Department of Energy
Fundamentals Handbook

INSTRUMENTATION AND CONTROL
Module 2
Pressure Detectors

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REFERENCES

- Kirk, Franklin W. and Rimboi, Nicholas R., Instrumentation, Third Edition, American Technical Publishers, ISBN 0-8269-3422-6.

- Academic Program for Nuclear Power Plant Personnel, Volume IV, General Physics Corporation, Library of Congress Card #A 397747, April 1982.

- Fozard, B., Instrumentation and Control of Nuclear Reactors, ILIFFE Books Ltd., London.

- Wightman, E.J., Instrumentation in Process Control, CRC Press, Cleveland, Ohio.

- Rhodes, T.J. and Carroll, G.C., Industrial Instruments for Measurement and Control, Second Edition, McGraw-Hill Book Company.

- Process Measurement Fundamentals, Volume I, General Physics Corporation, ISBN 0-87683-001-7, 1981.

TERMINAL OBJECTIVE

1.0 Given a pressure instrument, **RELATE** the fundamental principles, including possible failure modes, to that specific instrument.

ENABLING OBJECTIVES

1.1 **EXPLAIN** how a bellows-type pressure detector produces an output signal including:
  a. Method of detection
  b. Method of signal generation

1.2 **EXPLAIN** how a bourdon tube-type pressure detector produces an output signal including:
  a. Method of detection
  b. Method of signal generation

1.3 **STATE** the three functions of pressure measuring instrumentation.

1.4 **DESCRIBE** the three alternate methods of determining pressure when the normal pressure sensing devices are inoperable.

1.5 **STATE** the three environmental concerns which can affect the accuracy and reliability of pressure detection instrumentation.

1.6 **EXPLAIN** how a strain gauge pressure transducer produces an output signal including:
  a. Method of detection
  b. Method of signal generation

1.7 Given a basic block diagram of a typical pressure detection device, **STATE** the purpose of the following blocks:
  a. Sensing element
  b. Transducer
  c. Pressure detection circuitry
  d. Pressure indication

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PRESSURE DETECTORS

Many processes are controlled by measuring pressure. This chapter describes the detectors associated with measuring pressure.

EO 1.1 EXPLAIN how a bellows-type pressure detector produces an output signal including:
- **a. Method of detection**
- **b. Method of signal generation**

EO 1.2 EXPLAIN how a bourdon tube-type pressure detector produces an output signal including:
- **a. Method of detection**
- **b. Method of signal generation**

Bellows-Type Detectors

The need for a pressure sensing element that was extremely sensitive to low pressures and provided power for activating recording and indicating mechanisms resulted in the development of the metallic bellows pressure sensing element. The metallic bellows is most accurate when measuring pressures from 0.5 to 75 psig. However, when used in conjunction with a heavy range spring, some bellows can be used to measure pressures of over 1000 psig. Figure 1 shows a basic metallic bellows pressure sensing element.

