Principles of Mechanical Measurement
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Module -05
Displacement Measurement
Lecture – 14
Resistive Devices

Hello friends, welcome to the week number 5 of our MOOC course on the topic of principles of mechanical measurement. Over the last four weeks we have set up all the initial topics that we need to know about this topic of measurement; like we have discussed about the basic characteristics of the measurement system, both static and dynamic characteristics. We have developed generalized mathematical model and tried to see how we can solve those mathematical models to get idea about the characteristics of the systems.

We have primary discussed about the zeroth and first order of instruments and also a bit about the second order instruments. Then we have also discussed in a previous week about the output data or processing the output data. In the very first week itself we have discussed about how to analyze or identify the error that can be present in the output that you are getting from your instruments.

So, we have all this knowledge and of course, I should not miss the very interesting topic of digitalization that we have discussed in week number 3. And so with all these concepts now we are ready to discuss about individual instruments, which are suitable for measuring particular parameters. And the first one that we have in this line this chain is displacement or distance.

So, in every week from this one onwards we are going to talk about the measurement of any particular parameter. Like displacement here, then we shall be talking about velocity or motion measurement, force or dot measurement, pressure, temperature, flow etcetera one in one week. And the first one in this line is displacement which is probably the most fundamental among all them is parameter that we are going to measure.

Actually the term displacement we are going to use here, to represent any parameter having the dimension of length; such as set of dimension of something or displacement or distance covered by something or maybe the strain anything having a dimension of length. And immediately you can get the idea that we are talking about a very wide length scale.

Ah like the displacement or distance measurement can involve something at the molecular level, say the radius of a particular molecule or say the diameter of 1 molecule, or maybe the distance between different electrical or which that we can have inside in molecule etcetera, that can be one way or slightly larger than that the main free path of the molecules which can be very important in any kind of statistical approach an appraisal of molecular dynamics or we can be talking about extremely large length scale; that is the diameter of the planet diameter of the earth, maybe the radius or the diameter of the orbits of any particular planet, which is moving around the sun, maybe, we may be talking about lightyear.

Lightyear is very confusing term, because as the term suggests or as the name involves a year. It immediately gives an impression of being an unit of time, but actually it is a unit of length, because all you know, all of you know definitely that lightyear refers to the distance traveled by light in vacuum over a period of 1 calendar year. So, it is also unit of length and huge unit of length that we are talking about.

On the contrary we may be talking about Armstrong and even much smaller units than that, we are talking about molecules or intra molecular ventor. And therefore, the topic of displacement or distance measurement can involve a very very wide length scale, and the can be important in innumerable number of engineering applications. We can talk about any kind of velocity measurement or motion measurement and that will always involve an estimation of the displacement, because to measure the velocity of something you need to go the distance covered by that particular item over a particular period of time.

So, you have to measure the displacement and you have to measure the time and then will get the idea of the velocity. Similarly measurement of a several other parameters are actually or fundamentally can be reduced to the measurement of displacement. Like just think about the example that we are talking about from the very first class, how we measure temperature using a mercury thermometer or such liquid in glass thermometer. We measure the displacement of the mercury column within the capillary tube.

So, what actually measure is a distance, and now that it is a different thing that the scale of distance is given in terms of temperatures we can directly get a temperature reading, but the fundamental parameter that we are measuring there, is displacement or the change in the length of the mercury column or how we measure some pressure or differential pressure using a liquid nanometer. We basically measure the difference in height between two columns of liquid and then that is calibrated in terms of some kind of pressure quantity.

So, again the measurement of displacement gives us a measurement of pressure. Most of the transducers or electromechanical transducers, they work on the principle of measurement of displacement or I should say whatever parameters we are trying to measure, generally that is converted into form or some displacement and then it is converted to some electrical quantity to get the final output. And that is why the concept of displacement measurement is extremely important and that is the primary reason that we are taking this one is our first parameter.

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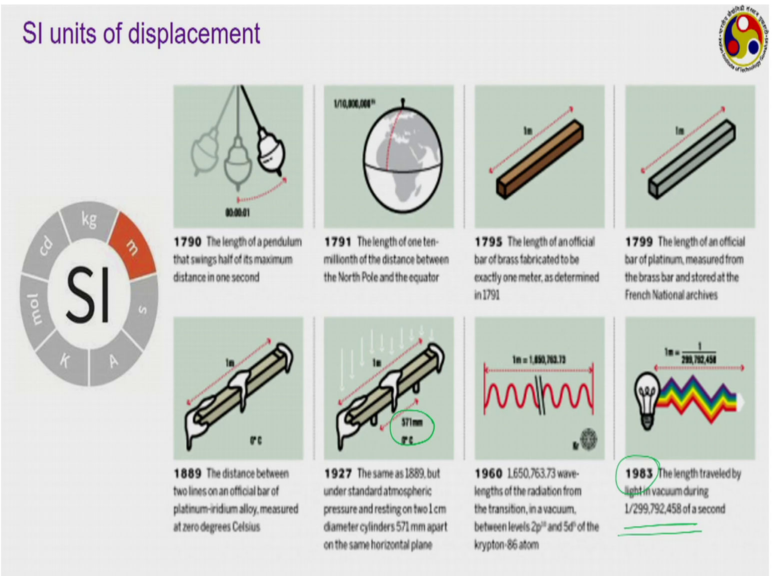

Now, all of you know that the fundamental SI unit of displacement is meter. In SI unit at present we generally defined 5 sorry 7 parameters as fundamental quantities and distance is one of them. So, meter is the unit, but how much is 1 meter, how much length do you refer to as 1 meter. that particular definition that kept on changing throughout the history. Like if we just look at the figures and numbers that we have here, like in the year 1790 around that time that is the time before SI unit was standardized people are mostly concerned about the use of the CGS systems, or the user matrix system has just become popular just started to become popular compared to the fundamental English units.

So, during that time 1 meter was defined as the length of a pendulum that swings half its maximum distance in 1 second. So, by measuring the half swing period as 1 second, whatever length we get that is 1 meter, but it soon changed to define the value of 1 meter, in terms of some distance along the periphery of the earth. Actually it was measured as the distance between the North Pole and the equator and 1 by 10 millionth of that distance was identified as 1 meter, because that distance was measured as approximately 10 million.

That again change very quickly around 1795 a length of an official bar of brass was fabricated to be exactly 1 meter that soon changed in four year times, where instead of brass, a bar of platinum was used and the length of that platinum bar was measured in terms of the brass bar. One of the reason for going for platinum was that, it has extremely less wear and tear compared to brass, and that particular platinum bar was stored in French national archives and it was there for about, it was just standard for about 100 years.

