2
Pressure Measurement
Chapter 2
Pressure Measurement

2.1 Principles of Pressure Measurement

2.1.1 Bar and Pascal

Pressure is defined as a force per unit area, and can be measured in units such as psi (pounds per square inch), inches of water, millimetres of mercury, pascals (Pa, or N/m²) or bar. Until the introduction of SI units, the 'bar' was quite common. The bar is equivalent to 100,000 N/m², which were the SI units for measurement. To simplify the units, the N/m² was adopted with the name of Pascal, abbreviated to Pa. Pressure is quite commonly measured in kilopascals (kPa), which is 1000 Pascals and equivalent to 0.145psi.

2.1.2 Absolute, Gauge and Differential Pressure

The Pascal is a means of measuring a quantity of pressure. When the pressure is measured in reference to an absolute vacuum (no atmospheric conditions), then the result will be in Pascal (Absolute). However when the pressure is measured relative to the atmospheric pressure, then the result will be termed Pascal (Gauge). If the gauge is used to measure the difference between two pressures, it then becomes Pascal (Differential).

Note 1: It is common practice to show gauge pressure without specifying the type, and to specify absolute or differential by stating 'absolute' or 'differential' for those pressures.

Note 2: Older measurement equipment may be in terms of psi (pounds per square inch) and as such represent gauge and absolute pressure as psig and psia respectively. Note that the ‘g’ and ‘a’ are not recognised in the SI unit symbols, and as such are no longer encouraged.

To determine differential in inches of mercury vacuum multiply psi by 2.036 (or approximately 2). Another common conversion is 1 Bar = 14.7 psi.
2.2 Pressure Sources

2.2.1 Static Pressure

In the atmosphere at any point, static pressure is exerted equally in all directions. Static pressure is the result of the weight of all the air molecules above that point pressing down.

Static pressure does not involve the relative movement of the air.

<table>
<thead>
<tr>
<th>Conversion Factors (Rounded)</th>
</tr>
</thead>
<tbody>
<tr>
<td>psi x 703.1 = mm/ H₂O</td>
</tr>
<tr>
<td>psi x 27.68 = in. H₂O</td>
</tr>
<tr>
<td>psi x 51/71 = mm/ H₂O</td>
</tr>
<tr>
<td>psi x 2.036 = in. Hg</td>
</tr>
<tr>
<td>psi x .0703 = kg/cm²</td>
</tr>
<tr>
<td>psi x .0689 = bar</td>
</tr>
<tr>
<td>psi x 68.95 = mbar</td>
</tr>
<tr>
<td>psi x 6895 = Pa</td>
</tr>
<tr>
<td>psi x 6.895 = kPa</td>
</tr>
</tbody>
</table>

Note: psi – pounds per square inch (gauge)
H₂O at 39.2°F
Hg at 32°F

Table 2.1
Conversion Factors

Figure 2.1
Static pressure
2.2.2 Dynamic Pressure

Quite simply, if you hold your hand up in a strong wind or out of the window of a moving car, then the extra wind pressure is felt due to the air impacting your hand.

This extra pressure is over and above the (always-present) static pressure, and is called the dynamic pressure. The dynamic pressure is due to relative movement. Dynamic pressure occurs when a body is moving through the air, or the air is flowing past the body.

Dynamic pressure is dependent on two factors:

- The speed of the body relative to the flowstream. The faster the car moves or the stronger the wind blows, then the stronger the dynamic pressure that you feel on your hand. This is because of the greater number of air molecules that impact upon it per second.

- The density of the air. The dynamic pressure depends also on the density of the air. If the flowrate was the same, and the air was less dense, then there would be less force and consequently a lower dynamic pressure.

![Figure 2.2 Dynamic pressure increases with airspeed](image1)

![Figure 2.3 Dynamic pressure depends upon air density](image2)
2.2.3 **Total Pressure**

In the atmosphere, some static pressure is always exerted, but for dynamic pressure to be exerted there must be motion of the body relative to the air. Total pressure is the sum of the static pressure and the dynamic pressure.

Total pressure is also known and referred to as impact pressure, pitot pressure or even ram pressure.

