FLOW MEASUREMENT

There are various methods used to measure the flow rate of steam, water, lubricants, air, etc., in a nuclear generating station. However, in this module will look at the most common, namely the DP cell type flow detector. Also in this section we will discuss the application of a square root extractor and cut-off relay plus the possible sources of errors in flow measurements and different failure modes that can occur.

1 Flow Detectors

To measure the rate of flow by the differential pressure method, some form of restriction is placed in the pipeline to create a pressure drop. Since flow in the pipe must pass through a reduced area, the pressure before the restriction is higher than after or downstream. Such a reduction in pressure will cause an increase in the fluid velocity because the same amount of flow must take place before the restriction as after it. Velocity will vary directly with the flow and as the flow increases a greater pressure differential will occur across the restriction. So by measuring the differential pressure across a restriction, one can measure the rate of flow.

Orifice Plate

The orifice plate is the most common form of restriction that is used in flow measurement. An orifice plate is basically a thin metal plate with a hole bored in the center. It has a tab on one side where the specification of the plate is stamped. The upstream side of the orifice plate usually has a sharp, edge. Figure 1 shows a representative orifice plate.

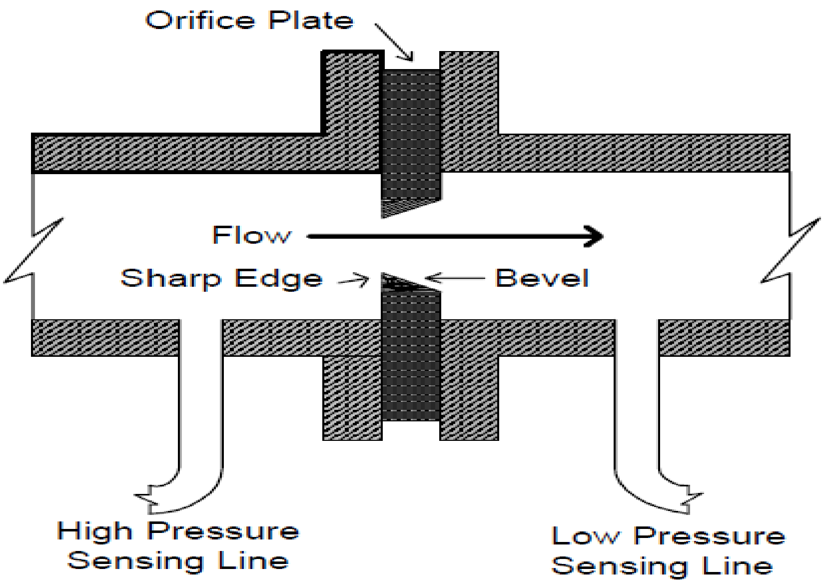

Figure 1
A Typical Orifice Plate

When an orifice plate is installed in a flow line (usually clamped between a pair of flanges), increase of fluid flow velocity through the reduced area at the orifice develops a differential pressure across the orifice. This pressure is a function of flow rate. With an orifice plate in the pipe work, static pressure increases slightly upstream of the orifice (due to back pressure effect) and then decreases sharply as the flow passes through the orifice, reaching a minimum at a point called the vena contracta

where the velocity of the flow is at a maximum. Beyond this point, static pressure starts to recover as the flow slows down. However, with an orifice plate, static pressure downstream is always considerably lower than the upstream pressure. In addition some pressure energy is converted to sound and heat due to friction and turbulence at the orifice plate. Figure 2 shows the pressure profile of an orifice plate installation.

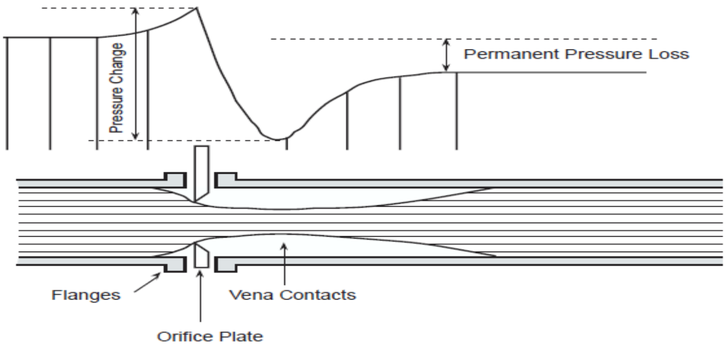

Figure 2
Orifice Plate Installation with Pressure Profile

On observing Figure 2, one can see that the measured differential pressure developed by an orifice plate also depends on the location of the pressure sensing points or pressure taps.

Flange Taps

Flange taps are the most widely used pressure tapping location for orifices. They are holes bored through the flanges, located one inch upstream and one inch downstream from the respective faces of the orifice plate. A typical flange tap installation is shown in Figure 3. The upstream and downstream sides of the orifice plate are connected to the high pressure and low-pressure sides of a DP transmitter. A pressure transmitter, when installed to measure flow, can be called a flow transmitter. As in the case of level measurement, the static pressure in the pipe-work could be many times higher than the differential pressure created by the orifice plate.

In order to use a capsule that is sensitive to low differential pressure, a three valve manifold has to be used to protect the DP capsule from being over ranged. The three valve manifold is discussed in more detail in the section on level measurement.

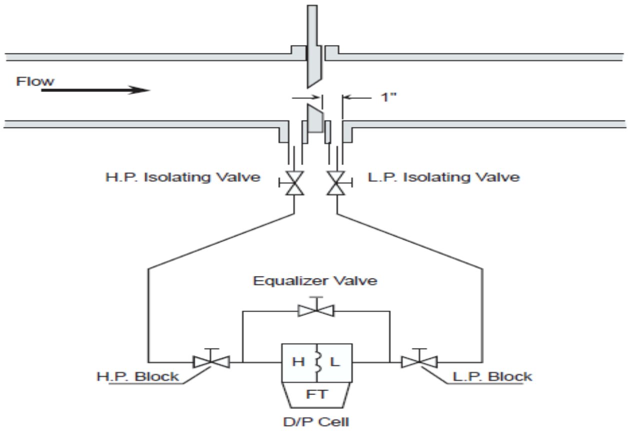

Figure 3
Orifice Plate with Flange Taps and Three Valve Manifold

Corner Taps

Corner taps are located right at upstream and downstream faces of the orifice plates (see Figure 4).

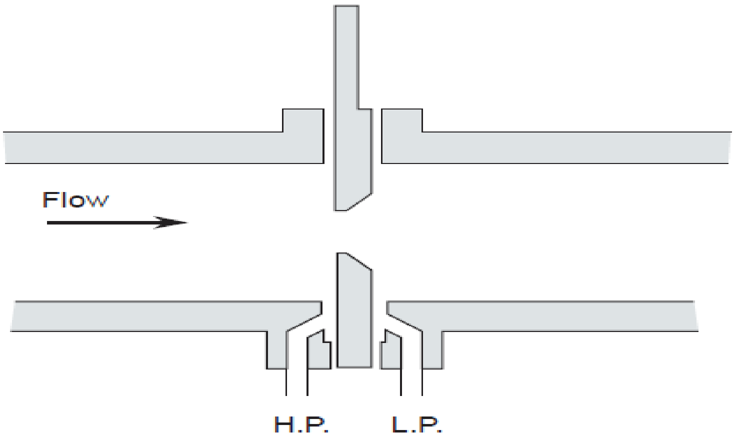

Figure 4
Orifice Plate with Corner Taps

Vena Contracta Taps

Vena contracta taps are located one pipe inner diameter upstream and at the point of minimum pressure, usually one half pipe inner diameter downstream (Figure 5).

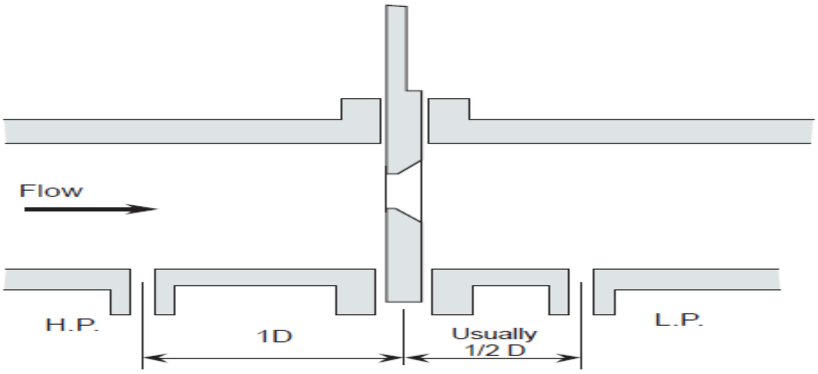

Figure 5
Orifice Plate with Vena Contracta Taps

Pipe Taps

Pipe taps are located two and a half pipe inner diameters upstream and eight pipe inner diameters downstream. When an orifice plate is used with one of the standardized pressure tap locations, an on-location calibration of the flow transmitter is not necessary. Once the ratio and the kind of pressure tap to be used are decided, there are empirically derived charts and tables available to facilitate calibration.

Advantages and Disadvantages of Orifice Plates

Advantages of orifice plates include:

- High differential pressure generated
- Exhaustive data available
- Low purchase price and installation cost
- Easy replacement

Disadvantages include:

- High permanent pressure loss implies higher pumping cost.
- Cannot be used on dirty fluids, slurries or wet steam as erosion will alter the differential pressure generated by the orifice plate.

Venturi Tubes

For applications where high permanent pressure loss is not tolerable, a venturi tube (Figure 6) can be used. Because of its gradually curved inlet and outlet cones, almost no permanent pressure drop occurs. This design also minimizes wear and plugging by allowing the flow to sweep suspended solids through without obstruction.

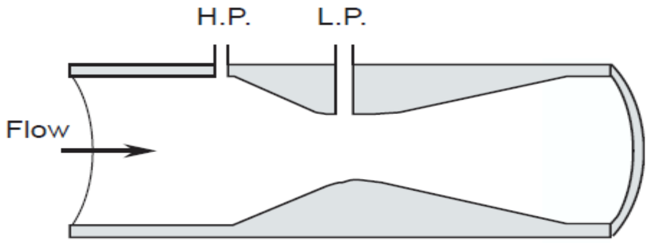

Figure 6
Venturi Tube Installation

However a Venturi tube does have disadvantages:

· Calculated calibration figures are less accurate than for orifice plates. For greater accuracy, each individual Venturi tube has to be flow calibrated by passing known flows through the Venturi and recording the resulting differential pressures.

· The differential pressure generated by a venturi tube is lower than for an orifice plate and, therefore, a high sensitivity flow transmitter is needed.

