Principles of Mechanical Measurement

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Module – 08
Pressure Measurement
Lecture – 3
Electric Pressure Transducer and High & Low Pressure Measurement

Hello friends. So, we are into the third lecture of our week number 8, where we are talking about the measurement of pressure. We have already gone through lectures on this particular topic, where we have primarily discussed about two very common methods of measuring pressure; one of them is manometry and other is of elastic transducers.

In case of manometry, we are trying to balance the pressure force against the weight of a liquid column, so that we can directly read the height of that liquid column to the pressure and different types of manometers. So we have discussed like the simple well type and U tube manometers, then the differential manometers, inverted tube manometers and then a couple of ways of increasing the sensitivity of manometer like in the form of inclined tube manometer and also micro manometers.

And then in the other category, where we are talking about elastic pressure transducers, they are actually we are trying to balance that pressure force or I should say we are trying to convert that pressure force or in the terminology of measurement, we are transducing the pressure force in the form of some deflection. Like in case of bourdon tube gauges, we are converting the deflection to the circular or angular motion of the pointer on some scale. Whereas, in case of diaphragms or bellows, we are transducing that pressure force into the deflection of some diaphragm or below that is linear deflection.

So, by converting that deflection subsequently by a second transducer into some kind of electronic signal or I should say electric signal, we can get a direct measure of the pressure or I should say again an indirect measure of the pressure with which all started that is in this elastic transducers, we basically have two transducing stages. In the primary stage, we are converting the pressure force to a deflection. And in the secondary stage, we are converting that deflection to some kind of electric signal generally voltage or current.

And finally, that secondary output that is that electric signal or voltage is directly calibrated in terms of pressure. So, today we shall be trying to see several other methods of pressure measurement, we shall be going through them quite quickly just to get an idea about their basic principle of operation. And sometimes their relative advantages or disadvantages compared to others. And then we shall be taking a look at devices, which are specifically suited for measurement of either very high pressure or very very low vacuum pressures.

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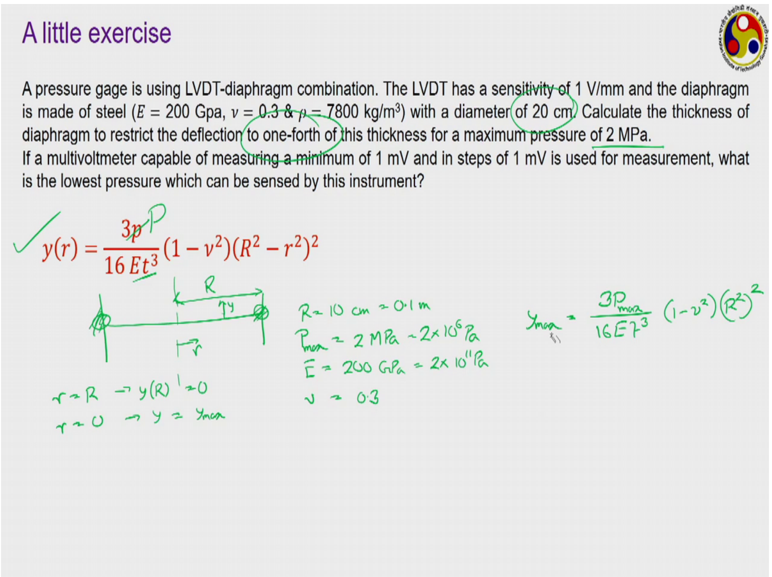

But, before that as we are always doing let us start with a little bit of exercise. In the previous lecture, we have discussed about several numerical examples involving manometers. So, today we shall be starting in the example of our diaphragm or an elastic pressure transducer. So, just read the problem carefully take a couple of seconds or maybe half a minute to read the problem carefully.

So, here we are talking about a pressure gauge which is using a LVDT-diaphragm combination that means, it is an elastic pressure transducer a diaphragm type and there we are having an LVDT as the secondary transducer that is the pressure force gets converted to the deflection of this diaphragm. And then there is this deflection is sensed by this LVDT to give a voltage output.

Now, this LVDT has a sensitivity of 1 volt per mini millimetre that is for 1 millimetre deflection of the diaphragm, it gives a voltage output of 1 volt or a change in voltage output as 1 volt. The diaphragm is made of steel, the properties are given where elastic the young's modulus is sorry 200 Gpa, we have nu that is a Poisson's ratio and also the density of steel that is given. The diaphragm is having a diameter of 20 centimetres. So, we can assume that these diaphragm is circular in nature with a diameter of 20 centimetre or radius of 10 centimetre.

Now, we have to calculate the thickness of this diaphragm, so that we can restrict the deflection to one-fourth of this thickness for a maximum pressure of 2 Mega Pascal that is the maximum pressure that we are trying to measure with this LVDT-diaphragm combination is that of 2 Mega Pascal. And we want to design the diaphragm with such a thickness that corresponding to this 2 Mega Pascal, the deflection which is expected to be the maximum deflection of this diaphragm is restricted to one-fourth of the thickness of the diaphragm itself. There is a second part, but I shall be coming to the second part later on.

So, we are talking about a circular diaphragm type pressure transducer, we have not done any mathematical analysis of that, because that will be a bit cumbersome and also not very much relevant for this particular course. But, to solve this problem, I shall be using one relation straightway which and with the objective being just to show you the importance of that relation and how to apply that relation instead of deriving that relation itself.

So, here we have a relation of the deflection of this diaphragm. The idea is that suppose this is your diaphragm, the diaphragm will be hinged at both these two ends, so that there it is not able to move. Let us say this is a centre of the diaphragm, then r refers to the radial coordinate system kappa rate that is radial distance from the centre line, capital R is the radius of the diaphragm itself. In this particular problem, the diameter is 20 centimetres, so this capital R is equal to 10 centimetre that is 0.1 meter.

And the relation this particular one this one is giving you, the deflection at a particular r location. Here y is measured perpendicular to r, so this is the direction at which y is being measured. And at a given r location, this relation gives you the measure of this deflection. We have other terms given, here T refers to the pressure corresponding face distillation is happening actually we are using capital P, so I should use capital T for in this particular relation also. E and gamma are given, then rho refers to the sorry T refers to the thickness this, and E and nu are given in this particular problem.

So, what are the information, then we know for this particular situation. Here we are trying to get a measure corresponding to a maximum pressure of 2 Mega Pascal that is 2 into 10 to the power 6 of Pascal's. We are having capital R sorry I have already noted capital R, then the properties are there E is equal to 200 Gpa that is 2 into 10 to the power 11 Pascal. The Poisson's ratio is equal to 0.3, these are the information's that are required.

