Cryogenic Engineering
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Lecture No. # 41
Instrumentation in Cryogenics

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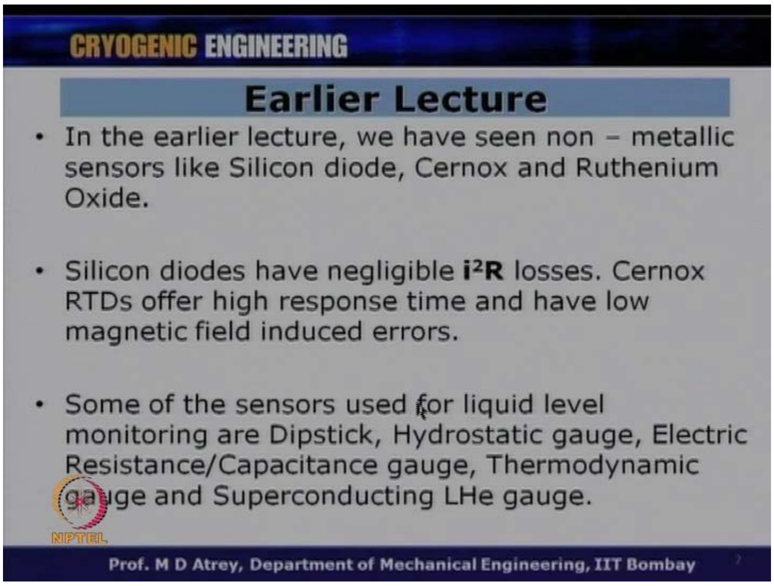

So, welcome to the forty first lecture on cryogenic engineering under the NPTEL program. We are talking about instrumentation in cryogenics, and in the earlier lecture we will talking about the sensors for temperature measurement at cryogenic temperature levels. And in the earlier lecture, we have seen nonmetallic sensors like Silicon diode, Cernox, and Ruthenlum Oxide. We have seen in detail how do they function? How does silicon diode function? How does Cernox function? What are the advantages and disadvantages of this various sensors are. So, we founded silicon diodes have negligible i square R losses, because they got a 10 micro amp current flowing through it; Cernox RTDs offer high response time, and have low magnetic field induced errors.

So, whenever that magnetic field, Cernox will be preferred. Some of the sensors used for liquid level also, when we saw the liquid level sensors to monitor the cryogen level, we saw the principal an which dipstick, hydrostatic gauge, electric resistance, capacitance gauge, thermodynamic gauge, and superconducting liquid helium gauge, how do the y function? How do they represent? How do they indicate the cryogen level or the liquid level. Now going ahead form temperature, and cryogen levels.

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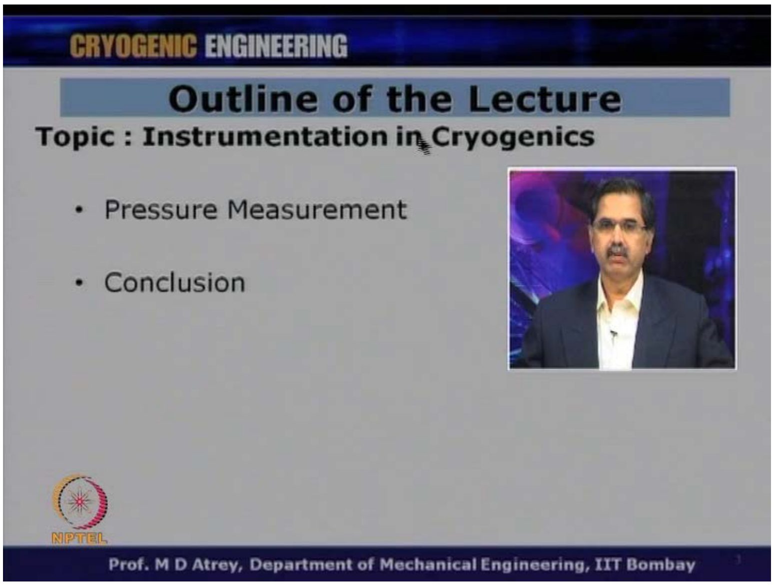

In this lecture we going to talk about pressure measurement. So, pressure measurement is a very important task in cryogenic engineering; however, where not talking about positive pressure, but we are talking about vacuum pressure; that is negative pressures, then will conclude this particular topic of instrumentation in cryogenics.

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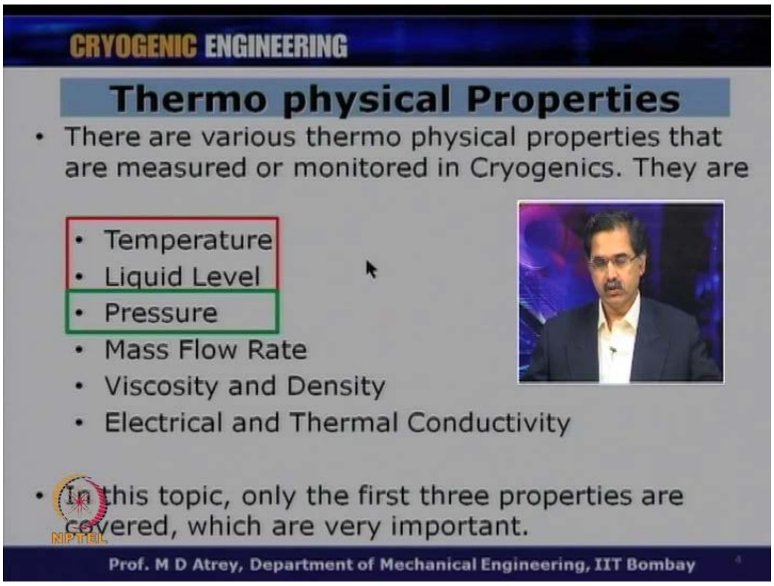

So, there are various thermo physical properties that are measured or monitor in cryogenics, and they are we know temperature, liquid level, pressure, mass flow rate, viscosity, and density, electric and thermal conductivity. Out of which we are said that we would see temperature, liquid level, and pressure in details, while others because these are the three which are normally used in all cryogenic experiments. So, the first three are going to be dealt out of which we have a already dealt with temperature, and liquid level. And in this particular lecture, we go to talk about pressure. So, this particular lecture is going to be on pressure measurement in cryogenic engineering.

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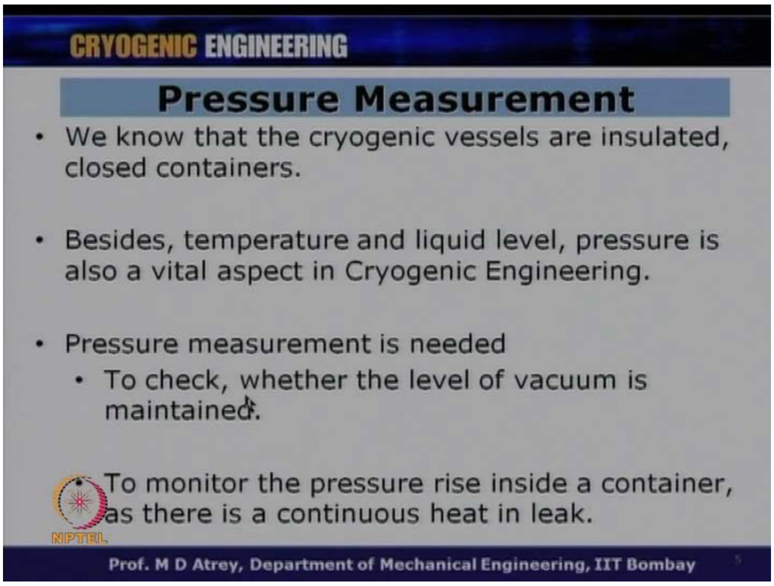

We know that cryogenic vessels are insulated closed containers, whenever I keep cryogen we know that it is it has to (( )) insulated, it has to be absolutely close. So, that the hit radiations or any other radiations will not come over there, they not been convection; the heat in leaks will be as in as minimums possible, so that the boil of his kept minimum.

Besides, temperature and liquid level, pressure is also a vital aspect in cryogenic engineering. The pressure measurement is needed to check whether the level of vacuum is maintained, because we are seen that vacuum is used everywhere; and therefore, vacuum monitoring is very very important. Therefore pressure measurement is required to see, if the level of vacuum is retained all through; if there is any leakage vacuum will be broken, and no experiments it can be conducted in cryogenics, because the moisture will come in side, all kinds of loses will happen and therefore, the experiments will not be able to to be carried out. Also be measure pressure to monitor the pressure rise inside a container as there is continuous heat in leak. So, if the boil of increases the heat in leaks increase, the pressure will rise in the container; and that also can be monitored if we founded, this is the important parameter to be monitored. However, there is normally a safety wall which will open if the pressure exits a particular pre-determined value. So, this can be normally taken care of while this is the most important thing to be monitored.

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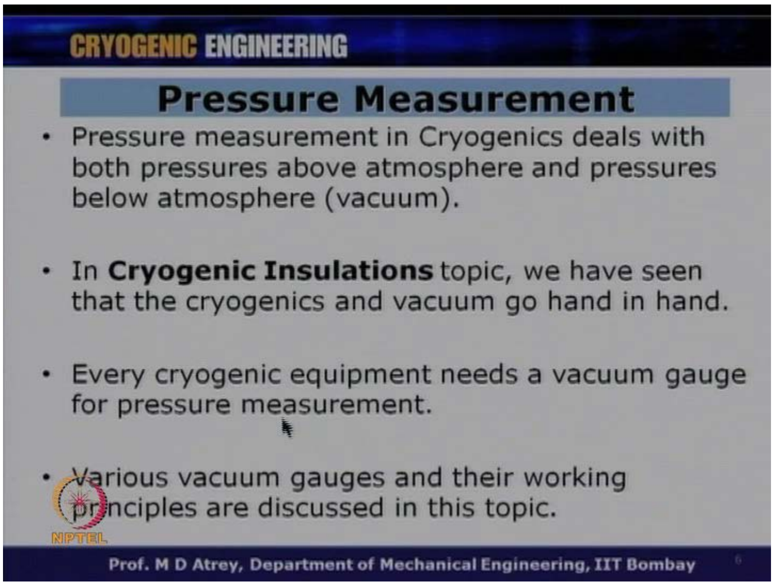

Pressure measurement in cryogenics deals with both pressure above atmosphere, and pressures below atmosphere which is vacuum, which is what we are talking about. In cryogenic insulation topic we have seen that cryogenics and vacuum go hand in hand. So, wherever cryogenics experiments are done we have seen that most of the cases will have vacuum or on it. Every cryogenic equipment therefore, needs a vacuum gauge for pressure measurements. So, wherever vacuum comes will talk about order of vacuum, what kind of vacuum talking about minus 2, minus 5, minus 10; and therefore, it need to be monitor and therefore, vacuum gauge is very very important.

So, every cryogenic most of the cryogenic experiments will need to have a vacuum gauge with it; basically it will come with a vacuum vacuum equipment also the rotary pump or diffusion pump or cry pump, they will have the vacuum gauges. So, vacuum gauge, vacuum pump, vacuum device, and integral part of cryogenic experiment, and for it is very important to understand how does a vacuum gauge function. What kind of vacuum gauge should have purchase for my system alright, how costly it is. Is it required in this particular application what kind of vacuum gauge? What principal of working should be they are all this things have to be monitored to select a particular vacuum gauge. Various vacuum gauges, and there working principal therefore, are discussed in this topic, because vacuum gauge becomes very important device to be used in the cryogenic instrumentation. And therefore, in this particular chapter, in this particular lecture will discuss various vacuum gauges, and there working principles.

