2015

Process Control Fundamentals

INTRODUCTION, PRESSURE MEASUREMENTS

Definition of basic process control loop and introducing some concepts about pressure measurements]

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16-Nov-15

The Importance of Process Control

PROCESS

Process as used in the terms *process control* and *process industry*, refers to the methods of changing or refining raw materials to create end products. The raw materials, which either pass through or remain in a liquid, gaseous, or slurry (a mix of solids and liquids) state during the process, are transferred, measured, mixed, heated or cooled, filtered, stored, or handled in some other way to produce the end product.

Process industries include the chemical industry, the oil and gas industry, the food and beverage industry, the pharmaceutical industry, the water treatment industry, and the power industry.

PROCESS CONTROL

Process control refers to the methods that are used to control process variables when manufacturing a product. For example, factors such as the proportion of one ingredient to another, the temperature of the materials, how well the ingredients are mixed, and the pressure under which the materials are held can significantly impact the quality of an end product. Manufacturers control the production process for three reasons:

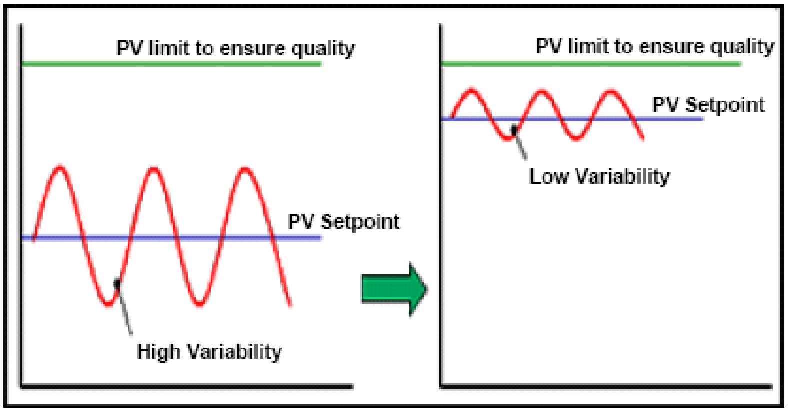
Reduce variability
Increase efficiency
Ensure safety

Reduce Variability

Process control can reduce variability in the end product, which ensures a consistently high-quality product. Manufacturers can also save money by reducing variability. For example, in a gasoline blending process, as many as 12 or more different components may be blended to make a specific grade of gasoline. If the refinery does not have precise control over the flow of the separate components, the gasoline may get too much of the high-octane components. As a result, customers would receive a higher grade and more expensive gasoline than they paid for, and the refinery would lose money. The opposite situation would be customers receiving a lower grade at a higher price.

The Importance of Process Control

Reducing variability can also save money by reducing the need for product padding to meet required product specifications. *Padding* refers to the process of making a product of higher-quality than it needs to be to meet specifications. When there is variability in the end product (i.e., when process control is poor), manufacturers are forced to pad the product to ensure that specifications are met, which adds to the cost. With accurate, dependable process control, the *set point* (desired or optimal point) can be moved closer to the actual product specification and thus save the manufacturer money.



Increase Efficiency

Some processes need to be maintained at a specific point to maximize efficiency. For example, a control point might be the temperature at which a chemical reaction takes place. Accurate control of temperature ensures process efficiency. Manufacturers save money by minimizing the resources required to produce the end product.

Ensure Safety

A run-away process, such as an out-of-control nuclear or chemical reaction, may result if manufacturers do not maintain precise control of all of the process variables. The consequences of a run-away process can be catastrophic.

Precise process control may also be required to ensure safety. For example, maintaining proper boiler pressure by controlling the inflow of air used in combustion and the outflow of exhaust gases is crucial in preventing boiler implosions that can clearly threaten the safety of workers.

