Process Control and Instrumentation

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Lecture - 42
Pressure Measurement

Now, on wards will talk about various instruments, that are available for measurements of process variable such as pressure, temperature flow, liquid level, etcetera. And will start our discussion with pressure measuring instruments.

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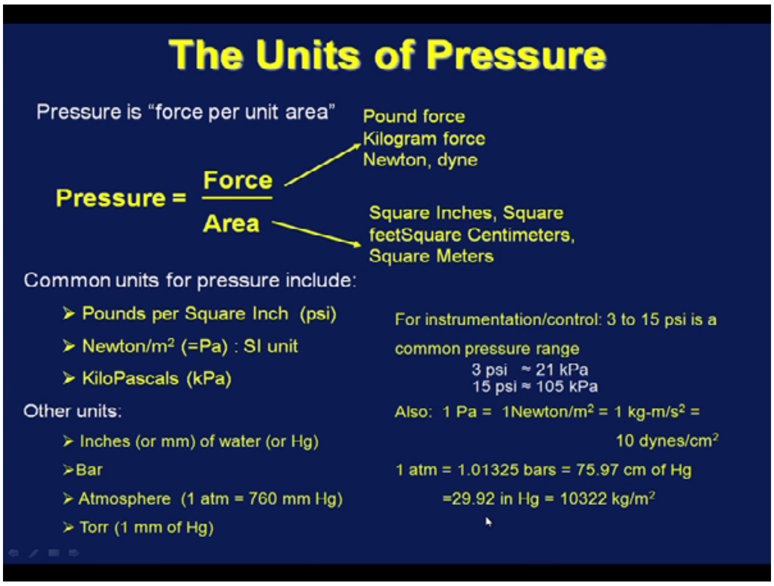

Pressure is very important process variable. Pressure is defined as force per unit area. So, pressure is force divided by area. Force can represent as found force, kilogram force, Newton, dyne, and etcetera. Similarly, area can be represented in terms of square inches, square feet, square centimeters, and square meters etcetera. Common unit of pressure include pounds per square inch also called PSI, Newton per meter square, which is SI unit of pressure, Newton per meter square is also known as Pascal symbol for Pascal is P a. We can also use Kilo Pascals. So, 1 kilo Pascal is 1000 Pascals. Other units that can also be used for pressures are inches of water or inches of mercury, millimeter of water or millimeter of mercury, bar, atmosphere, 1 atmosphere is 750 millimeter of mercury; we also express low pressure in in the unit of torr, where 1 torr is 1 millimeter of mercury.

So, let us we familiar with we should be familiar with these units, pounds per square inch of PSI, Newton per meter square or Pascal, which is SI unit kilo Pascals etcetera. Also inches or millimeter of mercury or water, bar, atmosphere, torr, etcetera. We have seen during our discussion on instrumentation process control. The 3 to 15 PSI is a common pressure range. So, let us remember 3 PSI is approximately 21 kilo Pascals, and 15 PSI is 105 kilo Pascals. So, like 3 to 15 PSI is a common pressure range in process instrumentation and control. The ranges translate to 21 to 105 in kilo Pascal unit.

We should also remember 1 pascal is equal to 1 Newton per meter square, which is nothing, but 1 Kg meter per second square which is same as ten dines per centimeter square. We may also remember 1 atmosphere pressure is equal to 1.01325 bars, which is equal to 75.97 centimeter of mercury, which we ordinarily say 76 centimeter of mercury or 76 millimeter of mercury, which is equivalent to 29.92 inches of mercury, which is same as 10322 k g per meter square. So, these gives us the relationship between 1 units to another. So, you can easily convert from 1 unit to another.

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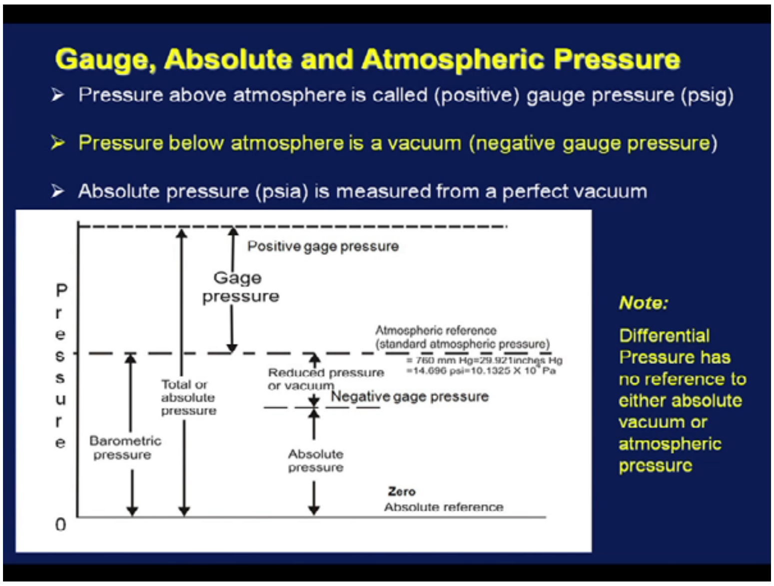

Let us now define gauge pressure, absolute pressure and atmospheric pressure. Pressure above atmosphere is called gage pressure or positive gage pressure, would denoted by psig. Similarly, pressure below atmosphere is negative gage pressure also known as vacuum. On the other hand absolute pressure is measured from a perfect vacuum. Let us look at this diagram, let us take this as 0 absolute references, and this as atmospheric pressure. This is the pressure axis and there is another pressure indicated here, which is above atmospheric pressure. So, this access pressure access pressure with respect to the atmospheric pressure is positive gage pressure, where as with respect to 0 or absolute reference this pressure is total or absolute pressure.

