Chemical Process Instrumentation

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Lecture – 23

Pressure Measurement: Moderate and High Pressure Measuring Instruments (Cont.)

Welcome to lecture 23, in this week we have started our discussion on pressure measuring instruments and specifically we have been talking about measurement of moderate pressures and high pressures. In today's lecture we will talk about an important pressure measuring instrument known as Bourdon tubes. This is an elastic element type pressure gage. See, if you remember our classifications of various pressure measuring instruments, bourdon tubes fall under elastic element type pressure gage.

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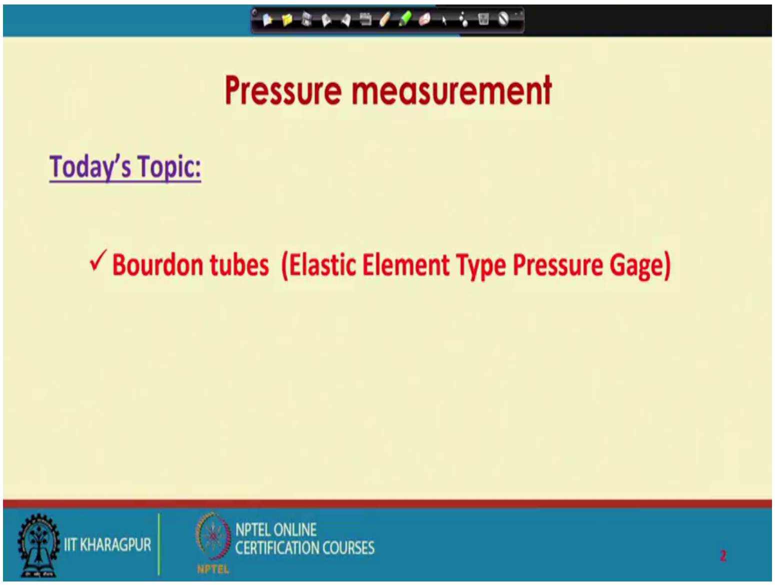

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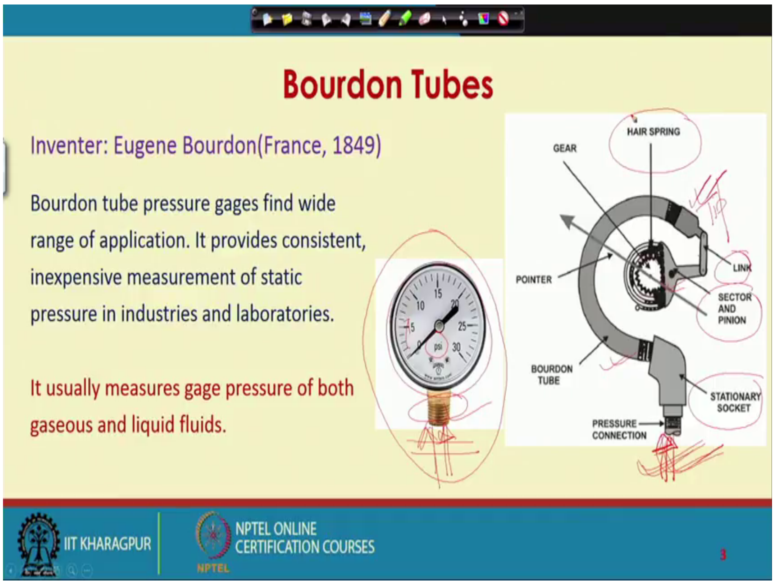

So, a bourdon tube pressure gage will look like this, you far as have seen this in laboratories. So, what you see is a pointer and the scale you look at here the scale is in psi unit of pressure pounds per square inch. Now as we apply pressure inside this, so this is the connection available for application of pressure. So, this is connected to a pipeline through which a fluid is moving and you want to measure the pressure of the fluid. So, as we apply pressure inside there will be movement of this pointer and from the position of the pointer against the scale you can read the measurement of the pressure.

Now, if you open this and look at the inside, you will see this. You may also see something called diaphragm element, which we will talk about later, but the bourdon tube is pressure gage we will see this, but there are pressure gages which will look exactly similar to this from outside, but you open instead of bourdon tube there can be a diaphragm element, but will talk about that later.

So, today we were talking about bourdon tubes pressure gages show if you open this, what you will see is, this. This is known as a bourdon tube. Is basically a tube with elliptical cross section and bent in the form of English letters C, so you look at here, this end of the tube is rigidly fixed, this is a stationary socket and this is the pressure connection? So, pressure will be applied here. Now, the other end of the bourdon tube is sealed, so this is known as tip of the bourdon tube, this is known as link and this is sector and pinion, you have a pointer attached.

