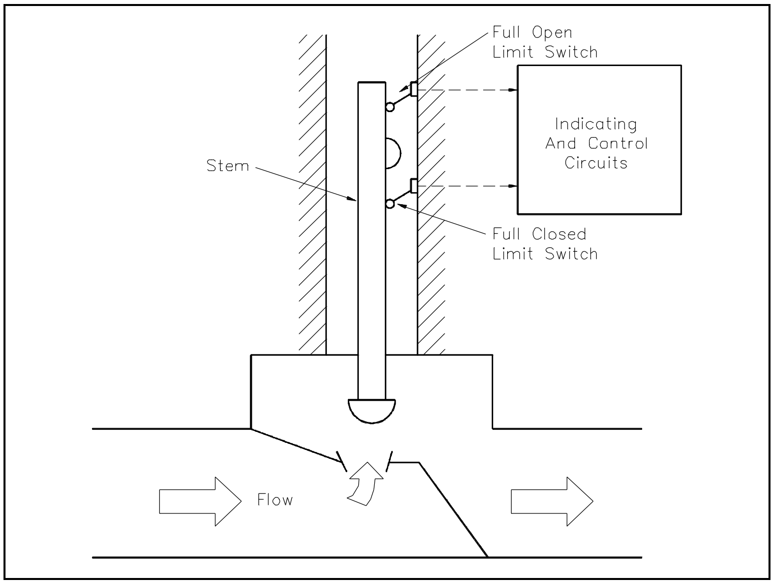

Figure 3 Limit Switches

Many limit switches are the push-button variety. When the valve extension comes in contact with the limit switch, the switch depresses to complete, or turn on, the electrical circuit. As the valve extension moves away from the limit switches, spring pressure opens the switch, turning off the circuit.

Limit switch failures are normally mechanical in nature. If the proper indication or control function is not achieved, the limit switch is probably faulty. In this case, local position indication should be used to verify equipment position.

Reed Switches

Reed switches, illustrated in Figure 4, are more reliable than limit switches, due to their simplified construction. The switches are constructed of flexible ferrous strips (reeds) and are placed near the intended travel of the valve stem or control rod extension.

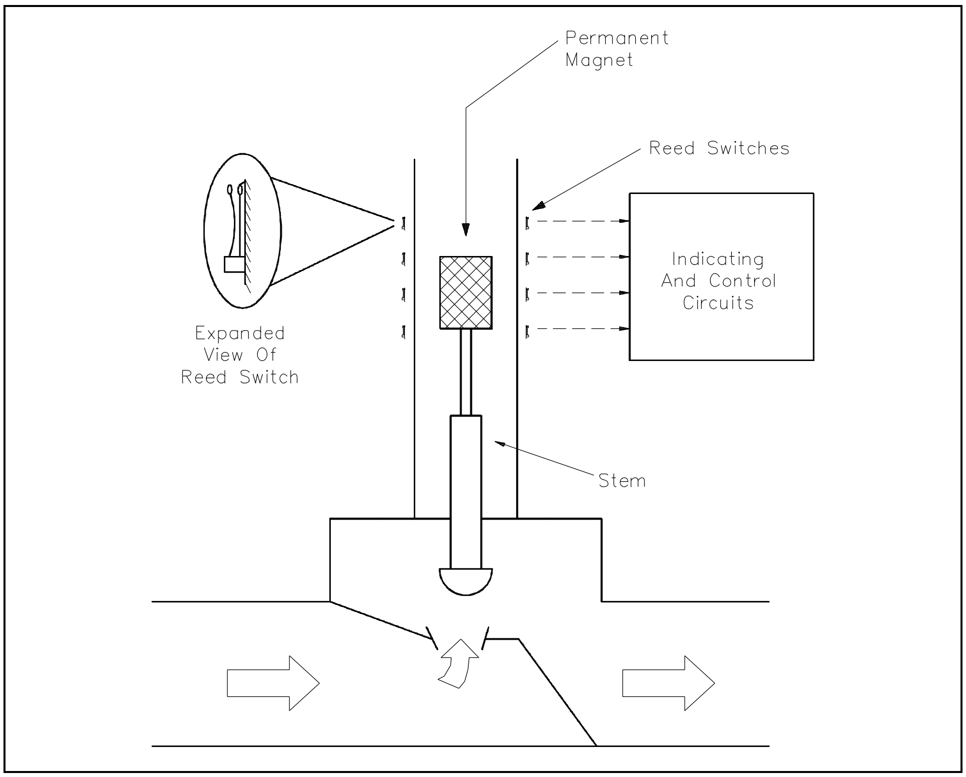

Figure 4 Reed Switches

When using reed switches, the extension used is a permanent magnet. As the magnet approaches the reed switch, the switch shuts. When the magnet moves away, the reed switch opens. This ON/OFF indicator is similar to mechanical limit switches. By using a large number of magnetic reed switches, incremental position can be measured. This technique is sometimes used in monitoring a reactor’s control rod position.