But, now look at this relation. When r becomes equal to capital R, what will be the deflection corresponding value of y should be equal to 0, and that is logical also, because it is hinged at both these two ends. And then at which point it is going to have the maximum deflection for any pressure load that definitely will suit when r is equal to 0, then y should be equal to y max corresponding to whatever pressure that you are imposing that means, when you are looking for a deflection of; the maximum deflection corresponding to a pressure, then for a given pressure y max should be equal to 3 P divided by 16 E t cube into y minus nu square into R square whole square.

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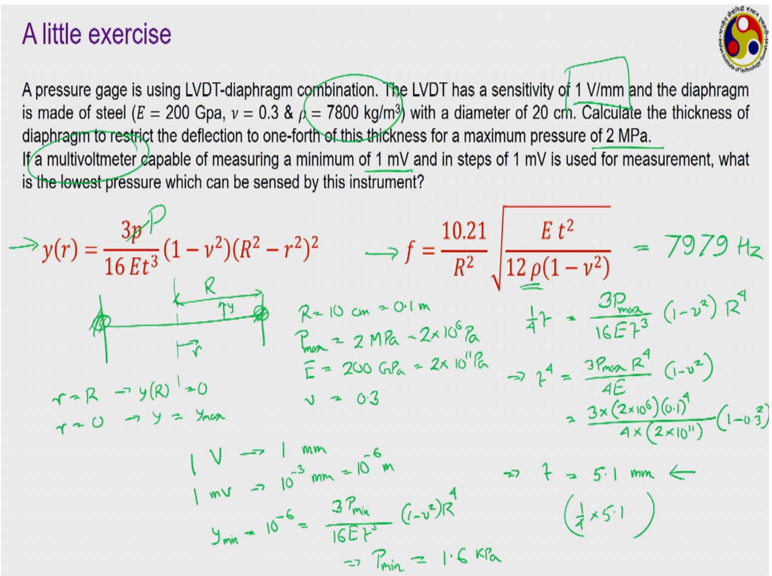

Now, in the given problem, we want to try; we were looking to calculate the maximum deflection corresponding to the maximum pressure. So, let us substitute this P as P max. And when P becomes P max, what will be a maximum deflection that should be we want that to be restricted to one-fourth of the thickness. And now this R square whole square can consciously be written as R to the power 4.

So, if you rearrange this, we have t to the power 4 is equal to 3 P max R to the power 4 by 4 E into 1 minus nu square. So, if we put the values, then what we have, we have 3 into P max as per the given problem is 2 into 10 to the power 6 Pascal R to the power 4 is 0.1 to the power 4 divided by 4 into E is given as 2 into 10 to the power 11 and Poisson's ratio being 0.3 is 1 minus 0.3 whole square.

So, if you calculate, I have pre calculate the final result that will be coming as 5.1 millimetre, please note the unit it is millimetre not in meters. So, we are having 5.1 millimetre or I should say t is equal to 5.1 millimetre that should be the thickness of this diaphragm, so that the maximum deflection corresponding to this 2 mega Pascal of maximum pressure is restricted to one-fourth of this 5.1 millimetre. So, this way we can calculate, the thickness of this diaphragm or in a way we can design a diaphragm from a given maximum load.

Now, then we will go to the next part of this problem. The second part of the problem which corresponds to the secondary transducer. Here we are talking about a multi voltmeter, which is which we are using to measure the output voltage. So, if a multi-voltmeter capable of measuring a minimum of 1 millivolt and in steps of 1 millivolt is used for measurement, what is the lowest pressure which can be sensed by this instrument. So, we have to calculate the lowest pressure corresponding to this 1 millivolt of output, the smallest possible output that we can measure using the multi voltmeter on the secondary output side is 1 millivolt.

Now, here the sensitivity of this LVDT comes into picture, which is 1 volt per millimetre. That is when we are having 1 volt of output corresponds to 1 millimetre of deflection that means, 1 millivolt of output will corresponds to 10 to the power minus 3 millimetre of deflection that is 10 to the power minus 6 meter of deflection.

Now, we have to calculate the pressure corresponding to this deflection. Again the maximum deflection will correspond to the centre location that is small or equal to 0. So, we can write this one that is the smallest possible deflection why mean, which is 10 to the power 6 meter in this case should corresponds to 3 into the minimum pressure P mean divided by 16 E t cube into 1 minus nu square into capital R to the power 4, put all the values here 6 capital E is given as 200 Gpa to the power 11 Pascal. t we have just calculated here as 5.1 millimetre that is 5.1 into 10 to the minus 3 meter, nu is given as 0.3, capital R is given as 0.1 meter if you put all of them, then the minimum pressure value it is coming to be approximately 1.6 kilo Pascal.

So, corresponding to the secondary transducer output, we can measure minimum four pressure a value of 1.6 kilo Pascal any pressure lower than this, we cannot measure using this multi voltmeter. Remember this 1.6 kilo Pascal has nothing to do with the primary transducer, it has nothing to do with this diaphragm itself, rather it is related to this secondary transducer or not even the secondary transducer, how you are measuring the out final output.

If we can use a multi voltmeter to measure the output voltage or any other voltage measuring instrument, which can give you a minimum lower than this 1 milli volt, then we can go to even lower value of this minimum pressure. So, this way we can calculate for any kind of elastic pressure transducers, just by knowing the relation between the deflection and pressure, like the one shown in red here.

Sometimes, we are also interested to know, what is the frequency of this particular oscillation that the diaphragm is going to have or I should say the natural frequency of the diaphragm. Particularly, if we are looking for some kind of dynamic measurement, so which this is not a part of this problem, but the frequency of this particular kind of diagram diaphragm, this natural frequency can be also given like this, where capital R, E, nu, t all refers to the value that we have already used. Here this rho refers to the density, which is 7800 kg per meter cube for steel in this particular problem.

So, you can just put the numbers in this. For this particular problem, the natural frequency will be coming as approximately 7979 Hertz; this will be the natural frequency for this particular diaphragm. So, if you have information of this deflection, and natural frequency a mathematical relation, I should say, you can do the calculation for any kind of electric pressure transducer, just like the one shown here. Procedure will remain just the same, only the mathematical relation may vary, if your diaphragm use of different kind.

Now, let us move to the topics that we are going to talk about today. We have already talked about the manometers, we have talked about the elastic pressure transducers. So, today let us talk about electric pressure transducers that is transducers, where the output is in the form of some kind of electric signal. Mind you like the problem, we have discussed here, here also your final output is in the form of electric signal. But, still it is not an electric pressure transducer, because the primary transducer is not giving you electric output that is only giving you deflection as the output. It is only because of your secondary transducer, you are getting an electric output.