So, this pointer is attached to the tip of the bourdon tube through this link and sector and pinion. You have a gear here and you also have a very fine spring known as hair spring. In this lecture I will show you a real bourdon tube and you will see these internal parts. Eugene bourdon of France, invented bourdon tube in 1849, bourdon tube pressure gages find wide range of application, it provides consistent inexpensive measurement of static pressure in industries and laboratories. It usually measure gage pressure of both gaseous and liquid fluids. You can have arrangements, where it will be possible to measure differential pressure using bourdon tubes we will see later.

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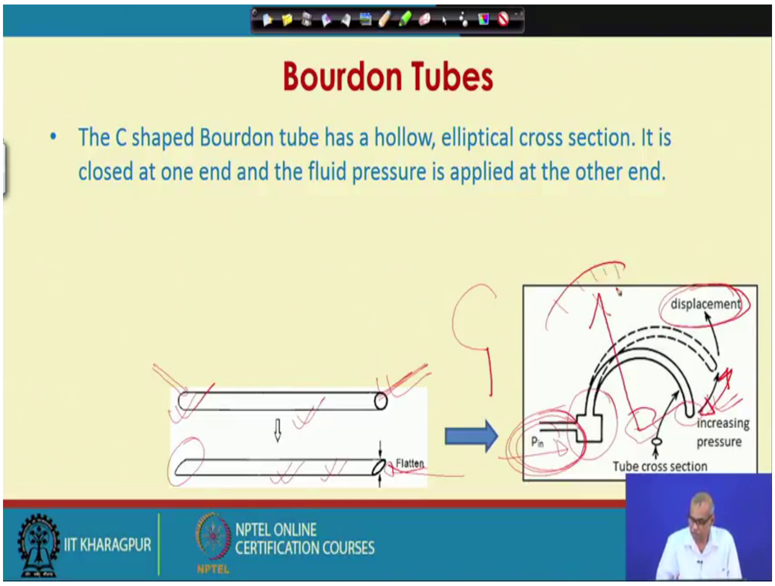

Now, let us try to understand the construction of bourdon tube in bit more details. The C shaped bourdon tube has a hollow, elliptical cross section. It is closed at 1 end and the fluid pressure is applied at the other end. Now, how is this bourdon tube made? You start with a tube with circular cross section. One end is free, other end is sealed. One end is open other end is sealed. Now, you flatten it, you flatten the tube and convert the cross section from circular to electrical. So, I started with a tube with a circular cross section, now I have a tube with electrical cross section.

Now this tube is now bent in the form of C. So, this is this open end and this is the closed end. Now what happens is when I apply pressure inside this tube, when I apply pressure inside such tube, this tube tries to regain its original circular cross section. Since this end of the bourdon tube is rigidly fixed, there will be movement of the bourdon tube or there will be displacement of the bourdon tube at the tip. So, you apply pressure here and the tube once to regain its original circular cross section. So, there will be displacement of the tip like this.

This tip displacement for a given bourdon tube is directly related to the amount of pressure that is being applied inside the bourdon tube. See if I can measure this displacement, I can relate this to the pressure that is being applied. So, this displacement is raid by attaching a pointer to the tip of the bourdon tube and that is done through a link a gear sector pinion hire spring assembly.

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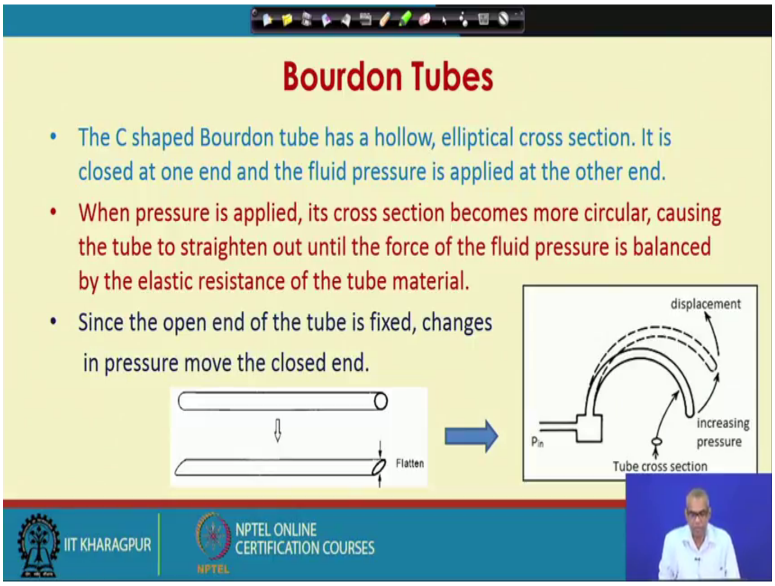

So, when pressure is applied, it is cross section becomes more circular, crossing the tube to straighten out until the force of the fluid pressure is balanced by elastic resistance of the tube material. That is why, this is known as elastic element. Since the open end of the tube is fixed, changes in pressure move the closed end and the displacement of the tip of the bourdon tube is a measure of the amount of pressure that is being applied inside the bourdon tube.

