Engineering Metrology

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Lecture – 28
Pressure Measurements (Part 1 of 2)

Welcome back, the next topic of discussion is going to be Pressure Measurement. So, as I told you earlier in manufacturing 3 parameters, one is temperature which we have covered next pressure. So, pressure is a very very important parameter. The performance of any manufacturing can change manufacturing process can change if you start playing with the pressure and pressure measurement is also very important.

For example, today we are trying to develop lot of exotic materials, these exotic materials have properties which are very difficult to machine. So, if you want to try machining the component or if you want to try during machining measuring the component whatever component response, then understanding the concept of pressure is very very important ok.

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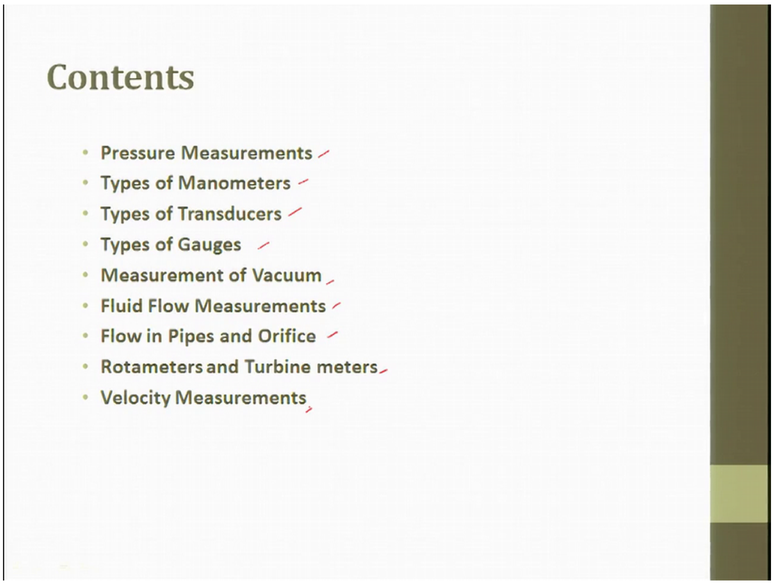

So, in this lecture we would like to cover pressure measurements, types of manometer, types of transducer, types of gauges, measurement of vacuum which is very, very important. Fluid flow measurement, then flow in a pipe and orifice, rotameter and turbine meter and the last one is going to be velocity measurement.

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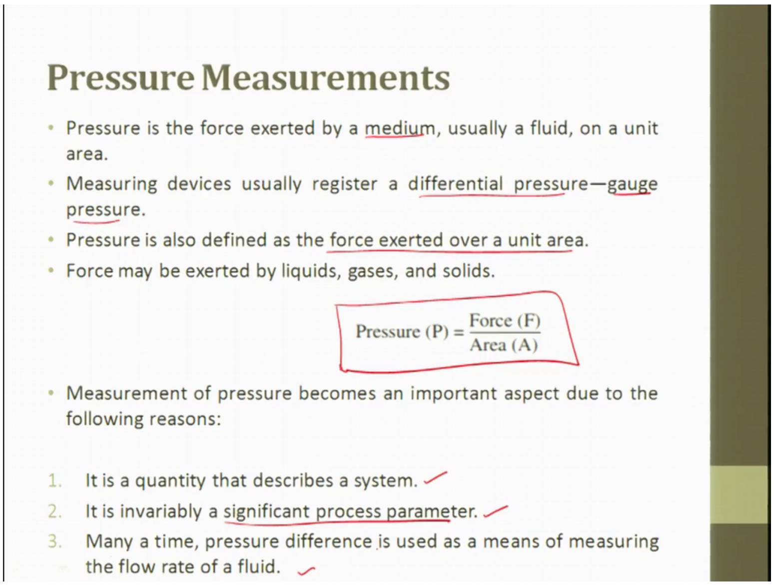

Pressure measurement, pressure is force exerted by a media usually a fluid or a unit area. Measuring devices usually resist a differential pressure for example, gauge pressure we will see what is gauge pressure later. That does not need the pressure is also defined as force exerted over a unit area, pressure may be exerted by liquid, gas or solid. So, this is the definition for pressure, pressure is nothing but force acted per unit area.

Measurement of pressure becomes important aspect due to the following reasons. It is a quantity that describes the system, it is a invariable a significant process parameter. Many a times pressure difference is used as a means of measuring a flow rate of a fluid. So, these are the 3 important parameters, it is invariably a significant process parameter this is very important which I told you. Then many a times pressure difference is used as a means of measuring the flow rate of a fluid.

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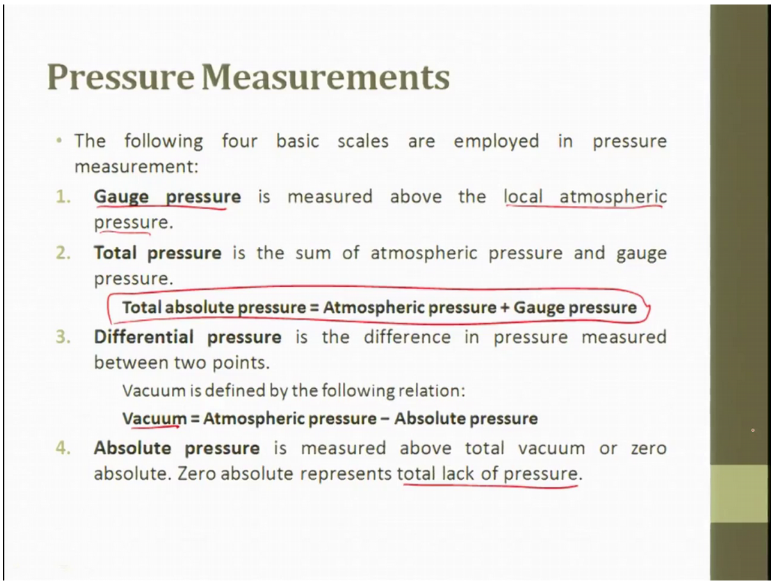

The following four basic skills are employed in pressure measurement. One is gauge pressure, total pressure, differential pressure and absolute pressure. Gauge pressure is measured above the local atmospheric pressure that is gauge pressure. For example, you put a gauge and then you try to measure the pressure the full pressure. So, then it is above the local atmospheric pressure. Total pressure is the sum of atmospheric pressure and gauge pressure so, here what happens is, low atmospheric pressure we subtract and then we what we get is gauge pressure. Differential pressure is the difference in pressure measured between two points.

Vacuum is defined by the following relationship; vacuum is equal to atmospheric pressure minus absolute pressure that is vacuum so, is the difference in pressure measured between two points. Absolute pressure is measured above total vacuum or zero absolute. Zero absolute represents the total lack of pressure, that is nothing but the absolute pressure.

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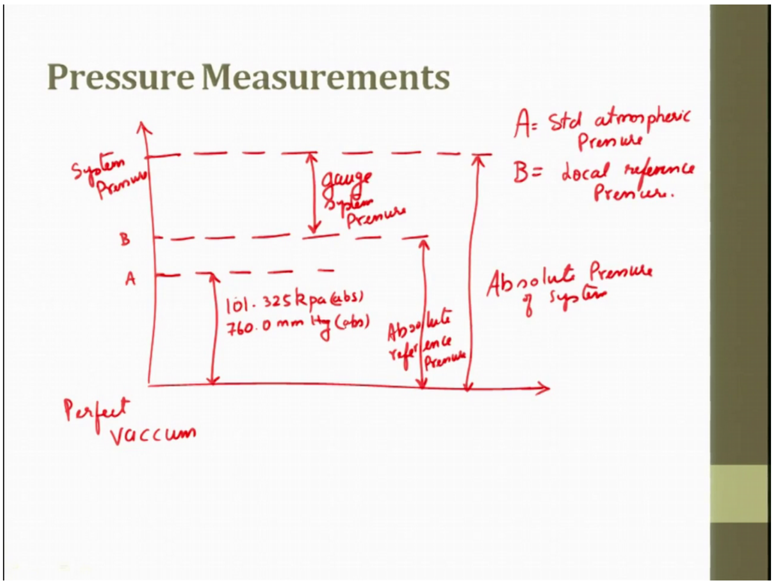

So, let us just put this in diagram. So, this is perfect vacuum, this is system pressure, this is I am write it as A and then I will write it as B; that A is nothing but standard atmospheric pressure and B is nothing but local reference pressure. This one is called as absolute pressure of a system pressure of a system, this one is called absolute reference pressure. The difference between these two are called as gauge system pressure.

So, let us put the values, this is 101.325 kilo pascal abs ok or it can be called 760 millimetre Hg absolute ok. So, whatever we have explained in the previous thing, 4 pressure, gauge pressure, total pressure, gauge pressure is above atmospheric pressure, total pressure is atmosphere plus gauge pressure. Differential pressure is atmosphere minus absolute pressure, what is absolute pressure? Is measured above total vacuum or zero absolute; zero absolute represents a total lack of a pressure. So, that is what we have represented in this diagram.