Similarly, if we consider another pressure level which is below atmospheric pressure with respect to atmospheric pressure this pressure will be turned negative gage pressure or vacuum. While this pressures the same pressure with respect to absolute 0 will be absolute pressure. Similarly, the atmospheric pressure with respect to absolute 0 references will be called barometric pressure.

So, pressure above atmosphere is positive gage pressure, pressure below atmosphere is a negative gage pressure vacuum and absolute pressure is measured from a perfect vacuum or absolute 0 reference. We may note that differential pressure has now reference to either absolute vacuum or atmospheric pressure. So, differential pressure has no reference to either absolute vacuum or atmospheric pressure.

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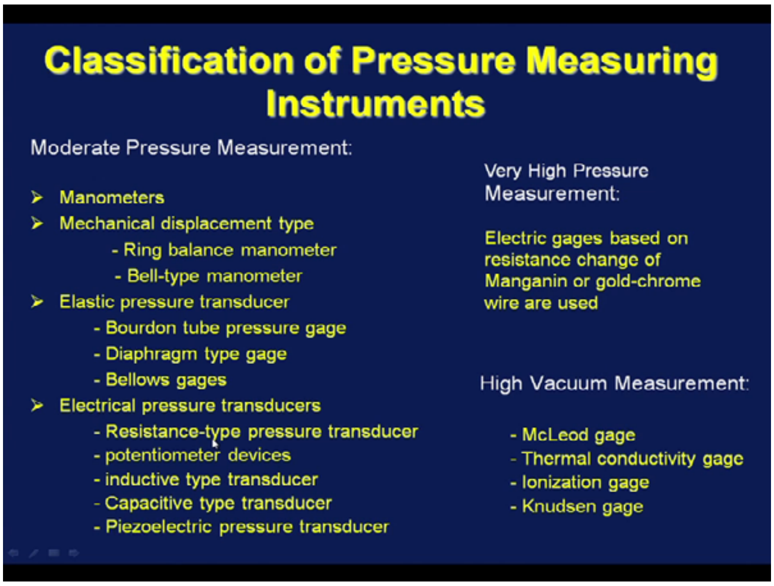

Let us now classify the pressure measuring instruments that frequently encounter with for measurement of pressure. We can broadly classify the pressuring the pressure measuring instrument under three different categories depending on what is the magnitude of pressure where measuring. We can measure a moderate pressure, we can measure a very high pressure or we may be interested in measuring very low pressure or high vacuum. There are various instruments available for measurements of moderate pressures and we can classify them as follows, we have manometers, we have various types of manometers, we have mechanical displacement type pressure measuring instruments such as ring balance manometer or bell-type manometers. Ring balance manometer or bell-type manometers can also be clubbed under manometers.

Then an important class of pressure measuring instruments is elastic pressure transducers, where we have bourdon tube pressure gage, diaphragm type gage and bellows gages. You also have various electrical pressure transducers such as resistance-type pressure transducer, potentiometer devices, inductive type transducer, capacitive type transducer, piezoelectric pressure transducer and so on and so forth.

So, we have various manometers, various elastic pressure transducers such as bourdon tubes, diaphragm types bellows gages and various electrical pressure transducers for measurement of moderate pressures. For measurement of very high pressure normally electric gages based on resistance change of manganin or gold-chrome where is used. On the other hand when we need to measure very low pressure or very high vacuum we have mcleod gage, thermal conductivity gage also called pirani gage, ionization gage and knudson gage. So, now will see some of these will see in some more details of some of these pressure measuring instruments.

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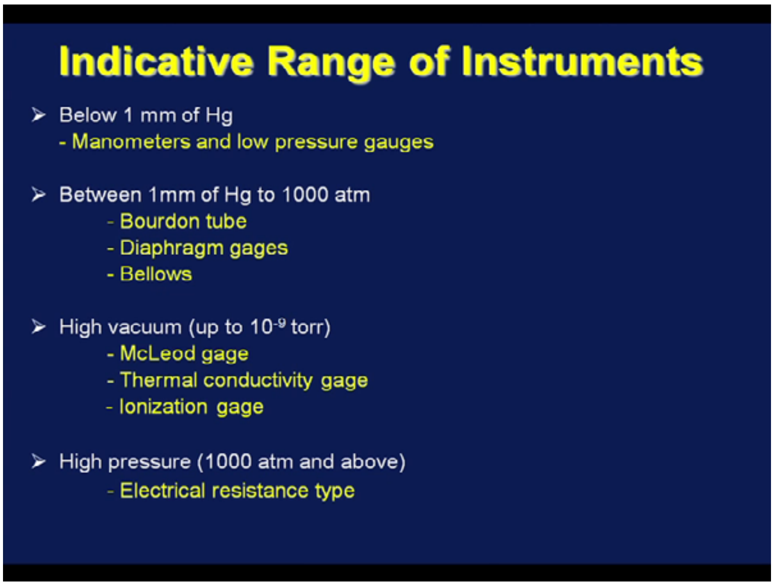

This is an indicative range of various pressure measuring instruments, is just an indicative range below 1 millimeter of mercury use manometers and low pressure gauges between 1 millimeter of mercury 2000 atmosphere, we can use elastic pressure transducer such bourdon tube, diaphragm gages and bellows gauges. For high vacuum that is up to 10 to the power minus 9or 10 to the power minus 9 millimeter of mercury we used mcleod gage, thermal conductivity gage, ionization gages, etcetera.

And for very high pressure measured in very high in the sense of 1000 atmosphere, and above we use electrical resistance type. So, why moderate pressure we mean up to 1000 atmosphere, very high pressure normally refer to 1000 atmosphere and above, and high vacuum may be 1 millimeter mercury to as low as 10 to the power minus 9 millimeter of mercury, where we need to use special instruments such as thermal conductivity gage or ionization gage etcetera.