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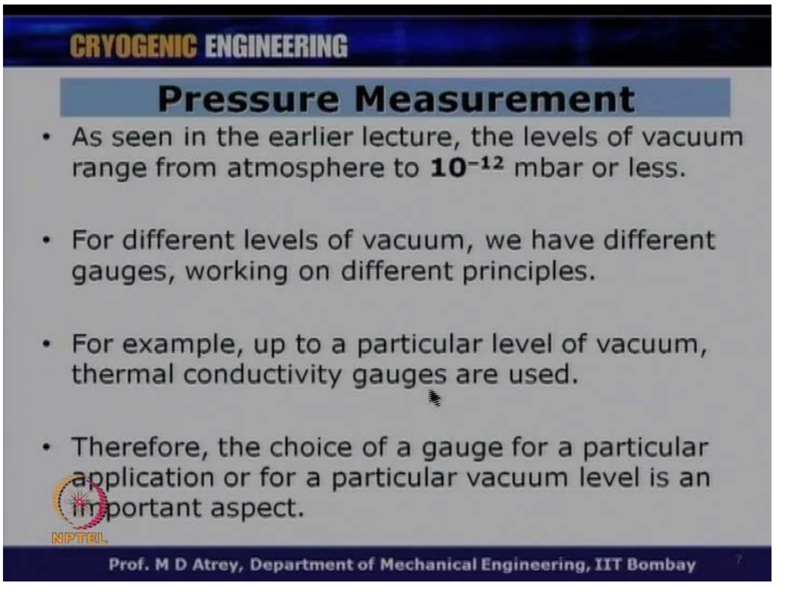

So, that we understand which vacuum gauge we should select for our particular application. As seen in the earlier lecture, the levels of the vacuum ranges from atmosphere to 10 to the power minus 12 milli bar or less. For different levels of vacuum, we have different gauges working on different principles is a most important thing, if we got a level up to minus 2 or minus 3 or minus 4, I can have a particular gauge. If I am talking between minus 4 and minus 6, I have got a (( )) other principle or vacuum gauge working in that on a difference principle or if I want to you know measure vacuum of very low grade, that means minus 9, minus 10, minus 11, etcetera. Then I have to have a different kind of a vacuum gauge; and therefore is very important to know all work principle this vacuum gauges work.

For example, up to a particular level of vacuum thermal conductivity gauges can be used. So, up to minus 3, I will say thermal conductivity gauge can be used; therefore, the choice of a gauge for a particular application or for a particular vacuum level is an important aspect. If I want to go for minus 9, I should is a (( )) gauge, in the four principle of the working of that particular vacuum gauge is different than as compare to the principle on which thermal conductivity gauge works, and this is very important.

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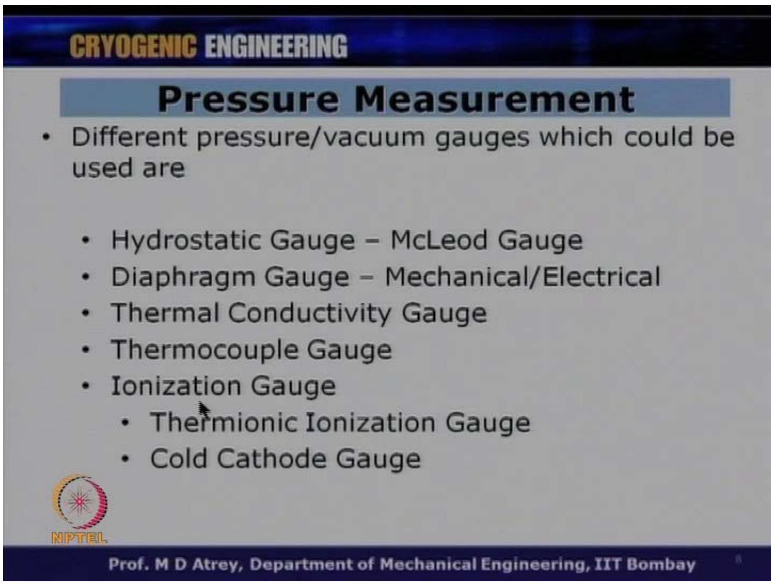

So, different pressure vacuum gauges which could be used are hydrostatic gauge which is McLeod gauge, which is a most primary gauge to measure vacuum. Diaphragm gauge, we can have a mechanical gauge or electrical gauge also we got a thermal conductivity gauge is just mentioned earlier, and you got a thermocouple gauge this two are normally would be use up to minus 3 or minus 4 levels of vacuum. Then we got a ionization gauge and under ionization gauge we got a thermionic ionization gauge, and we got a cold cathode gauge.

Now, all this gauges are actually representative of various other gauges; actually there are various other gauges are also used, but most of them would work on a principle similar to this. So, in minus 3 minus 4, I will have something similar to this in very very low vacuum or very low vacuum gauges , we will have a principle would almost kind of similar to now these principles alright. And therefore, we will have some miner advantages, and disadvantages related to vacuum; the process life and the accuracy.

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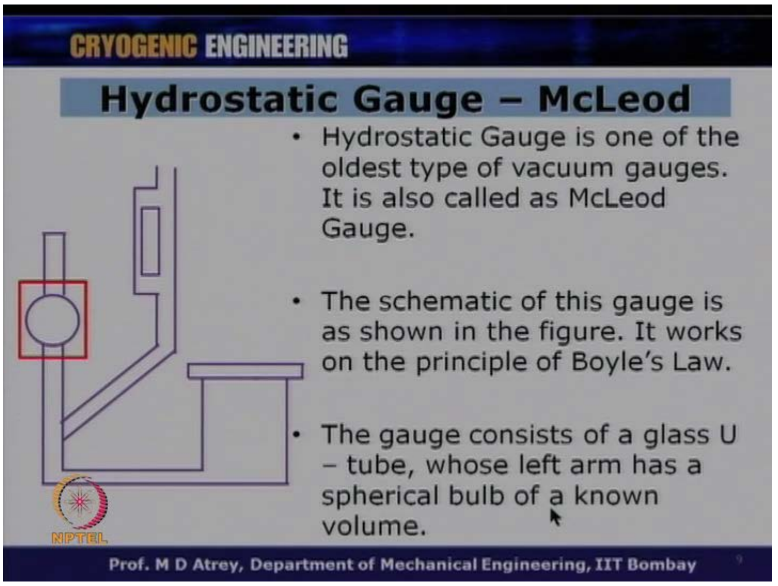

Now, let us see one by one on what principles these gauges work. Hydrostatic gauge is one of the oldest type of vacuum gauges, it is also called as McLeod gauge. The schematic of this gauge is as shown in the figure, and it works on the principle of simple Boyle's law - Boyle's law, pv is equal to constant; p 1 V 1 is equal to p 2 V 2, temperature meaning constant alright. So, this is what everybody knows. Now, this is schematic one which the McLeod gauge works, and we we can see this schematic as well as we try to understand the schematic as well as try to understand the principle on which this particular gauge works - the gauge consists of a glass U-tube, which is what you see here alright, whose left arm has a spherical bulb of a known volume.

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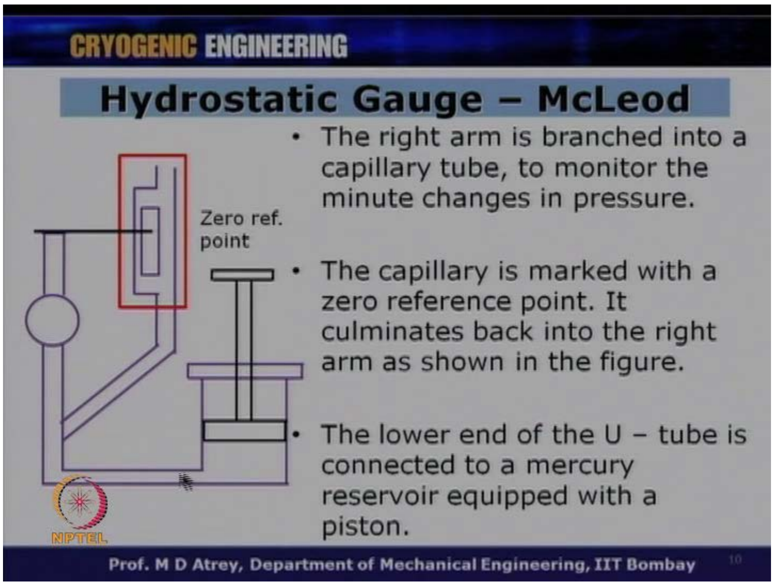

So, let us this is the U type, and this you got a spherical bulb of a known volume. The right arm is branched into a capillary tube should write arm, and then is one more branch which is capillary tube over here, and this again joins back the main arm. The right arm is branch into a capillary tube to monitor the minute changes in pressure. The capillary is marked with a zero tolerance zero reference point; if it is a zero reference point over here, it culminates back into the right arm as shown here. So, this capillary again culminates into the right arm as shown alright. No, this reference point - zero reference point also actually is in line with the top of this arm. So, this is always what we call as zero reference point. Now, the lower end of U tube is connected to a mercury reservoir equipped with a piston.

So, this lower end will have mercury, and this is connected to some kind of reservoir, where the piston moves up and down. So, that this piston motion up and down will control the motion of the mercury in and out of this device or this gauge. This is actually over gauge, while this piston will basically see that mercury is going up or down. So, that with the motion of this piston we can monitor the feeling, and empty of this U- tube.

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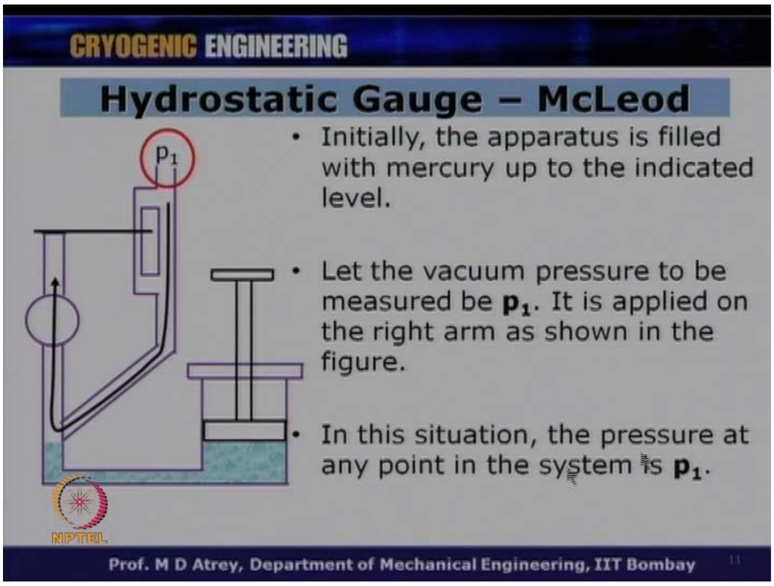

Initially, the upper rate is filled with mercury up to the indicated level. So, we can see that top got mercury up to this point before the branching happens

So, now I see that the mercury has come up to this an I will adjust this by pushing this piston up and down. So, the mercury has in has been up to this point, and the pressure working volume of wish the pressure has to be measure of is the vacuum has to be measured is connected to this place. So, my experimental device or whatever the cryogenic volume on which experimental are carried out, in which I want to have a vacuum, this volume is connected to displace alright. So, let us say we want to measure this p 1 value, let the vacuum pressure to be measured is p 1 it is applied on the right arm as shown in the figure alright. Now, this pressure is entire volume over here, and therefore, the entire volume here is at pressure p 1, which is a vacuum pressure actually; in this situation the pressure act any point in the system is p 1.

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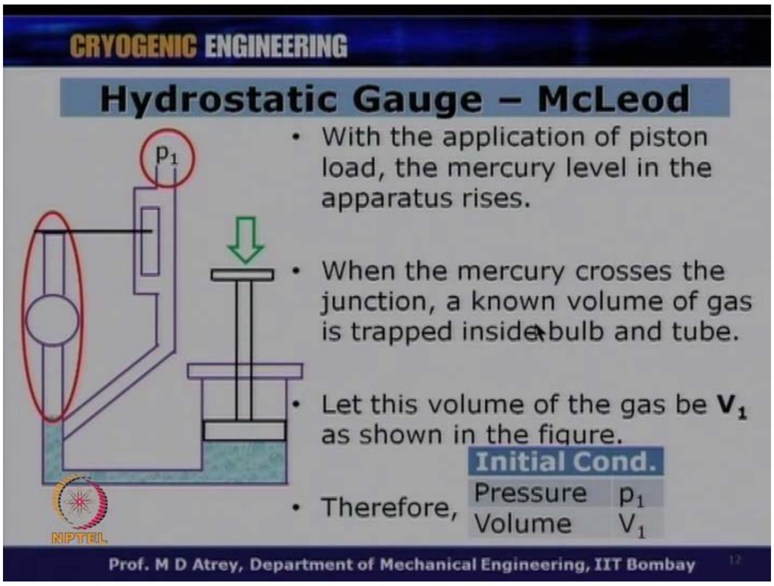

Now, with the application of piston load, when the piston is moved down, mercury now will move up; with the application piston load the mercury level in the operate rises, and we are bringing up from here to here first just to understand that now the gas in this region is now detach from right up alright. So, that the gas depending or whatever vacuum level we have, this is the volume of the gas which is fixed alright. We know this volume variable; I know the volume of this, I know the volume this, I know the volume here, and I know that now some volume has got trapped which cannot be now seen from this site alright.