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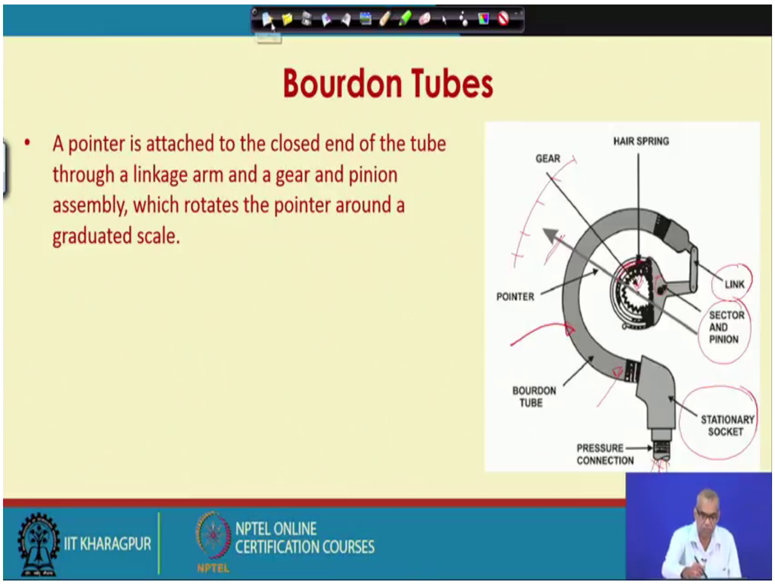

A pointer is attached to the closed end of the tube through a linkage arm and a gear and pinion assembly, which rotates the pointer around the graduated scale. So, there is this graduated scale. Once again look at the different important parts of the bourdon tube, this is link, this is sector and pinion, this is the pointer, we have gear here and you have a very fine spring, hair spring here, this is the bourdon tube. This end is open and this is rigidly fixed by the stationary socket and this is the pressure connection.

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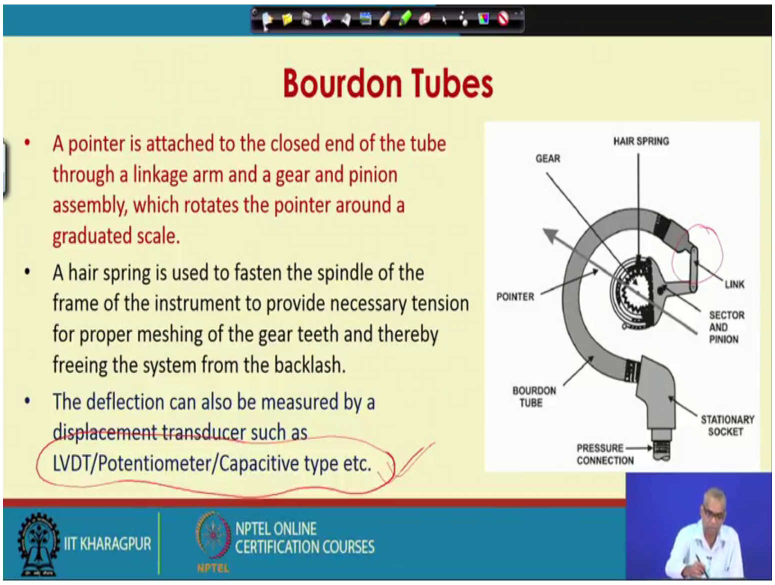

So, what does hair spring do? A hair spring is used to fasten the spindle of the frame of the instrument to provide necessary tension for the proper messing up the gear teeth and their by freeing the system from the backlash. So, the hair spring eliminates or tries to eliminate the backlash in the instrument.

The deflection can also be measured by a displacement transducers and we have started such transducers such as LVDT, linear variable differential transformer or potentiometer or a capacitive type transducers. So, the deflection ordinarily were reading by the movement of the pointer against the scale, but you can also attach LVDT or potentiometer or capacitive type transducer to the tip of the bourdon tube, so that you can read the displacement of the tip of the bourdon tube using such electromechanical displacement transducer.

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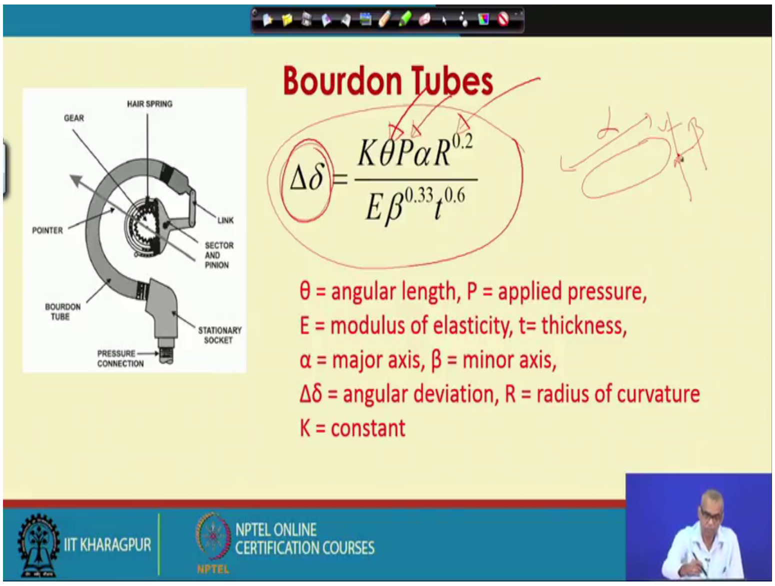

