Industrial Instrumentation
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Lecture - 19
Low Pressure Measurement

Welcome to the lesson 19 of Industrial Instrumentation. In this lesson we will basically cover the low pressure measurement. In lesson 18, we have seen that the, we have basically discussed the medium and high pressure measurements, but low pressure measurements also is a interest, is a part of interest for, even though not much for the industry, but for the academics and also scientific community. So, the low pressure measurement also is very much necessary and is a different class of instruments. We will find the principle of operations of these instruments is also totally different.

So let us look at lesson 19, low pressure measurement.

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Contents of this lesson are McLeod gauge, we will see the, we will cover the McLeod gauge. Then we will cover the pirani gauge, then thermocouple gauge, ionization gauge and Knudsen gauge. Now, we will see that the McLeod gauge actually, I mean these are, all these pressure gauges we will find it, they were, they have different application as well as different range of the pressure measurements. It is all lies between 1 torr to 10 to the power minus 10, 10 to the power minus 12 torr. Torr means 1 millimeter of …., so that we will cover. What are the units of the pressure measurements that we will discuss after sometime.

Now, in some instruments we will find it is basically monitoring sort of instruments or indicating instrument, but some instruments we will find, we will get electrical output. So we can utilize to offer control for transmission, all those facilities will be available. We will particularly see that the McLeod gauge and the Knudsen gauge, so let us discuss for the McLeod gauge. So, at the end of this lesson, so we will know all the details of these types of gauges. Also we will consider some problem solving. We will probably make some problems and we will give the solution to some pressure gauges, diaphragm gauges, especially and also on the McLeod gauges, right?

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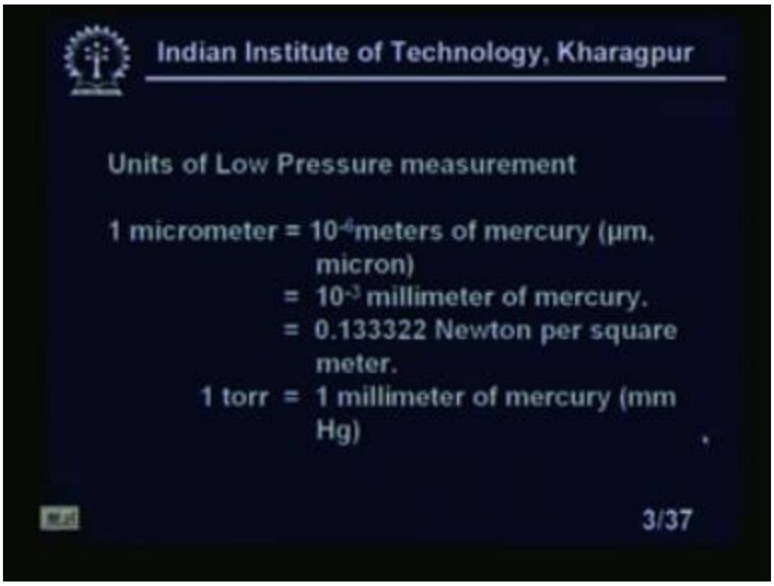

Now, before going to the details of the pressure measurement let us look at the units of the low pressure measurements. The different units are 1 micrometer equal to 10 to the minus 6 meters of mercury or sometimes we call it micro in million or micron which is 10 to the minus 3 millimeter of mercury and now 1 micron means, sorry you see that if I say that 10 to the minus 3 millimeter of mercury that means 10 to the minus 6, if it is SI unit, 10 to the minus 6 into the density of the liquid multiplied by the acceleration due to gravity that will give you the pressure. So, 1 micrometer is equal to 10 to the minus 3 millimeter of mercury equal to 0.133322 Newton per square meter, right and 1 torr we will find it is 1 millimeter of mercury. 1 torr is a lowest pressure measuring units. So, we call it 1 millimeter of mercury, right? So, 1 millimeter of Hg or 1 millimeter of mercury.

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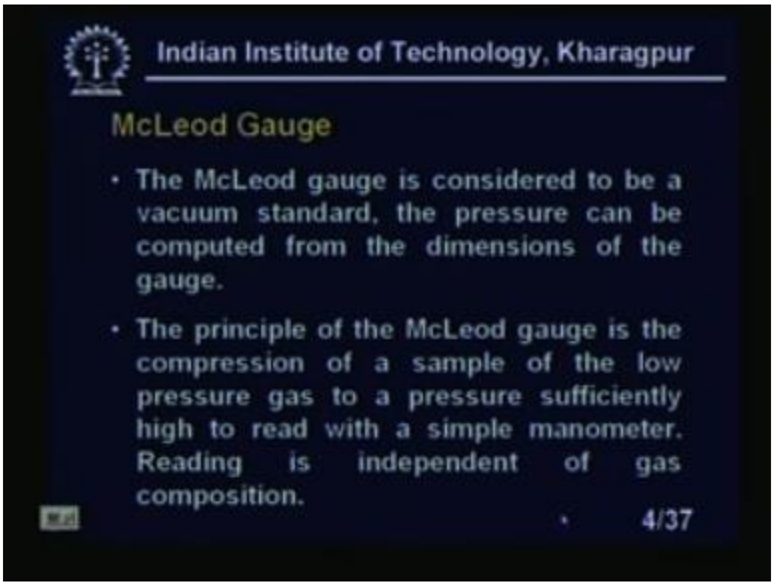

Let us look at the McLeod gauge. The McLeod gauge is considered to be a vacuum standard. We will find that the, the pressure can be computed from the dimensions of the gauge. It is very important, it is independent of the so many parameters, so it is, can use as a pressure standard. The principle of the McLeod gauge is the compression of a sample of the low pressure gas to a pressure sufficiently high to read with a simple manometer, right? We will compress the gas, low pressure gas to such a value, so that we can, simple manometric principle I can measure that pressure. That is the basic principles of the McLeod gauge.

A low pressure gas will be taken and it is systematically or very intelligently, we will compress it to sufficiently high pressure, so that a simple manometric, manometer method I can measure the pressure. That pressures will be calibrated in terms of that low pressure actually in which we are interested, right? So, that is why I am saying the principle of McLeod gauge is the compression of a sample of the low pressure gas to a pressure sufficiently high to read with a simple manometer. Reading is most important, reading is independent of gas composition. That means I can take any gas. So, I do not need, so I do not have to recalibrate the instrument and that is the great advantage of the McLeod gauge. This advantage is not there, we will find in other low pressure gauge like ionization gauge and all those things. It is totally different. Let us look at more details of the McLeod gauge.

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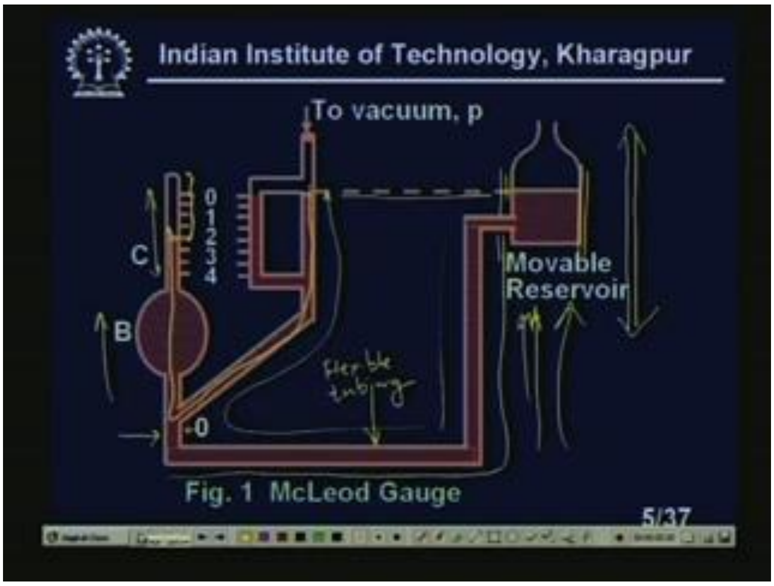

You see, this is the schematic of the McLeod gauge. You see, what will happen? You look at very carefully. You see here, we have a movable reservoir, right? So this reservoir I can put, move it up and down. This can be moved up and down. This is a flexible tubing; even though we have drawn like this one, this is a flexible tubing. This is a, these are all flexible rubber tubing, right? It is connected to the, this movable reservoir. This reservoir can go up and down. Actually there is a frame; there is a frame like things through which this reservoir actually moves, right?

Now, we have a capillary here. You see this capillary we have. Now, principle is that first this movable reservoir will go down. If I keep it go down you see the mercury from this reservoir is coming and it is filling up all these. You see, it is coming through this region. It is coming and filling up to this level. So, accordingly, this will be the same, this should be at the same level. Now, what will happen? Once I move this reservoir downward, is all these mercury in the, this tube as well as in this capillary and the bulb will be collected in the reservoir, fine.

Now, if I put the mercury below this level, below this zero level, you see what will happen? A gas which, in which we are interested to measure the pressure will enter. So far it cannot come down, now once I push the mercury down here at this region, then what will happen? You see this mercury will come, this gas will come down and it will enter this region, this capillary. Slowly it will enter the capillary also. So, basic principle is we will push this movable reservoir down as long as mercury comes down to this zero level.

Now, I push this reservoir, move this up. Then what will happen? If I put, go this, the, if I push this reservoir up, then what will happen? You will see the gas which is trapped inside this capillary and also the bulb will start to compress. Once it start to compress it will give some, because it is getting compressed and compressed it will give some pressure for which the mercury column cannot rise to this level. Now, this height, this blank height will be calibrated in terms of the low pressure. This is the basic principle of the McLeod gauge, right?

Again I am telling, this movable reservoir will come down, all the mercury will be collected here, because this is a flexible tubing; I should say this is a flexible tubing, right? So, it will come down. All the mercury will be collected in the reservoir. The gas will be trapped here. It will come down this position. Then it will come down, gas will come down through this region. It will enter here, then it will go up. Now, I will slowly move this reservoir up. Then what will happen? Simply the gas will be trapped. Gas will be getting compressed and compressed, mercury column is going up. As I move the reservoir up, this mercury column also will go up and this compressed gas, gas is getting compressed and compressed and it is giving a back pressure to this mercury column.

So, after certain time we will see that even though we have taken the reservoir at this level, this mercury cannot go up, because of the pressure created by the compressed gas, right, so that the region where that mercury, I mean cannot reach will be calibrated in terms of low pressure. This is the basic principle of the McLeod gauge, right? So, this will be elaborately, we will speak in the next slides.

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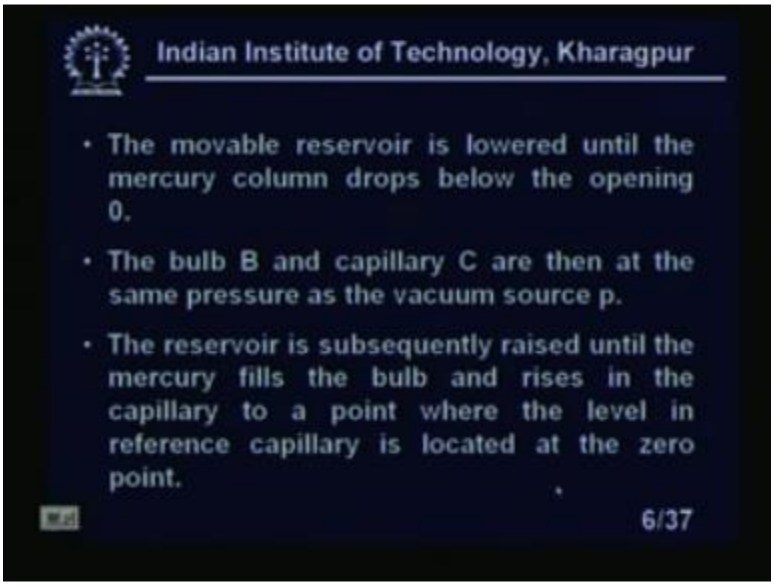

The movable reservoir is lowered until the mercury column drops below the opening zero or O, whatever you say. The bulb B and the capillary C are then at the same pressure as the vacuum source p. Now, one thing is important. You see this, this bulb B is purposefully made quite large compared to the capillary. We will see the mathematical relation, why it is made large, right? So, this is made quite large compared to that volume of the capillary. This is the volume of the total capillary, so height multiplied by the area of cross sections of the capillary that should be much less compared to the volume of the bulb, right?

The movable reservoir is lowered until the mercury column drops below the opening, O. The bulb B and the capillary C are then at the same pressure as the vacuum source p. This is the, actually the pressure which I want to measure. This is the pressure, this p is the pressure which I want to measure. The reservoir is subsequently raised until the mercury fills the bulb and rises in the capillary to a point where the level in the reference capillary is located at the zero point. What is that reference capillary, let us look at again.

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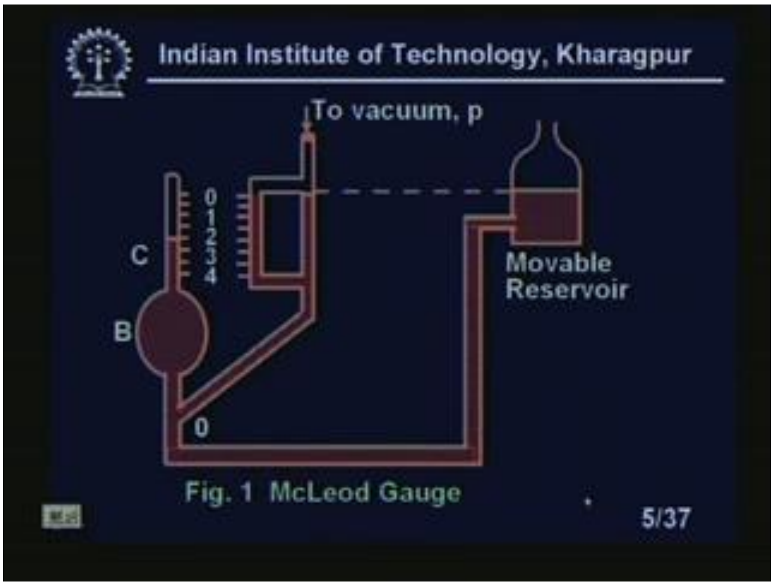

This is our reference capillary. So, until and unless this reservoir is, this mercury column in this reference capillary coming to this zero level. I will move the reservoir up and up, right? Once it comes to this zero level, I will stop moving the reservoir in the upward direction, right? The reservoir is subsequently raised until the mercury fills the bulb and rises in the cap, in the capillary to a point where the level in the reference capillary is located at the zero point, right?