And the secondary transducer is a deflection measuring instrument like an LVDT or maybe a strain gauge or those kind of instrument. So, we should not properly call it a electric pressure transducers, but there are a few examples where similar kind of situation arise and we still call it an electric pressure transducer.

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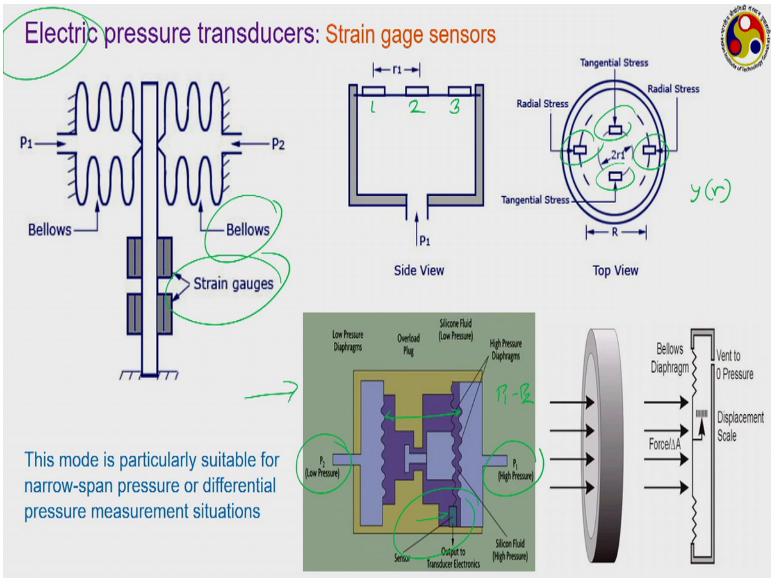

Like the first one that we have here. Here we are talking about strain gauge sensors, truly speaking strain gauge sensors are not electric pressure transducers. The role of strain gauge is quite similar to what LVDT was doing in the previous slide, it is just like a the figure shown here. Here you are talking about a bellow, and the operation or objective of the strain gauge is to measure the deflection on this bellow.

So, again the primary pressure sensing instrument here is this bellow and strain gauge is more part of the secondary transducers. So, this one is not a proper electric pressure transducer, this still is just the secondary transducers. Strain gauges like we have already seen though they are strain measuring instrument, but they generally find application in any kind of measurement, we have already seen for force, we are seeing here for pressure.

We shall also be seeing similar applications for temperature, similar other measurement devices, more as a secondary application that is some deflection is happening. And then the strain gauge is speaking of the deflection to give you a voltage output which can subsequently be calibrated or subsequently be related to the primary input. Whatever is given like force or pressure in this case or may be temperature or flow in subsequent discussions.

So, this is how we can also put strain gauges on diaphragms. Like here you can see there is a diaphragm on different locations of the diaphragm, we can have strain gauges. Here we have 1, 2, and 3 strain gauges, shown on this side view. If you look at the top view, there actually you can see there are four strain gauges located or mounted on the diaphragm, two of them on the periphery of a smaller circle, the other two on the periphery of a larger circle.

There are different other orientations are also possible, but each of them is going to give you the deflection at that corresponding location and then all of them can be summarized to get a deflection profile that is the deflection y as a function of r can be identified by combining this values of all these four readings.

This is another example again we are talking about a diaphragm generally, for a differential pressure measurement. One side we have high pressure P 1, on one side of the diaphragm. There is a second diaphragm, which is a low pressure direct from we have low pressure P 2 on the other side and the sensor is mounted at this particular location. This sensor is going to measure the deflection of both the diaphragm, particularly the high pressure diaphragm in this case.

And then relate the distance between these two to subsequent pressure difference that is P 1 minus P 2. This P 1 minus P 2 can be directly related to the distance between these two diaphragms which will be done by this sensor output. This type of strain gas pressure transducers are particularly suitable for narrow span pressure, a differential pressure measurement situation, just like shown in this particular example.

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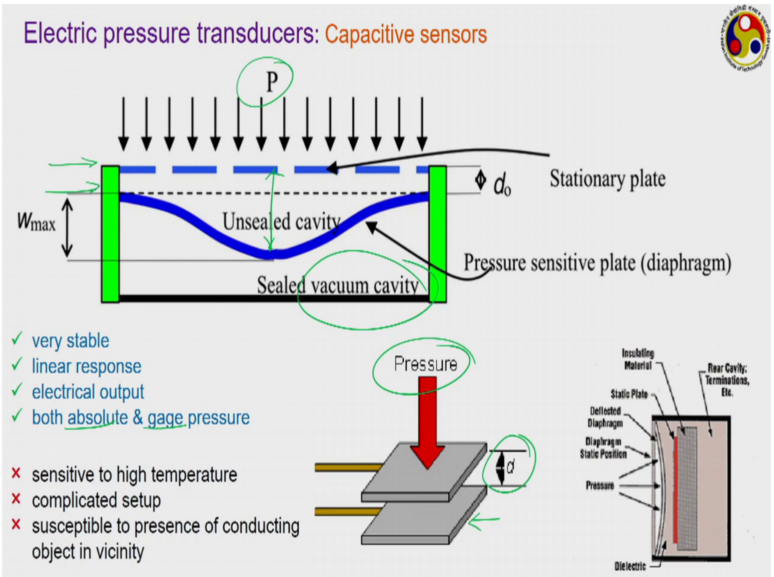

Next example is that of a proper electric pressure transducer, where we are talking about capacitive sensors. In capacitive sensors, we have like in any kind of capacity based devices, we have two plates. And so thereby giving a fixed capacitance, as the distance between the plates changes, the capacitance value also changes.

And if we can connect these two plates by some kind of suitable secondary circuitry, then we can convert these capacitance to a suitable output voltage, which can then subsequently be related to the distance between these two plates. Like shown in this particular situation, you have a secondary stationary plate which is being subjected to pressure in this particular configuration.

And the other one, where we have a vacuum cavity on one side and there is a pressure-sensitive diaphragm pressure sensitive plate is having some kind of deflection. Thereby changing a distance between these two plates and accordingly, changing the capacitance which we can pick up from these two output ports.

This is another scenario or quite similar thing, but here the plate which is being saved sensing the pressure that itself is moving, the other plate remains stationary, they are causing a change in the distance between them. And that distance causes change in the capacitance, thereby causing a change in the final voltage output which can subsequently be related to this particular pressure.