Now, this is an equation, which tells you the factors on which the deflection of the tip of the bourdon tube will depend. So, delta is the angular deviation, which is the measure of the displacement. So, tip displacement is directly proportional to the angular length. It is directly proportional to the pressure being applied; it is directly proportional to the radius of curvature. It also depends on the major axis and minor axis of the cross section of the bourdon tube. You remember the bourdon tube cross section is now elliptical, so the major axis is alpha, minor axis is beta.

Tip displacement is inversely proportional to the modulus of elasticity and it is also inversely proportional to the thickness of the tube. So, these are the parameters on which the tip deflection of the bourdon tube will depend. Remember, that the tip deflection depends on the modulus of elasticity and the tip deflection is inversely proportional to the modulus of elasticity.

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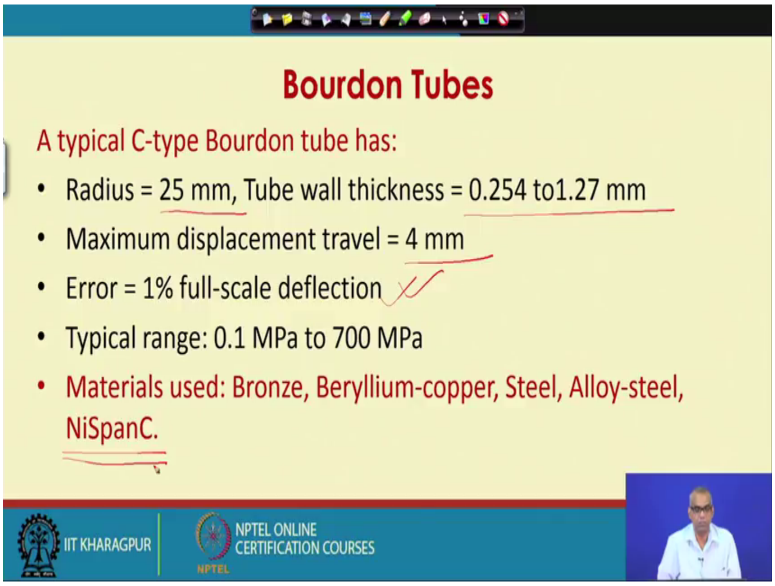

Let us look at some data for a typical C type bourdon tube. For a typical C type bourdon tube, the radius is about 25 millimetre, the tube wall thickness is 0.254 to 1.27 millimetre, maximum displacement travel is 4 millimetre, error is within 1 percent full scale deviation and the typical range of the bourdon tube is 0.1 Mega Pascal to 700 Mega Pascal. The materials used for construction of bourdon tubes are bronze, beryllium-copper, steel, alloy-steel and nickel span C. Nickel span C is an alloy, whose modulus of elasticity does not change, (Refer Time: 15:30) change in temperature.

So, basically we can use the materials for making a bourdon tube, which shows good elastic property. Commonly used materials are bronze, beryllium-copper, steel, alloy steel and nickel span C. Nickel span C is an interesting alloy, whose modulus of elasticity does not change with change in temperature.

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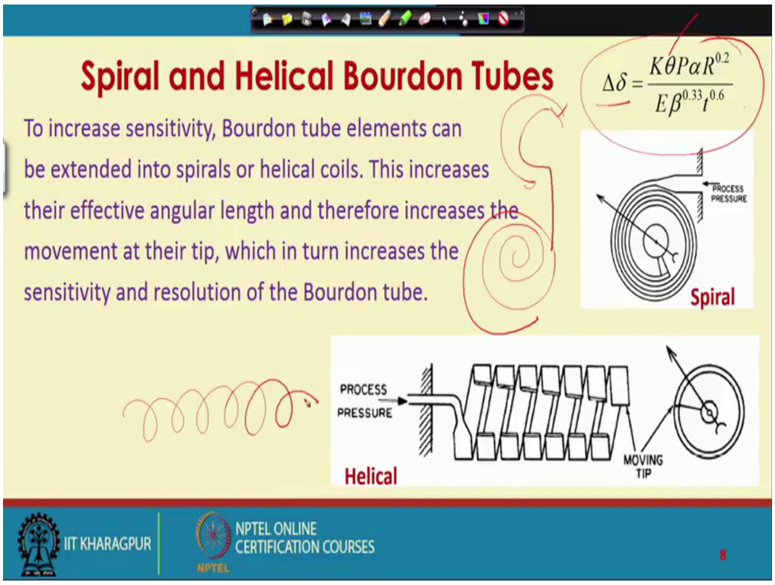

Now, to increase the sensitivity of the bourdon tube elements what we can do is, we can extend the length of the bourdon tube, again look at the equations which tells you, that the tip displacement is directly proportional to the angular length. So, we have this C type bourdon tube, so this is the angular length. Now, if you want to increase further angular length, what I can do is, I can make a spiral bourdon tube or I can form a helix structure.