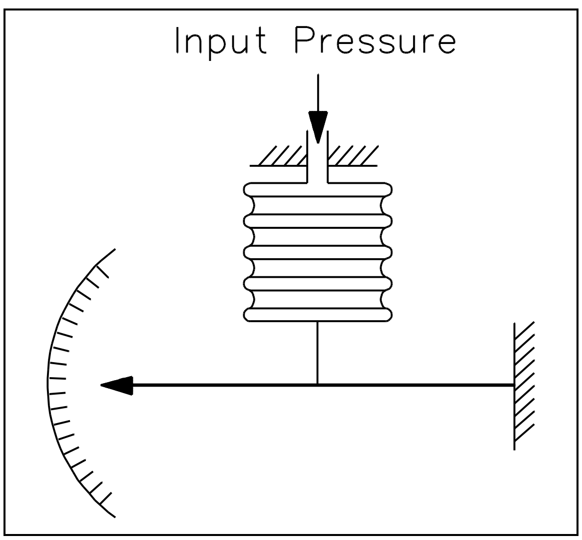

Figure 1 Basic Metallic Bellows

The bellows is a one-piece, collapsible, seamless metallic unit that has deep folds formed from very thin-walled tubing. The diameter of the bellows ranges from 0.5 to 12 in. and may have as many as 24 folds. System pressure is applied to the internal volume of the bellows. As the inlet pressure to the instrument varies, the bellows will expand or contract. The moving end of the bellows is connected to a mechanical linkage assembly. As the bellows and linkage assembly moves, either an electrical signal is generated or a direct pressure indication is provided. The flexibility of a metallic bellows is similar in character to that of a helical, coiled compression spring. Up to the elastic limit of the bellows, the relation between increments of load and deflection is linear. However, this relationship exists only when the bellows is under compression. It is necessary to construct the bellows such that all of the travel occurs on the compression side of the point of equilibrium. Therefore, in practice, the bellows must always be opposed by a spring, and the deflection characteristics will be the resulting force of the spring and bellows.

Bourdon Tube-Type Detectors

The bourdon tube pressure instrument is one of the oldest pressure sensing instruments in use today. The bourdon tube (refer to Figure 2) consists of a thin-walled tube that is flattened diametrically on opposite sides to produce a cross-sectional area elliptical in shape, having two long flat sides and two short round sides. The tube is bent lengthwise into an arc of a circle of 270 to 300 degrees. Pressure applied to the inside of the tube causes distention of the flat sections and tends to restore its original round cross-section. This change in cross-section causes the tube to straighten slightly. Since the tube is permanently fastened at one end, the tip of the tube traces a curve that is the result of the change in angular position with respect to the center. Within limits, the movement of the tip of the tube can then be used to position a pointer or to develop an equivalent electrical signal (which is discussed later in the text) to indicate the value of the applied internal pressure.

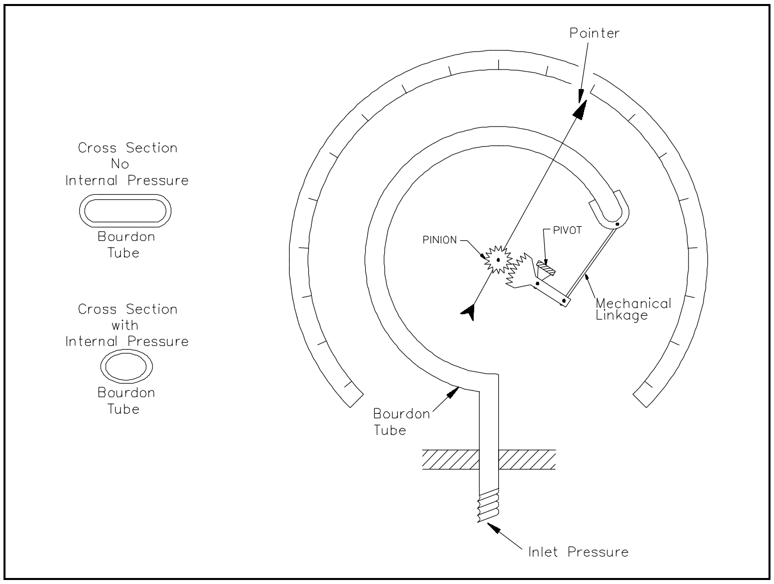

Figure 2 Bourdon Tube

Summary

The operation of bellows-type and bourdon tube-type pressure detectors is summarized below.

Bellows and Bourdon Tube Pressure Detectors Summary

- In a bellows-type detector:
  - System pressure is applied to the internal volume of a bellows and mechanical linkage assembly.
  - As pressure changes, the bellows and linkage assembly move to cause an electrical signal to be produced or to cause a gauge pointer to move.
- In a bourdon tube-type detector:
  - System pressure is applied to the inside of a slightly flattened arc-shaped tube. As pressure increases, the tube tends to restore to its original round cross-section. This change in cross-section causes the tube to straighten.
  - Since the tube is permanently fastened at one end, the tip of the tube traces a curve that is the result of the change in angular position with respect to the center. The tip movement can then be used to position a pointer or to develop an electrical signal.

PRESSURE DETECTOR FUNCTIONAL USES

Pressure measurement is a necessary function in the safe and efficient operation of DOE nuclear facilities.

EO 1.3 STATE the three functions of pressure measuring instrumentation.

EO 1.4 DESCRIBE the three alternate methods of determining pressure when the normal pressure sensing devices are inoperable.

EO 1.5 STATE the three environmental concerns which can affect the accuracy and reliability of pressure detection instrumentation.