Capacitive pressure transducers, like any other capacity devices can provide very very stable response, because their output is very stable. Generally, it is a linear response, because the deflection generally is linearly proportional to the pressure imposed and the capacitance is linearly proportional to the distance between the two plates. We are going to get electric output which is always very easy to measure and easy to perform post calibration on it, post-processing on it. Both absolute and gauge pressures, we can get like the situation shown in this two particular situation.

Like in here, if we go back to the first diagram, here we are having a vacuum cavity. So, what pressure it can be measure, it is giving you the absolute pressure. Whereas, instrumenting a vacuum if we can maintain a fixed reference pressure there, they are on the atmospheric pressure, then we can get a gauge pressure reading from this. So, it can give you both kinds of measurements.

However, one problem that it can face is it can be sensitive to high temperature also the setup is quite complicated particularly forming the situation, and also getting the corresponding voltage output. And it can be susceptible to presence of conducting object in the vicinity, which can lead to certain under stray voltage as output, which will be near impossible to separate from the actual voltage output. So, the device needs some kind of electrical isolation, so that it is not at all being influenced by any other kind of conducting object which is kept closed.

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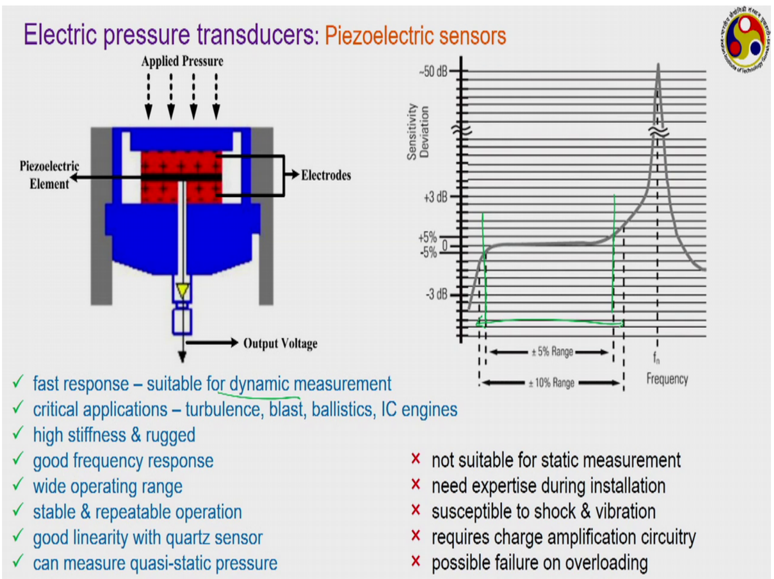

Another electric pressure transducer that we can talk about is the piezoelectric sensors, again the operation operating principle is the same like any piezoelectric devices. Here we have some kind of natural or synthetic crystals, which when being subjected to certain kind of force develops polarity that is positive wires go to closer to one plate and negative ions get accumulated closer to the other one.

And so if we connect them by a suitable output circuitry, we are going to get some kind of voltage output. So, this pressure force can really be related to this voltage output, and thereby giving a very easy way of pressure measurement. And we can operate this device over a wide range of pressure from a quite small to quite large special values.

They generally gave a very very fast response, thereby making them perfectly suitable for dynamical measurement. They are generally used in quite critical applications like measurement of turbulence inside IC engines for measurement of blast or ballistic kind of such applications. They are high stiffness, they are very very rugged device, good frequency response, again providing another reason for dynamical measurement.

Like this is the frequency response curve you can see. Here over a quite wide range of frequency from here to this the frequency remains very close to 0, and within plus minus 5 percent of 0. So, you can get any reading without bothering too much about the frequency response. If we can provide slightly larger say plus minus 10 percent range, then your band gets widened even more.

So, high frequency response allows us to use this kind of device for situations, where the pressure is oscillating quite rapidly like in case of IC engines. So, quite wide operating range they can provide from small to large, we can go for measurement, particularly again very suitable for turbulence or IC engine situation, where we can have pressure fluctuating from atmospheric level to 70, 80 times of atmospheric pressure.

The stable and repeatable operation, we can get from such piezoelectric sensors, they provide very good linearity, but of course that depends upon what kind of sensor you are using, quartz is a material which can provide you a good linear response that is a good variation of the output voltage or almost linear variation of the output voltage with the imposed pressure. And finally, we can also measure quasi static quasi-static pressure, again very suitable in case of transient situation.

However, there are quite a few factors also which are actually common in case of piezoelectric sensors. Like not suitable for static measurement, because like I have mentioned; may probably have mentioned in one of the earlier lectures related to the same topic that nature always finds a way to go back to the equilibrium. Accordingly, the charges will also try to diffuse across the crystal, so that we can get back to the neutral situation and thereby diffusing the outlet or output or nullifying the output.

So, they are not good for static measurement, but when we are looking for quite fast change in the output pressure or impose pressure, then they are very good devices. Generally, they need expertise during installation, while mounting on the on a particular location you need to be very very careful and to need to follow suitable procedure.

They can be susceptible to shock and vibration leading to the cracking of the crystal or some rupture of the crystal material requires charge amplification circuitry, because the charge that we get corresponding to general pressure levels can be quite small. And somehow you have to amplify that to get a measurable output voltage. And if they are subjected to some kind of overloading, they can there is possibility of failure of the crystal itself permanent damage to that.

So, we must adhere to the specified operating region, but still piezoelectric sensors like any other kind of measuring piezoelectric based measuring devices or again very good option for pressure measurement.

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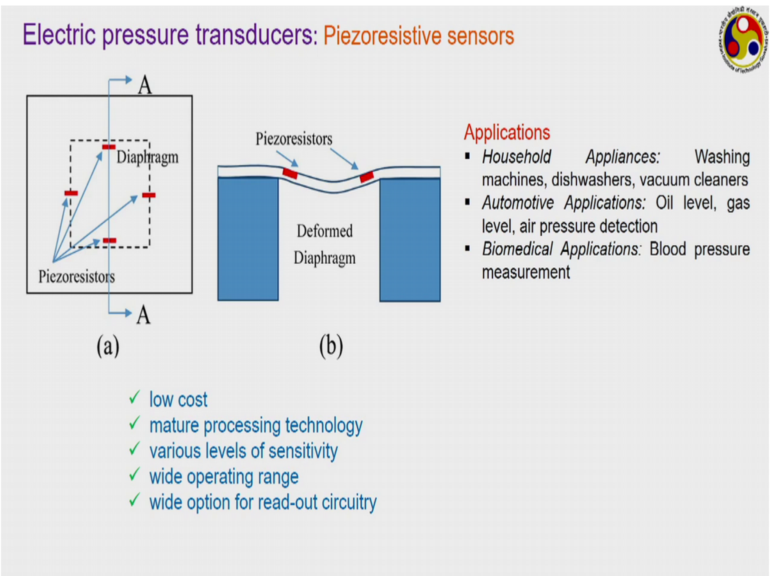

There is another variation of that piezoelectric sensors, which is piezoresistive sensor. Here the principle is slightly different; here we are not looking for any kind of charge reorientation on application of pressure rather we are talking about the change in the resistance of the crystal on application of any force.