![Figure 2.4: Total pressure as measured by a pilot tube](image)

2.3 **Pressure transducers and elements - Mechanical**

- Bourdon tube
- Helix and spiral tubes
- Spring and bellows
- Diaphragm
- Manometer
- Single and Double inverted bell

2.3.1 **C-Bourdon Tube**

The Bourdon tube works on a simple principle that a bent tube will change its shape when exposed to variations of internal and external pressure. As pressure is applied internally, the tube straightens and returns to its original form when the pressure is released.

The tip of the tube moves with the internal pressure change and is easily converted with a pointer onto a scale. A connector link is used to transfer the tip movement to the geared movement sector. The pointer is rotated through a toothed pinion by the geared sector.
This type of gauge may require vertical mounting (orientation dependent) for correct results. The element is subject to shock and vibration, which is also due to the mass of the tube. Because of this and the amount of movement with this type of sensing, they are prone to breakage, particularly at the base of the tube.

The main advantage with the Bourdon tube is that it has a wide operating (depending on the tube material). This type of pressure measurement can be used for positive or negative pressure ranges, although the accuracy is impaired when in a vacuum.

**Selection and Sizing**

The type of duty is one of the main selection criteria when choosing Bourdon tubes for pressure measurement. For applications which have rapid cycling of the process pressure, such in ON/OFF controlled systems, then the measuring transducer requires an internal snubber. They are also prone to failure in these applications.

Liquid filled devices are one way to reduce the wear and tear on the tube element.

**Advantages**

- Inexpensive
- Wide operating range
- Fast response
- Good sensitivity
- Direct pressure measurement

**Disadvantages**

- Primarily intended for indication only
- Non linear transducer, linearised by gear mechanism
- Hysteresis on cycling
- Sensitive to temperature variations
- Limited life when subject to shock and vibration

**Application Limitations**

These devices should be used in air if calibrated for air, and in liquid if calibrated for liquid. Special care is required for liquid applications in bleeding air from the liquid lines.
This type of pressure measurement is limited in applications where there is input shock (a sudden surge of pressure), and in fast moving processes.

If the application is for the use of oxygen, then the device cannot be calibrated using oil. Lower ranges are usually calibrated in air. Higher ranges, usually 1000kPa, are calibrated with a dead weight tester (hydraulic oil).

2.3.2 Helix and Spiral Tubes

Helix and spiral tubes are fabricated from tubing into shapes as per their naming. With one end sealed, the pressure exerted on the tube causes the tube to straighten out. The amount of straightening or uncoiling is determined by the pressure applied.

These two approaches use the Bourdon principle. The uncoiling part of the tube is mechanically linked to a pointer which indicates the applied pressure on a scale. This has the added advantage over the C-Bourdon tube as there are no movement losses due to links and levers.

The Spiral tube is suitable for pressure ranges up to 28,000 kPa and the Helical tube for ranges up to 500,000 kPa. The pressure sensing elements vary depending on the range of operating pressure and type of process involved.
The choice of spiral or helical elements is based on the pressure ranges. The pressure level between spiral and helical tubes varies depending on the manufacturer. Low pressure elements have only two or three coils to sense the span of pressures required, however high pressure sensing may require up to 20 coils.

One difference and advantage of these is the dampening they have with fluids under pressure.

The advantages and disadvantages of this type of measurement are similar to the C-Bourdon tube with the following differences:

**Advantages**
- Increased accuracy and sensitivity
- Higher overrange protection

**Disadvantages**
- Very expensive

![Spiral bourdon element](image)

**Application Limitations**

Process pressure changes cause problems with the increase in the coil size.

**Summary**

Very seldom used anymore.

**2.3.3 Spring and Bellows**

A bellows is an expandable element and is made up of a series of folds which allow expansion. One end of the Bellows is fixed and the other moves in response to the applied pressure. A spring is used to oppose the applied force and a linkage connects the end of the bellows to a pointer for indication. Bellows type sensors are also
available which have the sensing pressure on the outside and the atmospheric conditions within.

The spring is added to the bellows for more accurate measurement. The elastic action of the bellows by themselves is insufficient to precisely measure the force of the applied pressure.