Now in 1889, basically about 90 years since the platinum bar was identified as the standard. Now two lines or an official bar of platinum radium alloy what the, or I should say the distance between two fixed points on the platinum radium alloy bar was identified as 1 meter and that was measured in zero degrees Celsius in order to avoid the thermal expansion of the bar. Platinum radium is a very hard material which hardly suffers any kind of erosion over long period of time and therefore, it is able to maintain this length over a significant period of time.

In 1927 now the previous standard was slightly modified, the bar remains the same and the standard atmospheric conditions was still maintained as zero degrees Celsius; however, now institute, the bar was allowed to rest on 2 1 centimeter diameter cylinders each of which are or which are 5 centimeter 571 millimeter apart from each other.

But all these cases you can find that particularly starting from that brass bar that you can find that the standards that we are defining, they are not absolute standards truly speaking and, so scientists filled, filled the need of identifying some natural phenomenon, defining the value of meter in terms of some natural phenomenon or something more fundamental, which does not suffer the effects of aging or wear and tear or some kind of mechanical error or the effect of temperature kind of such things etcetera.

And therefore, in 1960 krypton 86 alloy atom was identified and the wavelength of radiation from, when it gets in vacuum, when it gets transmitted from this 2 p 10 to 5 d level, that was used as 1 meter. So, but that soon changed and the prison standard which was defined in 1983, where the length traveled by light in vacuum over this period, or I should say the length traveled by liking vacuum over 1 second, this particular fraction of that is defined as the value of 1 meter, and this is the prison standard that we still followed. It is very very fundamental quantity, it hardly suffer any change or there is very less chance of this one to get modified, because of any other external factors.

And therefore, we can consider this one to be very fundamental quantity or fundamental definition of meter. Now with this we can move on to a study, if you have the instruments which generally uses are generally measures the displacement. The first that we are going to talk about is gaged blocks which basically a standards or the param, or the option that is used generally for calibration of the devices, and then we shall be discussing about a few transducers.

Here in this module we are mostly going to talk about electromechanical transducers; that is where the displacement is modified to some electrical quantity and that electrical quantity is measured and calibrated back to get the displacement, but we shall also be talking about a few other kind of transducers for measurement of the displacement.

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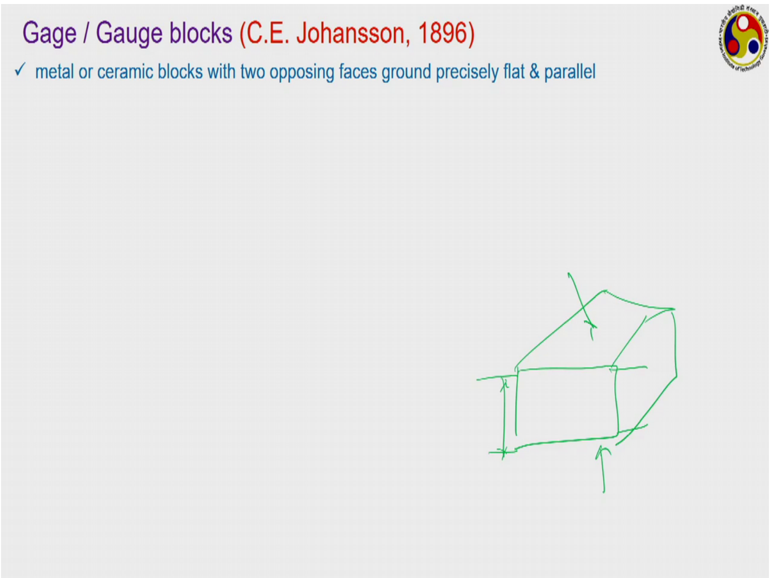

So, first we have the gage blocks. I am giving both the spellings depending on which kind of English system that you prefer; the British English or the US English, but the first one is the one that I am going to follow. Gage blocks are the industrial standards for calibrating any kind of distance or displacement measuring instrument. Even starting from a simple ruler to very very complicated laser based instruments, all of them can be calibrated in terms of gage blocks. Of course, there are several other excellent calibrating options.

But gage block is the one generally which is preferred in industry, primarily because of its simplicity. If they were first proposed by CE Johansson in 1896 and that is why they are often called Johansson block as well. Gage blocks are metal of ceramic blocks with two opposing faces, ground precisely flat and parallel, that is you are talking about something a blog, a three dimensional block like this, generally of rectangular cross section, but its cross section can be something else also.

Here two opposing faces, like this particular one and the one below this, they have to be extremely flat. And then the thickness of this particular, I should this one; this particular thickness of the block is the one that we are concerned about to get the measure of any particular length. So, gage blocks generally come in sets.

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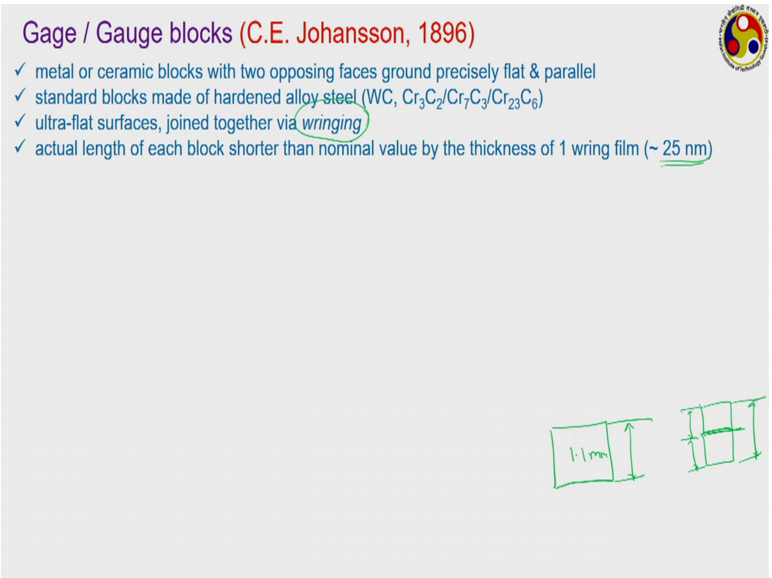

Standard blocks are made of hardened alloy steels, something like WC. Can you guess what is WC, or W is the symbol for why what? It is tungsten. So, W this is tungsten carbide and there can be chromium carbide as well. There are several kind of chromium carbide that we can identify, so I have given a few of them.

So, tungsten carbides are chromium carbides are very hard alloy steel which hardly suffers any kind of erosion or wear and tear, and that is why they are generally preferred as the material for forming this metal blocks. And we can of course, have ceramic blocks as well. they are ultra, they are characterized by ultra flat surfaces and these blocks are joined together, following a parameter phenomenon known as wringing.