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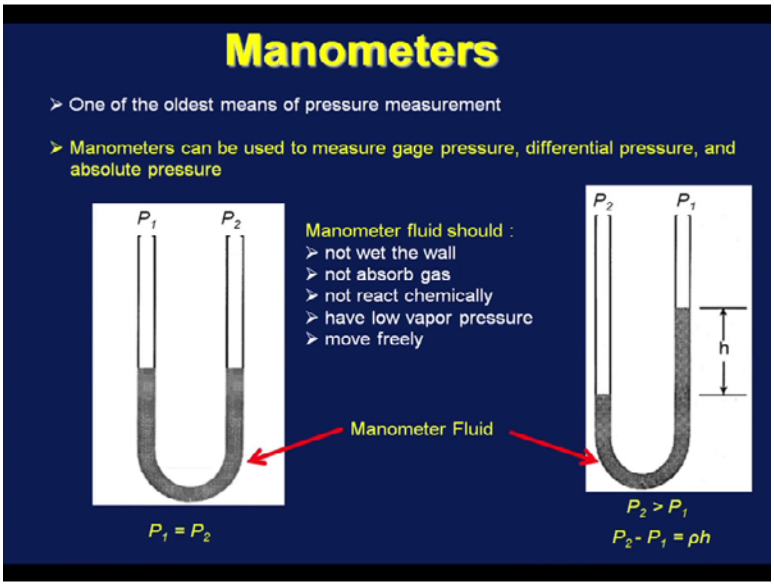

So, let us start, we manometers manometer is 1 of the oldest means of pressure measurement you are all familiar with at least U tube manometer which is shown here. So, it is a U tube may be made of glass, ordinarily made of glass and inside the tube we have a fluid known as manometer fluid frequently mercury and water we used. Now, when these two links are connected to same pressure source; that means, if P 1 is equal to P 2 the level of manometer fluid in both the links will be same, but if P 1 and P 2 are connected to two different pressure sources, then there will be a difference in level of the manometer fluids in both the links, for these for example, this link is connected to pressure source P 2. This link can be connected to pressure source P 1 and P 2 is greater than P 1. So, the manometer fluid is pushing down here and rises up here so, dealt. So, h is the difference between the levels of the manometer fluid in these two links.

So, h is the output of this manometer, and this h is the measure of differential pressure P2 minus P 1. So, P 2 minus P 1 is rho times h, where rho is the density of this manometer fluid. So, by measuring this h, we can easily calculate the differential pressure P 2 minus P 1 if we know the density of the manometer fluid. While choosing manometer fluid for a particular application we need to remember that the manometer fluid should not wet the wall, it should not absorb the gas, it should not react chemically with the fluid whose pressure we are interested in measuring, it should have a very low vapor pressure, and it should also move freely.

Mercury is one of the most commonly use manometer fluid. As it satisfies these conditions were. So, it is important to note that manometer fluid should not wet the wall; it should not absorb or react chemically. It should have a very low vapor pressure and it must move freely. So, this is how we can measure differential pressure with a U tube manometer. Remember the manometers can be used to measure gage pressure, differential pressure as well as absolute pressure.

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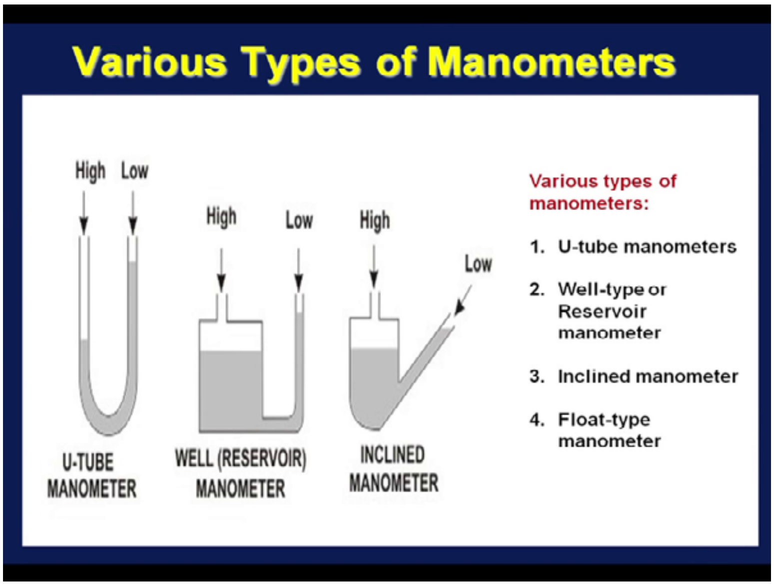

We can have various types of manometers I shown in this figure. We have U-tube manometer, which we just discussed. We can have will type or reservoir manometer which we shown by this figure. We can also have an inclined manometer, where one of the leg is inclined, and we can also have a float type manometer, which is essentially a modified version of well type or reservoir manometer. So, the various types of manometers can be U-tube manometer, well type or reservoir manometer, inclined manometer and float type manometer.