Since, with increase in length of the bourdon tube there will be more tip deflection for the same amount of pressure, the sensitivity of the bourdon tube will increase. So, to increase sensitivity bourdon tube elements can be extended into spirals or helical coils. This increases their effective angular length and therefore increases the movement at the tip, which in turn increases the sensitivity and resolution of the bourdon tube.

So here, again this is the open end, so here you apply pressure. This end of the spiral bourdon tube is sealed, so a pointer is attached to this sealed end. The same here, in case of helical structure, this is the open end which is rigidly fixed and you apply pressure here. This is the end, which is sealed and not rigidly fixed, so this is the moving tip. So, attach the pointer and scale to this moving tip.

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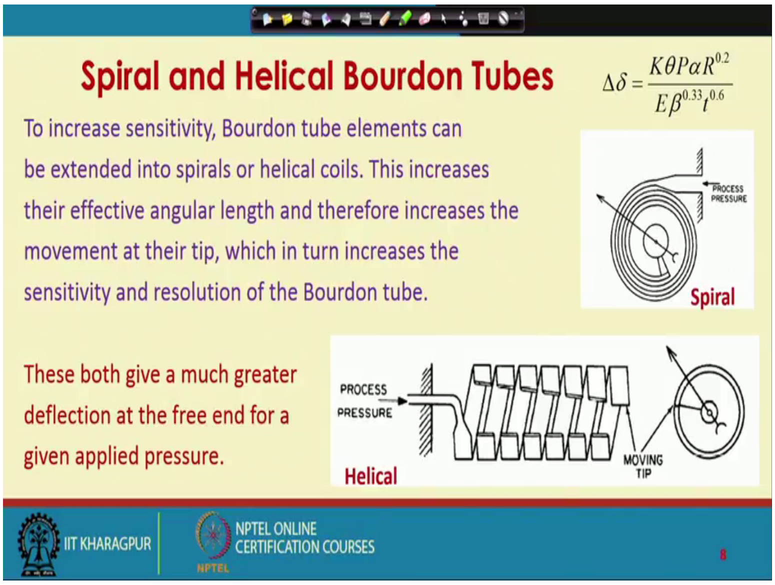

Both the spiral type bourdon tubes and helical coils give a much greater deflection at the free end for a given applied pressure, so, both increases sensitivity.

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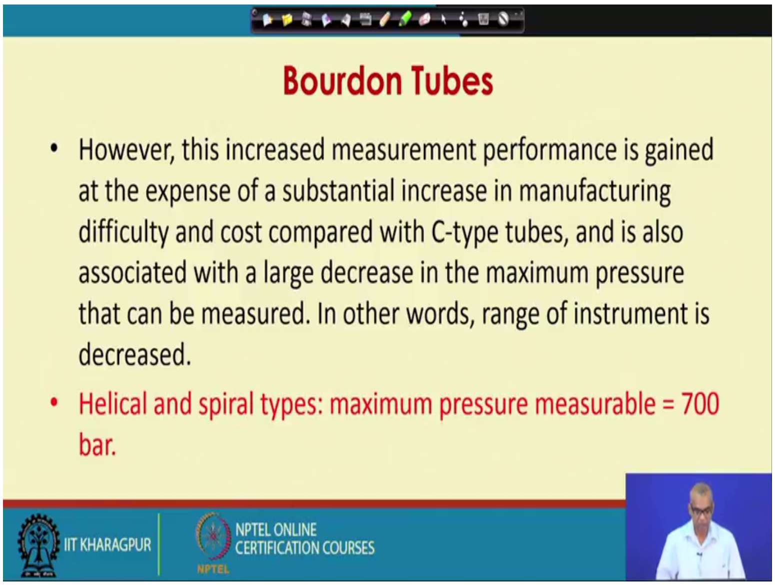

However, this increase measurement performance is gained at the expense of a substantial increase in manufacturing difficulty and cost compared with C type tubes, and is also associated with a large decrease in the maximum pressure that can be measured. In other words the range of the instrument is decreased, so you can increase the sensitivity of the instrument by increasing the length of the bourdon tube giving it a spiral or helical shape, but this comes with an increased cost and also the range of the instrument decreases.

Helical and spiral types; maximum pressure measurable is 700 bar.