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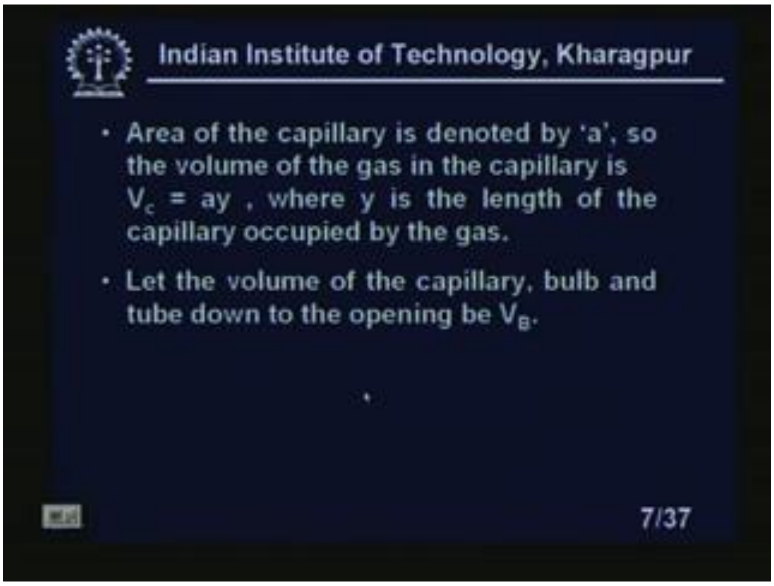

Area of the capillary is denoted by, area of cross-section of the capillary I should say, denoted by a. So, the volume of the gas in the capillary is V c into, V subscript c that means capillary, equal to a into y where, you see this, where y is the length of the capillary occupied by the gas, right? This is the length of the capillary which is occupied by the gas. What is that? I should go back again.

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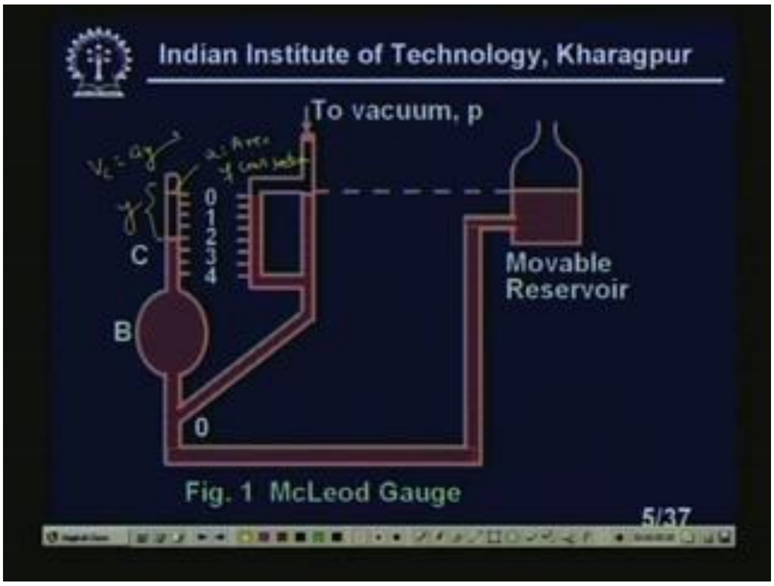

You see, this is the length of the capillary occupied by the gas, sorry. So, I should say this is the length of the capillary occupied by the gas, right? This is our y and this is the area of cross section, is a. This is area of cross section. So, obviously this volume V c, capillary volume, this volume will be equal to a into y, clear?

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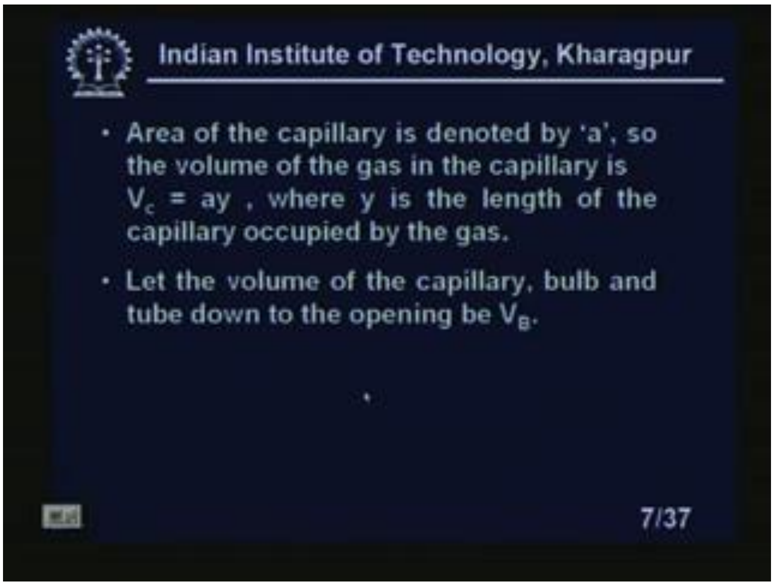

y is the length of the capillary occupied by the gas, right? That is true. Let the volume of the capillary, bulb and the tube down to the opening be V B. So, you see that V B is not only the volume of the capillary, it is volume of the capillary, bulb up to the point zero. I should, I refer back again.

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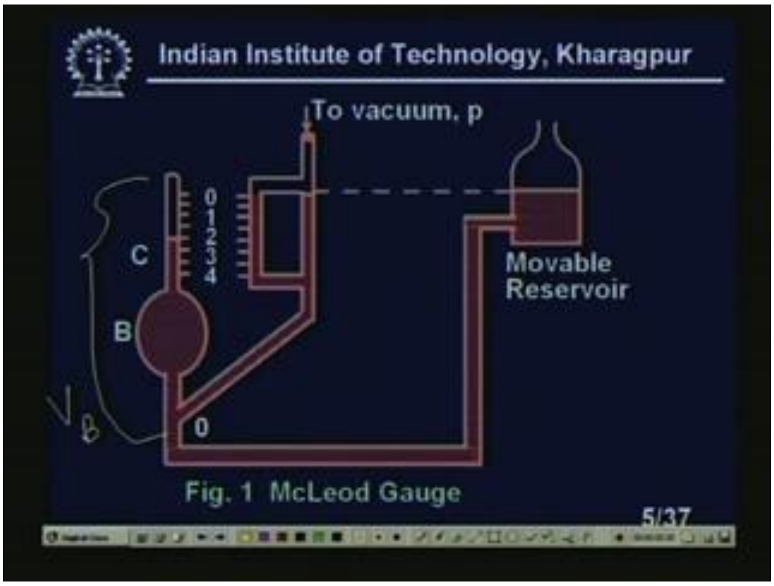

Fig. 1 McLeod Gauge

You see, the volume of the capillary that means I am telling the volume of the capillary up to this level, so this total volume I am telling is V B, subscript B, clear?

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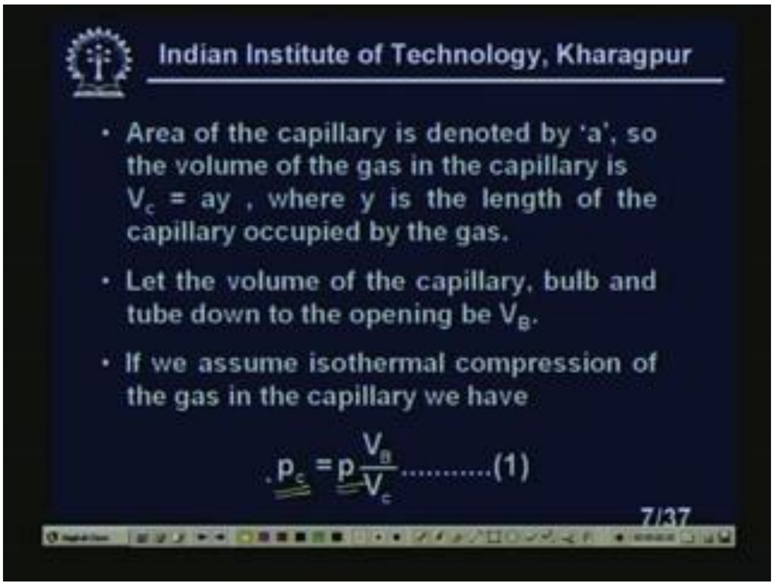

So, let the volume of the capillary, bulb and the tube down to the opening be V B.

If we assume the isothermal compression of the gas in the capillary we can write that p c that means the gas which is compressed equal to p actually that which I am to measure equal to V B capital, I mean this volume divided by the V c, the capillary bulb this is equation number 1, right? This is, actually gas was in pressure p. Please note it was in the pressure p. Now, I have compressed to p c, right, so which is higher compared to p, clear? So, it should be in such a high conditions or such a high value that I can measure by the simple manometer. That is the basic principle of the, our McLeod gauge.

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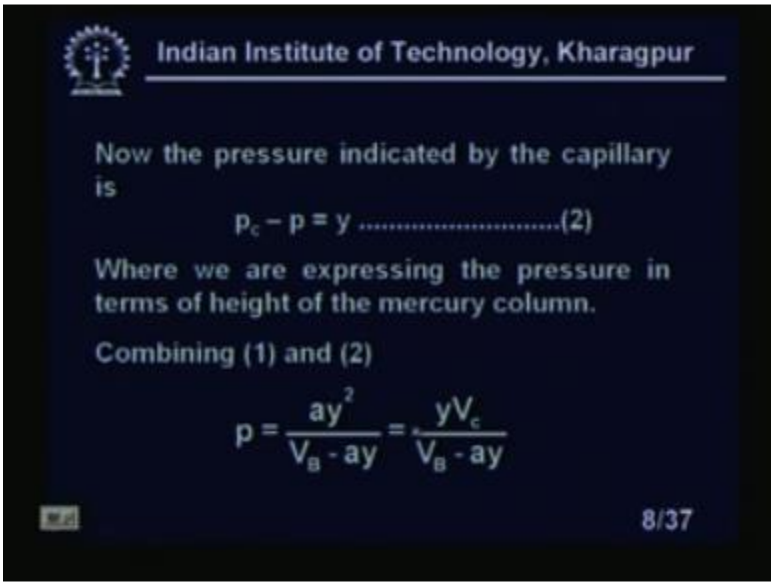

Now, the pressure is indicated by the cap, now the pressure indicated by the capillary is p c minus p that compressed pressure minus the pressure actually indicate, I, which I am interested to measure equal to y, right? If suppose, if it is in, I mean if we divide it by d and g, so obviously I will get that also in y that is in height. This is equation number 2. Because, obviously it should be divided by d and g, the density and the acceleration due to gravity to get the expressions of the pressure only in height, where we are expressing the pressure in terms of the height of the mercury column, right?

Now, combining 1 and 2, we get p equal to the, unknown pressure equal to ay square upon V B minus ay equal to yV c divided by V B minus ay.

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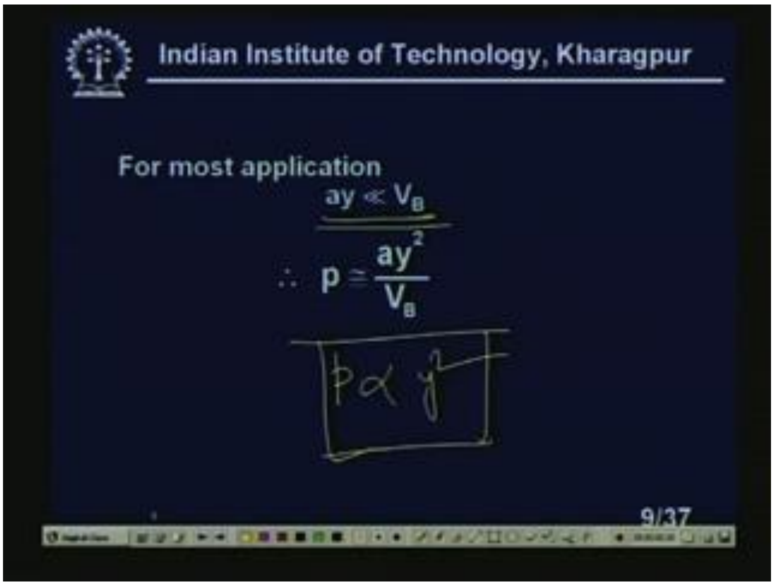

For most applications I can say the volume of the capillary is much smaller than the, much, much smaller than the volume of the, total volume of the capillary, then bulb, up to the leveling, opening O of the mercury. Actually, in fact you know that is actually the, what will happen? For most applications I can take that ay is much, much less than V B. So, I can write y, now it is clear that why I have taken V B much, much greater than ay, purposefully. You are using a bulb that is the reason there is no need, otherwise without bulb also system will work. We have taken so that I can write that unknown pressure p equal to ay square upon V B.

You see, a the area of cross section of the capillary is constant, V B is the area of the bulb, then capillary as up to the opening of the, this McLeod gauge, this is also constant. So, a is, p is directly proportional to p square. Even though is not linear instrument, so p is y, y square, right? With this approximation we will introduce obviously some error, because we have approximated by this, right?