The Control Loop

Imagine you are sitting in a cabin in front of a small fire on a cold winter evening. You feel uncomfortably cold, so you throw another log on the fire. This is an example of a *control loop*. In the control loop, a variable (temperature) fell below the set point (your comfort level), and you took action to bring the process back into the desired condition by adding fuel to the fire. The control loop will now remain static until the temperature again rises above or falls below your comfort level.

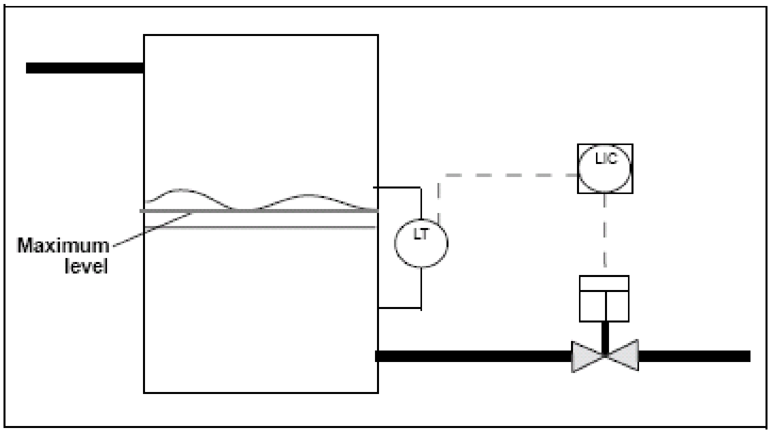
THREE TASKS

Control loops in the process control industry work in the same way, requiring three tasks to occur:

_ Measurement
_ Comparison
_ Adjustment

In Figure below, a level transmitter (LT) measures the level in the tank and transmits a signal associated with the level reading to a controller (LIC). The controller compares the reading to a predetermined value, in this case, the maximum tank level established by the plant operator, and finds that the values are equal. The controller then sends a signal to the device that can bring the tank level back to a lower level—a valve at the bottom of the tank. The valve opens to let some liquid out of the tank.

Many different instruments and devices may or may not be used in control loops (e.g., transmitters, sensors, controllers, valves, pumps), but the three tasks of measurement, comparison, and adjustment are always present.



A Simple Control Loop

Process Control Terms

As in any field, process control has its own set of common terms that you should be familiar with and that you will use when talking about control technology.

PROCESS VARIABLE

A *process variable* is a condition of the process fluid (a liquid or gas) that can change the manufacturing process in some way. In the example of you sitting by the fire, the process variable was temperature. In the example of the tank in Figure, the process variable is level. Common process variables include:

_ Pressure
_ Flow
_ Level
_ Temperature
_ Density
_ Ph (acidity or alkalinity)
_ Liquid interface (the relative amounts of different liquids that are combined in a vessel)
_ Mass
_ Conductivity

2.1 PRESSURE MEASUREMENT

This module will examine the theory and operation of pressure detectors (bourdon tubes, diaphragms, bellows, forced balance and variable capacitance). It also covers the variables of an operating environment (pressure, temperature) and the possible modes of failure.

2.1.1 General Theory

Pressure is probably one of the most commonly measured variables in the power plant. It includes the measurement of steam pressure; feed water pressure, condenser pressure, lubricating oil pressure and many more.
Pressure is actually the measurement of force acting on area of surface.
We could represent this as:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \quad \text{or} \quad P = \frac{F}{A}$$

2.1.2 Pressure Scales

Before we go into how pressure is sensed and measured, we have to establish a set of ground rules. Pressure varies depending on altitude above sea level, weather pressure fronts and other conditions.
The measure of pressure is, therefore, relative and pressure measurements are stated as either gauge or absolute.

Gauge pressure is the unit we encounter in everyday work (e.g., tire ratings are in gauge pressure).

A gauge pressure device will indicate zero pressure when bled down to atmospheric pressure (i.e., gauge pressure is referenced to atmospheric pressure). Gauge pressure is denoted by a (g) at the end of the pressure unit [e.g., kPa (g)].
Absolute pressure includes the effect of atmospheric pressure with the gauge pressure. It is denoted by an (a) at the end of the pressure unit [e.g., kPa (a)]. An absolute pressure indicator would indicate atmospheric pressure when completely vented down to atmosphere - it would not indicate scale zero.