· It is more bulky and more expensive. As a side note; one application of the Venturi tube is the measurement of flow in the primary heat transport system. Together with the temperature change across these fuel channels, thermal power of the reactor can be calculated.

Flow Nozzle

A flow nozzle is also called a half venturi. Figure 7 shows a typical flow nozzle installation.

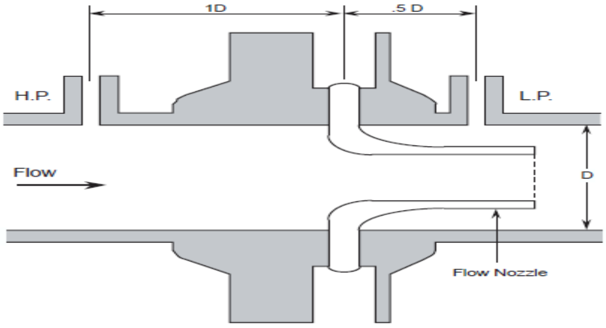

Figure 7
Flow Nozzle Installation

The flow nozzle has properties between an orifice plate and a venturi. Because of its streamlined contour, the flow nozzle has a lower permanent pressure loss than an orifice plate (but higher than a venturi). The differential it generates is also lower than an orifice plate (but again higher than the venturi tube). They are also less expensive than the venturi tubes. Flow nozzles are widely used for flow measurements at high velocities. They are more rugged and more resistant to erosion than the sharp-edged orifice plate. An example use of flow nozzles are the measurement of flow in the feed and bleed lines of the PHT system.

Elbow Taps

Centrifugal force generated by a fluid flowing through an elbow can be used to measure fluid flow. As fluid goes around an elbow, a high-pressure area appears on the outer face of the elbow. If a flow transmitter is used to sense this high pressure and the lower pressure at the inner face of the elbow, flow rate can be measured. Figure 8 shows an example of an elbow tap installation. One use of elbow taps is the measurement of steam flow from the boilers, where the large volume of saturated steam at high pressure and temperature could cause an erosion problem for other primary devices. Another advantage is that the elbows are often already in the regular piping configuration so no additional pressure loss is introduced.

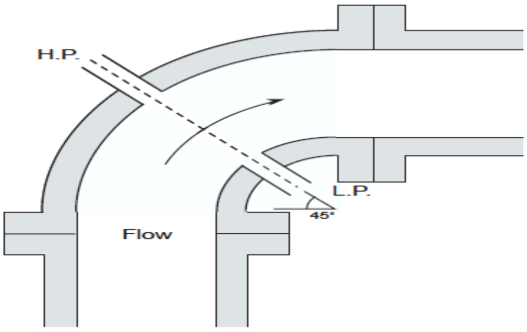

Figure 8
Elbow Tap Installation

Pitot Tubes

Pitot tubes also utilize the principles captured in Bernoulli.s equation, to measure flow. Most pitot tubes actually consist of two tubes. One, the low pressure tube measures the static pressure in the pipe. The second, the high pressure tube is inserted in the pipe in such a way that the flowing fluid is stopped in the tube. The pressure in the high-pressure tube will be the static pressure in the system plus a pressure dependant on the force required stopping the flow.

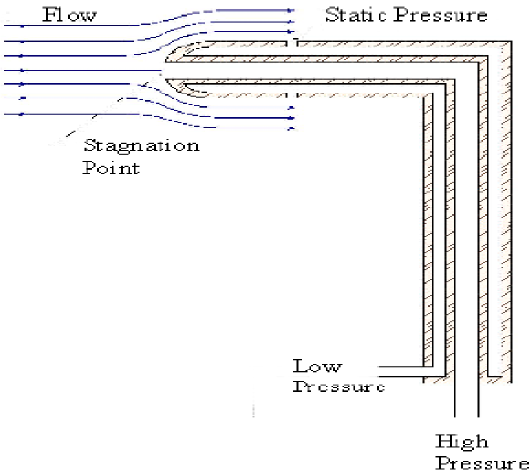

Figure 9
Pitot Tube

Pitot tubes are more common measuring gas flows that liquid flows. They suffer from a couple of problems. The pressure differential is usually small and hard to measure. The differing flow velocities across the pipe make the accuracy dependent on the flow profile of the fluid and the position of the pitot in the pipe.

Annubar

An annubar is very similar to a pitot tube. The difference is that there is more than one hole into the pressure measuring chambers. The pressure in the high-pressure chamber represents an average of the velocity across the pipe. Annubars are more accurate than pitots as they are not as position sensitive or as sensitive to the velocity profile of the fluid.

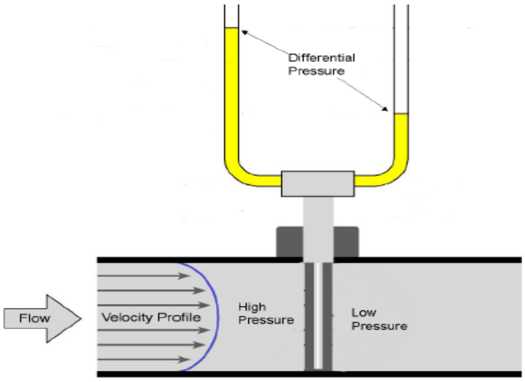

Figure 10
Annubar

2 Square Root Extractor

Up to now, our flow measurement loop can be represented by the installation shown in Figure 9. The high and low-pressure taps of the primary device (orifice type shown) are fed by sensing lines to a differential pressure (D/P) cell. The output of the D/P cell acts on a pressure to milliamp transducer, which transmits a variable 4-20 ma signal. The D/P cell and transmitter are shown together as a flow transmitter (FT).

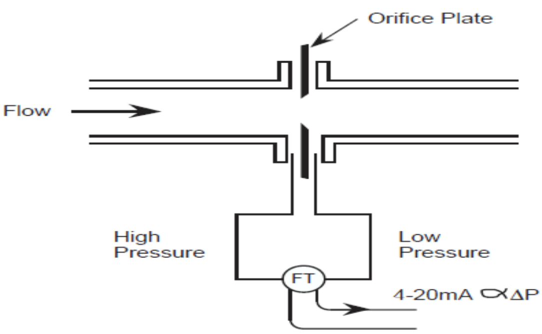

Figure 11
A Flow Loop with Orifice Plate

A Flow Loop with Orifice Plate

This simple system although giving an indication of the flow rate (Q), is actually transmitting a signal proportional to the differential pressure (Δ P). However, the

relationship between the volume of flow Q and ΔP is not linear. Thus such a system would not be appropriate in instrumentation or metering that requires a linear relationship or scale. In actuality the differential pressure increases in proportion to the square of the flow rate.

We can write this as: $\Delta P \propto Q^2$

In other words the flow rate (Q) is proportional; to the square root of the differential pressure.

Volumetric Flow Rate = $Q \propto \Delta P$

To convert the signal from the flow transmitter, (figure 9 above) to one that is directly proportional to the flow-rate, one has to obtain or extract the square root of the signal from the flow transmitter. Figure 10 illustrates the input - output relationship of a square root extractor.

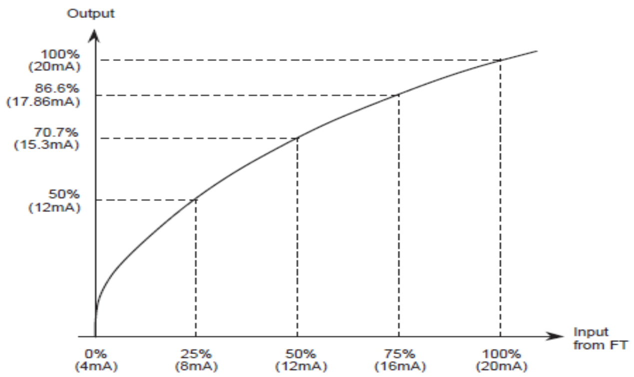

Figure 12
Square Root Extractor Input and Output

The square root extractor is an electronic (or pneumatic) device that takes the square root of the signal from the flow transmitter and outputs a corresponding linear flow signal. Several methods are used in the construction of square root extractors. However, it is beyond the scope of this course to discuss the actual circuitries.

A typical square root extractor installation is shown in Figure 13. This system would produce a 4-20-ma signal that is linear with the flow rate.

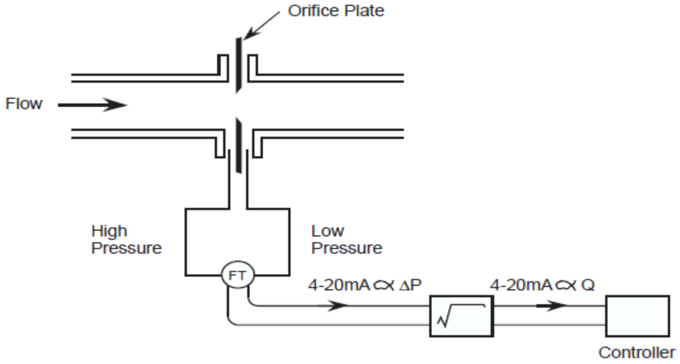

Figure 13

A Typical Square Root Extractor Installation

Square root extractors are usually current operated devices so they can be connected directly in the 4-20 mA current loop of a flow transmitter. The output of the square root extractor is again a 4-20 mA signal. This signal is directly proportional to the flow-rate in the pipe-work. The signal from the square root extractor usually goes to a controller, as shown in Figure 13. The controller (which can be regarded as an analog computer) is used to control the final control element, usually a valve.

Cut-off relay

Square root extractors do have a drawback. At low values of input, very small changes in the input (differential pressure) to the extractor will cause a large change in the square root output (flow indication). This system is described as having high gain at values close to zero input. Observe figure 14 below, which is an expanded version of figure 12 at the lower end. The amount of change from zero pressure to A and from A to B is identical. However, for the same input change (Δ P), the gain at low input is greater.