So, when the mercury crosses the junction, when the mercury has cross the junction in known volume of gas is trapped inside the bulb, and tube. So, this much volume which is the volume of this tube plus this tube plus the entire bulb, I know in known volume has been trapped now in this case. Let design volume of the gas be V 1 as shown in the figure. So, now, here we are got the pressure of p 1, and we are got a volume of V 1, because p 1 was initially wanted, we just came up and we know that there is the volume of V 1 over here, and we know that p 1 V 1 is the volume - pressure and volume respectively that is going to be here. Therefore, initial condition now is going to pressure at p 1, volume at V 1 alright. So, your clear about this.

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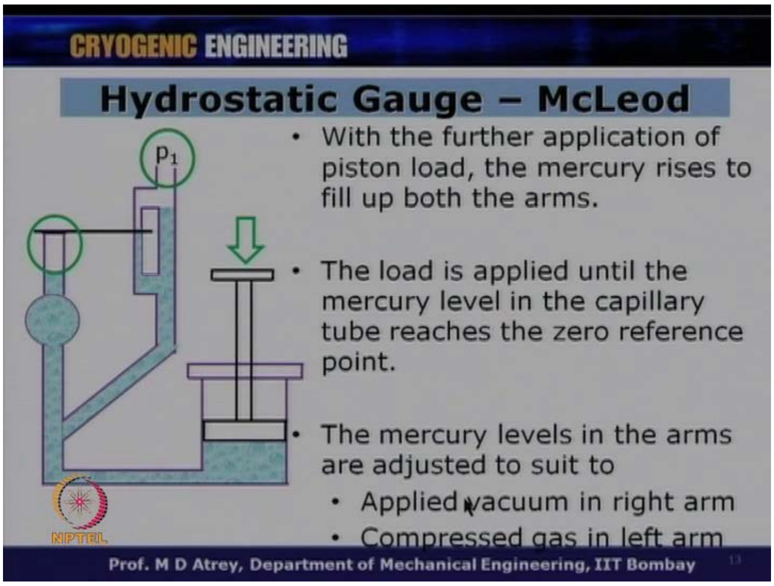

With the further application of piston load now, the mercury rises to fill up both the arms. Now, I will prices down, and the mercury come here, the mercury will come here. The load is applied until the mercury level in the capillary tube reaches the zero reference point.

So, I will go and pressing this piston till the point that is mercury goes up, and occupies position up to this alright. Depending on the vacuum level over here, depending on the whatever load I give, I will ensure that the piston is pressed to such an extent that the mercury will come here hands top, and this particular point my zero reference point as soon as mercury comes up to zero reference point I will stop pushing this piston down. So, the load is applied until the mercury level in the capillary tube reaches the zero reference point. Let us see what happen now alright.

So, now I have reached up to this point, and I am stopping the motion of this the pushing of this system. Now, what is happened? Whatever volume was there p 1 and V 1, now this gas which was previously over here is getting compressed to some pressure over here, and some volume over here. I will know this pressure I will know this volume, and now I will do for that calculations. The mercury levels in the arms are adjusted to suit to the applied vacuum in right arm, compressed gas in the left arm. So, I will do this motion is such a way that I have some significant volume over here, and in this arm and also is ensure that applied vacuum is taken care of. So, I can do this piston moment in such a way that these things get adjusted.

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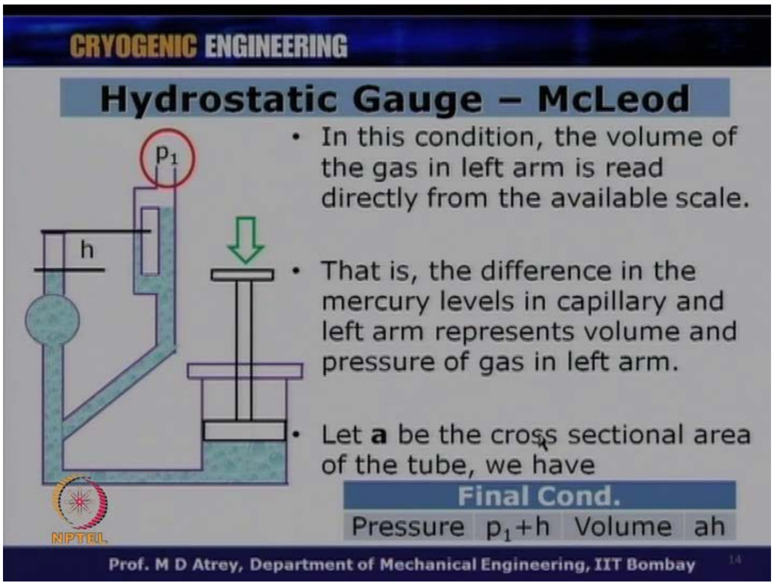

In this condition, the volume of the gas in left arm is read directly from the available scale. So, now, I got some scale over here, which tells may be that the volume of the gas in this left arm has and height of h, and I know the area over here. So, I can calculate the volume of the gas that is being trapped over here. So, there will be a scale over here, which can be directly rate the the value of gauge can be directly from that, and one can complete the volume therefore, that is the difference in the mercury levels in capillary, and left arm represents volume and pressure of the gas in left arm right.

The difference in the mercury levels in the capillary, and left arm represents volume and pressure of the gas in the left arm. So, I can calculate the pressure at this point right, which is going to be pressure at this point, and which is equal to p 1 plus corresponding to the height of this. This is my new pressure now alright, because this is exposed to pressure p 1, the pressure at this point will be p 1 plus the pressure correspond to height gauge, and volume I know because I know the cross sectional area of this I know the height of this. So, I know both pressure, and volume associated with this volume in this left are alright; and I know now in p 1 V 1 is equal to p 2 V 2, and I can do further calculations.

Let a be the cross sectional area of the tube, we have final condition as pressure at this point is going to be p 1 plus h equivalent, and volume is going to be a into h alright, these are my final condition of pressure and volume respectively.

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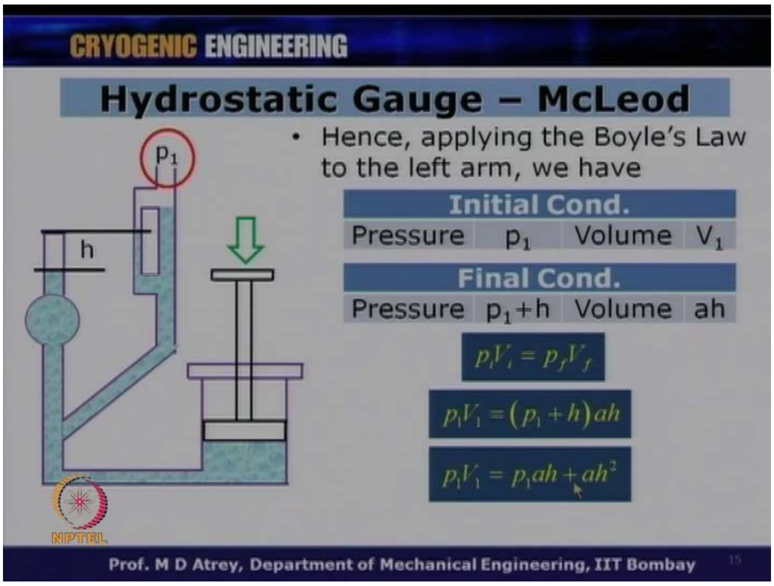

Hence, applying the Boyle's law to the left arm, we have initial condition - pressure p 1, volume V 1, final condition - pressure p 1 plus h volume ah, p i V i equal to p f V f initial p V is equal to final p V. So, p 1 V 1 is equal to p 1 plus h into h, p 1 V 1 is equal to p 1 ah plus ah square. Simple algebra it thing.

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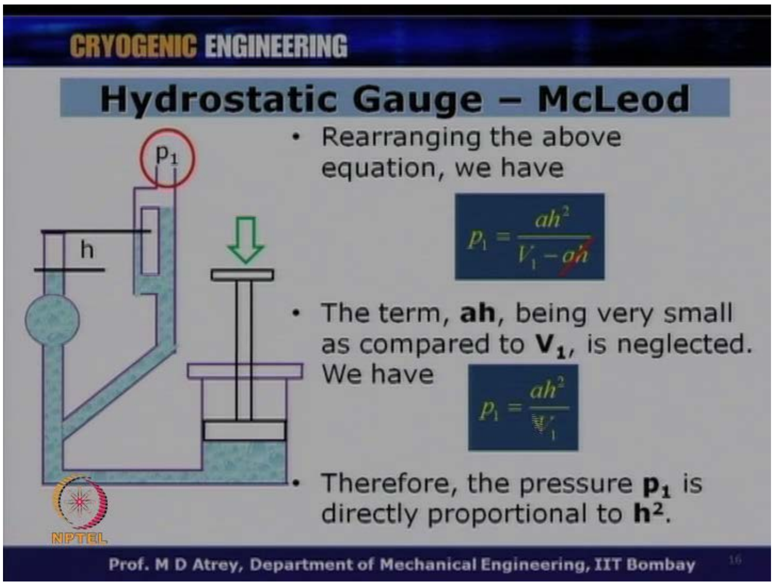

Rearranging the above terms, we have p 1 is equal to ah square divided by e 1 minus ah, and this ah term is very very small as compared to V 1, because V 1 is a very very week volume alright. The term ah being very small as compared to V 1 is neglected under for we have, I will take neglect this under for p 1 is equal to ah square upon V 1. And therefore, we can say now the pressure p 1 which we want to measure is a function of h square, and I can do a calibration accordingly, and I can complete the value of p 1 therefore. So, directly as soon as this is connected, I can adjust this things how the value of h and know h is going to be representative of the pressure we are talking about, because a is known to me, V 1 is non to be there constant basically alright.

So, pressure can be read directly as a function of now h square. And this is the way, the pressure in the basic principle using this basic principle can be (( )) by using the simple Boyle's law, but then we have seen that the gas (( )) Boyle's law.

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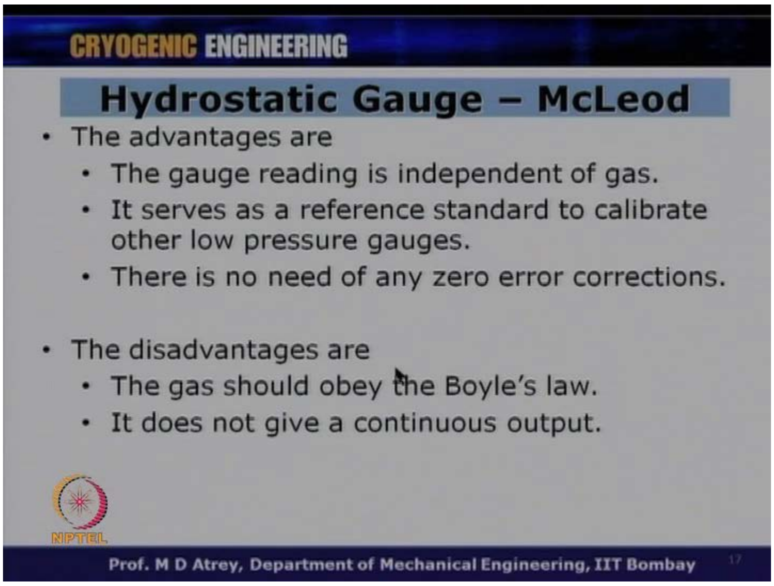

The advantages are the gauge reading is independent of gas, whatever gas I use I do not have the bother about it, I can get the pressure reading that. It serves as a reference standard to calibrate other low pressure gauges, I can use this technique to calibrate other sensor also, and there is no need for any zero error corrections.

There is nothing called as zero error connections, everything we are doing by push the piston up and down I do all the measurements. The disadvantages are the gas should obey the Boyle's law they said, which is important; that means, a gas should be a ideal gas, and it does not give a continuous output. So, whenever I want to measure I will do the piston up, and down. And therefore, I will not get a continuous reading, if the if the vacuum breaks I will not get a knowledge about this, because every time I will have to major the vacuum, whenever I want to the some disadvantages of this particular McLeod gauge. Coming from McLeod gauge now, let us see other gauges also for example, you have got a diaphragm gauge.