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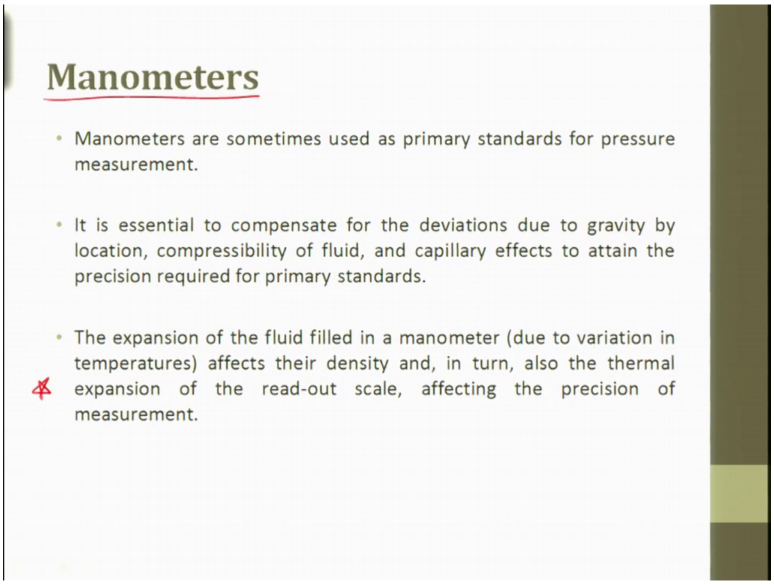

So, to measure we pressure we thought or a very primitive device for measuring pressure is a manometer. Manometer are sometimes used as a primary standard for pressure measurement, it is a very, very basic thing. It is essentially to compensate for the deviations due to gravity by location compressibility of fluid, capillary effect to attain the precision requirement for a primary standard ok.

It is self-explanatory, it is essential to compensate for the deviation due to gravity by location. The next one is the expansion of fluid filled in a manometer affects their density and in turn also the thermal expansion of the readout scale affecting the precision of the measurement. So, this point has to be taken as a precaution.

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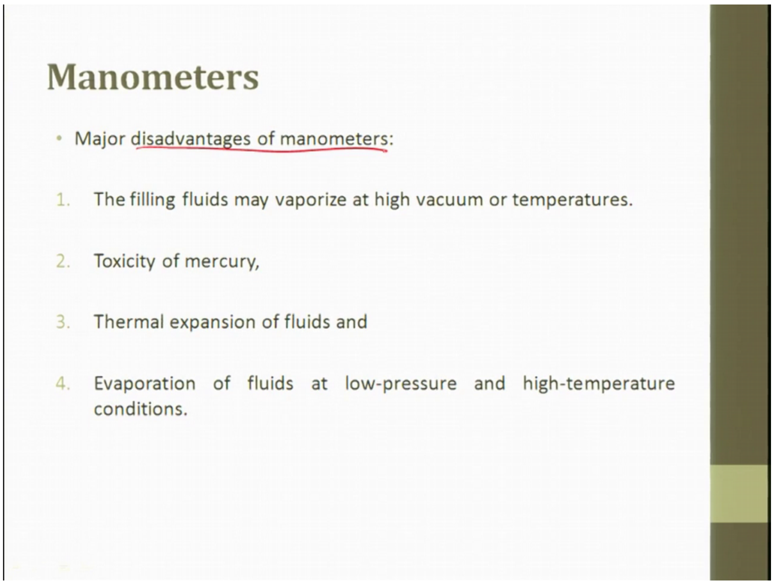

The main disadvantage of manometer is the filling fluid may vaporize at high vacuum or temperature. The filling fluid may vaporize at high vacuum or temperature. Toxicity of mercury is very very important point where mercury if it starts vaporizing. Thermal expansion of the fluid and evaporation of the fluid at low pressure and high temperature conditions, these are some of the very important points which makes difficulty in using manometer.

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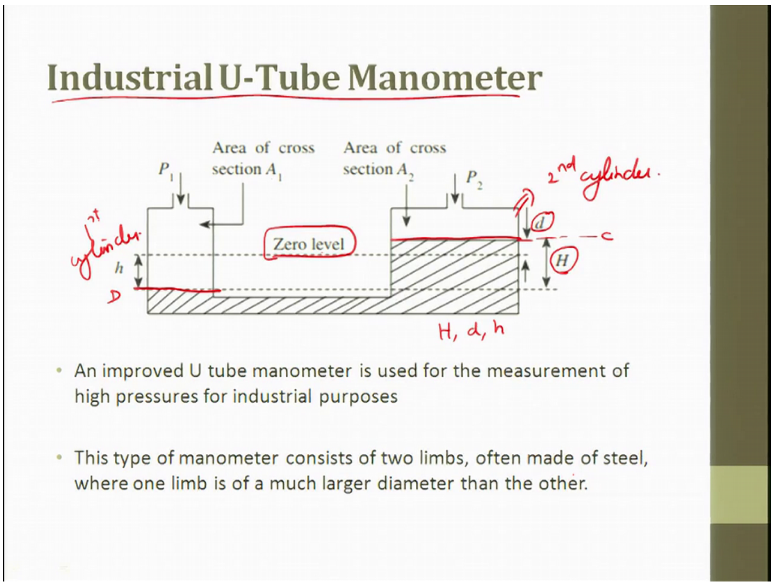

So, this is a typical industrial U-tube manometer you have a pressure 1 and then you have a pressure 2 which is applied. So, here the area of cross section is A of the tube or the container, area of cross section is A 2. So, A 1 is small A 2 is big P 1 P 2 pressures and this is the so, the from the level here and to the level here, the difference between two levels are called as heads. There is in between a level which is called as 0 level so, the difference between the 0 level and the bottom of this one; so, let me call it as 1st cylinder and this I will call it as connected to a 2nd cylinder.

Heads is the higher head ok so, 1st cylinder 2nd cylinder, 1st cylinder the mercury level goes to a point called as maybe we will name it as D. And here it goes to a point C so, this is a mercury level. So, here in between C and D there are 3 points to be noted. One is the level where C is there, the difference between C minus D is called heads H H capital. The difference between c and the 0 level we call it as d, small d. The difference between 0 level and big D is called as H ok.

So, important points to be noted are H d and h small h. In between there is a there is one point called as 0 level. And improved U-tube manometer is used for measurement of high pressure for industrial application this is one. This type of manometer consists of 2 limbs, often made of steel where one limb is of much larger diameter than the other so; this is what we have explained here. This is industrial type this is a manometer which is used even today.

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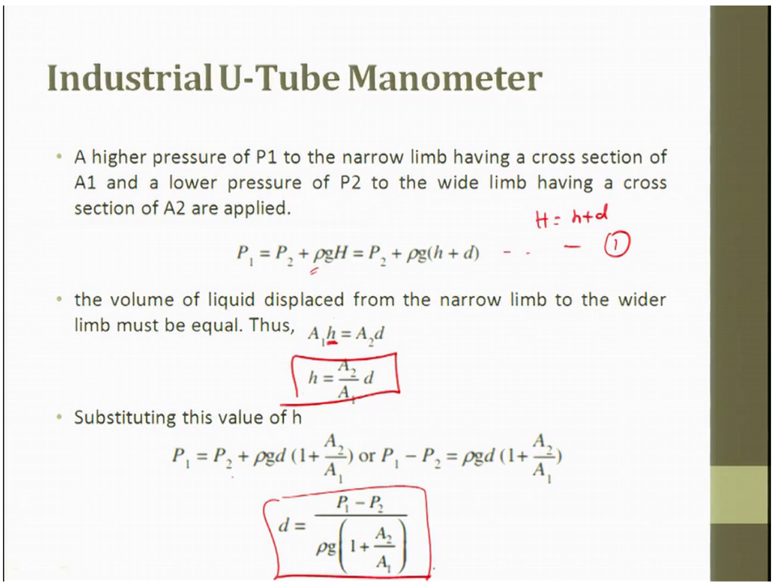

The higher pressure of P 1 to the narrow limb have a cross section area of A 1 and a lower pressure P 2 to a wider limb having a cross section area of A 2 is applied. So, P 1 equal to P 2 plus rho g H; where this heads if you go back to the figure and see it is H is equal to small h plus d.

And in between this comes a 0 level. The volume of the liquid displaced from the narrow limb to the wider limb will be equal to A 1 h equal to A 2 d. So, if you want to find out this heads h, h is nothing but A 2 by A 1 the multiplied by d. So, this is the volume of liquid displaced from a narrow limb to a wider limb have a must be equal. So, we can try to find out h, now substituting this h back into this equation 1,, what we get is to substituting h.