So, such piezo resistive sensors are again quite common generally one of the earlier types of electric pleasure transducers. And they again found find the application in several quite common day-to-day applications. Their biggest advantage is the cost, they are generally quite cheap. There is a mature processing technology, because for years people are working on this and we already have this applied in several very common devices, like we are going to see very shortly.

Various levels of sensitivity, we can get from the corresponding crystals or corresponding sensors. So, depending upon what level of sensitivity we want, we can choose what kind of sensors to go for, there have quite wide operating range as well. And also we can have a several options for readout circuitry as well. Most common application, you will find in several household appliances like in washing machines, dishwashers, vacuum cleaners, where actually we have piezo resistive kind of sensors mounted to sense the pressure.

Automotive applications as well, like gas level or oil level measurement, air pressure detection, several biomedical applications like blood pressure measurement can be very common example of such sensors. So, these are electric pressure transducers, which are commonly applied for low to moderate and moderately high pressure applications.

So, so far we have discussed about three different kinds of measuring technology or pressure measuring technology. Out of which manometers are generally used for low to moderate pressure levels because, if you are looking for very high pressure difference, then the liquid column level will be very high; so, even with a high density fluid like mercury.

So, we generally have to use manometers only up to moderate pressure levels. Elastic pressure transducers, can have quite good range like using bourdon tube gauges, we can go to quite high pressure values, they but they are also more suitable for moderate to relatively high pressure measurements. Whereas, the diaphragm kind of gauges are more used for low pressure measurement or small pressure difference measurement. Electric pressure transducers again can have good ranges for low to relatively high pressure measurement.

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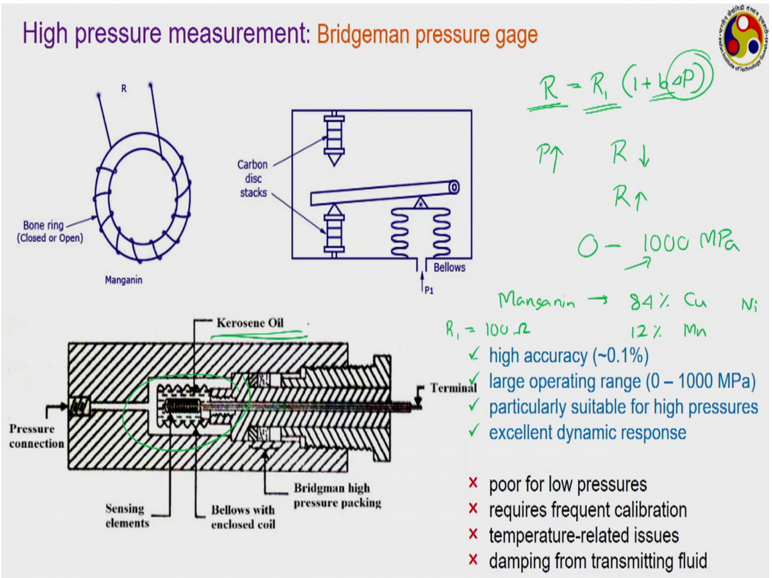

But, now we are going to talk about another one, which is again a electric pressure transducer, but that is specifically used for measuring high pressure. High means, it is really high pressure that we are going to talk about which is Bridgeman pressure gage.

Here the operating principle is probably it is a difficult to understand from the pictures that I am showing. But, the idea is that any common material generally have or common register generally have a pressure coefficient like, R is equal to R 1 into 1 plus b into delta P. Where R 1 refers to the pressure at one atmospheric pressure, b is called the pressure coefficient and delta P is the imposed pressure difference.

Now, one application of pressure difference certain material shows quite significant change in the value of this resistance. And that can subsequently be correlated to measure the pressure. So, as the pressure is imposed, there is a distortion causing the change in this resistance.

For most of the common material as the pressure increases, for most of the common metals the resistance decreases, but that may not be true for all materials. Like there are certain materials for which we generally find an increase in resistance like antimony, bismuth, lithium, these are and a few other alloys also. These are certain common examples, where we actually see an increase in resistance or application of pressure.

Caesium shows a very interesting property on application of pressure, it is resistance initially decreases, reaches a certain minima and then starts increasing. So, if we have proper idea about the value of this b, then just end of course the value of this R 1, then just by measuring the resistance R, we can easily measure this delta P. Accordingly, we can get a measurement of quite high pressure values. The pressure values can range from 0 to 1000 Mega Pascal. So, 1000 Mega Pascal is a huge pressure that we are talking about.

So, Bridgeman pressure gauges can give a very high range, but generally we use them more towards this 1000 Mpa pressure levels, because for smaller pressure the change in resistance may be quite small almost non miserable. So, and the pressure 1000 Mega Pascal has such a level of pressure and not measurable with the other instrument that we have discussed so far so, they are generally reserved for high pressure measurement.

Manganin in one of the common material that is generally used for measuring or fabricating such kind of pressure gauges, it comprises of 84 percent of copper, 12 percent of manganese and rest is nickel which is about 4 percent of nickel. It is one of the common materials, it generally we choose a register of 100 ohm under common atmospheric condition, and it has a b value of 2.5 into 10 to the power minus 11 Pascal inverse. So, the b value is quite small, accordingly we can keep on using it for quite high pressure range.

The biggest advantage of this one is high accuracy of the order of 10 to the power minus 0.1 percent, we can keep on using this. Then large operating range as I mentioned, particularly suitable for high pressures and excellent dynamic response, we can use them for both static and dynamic pressure measurement. But, their problem is they are not usable for low pressures, because as I mentioned for low pressure the change in resistance may be very very small without making any significant causing any significant change in output voltage.

They require frequent calibration, because there is chance of permanent distortion and application of pressures, so we need to keep on calibrating it from time to time. There can be temperature related issues, because we know resistance can also change with temperature. So, it is preferable to use them under constant temperature condition, which is quite restrictive.

And also another problem is that if you look to the diagram that is why, I have put the diagram actually. Here around the gauge, we have a fluid layer. Like in this example, it is kerosene oil which is giving you final pressure connection or I should say the pressure is being transmitted over this oil to the gauge. And this oil itself may have certain level of viscosity which will cause certain level of damping, so that can lead to certain kind of error in the final measurement, and we have to make proper adjustment corresponding to that. But, still Bridgeman pressure gauge is a very very popular device for such high level of pressure measurement.