Absolute Pressure = Gauge Pressure + Atmospheric Pressure

Figure 1 illustrates the relationship between absolute and gauge. Note that the base point for gauge scale is [0 kPa (g)] or standard atmospheric pressure 101.3 kPa (a).
The majority of pressure measurements in a plant are gauge.
Absolute measurements tend to be used where pressures are below atmosphere.
Typically this is around the condenser and vacuum building.

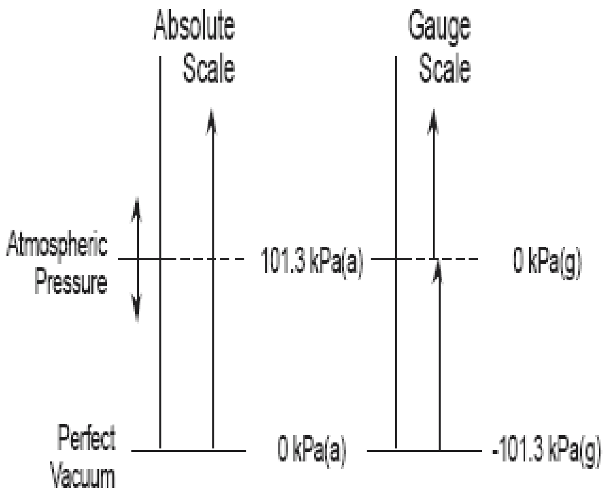


Figure 1

Relationship between Absolute and Gauge Pressures

2.1.3 Pressure Measurement

The object of pressure sensing is to produce a dial indication, control operation or a standard (4 - 20 mA) electronic signal that represents the pressure in a process.
To accomplish this, most pressure sensors translate pressure into physical motion that is in proportion to the applied pressure. The most common pressure sensors or primary pressure elements are described below.

They include diaphragms, pressure bellows, bourdon tubes and pressure capsules. With these pressure sensors, physical motion is proportional to the applied pressure within the operating range.
You will notice that the term differential pressure is often used. This term refers to the difference in pressure between two quantities, systems or devices

2.1.4 Common Pressure Detectors

Bourdon Tubes

Bourdon tubes are circular-shaped tubes with oval cross sections (refer to Figure 2). The pressure of the medium acts on the inside of the tube. The outward pressure on the oval cross section forces it to become rounded. Because of the curvature of the tube ring, the bourdon tube then bends as indicated in the direction of the arrow.

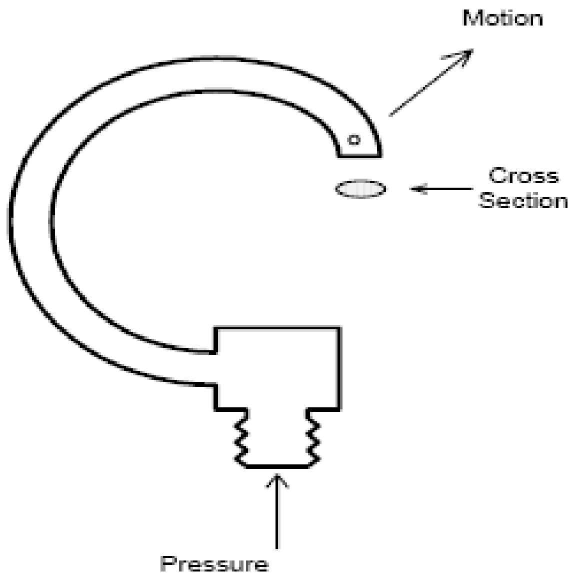


Figure 2
Bourdon Tube

Due to their robust construction, bourdon are often used in harsh environments and high pressures, but can also be used for very low pressures; the response time however, is slower than the bellows or diaphragm.