So, P 1 equal to P 2 plus rho into g into d, bracket 1 plus A 2 by A 1, or it can be written like this. So now, you can try to find out the d, what is d? If you go back to the previous figure, small d is nothing but above 0 level to the height where mercury stands in cylinder or limb 2, let me find out d.

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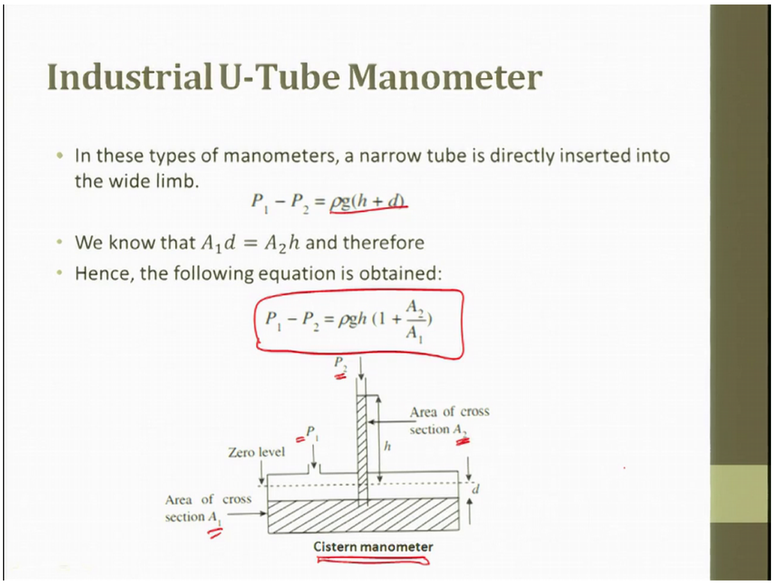

In this type of manometer a narrow tube is directly inserted into a wide tube. So, this is a second type so, this one we can try to find out d. So, we will look for another industrial U-tube manometer, which is called as cisterns manometer. So, almost the same thing can be done here so, what we do here is, we take a cylinder fill it up with liquid and then we have pressure which is applied here. And then we insert a tube with a with almost a very small cross section area. So, that is nothing but A 2 so, P 2 A 2 P 1 A 1 0 level d.

This is the h and you try to find out. So, in this type of manometer a narrow tube is inserted directly into the wider limb. So, P 1 minus P 2 is equal to rho g h the same formula what we wrote there. So, here also you see almost the same formula P 1 minus P 2 right so, rho g h. So, we know that A 1 d equal to A 2 h and therefore, we substitute it back into the equation and we get this ok. This is a cisterns manometer so, this is also it is a industrial type manometer used to measure the pressure.

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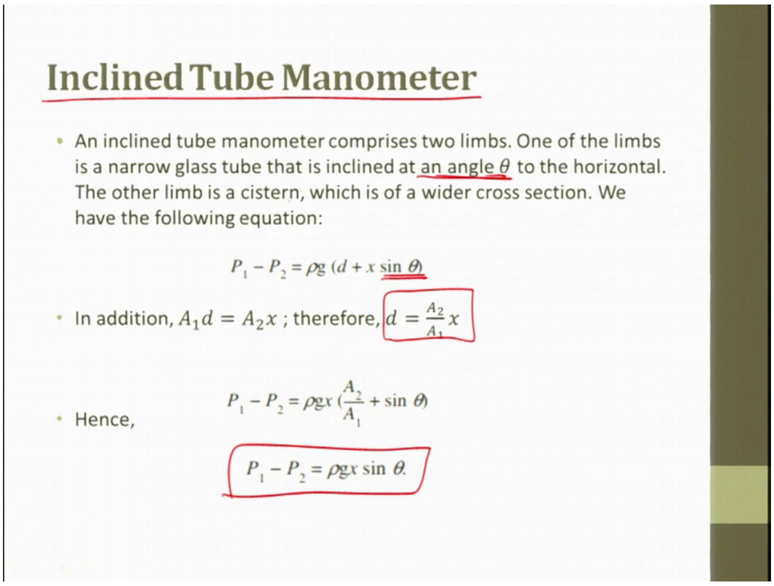

You can also have something called as inclined tube manometer. Incline tube manometer is an inclined tube manometer comprises two limbs. One of the limb is narrow glass tube; that is inclined at an angle theta to the horizontal just a variation a horizontal. The other limb is a cistern, which is a wider cross section area, we now have this theta term is added to it. If you go back and see to that equation, previous equation it was rho this d you have a theta form which is getting added so, plus x sin theta. So, A 1 d equal to A 2 x and therefore, d 2 equal to x sin theta. So, here if you substitute it back into the equation we get this inclination angle added to it.

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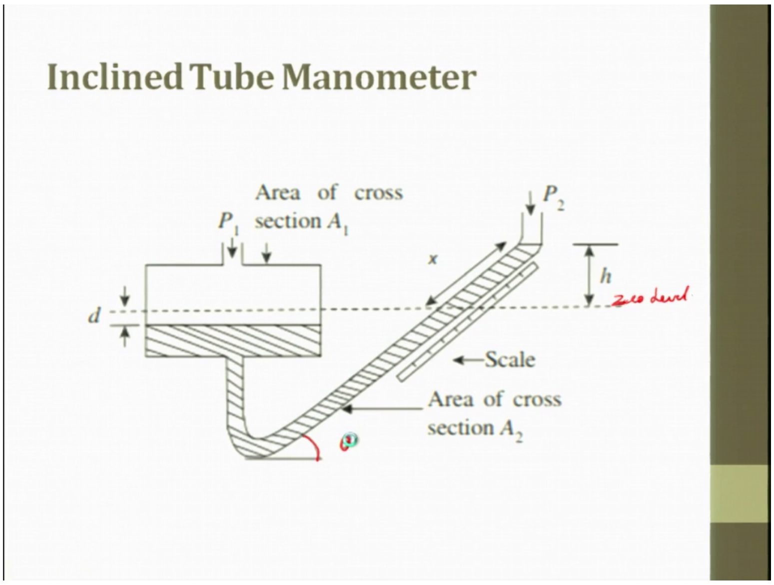

So, this is an inclined type tube type manometer. So, I here you have a 0 line this is called a zero level h d this is a scale here and here is the inclination which is there and this is the angle theta. Suppose here you want to find out what is d so, what is pressure difference P 1 minus P 2 it is rho into g into x sin theta.

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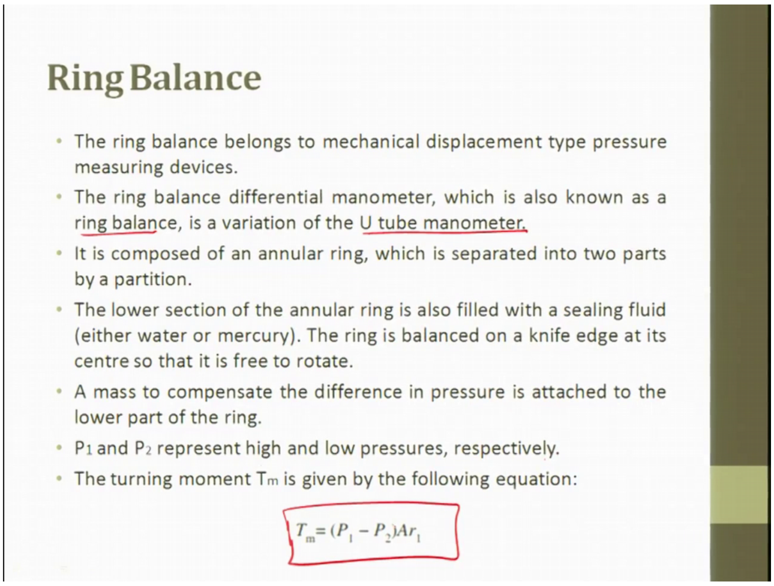

So, next one is ring balance, a ring balance belongs to a mechanical displacement type pressure measuring device. The ring balance differential manometer which is also known as ring balance is a variation of U-tube manometer. It is composed of an annular ring, which is separated into two parts by a partition. The lower section of the annular ring is also filled with the ceiling fluid, the ring is balanced on a knife edge and it is centre so that it is free to rotate. A mass to compensate the difference in pressure is attached to the lower part of the ring.

P one and P 2 represents high and low pressures respectively, the turning moment T m is given by this P 1 minus P 2 into A r 1. So, P 1 P 2 are the two pressures of high and low ok, A is the cross section r A is the area and r is the cross section.