This type of pressure measurement is primarily used for ON/OFF control providing clean contacts for opening and closing electrical circuits. This form of sensing responds to changes in pneumatic or hydraulic pressure.
**Figure 2.7**

*Basic mechanical structure*
Typical Application

The process pressure is connected to the sensor and is applied directly into the bellows. As the pressure increases, the bellows exert force on the main spring. When the threshold force of the main spring is overcome, the motion is transferred to the contact block causing the contacts to actuate. This is the Trip setting.

When the pressure decreases, the main spring will retract which causes the secondary differential blade spring to activate and reset the contacts. This is the Reset setting.

The force on the main spring is varied by turning the operating range adjustment screw. This determines where the contacts will trip.

The force on the secondary differential blade spring is varied by turning the differential adjustment screw. This determines where the contacts will reset.

Figure 2.8
Graphical illustration of technical terms

Copper alloy bellows may be used on water or air. Other liquids and gases may be used if non-corrosive to this alloy. Use type 316 stainless steel for more corrosive liquids or gases.

Diaphragm, bellows or piston?

The process pressure is applied to the actuator which can be either a diaphragm, bellows or piston type.

Piston controls are used for hydraulic fluids operating at high pressures. They are not intended for use with air or water as their accuracy is limited.
### Repeat Accuracy Table

<table>
<thead>
<tr>
<th>Type</th>
<th>Typical Characteristics (% of Maximum Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diaphragm</td>
<td>± 1%</td>
</tr>
<tr>
<td>Bellows</td>
<td>± 1%</td>
</tr>
<tr>
<td>Piston with seal</td>
<td>± 5% (†)</td>
</tr>
<tr>
<td>Piston without seal</td>
<td>± 3%</td>
</tr>
</tbody>
</table>

† Evaluation made from tests data and calculated using formula per NEMA ICS 2-225 Standards.

† Seal adds additional friction and value shown takes into consideration initial breakaway frictional force incurred during start-up or infrequent cycle operation. On continual cycle operation the repeat accuracy approaches ± 3%.

---

**Table 2.2**

Repeat Accuracy Table
## Condition Sensing

### Bulletin 836T Pressure Controls

#### Technical Data

<table>
<thead>
<tr>
<th>Bulletin Number</th>
<th>836T</th>
<th>836T</th>
<th>836T</th>
<th>836T</th>
<th>836T</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Actuator Type</strong></td>
<td>Diaphragm</td>
<td>Copper Alloy Bellows</td>
<td>Type 316 Stainless Steel Bellows</td>
<td>Piston Type without Seal</td>
<td>Piston Type with Seal</td>
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<tr>
<td>Adjustable Operating Ranges</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 – 30” Hg Vac</td>
<td>3 to 650 psi</td>
<td>3 to 375 psi</td>
<td>40 to 5000 psi</td>
<td>80 to 5000 psi</td>
<td></td>
</tr>
<tr>
<td>Adjustable Differentials</td>
<td>5 to 20” Hg Vac</td>
<td>1.5 to 125 psi</td>
<td>1.5 to 90 psi</td>
<td>20 to 650 psi</td>
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<td>Maximum Line Pressures</td>
<td>15 psi</td>
<td>1300 psi</td>
<td>600 psi</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Occasional Surge Pressures</td>
<td>15 psi</td>
<td>1600 psi</td>
<td>600 psi</td>
<td>15,000 psi</td>
<td>15,000 psi</td>
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</table>

### Pressure Media

<table>
<thead>
<tr>
<th></th>
<th>Air</th>
<th>Water</th>
<th>Hydraulic Fluids</th>
<th>Liquids – Corrosive</th>
<th>- Non Corrosive</th>
<th>Gases – Corrosive</th>
<th>- Non Corrosive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>!</td>
<td>!</td>
<td>!</td>
<td>!</td>
<td>!</td>
<td>!</td>
</tr>
</tbody>
</table>

### Enclosures

<table>
<thead>
<tr>
<th></th>
<th>NEMA Type 1,4 &amp; 13</th>
<th>NEMA Type 7 &amp; 9</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>!</td>
<td>!</td>
</tr>
</tbody>
</table>