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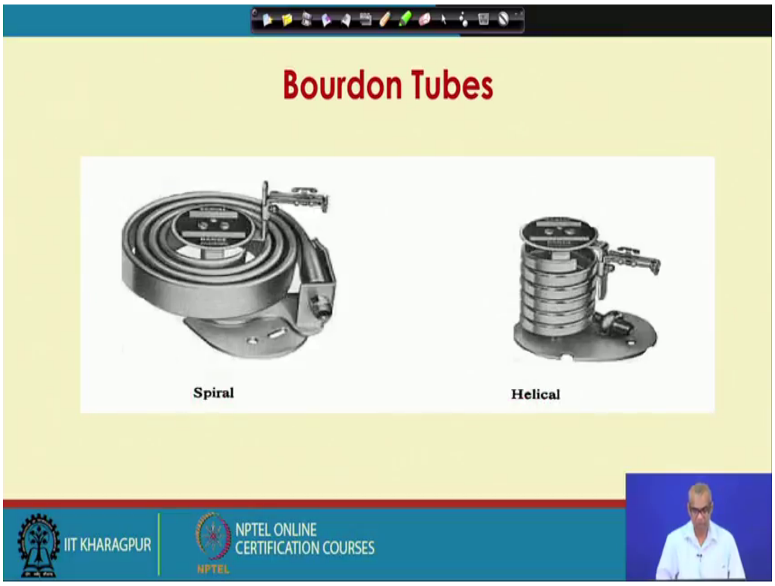

This is an indicative range. These are some, photographs of spiral type bourdon tube and helical type bourdon tube.

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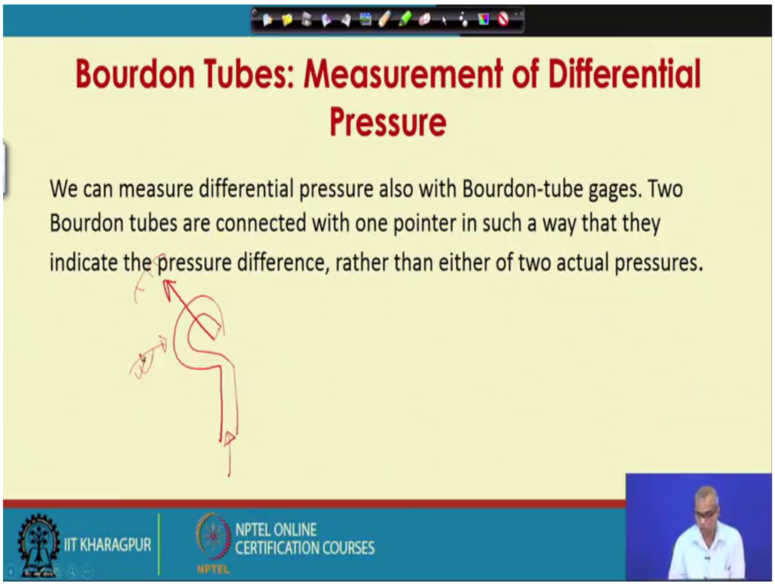

Now, bourdon tube as we have discussed measures gauge pressure because you have, you are applying pressure inside, so from outside you have atmospheric pressure, acting on the tube surface. So, the tip deflection is basically being measured against the ambient pressure. So, it measures gauge pressure, but can I measure differential pressure with bourdon tube? Yes we can. We can make the differential pressure also with bourdon tube gauges, 2 bourdon tubes are connected with 1 pointer in such a way that they indicate the pressure difference rather than either of 2 actual pressures. So, what we do is as follows.

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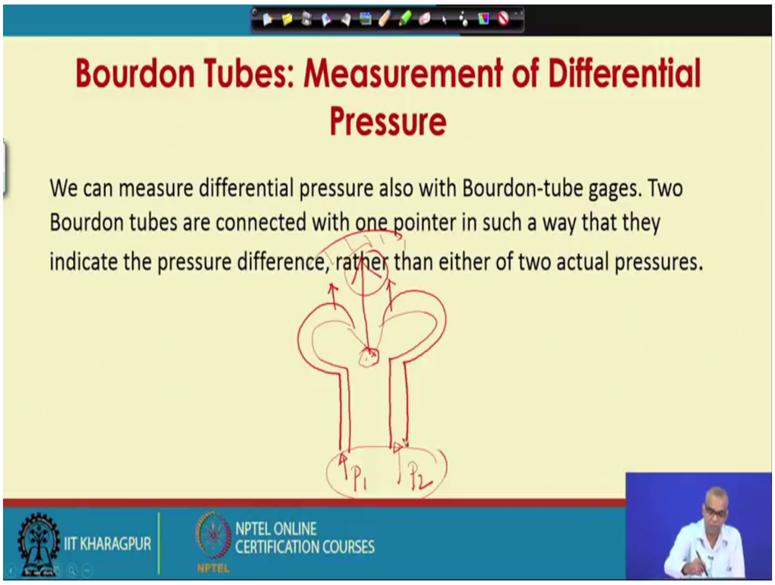

You have 1 bourdon tube and then you take another bourdon tube. Now these bourdon tubes are connected by a single pointer, now we apply pressure P 1 here, apply pressure P 2 here. Now, this will try to displace in this direction, this will try to displacement in this direction, so the movement of the pointer will be a result of difference between these 2 pressures. So, this way we can measure differential pressure using 2 bourdon tubes.