Pressure Detector Functions

Although the pressures that are monitored vary slightly depending on the details of facility design, all pressure detectors are used to provide up to three basic functions: indication, alarm, and control. Since the fluid system may operate at both saturation and subcooled conditions, accurate pressure indication must be available to maintain proper cooling. Some pressure detectors have audible and visual alarms associated with them when specified preset limits are exceeded. Some pressure detector applications are used as inputs to protective features and control functions.

Detector Failure

If a pressure instrument fails, spare detector elements may be utilized if installed. If spare detectors are not installed, the pressure may be read at an independent local mechanical gauge, if available, or a precision pressure gauge may be installed in the system at a convenient point. If the detector is functional, it may be possible to obtain pressure readings by measuring voltage or current values across the detector leads and comparing this reading with calibration curves.

Environmental Concerns

Pressure instruments are sensitive to variations in the atmospheric pressure surrounding the detector. This is especially apparent when the detector is located within an enclosed space. Variations in the pressure surrounding the detector will cause the indicated pressure from the detector to change. This will greatly reduce the accuracy of the pressure instrument and should be considered when installing and maintaining these instruments.

Ambient temperature variations will affect the accuracy and reliability of pressure detection 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 pressure detection instrumentation in the proper environment.

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.

Summary

The three functions of pressure monitoring instrumentation and alternate methods of monitoring pressure are summarized below.

Functional Uses Summary

- Pressure detectors perform the following basic functions:
  - Indication
  - Alarm
  - Control
- If a pressure detector becomes inoperative:
  - A spare detector element may be used (if installed).
  - A local mechanical pressure gauge can be used (if available).
  - A precision pressure gauge may be installed in the system.
- Environmental concerns:
  - Atmospheric pressure
  - Ambient temperature
  - Humidity

PRESSURE DETECTION CIRCUITRY

Any of the pressure detectors previously discussed can be joined to an electrical device to form a pressure transducer. Transducers can produce a change in resistance, inductance, or capacitance.

EO 1.6 EXPLAIN how a strain gauge pressure transducer produces an output signal including:
- **a. Method of detection**
- **b. Method of signal generation**

EO 1.7 Given a basic block diagram of a typical pressure detection device, STATE the purpose of the following blocks:
- **a. Sensing element**
- **b. Transducer**
- **c. Pressure detection circuitry**
- **d. Pressure indication**

Resistance-Type Transducers

Included in this category of transducers are strain gauges and moving contacts (slidewire variable resistors). Figure 3 illustrates a simple strain gauge. A strain gauge measures the external force (pressure) applied to a fine wire. The fine wire is usually arranged in the form of a grid. The pressure change causes a resistance change due to the distortion of the wire. The value of the pressure can be found by measuring the change in resistance of the wire grid. Equation 2-1 shows the pressure to resistance relationship.

$$R = K\frac{L}{A} \quad (2\text{-}1)$$

where

R = resistance of the wire grid in ohms
K = resistivity constant for the particular type of wire grid
L = length of wire grid
A = cross sectional area of wire grid

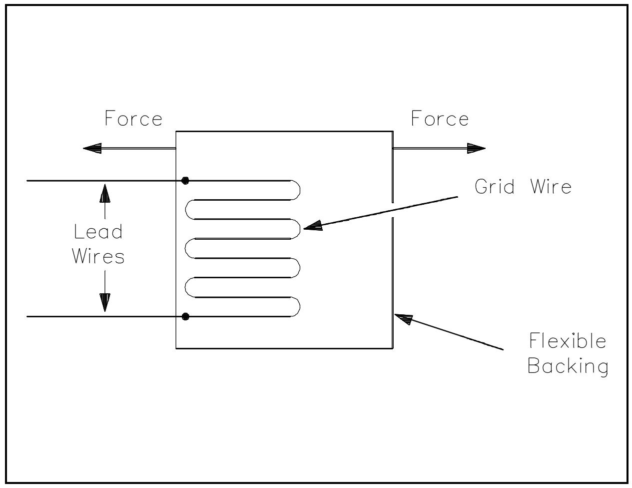

Figure 3 Strain Gauge

As the wire grid is distorted by elastic deformation, its length is increased, and its cross-sectional area decreases. These changes cause an increase in the resistance of the wire of the strain gauge. This change in resistance is used as the variable resistance in a bridge circuit that provides an electrical signal for indication of pressure. Figure 4 illustrates a strain gauge pressure transducer.