### Pipe Connections

<table>
<thead>
<tr>
<th>Pressure connection</th>
<th>¼” NPTF Female Pipe Thread</th>
<th>¼” NPTF Female Pipe Thread</th>
<th>½” NPTF Female Pipe Thread</th>
<th>3/8” NPTF Female Pipe Thread</th>
<th>3/8” NPTF Female Pipe Thread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosive liquids and gases must be compatible with Type 316 Stainless Steel Bellows.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Note: Pressure Difference Controls are supplied with either copper alloy or stainless steel bellows.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2.3

**Condition Sensing**
Refrigeration Applications

Refrigeration controls are constructed with additional pulsation dampening to filter out the severe pulsations generated by reciprocating refrigeration compressors. Pressure controls not fitted with the added snubber function may result in reduced bellows life.

The reduced life results from pulsations severe enough to cause the bellows to squeal at the pump frequency or at the distorted harmonic wave generated at specific pump loading demands. Refrigeration controls are generally supplied as standard with the pulsation snubber built into the stem of the bellows.

Advantages

- Simple construction
- Easily maintained
- Inexpensive

Disadvantages

- Sensitive to temperature variations
- Work hardening of bellows
- Hysteresis
- Poor overrange protection

Application Limitations

For applications where settings approach 0 psi, use a sensor that has a range that goes into vacuum.

Surges of pressure (transient pulses) can occur in a system prior to reaching the steady state condition. Generally, surge pressures within published values generated during start-up or shut-down of a machine or system (not exceeding 8 times in a 24 hour period), are negligible.

Bellows and fittings are specially prepared for oxygen and nitrous oxide service. The devices are tested with pure oxygen, bellows are plugged for protection from contamination, and a warning tag is generally applied to avoid contamination.
Summary

Mainly used for barometric measurement, and are not so common in industrial control applications as they are fragile and have low overrange protection.

2.3.4 Diaphragm

Many pressure sensors depend on the deflection of a diaphragm for measurement. The diaphragm is a flexible disc, which can be either flat or with concentric corrugations and is made from sheet metal with high tolerance dimensions.

The diaphragm can be used as a means of isolating the process fluids, or for high-pressure applications. It is also useful in providing pressure measurement with electrical transducers.

Diaphragms are well developed and proven. Modern designs have negligible hysteresis, friction and calibration problems when used with smart instrumentation.
They are used extensively on air conditioning plants and for ON/OFF switching applications.

**Selection**

The selection of diaphragm materials is important, and are very much dependent on the application. Beryllium copper has good elastic qualities, where Ni-Span C has a very low temperature coefficient of elasticity.

Stainless steel and Inconel are used in extreme temperature applications, and are also suited for corrosive environments. For minimum hysteresis and drift, then Quartz is the best choice.

There are two main types of construction and operation of diaphragm sensors. They are:

- Motion Balanced
- Force Balanced

Motion balanced designs are used to control local, direct reading indicators. They are however more prone to hysteresis and friction errors.

Force balanced designs are used as transmitters for relaying information with a high accuracy, however they do not have direct indication capability.

**Advantages**

- Provide isolation from process fluid
- Good for low pressure
- Inexpensive
- Wide range
- Reliable and proven
- Used to measure gauge, atmospheric and differential pressure

### 2.3.5 Manometer

The simplest form of a manometer is that of a U-shaped tube filled with liquid. The reference pressure and the pressure to be measured are applied to the open ends of the tube. If there is a difference in pressure, then the heights of the liquid on the two sides of the tube will be different.

This difference in the heights is the process pressure in mm of water (or mm of mercury). The conversion into kPa is quite simple:

for water, \[ \text{Pa} = \text{mm H}_2\text{O} \times 9.807 \]

for mercury, \[ \text{Pa} = \text{mm Hg} \times 133.3 \]
Typical Applications

This type of pressure measurement is mainly used for spot checks or for calibration. They are used for low range measurements, as higher measurements require mercury. Mercury is toxic and is therefore considered mildly hazardous.