I shall be talking a bit more about wringing shortly. actual length of each block is generally shorter than the nominal value of the thickness. Like suppose, if this is one block and it is given that the length of this block or nominal length of this block is 1.1 millimeter. Actual length or I should say this particular dimension of the block will be slightly shorter than 1.1 millimeter, because say if we want to join this particular block with another one or maybe a few more to measure slightly higher length, then the blocks will be placed like this; one on top of each other, fitting exactly with each other via the process of wringing.

Now between these two blocks means I am talking with this particular interface of this particular interface. We generally have a very thin flame of some lubricating oil and this lubricating oil or often referred to as the wring film. The thickness of the flame also you have to consider while taking the final reading which is like this.

So, if all, each of these blocks are having exact value as of, as whatever given on their dime, on the specification then the what final reading that we are getting here, that will be slightly larger than what actually it is what is, what is given by the gage blocks, because of the presence of these two sets of lubricating oil wring flames. Therefore, the nominal value each blocks are generally much slightly shorter than the nominal value of the thickness of one wring flame, and the thickness of wring fusion is very small just about 25 nanometer or there about.

So, that when two blocks are joined together like this, then we may have a film of 25 nanometer in between and therefore, the value dimensions of both of these blocks; that is this particular dimension and this particular dimension, both take care, takes care of this wring film and therefore, (Refer Time: 15:47) final when we take this measurement we get the exact value, because this 25 nanometer thickness of film is being taken care of, while fabricating the blocks themselves.

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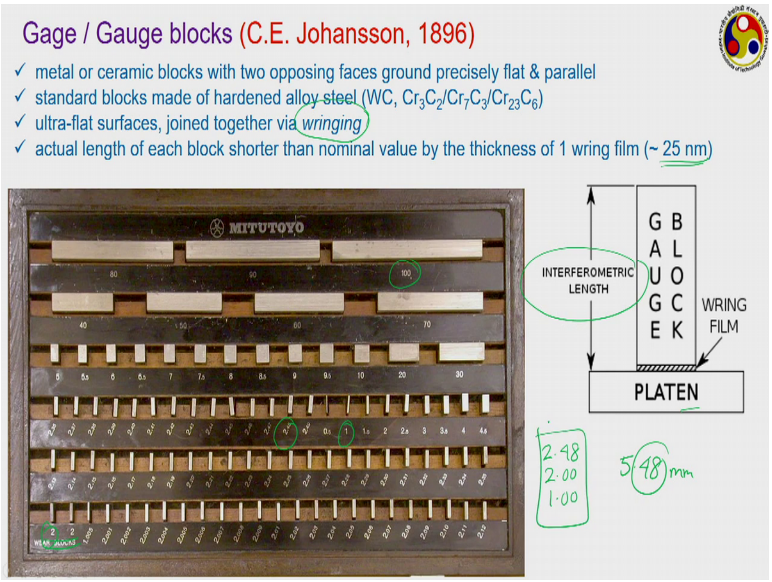

They come generally in. This is some the way generally they look like; the gage blocks and a small wring film, extremely thin thickness of wring film. The height of the blocks are often referred as interferometric lengths as well, and the blocks instead of platen they can be joined with each other with this thin film of blocks in between. This is how a typical set will look like. This is a very standard company picture (Refer Time: 16:27) very standard company and.

You can see there are so many blocks with different dimensions. Like the smallest one in the set that am showing, is having a value of 2 millimeter, whereas the largest one is having 100 millimeter. And some of them has been repeated as well, just you can see here. There are two blocks having dimensions of 2 millimeters. So, we can join them with each other to form any particular dimension. Like suppose you want to measure a value of say 5.48 millimeter or I should have 5.48 millimeter is the one that you are trying to measure.

Then what are the gage blocks that you should go for. There are several combinations that you can always go for, but generally we would like to go for something which gives us the smallest number of blocks. So, there are two ways you can go for, like what is the smallest dimensions that we are mostly bothered about; that is this 0.480 something that is we have to be concerned about, that is the smallest possible, or I should say 0.08 millimeter is the, has to be the smallest possible value that we can use, but there is no 0.08 millimeter, actually we are starting only 2 millimeter.

So, let us try to identify something which has these 0.08 millimeter as the last digit. We are lucky here that 2.48 is there. So, we can choose 2.48 as 1. So, let us take 2.48, then what else we can go for? We can take a 2 millimeter and we can take another 1 millimeter. So, 2.48, then 2.00 and 1.00, these three together will give you 5.48 millimeter.

So, we can join these three blocks and get the final value. Or if you are trying to measure the values of any unknown dimension, then we can keep on adding or stalking this blocks one on top of another, and try to match when you get the exact comparison. So, finally, getting the values of these blocks or adding the values of these blocks we get the final dimension.

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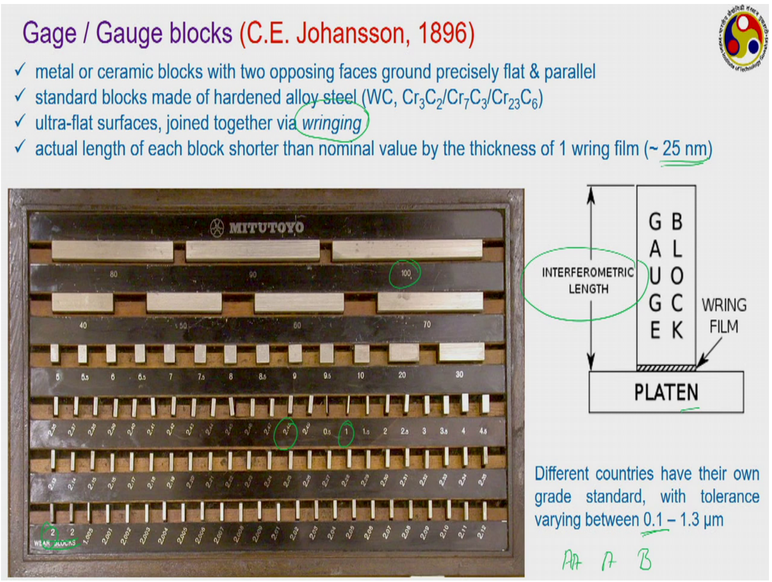

Each country has their own standards, the blocks can have different kinds of categories, like very commonly will find categories; such as double A category, A category, B category etcetera being the most precise one is extremely small level of error something that in your 0.01 micron or even lesser. Whereas, A or B are having a slightly larger uncertainty in their predictions, but typically the tolerance value varies between 0.01 to 1.3 microns across different countries and this is how gage blocks can be stacked up.