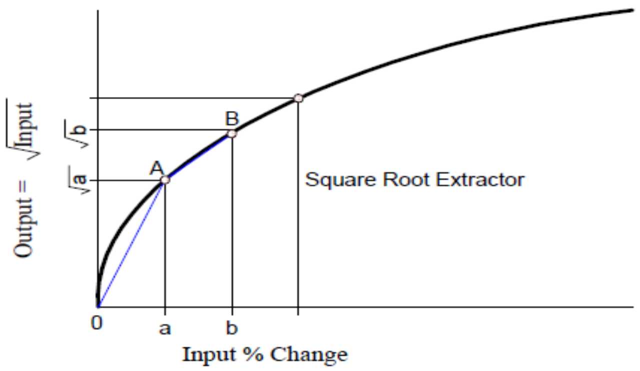

Figure 14
Square Root Extractor Graph Expanded View

To illustrate the effect of the very high gain in the square root extractor at low scale values consider a typical situation. A pipe valve is closed and the zero flow produces a 4 mA output from the flow transmitter. If due to noise, temperature or other disturbances, the input drifted from 0% to 1% (i.e., from 4 mA to 4.16 mA), the output would have changed from 0% to 10% (4 mA to 5.6 mA). It is obvious that this significant error sent to the controller has to be eliminated. For this reason, square root extractors are equipped with cut-off relays. The setting for the relay can be adjusted from 6% to 10% of output. Shown in Figure 15 is a response curve for a cut-off relay set at 7% output. In this case, any input signal below $(0.07)^2$ or 0.49% would be ignored by the extractor. The output of the extractor would remain at 0% as long as input is below 0.49%. When the input exceeded 0.49%, the output would resume its normal curve, starting at 7%.

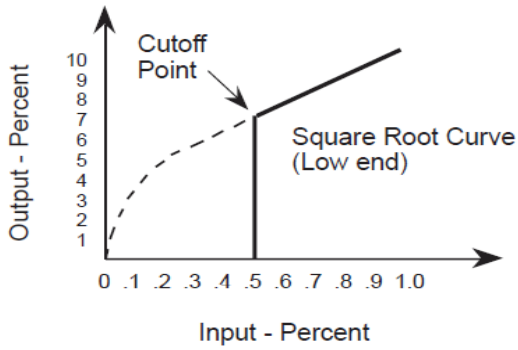

Figure 15
Response Curve for Extractor with 7% Cut-Off Setting

2.2.3 Density Compensating Flow Detectors

It must be remembered that a DP transmitter used for flow measurement, measures differential pressure, not the volume or mass of flow. We have shown that differential pressure instruments require that the square root differential pressure be taken to obtain volumetric flow Q:

Volume of Flow $= Q \propto \Delta P / \rho$

For compressible vapour such as steam, it is more important to know the mass of the flow *W* rather than the volume. To determine the mass of a liquid/gas the density (ρ = mass per unit volume) must also be obtained.

Mass of Flow $= W = \rho Q \propto \rho \Delta P$

We also know that density varies directly with pressure and inversely with temperature:

Temperature $= \rho \;\; \alpha \;\; K$ *pressure*

The coefficient *K* (which can be obtained from tables) depends on a number of variables including the pipe size and the characteristics of the fluid/gas. It is sufficient to say that if the process temperature and static pressure is known, then the density can be obtained.

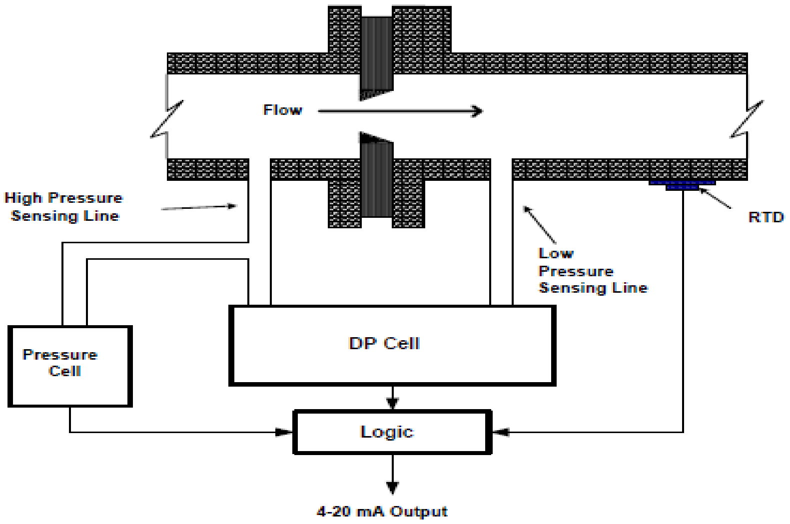

Figure 16
Density Compensating Flow Detector

The density compensating flow detector (shown schematically in figure 16) is a necessity for steam flow between the boilers, re-heaters and the turbines, where the mass (weight) of the steam is more important than the volume.

Process Conditions

As previously stated, the measurement of flow using any of the devices described above is purely inferential. It relies on the signal from a differential pressure (D/P) cell to obtain an inferred flow measurement. This flow measurement could be either the volume or mass of the liquid/gas. In either case the instrumentation can be affected by the process conditions. The three main parameters are:

Fluid Temperature

The temperature of the flow quantity has a dramatic effect on the flow measurement. Under the right conditions the liquid can either boil (producing gas pockets and turbulence) or freeze (producing blockages and distorted flow patterns) at the sensors. At the onset of temperature related flow instrumentation problems the meter readings will become unstable. Gas pockets (causing intermittent low pressure) at the high pressure sensing lines will cause apparent low flow fluctuations. This is more predominant in orifice and flow-nozzle installations. Turbulence at the low-pressure sensor will usually increase as the temperature increases to cause a more stable but incorrect high flow reading. Temperature also affects the density of the liquid/gas, as per the following relationship (where K is a constant for the liquid/gas).

$\rho \quad \alpha \quad K(\text{ pressure/ Temperature})$

The mass flow (i.e., pounds of steam per minute) varies inversely with temperature and must be compensated for using a density compensating flow detector. The elbow tap sensor uses centrifugal force to detect flow and is most sensitive to density changes. The flow readings will increase as the temperature decreases.

Fluid Pressure

As we have just seen, pressure also affects the density of the fluid/gas. For the elbow tap previously mentioned, the flow readings will increase as the process pressure increases.

$\rho \quad \alpha \quad K(\text{pressure/ Temperature})$

For all types of D/P flow sensors, mass flow will of course increase as the pressure increases. To obtain the correct measurement of mass flow, a density compensating flow detector must be used as described previously.

2.2.4 Flow Measurement Errors

We have already discussed the pros and cons of each type of flow detector commonly found in a generating station. Some, such as the orifice, are more prone to damage by particulate or saturated steam then others. However, there are common areas where the flow readings can be inaccurate or invalid.

Erosion

Particulate, suspended solids or debris in the piping will not only plug up the sensing lines, it will erode the sensing device. The orifice, by its design with a thin, sharp edge is most affected, but the flow nozzle and even venturi can also be damaged. As the material wears away, the differential pressure between the high and low sides of the sensor will drop and the flow reading will decrease.

Over ranging Damage to the D/P Cell

Again, as previously described, the system pressures are usually much greater than the differential pressure and three valve manifolds must be correctly used.

Vapour Formation in the Throat

D/P flow sensors operate on the relation between velocity and pressure. As gas requires less pressure to compress, there is a greater pressure differential across the D/P cell when the gas expands on the LP side of the sensor. The flow sensor will indicate a higher flow rate than there actually is. The turbulence created at the LP side of the sensor will also make the reading somewhat unstable. A small amount of gas or vapour will make a large difference in the indicated flow rate. The opposite can occur if the vapour forms in the HP side of the sensor due to cavitation or gas pockets when the fluid approaches the boiling point. In such an instance there will be a fluctuating pressure drop across the D/P cell that will give an erroneously low (or even negative) D/P reading.

Clogging of Throat

Particulate or suspended solids can damage the flow sensor by the high velocities wearing at the flow sensor surfaces. Also, the build-up of material in the throat of the sensor increases the differential pressure across the cell. The error in flow measurement will increase as the flow increases.

LEVEL MEASUREMENT

Accurate continuous measurement of volume of fluid in containers has always been a challenge to industry. This is even more so in the nuclear station environment where the fluid could be acidic/caustic or under very high pressure/temperature. We will now examine the measurement of fluid level in vessels and the effect of temperature and pressure on this measurement. We will also consider the operating environment on the measurement and the possible modes of device failure.

1 Level Measurement Basics

Very simple systems employ external sight glasses or tubes to view the height and hence the volume of the fluid. Others utilize floats connected to variable potentiometers or rheostats that will change the resistance according to the amount of motion of the float. This signal is then inputted to transmitters that send a signal to an instrument calibrated to read out the height or volume.

In this module, we will examine the more challenging situations that require inferential level measurement. This technique obtains a level indication indirectly by monitoring the pressure exerted by the height of the liquid in the vessel.

The pressure at the base of a vessel containing liquid is directly proportional to the height of the liquid in the vessel. This is termed hydrostatic pressure. As the level in the vessel rises, the pressure exerted by the liquid at the base of the vessel will increase linearly. Mathematically, we have:

$P = S \cdot H$

where

P = Pressure (Pa)

S = Weight density of the liquid (N/m^3) = ρg

H = Height of liquid column (m)

ρ = Density (kg/m^3)

g = acceleration due to gravity (9.81 m/s^2)

The level of liquid inside a tank can be determined from the pressure reading if the weight density of the liquid is constant. Differential Pressure (DP) capsules are the most commonly used devices to measure the pressure at the base of a tank.

When a DP transmitter is used for the purpose of measuring a level, it will be called a level transmitter. To obtain maximum sensitivity, a pressure capsule has to be used, that has a sensitivity range that closely matches the anticipated pressure of the measured liquid. However, system pressures are often much higher than the actual hydrostatic pressure that is to be measured. If the process pressure is accidentally applied to only one side of the DP capsule during installation or removal of the DP cell from service, over ranging of the capsule would occur and the capsule could be damaged causing erroneous indications.

2 Three Valve Manifold

A three-valve manifold is a device that is used to ensure that the capsule will not be over-ranged. It also allows isolation of the transmitter from the process loop. It consists of two block valves - high pressure and low pressure block valve - and an equalizing valve. Figure 1 shows a three valve manifold arrangement.

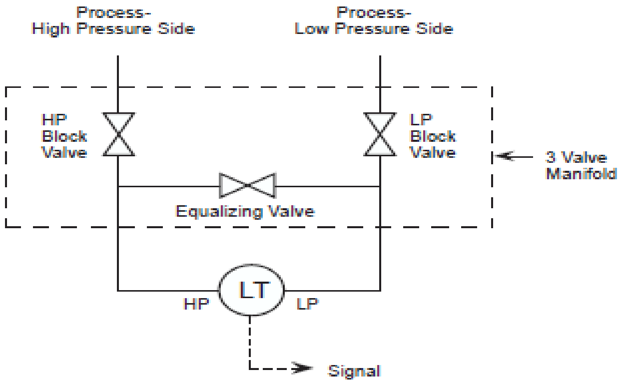

Figure 1
A Three Valve Manifold

During normal operation, the equalizing valve is closed and the two block valves are open. When the transmitter is put into or removed from service, the valves must be operated in such a manner that very high pressure is never applied to only one side of the DP capsule.