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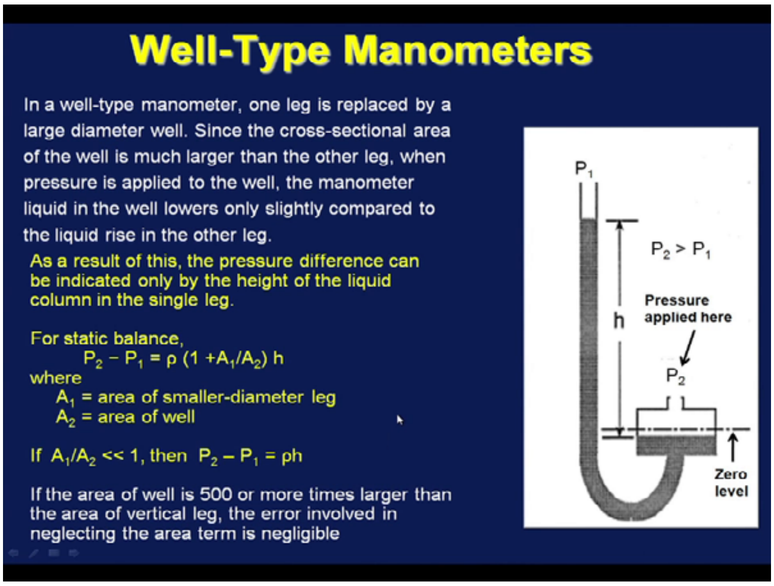

Let us now look at more closely a well type manometer. In a well type manometer one leg is replaced by a large diameter well, if you remember the U-tube manometer this would have been like this, but this leg is has been replaced by large diameter well. Since, the cross-sectional area of the well is much larger than the cross-sectional area of the other leg when the pressure is applied to the well. The manometer liquid in the well lowers only slightly compared to the liquid rise in the other leg.

Select P to P, in a well type manometer, one leg of the U-tube manometer by replaced by large diameter well. Now the cross-sectional area of the well is much larger than the cross-sectional area of the other leg. So, if we now apply pressure to the well since, it is cross-sectional area is much larger the manometer liquid in the well will lower only slightly, but there will be a significant liquid rise in the other leg. As the result of this the pressure difference can be indicated only by the height of the liquid column in the single leg.

In case of U-tube manometer, we have to read the difference of the liquid level in both the links, but here we have made one leg large. So, the liquid lowers only slightly here, and the liquid rises substantially in the other leg, which as much smaller diameter. So, effectively the pressure difference can be indicated by the liquid rise in the single leg. If this is connected to pressure source P 1, and the well is connected to pressure source P 2, and P 2 is greater than P 1. Higher pressure is the apply to the well. So, P 2 is greater than P 1, then it can be shown that for static balance. P 2 minus P 1 is equal to rho, which is density of the manometer liquid in to 1 plus A 1 divided by a two into h, where A 1 is the area of the smaller diameter leg and A 2 is the cross-sectional area of the well.

So, for static balance, we can write P 2 minus P 1 equal to density of the manometer liquid in to 1 plus A 1 divided by a two into h. Now since the cross-sectional area of the well is much larger, A 2 is much larger than A 1. In other words, A1 by a two is much less than 1 such that 1 plus A1 by a two can be approximated at 1. So, P 2 minus P 1 is equal to rho times h. So, the pressure difference can be measured by the height of the liquid column in the single leg that means the leg with much smaller diameter. In fact, if the area of the well is 500 or more times larger than the area of the vertical leg, the error involved in neglecting the area term is so small that it can be safety neglected. You can see from the figure that from the schematic that the liquid lowers only by this much in the well, but the liquid rise in the other leg is use.

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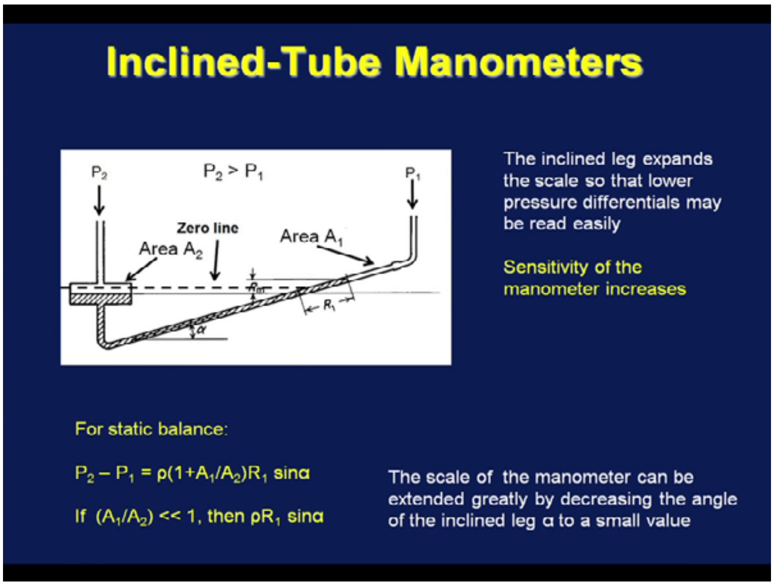

Let us now look at inclined tube manometer. In case of inclined manometer one leg of the U-tube manometer is inclined. The inclined leg expands the scale of the manometer such that lower differences can be writing very easily. Imagine, we are using an U-tube manometer to measure pressure differential between P 2 and P 1, where P 2 and P 1 are not widely different; that means, we are measuring a low pressure differential. Under this circumstance, the h that is the deference of liquid level in both the links will be very, very small. In fact, depending on the pressure differential it can be as it can be so small, such that it becomes extremely difficult to read. Overcome this what you can do is we can inclined one of the legs of the u-tube manometer. So, that way the mercury will travel along a distance along the incline leg.

So, by inclining 1 leg of the manometer we can expand the scale of the manometer, such that lower pressure differentials can be read easily. For example, if you look at this figure, this is the 0 line. So, if this leg was not incline, but if this leg was vertical, the pressure differential would have been the small amount R m, but by inclining it the equivalent portion of R m is R 1, which is much easier to read. So, essentially we increase the sensitivity of the manometer.