Bellows

Bellows type elements are constructed of tubular membranes that are convoluted around the circumference (see Figure 3). The membrane is attached at one end to the source and at the other end to an indicating device or instrument. The bellows element can provide a long range of motion (stroke) in the direction of the arrow when input pressure is applied.

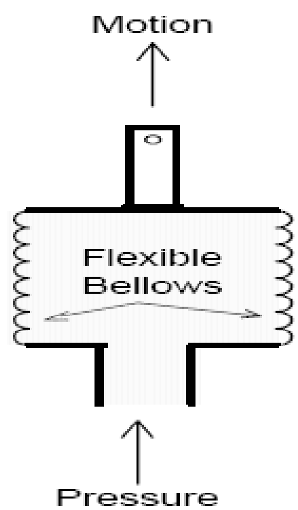


Figure 3
Bellows

Diaphragms

A diaphragm is a circular-shaped convoluted membrane that is attached to the pressure fixture around the circumference (refer to Figure 4). The pressure medium is on one side and the indication medium is on the other.

The deflection that is created by pressure in the vessel would be in the direction of the arrow indicated.

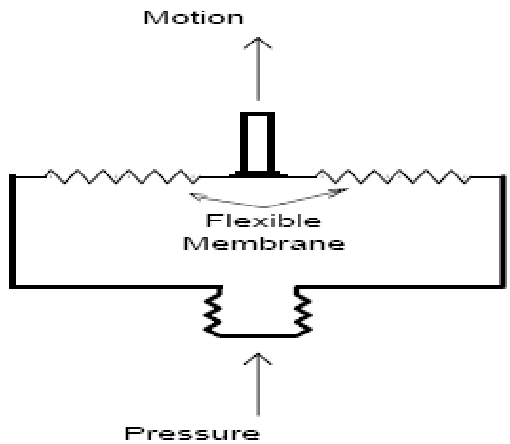


Figure 4
Diaphragm

Diaphragms provide fast acting and accurate pressure indication. However, the movement or stroke is not as large as the bellows.

Capsules

There are two different devices that are referred to as capsule. The first is shown in figure 5. The pressure is applied to the inside of the capsule and if it is fixed only at the air inlet it can expand like a balloon. This arrangement is not much different from the diaphragm except that it expands both ways.

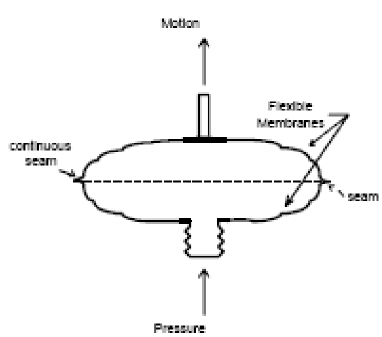


Figure 5
Capsule

The capsule consists of two circular shaped, convoluted membranes (usually stainless steel) sealed tight around the circumference. The pressure acts on the inside of the capsule and the generated stroke movement is shown by the direction of the arrow.

The second type of capsule is like the one shown in the differential pressure transmitter (DP transmitter) in figure 7. The capsule in the bottom is constructed with two diaphragms forming an outer case and the inter-space is filled with viscous oil. Pressure is applied to both side of the diaphragm and it will deflect towards the lower pressure.

To provide over-pressurized protection, a solid plate with diaphragm matching convolutions is usually mounted in the center of the capsule.
Silicone oil is then used to fill the cavity between the diaphragms for even pressure transmission.

Most DP capsules can withstand high static pressure of up to 14 MPa (2000 psi) on both sides of the capsule without any damaging effect. However, the sensitive range for most DP capsules is quite low. Typically, they are sensitive up to only a few hundred kPa of differential pressure.

Differential pressure that is significantly higher than the capsule range may damage the capsule permanently.

Capacitive Sensors:

Capacitors are the basic building blocks of the electronic world. To understand how capacitive sensors operate, it is important to understand the fundamental properties and principles of capacitors. This section provides details on the underlying principles of the capacitor.