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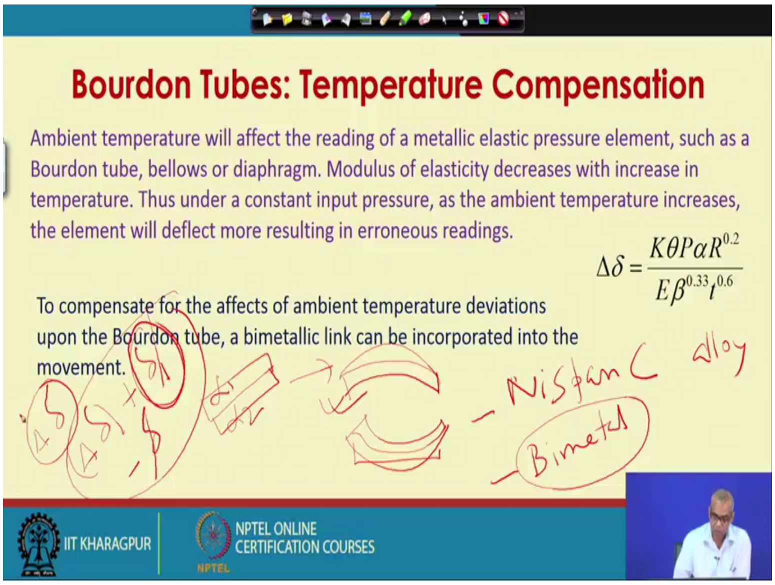

We have discussed that, bourdon tube deflections depends on the modulus of elasticity. If you remember the displacement of the bourdon tube of the bourdon tube is inversely proportional to the modulus of elasticity. Now, we know that modulus of elasticity changes with change in temperature, in fact, for most of the materials modulus of elasticity decreases with increase in temperature. So, if modulus of elasticity decreases for the bourdon tube material, the bourdon tube will now show more deflection for the same pressure.

So, it will cause an error in the reading. So, we need to compensate for the effect of ambient temperature change. So, one thing that can be done is, you use nickel span C alloy to make your bourdon tube because nickel span alloy C is, if you take as material construction it is modulus of elasticity does not change much with change in temperature. Another way of doing it is, to make use of a bimetal for compensation of the effect of ambient temperatures change.

So, the ambient temperature will affect the reading of a metallic elastic pressure elements, such as bourdon tube, bellows or diaphragm. So, this is common for bourdon tube, bellows or diaphragm because they are all elastic pressure elements and modulus of elasticity decreases with increase in temperature. Thus under a constant input pressure, as the ambient temperature increases, modulus of elasticity decreases and the element will deflect more resulting in erroneous reading, you can see it from the equation also.

So, to compensate for the effects of ambient temperature deviations upon the bourdon tube a bimetallic link can be incorporate into the movement. So, 1 solution is, use of nickel span C alloy, another is make use of a bimetal. You design a, bimetal is made of 2 metals and they have different expansion coefficients. So, you take 2 different metallic strips and they are rigidly bonded, now if this has say, thermal expansion coefficient alpha 1, this has thermal expansion coefficient alpha 2. If you now change the temperature, either it will bend like this or it will bend like this. Depending on whether alpha 1 is greater than alpha 2 or alpha 2 is greater than alpha 1.

Now, you can suitably design a bimetal strip and attach it to the bourdon tube link, idea is the bourdon tubes tip deflection will be more due to increase in temperature. Now we have to suitability design a bimetallic strip, whose deflection is same for the change in temperature, but opposite. What I mean is, let us say the tip deflection of the bourdon tube was delta. Now, for change in ambient temperature this becomes delta plus say delta 1. Now you design a bimetallic strip, which also undergoes the same amount of deflection, but this is in opposite direction. So, the net and if you attach this bimetallic strip to the link of the bourdon tube, these 2 will cancel each other out and the net deflection of the tip of the bourdon tube will be now free from the effect of ambient temperature.