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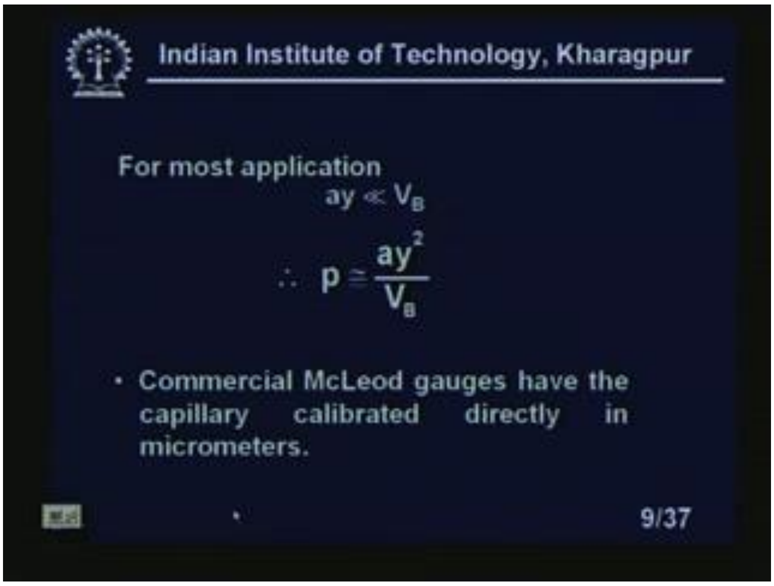

Commercial McLeod gauges have the capillary calibrated directly in the micrometers, right?

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Now, McLeod gauge is sensitive to the condensed vapours that may be present in a sample, because they can condense upon the compression and invalidate equation 1. So this, we should be careful about that. For dry gases the gauge is applicable to the

10 to the power minus 2 to 10 to the power plus 2 micron which is equal to 0.0013 to 13.3 Pascal.

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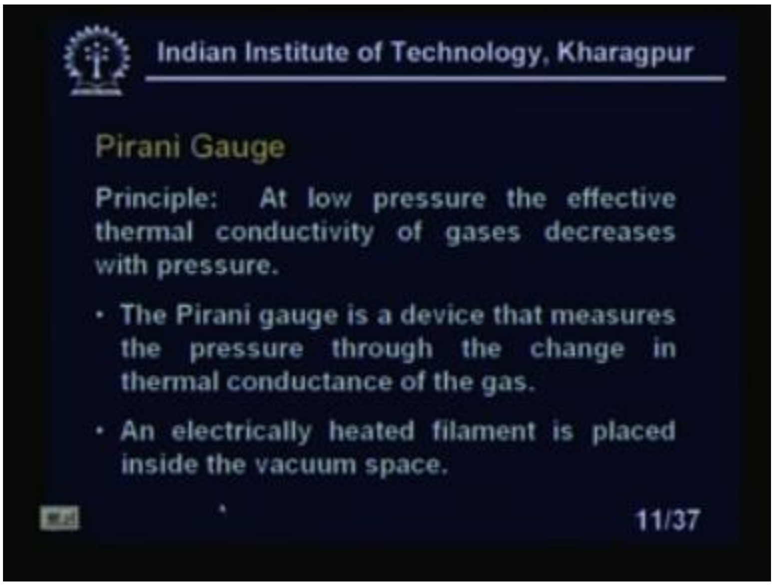

Now pirani gauge, now this is all about the McLeod gauge. Now, pirani gauge is basically is, is based on the thermal conductivity. Basic principle is something like that - a gas, a heated filament will be placed inside a chamber. But, there is a heat transfer from that chamber, from that heated surface to the outer surface, colder surface, colder surface is a glass envelope which is actually, in which actually the, those heated filament will be placed and as the number of molecules decreases, there will be less heat transfer from the heated filament to the cold, I mean cold valve, the colder surface.

So, the temperature of the heated filament, the filament will rise. So that temperature, so obviously if the temperature rises, the resistance of the heated filament also will rise, so that if I put that in the Wheatstone bridge, so I will get a unbalanced voltage. That unbalanced voltage it will be calibrated in terms of the low pressure. That is basic principle of the pirani gauge. It is, looks like this; you see, at low pressure the effective thermal conductivity of the gases decreases with pressure. How? That is I said that if the pressure decreases in a vessel, then what will happen?

Why I am getting the pressure? Kinetic theory of gases says that the, I am getting a pressure in the vessel, because this, it has a random motions of the molecules. So, it is heating the surface of the walls which is actually creating the pressure. If the number of molecules decreases, also the pressure will decrease, right? Because there is less number of molecules in the, if the less or in other way, if the low, the pressure is low, number of molecules in the vessel also will be low, right? So, what will happen that I have, it looks like this. We will show in the next slide that what is the basic principle?

At low pressure the effective thermal conductivity of the gas decreases with pressure. The pirani gauge is a device that measures the pressure through the change in thermal conductivity, conductance of the gas. An electrically heated filament is placed inside the vacuum space. So, it will be clear, you see here.

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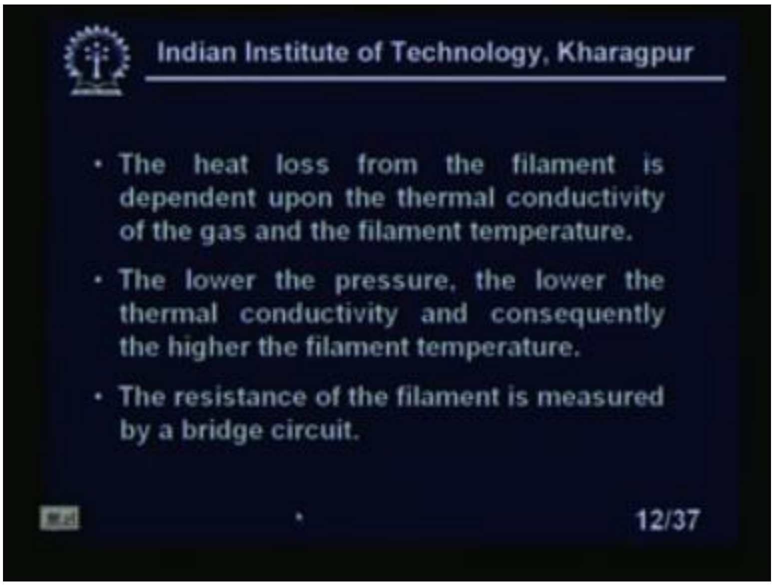

Heat loss from the filament is dependent upon the thermal conductivity of the gas and the filament temperature. Lower the pressure lower the thermal conductivities, because you see the, as the pressure decreases the number of molecules also will decrease, is not it? As the pressure decreases the number of molecules also will decrease, right and higher the filament temperature. So, temperature of the filament will rise. Temperature of the filament if rises, its resistance will rise, so the bridge unbalanced current also will, unbalanced voltage will also increase; so, that unbalanced voltage will be, actually we will measure, right? The resistance of the filament is measured by a bridge circuit, right?

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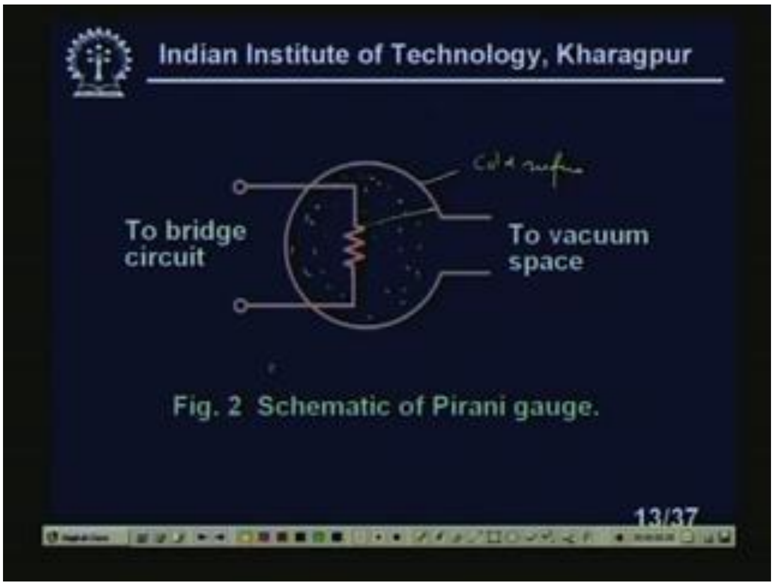

Now you see, this is schematic of the pirani gauge. It is not actual, it is the pirani gauge. You see what will happen here? I have a heated filament, so I have a number of molecules here, is not it? It will be very clear from this diagram. Molecules are here, so what will happen you see this is connected to the vacuum space where in, which we are interested to measure the pressure. So the filament, this molecule will heat this. This will come in contact with this heated filament and it will take away, due to random motion it will go and this surface is cold surface compared to the heated filament. So, this heat will be taken away in this direction, is not it?

So, as the number of molecule decreases, as the pressure decreases number of molecules also decrease. So, there is a less chance of taking the heat away from this heated surface to the colder surface. So, what will happen as the, as the pressure decreases the temperature of the heated filament will rise. If the temperature of the heated filament rises, then what will happen? Its resistance also will increase. Now, if I put in a bridge, if I measure this change of resistance by some, in one way, by some means or the other, I will get some change of resistance. So, that change of resistance either I can calibrate in terms of voltage or current that will be calibrated in terms of low pressure. That is the basic principle of the pirani gauge, right?

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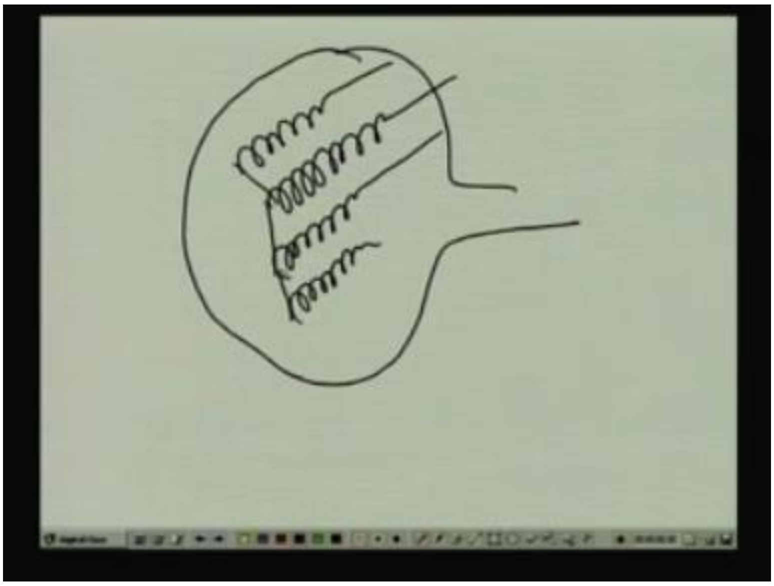

They have a coil tungsten wire, sorry, they have a coiled tungsten wire like this one. Several wires are there, four wires, usually they will find there are four wires. These wires are placed in a vessel. The wires cannot, I mean suspend like this. There must be some arrangement by which it is to be hold inside this chamber, right? Let us go back again. So, this is the schematic of the pirani gauge.

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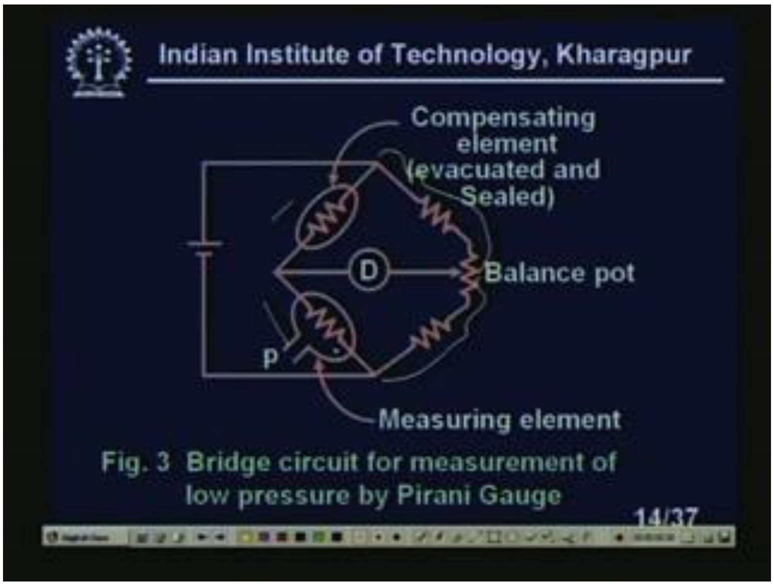

Now see this is the bridge circuit which is actually used for measurement of low pressure by pirani gauge. Now you see, for because since it is a resistance devices, so it should be changed. It should be affected by the ambient temperature variation. If the ambient temperature changes, so what will happen? This resistance will change. To avoid that you will use two pirani gauges and put on a two arms of the Wheatstone bridge, right and one particular gauge which is compensating gauge, as it, as it happens in the case of, in the case of Wheatstone bridge we have seen, in the case of strain measurements we have seen this is called a dummy gauge. This will be compensating element. So, this will be evacuated at very low pressure, then it is sealed, right and this will be, as usual the normal pirani gauges which is the low pressure will go inside through this region.

Now, what will happen? You see, if due to environment temperature change if the, there is any change of temperature due to any change of resistance, so there will be a similar change of resistance here in the same, because these two gauges elements are also exactly identical. So, the environment ambient temperature variations or bridge unbalance due to ambient temperature variations will be totally nullified if I use this type of configurations, right? So, this is called the compensating element or dummy gauge, dummy pirani gauge. You see the, this is evacuated and sealed. Now, there is a balance pot. I will explain what is the, I mean what is the function of this balance pot.

Initially we need it, because once you put this gauge and this is also at low pressure, so we will see, we will balance these bridges. That means we will make the resistance in the two arms exactly equal, then I will make it null. Now, the unknown pressure will go inside. Initially these two gauges are at the same pressure, please note. These two gauges that means these gauges, this dummy gauges, this dummy gauge and this gauge were at the same pressure, right, now and I will balance, using the balance pot I will make these two resistances equal, because these two resistances may not be equal, exactly equal, there will be slight difference.

So, I will use this balance pot to make these two resistance in the two arms that means arm from this region to this and this region to this, exactly equal. If it is equal, then what will happen? So, it will be totally balanced, right? Now the unknown pressure will be, go inside. So, I will get a bridge unbalance. That bridge unbalance will be calibrated in terms of the low pressure. That is the basic principle of the pirani gauge, right?