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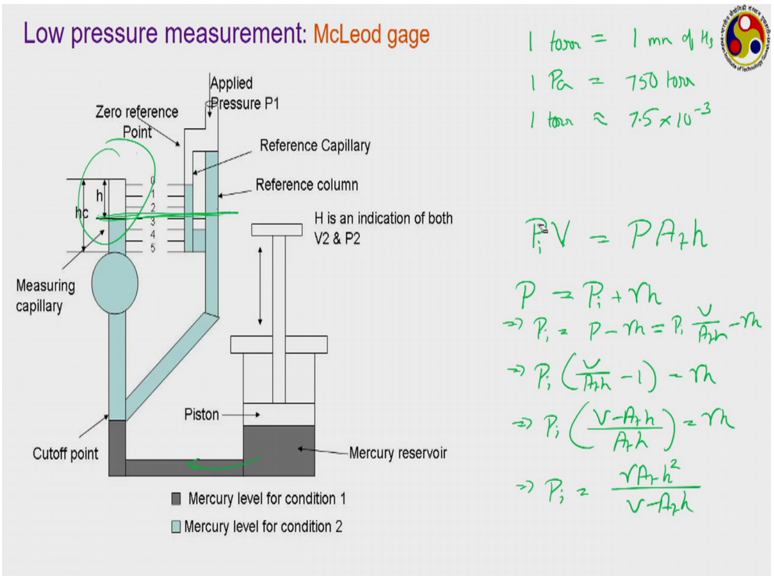

Next we go to low pressure measurement. Low pressure measurement is or we often call them vacuum pressure as well, because here we are talking about very very small value of pressure well below the atmospheric pressure level, which we conventionally called the vacuum pressure.

Now, as we have discussed earlier, the common unit that we use for measuring vacuum pressure is torr, 1 torr is just 1 millimetre of mercury column. So, accordingly 1 Pascal is approximately 750 torr thereby giving 1 torr is typically about 7.5 into 10 to the power minus 3 Pascal. So, 1 tour is a very small value of pressure and here we are talking about measuring pressures which are of the level of 1 torr or even well below that. One classical instrument for measuring such low pressure level is this McLeod gauge.

Now, look at the configuration that is shown here. Here we have this two tubes almost like an U tube kind of configuration, but these two tubes are connected to this particular line to another big chamber, which is generally which is filled with certain liquid maybe mercury. And on top of this cylinder, we have this kind of piston or a plunger arrangement.

Now, initially we open this particular line to the pressure which you are trying to measure like the pressure in this case is P 1, which we are trying to measure. So, as the pressure is applied, the gas which is at this particular pressure P 1 is allowed to enter through these tubes. We remove this plunger, we keep open or this piston, so that the mercury can flow out of the cylinder. And the gas can come in the blue portion shows the gas. And it is allowed to enter till it occupies this particular volume, which is mentioned as cut-off volume.

Let us say V is this volume, the cut-off volume is V. So, at this position we have V volume of gas occupying the blue portion of the tubes and the darkish gray portion is the mercury, which is still left in the reservoir. At this portion, we lock the plunger. And this particular portion is also blocked.

Now, in the second step, we start pushing the plunger; pushing the piston, so that mercury we starts flowing from the cylinder towards the tube into these two lines and thereby forcing the gas to move out. Now, here the pressure remains P 1, because it is still atmospheric to the pressure P 1. And accordingly, the gas gets trapped up in this portion of this but vertical channel.

We keep on pushing this mercury, till the entire gas which was initially having a volume of V which was initially inducted into the cylinder. They get strapped up into the small volume of H. Now, how it is looking like. We can still visualize this one like a U tube, because this entire portion is filled up with mercury and then they are pushing below this.

Here we have if we compare at this particular pressure level, as they are a connected body of liquid, so where pressure at this particular point refers to this applied pressure plus the pressure of this particular column of height h this that means, the initial volume of liquid that was or mass of gas that was inducted, the P into V the initial one, which we had that is now having if P is a new pressure into 80 is the cross-section area of this capillary tube into h is the height.

And if initial pressure was P, say P is the pressure at this particular point you are talking about, there should be how much following the principle of an U tube manometer (Refer Time: 38:32) P i plus gamma into h, where gamma is rho into g, rho referring to the corresponding mercury. That means, now from the previous relation if we take P out, so P i refers to P minus gamma h that is P from the previous relation can be written as P i into V by A th minus gamma into h which is P i V by A th minus 1 is equal to gamma h that is P i into A th V minus A th, h is equal to gamma h. So, P i is equal to gamma A th square by V minus A th.

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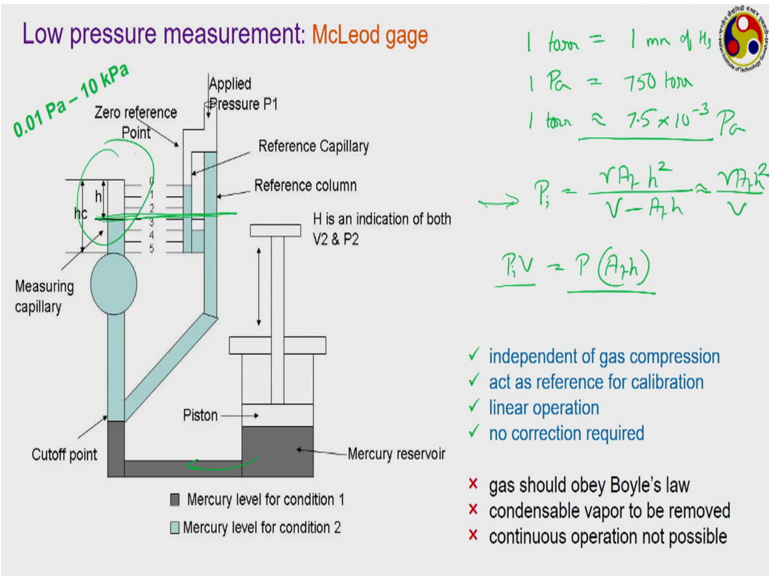

So, if I make some space on top, so finally we are getting P i is equal to gamma A t h square by V minus A t into h or quite frequently this V is quite large compared to A t into h, so gamma A t h by V. So, this is how we generally can measure the pressure, the P i just by using this measurement of this gas column height h.