Operational Sequences of Three-Valve Manifold Valving Transmitter into Service

To valve a DP transmitter into service an operator would perform the following steps:

1. Check all valves closed.
2. Open the equalizing valve . this ensures that the same pressure will be applied to both sides of the transmitter, i.e., zero differential pressure.
3. Open the High Pressure block valve slowly, check for leakage from both the high pressure and low-pressure side of the transmitter.
4. Close the equalizing valve . this locks the pressure on both sides of the transmitter.
5. Open the low-pressure block valve to apply process pressure to the low-pressure side of the transmitter and establish the working differential pressure.
6. The transmitter is now in service. Note it may be necessary to bleed any trapped air from the capsule housing.

Removing Transmitter from Service

Reversal of the above steps allows the DP transmitter to be removed from service.

1. Close the low-pressure block valve.
2. Open the equalizing valve.
3. Close the high-pressure block valve.

The transmitter is now out of service. Note the transmitter capsule housing still contains process pressure; this will require bleeding.

3 Open Tank Measurement

The simplest application is the fluid level in an open tank. Figure 2 shows a typical open tank level measurement installation using a pressure capsule level transmitter. If the tank is open to atmosphere, the high-pressure side of the level transmitter will be connected to the base of the tank while

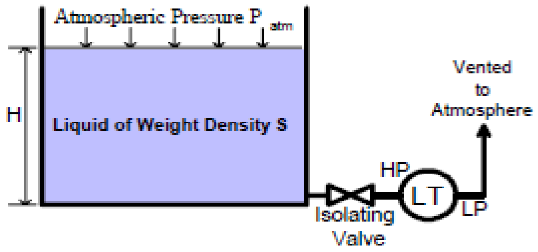

Figure 2
Open Tank Level Measurement Installation

the low-pressure side will be vented to atmosphere. In this manner, the level transmitter acts as a simple pressure transmitter. We have:

$P_{high} = P_{atm} + S \cdot H$

$P_{low} = P_{atm}$

Differential pressure $\Delta P = P_{high} - P_{low} = S \cdot H$

The level transmitter can be calibrated to output 4 mA when the tank is at 0% level and 20 mA when the tank is at 100% level.

4 Closed Tank Measurement

Should the tank be closed and a gas or vapour exists on top of the liquid, the gas pressure must be compensated for. A change in the gas pressure will cause a change in transmitter output. Moreover, the pressure exerted by the gas phase may be so high that the hydrostatic pressure of the liquid column becomes insignificant. For example, the measured hydrostatic head in a CANDU boiler may be only three meters (30 kPa) or so, whereas the steam pressure is typically 5 MPa. Compensation can be achieved by applying the gas pressure to both the high and low-pressure sides of the level transmitter. This cover gas pressure is thus used as a back pressure or reference pressure on the LP side of the DP cell. One can also immediately see the need for the three-valve manifold to protect the DP cell against these pressures. The different arrangement of the sensing lines to the DP cell is indicated a typical closed tank application (figure 3). Figure 3 shows a typical closed tank installation.

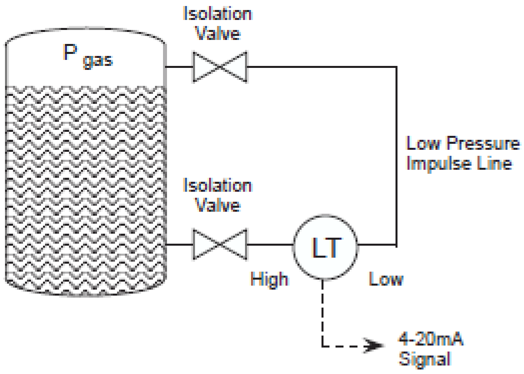

Figure 3
Typical Closed Tank Level Measurement System

We have:

$P_{high} = P_{gas} + S \cdot H$

$P_{low} = P_{gas}$

$\Delta P = P_{high} - P_{low} = S \cdot H$

The effect of the gas pressure is cancelled and only the pressure due to the hydrostatic head of the liquid is sensed. When the low-pressure impulse line is connected directly to the gas phase above the liquid level, it is called a dry leg.

Dry Leg System

A full dry leg installation with three-valve manifold is shown in Figure 4 below.

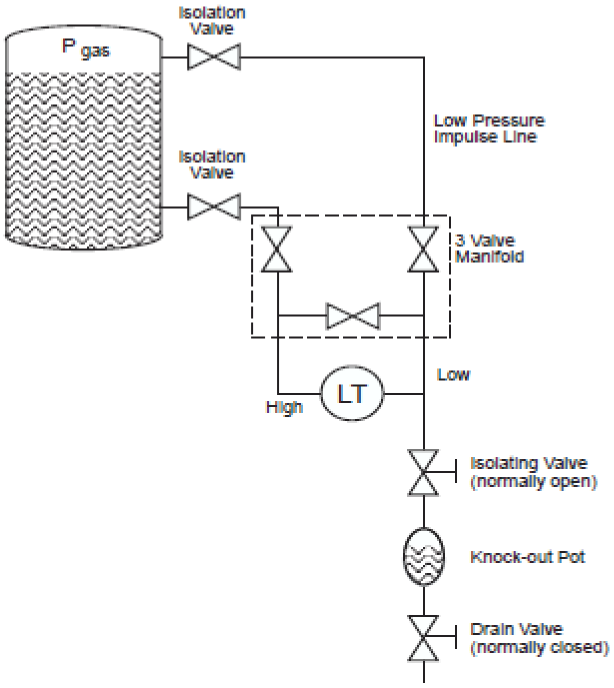

Figure 4
Dry Leg Installation with Three-Valve Manifold

If the gas phase is condensable, say steam, condensate will form in the low pressure impulse line resulting in a column of liquid, which exerts extra pressure on the low-pressure side of the transmitter. A technique to solve this problem is to add a knockout pot below the transmitter in the low pressure side as shown in Figure 4. Periodic draining of the condensate in the knockout pot will ensure that the impulse line is free of liquid. In practice, a dry leg is seldom used because frequent maintenance is required. One example of a dry leg application is the measurement of liquid poison level in the poison injection tank, where the gas phase is noncondensable helium. In most closed tank applications, a wet leg level measurement system is used.

Wet Leg System

In a wet leg system, the low-pressure impulse line is completely filled with liquid (usually the same liquid as the process) and hence the name wet leg. A level transmitter, with the associated three-valve manifold, is used in an identical manner to the dry leg system. Figure 5 shows a typical wet leg installation.

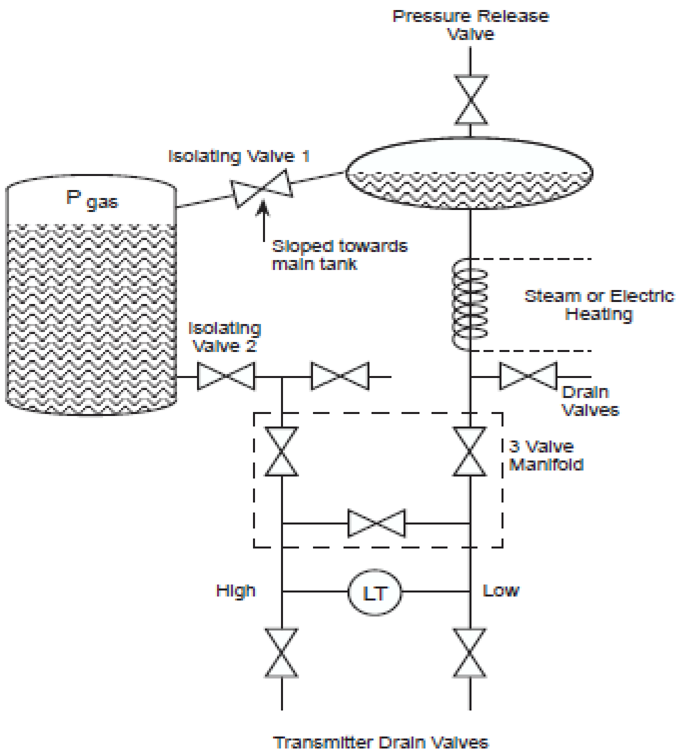

Figure 5
A Wet Leg Installation

At the top of the low pressure impulse line is a small catch tank. The gas phase or vapour will condense in the wet leg and the catch tank. The catch tank, with the inclined interconnecting line, maintains a constant hydrostatic pressure on the low-pressure side of the level transmitter. This pressure, being a constant, can easily be compensated for by calibration. (Note that operating the three-valve manifold in the prescribed manner helps to preserve the wet leg.) If the tank is located outdoors, trace heating of the wet leg might be necessary to prevent it from freezing. Steam lines or an electric heating element can be wound around the wet leg to keep the temperature of the condensate above its freezing point. Note the two sets of drain valves. The transmitter drain valves would be used to drain (bleed) the transmitter only. The two drain valves located immediately above the three-valve manifold are used for impulse and wet leg draining and filling. In addition to the three-valve manifold most transmitter installations have valves where the impulse lines connect to the process. These isolating valves, sometimes referred to as the root valves, are used to isolate the transmitter for maintenance.

Level Compensation

It would be idealistic to say that the DP cell can always be located at the exact the bottom of the vessel we are measuring fluid level in. Hence, the measuring system has to consider the hydrostatic pressure of the fluid in the sensing lines themselves. This leads to two compensations required.

Zero Suppression

In some cases, it is not possible to mount the level transmitter right at the base level of the tank. Say for maintenance purposes, the level transmitter has to be mounted X meters below the base of an open tank as shown in Figure 6.