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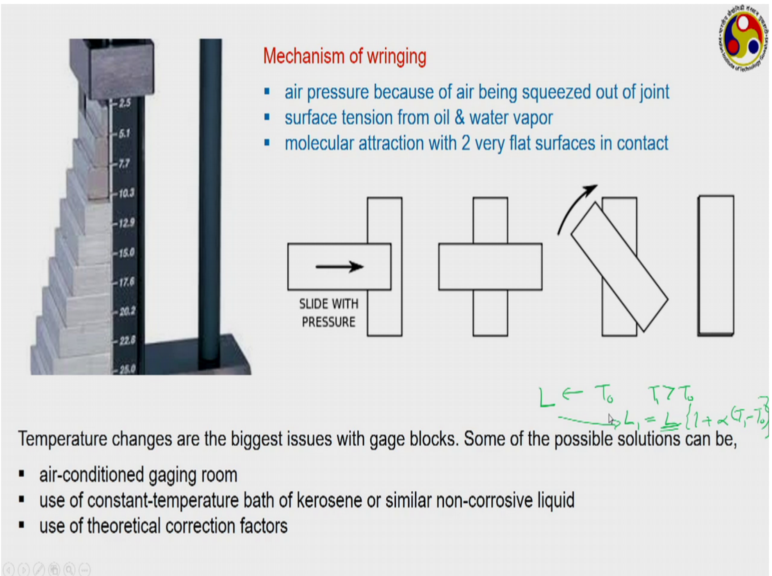

You can see there are so many gage blocks that we have stacked up to get a final value and once they gives an exact comparison, then by joining their values we are getting the final reading. But the way these blocks are stacked up that particular phenomenon is called wringing. As I have mentioned like we have said this is one block, in this another block and in between somewhere this blocks are joined with each other. And do not feel that it is something like stacking bricks on one on top of another or just boxes one on top of another, rather this a very very strong bond.

Instead of having the blocks this way we can, most cases we can also tell the blocks this way and they will still be still remain joined with each other, almost like magnetic attraction. So, this phenomenon of wringing is the one that is responsible for this. Unfortunately there are several theories behind the appearance of wringing and we are yet to reach any particular consensus, but some of the common cause or common mechanism for wringing can be mentioned.

One can be the air pressure, because when two blocks are coming in contact with each other, the air in from the intermittent space or intermediate space that goes off and as the air is squeezed out, that surrounding air creates a very high pressure on this, allowing this phenomenon of wringing. A more reasonable reason or I should say a more a better reason can be the surface tension, because of the presence of oil and water vapor in the gap. The molecular attraction can also be a reason we do very flat surfaces coming in contact with each other the adhesive. The cohesive forces of the molecules of the metallic alloys.

Or metallic ceramic alloys which are there that can also lead to very strong bonds. These are some of the reasons the surface tension and molecular attraction based theories being the most common one, but I repeat there is still no consensus about why wringing happens, but wringing do happen and this blocks can stick to each other forming very strike tied bonds. This is generally the way the blocks are placed on top of each other. Like this is our block number 1 and we want to put this block number 2 on top of this.

Then generally the blocks are, the second block is placed perpendicular to the first one and it is slide with pressure on top of the first one. So, that the air is squeezed out of this. And now once we reach this cross kind of position then this is rotated in a particular clockwise or anticlockwise direction, till we get a perfect match like this. And once they are into this particular position, it will be very tight bond just we have mentioned.

One big problem with the use of gage block is that the, being made of metal they suffer from the problem of thermal expansion. As the temperature changes their length can change and therefore, they can give accurate reading, only at the value at which they have been calibrated or they have been fabricated.

So, maintaining the temperature is extremely important while using the gage blocks.. Several options are there; one option can be the use of air condition gaging rooms.

Now, using, it may not be possible always like if you are trying to measure something related to an industrial process, we have to get the gage blocks to that particular location. And also suppose we want to measure the length of one particular sample. Now we take it inside the air conditioned room where the gage blocks are there, but generally the, generally the parameter or I should say the component who's length you want to measure, that itself may take 10 to 15 minutes or even more time to come in thermal equilibrium with the room itself, so you have to allow that amount of time.

Second option can be used for constant temperature both made of bath of kerosene are certain non corrosive liquids. The gage blocks will remain immersed into this, and while taking the reading they will be taken out for a very short interval, reading will be taken and immediately they will go back to the pool of liquid. If you are looking for very precise instrument, then our specimen or the subject itself can also be immersed and entire measurement can be done in the immersed condition.

But again that may not be possible in all the all scenarios. So, in that case when we cannot allow you air conditioned room or we cannot do the measurement in submerged condition, then we can make use of the theoretical correction factors. Like suppose if we know that the length of the block is L, at the standard reference temperature t naught and we are actually breaking the reading at some temperature T 1 which is higher than T naught. Then if we have complete idea about the properties of the metal which are being used to fabricate this block then we know that at this temperature T 1, the length of the block will be L in to 1 minus sorry 1 plus alpha into T 1 minus T naught. So, they will be the modified length so, but actual reading will be shown for L only.

So, we can you by knowing knowledge, by having a knowledge of this temperature T naught and T 1. We can correct this value of L to get back to this L 1 and there by getting the exact length of the subject. So, this we gage blocks are used in industries to calibrate different kind of measuring devices and sometimes also for direct measurement of dimensions.

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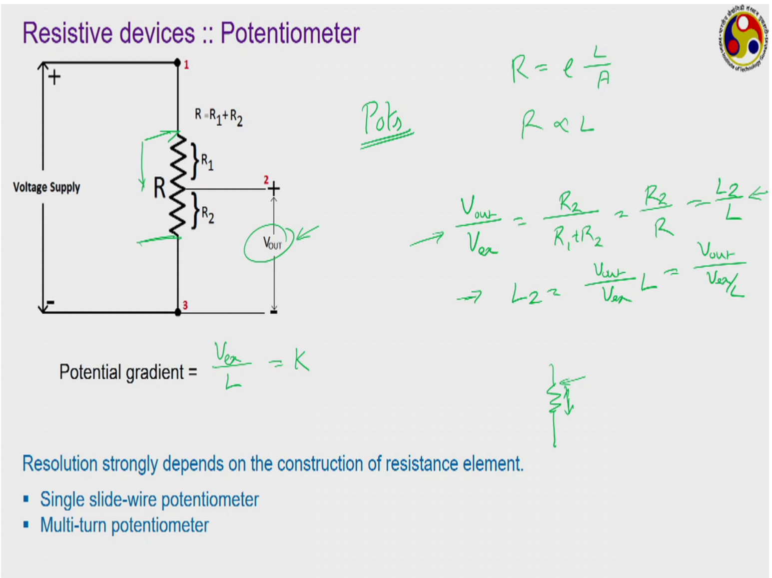

Now, the first instrument that we are going to talk about, first kind of electromechanical transducer; that is based upon the thermal, sorry electrical resistance and that is known as a potentiometer. Do you remember this term where we have used earlier, if remember correctly potentiometer is one of the example of a zeroth order instrument where we have made use of this name. Its working principle is very simple, as we know the resistance of any resistor R is equal to rho into L by A, where L is the length of the resistor, A is its cross section area and rho is the resistivity of the property of the material.