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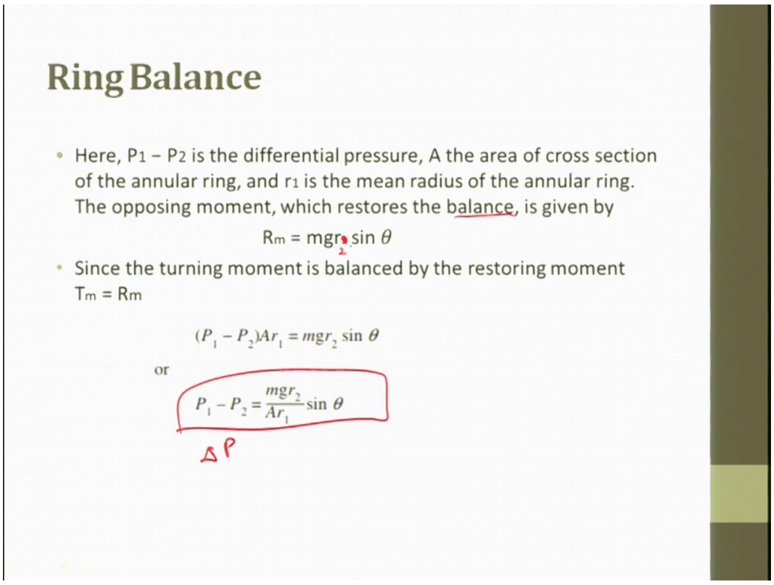

So, here P 1 minus P 2 is the differential pressure. A is the area of cross section of the annular ring, r is a mean radius of the annular ring. The opposing moment so, here what we are trying to do is turning moment T m is equal to this.

So, then the opposing moment with restore the balance is given by R m equal to m g r 2 sin theta. So, hence the turning moment is balanced with this and finally, what we get is, P 1 minus P 2 this is otherwise called as delta P is nothing but m g r 2 A r 1 divided by sin theta. This is restoring balance so, this is the ring type ring balance type.

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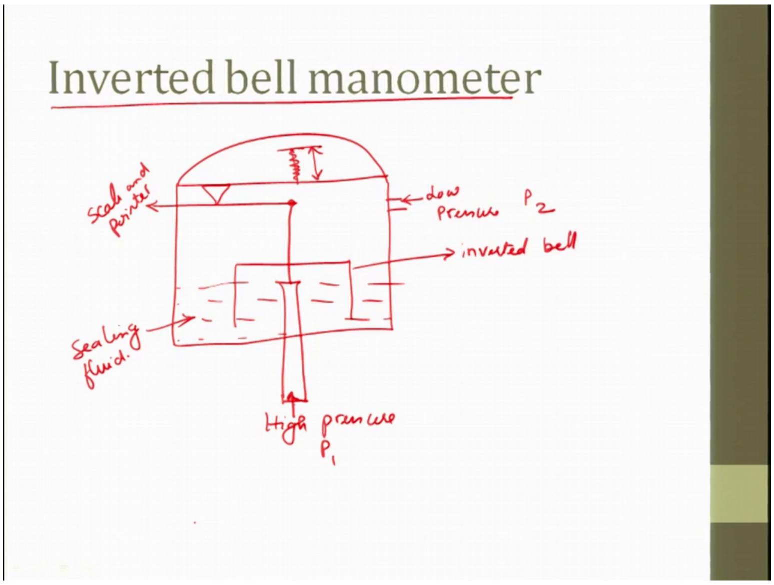

So, the next type manometer is going to be inverted bell type manometer. So, let me draw the figure of a inverted bell type manometer. So, this is a low pressure low pressure P 2, this is high pressure high pressure high pressure P 1 ok. This is a sealed sealing fluid, this is a pointer scale or a pointer scale and pointer ok. And this is the inverted bell, this is a inverted bell. So, this is how a inverted bell manometer looks like.

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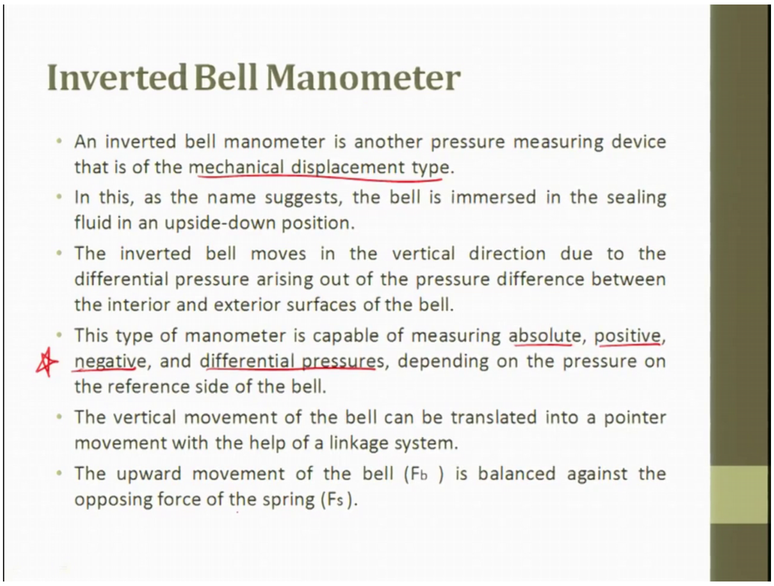

So, let us see the explanation, an inverted manometer is an another pressure measuring device that is of mechanical displacement type. This type as the name suggested the bell is immersed in a sealing fluid in an upside down position. The inverted bell moves in the vertical position due to the differential pressure arising out of the pressure difference between the interior and the exterior surface of the bell; between the interior and the exterior surface of the bell.

This type of manometer is capable of measuring absolute positive negative and the differential pressures depending on the pressure of the reference side of the bell. This is very, very important, it can measure multiple things it is capable of measuring absolute, positive, negative and differential pressure depending on the pressure on the reference side of the bell.

The vertical movement of the bell can be translated into a pointer reading. So, the upward movement of the bell F b is balanced against the opposing spring of F s so, this is F s and this is F b whatever. So, there is a balance which is happening so, the upward movement of the bell F b and is balanced against the opposing force of the spring F s.

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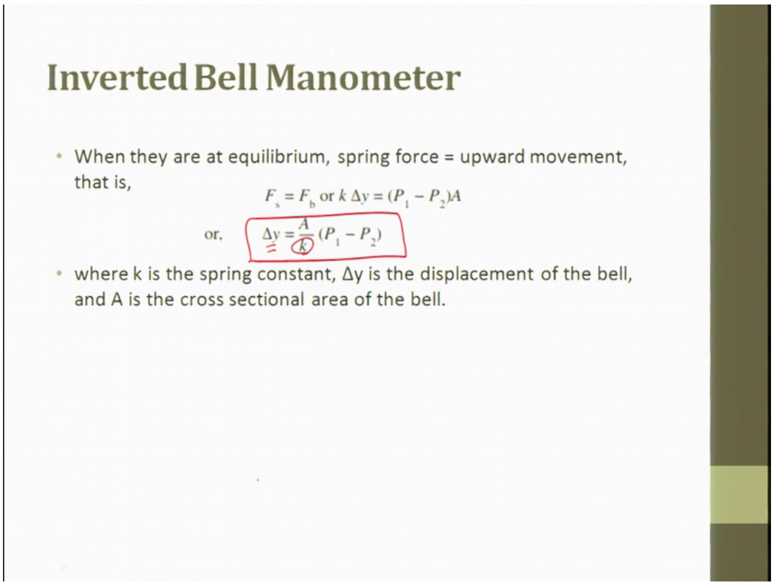

So, when they are at equilibrium it is F s equal to F b or it is stiffness into delta y which is nothing but P 1 minus P 2 into A. So, this delta y can be represented as A by k P 1 minus P 2, k is the spring constant and delta y is the displacement of the bell and A is the cross section area of the bell. It is another type of manometer which is used to measure the pressure, but the most important point is it is capable of measuring absolute, positive, negative and differential pressure.

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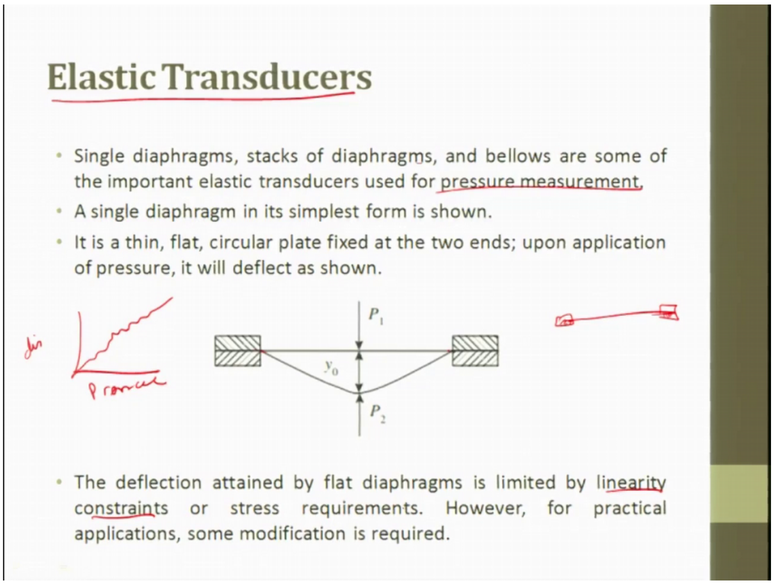

The next type is going to be a transducer, so, basically a transducer is we studied transducers in detail. So, elastic transducers this is nothing but you have a diaphragm, a single diaphragm stack of diaphragm single diaphragm can be there, a stack of diaphragm can be there, the bellows are some of the important elastic transducer used for pressure.