But, now you can tell me what is the principle, we are using in this particular measurement a very common principle that you have learned in school level physics. What equation we started with that is P i into V was a initial situation, at the end we have t into A t h, which is the final volume. What is this relation P i into V refers to the initial situation the product of pressure and volume, this is the final sorry this is not P t P into a final pressure 80 into h is the final volume. So, this is simply the Boyle's law that means, you are using the Boyles law principle in this particular example to measure this low pressure P i.

If say give can give you pressure in the range of 0.1 Pascal to 10 kilo Pascal that is 0.1 Pascal refers to 0.1 Pascal refers to about 0.01 torr sorry, 0.01 Pascal is a quite small pressure which and as we have seen here 0.1 torr is about 7.5 into 10 to power minus 3 Pascal; so, 0.01 Pascal is of the order of 1 torr or slightly larger than that. So, it is in the range of 1 torr or higher, that we can measure through this particular situation. It is independent of gas compression, this particular measuring principle initial pressure does not matter and also the compression by the mercury, it does not affect the operation. We it is generally used as a calibrating tool for other kind of vacuum gauges. And the very linear operation because we are using a simple Boyles law for measuring principle and finally, we are getting a linear relationship, here we have the h square that I have missed.

So, we are getting a straightforward relationship between this P i and h. And no correction required, whatever we are getting from this relation that is the final pressure that we are looking for. Our problem is that gas should obey the Boyle's law, because that is the initial principle you thing you are starting. Then there may be some kind of condensable vapour that may be mixed with the gas and that can significantly affect the measurement. So, if vapour is present there, we have to apply some kind of corresponding correction. Continuous operation is not possible also, because we have to get the system back to the initial position, before we can start another reading.

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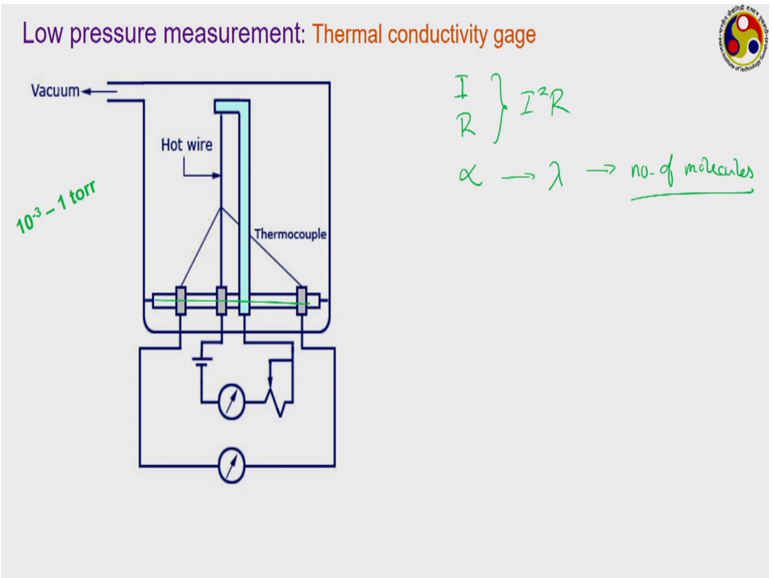

So, the other one vacuum gauge that we can talk about is referred to as a thermal conductivity gauge. Thermal conductivity gauge also often called the thermocouple pressure gauge. Here the idea is that as the pressure falls pressure; we are talking about extremely low pressure level. When we go below a critical pressure level with reduction in pressure the thermal conductivity of the gas also falls, because the number of molecules are less, accordingly it has much lesser capability of transmitting energy.

Now, here your idea is that we have a conductor and we allow some current to flow through this conductor. As the current flows through this conductor than the temperature of the conductor depends on three things. This conductor is surrounded by a fixed mass of gas, so it is conductivity or I should say it is temperature will depend on three things. One is the current that is flowing through this second is its resistance, these two combined will give you the I square R amount of heat that is being produced. And third factor is the capability of the surrounding medium to take away this heat that is by the mechanism of convection and radiation.

If the temperature is not very significant, then radiation can be neglected. Then the convection or corresponding convective heat transfer coefficient say alpha that depends upon the thermal conductivity of the gas fuel. And the thermal conductivity itself is dependent upon the number of molecules of that gas, when we are talking about very low pressure and the number of molecules are much less. Actually, we are talking about situations, where we are below the continuum limit that is the mean free path of these gas molecules are significant compared to the dimension of the system.

In that case, each molecule has to be considered separately and the number of molecules affect the thermal conductivity value for this. So, as we supply some current through this conductor, it is temper; there is an I square loss and the energy produced by this will be taken care of by convection and radiation. And accordingly, it will reach certain kind of equilibrium over a period of time. And the equilibrium temperature can directly related to the number of molecules present in this and accordingly the pressure of this gas that we are talking about.

One issue is that we have to keep the radiation small, so we can use low emissivity materials etcetera, so that we can have only convection as a primary mechanism. We can measure extremely low pressure from 10 to the minus 3 to 1 torr in this particular level. This gauges one issue is that they can reach high temperature and therefore there is a probability for this that the gauge that is thermocouple material itself may get oxidized. So, we generally use some kind of normal metal like platinum etcetera for fabricating these gauges, sorry I keep on forgetting exactly, where I have the graphs.

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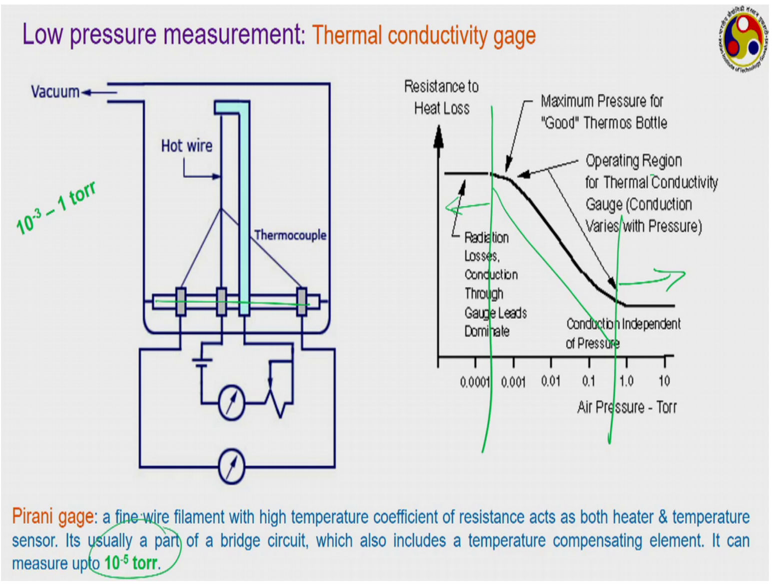

So, this is a typical situation you can see, we are above this particular pressure level, then conduction is independent of pressure or thermal conductivity. Below this the radiation becomes significant in this zone, so the temperature is quite high to so and we cannot get the measurement. But, what this range, the thermal conductivity is varying almost linearly with pressure. And accordingly, we can use these gauges to get a measurement of pressure using this principle.