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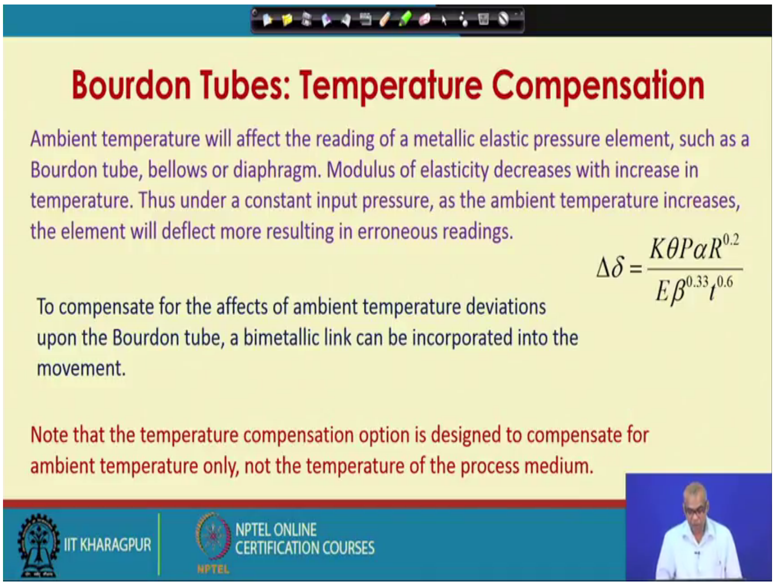

Note that the temperature compensation option is designed to compensate for ambient temperature only, not the temperature of the process medium.

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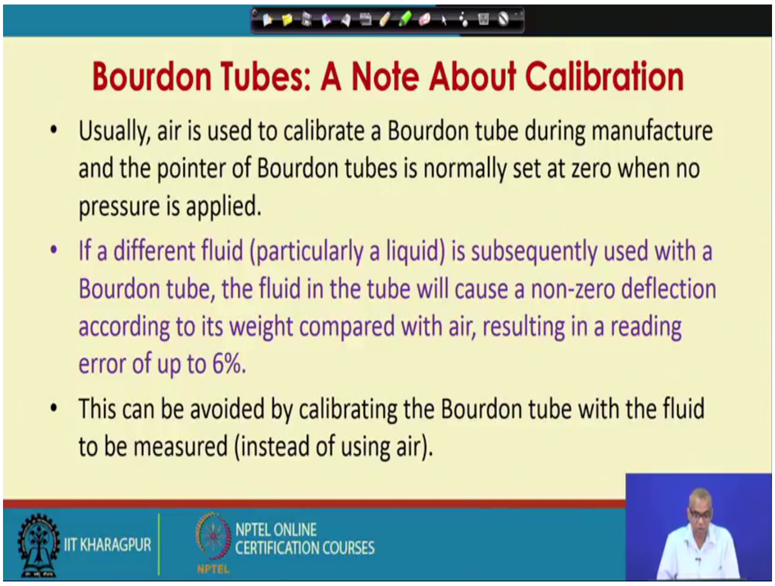

Finally, we talk about something on calibration of the bourdon tube. Bourdon tube can be calibrated using the dead weight pressure gauges that we have talked about; we have talked about the procedure. So, following the procedure you can calibrate a bourdon tube.

Usually, air is used to calibrate bourdon tube during manufacture and the pointer of bourdon tubes is normally set at zero when no pressure is applied. If a difference fluid, particularly liquid is subsequently used with a bourdon tube, the fluid in the tube will cause a non-zero deflection according to it is weight compared with air, resulting in a reading error of up to 6 percent. This can be avoided by calibrating the bourdon tube with the fluid to be measured, instead of using air.

So, what I mean is suppose the bourdon tube, when you purchase the manufacturer calibrated it using air as fluid. Now, suppose you are using this bourdon tube for measurement of pressure for some other fluid, particularly let us say liquid, whose density is much more than that of air. So, now, this calibration; original calibration will no longer be valid. So, ideally you should recalibrate it using the process fluid you are going to handle, but remember 1 thing that whenever you use a bourdon tube, to measure a new fluid pressure you must take care that all the fluids from the bourdon tube has been taken out. Typically it is sometimes difficult to get rid of the fluids that is tapped in the tip of the bourdon tube.

Now, I want to show you a real bourdon tube.

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So, look at here, this is a pressure gauge and inside there is a bourdon tube. So, what you see now is a circular scale and a pointer. So, the back side is like this.

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So, this is the pressure connection. So, through this the pressure will be applied. So, now, let me take it out, is not that easy to take out, but I have already kept it open for demonstration. So, this the pointer and this is the scale. Now look at here.

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This is the link and this is, you can see that cross section of this bourdon tube is circular, not circular it is elliptical. It was originally circular, then, they have flattened it to give it an elliptical shape. Now, when you apply pressure here, this tries to straighten up like this and as it tries to straighten up, you see this liver, the in sector pinion assembly all this moves and look at here, this is the hair spring that was talking about. So, this hair spring tries to eliminate the backlash. It keeps, these all these delicate in under proper tension. So, there will not be any free motion, lost motion.

So, this eliminates backlash. So, you apply, when you apply pressure here, the pressure comes through this. This end is now sealed, so this will try to straighten like this. As it tries to straighten like this, the pointer is attached here. Now, this pointer is attached here and you see there is this movement of the pointer.

So, this is how you can measure pressure, but this is a care that we have to take. So, we stop our lecture 23 here.