So, what happens is, you have one diaphragm or you have multiple diaphragms or you have a bellows so, when the pressure is applied it tries to deflect. So, are some of the important elastic transducers used for pressure measurement they are single is a simplest one which we have shown here. A thin flat circular plate fixed at both ends; this end this end is fixed and this end is fixed. So, they so, fixed at both ends upon application of pressure till it will deflect as shown.

The deflection attained by flat diaphragm is limited by linearity constraints or stress requirements; however, for practical applications some modifications is required. So, this is for single for simplicity and understanding we have put one, the deflection attained by the flat diaphragm is limited by the linearity constraints. Linearity constraints is as the pressure this can be displacement, this can be pressure ok and we are only worried about the linearity ok. The linearity is limited by the linearity constraints or stress requirements; however, for practical applications some modifications is required.

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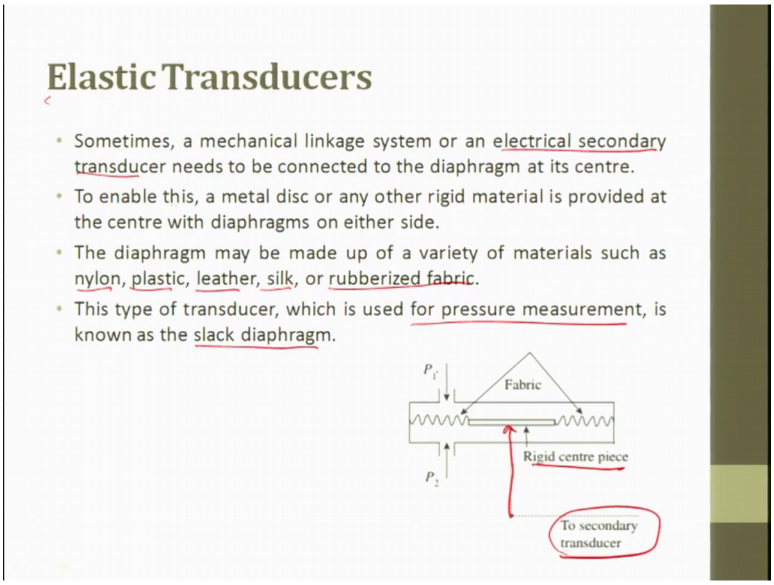

So, elastic transducer sometimes a mechanical linkage system or an mechanical linkage system. So, you can see pressure springs are applied mechanical linkage system, or an electrical secondary transducer need to be connected to the diaphragm at the centre. So, this is a secondary transducer which is connected to the centre. So, this enables a metal disc or a rigid material is provided at the centre with diaphragm on either sides.

So, this will be the stiffness which is given. So, here is the centre portion of the transducer ok, a rigid centre piece is there, from the centre piece you have attached to the secondary transducer either here you can use the concept of null, or you can use the concept of a displacement. So, this tries to maintain both sides so, to enable this a metal disc or yeah any other rigid material is provided at the centre with diaphragms on both sides.

This diaphragm may be made of variety of material such as nylon, plastic, leather, silk or rubberized fabric. This type of transducer which is used to measure pressure is known as slack diaphragm ok. So, we use pressures are applied here P 1 P 2 differential pressure. So, here is a fabric which is there this is attached at both ends and then you have a centre piece which is yeah a rigid piece with which you try to measure the pressure.

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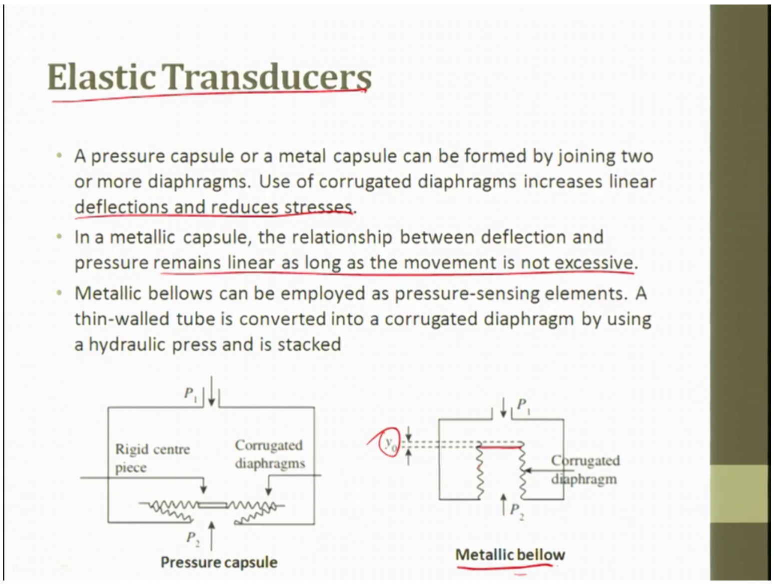

The pressure capsule or the metal capsule can be formed by joining two or more diaphragms ok. Use of corrugated diaphragm increases the linear deflection and reduces the stresses ok, we are now trying to play or increase the linearity. So, this is pressure capsule, this is metallic bellow so, you can see here a rigid centre piece what we saw in the previous diagram we have it here. And here is a corrugated diaphragm so, that it adds more stiffness right. So, use of corrugated diaphragm increases linear deflection and reduces the stresses. In metallic capsule, the relationship between the deflection and pressure remains linear as long as the movement is not excessive.

So, this is the pressure capsule or it is called as metal. In metallic capsule we do this metallic bellows can be employed as a pressure sensing so, these are metallic bellows. So, here are corrugated diaphragms, you can see here this is placed here the centre piece and then this is a displacement is delta y naught, and pressure difference is P1 P 2. So, a pressure sensing element a thin valve tube is converted into a corrugated diaphragm by using a hydraulic press and it is stacked on both sides you can find measure it. So, these are nothing but elastic transducers which are used to measure the pressure difference.

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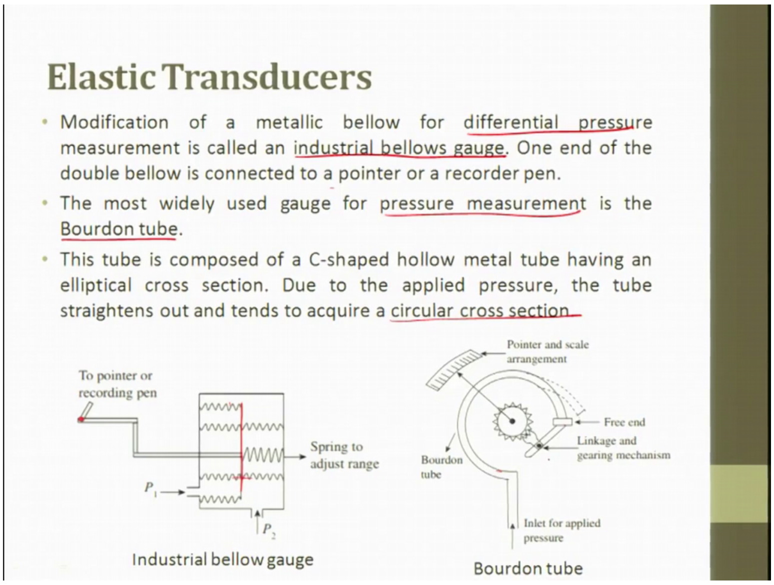

So, you can modify the metallic bellows for differential pressure basically pressure has to be measured. So, we are trying to see various ways where in which you can build up gauges or transducers such that you can measure small differential pressure. So, when we modify the metallic bellows which is here for measuring differential pressure, it is also called as industrial bellow gauges. One end of the double bellow is connected; one end of the double bellow is connected to a pointer which can record so, to point a recording pen you have.

So, then you will have yeah diaphragm this is a centre portion and here are the corrugated diaphragms which are there on both sides. This in turn is attached to a spring which can be the stiffness can be adjusted, such that you can try to get the response. So, the differential pressure measurement is called as industrial bellow gauges. One end of the double bellow is connected to the pointer or to the pen. The most widely used gauge for pressure measurement is bourdon tube which is this way pressure.