![Simplest form of manometer](image)

**Figure 2.10**  
*Simplest form of manometer*

**Advantages**

- Simple operation and construction
- Inexpensive

**Disadvantages**

- Low pressure range (water)
- Higher pressure range requires mercury
- Readings are localised

**Application Limitations**

Manometers are limited to a low range of operation due to size restrictions. They are also difficult to integrate into a continuous control system.
2.3.6 Single and Double Inverted Bell

The Bell instrument measures the pressure difference in a compartment on each side of a bell-shaped chamber. If the pressure to be measured is referenced to the surrounding conditions, then the lower compartment is vented to the atmosphere and gauge pressure is measured. If the lower compartment is evacuated to form a vacuum, then the pressure measured will be in absolute units. However, to measure differential pressure, the higher pressure is connected to the top of the chamber and the lower pressure to the bottom.

![Inverted bell d/p detector](image)

*Figure 2.11 Inverted bell d/p detector*

The bell instrument is used in applications where very low pressures are required to be measured, typically in the order of 0 - 250 Pa.
2.4 Pressure Transducers and Elements - Electrical

The typical range of transducers here is:
- Strain gauge
- Vibrating wire
- Piezoelectric
- Capacitance
- Linear Variable Differential Transformer
- Optical

2.4.1 Strain Gauge

Strain gauge sensing uses a metal wire or semiconductor chip to measure changes in pressure. A change in pressure causes a change in resistance as the metal is deformed. This deformation is not permanent as the pressure (applied force) does not exceed the elastic limit of the metal. If the elastic limit is exceeded than permanent deformation will occur.

This is commonly used in a Wheatstone bridge arrangement where the change in pressure is detected as a change in the measured voltage.

Strain gauges in their infancy were metal wires supported by a frame. Advances in the technology of bonding materials mean that the wire can be adhered directly to the strained surface. Since the measurement of strain involves the deformation of metal, the strain material need not be limited to being a wire. As such, further developments also involve metal foil gauges. Bonded strain gauges are the more commonly used type.

As strain gauges are temperature sensitive, temperature compensation is required. One of the most common forms of temperature compensation is to use a wheatstone bridge. Apart from the sensing gauge, a dummy gauge is used which is not subjected to the forces but is also affected by temperature variations. In the bridge arrangement the dummy gauge cancels with the sensing gauge and eliminates temperature variations in the measurement.
Strain gauges are mainly used due to their small size and fast response to load changes.

**Typical Application**

Pressure is applied to an isolating diaphragm, where the force is transmitted to the polysilicon sensor by means of a silicone fill fluid. The reference side of the sensor is exposed to atmospheric pressure for gauge pressure transmitters. A sealed vacuum reference is used for absolute pressure transmitters.

When the process pressure is applied to the sensor, this creates a small deflection of the sensing diaphragm, which applies strain to the Wheatstone bridge circuit within the sensor. The change in resistance is sensed and converted to a digital signal for processing by the microprocessor.

**Selection and Sizing**

There exists a very wide selection of strain gauge transducers, in range, accuracy and the associated cost.

**Advantages**

- Wide range, 7.5kPa to 1400 Mpa
- Inaccuracy of 0.1%
- Small in size
- Stable devices with fast response
- Most have no moving parts
- Good over-range capability
Disadvantages

- Unstable due to bonding material
- Temperature sensitive
- Thermoelastic strain causes hysteresis

Application Limitations

All strain gauge applications require regulated power supplies for the excitation voltage, although this is commonly internal with the sensing circuits.

2.4.2 Vibrating Wire

This type of sensor consists of an electronic oscillator circuit which causes a wire to vibrate at its natural frequency when under tension. The principle is similar to that of a guitar string. The vibrating wire is located in a diaphragm. As the pressure changes on the diaphragm so does the tension on the wire which affects the frequency that the wire vibrates or resonates at. These frequency changes are a direct consequence of pressure changes and as such are detected and shown as pressure.

The frequency can be sensed as digital pulses from a electromagnetic pickup or sensing coil. An electronic transmitter would then convert this into an electrical signal suitable for transmission.

This type of pressure measurement can be used for differential, absolute or gauge installations. Absolute pressure measurement is achieved by evacuating the low-pressure diaphragm. A typical vacuum pressure for such a case would be about 0.5 Pa.