If the angle of inclination is alpha, we can show that for static balance P 2 minus P 1 is equal to rho, which is density of the manometer liquid in to 1 plus A 1 by a two times R 1 sine alpha, where R 1 is the this distance, which is essentially the output from the U-tube from the incline tube manometer. Again if A 1 by a two is much smaller than 1 because, if we use involve here with much larger diameter corresponding to the diameter of the incline leg we can neglect A 1 by a two in that case P 2 minus P 1 will equal to rho times R 1 sine alpha. The scale of the manometer can be extended greatly by decreasing the angle of the incline leg alpha to a small value. So, we can increase the scale of the manometer by decreasing the angle of the incline leg.

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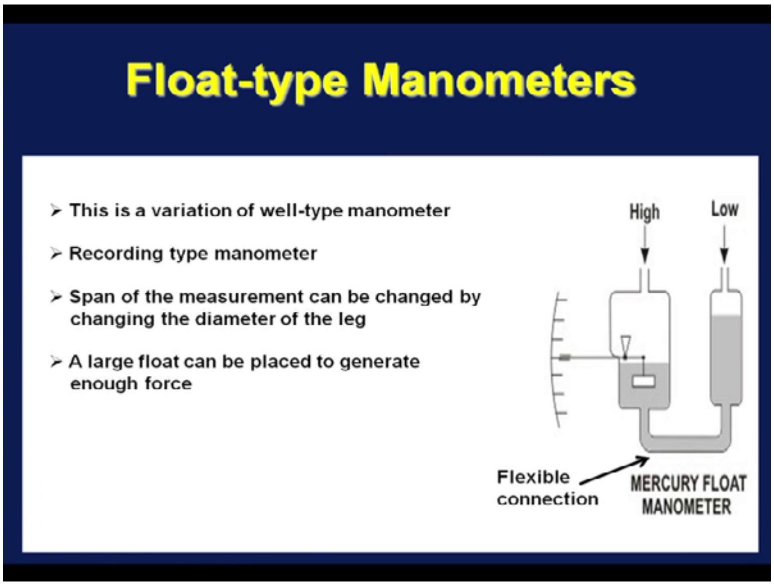

Let us now look at float-type manometers. This is a variation of well type manometer. We have a well with much larger diameter, and we have another tube another leg whose diameter is less than this. These two this well and this leg is connected by flexible connection, and this well diameter is larger than such that you can put a float inside. Now, this is connected to the high pressure source this is connected to the low pressure source.

Now as the manometer liquid changes its position the flow inside the well also changes its position, and the position of the float can be taken as a measure of pressure. We can choose a large flow, such that it generates enough force to move a pointer against the scale. So, the scale can be calibrated in the unit of pressure and from the pointer under scale the pressure can be indicated.

By replacing the pointer by a plain, and by replacing the scale by a charge this float-type manometer can be converted to a recording type manometer. It is also easy to change the span of the measurement by changing the diameter of this leg. So, this is frequently called range tube since these two are connected by a flexible connection, if I change the diameter of this leg the span of the instrument can be easily changed. So, this is essentially a variation of well-type manometer, where replace a float in the well.

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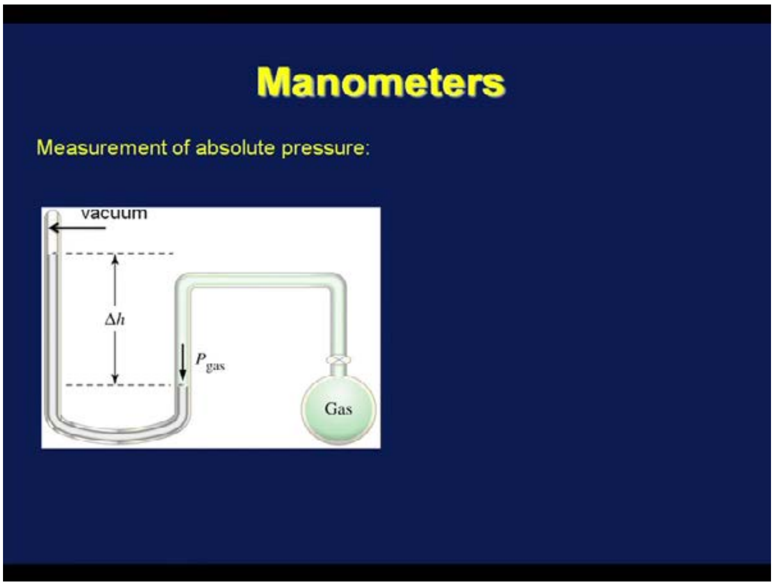

If one in of the U-tube manometer is seemed, and the other end is connected to the pressure source, and this is vacuum then the manometer is essentially measuring absolute pressure.

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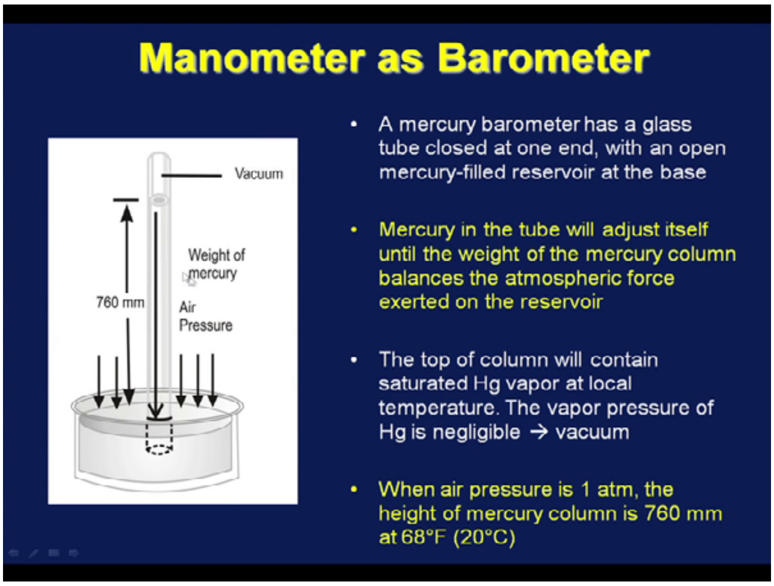

You are all familiar with barometer shown schematically by this figure. A mercury barometer has a glass tube closed that one end with an open mercuric fill reservoir at the base. So, what we do is we take a glass tube closed at one end fill it completely mercury, invert it and place it in a mercuric filled reservoir. Mercury in the tube will adjust itself until the weight of the mercuric column balances the atmospheric source exactor on the reservoir.