A capacitor is a device that consists of two electrodes separated by an insulator. Capacitors are generally composed of two conducting plates separated by a non-conducting substance called dielectric. The dielectric may be air, mica, ceramic, fuel, or other suitable insulating material. The electrical energy or charge is stored on these plates. Figure 6 illustrates a basic circuit configuration that charges the capacitor as soon as the switch is closed.

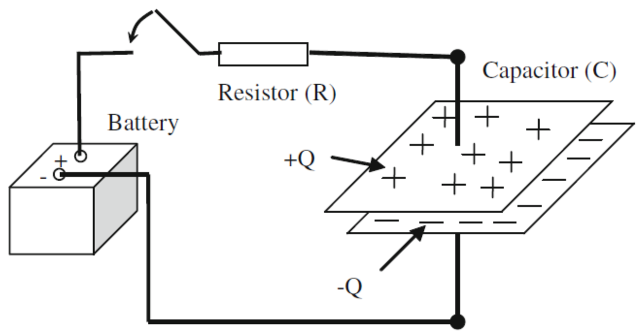


Figure 6

Capacitor used in a circuit to store electrical charge

The capacitance of a capacitor is directly proportional to the area of the metal plates and inversely proportional to the distance between them. It also depends on a characteristic of the insulating material between them. This characteristic, called permittivity is a measure of how well the insulating material increases the ability of the capacitor to store charge.

$C = \varepsilon A / d$

- ***C** is the capacitance in Farads.*

- ***A*** *is the area of the plates.*
- ***d*** *is the distance of the plates.*
- ***ε*** *is the permittivity of the insulator.*

2.1.5 Differential Pressure Transmitters

Most pressure transmitters are built around the pressure capsule concept. They are usually capable of measuring differential pressure (that is, the difference between a high pressure input and a low pressure input) and therefore, are usually called DP transmitters or DP cells.

Figure 7 illustrates a typical DP transmitter. A differential pressure capsule is mounted inside housing. One end of a force bar is connected to the capsule assembly so that the motion of the capsule can be transmitted to outside the housing. A sealing mechanism is used where the force bar penetrates the housing and also acts as the pivot point for the force bar. Provision is made in the housing for high- pressure fluid to be applied on one side of the capsule and low-pressure fluid on the other.
Any difference in pressure will cause the capsule to deflect and create motion in the force bar. The top end of the force bar is then connected to a position detector, which via an electronic system will produce a 4 - 20 ma signal that is proportional to the force bar movement.

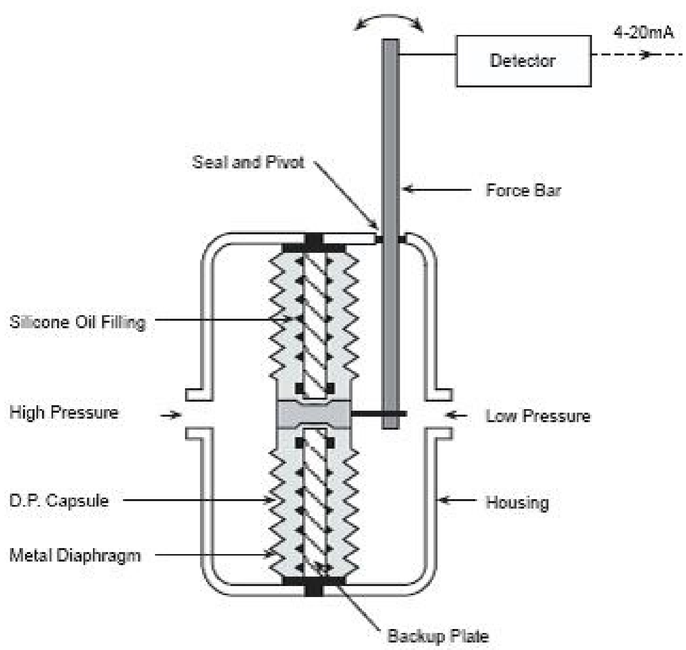


Figure 7
Typical DP Transmitter Construction

This DP transmitter would be used in an installation as shown in Figure 8.