Failures are normally limited to a reed switch which is stuck open or stuck shut. If a reed switch is stuck shut, the open (closed) indication will be continuously illuminated. If a reed switch is stuck open, the position indication for that switch remains extinguished regardless of valve position.

Summary

Switch position indicators are summarized below.

Switch Position Indicators Summary

- A limit switch is a mechanical device used to determine the physical position of valves. An extension on a valve shaft mechanically trips the switch as it moves from open to shut or shut to open. The limit switch gives ON/OFF output which corresponds to the valve position.

- Reed switches are constructed of flexible ferrous strips placed near the intended travel of the valve stem or control rod extension. The extension used is a permanent magnet. As the magnet approaches the reed switch, the switch shuts. When the magnet moves away, the reed switch opens.

VARIABLE OUTPUT DEVICES

Variable output devices provide an accurate position indication of a valve or control rod.

EO 1.3 DESCRIBE the following variable output position indicators to include basic construction and theory of operation.
a. Potentiometer
b. Linear variable differential transformers (LVDT)

Potentiometer

Potentiometer valve position indicators (Figure 5) provide an accurate indication of position throughout the travel of a valve or control rod. The extension is physically attached to a variable resistor. As the extension moves up or down, the resistance of the attached circuit changes, changing the amount of current flow in the circuit. The amount of current is proportional to the valve position.

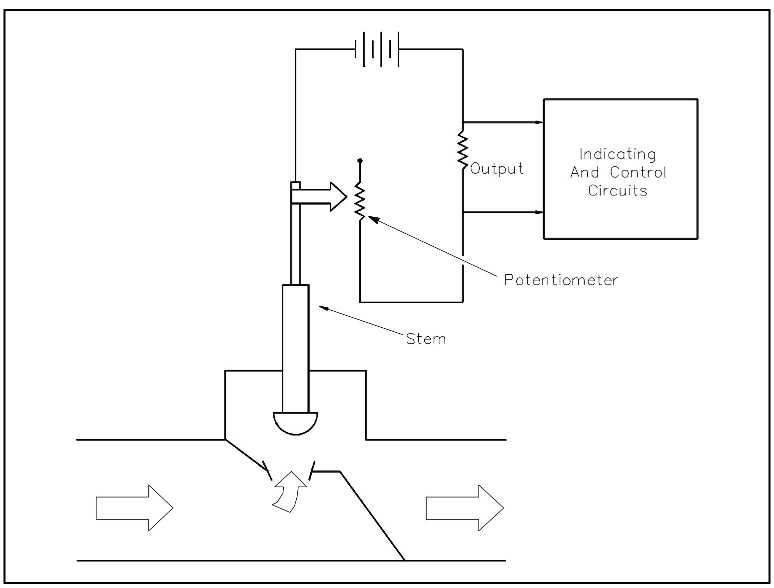

Figure 5 Potentiometer Valve Position Indicator

Potentiometer valve position indicator failures are normally electrical in nature. An electrical short or open will cause the indication to fail at one extreme or the other. If an increase or decrease in the potentiometer resistance occurs, erratic indicated valve position occurs.

Linear Variable Differential Transformers (LVDT)

A device which provides accurate position indication throughout the range of valve or control rod travel is a linear variable differential transformer (LVDT), illustrated in Figure 6. Unlike the potentiometer position indicator, no physical connection to the extension is required.

The extension valve shaft, or control rod, is made of a metal suitable for acting as the movable core of a transformer. Moving the extension between the primary and secondary windings of a transformer causes the inductance between the two windings to vary, thereby varying the output voltage proportional to the position of the valve or control rod extension. Figure 6 illustrates a valve whose position is indicated by an LVDT. If the open and shut position is all that is desired, two small secondary coils could be utilized at each end of the extension's travel.