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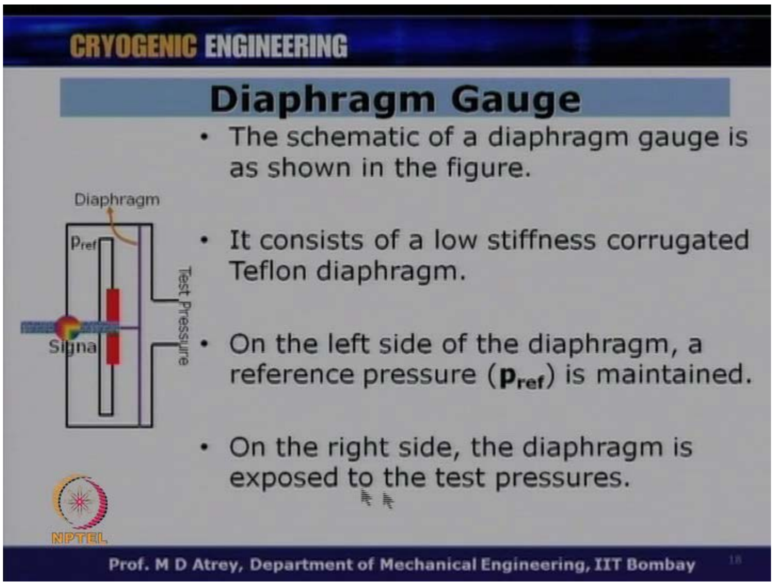

The schematic of a diaphragm diaphragm gauge is as shown in the figure. So, we got a diaphragm which is shown over here, we got a working space here, and we got a vacuum to be measure alright. And they got a p reference point over here, and some signal at this point. So, it consists of a low stiffness corrugated Teflon diaphragm which is my diaphragm over here.

On the left side of the diaphragm, a reference pressure p reference is maintained. So, I got a some reference pressure on this side, and I got some vacuum or some pressure which is to be measured on the right side of this diaphragm. On the right side the diaphragm is exposed to the test pressure alright. So, the test pressure is the one which which we want to measure.

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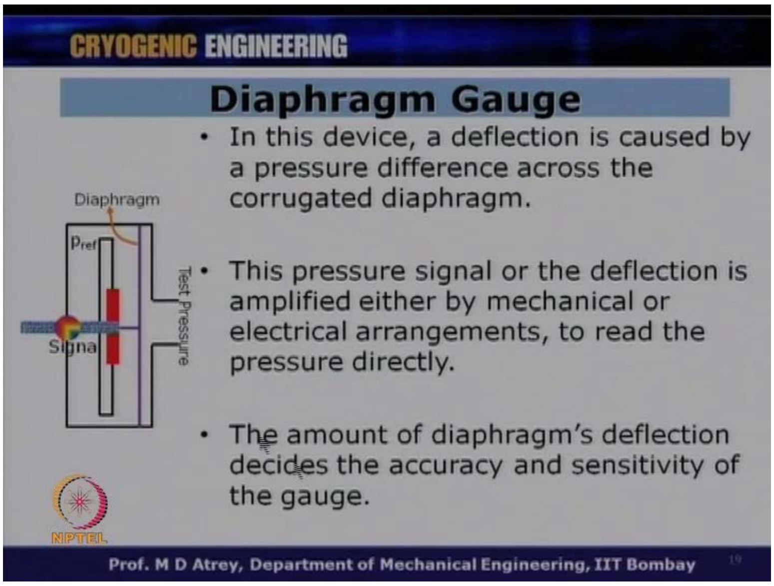

In this device, a deflection is caused by a pressure difference across the corrugated diaphragm; that means, you will have some pressure difference between the pressure to be measured, and reference pressure on this side. Depending on this pressure difference this corrugated diaphragm will go up or down it will come on this side, it will come on that side, depending on who is higher. Now, this deflection of the diaphragm actually is getting calibrated, it will send a signal to over a measure in devise, and that is a simple principle of a diaphragm gauge. This pressure signal or the deflection is amplified either by mechanical or electrical arrangement to read the pressure directly. So, simple diaphragm motion is going to be amplified, and it will fit some kind of a signal which would mechanical signal or electrical signal, and this is simple principle of diaphragm gauge. The amount of diaphragm's deflection decides the accuracy, and sensitivity of the gauge. So, how much deflection occurs will show the sensitivity of the device.

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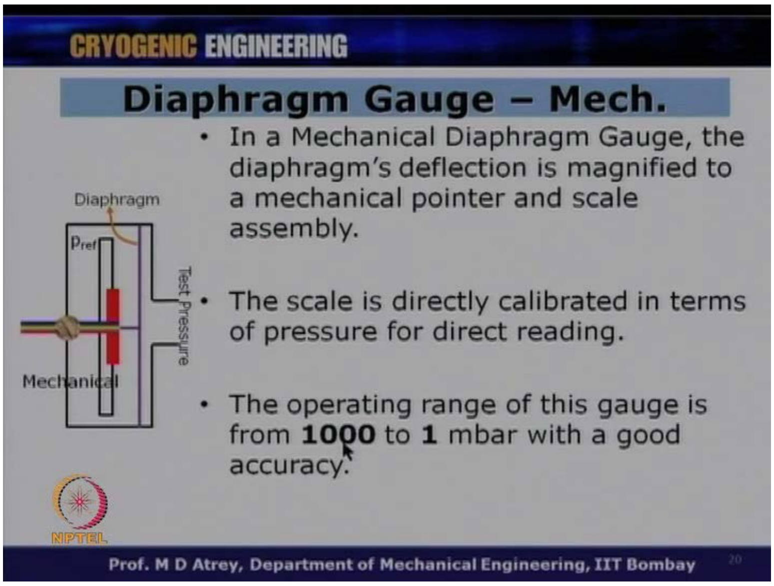

So, if you got a mechanical arrangement to see the motion of this diaphragm, we can have some (( )) arrangement, you can some middle, and thing like that and that can be used. In a mechanical diaphragm gauge, the diaphragm's deflection is magnified to a mechanical pointer and scale assembly.

The scale is directly calibrated in terms of pressure for direct reading. The operating range of this gauge is going to be from 1000 to 1 milli bar with a good accuracy alright.

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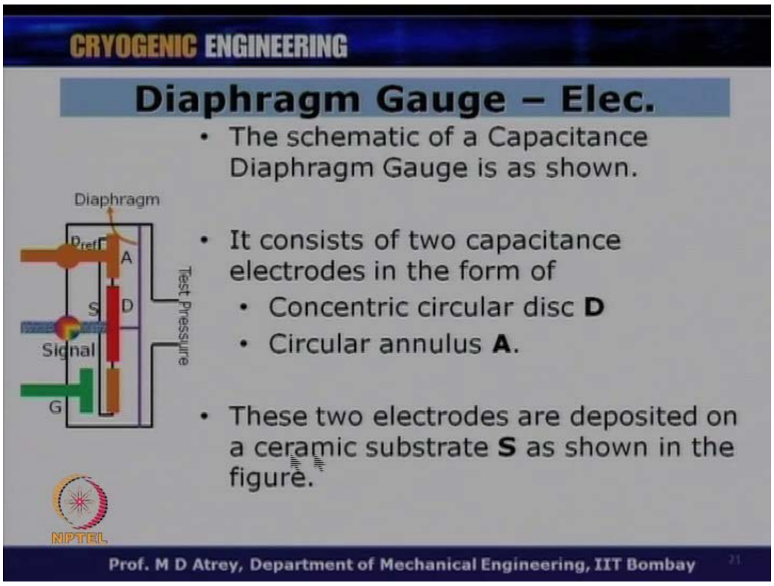

Instead of mechanical, I can have some electrical signal coming out of it. So, in this case I have got different arrangement over here on the left side of the diaphragm alright. So, here, the schematic of a capacitance diaphragm gauge is as shown.

So, when never electrical signal I want I can use a capacitor diaphragm gauge. So, depending on the motion of the diaphragm, the capacitance on the left suitable change which will representative or which will be calibrates to tell me what the pressure is there on the right side. So, it consists of two capacitance electrodes in the form of concentric circular disc D, which is what you C alright there disk D, and A also circular annulus A. So, got a two discs - one eight D, and annulus A alright.

These two electrodes are deposited on a ceramic substrate S, and you can see there is S ceramic on which this, these two capacitors electrodes are placed alright.

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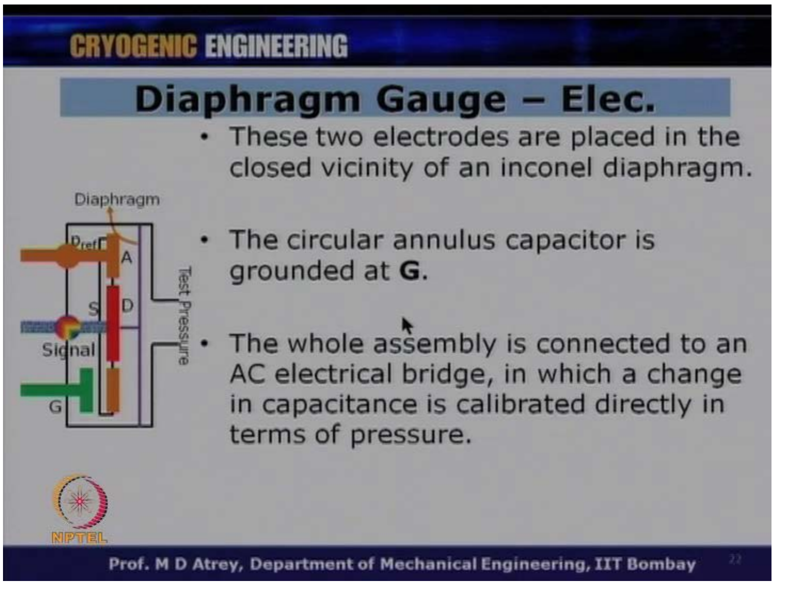

These two electrodes are placed in the close vicinity of an inconel diaphragm. So, you got a diaphragm which is this, and its connected to the this now. The circular annulus capacitor is grounded at G, and this is going to be grounded at G. The whole assembly is connected to an AC electrical bridge, in which a change in capacitors is calibrated directly in terms of pressure. So, whenever there is the motion of diaphragm, the capacitors change would happen over here; and this capacitance change is going to be connected to AC electrical bridge, and whatever changes happen in the capacitance depending on the pressure change on right side. It will be shown of over there or this capacitance change directly can be calibrated in terms of vacuum pressure, and that is a simple principle of electric diaphragm gauge.

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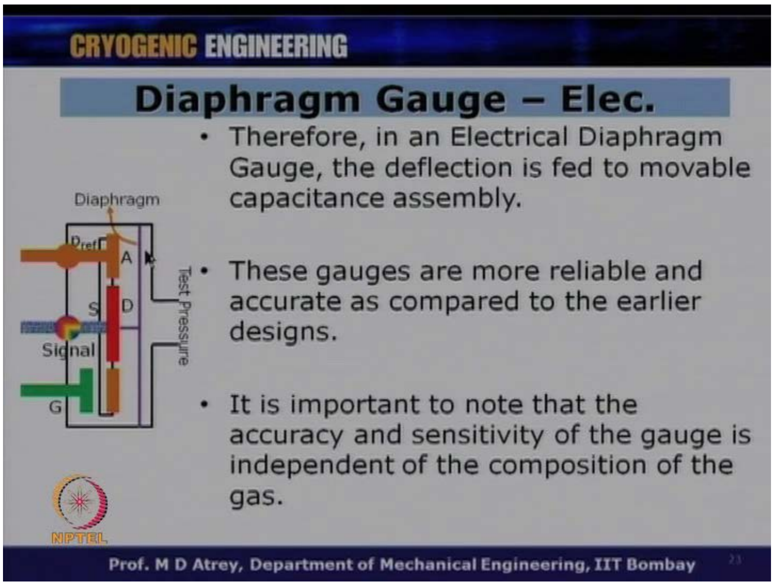

Therefore, in an electrical diaphragm gauge, the deflection is fed to movable capacitance assembly. These gauges are more reliable, and accurate as compared to the earlier designs, did not be any in you know mechanical assembly there is not be any herring mechanism I think like that; it is just the capacitors change which may be amplified, and fit where signal, and directly the reading of the vacuum on this side and be taken using this electrical diaphragm gauge. It is important not the accuracy and sensitivity of the gauge is independent of the composition of the gas alright.

So, basically this assembly does not see the gas - the gas pressure just you know presses this inconel or inconel motion is occurring on valuable gas, that is it the compression of the gas they come into picture.