Now, if the resistor is made of uniform cross section and also a, if the material properties remain uniform then R is directly proportional to L. So, as the length changes, resistance will also change and accordingly we can get a measure about this length. Just like the arrangement shown here. Here generally the potentiometer, sometimes also called rheostats or in short pots. They are connected with a voltage source, commonly a DC voltage source, and then this is a resistor over which we have a slide in contact which is, which keeps on moving along this.

This sliding contact is connected to the location where you want to measure the displacement, and now, as the sliding contract keeps on moving over the resistor the corresponding output voltage that keeps on changing. as you can see R is the total resistance, but the output is connected only to this R 2 portion. So, what will be the relation between your output voltage and a supply voltage?

So, your output voltage divided by your supplier excitation voltage should be equal to R 2 divided by the total resistance R 1 plus R 2 or R 2 by R and resistance being proportional to length. So, this length can be L to upon L, where L 2 we are referring to as this particular length, we are talking about L 2 and L is the total length of the resistor.

So, by measuring this voltage V out we can directly get the value of this resistance or, sorry output length L 2, or we can say L 2 becomes equal to V out by Vex into L or can say, I can write this way V out by Vex by L. this Ves by L is called potential gradient which is Vex by l; generally given a k 1 it is non standard symbol you can use any other symbol for this potential gradient also. What this is looking like? This is sensitivity of the instrument, longer the length for a given value of Vex, so the higher will be the precision of the measurement, and as the length changes resistance will also change. And so for small change in resistance, so small change in length, you will get a larger change in resistance and accordingly a larger or more significant change in the value of V out.

So, this is the working principle of potentiometer. Ideal potentiometer is the perfect example of a zeroth order instrument as there is no storage properties and output and in output and input are linearly related like, just like here, this V out is output Vex is the input and we get a very straightforward linear relationship something like this. The resolution of the instrument which is strongly depends on the construction of the resistance element itself. Depending on what kind of resistance elements you are putting we can have different kinds of potentiometers.

Like one kind of potentiometer can be, just the one that shown here that is linear potentiometer or sometimes called single slide wire potentiometer where you just have one slide wire like this and the content keeps on moving up and down over this. Initially if say like if I go back to the original diagram, if the contact is connected to this particular position then your entire resistor is available to the output, so V out will be equal to Vex however, as the contact keeps on moving down as the displacement happens, corresponding V out also keeps on changing, and when the contact reaches somewhere here V out will become equal to 0. So, this is single slide or potentiometer; however, if we are looking for measurement of angular deflection. I have not talked about angular deflection so far, but remember whenever you are talking about the deflection or displacement it can be linear, it can be angular as well.

We shall be discussing about a few specific instruments for angular deflection measurement towards the end of this module, but potentiometer can also give us that option, to make a resistive potentiometer to give angular deflection, we can measure the potentiometer or the resistance resistor can be given a shape like this where voltage are measured along this, and the slider.

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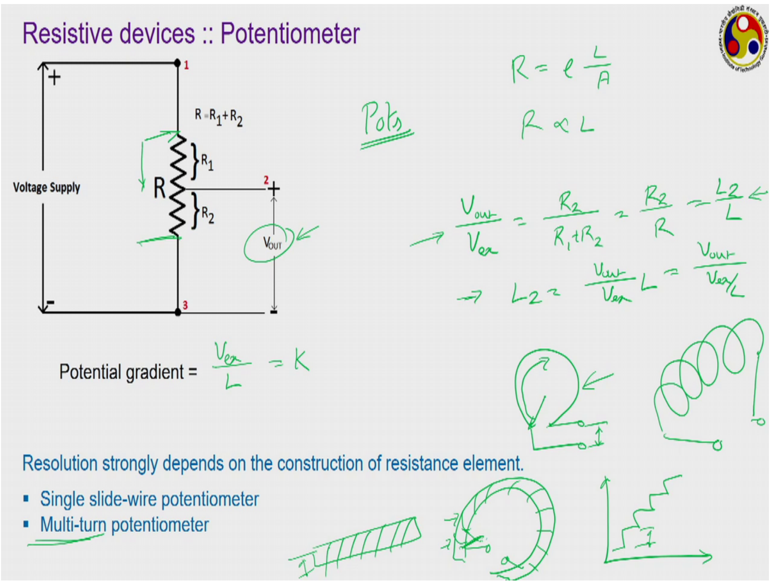

This is the initial position of the slider and that keeps on moving along this. And therefore, its angle of rotation is a direct measure of the resistance, and or I should say the other way the resistance is a direct measure of the angular deflection and accordingly this output voltage is a measure of the angular deflection. And instead of one we can also have multiple turns if we are looking for very large resistance measurement or large deflection measurement, where we can form the resistors quite resistors to form such kind of helical structure, to give the voltage. These are the two ends and this helical structure allows the contact or I should say they slightly come into contact to move over a very long resisting resistive element, thereby giving option for large displacement measurement.

However, one problem in this kind of situation is that, while making such helical coils or even such single turn. Generally we take one small flexible pads like this and the resistive coil is around this one, I should not draw this way, resistive coil is wound around this, something like this. And then this flexible paired is bend to form the single turn or if required multi turned potentiometer. So, the resistive coil is wound around this one with, maybe these are the two end points for final voltage measurement.

So, as the contact moves over this the, at a particular instant of time the contact may be maybe touching this particular element and the next instant with small rotation it is touching this one. Now bit from the first coil this one to the second turn, it is not a linear change, but there is a certain portion on the coil the in, the slider is not at all coming in contact with. So, the change in the resistive value is more like a staircase kind of thing, but the value of the staircase or the height of each of these stairs can be kept very small or to negligible amount by choosing a proper resistor coil and also by choosing a the this particular dimension of the pad suitably.

So, potentiometer is the most common instrument for measurement of both linear and angular deflections.