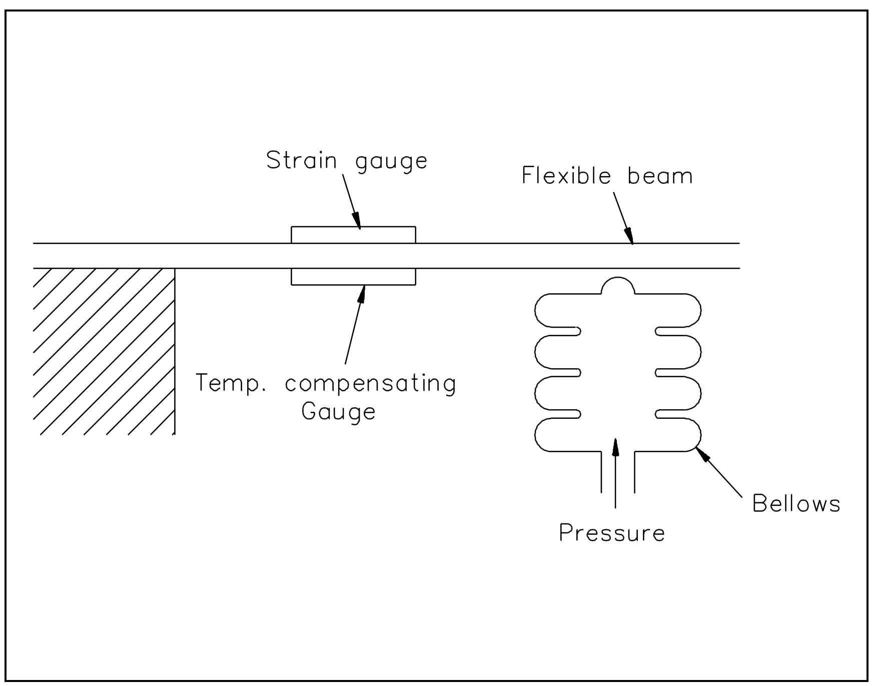

Figure 4 Strain Gauge Pressure Transducer

An increase in pressure at the inlet of the bellows causes the bellows to expand. The expansion of the bellows moves a flexible beam to which a strain gauge has been attached. The movement of the beam causes the resistance of the strain gauge to change. The temperature compensating gauge compensates for the heat produced by current flowing through the fine wire of the strain gauge. Strain gauges, which are nothing more than resistors, are used with bridge circuits as shown in Figure 5.