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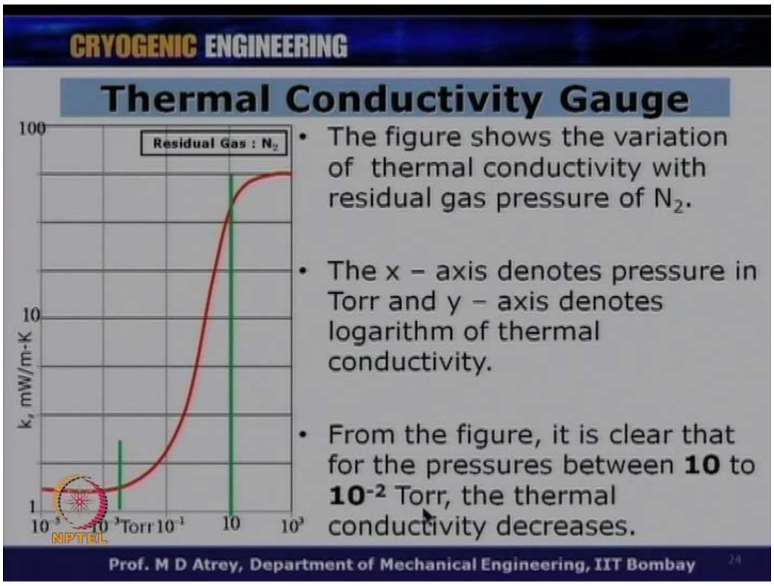

Now, let us come to the other respect which is thermal conductivity gauge, and this is like commonly used gauge thermal conductivity gauge. Now, it is based on a simple principle that this figure shows, what is this figure show? It shows the figure shows the variation of thermal conductivity of a gas with residual gas pressure of N 2. So, we have got a gas pressure given over here, and these gas pressure and thermal conductivity with the gas the variation of the thermal conductivity of the gas with this gas pressure acts as a principle on which this particular thermal conductivity gauge works. The x axis denotes pressure in torr, and y axis denotes logarithm of thermal conductivity alright.

So, these these are logarithmic skill of thermal conductivity of the gas, while the x axis gives the pressure. So, we can see the pressure in torr minus 1, minus 3, minus 5 etcetera. Now, what you can see from here, when you got a pressure range of 10 to 10 to the power minus 3, the variation of the conductivities almost linear approximately linear, while above that it is flattened, and below that also it hardly so any change.

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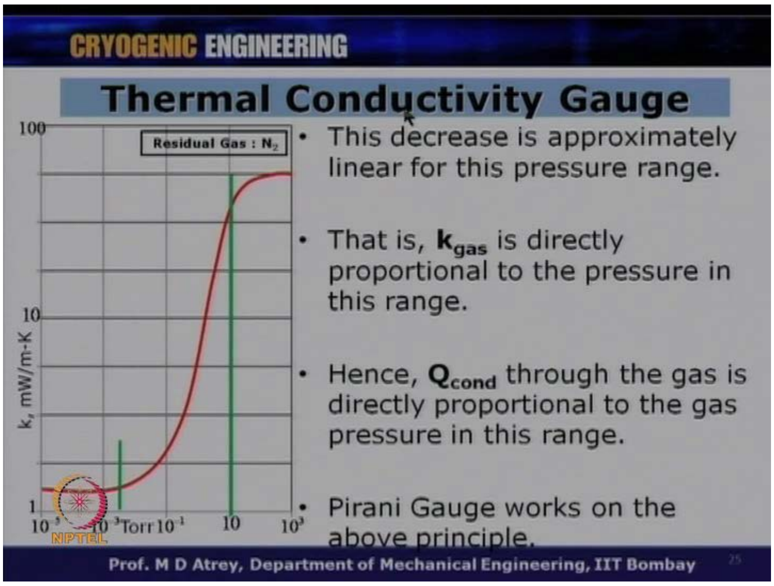

But we need goes from 10 to 10 to the power minus three, these variation is quite linear approximately from the figure it is clear that for the pressure between 10 to 10 to the power minus 2 torr the thermal conductivity decreases, that is A, and this decrease approximately linear for the pressure range - for this pressure ranges these decreases approximately linear. So, what is linear the variation in conductivity - the conductivity where is linearly for this particular pressure range; and therefore, this conductivity change can be consider to calibrate the pressure. So, whenever the conductivity change, the Q conduction will change and therefore, that Q conduction will be indicative of the pressure during this pressure range, that is K gas is directly proportional to the pressure in this range.

Once you say K gas, the heat conducted by that gas is the function of K gas. And therefore, conductive conduction through the gas is directly proportional to the gas pressure in this range. So, if I can calculate Q conduction, if I got some representative value of Q conduction, I can relate Q conduction to the pressure of the gas. Piano gauge works on the above principle under therefore, piano gauge always works on thermal conductivity, and very commonly piano gauge is use up to 10 to the power minus 3 torr pressure measurement alright.

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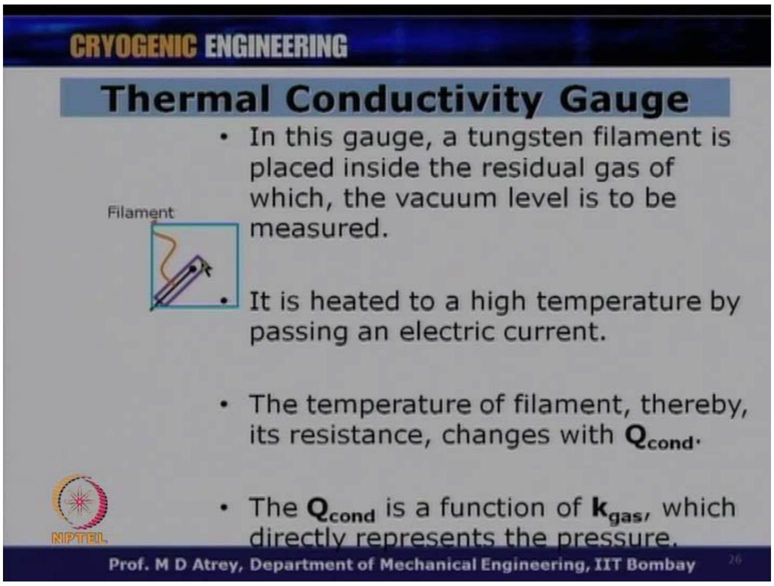

So, thermal conductivity gauge also called as piano gauge. In this gauge, a tungsten filament is placed inside the residual gas of which, the vacuum level is to be measured. Now, what is function? So, we got a tungsten filament which is placed in the gas, and this is residual gas in around this pressure range 10 to 10 to power minus 3 torr.

So, we can see this is the filament in this, and I got a gas around is of pitch I want to measure the pressure, and this tungsten filament is placed some current and therefore, it will get heated now. It is heated to a high temperature by passing an electric current. So, while pass some electric current through this, and I got a gas around is because the which heat transfer will happen. No, depending on whatever I am doing heating, the gas we try to cool it, and amount of Q that is going to be conducted is going to be function of K of gas or thermal conductivity of gas.

And we know that in a given pressure range the thermal conductivity is a function of that pressure range. So, if I could get the temperature over here or if I can have some representation of this Q conduction, this temperature also will change the resistance of this filament alright. So, the change in the resistance of this filament is representative of Q conduction, which is representative of the temperature at this point. So, it is heated to a high temperature by passing an electric current, the temperature of filament there by its resistance changes with Q conduction. So, whatever Q conduction happens over here will change the temperature and thereby the resistance of this particular filament.

Now, if I put this particular element in a (( )) circuit alright, some imbalance will get created, because of the change of resistance of this. And this will be indication of the pressure at this point. The Q conduction is a function of K gas which directly represents the pressure. So, ultimately the change in resistance of this filament would represent the change in pressure alright.

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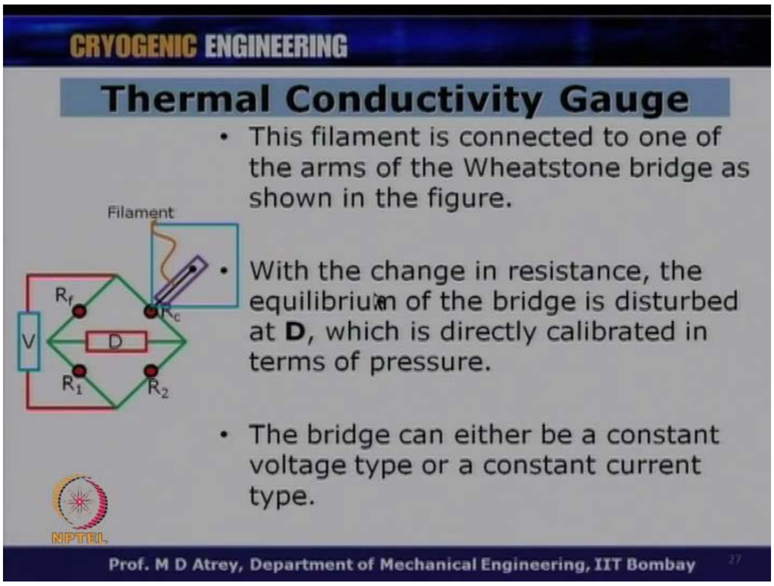

This filament is connected to one of the arms of the Wheatstone bridge as shown in the figure. So, now, I can put this filament and this resistance in the Wheatstone bridge as soon in the figure. So, now I can put this filament, and this resistance in the Wheatstone bridge, and I words some voltage and I can see the imbalance D, because of the change of resistance over here which will happen, because of the change of pressure in the residual gas around here. With the change in the resistance the equilibrium of the bridge is disturbed at d, which is directly calibrated in terms of pressure.

The bridge can either be a constant voltage type, and a constant current type. So, can I have a constant voltage all constant current over here, and this is the principle which thermal conductivity gauge works, very commonly use piano gauge works on this principle. Similarly, now instead of monitoring the resistance over there, I can monitor directly temperature, and that is called as thermo couple gauge. T his is also very commonly used basic principle as same, but instead of having with stone bridge instead of monitoring resistance, I can directly measure the temperature by putting a thermo couple there, and this temperature would indicate with the pressure, because Q conduction will change temperature just measure the temperature, and get the value of pressure.

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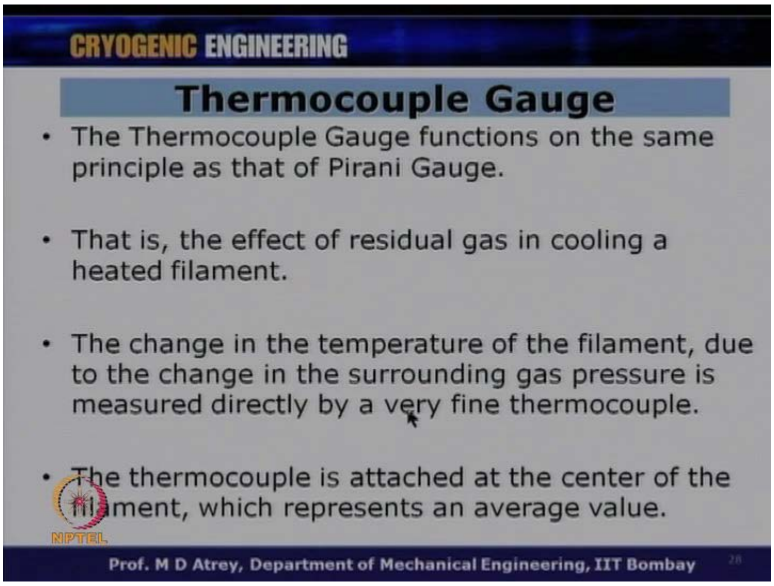

The thermocouple gauge function on the same principle as that of pirani gauge, that is the effect of residual gas in cooling a heated filament, this is what exactly talking about. The change in the temperature of the filament due to the change in the surrounding gas pressure is measured directly by a very fine thermocouple. So, what we are doing in a pirani gauge, change in the pressure would change in the temperature, change in the temperature would change the resistance of the filament, and this resistance change will be captured by the west on bridge. Now, here I am not going to a resistance, I will just monitor to temperature by putting a fine thermocouple over there; and this temperature change or thermocouple temperature will tell me what is the pressure over there. The thermocouple is attached at the center of the filament which representation an average value of the temperature.

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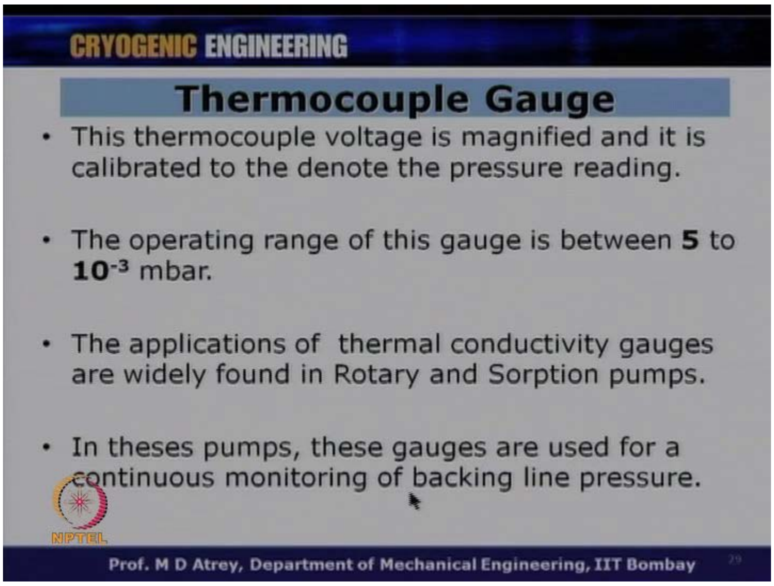

This thermocouple voltage is magnified, and it is calibrated to the denote the pressure reading. So, whatever temperature I see, because of thermocouple it can be magnified, and you can see the pressure reading directly. The operating range of this gauge of this pirani gauge as well as thermocouple gauge is between 5 to 10 to the minus 3 milli bar.