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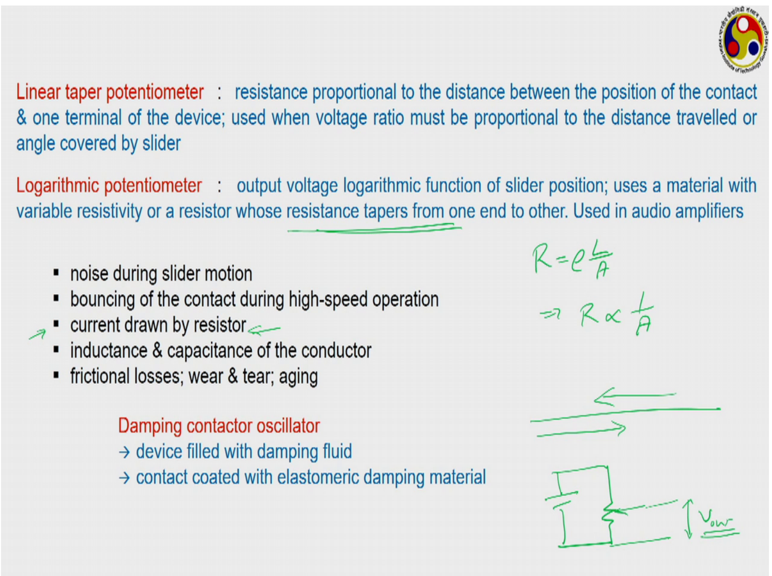

Now, potentiometer can primarily be of two types; one is a linear type of potentiometer, the one that we are talking about, where the resistance is proportional to the distance traveled between the position of the contact and one terminal of the device. Here when voltage ratio must be proportional to the distance traveled or angle covered by the slider we use this, but there can be another option also which is referred as a logarithmic potentiometer.

Here the output voltage is a logarithmic function of the slider position, we can achieve that either by using a material whose resistivity keeps on changing along the length or a resistor whose resistor tapers from one into other. Now how we can achieve this? Remember what relation we use between resistance and the dimension of the resistor were. We know that R is equal to rho into L by a or R is inversely proportional the cross section area therefore, if this is the resistor coil and if we keep on changing the cross section area from one end to the other.

Suppose if we keep on increasing the cross section in this direction then the resistors will keep, resistance will keep on decreasing, accordingly it will be giving you a tapered measurement of the deflection. This kind of logarithmic potentiometer is a particularly used in audio amplifiers because our sense of hearing goes in a logarithmic way and that is why the logarithmic potentiometer can be a good choice there. Potentiometer despite theoretically being a zero order instruments is can deviate from zero order behavior quite significantly because of the presence because of several factors, some of which we have mentioned that time itself; like when the slider keeps on moving over the over the resistor there can be noise, there can be lots of fictional losses wear and tear, aging.

If the contact is we want in the contact to move very rapidly it may bounce of the contact. the ideally resistor coil should not have any inductance and capacitance, but practically it is not possible to find any conductor which is zero inductance and zero capacitance and so those effects can also come into play sometimes. And something that I should be talking shortly is the current drawn by the resistor itself, the frictional losses also. The noises excetra can be eliminated or at least minimized by using the damping contactor oscillator where the potentiometer slider is allowed to, potentiometer is allowed to be filled with some kind of damping fluids, some kind of high viscosity fluid.

So, that has the contact most, it suffers quick resistance from the fluid thereby eliminating the losses and also the noise. We can also use content coated with some kind of elastomeric damping material and similar other takings can also be employed. Now we go to this particular point current drawn by the resistor. We are saying that we are applying certain kind of voltage, and now this is your resister coil and as the sliding contact keeps on moving over this we get output voltage, but here we are getting this output voltage that is fine, but somehow we have to measure this way out and then only we shall be able to get an idea about the displacement.

And how to measure the V out? Of course, we have to use some voltage measuring instrument like a voltmeter and that voltmeter itself has some kind of resistance depending on the value of the resistance your instrument will also draw some current, and as it is drawing some current then the output voltage will keep on decreasing based on that. So, there will be some loss.

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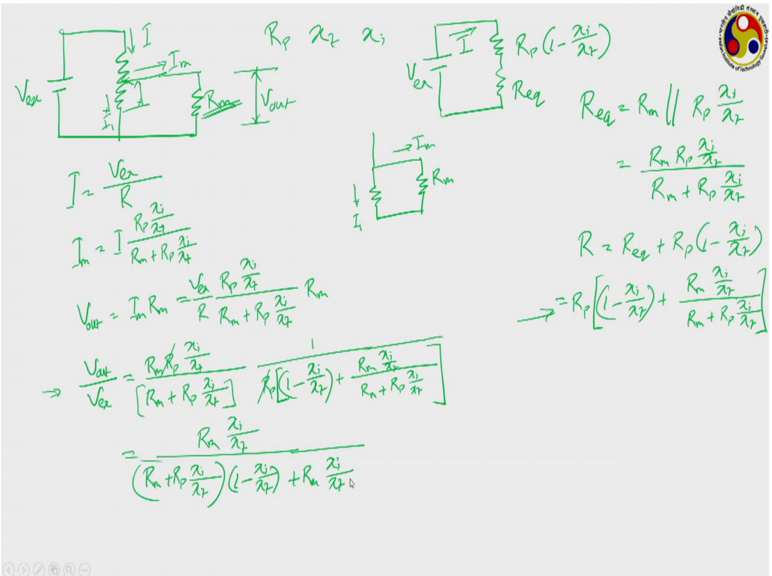

Let us do a bit of calculation from this. Let us draw one small potentiometer, let us say this is the source voltage and this is the. Sorry I should draw in a continuous way, so this is the resistor and this is a position of the contact at a particular instant. And to measure the output voltage, here we have connected 1 volt meter which itself is having a resistance Rm.

So, Rp is the total potentiometer resistance, the length of the resistor is Xt, and this particular resistance is, sorry this particular distance is given by x i say Ve x is the excitation voltage and V out is the output voltage. So, we have to see how this output voltage V out is being modified or affected by the presence of this Rm or maybe the relation between Rp and Rm.

So, we can modify this circuit to represent like this. So, this is your source voltage, then this is the left out portion of the resistance, potentiometer resistance. This is the portion which is in contact with the slider and this is the Rm that we are talking about, and now we can combine these two into one equivalent resistance. So, this is your R equivalent, this is Rp in to 1 minus xy upon xt. We are not considering any kind of tapering, we are considering in uniform slide, uniform resistance of the resistor, then what is the net resistance ok.