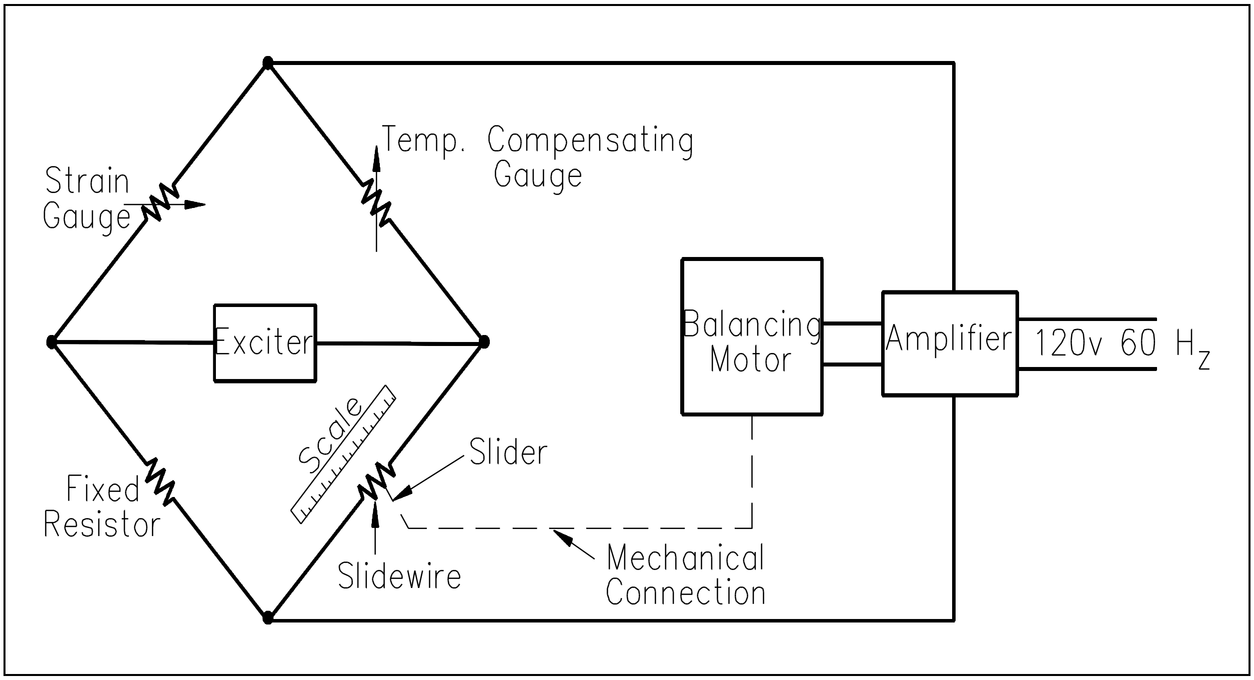

Figure 5 Strain Gauge Used in a Bridge Circuit

Alternating current is provided by an exciter that is used in place of a battery to eliminate the need for a galvanometer. When a change in resistance in the strain gauge causes an unbalanced condition, an error signal enters the amplifier and actuates the balancing motor. The balancing motor moves the slider along the slidewire, restoring the bridge to a balanced condition. The slider's position is noted on a scale marked in units of pressure.

Other resistance-type transducers combine a bellows or a bourdon tube with a variable resistor, as shown in Figure 6. As pressure changes, the bellows will either expand or contract. This expansion and contraction causes the attached slider to move along the slidewire, increasing or decreasing the resistance, and thereby indicating an increase or decrease in pressure.

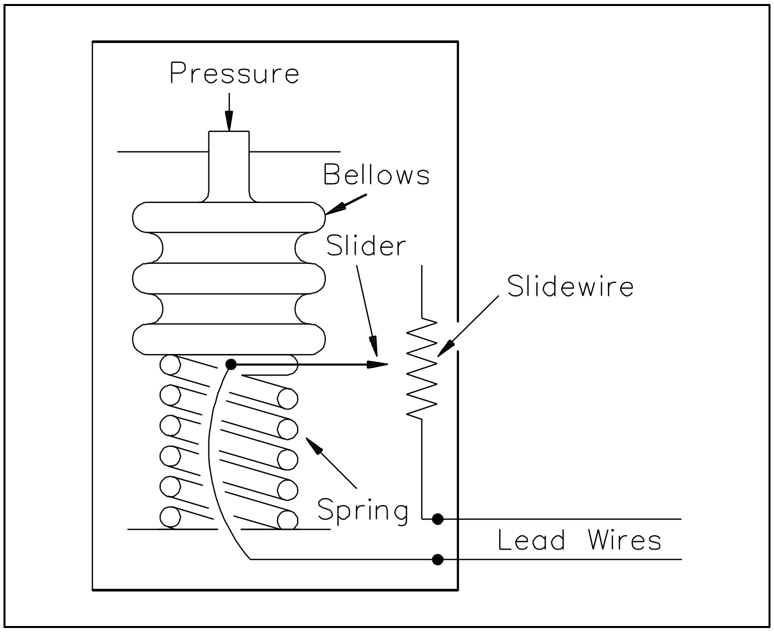

Figure 6 Bellows Resistance Transducer

Inductance-Type Transducers

The inductance-type transducer consists of three parts: a coil, a movable magnetic core, and a pressure sensing element. The element is attached to the core, and, as pressure varies, the element causes the core to move inside the coil. An AC voltage is applied to the coil, and, as the core moves, the inductance of the coil changes. The current through the coil will increase as the inductance decreases. For increased sensitivity, the coil can be separated into two coils by utilizing a center tap, as shown in Figure 7. As the core moves within the coils, the inductance of one coil will increase, while the other will decrease.