So, this example we saw earlier also so, this is an inlet pressure here is a bourdon tube so, this in turn will be attached to a free this is a free end. This in turn is attached to a link, this link is attached to a gear, this gear in turn is attached to a pointer. This tube is composed of a C shaped hollow metal tube, having an elliptical cross section. Due to the applied pressure the tube straightens out and tends to acquire a required cross section area with this you can also try to measure pressure difference.

So, till now what we saw was, we saw transducer we saw first manometers different types of manometers and then different types also what we saw is we saw all are industrial type. So, industrial type we saw with two limbs then one large limb with one tube inside, then inverted bellow manometer we saw. Then after that we saw elastic transducer, elastic transducer with a single diaphragm. Then you can attach it with multiple diaphragm, then the diaphragm response is measured to an electrical sensor we saw. Then we also saw pressure capsules then metal bellows, then for differential pressure industrial bellow gauge we saw and bourdon tubes we saw.

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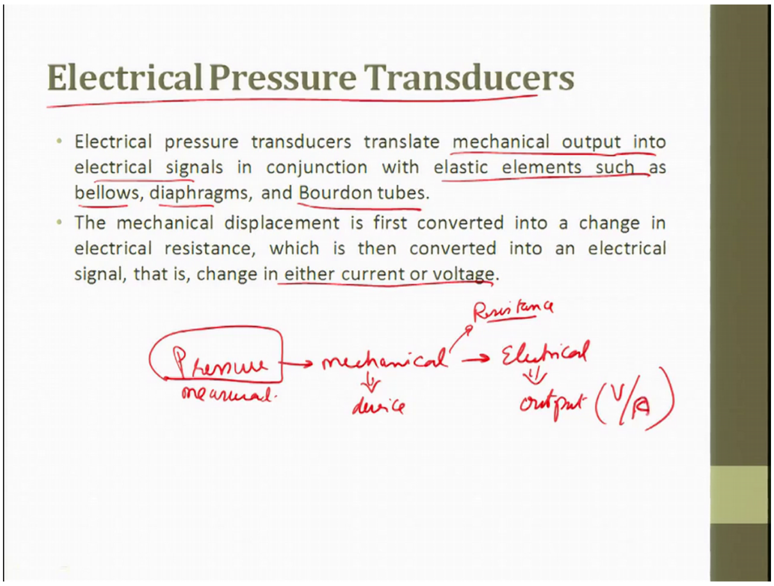

The electrical pressure transducer is the latest one which is coming up here. The electric pressure transducer translates mechanical output into an electrical signal in conjunction with the elastic elements such as bellows, diaphragms and bourdons. So, basically what we wanted is the pressure is to be measured they measure it in a mechanical means and then this mechanical values are converted into electrical value so that it can be processed for further action.

The mechanical displacement is first converted into a change in the electric resistance; which is then converted into an electrical signal, that is changed in the current or the voltage it is done so, that you can try to measure it. So, pressure which is to be measured this is a measurand and this is what is the device or a transducer and this is the output. And here this mechanical can you can link this mechanical with change in resistance, change in capacitance all these things you can do and finally, what we get is a voltage or current whatever it is will be used as the output which you can modify.

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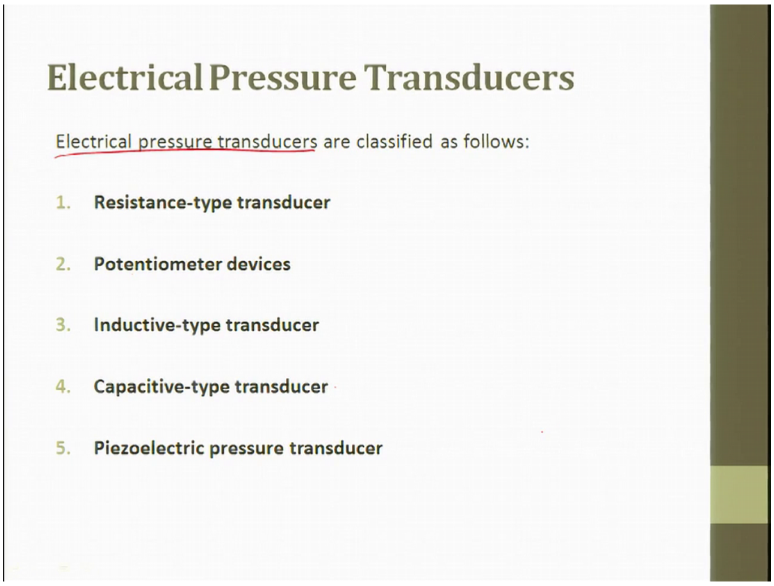

The electric pressure gauge are classified as follows; that is resistance type transducer, potentiometric device, inductive type transducers capacitive type transducers and piezoelectric pressure transducers. These are some of the electric pressure transducers which are available in the market today.

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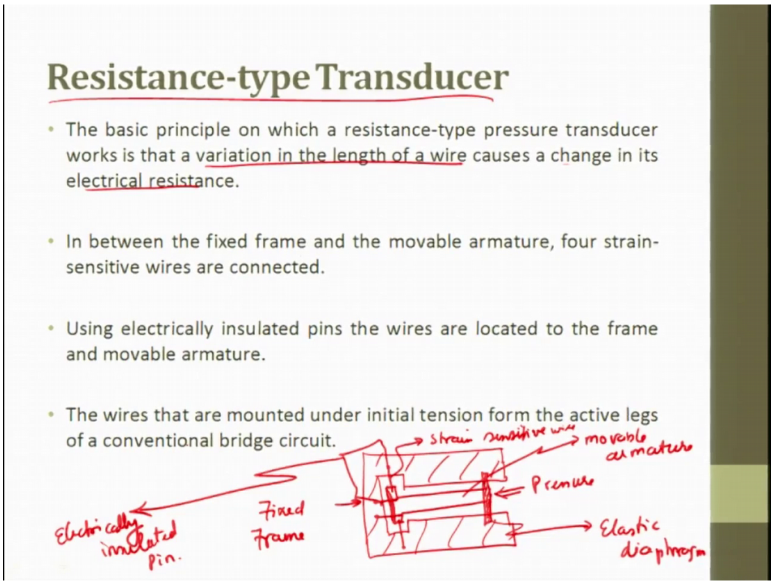

So, let us see one by one, resistance type transducer, the basic principle of which is a resistance type pressure transducer works in which the variation in the length of the wire causes a change in it is electrical resistance. So, variation in the length of the wire, in between the fixed frame and the moving armature four strain sensitive wires are connected. Using electrical insulating pins, the wires are located to the frame and a moving armature.

The wires that are mounted under initial tension form the active legs of a conventional bridge circuit. So, let us try to have a small schematic diagram for an understanding. This is a fixed frame ok, you have a elastic, this is called elastic diaphragm ok so, here when we apply pressure ok here can we do that.

So, here what happens is, you will have this is fixed to this and this is fixed to this portion. So, what are these fixed portions, these ones are called as electrically insulated pin ok. So, the string so this one and what is this is called as a moving movable armature movable armature this is movable. And then what are you trying to do so, this is pressure is applied this is moving so, then you have a strain sensitive wire which is used.

So, this fixing whatever we do here this is done by a strain sensitive wire. So, as and when the pressure is applied, the armature moves, when the armature moves the strains are getting introduced right. Thus, when the strains are getting introduced from that we try to get the electrical signal output so, that is what we say the basic principle of which is a resistance type pressure transducer working in which a variation in the length of the wire, causes a change in the electrical resistance various mean change other.

In a in between the fixed frame and a moving armature, four strain gauges are used these are all strain gauges strain sensitive wires, strain gauges using electrical insulating pins. So, these are electrically insulating pins, the wires are located to the frame otherwise this becomes a freely hanging right and located to the frame and the moving armature; which are mounted under the initial tension forms the active legs of the conventional bridge type circuit. So, with this we can try to measure the resistance type.

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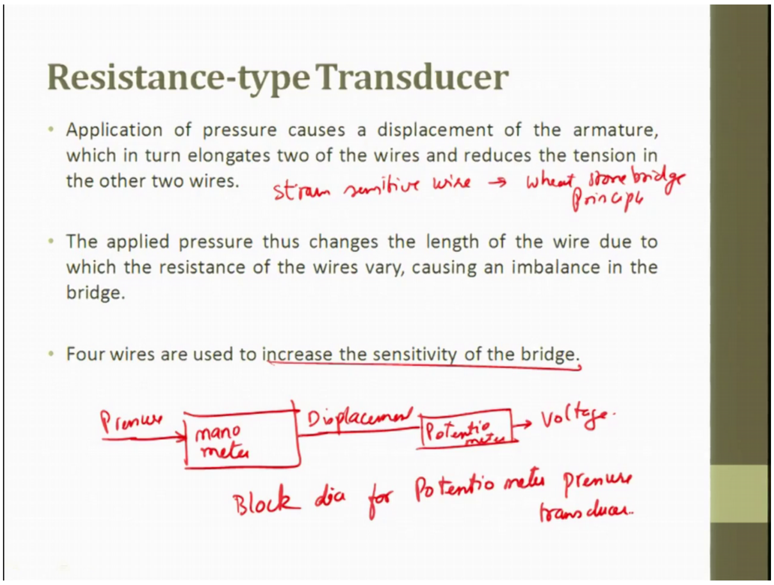

So, the application of pressure causes a displacement to the armature which in turn a elongates two of the wires. So, finally, I said that the strain gauges, the strain sensitive I said the strain sensitive wire ok this is nothing but this leads to the Wheatstone bridge principle so, four arms are there. So, two wires two of the wires elongate and reduces the tension in the other two wires. The applied pressure just changes the length of the wire due to which the resistance of the wire varies causing an imbalance in the bridge the four wires are used to increase the sensitivity of the bridge.