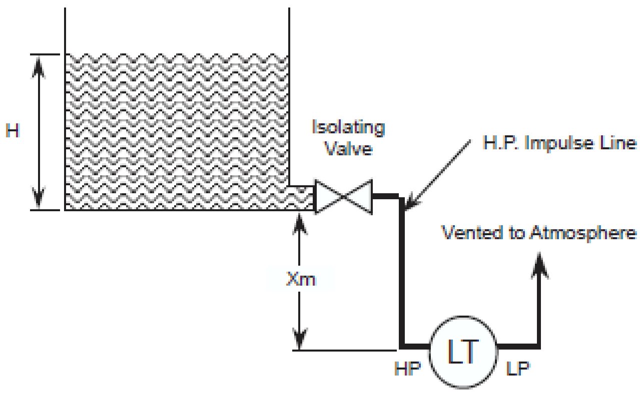

Figure 6
Level Transmitter with Zero Suppression

The liquid in the tank exerts a varying pressure that is proportional to its level H on the high-pressure side of the transmitter. The liquid in the highpressure impulse line also exerts a pressure on the high-pressure side. However, this pressure is a constant ($P = S \cdot X$) and is present at all times. When the liquid level is at H meters, pressure on the high-pressure side of the transmitter will be:

$P_{high} = S \cdot H + S \cdot X + P_{atm}$

$P_{low} = P_{atm}$

$\Delta P = P_{high} - P_{low} = S \cdot H + S \cdot X$

That is, the pressure on the high-pressure side is always higher than the actual pressure exerted by the liquid column in the tank (by a value of $S \cdot X$). This constant pressure would cause an output signal that is higher than 4 mA when the tank is empty and above 20 mA when it is full. The transmitter has to be negatively biased by a value of $-S \cdot X$ so that the output of the transmitter is proportional to the tank level ($S \cdot H$) only. This procedure is called Zero Suppression and it can be done during calibration of the transmitter. A zero suppression kit can be installed in the transmitter for this purpose.

Zero Elevation

When a wet leg installation is used (see Figure 7 below), the low-pressure side of the level transmitter will always experience a higher pressure than the high-pressure side. This is due to the fact that the height of the wet leg (X) is always equal to or greater than the maximum height of the liquid column (H) inside the tank.

When the liquid level is at H meters, we have:

$P_{high} = P_{gas} + S \cdot H$

$P_{low} = P_{gas} + S \cdot X$

$\Delta P = P_{high} - P_{low} = S \cdot H - S \cdot X$

$= - S (X - H)$

The differential pressure ΔP sensed by the transmitter is always a negative number (i.e., low pressure side is at a higher pressure than high pressure side). ΔP increases from $P = -S \cdot X$ to $P = -S (X-H)$ as the tank level rises from 0% to 100%.

If the transmitter were not calibrated for this constant negative error ($-S \cdot X$), the transmitter output would read low at all times. To properly calibrate the transmitter, a positive bias ($+S \cdot X$) is needed to elevate the transmitter output.

This positive biasing technique is called zero elevation.

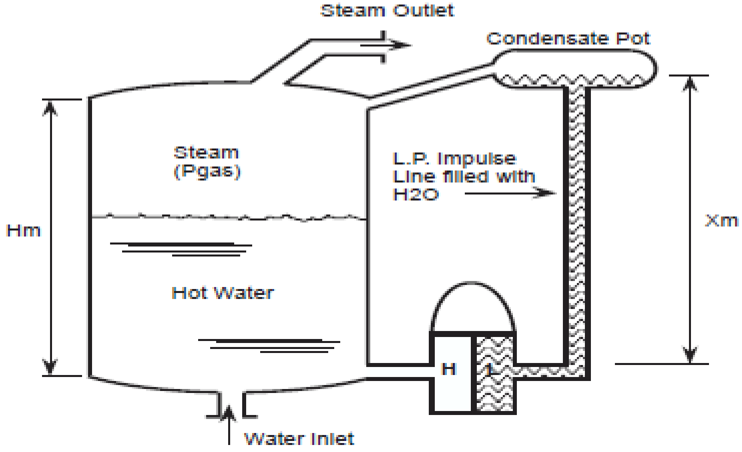

Figure 7
Requirement for Zero Elevation

5 Bubbler Level Measurement System

If the process liquid contains suspended solids or is chemically corrosive or radioactive, it is desirable to prevent it from coming into direct contact with the level transmitter. In these cases, a bubbler level measurement system, which utilizes a purge gas, can be used.

Open Tank Application for Bubbler System

Figure 8 illustrates a typical bubbler system installation.

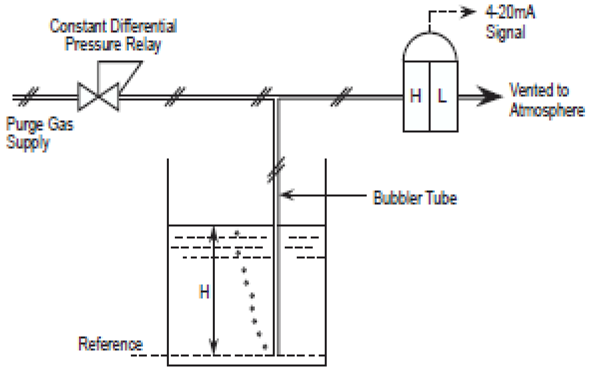

Figure 8
Bubbler Level Measurement System in Open Tank Application

As shown in Figure 8, a bubbler tube is immersed to the bottom of the vessel in which the liquid level is to be measured. A gas (called purge gas) is allowed to pass through the bubbler tube. Consider that the tank is empty. In this case, the gas will escape freely at the end of the tube and therefore the gas pressure inside the bubbler tube (called back pressure) will be at atmospheric pressure. However, as the liquid level inside the tank increases, pressure exerted by the liquid at the base of the tank (and at the opening of the bubbler tube) increases. The hydrostatic pressure of the liquid in effect acts as a seal, which restricts the escape of, purge gas from the bubbler tube. As a result, the gas pressure in the bubbler tube will continue to increase until it just balances the hydrostatic pressure ($P = S \cdot H$) of the liquid. At this point the backpressure in the bubbler tube is exactly the same as the hydrostatic pressure of the

liquid and it will remain constant until any change in the liquid level occurs. Any excess supply pressure will escape as bubbles through the liquid.
As the liquid level rises, the backpressure in the bubbler tube increases proportionally, since the density of the liquid is constant. A level transmitter (DP cell) can be used to monitor this backpressure. In an open tank installation, the bubbler tube is connected to the high-pressure side of the transmitter, while the low pressure side is vented to atmosphere. The output of the transmitter will be proportional to the tank level.
A constant differential pressure relay is often used in the purge gas line to ensure that constant bubbling action occurs at all tank levels. The constant differential pressure relay maintains a constant flow rate of purge gas in the bubbler tube regardless of tank level variations or supply fluctuation. This ensures that bubbling will occur to maximum tank level and the flow rate does not increase at low tank level in such a way as to cause excessive disturbances at the surface of the liquid. Note that bubbling action has to be continuous or the measurement signal will not be accurate.
An additional advantage of the bubbler system is that, since it measures only the backpressure of the purge gas, the exact location of the level transmitter is not important. The transmitter can be mounted some distance from the process. Open loop bubblers are used to measure levels in spent fuel bays.

Closed Tank Application for Bubbler System

If the bubbler system is to be applied to measure level in a closed tank, some pressure-regulating scheme must be provided for the gas space in the tank. Otherwise, the gas bubbling through the liquid will pressurize the gas space to a point where bubbler supply pressure cannot overcome the static pressure it acts against. The result would be no bubble flow and, therefore, inaccurate measurement signal. Also, as in the case of a closed tank inferential level measurement system, the low-pressure side of the level transmitter has to be connected to the gas space in order to compensate for the effect of gas pressure. Some typical examples of closed tank application of bubbler systems are the measurement of water level in the irradiated fuel bays and the light water level in the liquid zone control tanks.

6 Effect of Temperature on Level Measurement

Level measurement systems that use differential pressure ΔP as the sensing method, are by their very nature affected by temperature and pressure. Recall that the measured height H of a column of liquid is directly proportional to the pressure P exerted at the base of the column and inversely proportional to the density ρ of the liquid.

H α P/ρ

Density (mass per unit volume) of a liquid or gas is inversely proportional to its temperature.

ρ☐ α 1/☐T

Thus, for any given amount of liquid in a container, the pressure P exerted at the base will remain constant, but the height will vary directly with the temperature.

H α T

Consider the following scenario. A given amount of liquid in a container [figure 9(a)] is exposed to higher process temperatures [figure 9(b)].

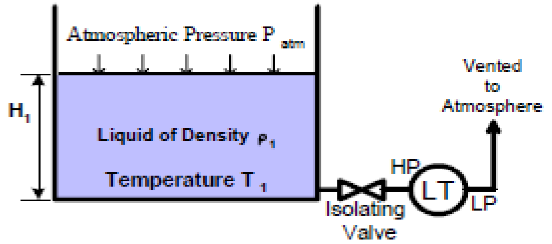

Figure 9(a)
Low Process Temperature

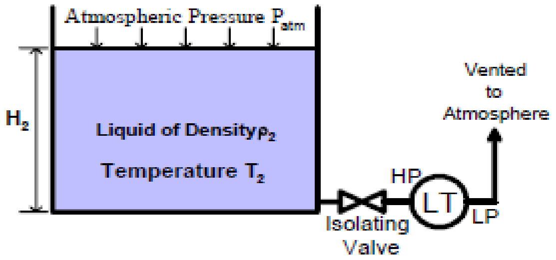

Figure 9(b)
High Process Temperature

As the amount (mass) of liquid does not change from figure 9(a) to 9(b), the pressure exerted on the base of the container has not changed and the indicated height of the liquid does not change. However, the volume occupied by the liquid has increased and thus the actual height has increased.
The above scenario of figure (9) is a common occurrence in plant operations. Consider a level transmitter calibrated to read correctly at 75_0C. If the process temperature is increased to 90_0C as in figure 9 (c), the actual level will be higher than indicated. The temperature error can also occur in wet-leg systems (figure 10).

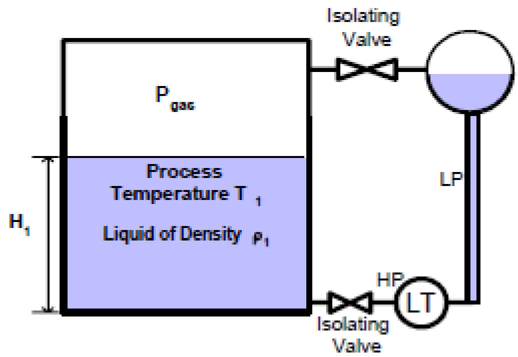

Figure 10
Temperature Effect on Wet-Leg System

If the reference leg and variable leg are at the same temperature that the level transmitter (LT) is calibrated for, the system will accurately measure liquid level. However, as the process temperature increases, the actual process fluid level increases (as previously discussed), while the indicated measurement remains unchanged. Further errors can occur if the reference leg and the variable (sensing) leg are at different temperatures. The level indication will have increasing positive (high) error as the temperature of the wet reference leg increases above the variable (process) leg.