Let us first try R equivalent, R equivalent refers to two resistances; one is Rm and other is Rp into xi upon xt, they are in parallel to each other. So, very standard we can calculate Rm into Rp into xi upon xt divided by R m plus Rp into xi upon xt. This is the value of R equivalent and so the total resistor R will be R equivalent plus Rp into 1 minus xi upon x t, there is a total resistance that is prevalent in the circuit, so R equivalent expression is there.

So, let us take R p common from this. So, we have 1 minus xi upon xt plus from this expression this we have Rm into xi upon xt divided by Rm plus Rp in to xi upon xt. So, this is the total resistance that is present in the circuit. Here the voltage is V out if I right properly. Let us say I is the current that is flowing through this circuit. So, your i will be equal to. Oh sorry i this is not V out, this is a Vex and V out is a voltage that is prevailing here. So, V ex divided by the total resistance of the circuit is your current, let us say this current I which is coming here that gets divided into two components; one is this I m is going to the voltage measuring meter and other is say I 1.

If we draw that particular portion of the circuit, the current gets divided into these two components. So, this I m passes through this Rm and this I 1 passes through these remaining portion whose resistance is Rp into xi upon xt. So, what will be your I m. I m will be equal to i into Rp into xi upon xt divided by Rm plus Rp in to xi upon xt, is how we calculate the value of I m. And now how much will be the output voltage then the V out, V out should be equal to I m into Rm.

So, let us put all the expressions into this. So, putting I m we have I into Rp into xi upon xt divided by Rm plus Rp in to xi upon xt this is I m which we are just written into Rm. Now I is as per our earlier definition, I m is, I is V excitation by R and R is this particular quantity. So, let us, let us make every shorter, so let us take it as V out divided by Va x, there is the ratio output voltage to the excitation voltage.

Then what we have here, let us just try to simplify this entire thing, we have Rm R p into xi upon xt divided by Rm plus Rp into xi upon xt into R R is a big expression that we have already got. So, it will be 1 by R Rp into 1 minus xi upon x t plus R m into xi upon xt by R m plus Rp into xi upon xt. So, we have to simplify this big expression, let us multiply this entire denominator with this quantity.

Let us simplify the denominator. So, what we have is, in the numerator? We have left with or there is no change in the numerator R m R p by to xi upon xt and in the denominator we have ok. We can cancel out one Rp that is this one and this one cancels out. So, this goes off from this, we have only Rm left in the numerator into xi upon xt and in the denominator.

Now we have Rm plus Rp in to xi upon xt into 1 minus xi upon x t plus Rm into xi upon xt. So, we have to simplify this, lots of calculations we are doing, but I am still instead of directly writing the expressions I am doing all this steps, so that you can get the idea about how to read the final calculation, let me erase this part to make some space.

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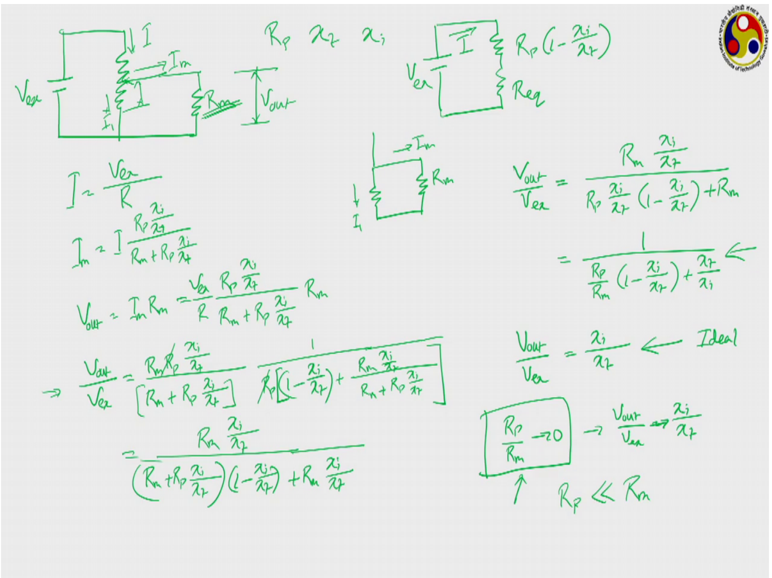

So, how we can simplify this let us see, so Rm xi minus xt cancel out and what we are left with. In the numerator we are still having the same quantity Rm into xi upon xt, and in the denominator we have Rp into xi upon xt into 1 minus xi xt plus Rm and if we divide. now this whatever we have in the numerator we are dividing everything by the numerator. So, in the denominator what we are going to get, here making the numerator one. So, in the denominator xi upon xt cancel out.

So, we are getting Rp by Rm into 1 minus xi upon xt plus xt upon x i. So, it is a very interesting expression to have. Look at this, at earlier what we told, earlier we told that to have the perfect zero order behavior V out by Vex should be equal to x i upon x t that is when you have the ideal zero order behavior, but now in the actual scenario when the Rm is coming to picture we have this.

Now in which situation this two will be equivalent to each other; that is the situation when this Rp by Rm that tends to zero, then you will be having V out by Vex to be equal to or to approach xi upon xt, which is ideal behavior. That means, this is the ideal scenario, the ratio of Rp to Rm should be very, should be tending to zero or the resistivity of the, resistance of the potentiometer should be very small compared to the meter resistance. Now practically it is never possible for the meter to have infinite resistance.

So, practically it is possible only when this Rp is very very small compared to the Rm, but again a smaller value of Rp will affect the sensitivity of the instrument, and therefore, we have to go for some kind of trade off here; that is value of Rp should be chosen such that we have, for a given Rm we can have a certain level of sensitivity as well as a certain level of error or we can minimize the corresponding error; that is present, that can be present there. What can be the effect of this?