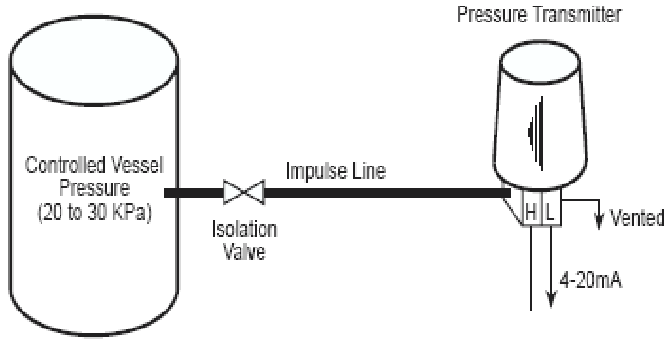


Figure 8
DP Transmitter Application

A DP transmitter is used to measure the gas pressure (in gauge scale) inside a vessel. In this case, the low-pressure side of the transmitter is vented to atmosphere and the high-pressure side is connected to the vessel through an isolating valve. The isolating valve facilitates the removal of the transmitter.

The output of the DP transmitter is proportional to the gauge pressure of the gas, i.e., 4 mA when pressure is 20 kPa and 20 mA when pressure is 30 kPa.

2.1.6 Strain Gauges

The strain gauge is a device that can be affixed to the surface of an object to detect the force applied to the object. One form of the strain gauge is a metal wire of very small diameter that is attached to the surface of a device being monitored.

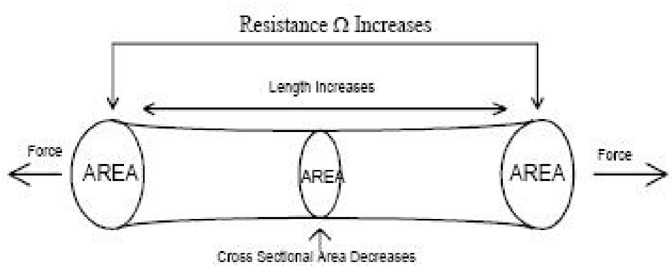


Figure 9
Strain Gauge

For a metal, the electrical resistance will increase as the length of the metal increases or as the cross sectional diameter decreases.

When force is applied as indicated in Figure 9, the overall length of the wire tends to increase while the cross-sectional area decreases.

The amount of increase in resistance is proportional to the force that produced the change in length and area. The output of the strain gauge is a change in resistance that can be measured by the input circuit of an amplifier.

Strain gauges can be bonded to the surface of a pressure capsule or to a force bar positioned by the measuring element. Shown in Figure 10 (next page) is a strain gauge that is bonded to a force beam inside the DP capsule. The change in the process pressure will cause a resistive change in the strain gauges, which is then used to produce a 4-20 mA signal.