The application of thermal conductivity gauge are widely found in rotary and sorption pumps, most of the pumps will have pirani gauge or thermal conductivity gauge, this is widely use up to 10 to the power minus 3 milli bar. In this pumps theses gauges are used for a continuous monitoring of backing line pressure; these are commonly use continuously used.

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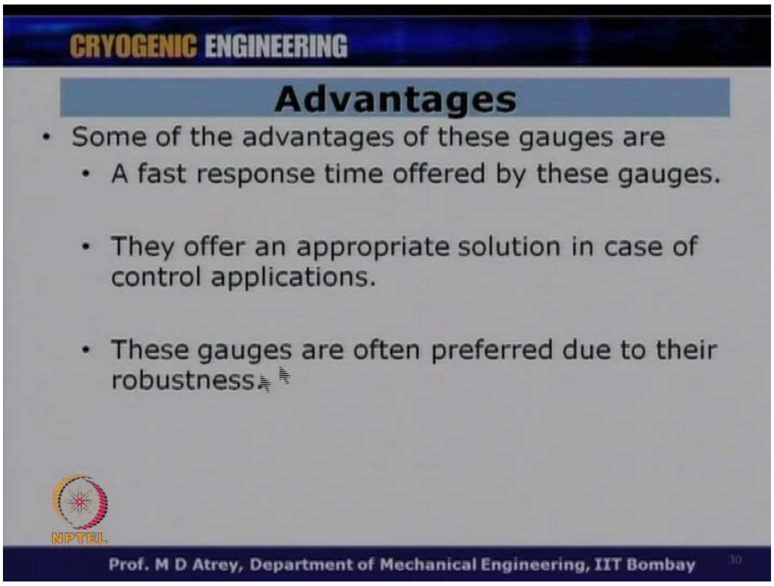

The advantages of this gauges are a fast respond time offered by this gauges, they offer an appropriate solution in case of control application, because it is the fast respond you can take corrective action immediately looking at this gauge, and therefore, there always use in some kind of control applications. These gauges are often preferred due to their robustness, they are low cost devices also as compared to other gauges. So, after pirani gauge, thermocouple gauge, let us see thermionic ionization gauge, and let us see the principle on it, on which it works.

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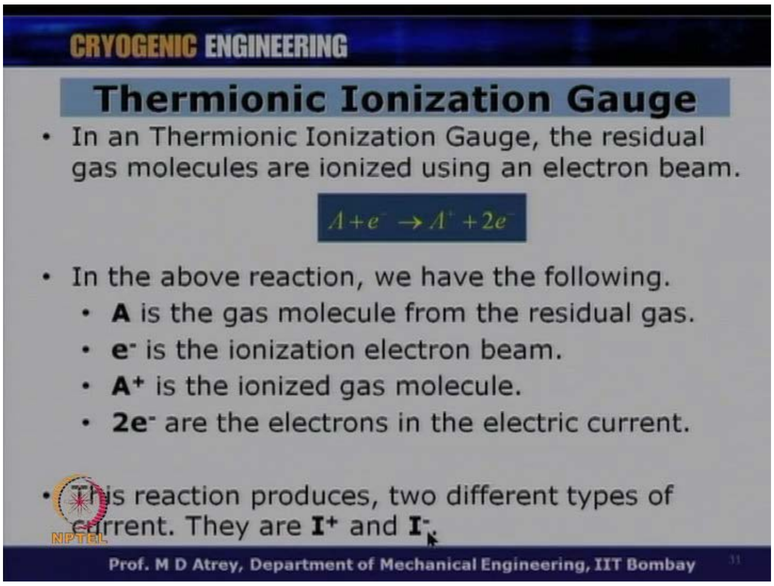

In a thermionic ionization gauge, the residual gas molecules are ionized using an electron beam; simple principle ionization. So, you got a simple principle of A in the above reaction we see that, A is a gas molecule. So, A is a gas molecule which is heat by an electron as result of which A gets ionize to A plus, and you got two electrons. So, we can see that as soon as electrons are bombarded on this gas molecule, you got ionization current you got A plus, and 2 e minus alright.

So, we can see that some ionization current will getting generated, as soon as the gas molecule A is bombarded some electrons, and this is a simple principle of thermionic ionization gauge. Here A is the gas molecule of the residual gas, in e minus is the ionization electron beam, And A plus is the ionized gas molecule A plus, while 2 e minus are the electrons in the electric circuit. This reaction produces to different types of current there I plus an I minus; both we called as ionic current. And this is simple principle what we are doing basically is bombarding electrons on the residual gas molecules, and producing this current when we measure this current - this current indicates the amount of molecules where there; that means, the level of vacuum this current will actually be indicating the level of molecules or the or the pressures over there, and this the principle of thermionic ionization gauge.

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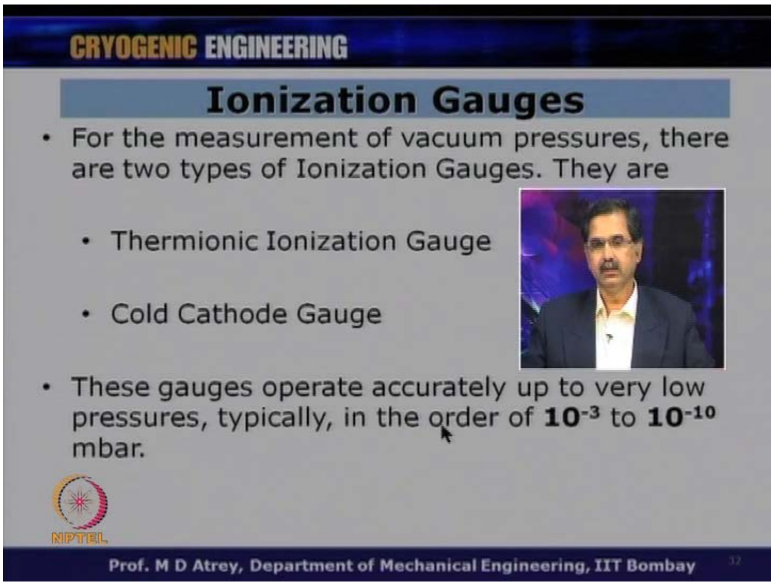

So, ionization gauge is for the measurement of vacuum pressure, there are two types of ionization gauges: they are thermionic ionization gauge, and cold cathode gauge; both base on principle how are this electrons produced alright. So, here we heat them and produce electrons here we got a high potential across cathode and anode, and electrons get produced these gauges operate accurately up to very low pressures typically in the order of minus 3 to minus 10 milli bar. So, these are gauges which are used for very low pressures for very low vacuum up to minus 10 mille bars while the earlier one which we have seen there have to minus 3 mille bars.

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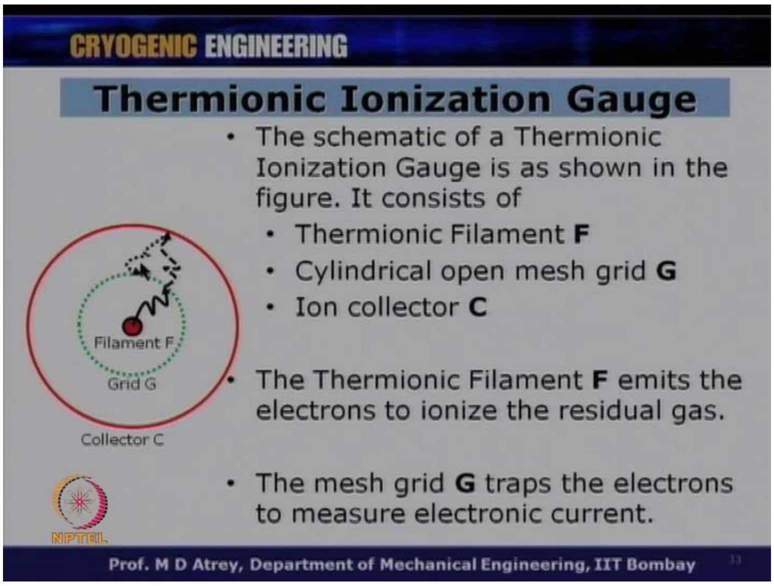

So, the principle of its working this thermionic ionization gauge the schematic of a thermionic ionization gauge is as shown in the figure. It consists of as you can see here a filament grid, and collector three elements it consist of thermionic filament F cylindrical open mesh grid G.

So, you can see a grid over here which has mesh kind of thing. So, it has got some porosity associated with it and then what we have is a ion collector C alright, and the working gas the residual gas will be around over here. So, it is happening the thermionic filament F emits the electrons to ionize the residual gas, when heated this thermionic filament F will produce the electrons and this electrons will travel from here to here. And they will ionize the gas around here. The mesh grid G, trap the electron to measure the electron currents. This grid actually ultimate trap all the electrons coming on it, and this will measure the electronic current.

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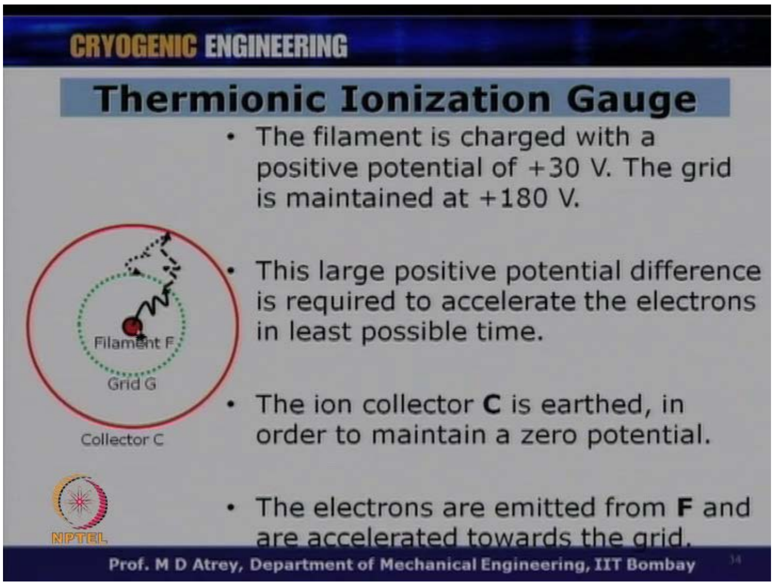

The filament is charged with the positive potential of plus 30 volt. The grid is maintained at high voltage which is 180 volt over here. This large positive potential difference is required to accelerate the electrons in least possible time alright. So, the high voltage over here, and therefore the electrons will come over here in as fast as possible. The ion collector C is earthed, in order to maintain is zero potential, while this is at zero potential alright.

So, high potential in between you got some potential at filament F, and this is earth and zero potential. Now, the electrons are emitted for F after heating, and accelerated towards the grid. So, these electrons which will get accelerated towards the grid, and you can see this grid is meshed kind of formed.

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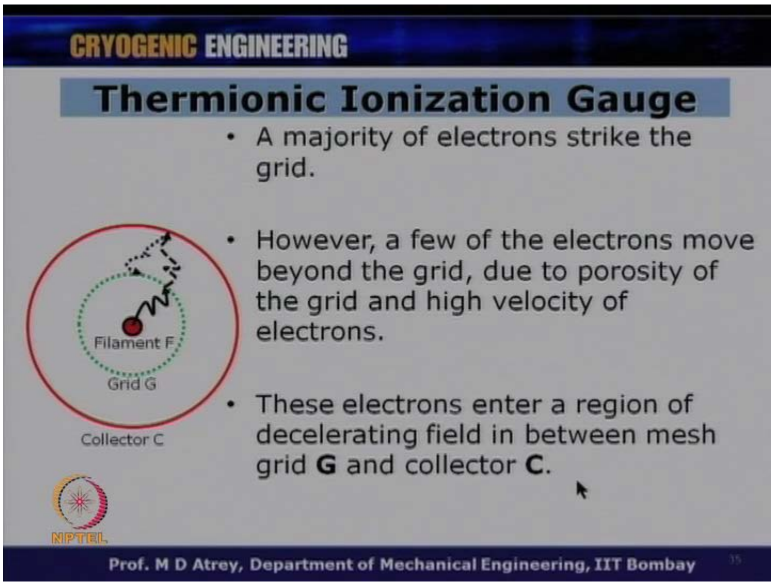

The majority of electrons strike the grid. However, a few of the electrons move beyond the grid now, some electron will come out of heat, and due to; and how to they come out, because of the porosity, did the porosity of the grid, and high velocity of electrons. The electrons come out very fast, and because of the porosity they will come out of disagreed also, and go beyond it. These electrons enter a region of decelerating field, once it comes out divide a high potential here, and zero potential on the collector side. And therefore, they will get the decelerated there motion will come very very slow, now the velocity will decrease further. These electrons enter a region of decelerating field in between the mesh grid G, and the collector C.