So, atmospheric air is acting pressure on the reservoir. So, the mercury in the tube will adjust itself until the weight of this mercuric column inside the tube balances the atmospheric force exactor on the reservoir. When the pressure with the air pressure is 1 atmosphere the height of mercuric column will normally be 760 millimeter at 68 degree fahrenheit or 20 degree Celcius. The top of the column will be vacuum. It will essentially contain saturated mercury vapor at the local temperature, but since the vapor pressure of mercury is extremely low and can be neglected safely, this is essentially vacuum.

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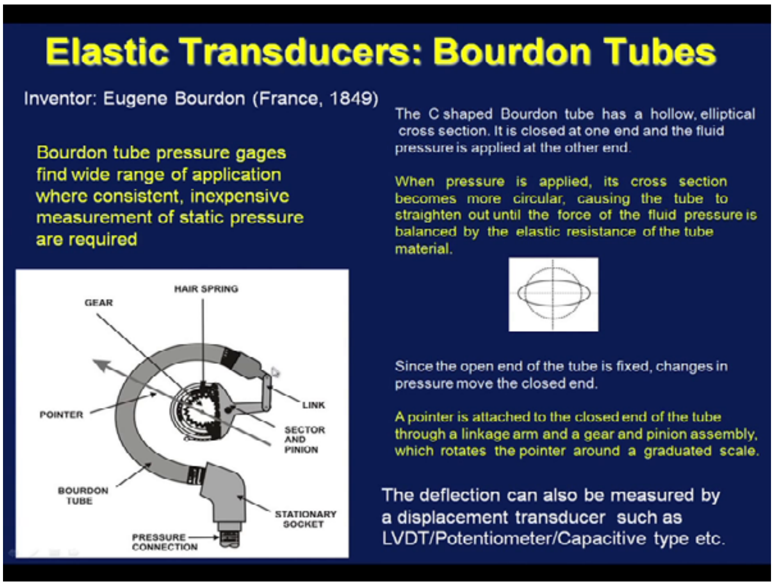

Now, let us move on to elastic pressure transducers and we start our discussion with bourdon tubes. Bourdon tube was past patented by eugene bourdon in France in 1849. So, it is a very old instrument. Bourdon tube filnds wide range of application, where consistent in extensive measurement of state equation a required. There are very types of bourdon tubes C-type or C-shape bourdon tube is one of the most commonly used bourdon tube. The figure shown here is the C-shaped bourdon tube. The C-shaped bourdon tube has a hollow electrical cross-section. So, this tube is hollow and electrical cross-section. It is close at one end and the fluid was pressure we are going to measure is applied at the other end. This end is also rigidly takes.

So, to to make a bourdon tube we start with a tube with surplus cross-section then flatten the tube to make the cross-section electrical seal one end of the tube and bend the tube in the form of C. The fluid whose pressure I am going to measure is applied here and this is rigidly fixed. A pointer is connected to the sealed end of the tube through a gear and linkage system. Now when pressure is applied that the end which is rigidly fixed the cross-section of the bourdon tube tries to become circular. So, we have bourdon tube with electrical cross-section when the pressure is applied here.

The cross-section of the bourdon tube tries to become circular from electrical one. This will cause the tube to straight now until the force of the fluid pressure is balanced by the elastic resistance of the tube material. So, when pressure is applied inside the bourdon tube the cross-section of the bourdon tube tries to becomes circular, and these causes the tube to straight a now until the force of the fluid pressure is balanced by the elastic resistance of the tube material. Since the open end of the bourdon tube is fixed the changes in the pressure will move at closed end. A pointer is attached to the closed end of the tube through a linkage gear and pinion assembly, and this will rooted the pointer around a graduated scale we can have graduated scale.

So, when the fluid pressure is being applied inside the bourdon tube, the bourdon tube will tries to taken out as its cross-section tries to become circular, and this will cause the sealed end of the bourdon tube move. So, the sealed end of the bourdon tube will move as I apply pressure inside the bourdon tube, and this movement or this movement of the tip of the bourdon tube is a measure of the pressure. The tip movement can be indicated by connecting a pointer to the tip of the bourdon tube through this gear link sector and pinion assembly.

We are talked about displacement measuring transducer such as LVDT potentiometer, capacitive type etcetera previously. So, the deflection of the tip of the bourdon tube can also be measure by displacement transducer such as LVDT potentiometer and capacitive type etcetera. So, the key point is that when I apply pressure inside the bourdon tube there will be deflection of the tip of the bourdon tube which is sealed, and this tip deflection is direct measure of the pressure being applied.