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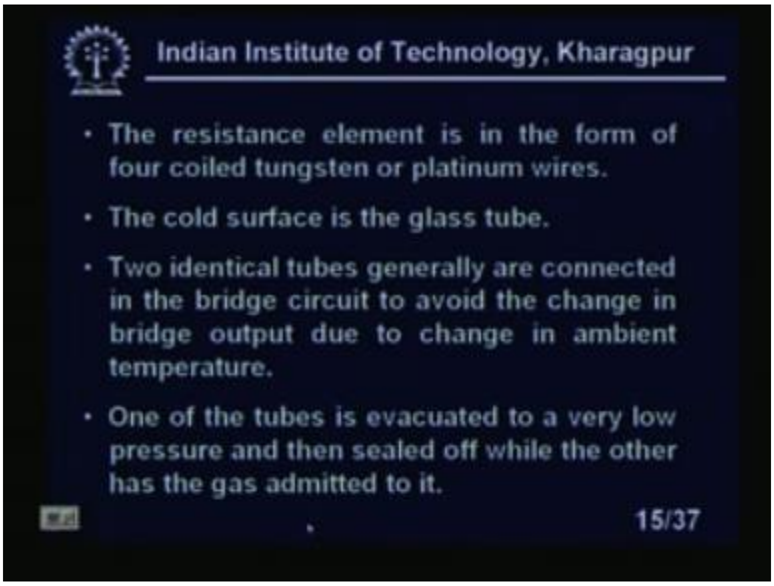

Now, the resistance element is in the form of four coiled tungsten or platinum wires as I have shown, right? The cold surface is the glass tube. The outer surface of the glass is a cold surface. Two identical tubes generally are connected in the bridge circuit to avoid the change in bridge output due to change in ambient temperature. One of the tubes is evacuated to a very low pressure and then sealed off while the other has a gas admitted to it.

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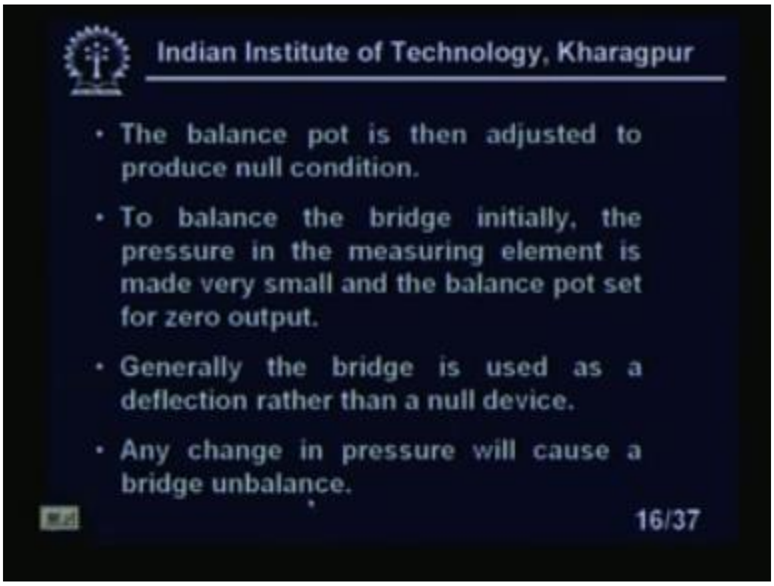

The balance pot is then adjusted to produce null condition, right? We have used that null condition; I have explained that thing. To balance the bridge initially, the pressure in the measuring element is made very small and the balance pot set for zero output. Generally the bridge is used as a deflection rather than a null device. Any change in pressure will cause a bridge unbalance. So, this unbalance we will calibrate in terms of …

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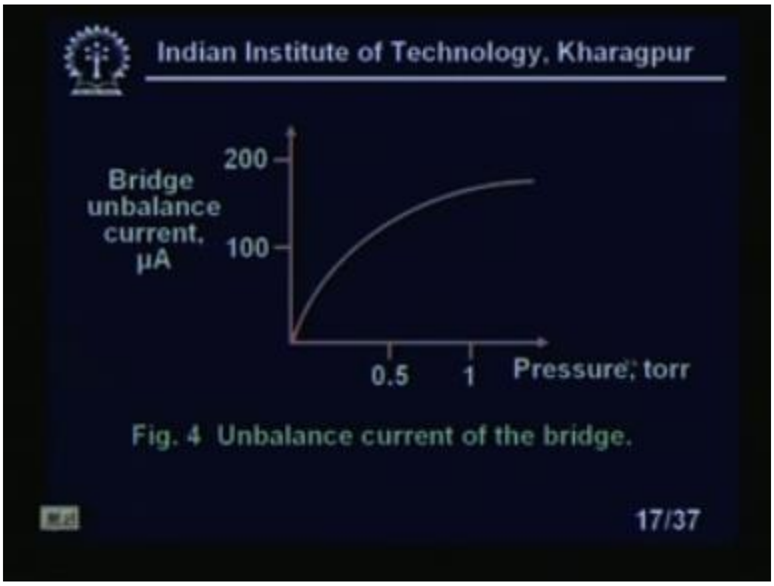

You see, this is the bridge unbalance current in microampere of a pirani gauge by a pressure. Now see, after some time as the pressure increases there is saturations of the bridge unbalance. There is a definite reason why it is coming saturation. This is the current in micro ampere, 100, 200 micro ampere, right? So, as the low pressure it is quite good response, I am, what change I am getting, but at high pressure, when the pressure is coming beyond 1 torr, so it is getting a saturation. There is no change and in fact if the pressure increase further there is no change in the bridge unbalance current, right?

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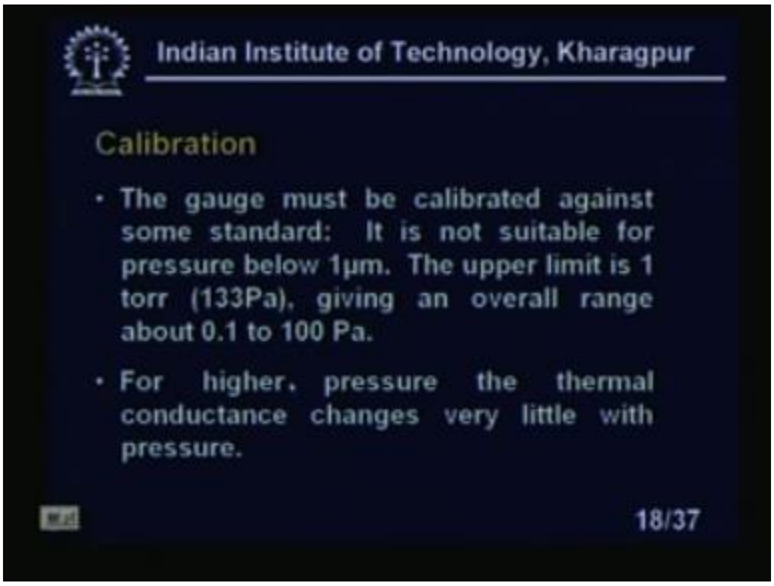

The calibration you see, the gauge must, must be calibrated against some standard. It is not suitable for pressure below 1 micron. The upper limit is 1 torr, 133 Pascal giving an overall range from 0.1 to 100 Pascal. For higher pressures, the thermal conductance changes very little with the pressure; thermal conductance changes very little with the pressure.

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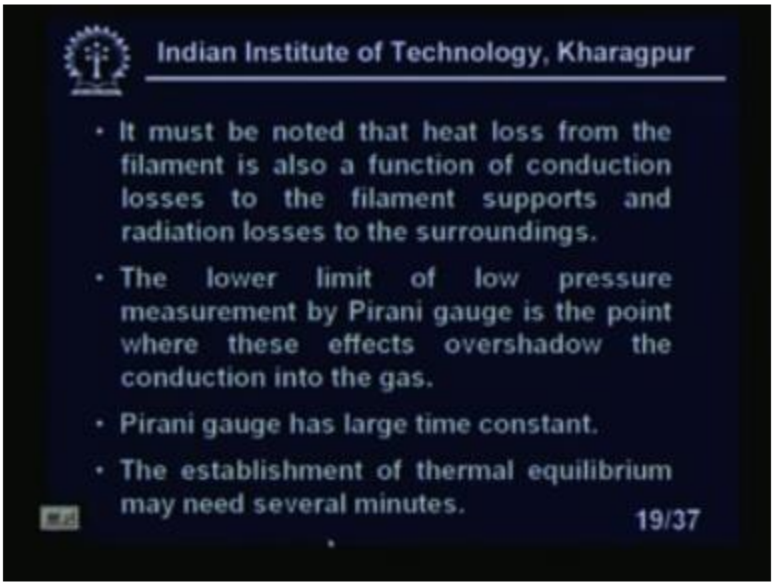

It must be noted that the heat loss from the filament is also a function of the conduction losses to the filament supports and radiation losses to the surroundings, right? The lower limit of the low pressure measurement by pirani gauge is the point where these effects overshadow the conduction into the gas, right? Now, pirani gauge, one of the greatest drawback it has the large time constant. It is not the, I mean the measurement is immediate, so and so that is one of the greatest drawback of the pirani gauge, right? The establishment of the thermal equilibrium may need several minutes, because it is thermal systems, it may take several minutes before it settles down.

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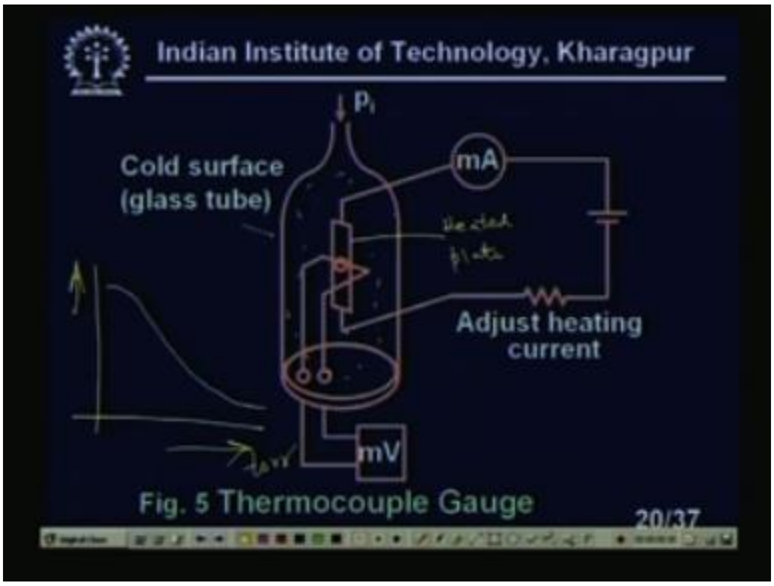

Now, this thermocouple gauges we will find its response time is quite fast. Even though it is slightly different principle, but its response time, since in the, if you compare with the pirani gauge, it is much less in the case of thermocouple gauge. The basic principle is like this. You see, it is also based on the thermal conductivity. What is that? I am saying that there is a molecule, gas molecules are there. So, these gas molecules will try to take away, this is the heated filament. So we have with the, with the some battery we are heating this filament. This is a heated filament, note it this is our heated filament, heated plate rather I should say. So, principle is same; instead of coil I am using the heated plate.

So, this will be heated. So, as the temperature, as the pressure falls, there is a less chance the molecules to take away heat to the colder surface. This is the cold surface glass tube. So, the temperature of this, with the same current, the temperature, the same battery voltage what will happen? The temperature of this heated plate will increase. There is one thermocouple welded here. So, that will measure the, the fall or rise of temperature of this heated filament. Because if the temperature rises, what will happen? If the pressure increases, then what will happen that it, temperature, actually the filament will fall, filament current will fall, if the temperature, pressure increases, is not it?

Why you see, because there is more chance of the heat, heat to be taken away, so that is the reason the pressure will fall, the current will fall or voltage will fall, right? So, what will happen? You see in that type of situations, I will measure the temperature, right? I will measure the temperature and this temperatures is, are in, this millivolt is calibrated in terms of the low pressure. That is the basic principle of the pirani, of the thermocouple. This is also basically depends on the thermal conductivity. That means as the pressure increases the current will decrease or the voltage will decrease, because it will have less temperature rise if the pressure increases, right?

So, it looks like this. The response curve will be, look like this one, so like this one. As the pressure increases in torr, the current or voltage of the, this thermocouple voltage will fall, right? So, as the pressure decreases what will happen? So, less number of molecules will try to heat this one. So, its temperature will rise. So, this filament temperature, this heated plate temperature will rise, so that so you see here, so as the pressure decreases, here you see the temperature will, the output voltage will rise. So, that is measured by the thermocouple, you see.

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Hot surface is a thin metal strip. I am still discussing about the thermocouple gauge.

Its temperature may be varied by varying the heated current, heating current. For a given heating current and gas, the temperature assumed by the hot surface depends on pressure, obviously. This temperature is measured by the thermocouple welded to the hot surface, right? Gauge is not independent of ambient temperature change, because there is no such bridge arrangement or something like that, so that the advantage what we have using a dummy gauges or compensating gauges in pirani gauge, in pirani measurement systems that is not there, absent in particular, the thermocouple gauge, right? So, range is typically 10 to the power minus 4 to 1 torr. Range is also I should know, I should say is not that good; that good means it cannot measure that low pressure, right?