Advantages

- Good accuracy and repeatability
- Stable
- Low hysteresis
- high resolution
- Absolute, gauge or differential measurement

Disadvantages

- Temperature sensitive
- Affected by shock and vibration
- Non linear
- Physically large
Application Limitations

Temperature variations require temperature compensation within the sensor, this problem limits the sensitivity of the device. The output generated is non-linear which can cause continuous control problems.

This technology is seldom used any more. Being older technology it is typically found with analogue control circuitry.

2.4.3 Piezoelectric

When pressure is applied to crystals, they are elastically deformed. Piezoelectric pressure sensing involves the measurement of such deformation. When a crystal is deformed, an electric charge is generated for only a few seconds. The electrical signal is proportional to the applied force.

Because these sensors can only measure for a short period, they are not suitable for static pressure measurement.

More suitable measurements are made of dynamic pressures caused from:

- shock
- vibration
- explosions
- pulsations
- engines
- compressors

This type of pressure sensing does not measure static pressure, and as such requires some means of identifying the pressure measured. As it measures dynamic pressure, the measurement needs to be referenced to the initial conditions before the impact of the pressure disturbance. The pressure can be expressed in relative pressure units, Pascal RELATIVE.

Quartz is commonly used as the sensing crystal as it is inexpensive, stable and insensitive to temperature variations. Tourmaline is an alternative which gives faster response speeds, typically in the order of microseconds.

Advantages

- Accuracy 0.075%
- Very high pressure measurement, up to 70MPa
- small size
- robust
- fast response, < 1 nanosecond
- self-generated signal
Disadvantages

- Dynamic sensing only
- Temperature sensitive

Application Limitations

Require special cabling and signal conditioning.

2.4.4 Capacitance

Capacitive pressure measurement involves sensing the change in capacitance that results from the movement of a diaphragm. The sensor is energised electrically with a high frequency oscillator. As the diaphragm is deflected due to pressure changes, the relative capacitance is measured by a bridge circuit.

Two designs are quite common. The first is the two-plate design and is configured to operate in the balanced or unbalanced mode. The other is a single capacitor design.

The balanced mode is where the reference capacitor is varied to give zero voltage on the output. The unbalanced mode requires measuring the ratio of output to excitation voltage to determine pressure.

This type of pressure measurement is quite accurate and has a wide operating range. Capacitive pressure measurement is also quite common for determining the level in a tank or vessel.
Figure 2.13
Cross section of the Rosemount S-Cell™ Sensor
(courtesy of Rosemount)
Figure 2.14
Capacitance pressure detector

Advantages

- Inaccuracy 0.01 to 0.2%
- Range of 80Pa to 35MPa
- Linearity
- Fast response

Disadvantages

- Temperature sensitive
- Stray capacitance problems
- Vibration
- Limited overpressure capability
- Cost
Application Limitations

Many of the disadvantages above have been addressed and their problems reduced in newer designs. Temperature controlled sensors are available for applications requiring a high accuracy.

With strain gauges being the most popular form of pressure measurement, capacitance sensors are the next most common solution.

2.4.5 Linear Variable Differential Transformer

This type of pressure measurement relies on the movement of a high permeability core within transformer coils. The movement is transferred from the process medium to the core by use of a diaphragm, bellows or bourdon tube.

The LVDT operates on the inductance ratio between the coils. Three coils are wound onto the same insulating tube containing the high permeability iron core. The primary coil is located between the two secondary coils and is energised with an alternating current.

Equal voltages are induced in the secondary coils if the core is in the centre. The voltages are induced by the magnetic flux. When the core is moved from the centre position, the result of the voltages in the secondary windings will be different. The secondary coils are usually wired in series.

LVDT’s are sensitive to vibration and are subject to mechanical wear.

Disadvantages

- Mechanical wear
- Vibration
Summary

The is an older technology, used before strain gauges were developed. Typically found on old weighframes or may be used for position control applications.

Very seldom used anymore.

2.4.6 Optical

Optical sensors can be used to measure the movement of a diaphragm due to pressure. An opaque vane is mounted to the diaphragm and moves in front of an infrared light beam. As the light is disturbed, the received light on the measuring diode indicates the position of the diaphragm.