So, this is how a resistance type transducer works, if you wanted to put it in a block diagram so, it is like this pressure ok. We have any manometer; we can take any manometer so, what you get out of it is displacement this displacement in turn can be attached to an electrical. So, for example, you can put it with a potentiometer, and then what you get is an output on voltage. This is a block diagram for maybe you can say potentiobased block diagram for potentio meter, pressure transducer. So, this block diagram so, it is a typical one which is used for the applications right.

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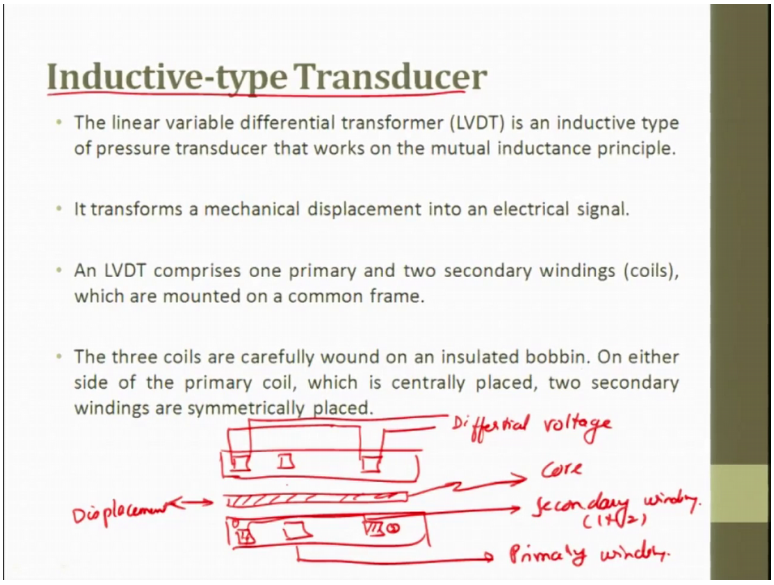

So, the next one is inductive type transducer which is the other which is otherwise called as a linear variable transducer LVDT. So, here what happens is like we saw in the previous slides also, you have two things. And in between you have a core, this is called the core ok and here you will have primary winding and you will have secondary winding. So, you can call this as primary winding, this and this are called as secondary winding ok.

And so, this is secondary winding which is 1 and 2 so, this is 1 and this is 2. And then what we have is we have a output which is taken so, this from here it can come to here and then plus 1. So, something like so here what we get is a differential voltage ok. This is a typical LVDT so, this only gives you the displacement. So, this is a inductive type transducer, the linear variable differential transformer is an inductive type of pressure transducer that works on mutual inductance principle.

It transforms a mechanical displacement into an electrical signal the LVDT comprises of a primary this is primary and two secondary winding coils; that are mounted on a common frame ok. This is the that are mounted on a common frame this is a common frame. The 3 coils here I have drawn 4 coils so, you can have so, for simplicity let me remove one so, there are 3 coils which are carefully wound on the insulating bobbin; on either side of the primary coil ok, primary winding which is centrally placed two secondary windings are symmetrical. So, if you try to take an output from this you get the differential voltage.

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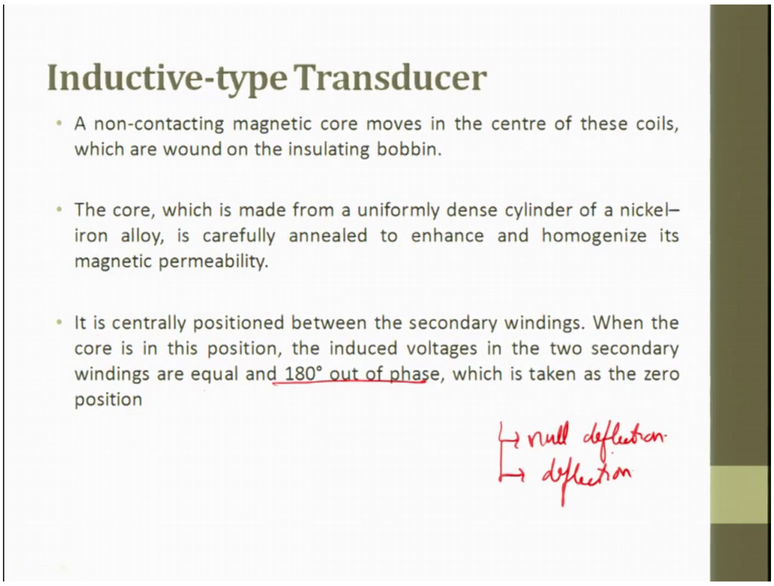

A non-contacting magnetic core moves in the centre of the coil which are mounted is the insulating bobbin, the core which is made has a uniform dense cylinder of nickel iron alloy is and carefully annealed, to get the output the it is centrally positioned between the secondary windings. When the core is in this position the induced voltage in the secondary winding are equal and 180 degrees out of phase, which tries to maintain zero. So, as I said earlier it can have a null deflection or it can have a deflection transducers. So, it can have deflection so, here it is almost null deflection is what we follow.

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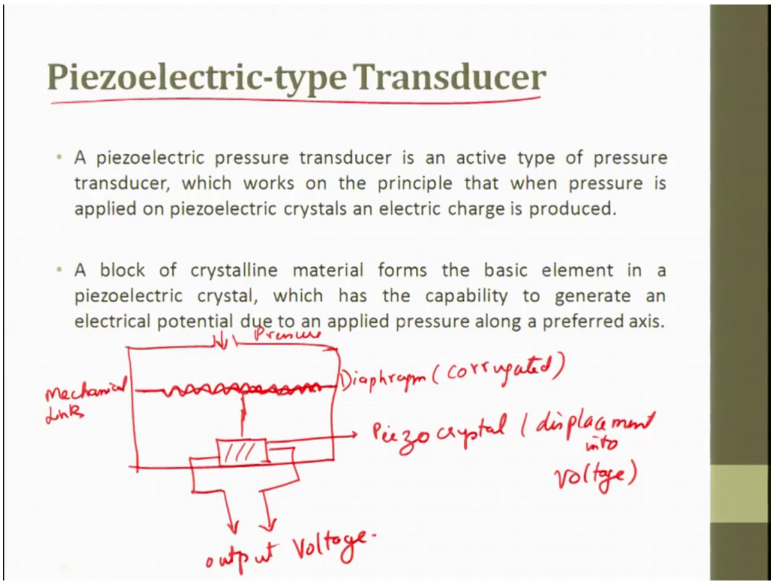

Next one is piezo type transducer, the piezo type transducer so; here what will happen is you will have a piezo crystal from which you take outputs. So, this is the output voltage and this is a piezo crystal ok. So, this in turn is attached to a diaphragm so, this is your diaphragm if you want to increase sensitivity you can make it corrugated.

I can make it corrugated gives better stiffness that is what it is so, it is corrugated so now, it has to be inside a system. So, what we do is let us put it inside a system and close it, here and this is here ok. So, I have to so, through here we will apply pressure ok, here it is mechanically linked, this is a piezo crystal. So, the pressure is applied the diaphragm corrugated diaphragm moves and this movement in turn is give is attached to a piezo crystal, piezo crystal converts displacement into voltage.

And again the voltage is too small it is getting amplified there is a separate circuit. So, piezo crystal pressure transducer is an active type of pressure transducer, which works on the principle when the pressure is applied on a piezo crystal an electric charge is generated. A block of crystalline material forms a basic element in the piezo crystal; which has the capacity to generate an electric potential due to the applied pressure along the preferred axis.