As an example, consider temperature changes around a liquid storage tank with a wet leg. As temperature falls and the wet leg cools off, the density of the liquid inside it increases, while the temperature in the tank remains practically unchanged (because of a much bigger volume and connection to the process). As a result the pressure of the reference leg rises and the indicated level decreases. If it happens to the boiler level measurement for a shutdown system it can even lead to an unnecessary reactor trip on boiler low level. However, high-level trips may be prevented under these circumstances. In an extreme case the wet leg may freeze invalidating the measurement scheme completely, but it could be easily prevented with trace heating as indicated earlier (Figure 5). False high level indication can be caused by an increased wet leg temperature, gas or vapour bubbles or a drained wet leg.
A high measured tank level, with the real level being dangerously low, may prevent the actuation of a safety system on a low value of the trip parameter. The real level may even get sufficiently low to cause either the cavitation of the pumps that take suction from the tank or gas ingress into the pumps and result in gas locking and a reduced or no flow condition. If the pumps are associated with a safety system like ECI or a safety related system like PHT shutdown cooling, it can lead to possible safety system impairments and increased probability of resultant fuel damage.

7 Effect of Pressure on Level Measurement

Level measurement systems that use differential pressure ΔP as the sensing method, are also affected by pressure, although not to the same degree as temperature mentioned in the previous section. Again the measured height H of a column of liquid is directly proportional to the pressure P_L exerted at the base of the column by the liquid and inversely proportional to the density ρ of the liquid:

$H \propto P_L/\rho$

Density (mass per unit volume) of a liquid or gas is directly proportional to the process or system pressure Ps.

$\rho \propto P_s$

Thus, for any given amount of liquid in a container, the pressure P_L (liquid pressure) exerted at the base of the container by the liquid will remain constant, but the height will vary inversely with the process or system pressure.

$H \propto 1/P_s$

Most liquids are fairly incompressible and the process pressure will not affect the level unless there is significant vapour content.

8 Level Measurement System Errors

The level measurement techniques described in this module use inferred processes and not direct measurements. Namely, the indication of fluid level is based on the pressure exerted on a differential pressure (DP) cell by the height of the liquid in the vessel. This places great importance on the physical and environmental problems that can affect the accuracy of this indirect measurement.

Connections

As amusing as it may sound, many avoidable errors occur because the DP cell had the sensing line connections reversed. In systems that have high operating pressure but low hydrostatic pressure due to weight of the fluid, this is easy to occur. This is particularly important for closed tank systems. With an incorrectly connected DP cell the indicated level would go down while the true tank level increases.

Over-Pressuring

Three valve manifolds are provided on DP cells to prevent over-pressuring and aid in the removal of cells for maintenance. Incorrect procedures can inadvertently over-pressure the differential pressure cell. If the cell does not fail immediately the internal diaphragm may become distorted. The measurements could read either high or low depending on the mode of failure.

Note that if the equalizing valve on the three-valve manifold is inadvertently opened, the level indication will of course drop to a very low level as the pressure across the DP cell equalizes.

Sensing lines

The sensing lines are the umbilical cord to the DP cell and must be functioning correctly. Some of the errors that can occur are:

Obstructed sensing lines

The small diameter lines can become clogged with particulate, with resulting inaccurate readings. Sometimes the problem is first noted as an unusually sluggish response to a predicted change in level. Periodic draining and flushing of sensing lines is a must.

Draining sensing lines

As mentioned previously, the lines must be drained to remove any debris or particulate that may settle to the bottom of the tank and in the line. Also, in closed tank dry leg systems, condensate must be removed regularly to prevent fluid pressure building up on the low-pressure impulse line. Failure to do so will of course give a low tank level reading. Procedural care must be exercised to ensure the DP cell is not over-ranged inadvertently during draining. Such could happen if the block valves are not closed and equalizing valve opened beforehand. False high level indication can be caused by a leaking or drained wet leg. A leaking variable (process) leg can cause false low-level indication.

TEMPERATURE MEASUREMENT

Every aspect of our lives, both at home and at work, is influenced by temperature. Temperature measuring devices have been in existence for centuries. The age-old mercury in glass thermometer is still used today and why not? The principle of operation is ageless as the device itself. Its operation was based on the temperature expansion of fluids (mercury or alcohol). As the temperature increased the fluid in a small reservoir or bulb expanded and a small column of the fluid was forced up a tube. You will find the same theory is used in many modern thermostats today. In this module we will look at the theory and operation of some temperature measuring devices commonly found in a generating station. These include thermocouples, thermostats and resistive temperature devices. Thermocouples (T/C) and resistive temperature devices (RTD) are generally connected to control logic or instrumentation for continuous monitoring of temperature. Thermostats are used for direct positive control of the temperature of a system within preset limits.

1 Resistance Temperature Detector (RTD)

Every type of metal has a unique composition and has a different resistance to the flow of electrical current. This is termed the resistively constant for that metal. For most metals the change in electrical resistance is directly proportional to its change in temperature and is linear over a range of temperatures. This constant factor called the temperature coefficient of electrical resistance (short formed TCR) is the basis of resistance temperature detectors. The RTD can actually be regarded as a high precision wire wound resistor whose resistance varies with temperature. By measuring the resistance of the metal, its temperature can be determined. Several different pure metals (such as platinum, nickel and copper) can be used in the manufacture of an RTD. A typical RTD probe contains a coil of very fine metal wire, allowing for a large resistance change without a great space requirement. Usually, platinum RTDs are used as process temperature monitors because of their accuracy and linearity. To detect the small variations of resistance of the RTD, a temperature transmitter in the form of a Wheatstone bridge is generally used. The circuit compares the RTD value with three known and highly accurate resistors.

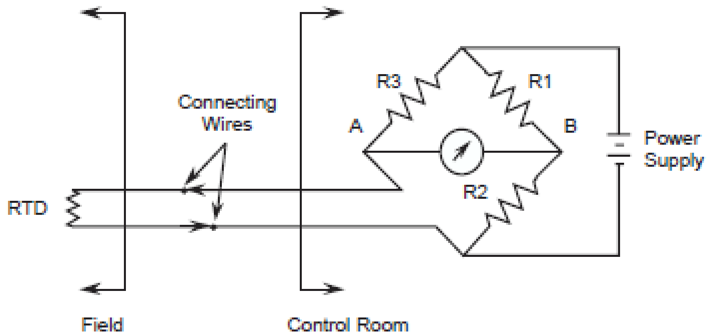

Figure 1
RTD using a Wheatstone Bridge

A Wheatstone bridge consisting of an RTD, three resistors, a voltmeter and a voltage source is illustrated in Figure 1. In this circuit, when the current flow in the meter is zero (the voltage at point A equals the voltage at point B) the bridge is said to be in null balance. This would be the zero or set point on the RTD temperature output. As the RTD temperature increases, the voltage read by the voltmeter increases. If a voltage transducer replaces the voltmeter, a 4-20 mA signal, which is proportional to the temperature range being monitored, can be generated.

As in the case of a thermocouple, a problem arises when the RTD is installed some distance away from the transmitter. Since the connecting wires are long, resistance of the wires changes as ambient temperature fluctuates. The variations in wire resistance would introduce an error in the transmitter. To eliminate this problem, a three-wire RTD is used.

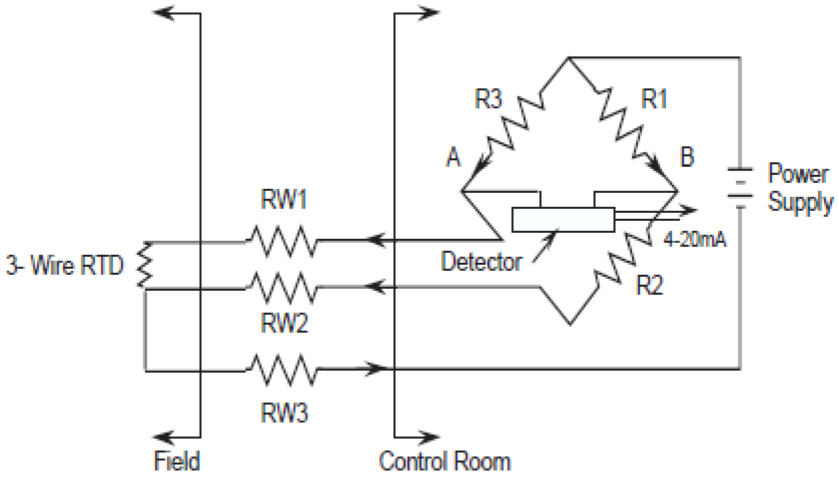

Figure 2
Three-Wired RTD

Figure 2 illustrates a three-wire RTD installation.

Figure 2 illustrates a three-wire RTD installation. The connecting wires (w1, w2, w3) are made the same length and therefore the same resistance. The power supply is connected to one end of the RTD and the top of the Wheatstone bridge. It can be seen that the resistance of the right leg of the Wheatstone bridge is $R_1 + R_2 + R_{W2}$. The resistance of the left leg of the bridge is $R_3 + R_{W3}$ + RTD. Since $R_{W1} = R_{W2}$, the result is that the resistances of the wires cancel and therefore the effect of the connecting wires is eliminated.

RTD Advantages and Disadvantages Advantages:

- The response time compared to thermocouples is very fast . in the order of fractions of a second.
- An RTD will not experience drift problems because it is not self powered.
- Within its range it is more accurate and has higher sensitivity than a thermocouple.
- In an installation where long leads are required, the RTD does not require special extension cable.
- Unlike thermocouples, radioactive radiation (beta, gamma and neutrons) has minimal effect on RTDs since the parameter measured is resistance, not voltage.

Disadvantages:

- Because the metal used for a RTD must be in its purest form, they are much more expensive than thermocouples.
- In general, an RTD is not capable of measuring as wide a temperature range as a thermocouple.
- A power supply failure can cause erroneous readings
- Small changes in resistance are being measured, thus all connections must be tight and free of corrosion, which will create errors.
- Among the many uses in a nuclear station, RTDs can be found in the reactor area temperature measurement and fuel channel coolant temperature.

Failure Modes:

- An open circuit in the RTD or in the wiring between the RTD and the bridge will cause a high temperature reading.
- Loss of power or a short within the RTD will cause a low temperature reading.

2 Thermocouple (T/C)

A thermocouple consists of two pieces of dissimilar metals with their ends joined together (by twisting, soldering or welding). When heat is applied to the junction, a voltage, in the range of milli-volts (mV), is generated. A thermocouple is therefore said to be self-powered. Shown in Figure 3 is a completed thermocouple circuit.