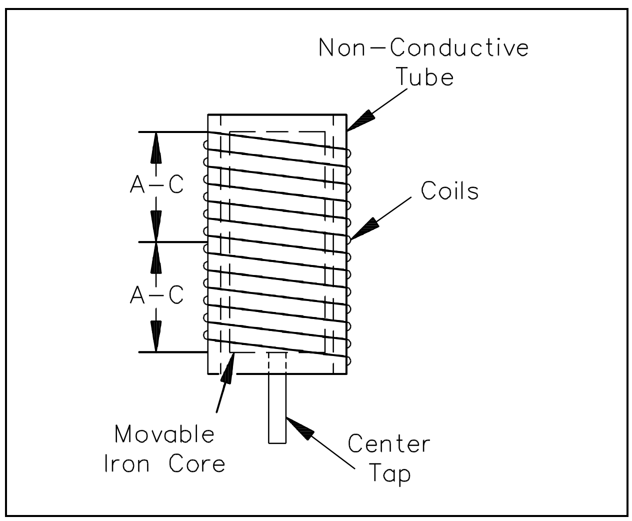

Figure 7 Inductance-Type Pressure Transducer Coil

Another type of inductance transducer, illustrated in Figure 8, utilizes two coils wound on a single tube and is commonly referred to as a Differential Transformer.

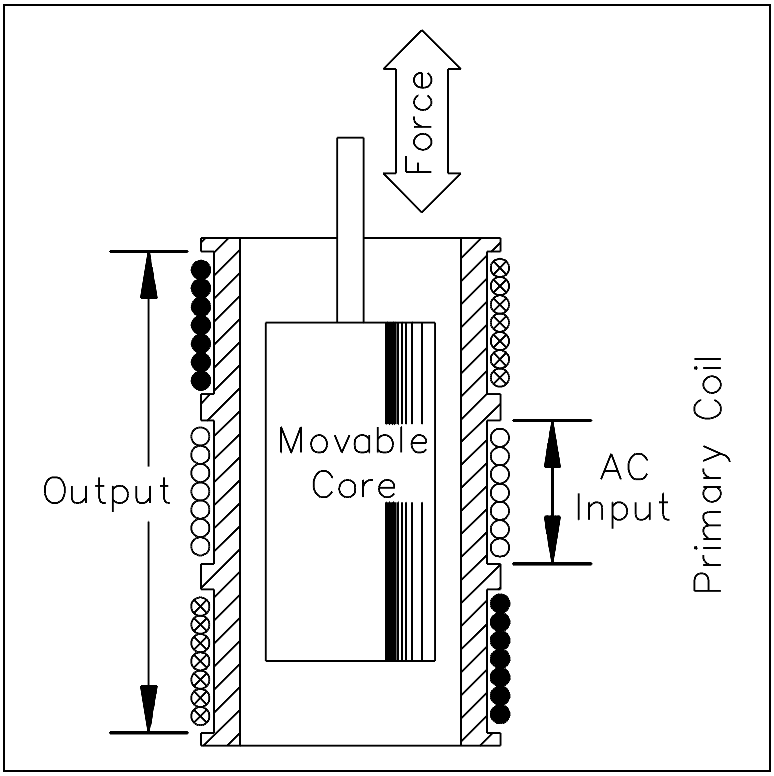

Figure 8 Differential Transformer

The primary coil is wound around the center of the tube. The secondary coil is divided with one half wound around each end of the tube. Each end is wound in the opposite direction, which causes the voltages induced to oppose one another. A core, positioned by a pressure element, is movable within the tube. When the core is in the lower position, the lower half of the secondary coil provides the output. When the core is in the upper position, the upper half of the secondary coil provides the output. The magnitude and direction of the output depends on the amount the core is displaced from its center position. When the core is in the mid-position, there is no secondary output.

Capacitive-Type Transducers

Capacitive-type transducers, illustrated in Figure 9, consist of two flexible conductive plates and a dielectric. In this case, the dielectric is the fluid.