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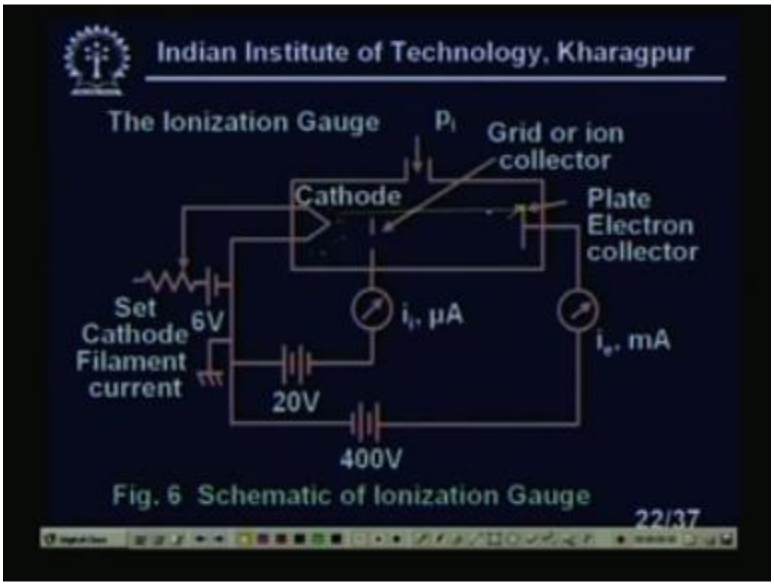

Now, third pressure gauge I should discuss is ionization gauge. Ionization gauge is the, one of the gauges which can go to extreme low pressures. This is the lowest pressure measuring devices. It is, the basic principle is that it will try to ionize some gases and that ion current, that ion will be collected by some plate and that current will be measured. Now, let us look at the, this ionization gauge. You see, this is the chamber in which we put the gas in which we are interested to measure the pressure.

We have a cathode, we have a grid and we have a plate. Now you see, there is always some electron will lie here, right? So, this electron will be collected by this plate, is not it? So, electron will emit here, it will be collected by the plate. There is no doubt about that, fine, because there is, number of electrons will be large here.

Now, if I put some gas inside what will happen? If I put some gas inside, while these electrons by this high voltage, you see this 400 volt will try to, will accelerate from this to this position. It will knock out some of the electrons of the outermost shell of the gas molecule, so that gas will be ionized. If that gas is ionized, then what will happen you see? This, since this is a, you see this is the, connected to the negative terminal of the battery, so ion will be connected by this grid or ion collector, we have given the name grid or ion collector, will be collected by this grid. So, I will get a ion current.

At the same time what will happen you see? When these knock out electrons will be collected by this plate, so there is an increase of current, in the electron current. Previously suppose there is no gas inside, there is no gas inside, then what will happen? I will get a simple current. Suppose it is total vacuum, then what will happen? I will get a simple and the current which is due to this electron which is, I mean continuously emitted from this cathode, it is collected by this plate.

Now, the gas is ionized. Gas is ionized means we have electrons as well as ion. Ion will be collected by the ion collectors and electron will be again collected by this one. But the change of electron due to the ionized gas, due to the change of electron current, due to the ionized gas will be, will be very, very small compared to the current which is I am getting by i i.

What does it mean? Suppose previously I am getting some, some current here due to the, some, these electrons are coming down here, I am getting some current i, which is usually in milliampere range. Now, how many ions will be, how many gas molecules will be ionized? Very small, is not it? Suppose ….., suppose if I say the 10 molecules are ionized, then what will happen? What will be the change of the electron current for that? Nothing; negligible, is not it? But, I will get a ion current. This ion current even though small will be measured by some micro ammeter. So, I can say that this electron, that pressure, low pressure will be, can be measured if I measured this i i, because increase of the electron current will be negligible for the ionised gas, is not it?

You see, the different voltages here. This is the 6 volts we have given to the cathode. The cathode can be directly heated or can be indirectly heated. So also as it is in case of the picture tube of our television, these are basically indirectly heated cathode, whereas say it will be fine, thus we are giving only 20 volt here for the cathode. We have given 400 volt because the electron is to be accelerated through this region, so that, I mean it moves very fast with high energy and heat the gas molecule to ionize it. Basic principle is that with high voltage 400 volts, so we will ionize some gas molecules inside. This is the basic principles of the ionization gauge, let us look at.

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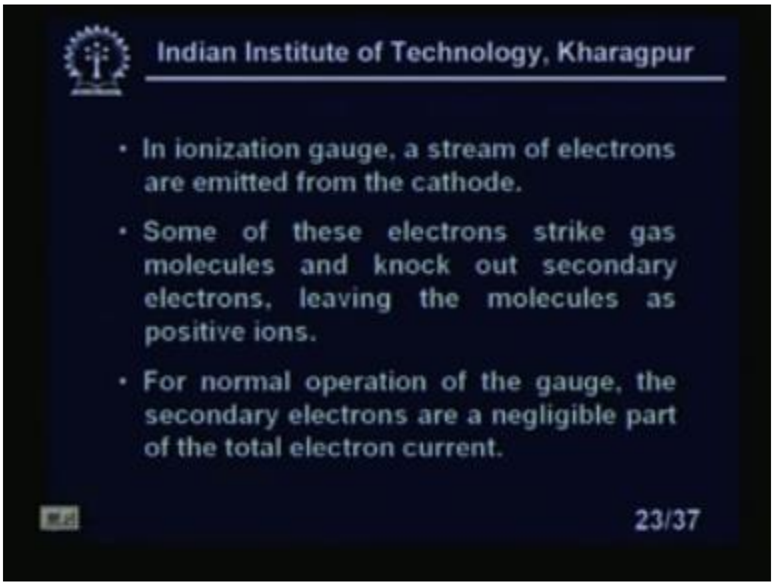

In ionization gauges, stream of electrons are emitted from the cathode. Some of these electrons strike gas molecules and knock out secondary electrons leaving the molecules as positive ions, as I said. For normal operation of the gauge, the secondary electrons are a negligible part of the total electron current. Total electron current is very, very negligible, because electron current is already existing there, is not it? That could be due to the electrons which is around the space charge region of the cathode, continuous electrons are moving around. So, whether the gas is ionized or does not ionize or not ionize, it does not matter. Always there is some electron that will be collected by the plate, right? That is I am saying for normal operation of the gauge, the secondary electrons are a negligible part. So, the electrons which is generated by the ions, by, in formation of the ions will be very, very negligible. So, it is a negligible part of the total current.

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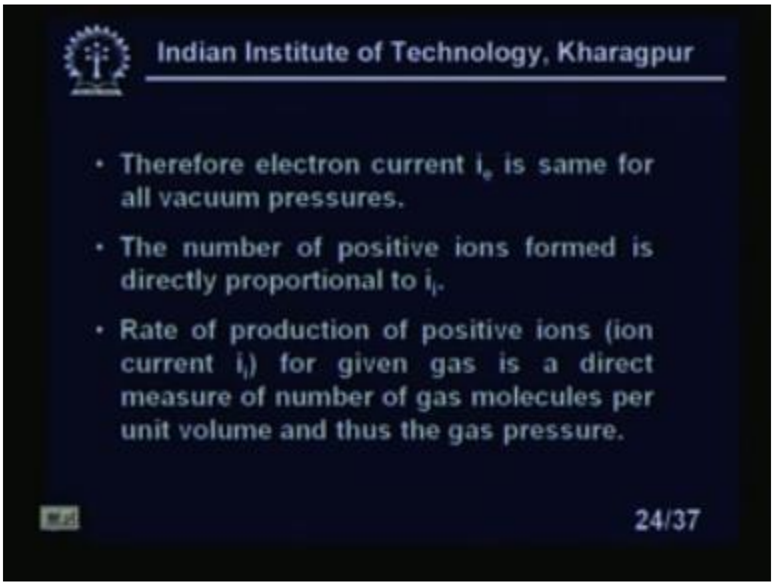

Therefore, electron current i e is same for all vacuum pressures. This is a great advantage. We will see the expressions. The number of positive ions formed is directly proportional to i i, ion current i i, I am giving the name. Rate of production of the positive ions, ion current i i for a given gas is a direct measure of the number of gas molecules per unit volume and thus the gas pressure, right?

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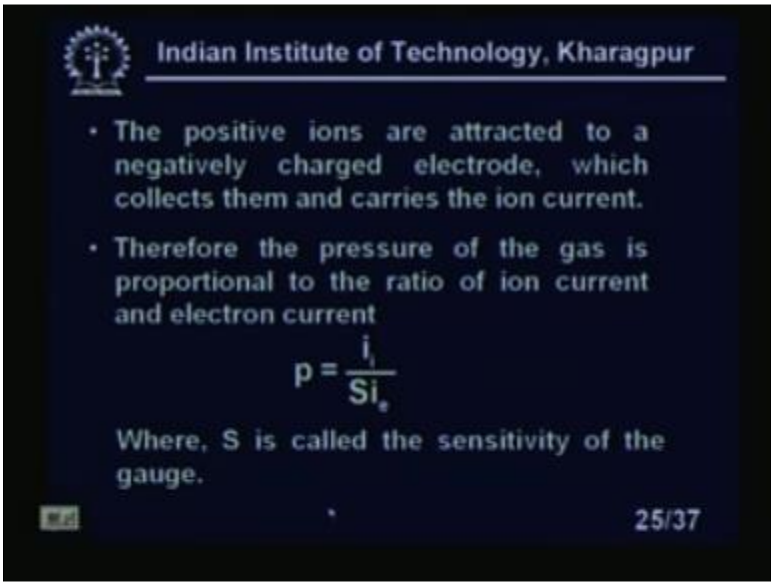

The positive ions are attracted to a negatively charged electrode which collects them and carries the ion current. Therefore, the pressure of the gas is proportional to the ratio of the ion current and electron current, right, even though the electron currents is constant. The expression, this is a very famous expression, you see this is our relations. This is ion current and this is electron current. This is almost constant and this is a emitter constant, S. So, as the pressure decrease, I mean the pressure decreases, I should say the i i will also decrease. If the pressure increases at that low pressure region you cannot give it some 100 psi there, right?

These are the pressure increases. This current will increase because more number of molecules, so there is a more number of ionized gas, ionized gas molecules. So more, if the more number of ions, the more current, right? If the pressure falls, the less number of molecules, less number of chances of the gas to be ionized; less number of molecules less the, lesser chance of gas to be, molecules to be ionized, right? So, the current i i also will be less, right, where S is called the sensitivity of the gauge, right?

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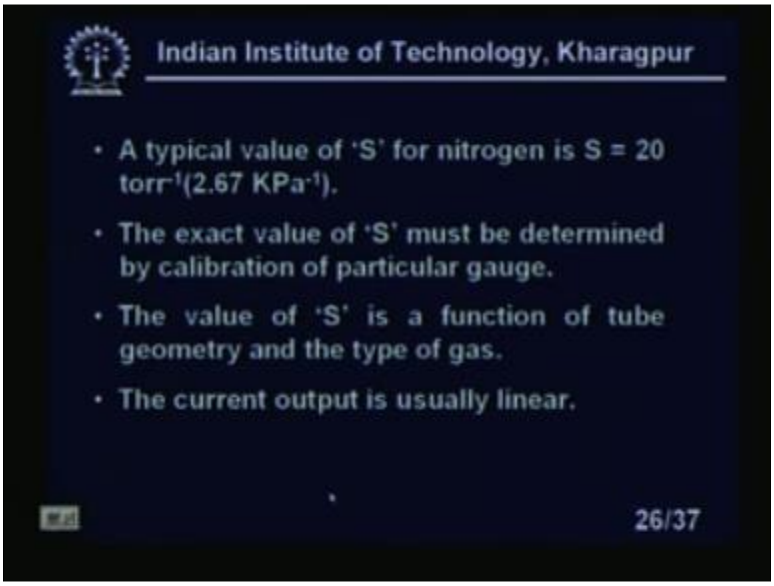

A typical value of the S for nitrogen is S equal to 20 torr to the power minus, which is 2.67 kilo Pascal to the power minus 1, right? The exact value of S must be determined by calibration of the particular gauge, right? So, for each gauge it is not gas independent, I mean like McLeod gauge and all those things. So, you have to measure it, you have to calibrate it separately for a particular gauge, particular gas, particular gas and particular gauge also. The value of S is a function of the tube geometry and the type of gas. So, it depends on the, both the tube geometry as well as of the gas. So, you have to calibrate it separately to find the value of S. The current output is usually is linear. So, it is a linear instrument. So, p is directly proportional to ion current, low pressure is directly proportional to the, proportional to the ion current.

Now, what is it? There is some disadvantage of this particular gauge, ionization gauge.

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You see, the filament may burn out if exposed to air while hot, decomposition of some gases by hot filament and contaminations of the measured gas by the gases forced out of the hot filament. So there is a, this chance is there. So, because at the hot filament what will happen? It will decompose. It will, I mean some decomposition of the gases hot filament and contamination of the measured gas, but the gas is forced out of the hot filament, so that will create, contaminate the gas actually where, which I am measuring. In some situation this is not allowed. So, hot cathode ionization gauges covers the range of 10 to the power minus 10 to 1 torr.

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Now, Knudsen gauge is another instrument. Even though it has very scientific applications, but it is, do not have any electrical output. You have seen the pirani gauge, thermocouple gauge, ionization gauge, has the direct electrical output, whereas we will find in the case of Knudsen gauge, like your McLeod gauge it is basically monitoring instruments. There is no, actually they are electrical output. Knudsen gauge you will find, it is rather difficult, I mean you will find there is a, in the case of McLeod gauge I am getting a manometric reading, whereas in the case of Knudsen gauge a spot of light is moving on a scale which is calibrated in terms of low pressure.

Let us look at Knudsen gauge. It is relatively, that is another advantage which is not there in the other gauge like pirani and the ionization. It is relatively insensitive to gas composition and thus gives promise to the development into a standard for pressure too low for McLeod gauge. McLeod gauge is not, as I discussed even though we are using as a pressure of standard, dimensions, pressures can be expressed in the dimensions of the gauge, but it is not suitable for the pressure below 1 torr. So, in that type of situation, this Knudsen gauge can be used as a pressure standard.