A reference diode is used to compensate for the ageing of the light source. Also, by using a reference diode, the temperature effects are nulled as they affect the sensing and reference diodes in the same way.

Advantages

- Temperature corrected
- Good repeatability
- Negligible hysteresis

Disadvantages

- Expensive

Summary

Optical sensors require very little movement for accurate sensing. Because of this, optical pressure measurement provides very good repeatability with negligible hysteresis.

2.5 Installation Considerations

There are a number of points to consider in a pressure measurement application. All require some thought in both the planning and execution.

Location of Process Connections

Process connections should be located on the top of the process line for gases, and on the side of the lines for other fluids.
Isolation Valves

Many pressure devices require tapping points into the process. Isolation valves should be considered between the process fluid and the measuring equipment if the device is required to be taken out of service for replacement or calibration.

Use of Impulse Tubing

Impulse piping should be as short as possible. Instruments in gas applications should be self-draining. Self-draining can be achieved by sloping the lines towards the process to avoid trapping condensables and liquids.

Instruments used in liquid and condensable applications should be self-venting. Self-venting is performed by sloping the lines towards the instrument to avoid trapping gas.

If solids can accumulate in the impulse line, tees and plug fittings should be installed in the place of elbows to allow for “rodding” of plugged lines.

Test And Drain Valves

Apart from the isolation valve at the process connection, the need for test and drain valves must be evaluated. If the fluid to be measured is toxic or corrosive, a blowdown valve line should be provided.

For maintenance reasons, all valves must be accessible from either the ground or suitable platforms.

Sensor Construction

Depending on the environment in which the instrument is to be used, selection of the correct sensor should also involve physical conditions. The sensor may need to be isolated mechanically, electronically and thermally from the process medium and the external environment.

Mechanical and thermal isolation can be achieved by moving the sensor away from the process flange to a position in the neck of the electronics housing. Designs of this type relieve mechanical stress on the cell. This can result in improved static pressure performance and removes the sensor from direct heat.

Glass-sealed pressure transport tubes and insulated cell mountings provide electrical isolation. This improves performance and provides transient protection for the electronics.
**Temperature Effects**

High temperatures and large temperature variations can affect pressure measuring equipment.

One of the most common forms of temperature compensation is to use a Wheatstone bridge. Apart from the primary sensor, a dummy sensor is used which is not subjected to the forces but is also affected by temperature variations. In the bridge arrangement the dummy sensor cancels the primary sensor’s voltage and thus eliminates temperature variations in the measurement.

Temperature measurement and correction within the device is another form of compensation for thermal effects, but is the more expensive choice.

**Remote Diaphragm Seals**

Remote diaphragm seals can be used to prevent the process medium from contacting the transmitter diaphragm while measuring process pressure.

Remote seal systems should be considered if:

- corrosion may cause a problem to the transmitter and pressure sensing element.
- the sensing fluid contains suspended solids or is sufficiently viscous to clog the piping.
- the process temperature is outside of the normal operating range of the transmitter.
- the process fluid may freeze or solidify in the transmitter or impulse piping.
- the process medium needs to be flushed out of the process connections when changing batches.
- maintaining sanitary or aseptic conditions.
- eliminating the maintenance required with wet leg applications.
- making density or other measurements.

**Precautions With Remote Diaphragm Seals**

Although the benefits of using remote diaphragm seals are listed above, they can however have an effect on the overall transmitter response. By selecting the correct seals, capillaries and fill fluid, the effects of transmitter performance can be minimised while still achieving process requirements.
The following points can assist when selecting the different parts of a remote seal system:

- Larger diameter diaphragms minimise the temperature effects that are common with remote seals.

- Minimising the length of the capillary reduces temperature effects and also improves response time.

- In a two-seal system, the same diaphragm size, capillary length and fill fluid should be used on each side of the transmitter.

- Mount the transmitter at or below the lower tap for vacuum applications. Capillary length may be an inhibiting factor.

- The fill fluid should be selected to perform in the most extreme process conditions. The two critical criteria being highest temperature and lowest pressure.