Another variation of this thermal conductivity gauge or thermocouple gauge is called the pirani gauge, where instead of a separate heater, we are using just a same filament which acts as both the heater and the sensing element. Here if this filament is generally part of a huge stone, which kind of circuit just one of the four arms, we may have also a temperature compensating device to limit the temperature within a range. And this pirani gauge despite being just a variation of this thermal conductivity gauge, can give you even lower pressure can go up to 10 to the power minus 5 tall levels.

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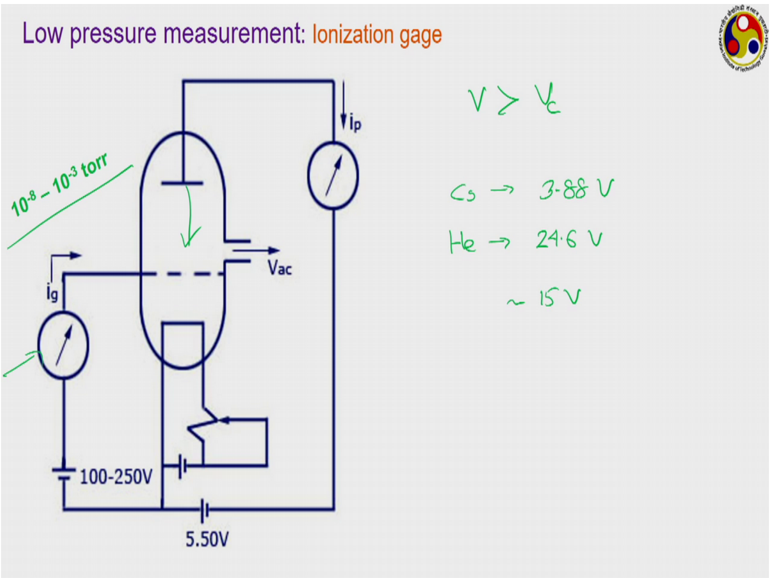

And another device which can go to an even lower pressure level can go up to 10 to the power minus 8 torr even that is called the ionization gauge. And ionization gauge is nothing but the conventional triode, where we have a grid, we have a plate and we have a cathode. And we have a very very low pressure gas inside this that is very less number of gas molecules.

Now, this high temperature gas column which may be somewhere in this particular zone. Here they are subjected to a potential difference between this the plate and the cathode. And when the pressure falls below a typical critical pressure level, then if we are able to impose a sufficient voltage generally a voltage value greater than certain critical voltage, then it is able to lead to ionization that is a electrons will be it will come out of the new the molecules. And as the electron passes through from the cathode towards this plate, then as the strike some molecules it will lead to positive ion formation by dislodging some more electrons.

So, the positive ion formation actually is a results of this low pressure gas or I should say to just to clarify, when the gas pressure is so low that is in this particular pressure level. Then we can almost assume that during this passage from this cathode to the plate, there is not too many molecules for the electron to cause more than one collision. So, the number of positive ions produced can then directly related to the number of molecules present there accordingly the pressure inside this cylinder.

The value of V C which is also called the ionization potential that varies depending upon what kind of material you are using. Like if you are using say something like caesium, for caesium it is just 3.88 volt which is probably the lowest we can have, whereas something like helium which it is about 24.6 volt, it is the maximum among the mono atomic gaseous. If you are using some kind of diatomic gas like hydrogen, oxygen, etcetera, it is typically of the order of 15 volt.

So, we have to impose a voltage higher than this ionization potential, and also you have to ensure that the pressure is lower than certain critical level. Then this ionization gauge can easily give you a measurement of pressure a very very low vacuum with pressure as shown here. So, there are a few other kind of gauges as well, like Knudsen gauge is another name that is coming to my mind as a vacuum gauge, but generally these are the most common one for which I have just described the principles.

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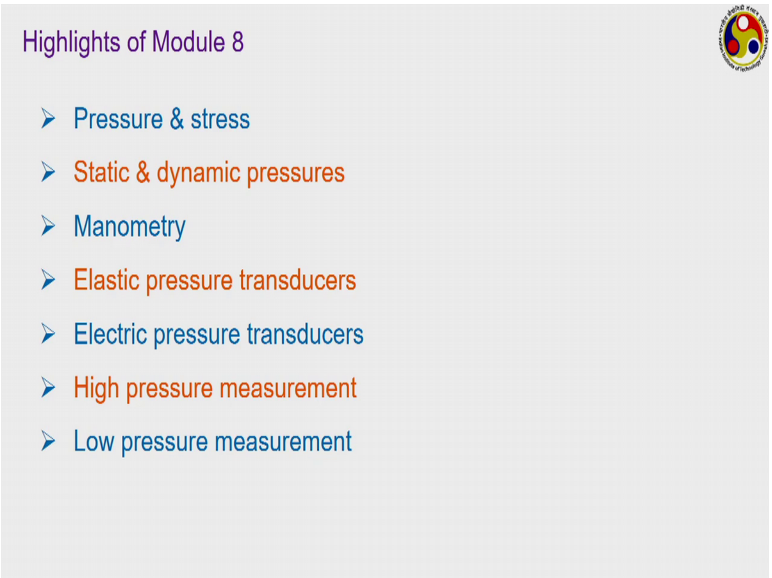

So, this takes me to the end of this particular module, where we have talked about different ways of measuring pressure. We started with a discussion about pressure versus stress, then we talked about different kinds of pressure like the static and dynamic pressures, absolute and gauge pressure. Then we have spend significant amount of time discussing about manometry, we talked about elastic pressure transducers. Today, we have talked about electric pressure transducers, several kind of electric pressure transducers like the piezoelectric and piezo resistive devices, capacitive sensors etcetera.

Then we have talked about the high pressure measurement that is only the Bridgeman gauge that we have talked about there are a few other options, but not that popular. And then we have talked about three different ways of vacuum pressure measurement using the McLeod gauge, ionization gauge and thermal conductivity based gauges.

So, that is the end of pressure measurement. I would like to thank you for your attention for this particular, we can also request you to send me the queries whatever you have, so that I can immediately respond and clear your confusions. In the next week, we shall be talking about the measurement of flow and fluid velocity measurement.

Thank you very much.