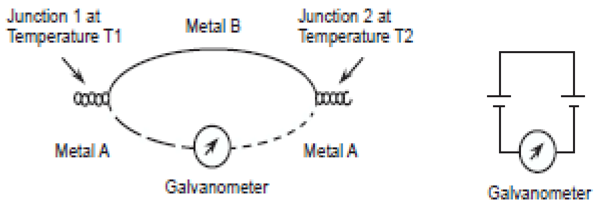

Figure 3
A Thermocouple Circuit

The voltage generated at each junction depends on junction temperature. If temperature T1 is higher than T2, then the voltage generated at Junction 1 will be higher than that at Junction 2. In the above circuit, the loop current shown on the galvanometer depends on the relative magnitude of the voltages at the two junctions. In order to use a thermocouple to measure process temperature, one end of the thermocouple has to be kept in contact with the process while the other end has to be kept at a constant temperature. The end that is in contact with the process is called the hot or measurement junction. The one that is kept at constant temperature is called cold or reference junction. The relationship between total circuit voltage (emf) and the emf at the junctions is:

Circuit emf = Measurement emf - Reference emf

If circuit emf and reference emf are known, measurement emf can be calculated and the relative temperature determined. To convert the emf generated by a thermocouple to the standard 4-20 mA signal, a transmitter is needed. This kind of transmitter is called a temperature transmitter. Figure 4 shows a simplified temperature transmitter connection.

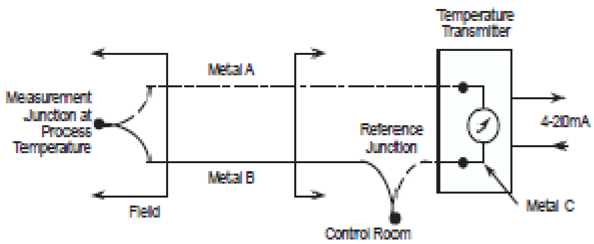

Figure 4
A Simplified Thermocouple Temperature Transmitter

In Figure 4 above, the temperature measurement circuit consists of a thermocouple connected directly to the temperature transmitter. The hot and cold junctions can be located wherever required to measure the temperature difference between the two junctions. In most situations, we need monitor the temperature rise of equipment to

ensure the safe operation. Temperature rise of a device is the operating temperature using ambient or room temperature as a reference. To accomplish this the hot junction is located in or on the device and the cold junction at the meter or transmitter as illustrated in figure 5.

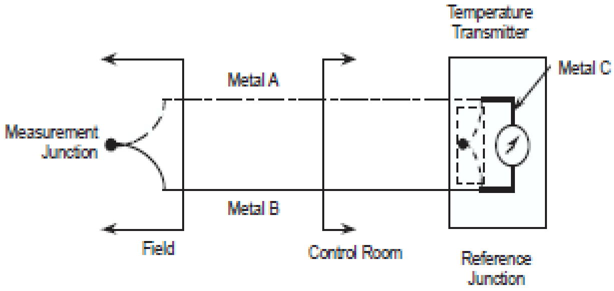

Figure 5
Typical Thermocouple Circuit

Thermocouple Advantages and Disadvantages

Advantages:

- Thermocouples are used on most transformers. The hot junction is inside the transformer oil and the cold junction at the meter mounted on the outside. With this simple and rugged installation, the meter directly reads the temperature rise of oil above the ambient temperature of the location.
- In general, thermocouples are used exclusively around the turbine hall because of their rugged construction and low cost.
- A thermocouple is capable of measuring a wider temperature range than an RTD.

Disadvantages:

- If the thermocouple is located some distance away from the measuring device, expensive extension grade thermocouple wires or compensating cables have to be used.
- Thermocouples are not used in areas where high radiation fields are present (for example, in the reactor vault). Radioactive radiation (e.g., Beta radiation from neutron activation), will induce a voltage in the thermocouple wires. Since the signal from thermocouple is also a voltage, the induced voltage will cause an error in the temperature transmitter output.
- Thermocouples are slower in response than RTDs
- If the control logic is remotely located and temperature transmitters (milli-volt to milli- amp transducers) are used, a power supply failure will of course cause faulty readings.

Failure Modes:

An open circuit in the thermocouple detector means that there is no path for current flow, thus it will cause a low (off-scale) temperature reading. A short circuit in the thermocouple detector will also cause a low temperature reading because it creates a leakage current path to the ground and a smaller measured voltage.

3 Thermal Wells

The process environment where temperature monitoring is required, is often not only hot, but also pressurized and possibly chemically corrosive or radioactive. To facilitate removal of the temperature sensors (RTD and TC), for examination or replacement and to provide mechanical protection, the sensors are usually mounted inside thermal wells (Figure 6).

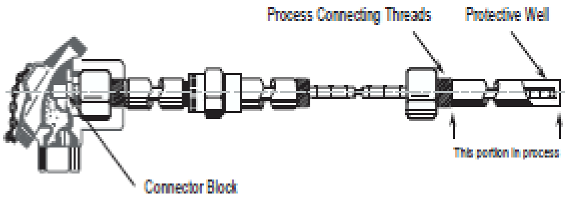

Figure 6
Typical Thermal Well Installation

A thermal well is basically a hollow metal tube with one end sealed. It is usually mounted permanently in the pipe work. The sensor is inserted into it and makes contact with the sealed end.
A drawback to thermal wells is their long response time because heat must be transferred through the well to the sensor. An example of the temperature response for bare and thermal well installed sensors is shown in Figure 7. Minimizing the air space between the sensor and the well, however, can decrease this thermal lag.

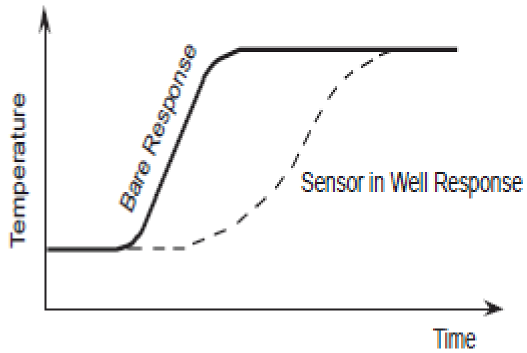

Figure 7
Response Curves of Bare and Thermal Well Installation

4 Thermostats
Thermostats have a different function than the resistive temperature detectors and thermocouples that we have just discussed. The thermostats directly regulate the temperature of a system by maintaining it constant or varying it over a specific range. The T/C or RTD could be used as the temperature-sensing element of a thermostat, but generally thermostats are direct acting devices. The two common types of thermostats are:
Pressure cylinder
Bimetallic strip
Pressure Cylinders
The most common thermostat depends on the expansion of a fluid such as mercury or a solid with an increase in temperature as in figure 8.

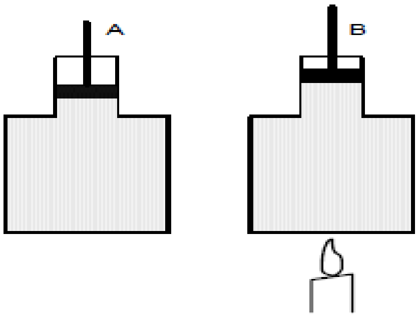

Figure 8
Thermostat Pressure Cylinder

The plunger connected to the piston is used to force contacts open and closed to control valve positions or pump control. Often the plunger is directly connected to the valve as in figure 9 below. This is the same principle as used in automobile water thermostats where the substance in the cylinder is a wax with a melting point of around 180^{o} F.

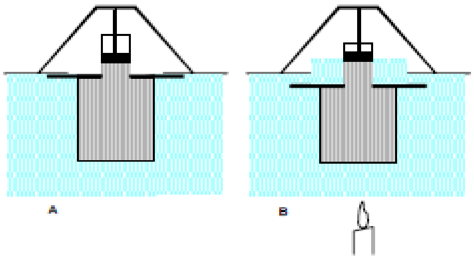

Figure 9
Thermostat Pressure Cylinder Application

Bimetallic Strips

A bimetallic strip is constructed by bonding two metals with different coefficients of thermal expansion (Figure 10). If heat is applied to one end of the strip, the metal with the higher coefficient of expansion will expand more readily than the lower one. As a result, the whole metallic strip will bend in the direction of the metal with the lower coefficient (Figure 11).

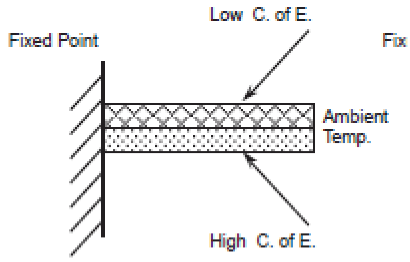

Figure 10
A Bimetallic Strip

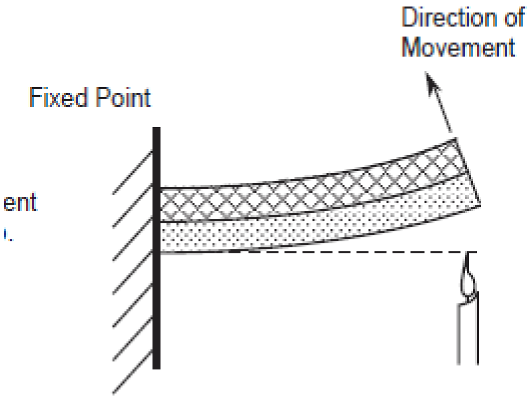

Figure 11
Bimetallic Strip Bent after Heat is Applied

When contacts are attached to the strip, it can be used as a fast acting thermostat to control air temperature as per figure 12. One drawback is that there cannot be any flammable vapours surrounding the strip due to arcing generated across the contacts.

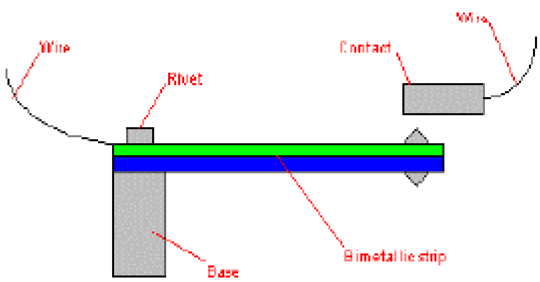

Figure 12
Bimetallic Thermostat

One main advantage of the bimetallic strip is that it can be used to operate over a range of temperatures when the strip is fashioned into a coil (for larger swing) and placed on an adjustable pivot (figure 13). Most room thermostats operate on this principle.