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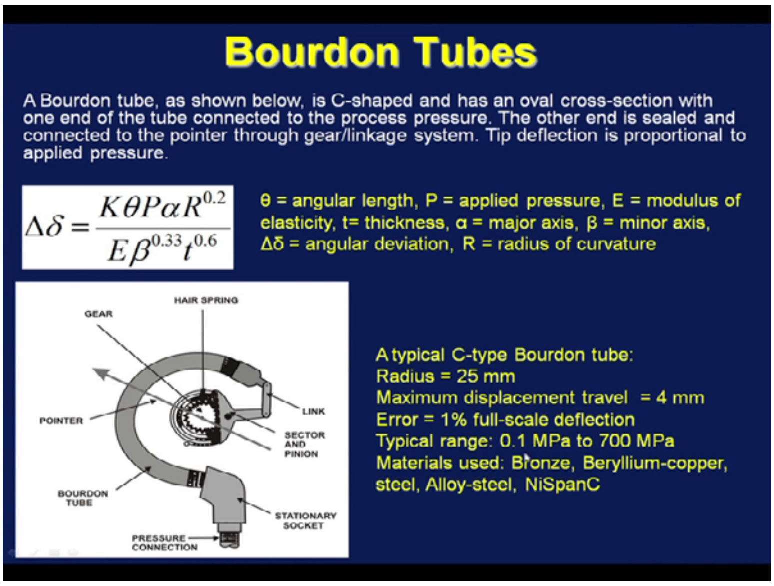

The deflection of the tip of the bourdon tube is proportional to the pressure being applied. In fact, the tip deflection depends on various other factors. For example, for a particular design the tip deflection can be expressed by this equation, which relates the deflection of the bourdon tube to K times, theta times, P times, alpha times or to the power point two divided by E beta to the power 0.33 to t to the power 0.6. What it means is the deflection of the bourdon tube defense on theta, which is angular length this length angular length it depends on pressure being applied directly proportional to pressure being applied on the angular length depends on the radius of curvature to which the bourdon tube has been bend depends on geometry of the cross-section is electrical one. So, it has a major axis and minor axis.

So, tip deflection depends on major axis and minor axis tip deflection depends on the modulus of elasticity of the material that has been use for making the bourdon tube. The tip deflection also depends on the thickness of the bourdon tube. Tip deflection of the tip of the bourdon tube is inversely proportional to the modulus of elasticity of the material as well as thickness of the bourdon tube.

A typical C-type bourdon tube may have a radius 25 millimeter, may have a maximum displacement level of four millimeter error in measurement maybe one person full scale deflection typical range is 0.1 megapascal to 700 megapascal and the materials use for making bourdon tube a normally those materials which as very good elastic property such as bronze, beryllium-coper steel, alloy-steel and nickel span C-alloy. Nickel span C-alloy is an interesting alloy whose modulus of elasticity does not change with change temperature. For an appreciable change in temperature the modulus of elasticity of nickel span C alloy does not change.

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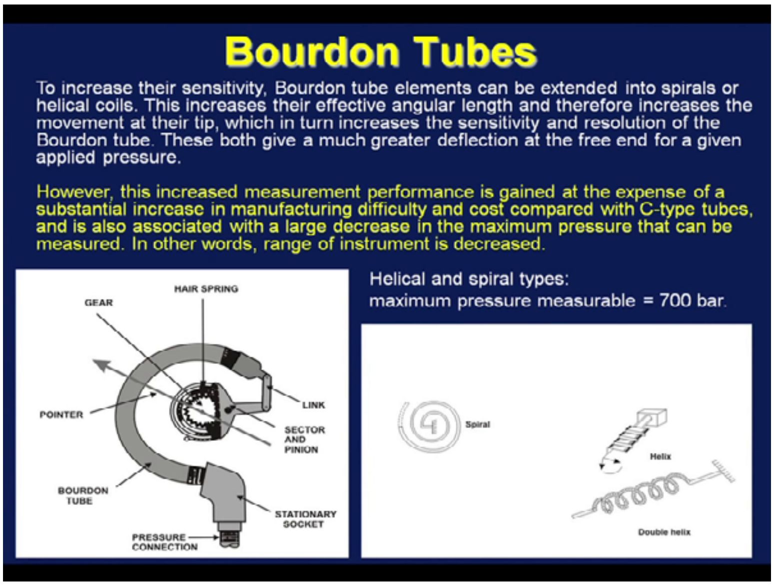

Now, to increase the sensitivity of the bourdon tubes, the bourdon tube element can be extended into spirals or helical coils. This increases their effective angular length. Remember, from the previous equation we have seen the deflection of the tip of the bourdon tube is directly proportional to the angular length. So, move the angular length higher the deflection of the bourdon tube. So, to increase the sensitivity of the bourdon tube we can increase the angular length and one way to increase the angular length it is to extend the bourdon tube element into spiral or a helical coils, this will increase the effective angular length and therefore, increases the movement of the tip of the bourdon tube.

Thus it increases the sensitivity and resolution of the bourdon tube. So, both the spiral or helical or double helix will increase the sensitivity of the bourdon tube. So, for the if I apply the same amount of pressure in C-type bourdon tube, and if I apply the same amount of pressure in spiral or helical bourdon tube, the tip deflection in case of spiral or helical bourdon tube will be much higher then that of C-type bourdon tube.

However this increased measurement performance is gained at the expansion at the expense of a substantial increase in manufacturing difficulty and cause compared with C-type bourdon tubes, and this also decreases the maximum pressure that can be measured. In other words, the range of the instruments is decreased. So, increase the sensitivity of the bourdon tube by using spiral or helical bourdon element, but the cost of the instrument includes, because a manufacturing difficulty and at the same time, we decrease the range of the instrument. So, the maximum pressure that can be measure with C-type bourdon tube is much higher then compared to spiral type or helical type bourdon tube. Helical and spiral types can measure a maximum pressure up to 700 bar.