- Select a fill fluid that is compatible with the process fluid, in case of contamination.

**Process Flanges**

- Coplanar flange

  These are becoming more standard for newer pressure transmitters. They are generally small and lightweight which makes for easier installation. They have a process operating temperature up to 120°C.

- Traditional flange

  These are used in installations that require traditional biplanar configurations. An increased operating temperature at process connections, up to 150°C is possible.

- Level flange

  This permits direct process mounting and is of a simple construction and low cost.
**Additional Hardware**

If pulsation dampeners are required, the materials and fill fluid must be compatible with the process fluid being measured. In addition, siphons of the correct material are required for all vapours above 60°C, where condensation will occur.

If diaphragm seals are required, a flushing connection requirement must be assessed.

**2.6 Impact on the Overall Control Loop**

Sensing devices that are situated in a control loop generally have an effect when the range of operation or response time changes.

With pressure measurement devices, problems occur due to:

- Material build-up on the sensing element causing a longer response
- Overranging causing incorrect readings
2.7 Selection Tables

Table 2.4
Selection table.
## Table 2.5

<table>
<thead>
<tr>
<th>Type of Design</th>
<th>Features</th>
<th>Applicable Pressure Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Pressure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dead Weight Piston Gauge</td>
<td>✓</td>
<td>300 - 3000</td>
</tr>
<tr>
<td>Bulk Modulus Cell</td>
<td>✓</td>
<td>50 - 1000</td>
</tr>
<tr>
<td>Manganin Cell</td>
<td>✓</td>
<td>50 - 1000</td>
</tr>
<tr>
<td><strong>Manometers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inverted Bell</td>
<td>✓</td>
<td>100 - 1000</td>
</tr>
<tr>
<td>Ring Balance</td>
<td>✓</td>
<td>100 - 1000</td>
</tr>
<tr>
<td>Float Manometer</td>
<td>✓</td>
<td>10 - 1000</td>
</tr>
<tr>
<td>Barometers</td>
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<tr>
<td>Visual Manometers</td>
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</tr>
<tr>
<td>Micromanometers</td>
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<tr>
<td><strong>Pressure Transducers</strong></td>
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<tr>
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<td><strong>Ionization</strong></td>
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<tr>
<td>Hot Cathode</td>
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<tr>
<td>Cold Cathode</td>
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<tr>
<td><strong>Thermal</strong></td>
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<td></td>
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<tr>
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<tr>
<td>Thermopile</td>
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</tr>
<tr>
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<tr>
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<tr>
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</tr>
<tr>
<td>Spinning Bell</td>
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<td>5 - 1000</td>
</tr>
</tbody>
</table>

- ✓ Indicates that the device uses full-vacuum reference in its operation.
- ○ Indicates that the device uses atmospheric pressure reference.
- ● Indicates that the operating principle used does not involve the use of reference pressures.

**Features**
- Local Readout
- Remote Readout
- On-Site Readout
- Replaceable Sensors
- Standardized

**Applicable Pressure Ranges**
- **mmHg absolute**
  - (1 mmHg = 133.32 Pa)
  - 10⁻² - 10⁻¹ - 10⁰ - 10¹ - 10²
  - -300 - 200 - 100 - 5 - 1
- **°H₂O**
  - (1 °H₂O = 250 Pa)
  - +0.1 - +1 - +5 - +10 - +100 - +300
- **PSIG**
  - (1 PSIG = 6.9 kPa)
  - 4 - 7 - 11 - 10² - 10³ - 10⁴ - 10⁵
2.8 Future Technologies

Sensor Characterisation

Sensors show slightly different characteristics depending on the pressure and temperature ranges they operate at. By running sensors through pressure and temperature cycles over their full operating range, it is possible to gather enough data to generate correction coefficients. This information is stored in the sensor module and ensures precise signal correction during normal operation.

Errors due to hysteresis and non-linearity can be improved upon with the use of smart instruments. The microprocessor does not eliminate the nonlinearity, but it does memorise the amount of nonlinearity and electronically corrects for it.

Smart pressure transmitters provide two main functions:

- Maximise accuracy and rangeability.
- Easily interfaced between field sensors and main control system.