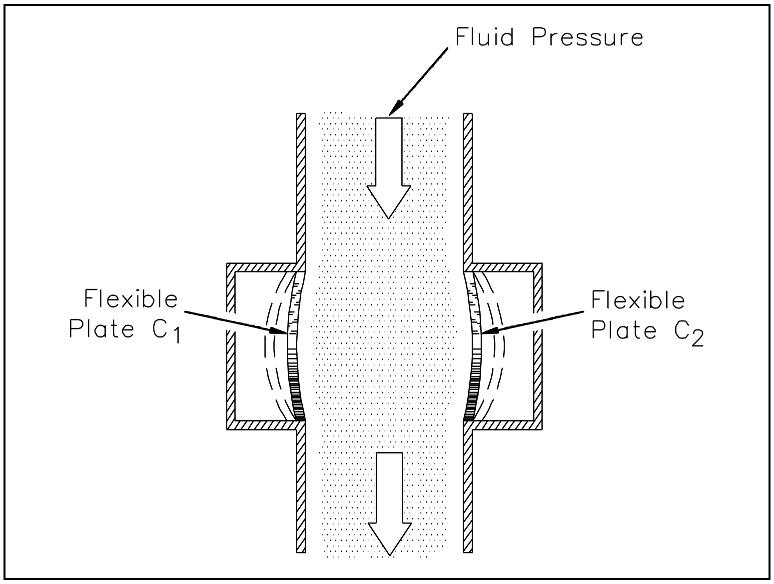

Figure 9 Capacitive Pressure Transducer

As pressure increases, the flexible conductive plates will move farther apart, changing the capacitance of the transducer. This change in capacitance is measurable and is proportional to the change in pressure.

Detection Circuitry

Figure 10 shows a block diagram of a typical pressure detection circuit.

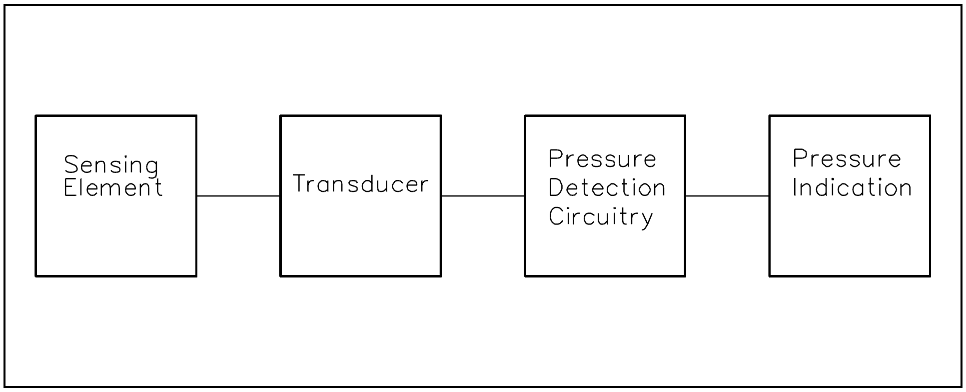

Figure 10 Typical Pressure Detection Block Diagram

The sensing element senses the pressure of the monitored system and converts the pressure to a mechanical signal. The sensing element supplies the mechanical signal to a transducer, as discussed above. The transducer converts the mechanical signal to an electrical signal that is proportional to system pressure. If the mechanical signal from the sensing element is used directly, a transducer is not required and therefore not used. The detector circuitry will amplify and/or transmit this signal to the pressure indicator. The electrical signal generated by the detection circuitry is proportional to system pressure. The exact operation of detector circuitry depends upon the type of transducer used. The pressure indicator provides remote indication of the system pressure being measured.

Summary

The operation of a strain guage and a typical pressure detection device is summarized below.

Circuit Operation Summary

- The operation of a strain gauge is as follows:

  - A strain gauge measures the pressure applied to a fine wire. The fine wire is usually arranged in the form of a grid. The pressure change causes a resistance change due to the distortion of the wire.

  - This change in resistance is used as the variable resistance in a bridge circuit that provides an electrical signal for indication of pressure.

- The operation of a typical pressure detection device is as follows:

  - The detector senses the pressure of the monitored system and converts this pressure to a mechanical signal. The mechanical signal from the detector is supplied to the transducer.

  - The transducer will convert this signal to a usable electrical signal and send a signal proportional to the detected pressure to the detection circuitry.

  - The detector circuitry will amplify and/or transmit this signal to the pressure indicator.

  - The pressure indicator will provide remote indication of the system pressure being measured.

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