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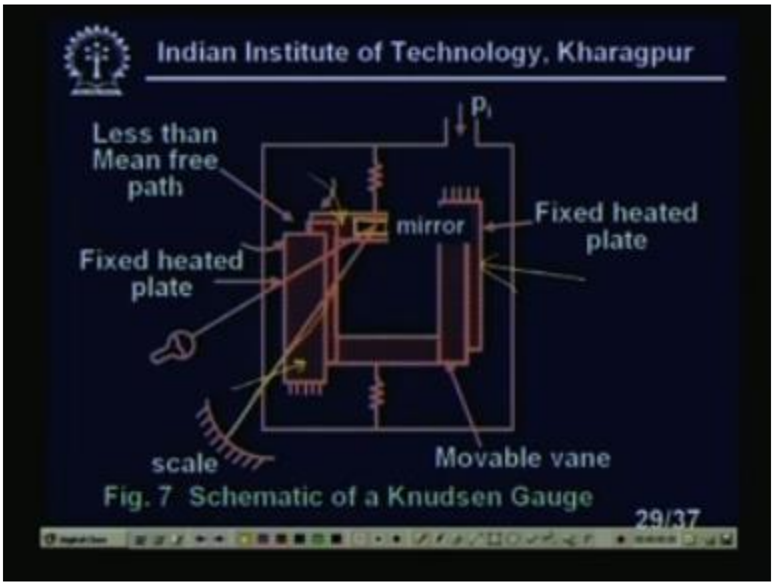

You see, this is the diagrams of the Knudsen gauge. We have, you see there is a gas chamber here. The gas which we are measuring p i, it is inside, is going inside. There is two fixed plates. You see, this is one fixed plate. You see, this is one fixed plate and this one fixed plate. In between two fixed plates we have a movable plate. This is our movable plate, right and mirror is installed here. A light spot is moving inside this, falling on the mirror and this is getting deflected and coming to this and it is putting on a scale.

This scale is calibrated in terms of, now what will happen? It is like this one. There is, there is two plates, heated plate is there. Two heated plates like this one and in between this heated plates there is a movable plate, right? Movable plate is inside, right, like this one. Now see, what will happen? The, now the distance between this heated plate and this should be less than the mean free path of the gas molecule. This is the one condition we have in the case of Knudsen gauge, right? Let us look at.

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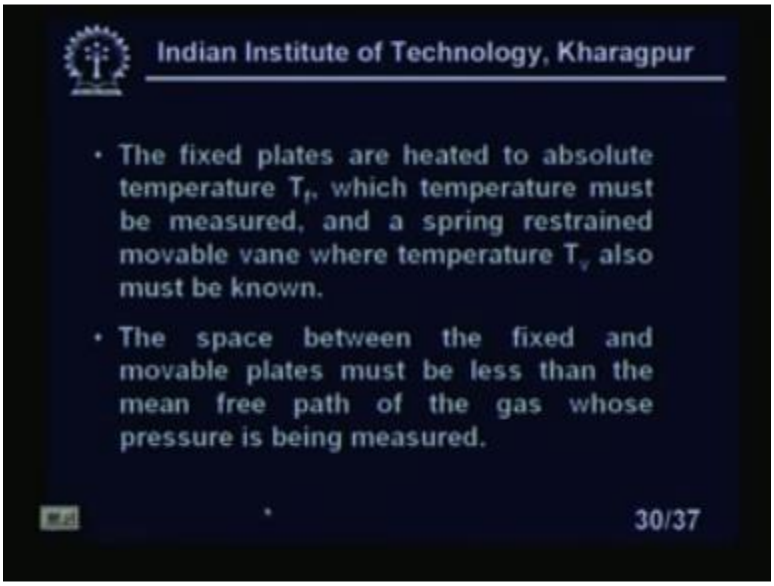

The fixed plates are heated to absolute temperature T f which temperature must be measured and a spring restrained movable vane where temperature T v also must be known. The space between the fixed and the movable plates must be less than the mean free path of the gas whose pressure is being measured.

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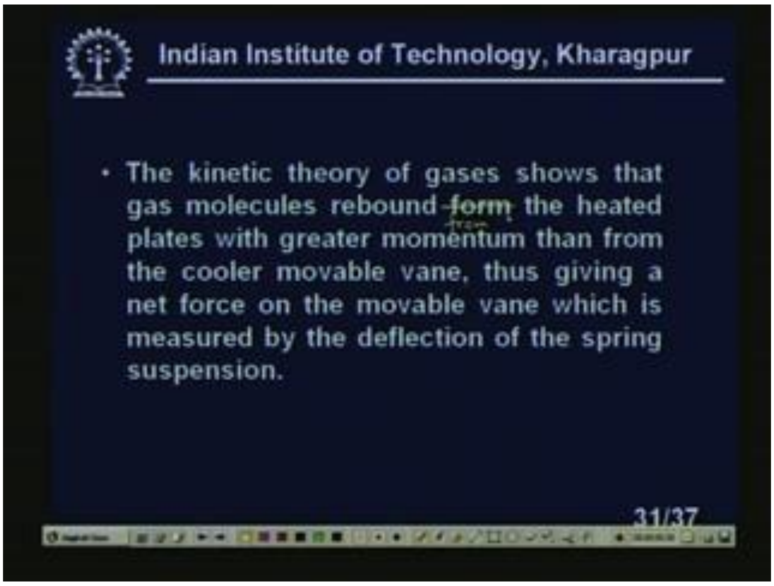

Now, kinetic theory of the gases shows that the gas molecules rebound from the, it is not from, I am sorry, this is from, from the heated plates with greater momentum than from the cooler movable vane thus gives a, giving a net force on the movable vane which is measured by the deflection of the spring suspension. What is that actually?

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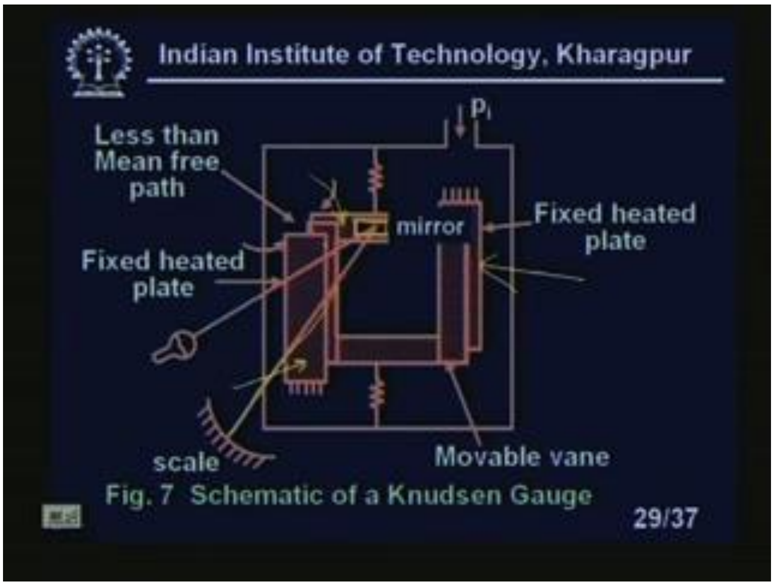

You see, see that there is a gas molecule inside, is not it? It is everywhere. So, this is a fixed heated plate. With a coil we are heating this and the gas molecules are getting rebounced from this one. So, we are assuming that the gas which is, gas molecule which is rebounced from this heated plate to a greater momentum than those which are reflected from the movable plates which is colder one. So, what will happen? There is a moment, a couple will act on this movable plate. So, it will rotate. So, the light is there, so it will fall on the mirror. Mirror will also rotate. The light spot will rotate on this scale. This is the basic principle.

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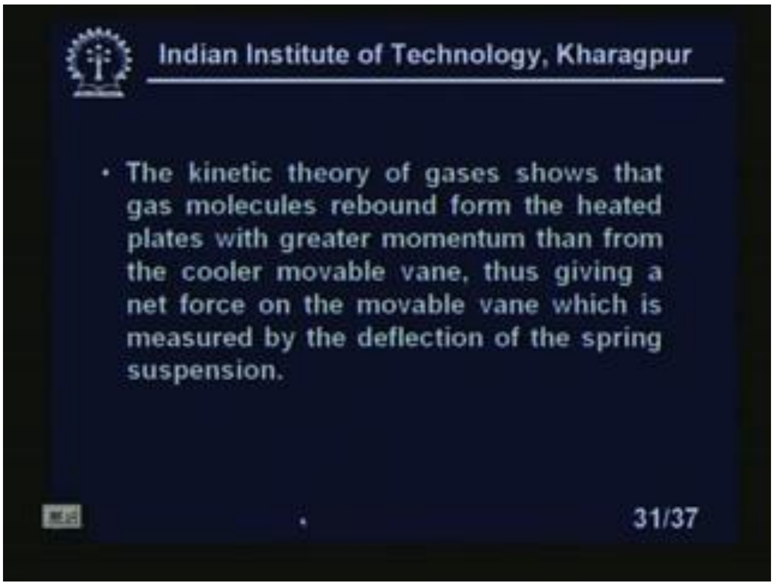

Now, kinetic theory of gas molecules rebound from the heated plates with greater momentum than from the cooler vane, movable vane thus giving a net force on the movable vane which is measured by the deflection of the spring suspension.

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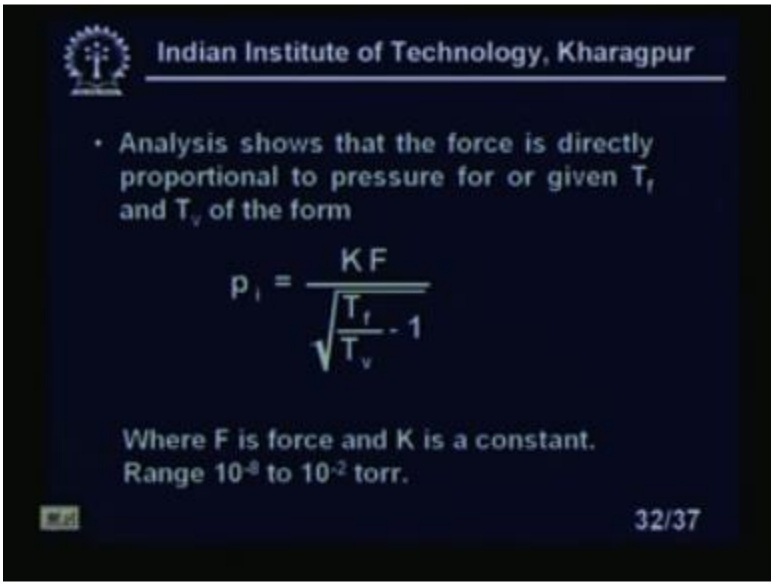

The analysis shows that the force is directly proportional to the pressure for a given T f and T v of the form, p i equal to K F upon under the square root T f upon T v minus 1, right, where F is a force and K is a constant. The range of the Knudsen gauge is 10 to the power minus 8 to 10 to the power minus 2 torr. This is a typical range. So, we can see that pressure can be measured, low pressure can be measured by this particular type of instrument, right?

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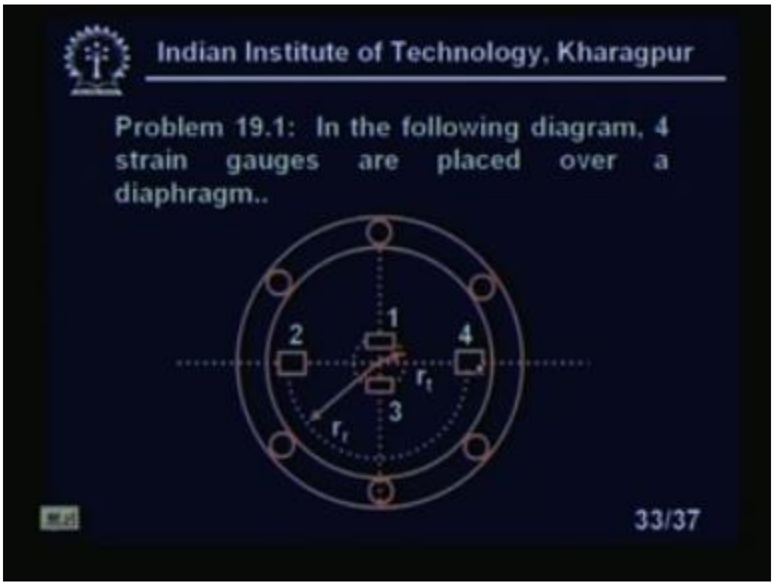

Now, let us solve a problem on a diaphragm gauge. In the following diagram, four strain gauges are placed over a diaphragm. We have seen this one already; four strain we have seen this already, rosettes this types of things are there. So, two strain gauges 2 and 4 which will actually sense the actual strain and two strain gauges at the centre which will sense the tangential strain, right?

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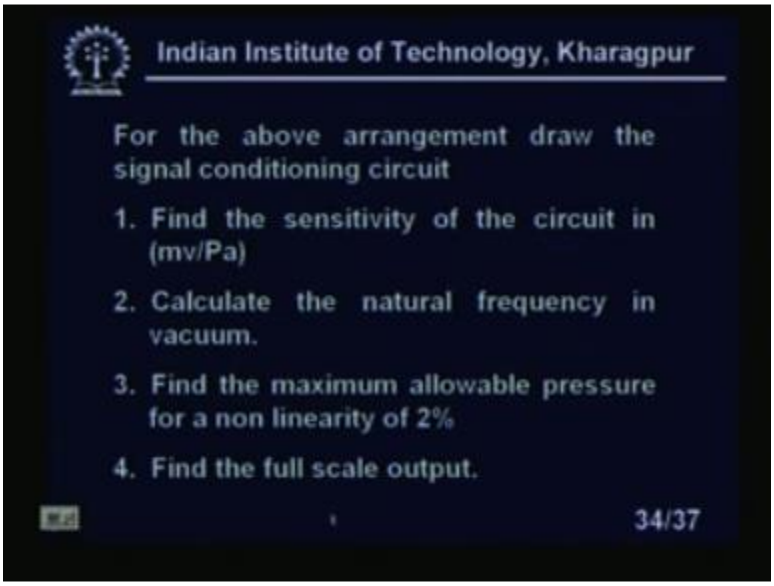

The problem is, for the above arrangement draw the signal conditioning circuit, first of all. Find the sensitivity of the circuit in millivolt per Pascal. Calculate the natural frequency in vacuum. Find the maximum allowable pressure for a non linearity of 2%. Find the full scale output, right?