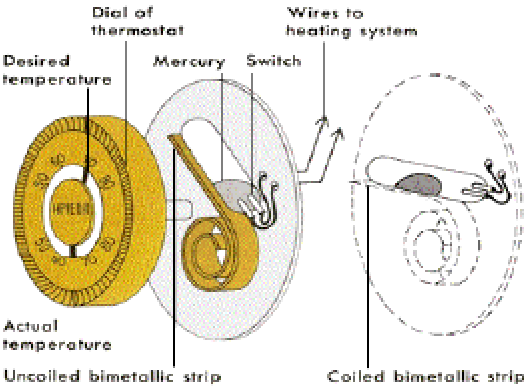

Figure 13
Application of Bimetallic Strip

Bimetallic Thermometers

Another common configuration of the bimetallic strip is coiled in a helix to increase the swing or displacement similar to the coil above. In this shape, the strip is more rugged and less subject to vibration. A helical bimetallic thermometer is shown in Figure 14 below. Bimetallic thermometers in general are very rugged and require little maintenance. They are usually used to measure process parameters such as pump and bearing temperature.

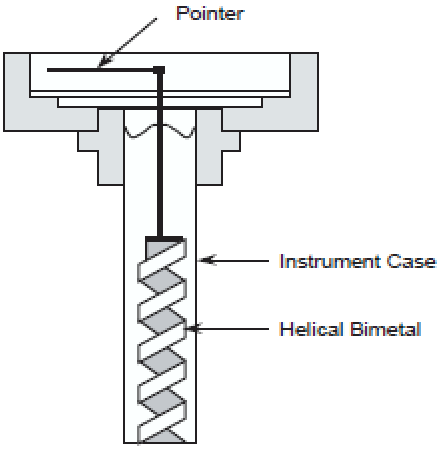

Figure 14
Helical Bimetallic Thermometer

PRESSURE MEASUREMENT AS CONTROL SYSTEM

This lecture 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.

- **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:

Pressure = Force/ Area or P = F/A

The units of measurement are either in pounds per square inch (PSI) in British units or Pascals (Pa) in metric. As one PSI is approximately 7000 Pa, we often use kPa and MPa as units of pressure.

- **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.

Note : (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.

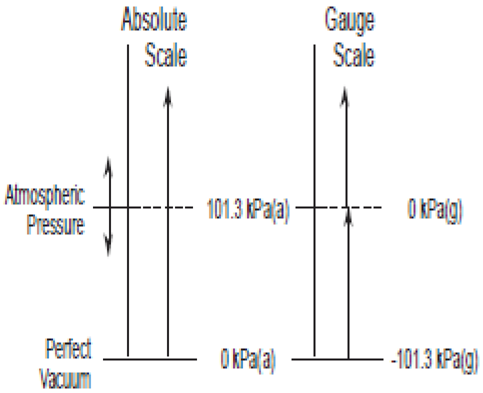

Figure 1
Relationship between Absolute and Gauge Pressures

- **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. Note 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

- **Common Pressure Detectors**

1 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.

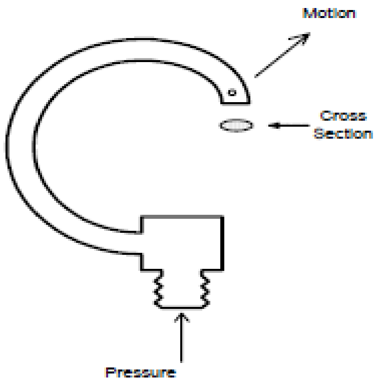

Figure 2
Bourdon Tube

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.

2 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.

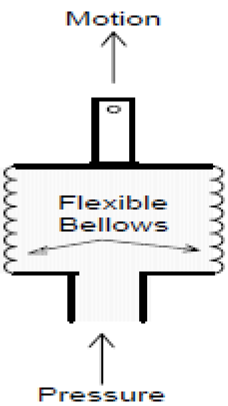

Figure 3
Bellows

3 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.

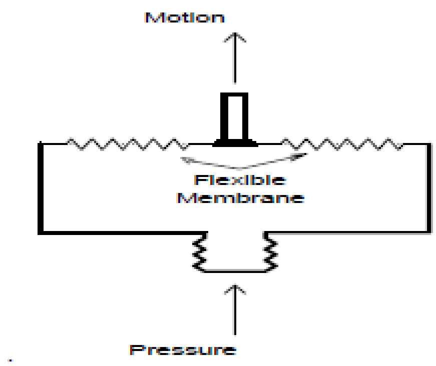

Figure 4
Diaphragm

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

4 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.

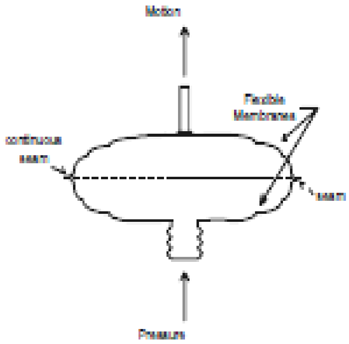

Figure 5
Capsule

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 interspace 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.

- **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 6 illustrates a typical DP transmitter. A differential pressure capsule is mounted inside a 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.

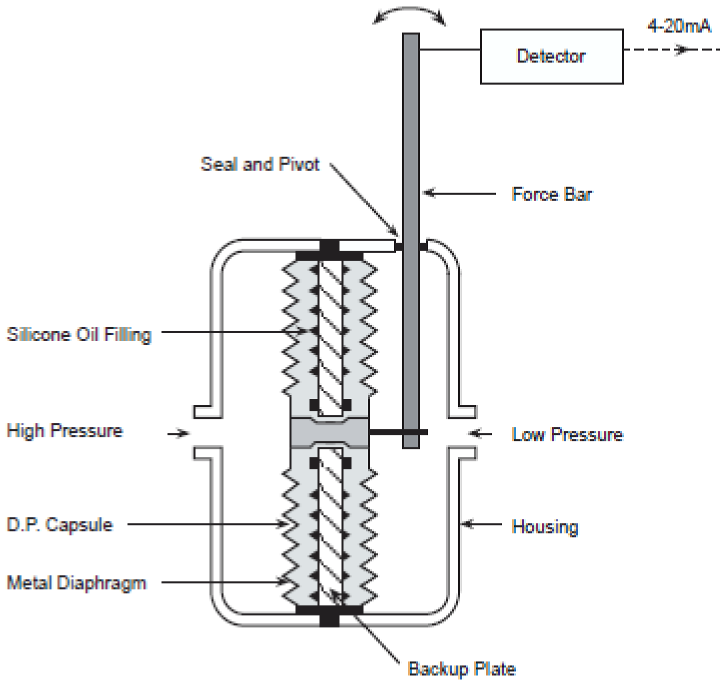

Figure 6
Typical DP Transmitter Construction

This DP transmitter would be used in an installation as shown in Figure 7.

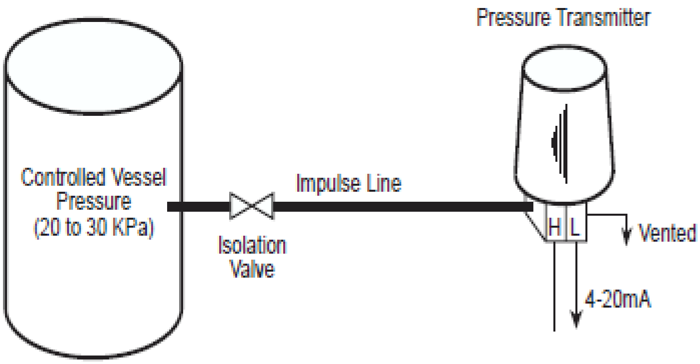

Figure 7
DP Transmitter Application

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.

- **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.

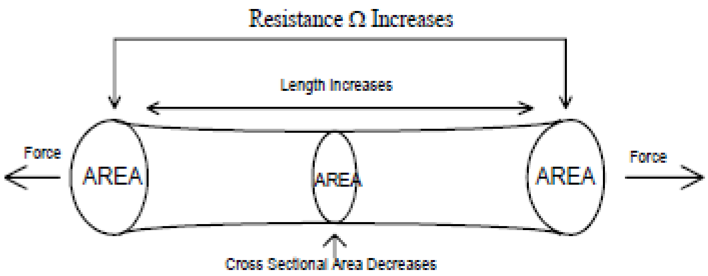

Figure 8
Strain Gauge

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 8, 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 9 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.

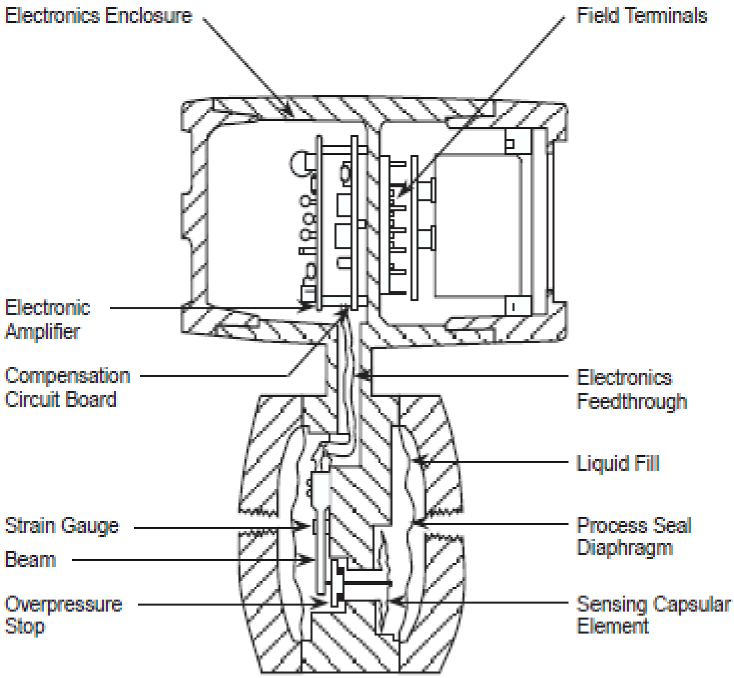

Figure 9
Resistive Pressure Transmitter

- **Capacitance Capsule**

Similar to the strain gauge, a capacitance cell measures changes in electrical characteristic. As the name implies the capacitance cell measures changes in capacitance. The capacitor is a device that stores electrical charge. It consists of metal plates separated by an electrical insulator. The metal plates are connected to an external electrical circuit through which electrical charge can be transferred from one metal plate to the other. The capacitance of a capacitor is a measure of its ability to store charge. The capacitance of 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

By building a DP cell capsule so there are capacitors inside the cell capsule, differential pressures can be sensed by the changes in capacitance of the capacitors as the pressure across the cell is varied.

- **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 manufacturers. 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.

- **Vapor 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.

- **Failures and Abnormalities**

1 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.

2 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.

3 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.