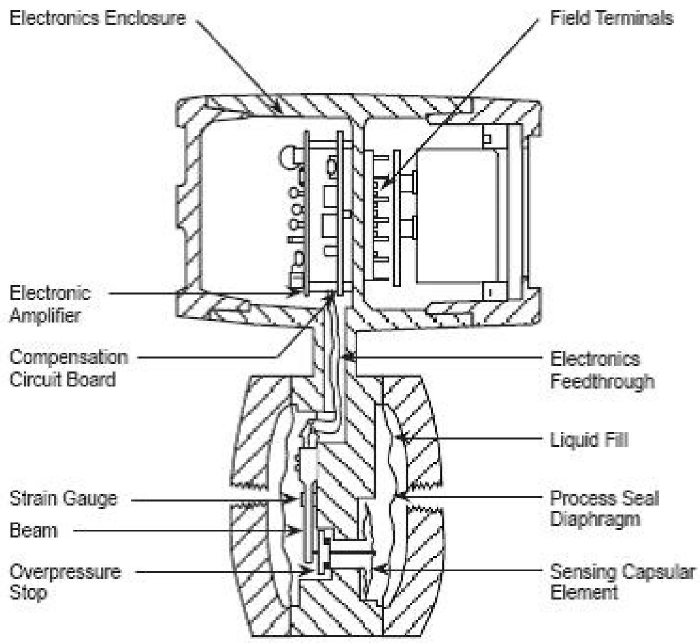


Figure 10
Resistive Pressure Transmitter

2.1.7 Impact of Operating Environment

All of the sensors described in this module are widely used in control and instrumentation systems throughout the power station. Their existence will not normally be evident because the physical construction will be enclosed inside manufacturer’s packaging. However, each is highly accurate when used to measure the right quantity and within the rating of the device. The constraints are not limited to operating pressure. Other factors include temperature, vapor content and vibration.

Vibration

The effect of vibration is obvious in the inconsistency of measurements, but the more dangerous result is the stress on the sensitive membranes, diaphragms and linkages that can cause the sensor to fail. Vibration can come from many sources.

Some of the most common are the low level constant vibration of an unbalanced pump impeller and the larger effects of steam hammer.

External vibration (loose support brackets and insecure mounting) can have the same effect.

Temperature

The temperature effects on pressure sensing will occur in two main areas: The volumetric expansion of vapor is of course temperature dependent. Depending on the system, the increased pressure exerted is usually already factored in.

The second effect of temperature is not so apparent. An operating temperature outside the rating of the sensor will create significant error in the readings. The bourdon tube will indicate a higher reading when exposed to higher temperatures and lower readings when abnormally cold - due to the strength and elasticity of the metal tube. This same effect applies to the other forms of sensors listed.

Vapour Content

The content of the gas or fluid is usually controlled and known. However, it is mentioned at this point because the purity of the substance whose pressure is being monitored is of importance - whether gaseous or fluid, especially, if the device is used as a differential pressure device in measuring flow of a gas or fluid.

Higher than normal density can force a higher dynamic reading depending on where the sensors are located and how they are used. Also, the vapor density or ambient air density can affect the static pressure sensor readings and DP cell readings. Usually, lower readings are a result of the lower available pressure of the substance. However, a DP sensor located in a hot and very humid room will tend to read high.

2.1.8 Failures and Abnormalities

Over-Pressure

All of the pressure sensors we have analyzed are designed to operate over

a rated pressure range. Plant operating systems rely on these pressure sensors to maintain high accuracy over that given range. Instrument readings and control functions derived from these devices could place plant operations in jeopardy if the equipment is subjected to over pressure (over range) and subsequently damaged. If a pressure sensor is over ranged, pressure is applied to the point where it can no longer return to its original shape, thus the indication would return to some value greater than the original.

Diaphragms and bellows are usually the most sensitive and fast-acting of all pressure sensors.

They are also however, the most prone to fracture on over-pressuring. Even a small fracture will cause them to read low and be less responsive to pressure changes. Also, the linkages and internal movements of the sensors often become distorted and can leave a permanent offset in the measurement. Bourdon tubes are very robust and can handle extremely high pressures although, when exposed to over-pressure, they become slightly distended and will read high. Very high over-pressuring will of course rupture the tube.

Faulty Sensing Lines

Faulty sensing lines create inaccurate readings and totally misrepresent the actual pressure when the pressure lines become partially blocked, the dynamic response of the sensor is naturally reduced and it will have a slow response to change in pressure. Depending on the severity of the blockage, the sensor could even retain an incorrect zero or low reading, long after the change in vessel pressure.

A cracked or punctured sensing line has the characteristic of consistently low readings. Sometimes, there can be detectable down-swings of pressure followed by slow increases.

Loss of Loop Electrical Power

As with any instrument that relies on AC power, the output of the D/P transmitters will drop to zero or become irrational with a loss of power supply.