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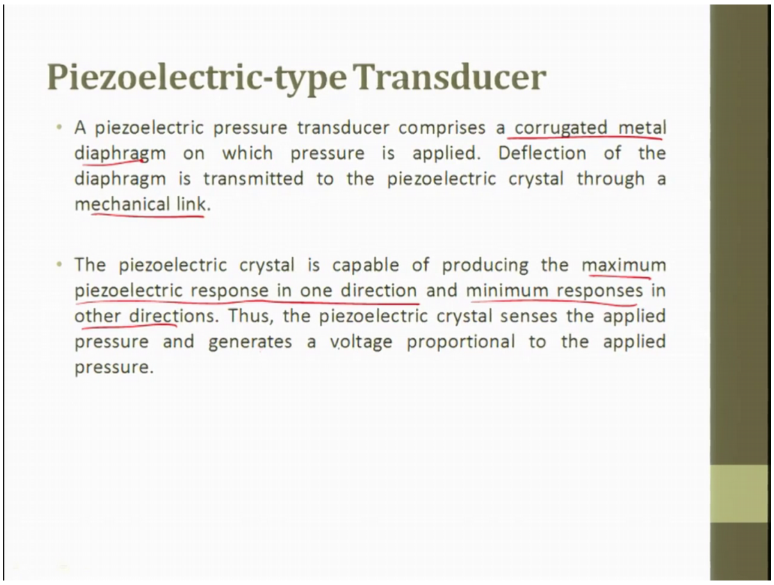

So, as I told you the transducer comprises of a corrugated metal diaphragm on which the pressure is applied. So, there is a mechanical link to attach it with the sealing and it the piezo crystal is capable of producing the maximum piezo response in one direction and minimum response in the other direction. Thus, the piezo crystal senses the applied pressure and generates a voltage proportional to the applied pressure so, this is what is a diagram we saw here.

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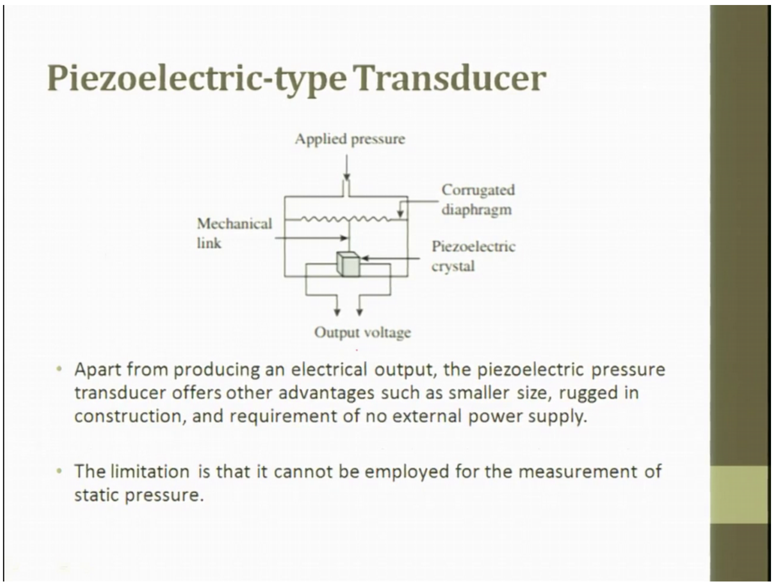

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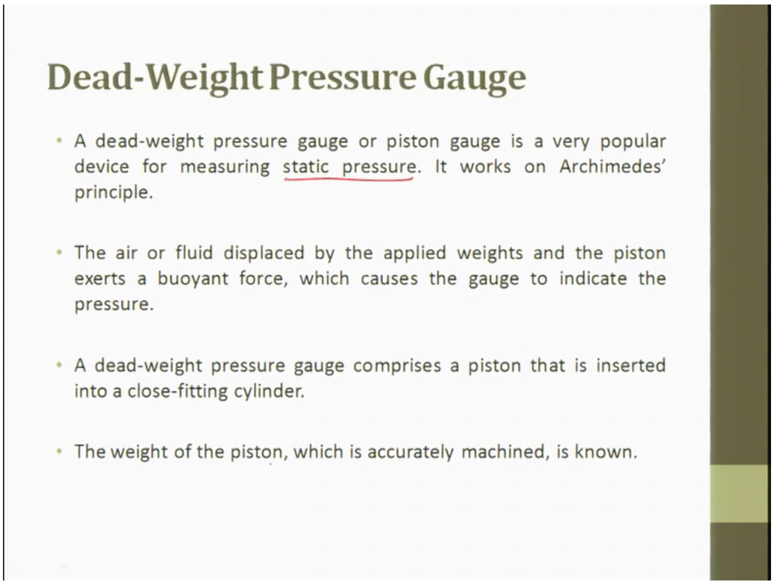

The next type is dead weight pressure gauge; dead weight pressure gauge or a piston gauge is very popular device for measuring the static pressure, it works on Archimedes principle. So, the air or a fluid displaced by the applied weight and the piston exerts a buoyant force, which causes the gas to indicate the pressure. The dead weight pressure gauge comprises a piston that is inserted into a closed fitted cylinder like your syringe which you use for injection. The weight of the piston which is accurately machined is known.

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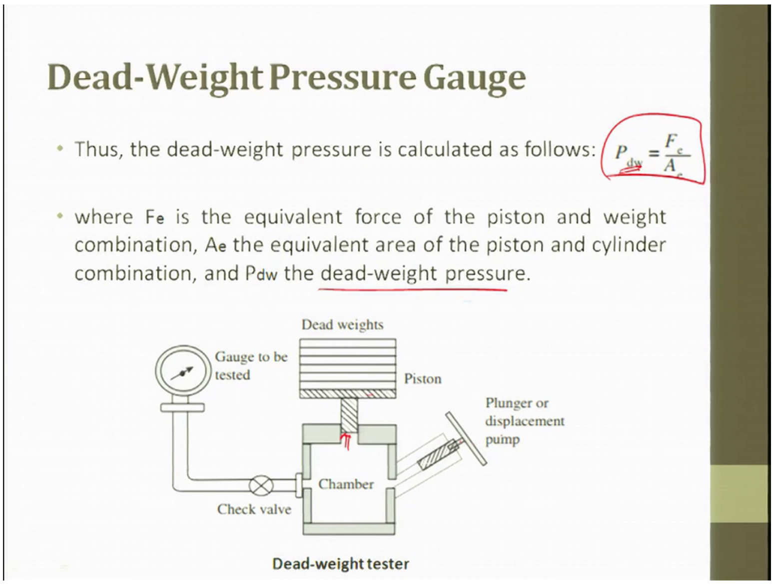

So, if you look at it this is like this so, here is a pressure gauge so, here is a chamber a dead weight is there. So, a plunger or a displacement pump is there so, here so, this weight is balanced and we try to measure the gauge it works on Archimedes principle.

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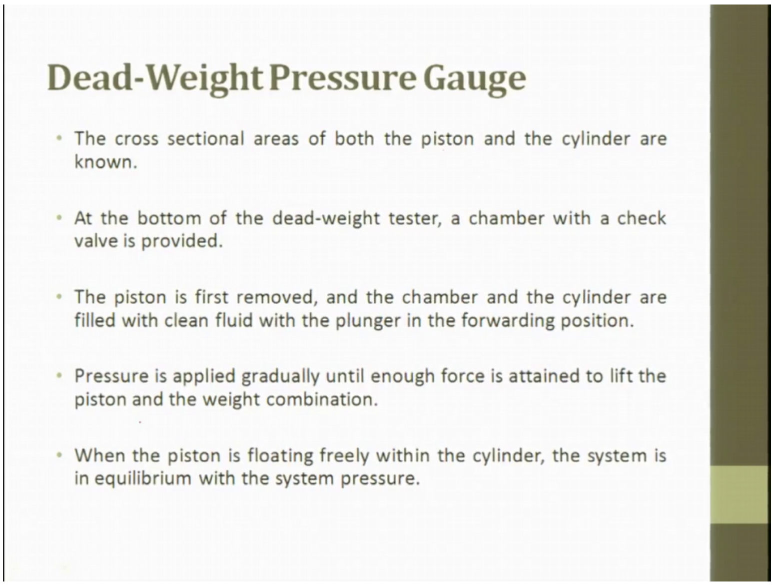

The cross section area of both the piston and cylinder are known. The bottom of the dead weight tester chamber with a check valve is provided. The piston is first removed and the chamber and the cylinder are filled with clean fluid with the plunger in the forward position. The pressure is applied gradually until enough force is attained to lift the piston and the weight combination. So, if you look at it this is the piston and the weight. So, when you try to slowly this one the moves so, we set it as the value. So, the pressure is applied gradually until enough force is attained to lift the piston and the weight combination, when the piston is floating freely within the cylinder, the system is in equilibrium with the system pressure.

So, the thus the dead weight pressure is calculated as force by area. F e is the effective force of the piston and the weight combination, A e is the equivalent area of the piston and cylinder combination, P wd is the way the dead weight pressure we can measure. So, gauge to be tested you see at reading here so, this is a check valve, the check valve is adjusted until there is a proper balance between the chamber pressure piston head and plunger or the displacement pump.

Thank you.