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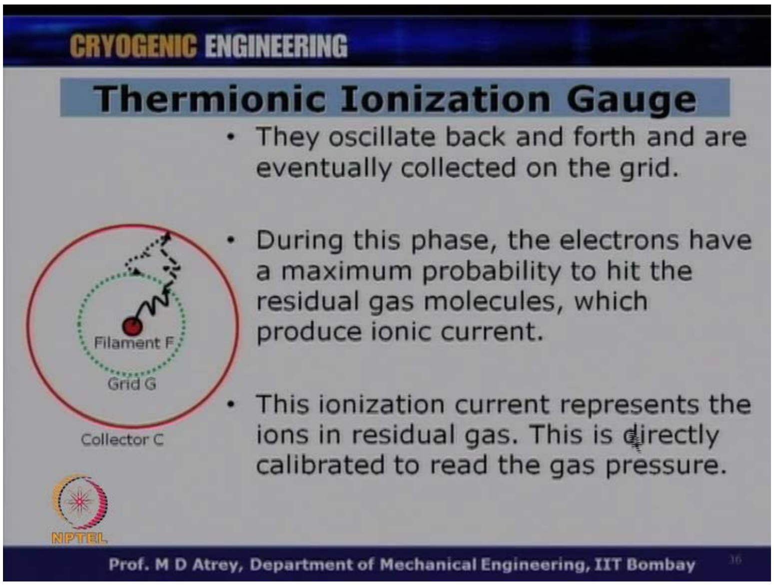

They oscillate back and forth now, here the electrons will go back and forth, because of the decelerating field it will not have any particular direction as such. And therefore, they will spend most of their time in this region between the collector, and the grid. During this phase the electrons have a maximum probability to hit the residual gas molecules which produces ionic current. So, if we remember the first slide, when we talked about the thermionic ionic gauge, A will be over here gas molecules A will be over here. The electrodes will come and strike, and we are basically increase in the probability of heating; theses electrons heating these molecules by this electrons which are now decelerating field. And therefore, they will spend more time over here and therefore, they will be high probability that this electrons will strike this molecules, and ionize them.

This ionization current represents the ions in residual gas. So, when electrons strike the molecules ions will get formed; and therefore, ionization current will get formed, and these ions will ultimate come on the grid over here alright. And therefore, that will measure these ions T also come on this grid G, and this will be indicative of the ionic current, which will talk about the pressure of the gas in this particular area. This ionization current represents the ions in the residual gas. This is directly calibrated to read the gas pressure alright. So, ionization current is going to be indicative of the gas pressure over here.

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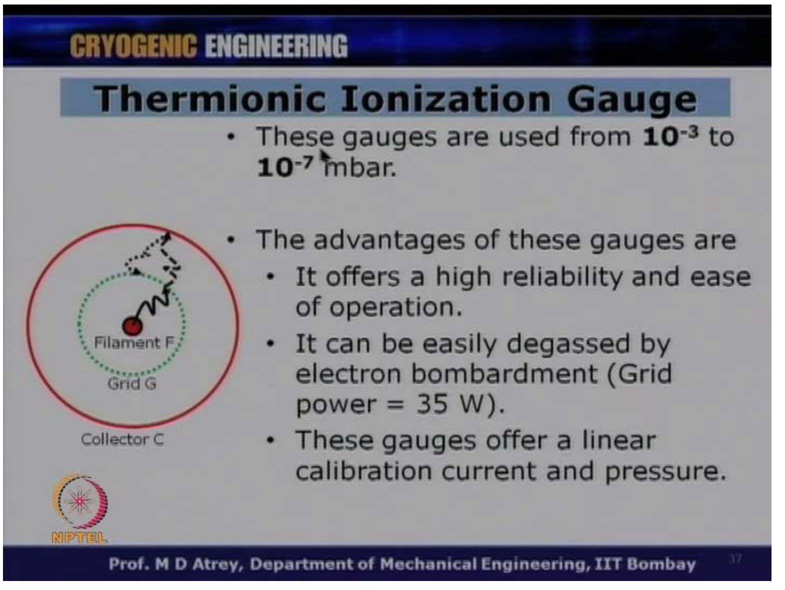

These gauges are used from 10 to the power minus 3 to 10 to the power minus 7 milli bar thermionic ionization gauges. The advantage of these gauges are it offers a high reliability, and ease of operation very simple. It can be easily degassed by electron bombardment. So, the gas is going to come on this, and gets told on this; and this gas can be taken care of it can just remove this gas. So, that this is the ready to the phase next bombardment by you know just have power 35 watt heat it, and the gas will be realized basically. All the gas which is captured over here, can get released out of that; it will get clean, it can get easily gassed. These gauges offer a linear calibration current, and pressure. So, ionization current is going to be linearly linear variation with the pressure, and again therefore, the calibration becomes very very simple. And this is the principle on which thermionic ionization gauge works.

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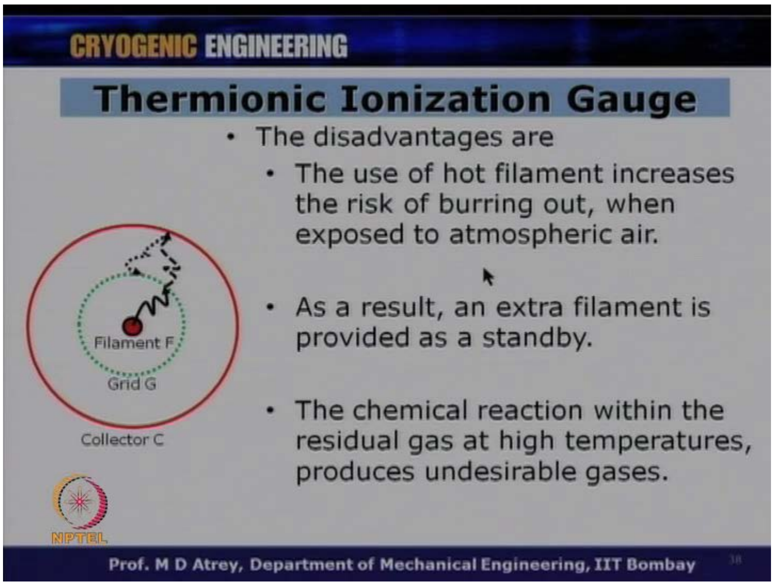

The disadvantages of this gauge are: the use of hot filament - this filament is going to be hot, because when it is hot then only it will release electrons. The use of hot filament increases the risk of burring out sometime it can get point out, especially when it is exposed to atmospheric air, and you got a oxygen over there, and you can have a some burning of this filament also. So, normally this will be use in a molecular region from minus 3 to minus 8 minus 3 is the minus 7 milli bar, but by mistake if it get exposed to atmospheric condition, that means you start right on the beginning this gauge, this gauge cannot be use from room temperature or from I am (( )), but if it happen somebody just press this button the filament can be get burned, because it will be surrounded by all oxygen high density gas. The use of hot filament increases the risk of burring out, when exposed atmospheric air.

So, once the phlegmatic gone, you cannot work we cannot use this particular gauge, you to reply this filament. So, many time this gauge will covariance matrix with extra filament also, but this is very costly element; and therefore, working with these guess should be very very carefully handle alright. As a result an extra filament is provided as a standby, but then it cost alright.

So, thermionic ionization gauge always has these problems. One has to be really expert to handle these gauges. The chemical reaction within the residual gas at high temperature produces undesirable gasses, because of the generation of high temperature sometimes there could be some reaction also between the residual gases, and that also should be avoided. So, there some risk associated with this usage of this thermionic ionization gauge.

Now, let us come to the next one is cold cathode ionization gauge, as the names suggest it is cold; while the earlier one what we talked about is hot. And therefore, you have some problem. So, all this problem can be taken care of, if we go with cold cathode ionization gauge, and this is normally use as very powerful gauge called penning gauge alright. So, penning gauge works on this principle.

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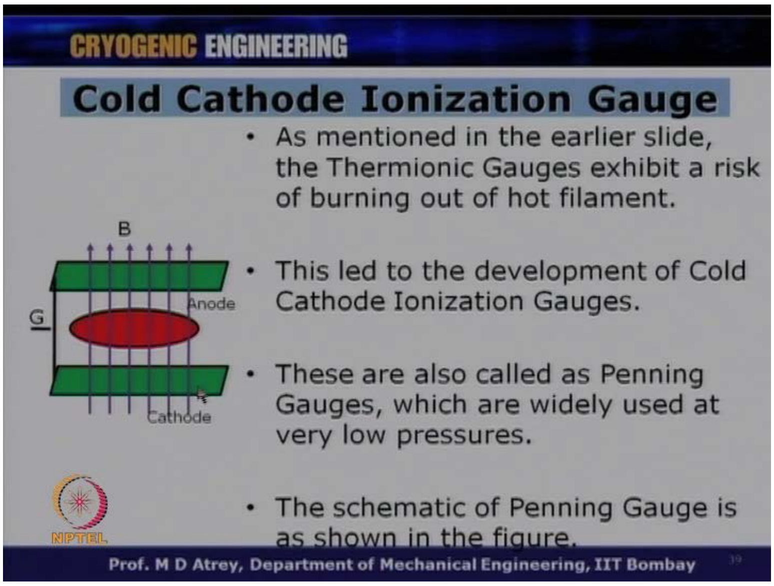

As mentioned in the earlier slide, the thermionic gauges exhibit risk of burning out of hot filament. This led to the development of cold cathode ionization gauges. These are also called as penning gauges, which are widely use at very low pressure. So, every device which what is to have a pressure of minus 6 to minus 7 will have a pirani gauge, and penning gauge is combination, pirani penning. So, pirani penning is measure the measure of up to minus 3, while from a minus 3 to minus 7 pirani will not be use now, and penning gauge will be used. And this is generally observed two gauges that will come on every machine every vacuum equipment, let us see how it works; the schematic of a paining gauge is as shown in the figure. So, the schematic you can see that it has got cathode and therefore, it has to have some an all also.

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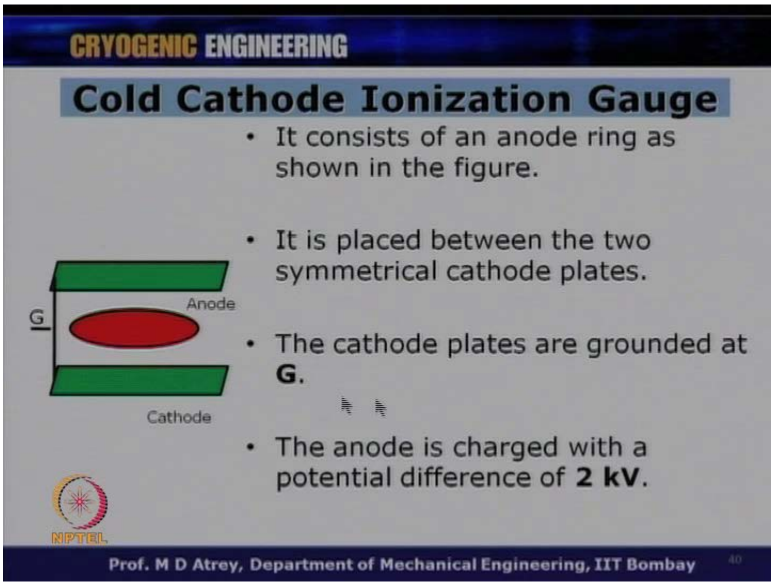

It consists of anode ring as shown over here; so this is the anode ring a circular anode ring. It is displace between the two symmetrical cathode plates. So, we have got a cathode plate top, and bottom and in between anode. The cathode plates are grounded at G, you can see grounding at point G. So, we got a positive, negative and grounding at G here. The anode is charged with a potential difference of two kilo volt, the high potential between cathode, and anode anode has two kilo volt potential difference here.