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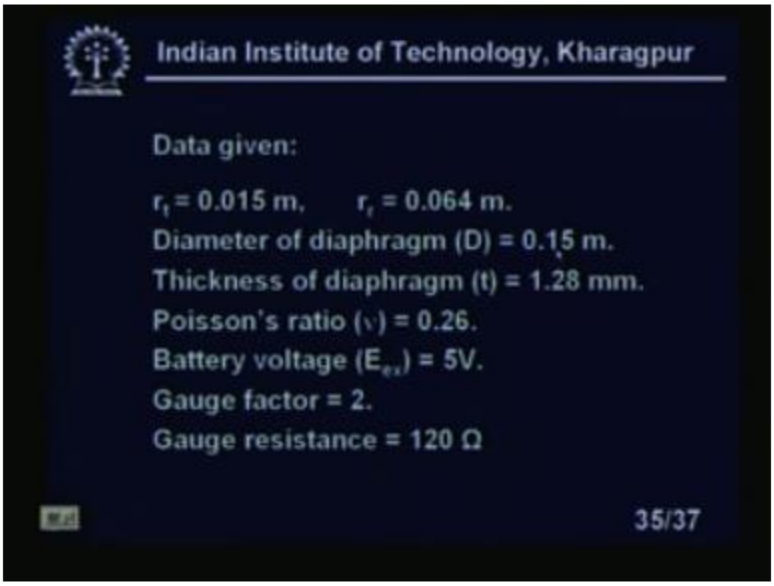

Data given are that r t, the radius r t, where is r t, please note.

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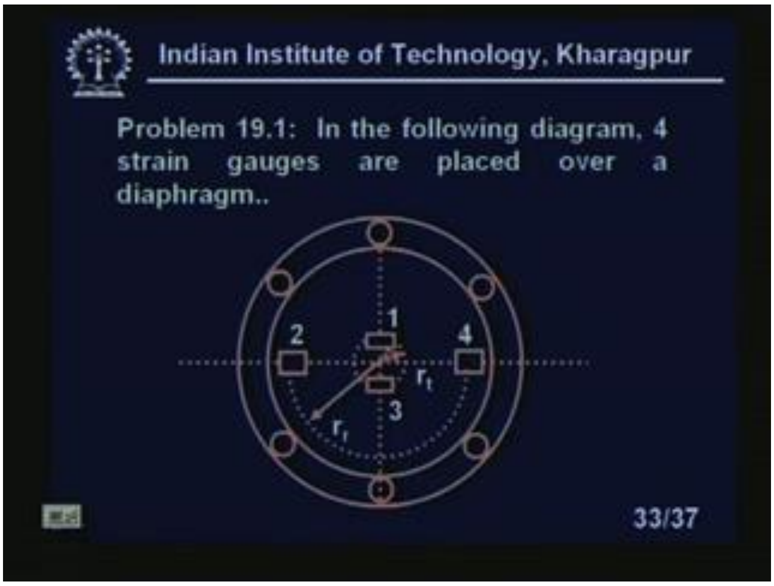

This r t is just the radius, where the, our circle on which this is the tangential strain gauges are placed, where r r is the radius of the circle on which, on which these two strain gauges which will sense the radial strain, this will sense the tangential strain, this will sense the radial strain, are installed, right, right? Let us go back again; already discussed.

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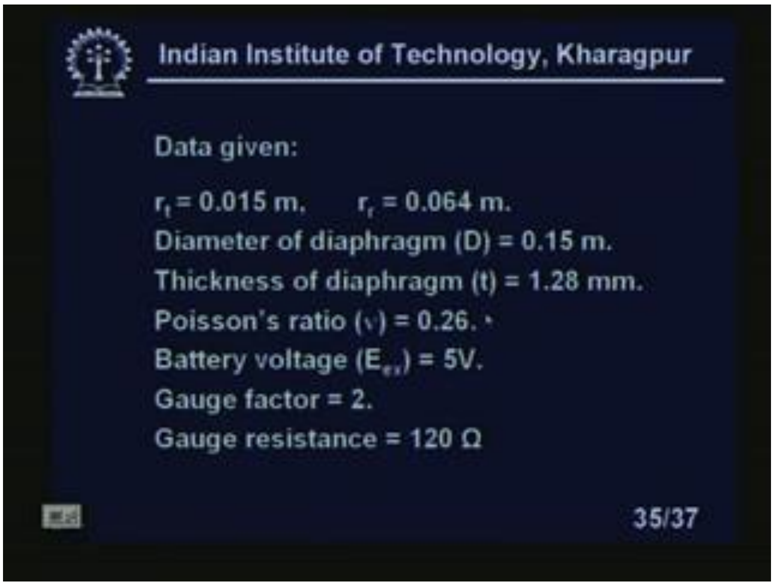

So, this is our data given. r t is the point, zero point zero, 0.015 meter. r r equal to 0.064 meter, diameter of the diaphragm is 15 meter and thickness of the diaphragm is t, 1.28 millimeter. In the case of rosette we will find this is quite valid, because rosettes even though it is large in size, because the diameter will be, the circle on which it is placed, the tangential and the radial will be much less than the diameter of the, you see, almost you see it is 0.15 that is 0.075, 0,075, it is 0.064, correct. Now you see, thickness of the diaphragm t is 1.28 millimeter. Poisson's ratio nu equal to 0.26, battery voltage E ex of 5 volt, gauge factor is advance we are using, it is 2 and gauge resistance we are saying 120 ohm.

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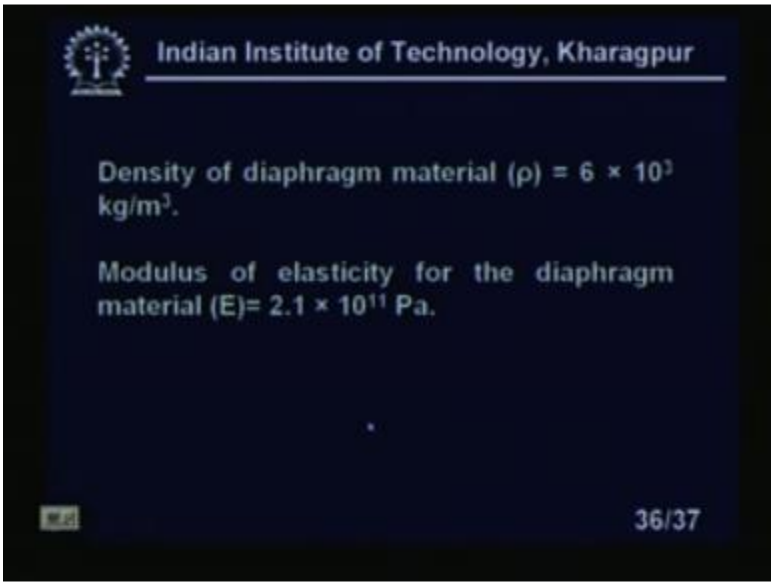

Density of the diaphragm material row is 6 into 10 to the power 3 kg per meter cube and the modulus of elasticity for the diaphragm material is 2.1 into 10 to the power 11 Pascal, right? So, let us look at the solution.

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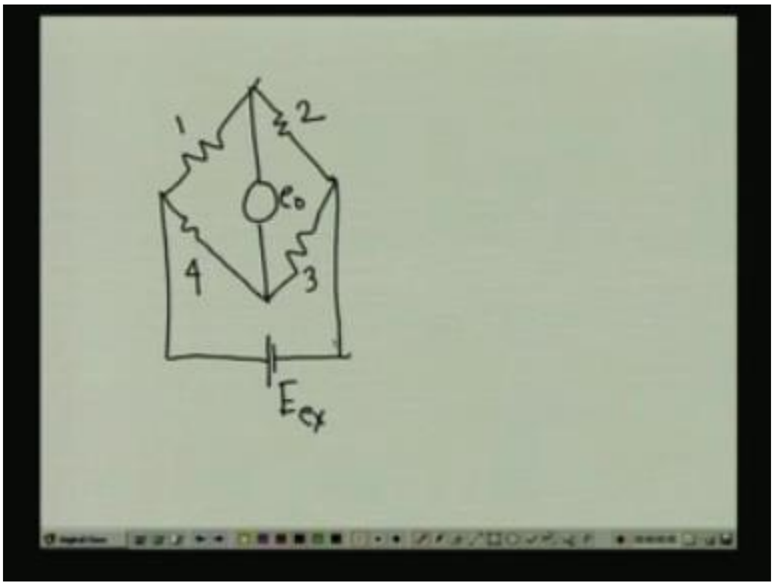

This is gauge 1, this is gauge 2, this is gauge 3, this is gauge 4. We have output voltage here, right, E ex, right? Now, the tangential stress are given by, we take a new page.

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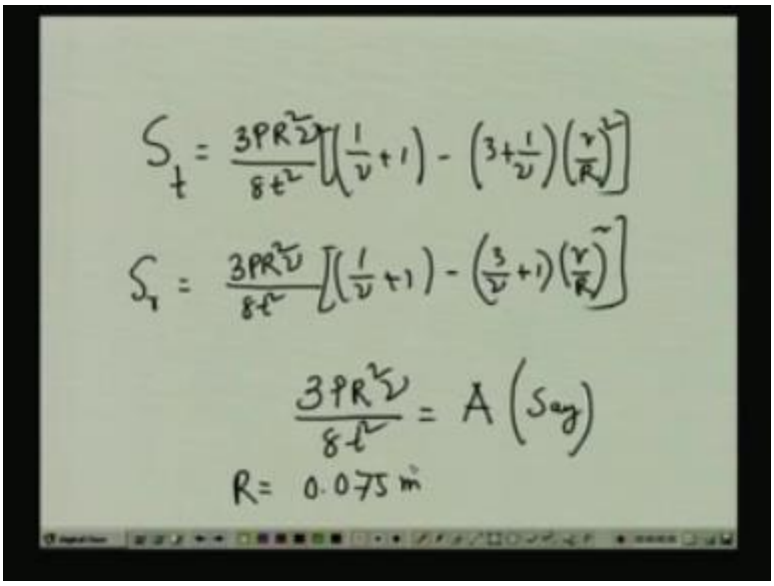

S t equal to 3 PR square nu 8 t square 1 by nu plus 1 minus 3 1 upon nu small r by capital R whole square, like this one and radial stress will be given by S r equal to 3 PR square 8 t square, square and biaxial stresses we know that also; expressions we know, we will give after some time. Now, let us represent this we assume the 3 PR square nu by 8 t square equal to, we are writing capital A. Now this, say this is A and R equal to 0.075 meter, right?

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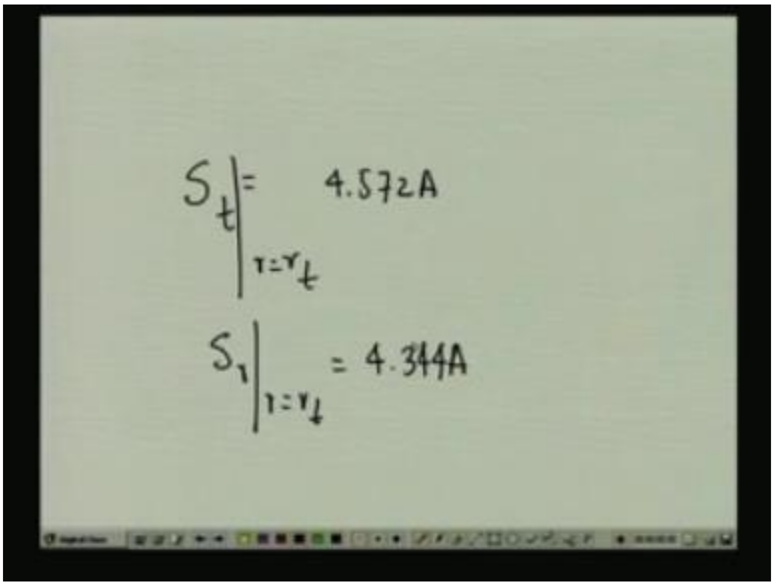

So I can say, sorry, S t at r equal to r t is equal to 4.572 A, right? S r r equal to r t equal to 4.344 A.

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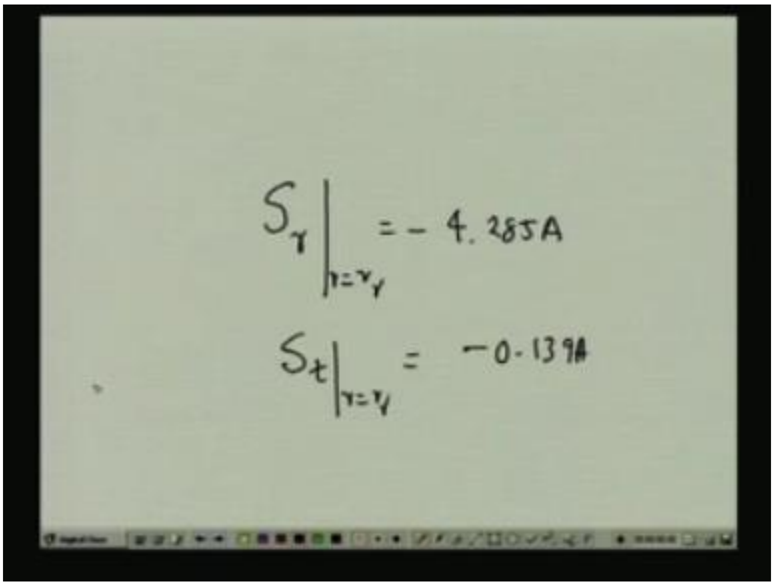

Now, again S r at r equal to r r equal to minus 4.285 A and S t at r equal to r r minus 0.139 A. Now, the diaphragm is in the state of biaxial stress and both the radial and tangential stress continue to the radial and tangential strain.