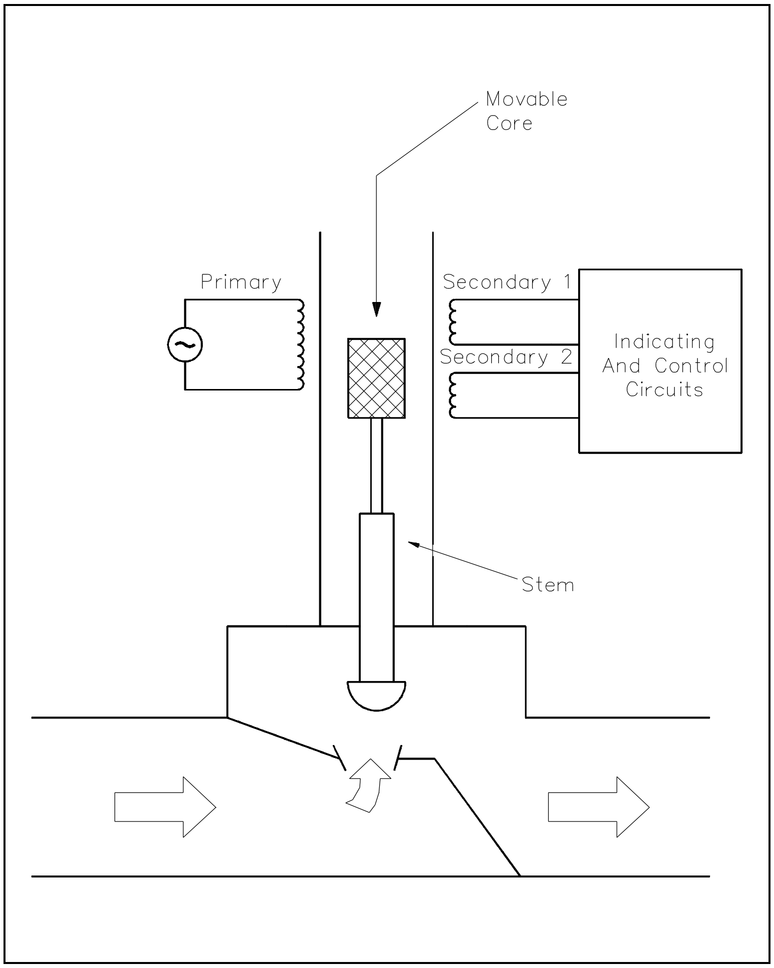

Figure 6 Linear Variable Differential Transformer

LVDTs are extremely reliable. As a rule, failures are limited to rare electrical faults which cause erratic or erroneous indications. An open primary winding will cause the indication to fail to some predetermined value equal to zero differential voltage. This normally corresponds to mid-stroke of the valve. A failure of either secondary winding will cause the output to indicate either full open or full closed.

Summary

Variable output position indicators are summarized below.

Variable Position Indicator Summary

- Potentiometer valve position indicators use an extension which is physically attached to a variable resistor. As the extension moves up or down, the resistance of the attached circuit changes, changing the amount of current flow in the circuit.
- An LVDT uses the extension shaft or control rod as a movable core of a transformer. Moving the extension between the primary and secondary windings of a transformer causes the inductance between the two windings to vary, thereby varying the output voltage proportional to the position of the valve or control rod extension.

POSITION INDICATION CIRCUITRY

Valve position circuitry provides indication and control functions.

EO 1.4 Given a diagram of a position indicator, STATE the purpose of the following components:
a. Detection device
b. Indicator and control circuits

EO 1.5 STATE the two environmental concerns which can affect the accuracy and reliability of position indication equipment.

As described above, position detection devices provide a method to determine the position of a valve or control rod. The four types of position indicators discussed were limit switches, reed switches, potentiometer valve position indicators, and LVDTs (Figure 7). Reed and limit switches act as ON/OFF indicators to provide open and closed indications and control functions. Reed switches can also be used to provide coarse, incremental position indication.

Potentiometer and LVDT position indicators provide accurate indication of valve and rod position throughout their travel. In some applications, LVDTs can be used to indicate open and closed positions when small secondary windings are used at either end of the valve stem stroke.

The indicating and control circuitry provides for remote indication of valve or rod position and/or various control functions. Position indications vary from simple indications such as a light to meter indications showing exact position.

Control functions are usually in the form of interlocks. Pump isolation valves are sometimes interlocked with the pump. In some applications, these interlocks act to prevent the pump from being started with the valves shut. The pump/valve interlocks can also be used to automatically turn off the pump if one of its isolation valves go shut or to open a discharge valve at some time interval after the pump starts.

Valves are sometimes interlocked with each other. In some systems, two valves may be interlocked to prevent both of the valves from being opened at the same time. This feature is used to prevent undesirable system flowpaths.

Control rod interlocks are normally used to prevent outward motion of certain rods unless certain conditions are met. One such interlock does not allow outward motion of control rods until the rods used to scram the reactor have been withdrawn to a predetermined height. This and all other rod interlocks ensure that the safety of the reactor remains intact.