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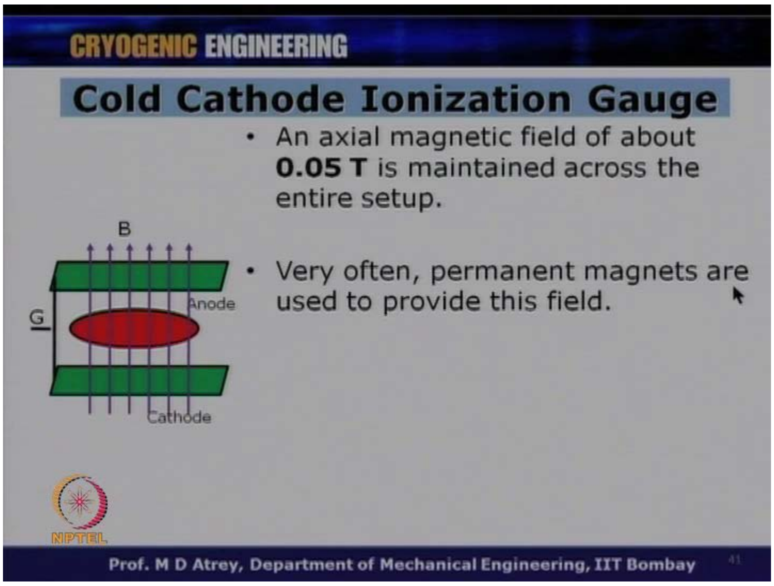

Now, in this now. So, got a electrical field which is coming over here, in addition to that what we have is a magnetic field. An actually magnetic field of about 0.05 T is maintained across the entire setup alright. So, we got a magnate on this side magnate on this side, you got a magnetic field at a perpendicular direction to this. So, got an electric field you got a magnetic field; and therefore, the motion of electrons is going to be subjected to electrical field, and magnetic field and also; very often a permanent magnets are used to provide this field.

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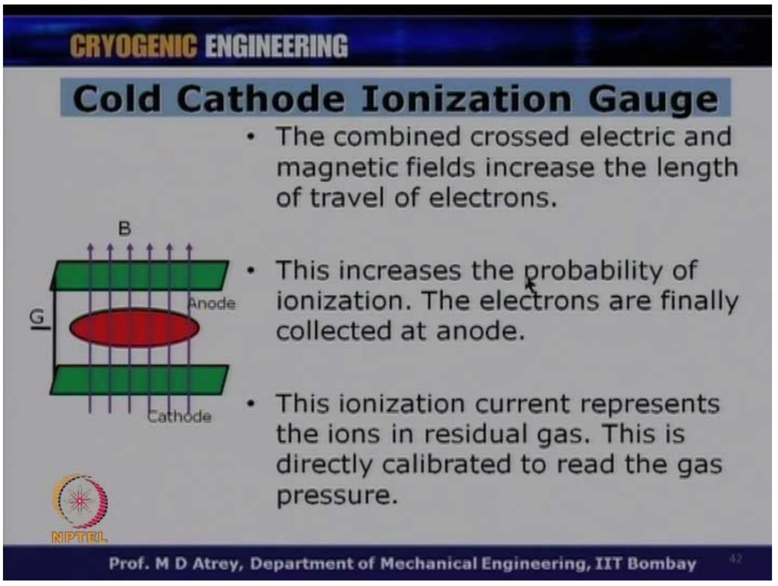

The combined cross electric and magnetic field produces increased length of travel of electrons. So, when operation starts, the cathode will release electron, and they will go to anode, but because of this magnetic field, they will take a large time, very long time, they will take a long time to reach from cathode to anode from a other side. And this increases the probability of heating the electrons as we saw in earlier case. This increases the probability of ionization, we have got working gas of which you want to measure the pressure would be here. And what we want to do basically here is to see that the electrons going from method to anode, because of high potential between them will heat these molecules, and we want to increase the probability of heating these molecules, because of application of magnetic field, because the the electrons are moving in the magnetic field, they will go in varies in a spiral way, they will go up and down spiral way, they will take a very long time to reach from cathode to anode.

This will increase the probability of electrons heating the working gas molecules, this increases the probability of ionization, the electrons are a finally, collected at anode. So, cathode electrons get released, they will go to anode, because of magnetic field around there, they will take a long time to reach anode; and during this travel from cathode to anode, they will heat the molecules, and thereby the electrons will finally be reaching up to this. And they will ensure that each electron hits the molecule.

This ionization current represents the ions in residual gas. This is directly calibrated to read the gas pressure. So, once the ionization current to each over here, it is representative of the pressure of the work residual gas over here. This is the principle on which the cold cathode ionization gauge works of the pyramid, on the penning gauge works.

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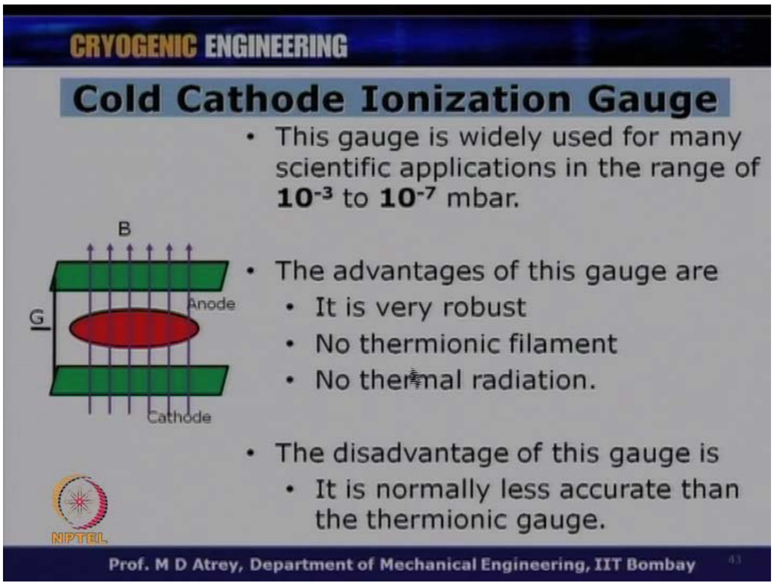

This gauge is widely used for many scientific applications in the range of minus 3 to minus 7 milli bar. The advantages of this gauges are it is very robust, no thermionic filament, the best the biggest advantage of this is the no filament, there is no heating of filament. And therefore, there is no filament cannot be did not be sacrifices did not be sacrificed did not be burned basically alright.

So, got a simple cathode and anode, no thermal radiation, no hitting business involved over here. The disadvantage of this gauge is it, it is normally less accurate than the thermionic gauge. So, if this is tolerable to you, themes; if you want a very accurate measurement vacuum measurement be done, in that case you will have to go for a thermionic gauge, in that principle.

So, after understanding how the cold cathode ionization gauge works or how does not penning gauge work, I just want to show how it works basically, and whatever we just learned you can see in actual case. So, this is how a penning gauge looks like, and this I would connect this portion I would correct in a line of pitch I want to measure the pressure. So, if I want to measure the pressure to minus 6 milli bar minus 7 milli bar, this element of this this is the penning gauge or this is the head of the vacuum gauge is going to be connected over there. And this will be faced in what we have an arrangement for cathode, and anode here. So, here if you can see you can see at the center, there is anode, and on the other side's we got a cathode I do not whether you can see, but please (( )) imagine that you got a cathode over other side alright.

To which, the voltage is given from this side. So, the the voltage is given over here, why the anode is going to come at the center, and the ionic current is going to measure from here, and connected to the gauge. So, this is basically kind of a head, and you can have some gauge where this ionic current which is going to come at anode is going to measure. First, what you see from other side is the magnet, you got a permanent magnet over here. So, you can see the magnet, you can see the cathode - the cold cathode and what you see in the middle is the anode, and you got a high voltage to the supply cathode from this side. So, whenever the electrons get release from cathode to anode, the residual gas will come in between, and it will get ionized and this ionization current is going to be fade to the gauge over here which is calibrated as a function of this residual gas pressure.

Now, this electrons when the leave from cathode, and go up to anode they will take lot of time, because of this magnetic field. They will not go straight from cathode to anode, but they will go in a spiral way, they will take a lot of time, because of magnetic field over there. This magnetic field is therefore, responsible for that; this electron while travelling from cathode to anode will ionize the gas molecule, and depending upon this ionization current getting proved is because of this heating of a electron to the molecule ionization current will be there, and this ionization correct current will be fed to the gauge, which is going to be calibrated in order that we know what is the residual gas should over here. And this is the way the preening gauge works, this the way the cold cathode ionization gauge works.

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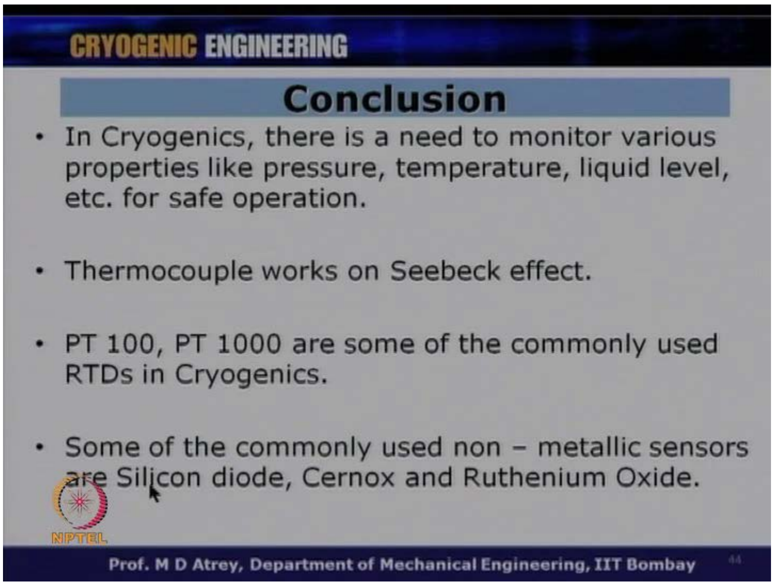

The conclusion that could be drop on from the entire topic of instrumentation in cryogenics, there is a need to monitor various properties like pressure, temperature, liquid level, etcetera for safe operation.

Thermocouple works on see back effect, this what we saw, where seen PT 100, PT 1000 are some of the commonly used RTDs in cryogenics. So, we have seen thermocouples, and RTDs that are normally use up to 30 to 40 kelvin from room temperature to 30 to 40 kelvin temperatures. Some of the commonly used non-metallic sensors are Silicon diode, Cernox, and Ruthenium oxide.

So, for lower temperatures now, below 30, 40 Kelvin to have a very good measurement these are the sensors that could be use, which are Silicon diode, Cernox and Ruthenium oxide.

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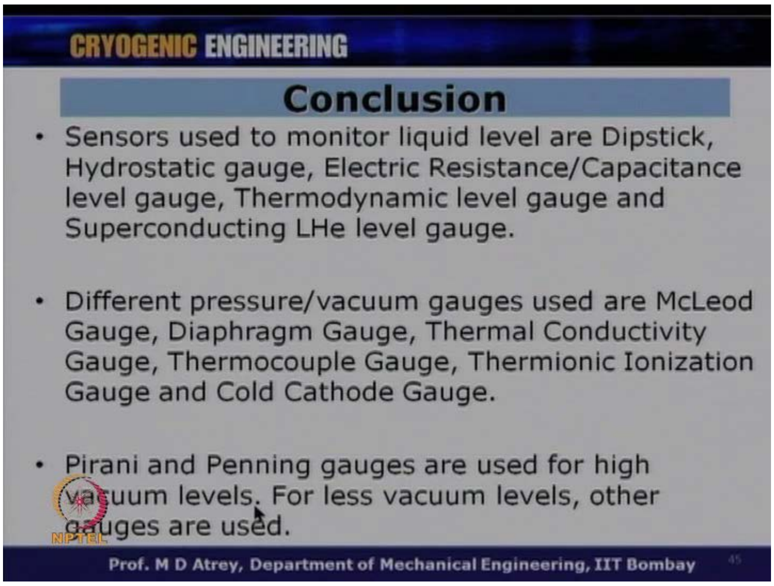

Sensor used to monitor liquid level are dipstick, hydrostatic gauge, electric resistance, capacitance level gauge, thermodynamic level gauge, and superconducting liquid helium level gauge. We have seen how this level gauges work, we have seen the principles of there working. And in this particular lecture, we have seen different pressure public vacuum gauges used, and we have seen the principles of working of McLeod gauge, diaphragm gauge, thermal conductivity gauge, thermocouple gauge, thermionic ionization gauge, and cold cathode gauge of which as a told you the thermal conductivity gauge is called as a pirani gauge normally, and cold cathode gauge is normally refer to as penning gauge.

And desire normally used to measure the vacuum up to minus 7 bit minus 3 to minus 7 milli bar, while thermocouple gauge and thermal conductivity gauge will be used up to minus three vacuum. So, up to minus three we can use thermal conductivity as well as thermal couple gauge, while cold cathode gauge and thermionic ionization gauge could be use up to minus 7 milli bar. Pirani and penning gauges are used for higher vacuum levels. For less vacuum levels, other gauges are used. Thank you.