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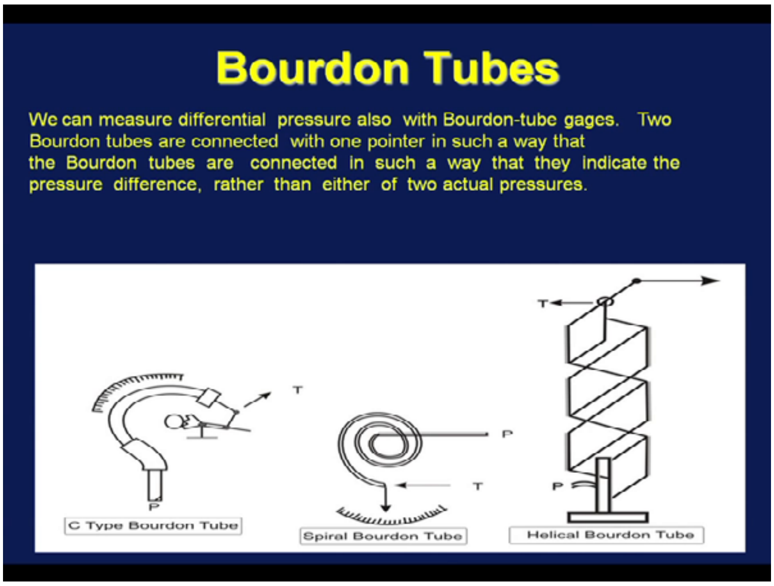

So, once again C-type bourdon tube, spiral type bourdon tube and helical type bourdon tube we can use a double helix, where a single helix is used to make another helix. We can also measure differential pressure with help of a bourdon tube. We need to use two bourdon tubes for that. Two bourdon tubes are connected with one pointer in such a way that the bourdon tubes indicate the pressure difference.

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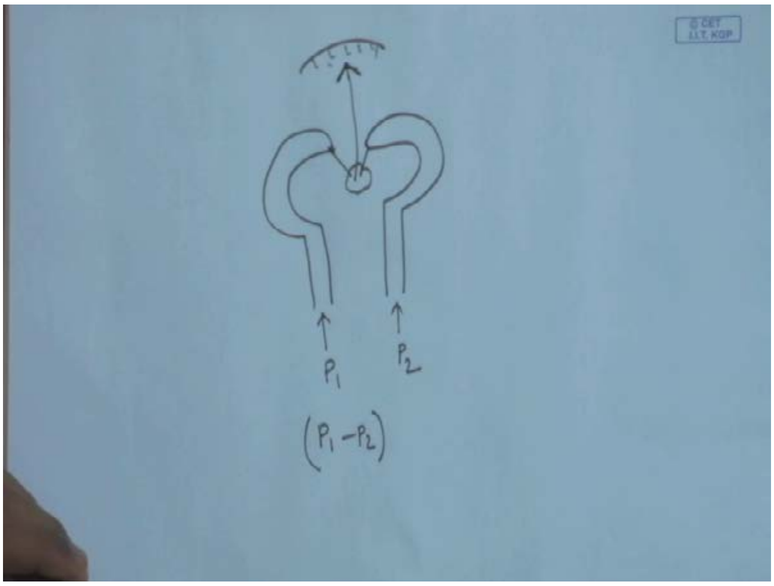

Let us look at this. Let us say we have a bourdon tube we have another bourdon tube the tip of the bourdon tubes are connected such that these two tips move in opposite direction such that the deflection of this pointer against the scale is a measure of P 1 minus P 2 or P 2 minus P 1. So, this way we can measure differential pressure with help of two bourdon tubes.

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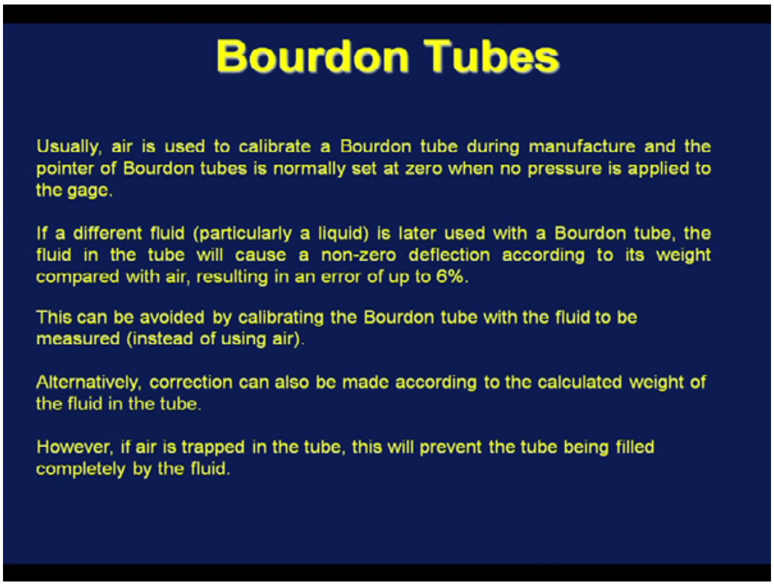

Usually air is used to calibrate a bourdon tube during manufacture and the pointer of the bourdon tube is normally set at 0 when no pressure is applied to the bourdon tube pressure gage. Now if a different fluid particularly a liquid is later used with a bourdon tube the fluid in the tube will cause a non-zero deflection according to its weight compared with air resulting in an error of up to six percent.

Usually air is used to calibrate the bourdon tube during manufacture and the pointer of the bourdon tube will be set at 0 when no pressure is apply to the gage now if I apply a different fluid and the problem is over say if we use a liquid, a non-zero deflection we may get and this will result in an error of up to six percent this can be avoided by calibrating the bourdon tube with the fluid to be measure. So, instead of using air during the manufacturing state we can use the fluid that will finally, use to calibrate the bourdon tube.

Alternatively, we can also apply a correction factor; however, it air is strapped in the tube this will prevent the tube being completely filled with fluid and the solution proposed by both the methods will be difficult. However, if air is strapped in the tube this will prevent the tube being filled completely by the fluid and none of the solution will work properly.