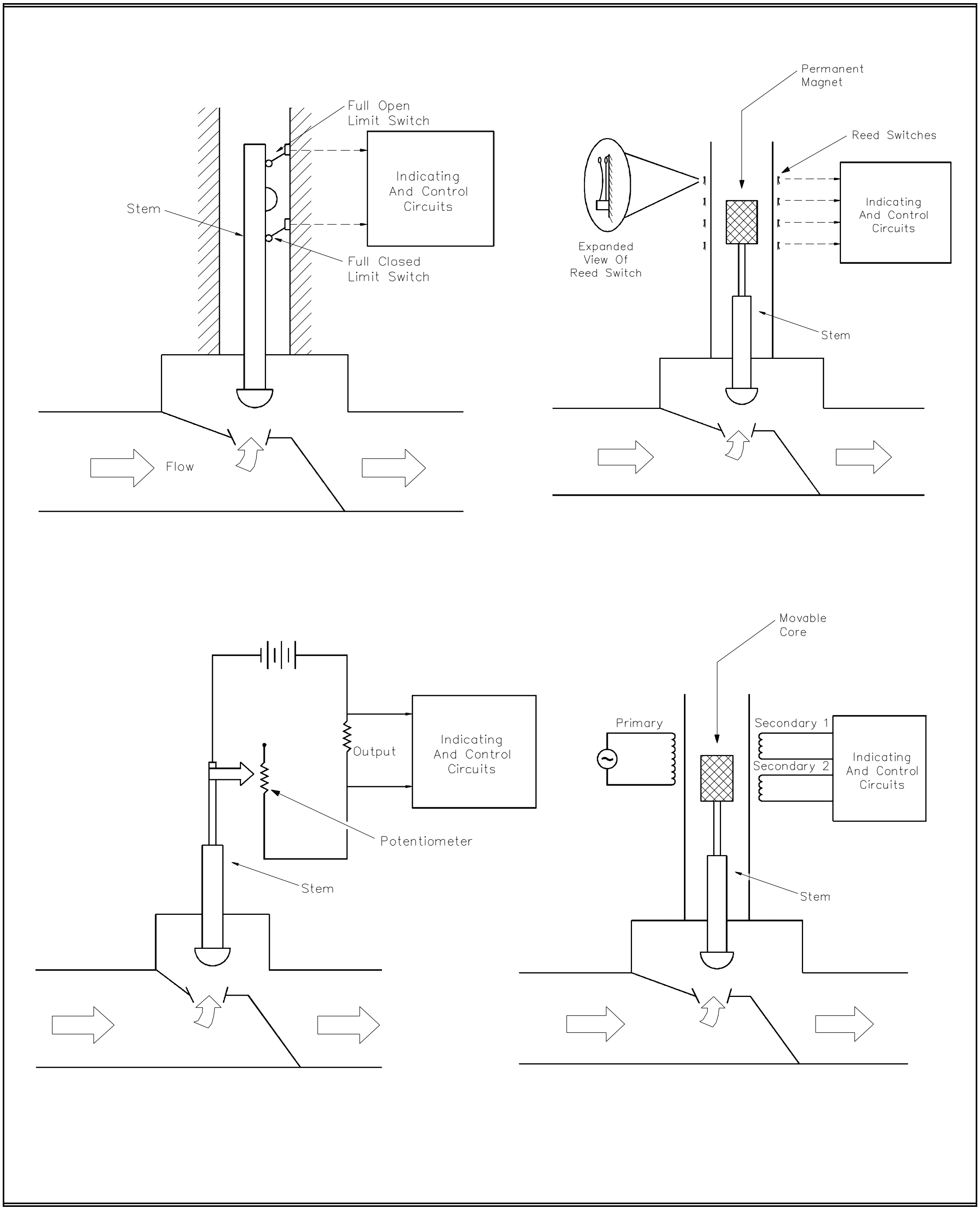

Figure 7 Position Indicators

Environmental Concerns

Ambient temperature variations can affect the accuracy and reliability of certain types of position indication instrumentation. Variations in ambient temperature can directly affect the resistance of components in the instrumentation circuitry, and, therefore, affect the calibration of electric/electronic equipment. The effects of temperature variations are reduced by the design of the circuitry and by maintaining the position indication instrumentation in the proper environment, where possible.

The presence of humidity will also affect most electrical equipment, especially electronic equipment. High humidity causes moisture to collect on the equipment. This moisture can cause short circuits, grounds, and corrosion, which, in turn, may damage components. The effects due to humidity are controlled by maintaining the equipment in the proper environment, where possible.

Summary

The accuracy and reliability of position indication instrumentation can be affected by ambient temperature and humidity. The purposes of position indicator components are summarized below.

Position Indicator Components Summary

- Detection devices provide a method to determine the position of a valve or control rod.

- The indicating and control circuitry provides for remote indication of valve or rod position and/or various control functions.