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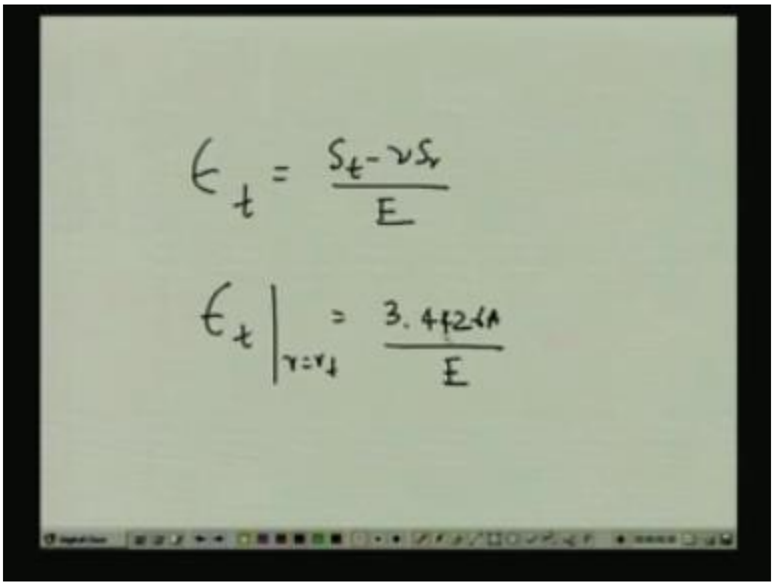

So, epsilon t we know S t minus nu S r by E. So, epsilon t at r equal to r t, I should say 3.4426 A by E, right?

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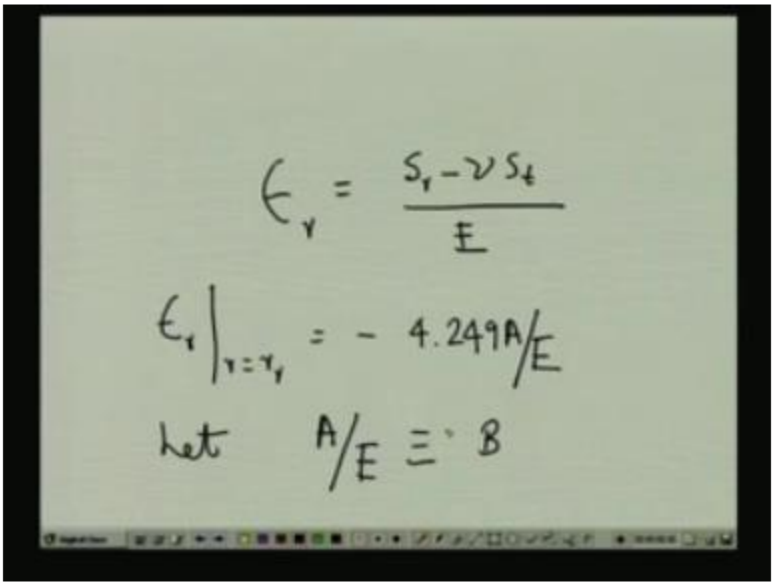

Radial strain epsilon r equal to S r minus nu S t by E. So, epsilon r at r equal to r r minus 4.249 A by E. Let E represented by, suppose this is represented by B, then what will happen?

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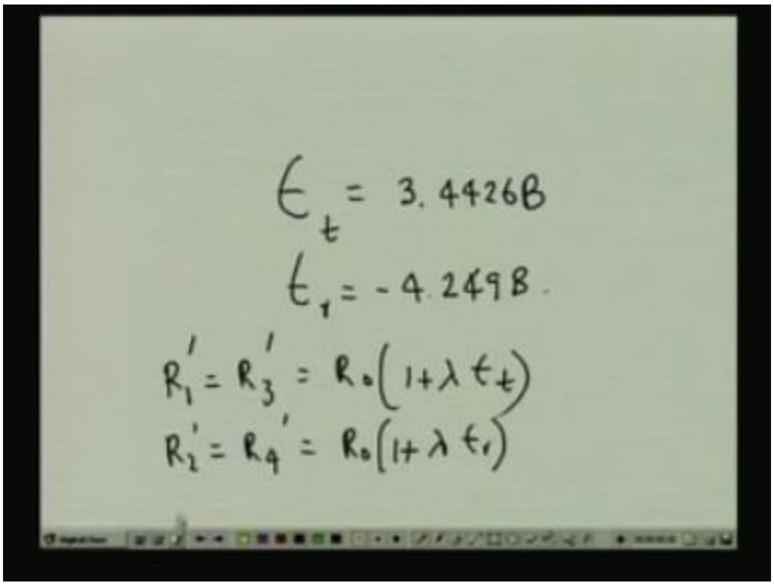

You know that epsilon t will be given by 3.4426 B and epsilon r equal to minus 4.249 B. Now, the gauge factor is equal to 2 and with the application of the pressure, so I can say that the change of resistance R 1 dash will be R 3 dash equal to R naught, initial value of the resistance 1 plus lambda epsilon t and R 2 dash R 4 dash R naught 1 plus lambda into epsilon r, right?

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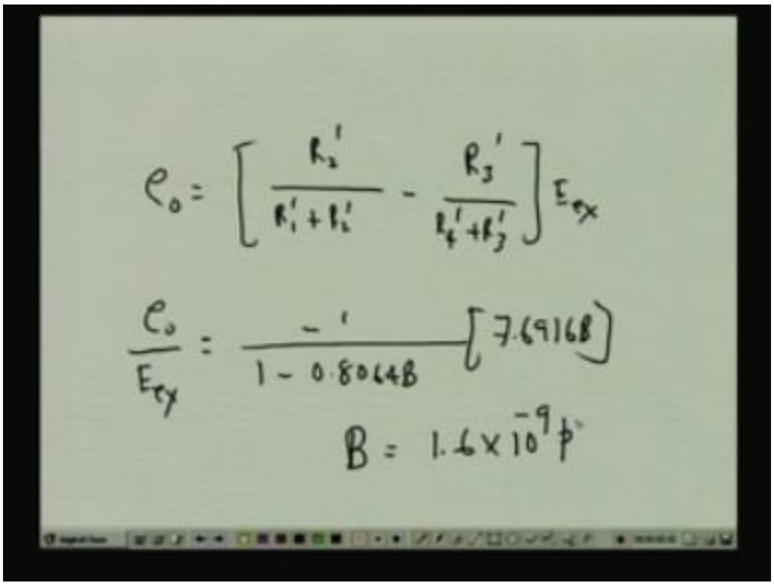

So, the unbalanced voltage will be given by e naught equal to R 2 dash by R 1 dash plus R 2 dash minus R 3 dash upon R 4 dash plus R 3 dash, excitation E ex. So, this will lead to, substituting all these values of R 1 dash, R 2 dash, R 3 dash, R 4 dash, I will get, e naught by E ex equal to minus 1 upon 1 minus 0.8064 B 7.6916 B. Now, substituting all the values, we get that B equal to, if I substitute all the values of B, B equal to 1.6 into 10 to the power of minus 9 into p, unknown pressure, right?

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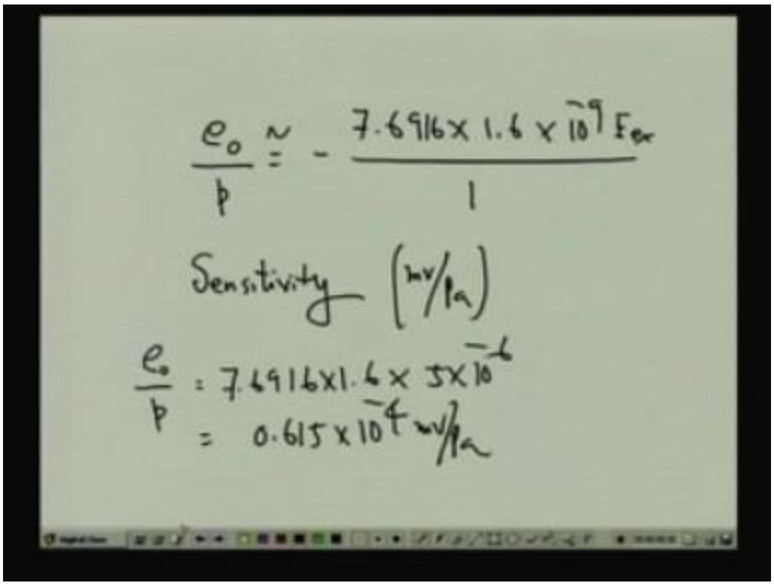

So, sorry, so I will get, e naught by E ex equal to e naught by E ex equal to or I should directly write instead of e naught by E ex, I can directly write that e naught by p equal to minus 7.6916 into 1.6 10 to the power minus 9 E ex upon 1. So, neglecting the term that means this small value of, it is almost I should say, almost equal to this. So, sensitivity, I will find sensitivity that is in millivolt per Pascal will be given by e naught by p 7.6916 into 1.6 into 5 into 10 to the power minus 6. So, it will be 0.615 10 to the power minus 4 millivolt per Pascal.

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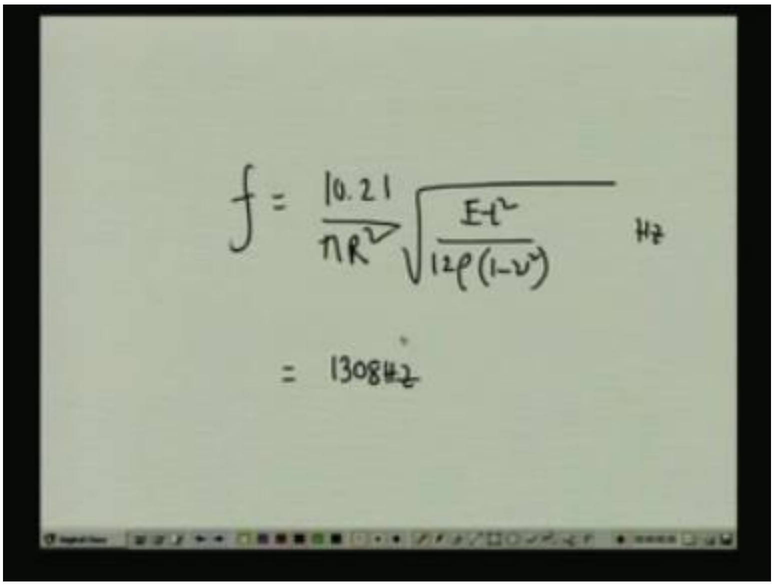

Now, for the second part you see that we know the expressions that f is natural frequency 10.21 pi R square, radius of the diaphragm E t square upon 12 rho 1 minus nu square. This is in Hertz. So, if I put all the values, I will get 1308 Hertz, right?

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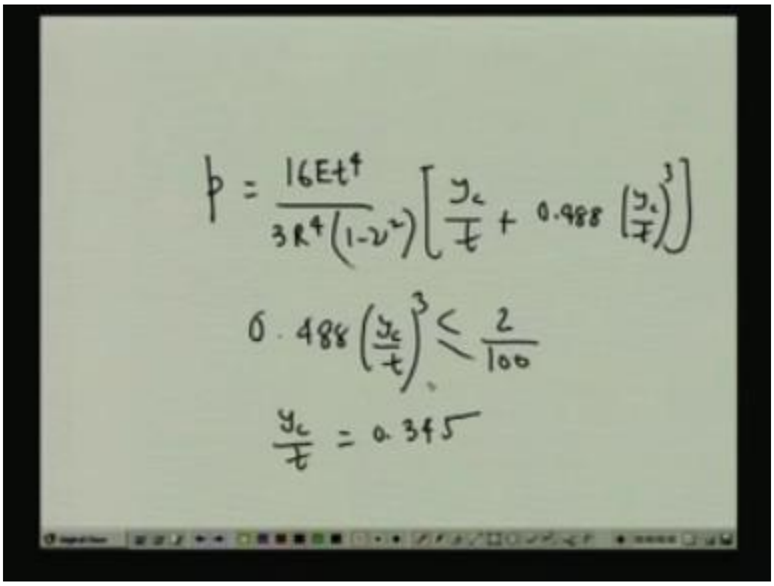

Now, third problem what we said that the, you know the p can be related as 16 Et power 4, the third part of your problem 3R to the power 4 1 minus nu square y c by t plus 0.48 y c by t cube. This is our non-linear term, is not it? So, non-linearity, non-linearity is introduced due to second terms. So, it is given 0.488 y c by t whole cube 2 by 100, right? So, this will give me y c by t equal to 0.345.

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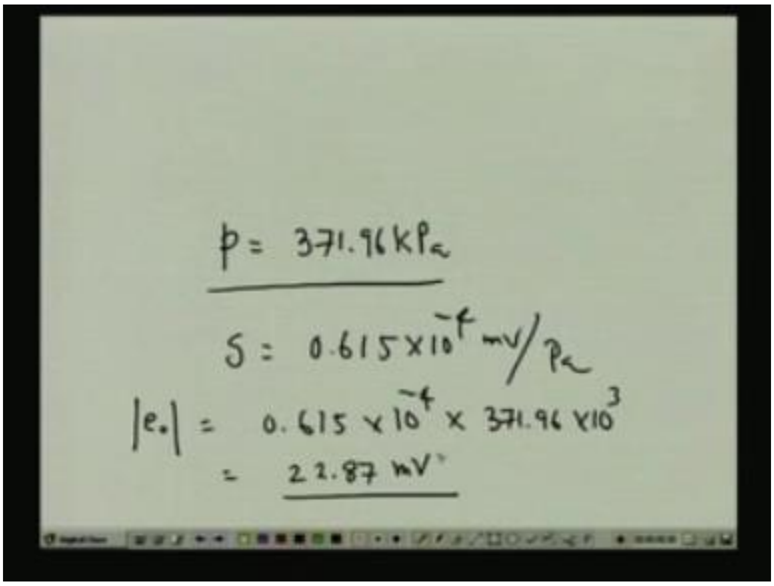

So, the maximum available pressure from this we can write is that p is, if we can compute this thing, we will get p equal to p equal to 371.96 kilo Pascal, right? Sensitivity, S will be given by 615 into 10 to the power minus 4 millivolt per Pascal. So, the maximum available pressure is this one and the full scale output will be given by e r e naught 615 10 to the power minus 4 into 371. 96 into 10 to the power 3 equal to 22.87 millivolt, right? This is your answer. This ends the lesson 19 of Industrial Instrumentation.