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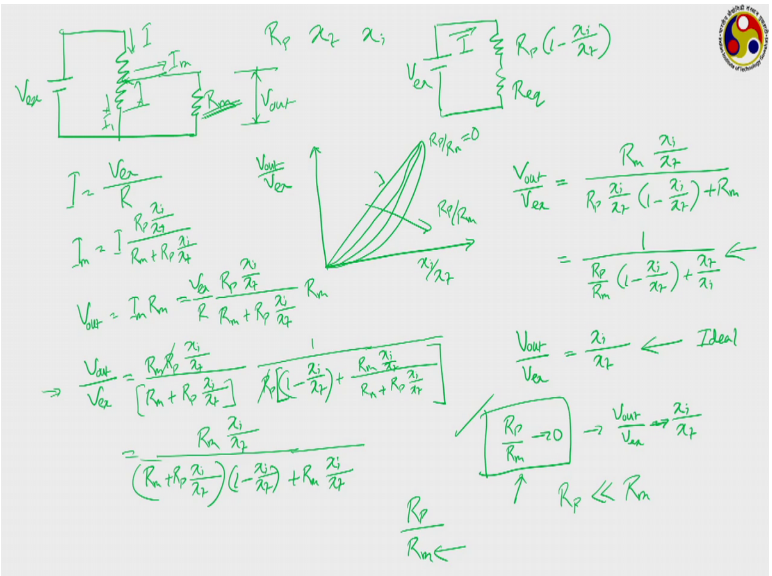

Like suppose if we plot this, we have the V out by Vex on 1 axis and xi upon xt on the other axis. When we have this particular scenario then it will be a perfect straight line like this. This is the ideal curve. So, this is a scenario when Rp upon Rm is equal to zero; however as Rp by Rm this ratio keeps on increasing your curve will deviate from this and it will follow a pattern somewhat like this. So, this is a direction on which this Rp upon Rm that keeps on increasing. So, the in the while in the ideal scenario we should have this particular curve. In actual case we are getting a deviation and that deviation is governed by the ratio of this Rp upon Rm.

So, the Gst is that why you really want a high value of Rp, you to have a high sensitivity for the instrument and the variable Rp still has to be very very small compared to the meter resistance or the voltage measuring instrument. This particular effect is called the loading effect, means the effect that is being brought in by your measuring instrument in this case the rm. This effect is called loading effect and it can be very very important.

In a nutshell you can say that once you are given with the potentiometer, you have some idea what the value of Rp, then you should choose your voltage measuring instrument to have a suitable, to give you a suitable value of this Rp upon Rm ratio, depending on the value of Rp your value of Rm should be selected. So, that is it for potentiometer.

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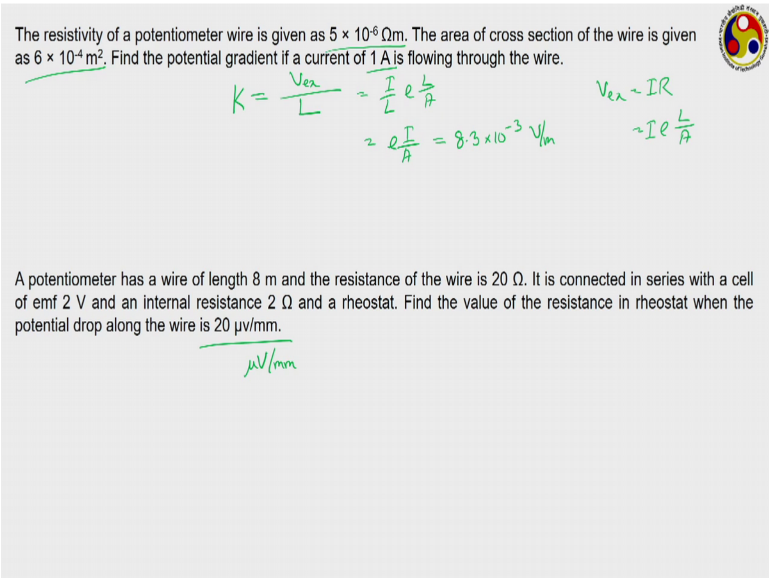

A potentiometer let us try to get some idea about one small problem involving potentiometer. Now here our problem is we have the resistivity for a potentiometer where is given, the cross section area is also given, you have to find the potential gradient, if 1 ampere current is flowing through the wire. Let us say k is the potential gradient. And now how we have to define this? We have defined this as the excitation voltage differ by the length of the resistor, and again your, how the Vex is related to the current, this related as I into R, where R is the resistance.

So, and R is known as rho L by A. So, let us put it here. So, we have I upon L into rho L by A, which leads to the cancellation of this L. So, we are left with rho I by A. Now all these parameters are given, your rho is 5 into 10 to the power 6 ohm meter, your I is given as 1 ampere area is given as 6 into 10 to the power minus 4 meters square. If you put all this value, I have got this calculated for you.

So, we our value is 8.3 into 10 to the power minus 3 volt per meter. So, this is the potential gradient of the instrument. Here I am throwing another problem to you, a potentiometer has a wire of length 8 meter and the resistance of the wire is 20 ohm. It is now connected in series with a cell of emf 2 volt and an internal resistance of 2 ohm, and we also have a rheostat. Rheostat is basically the arrangement which will measure the output voltage.

And there will be this conducted with the sliding contact. Now you have to find the value of the resistance in rheostat when the potential drop along the wire is 20 micro volt. This should be capital V actually; it should be micro volt per millimeter, now if we write it properly. how to solve this? Ok I am leaving this one to you try to solve this, otherwise in the next class I shall be discussing about this one, but let us quickly move to the next instrument in online.

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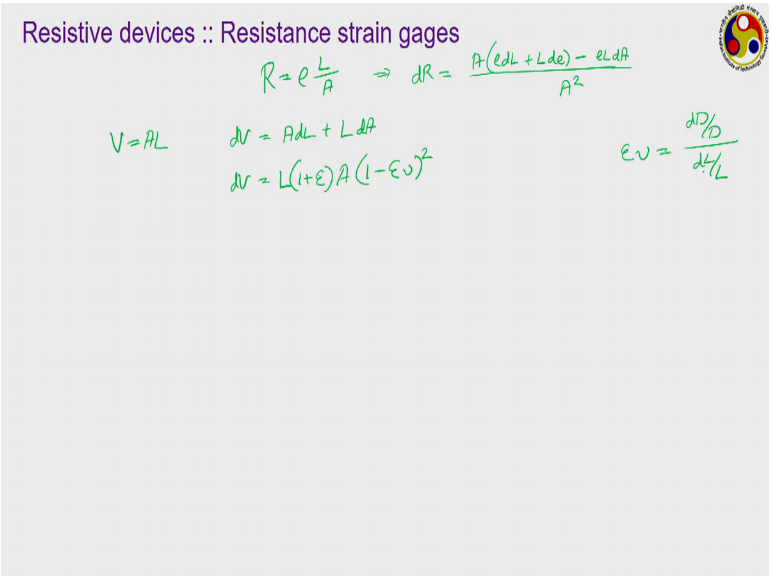

Another resistive instrument, but a very advanced one which is resistant strain gages. The operation of strain gages again based upon the change of resistance with the change of length, but strain gages are very important instruments, because such gages are used for measurement of several other parameters like I mentioned earlier, measurement several gages, several sustained strain gages are used for measurement of pressure temperatures, etcetera. So, strain gages are very important instrument, but their working principles are very simple, we know that for a resistor again R is equal to rho L by A. So, if any of these three that is resistivity or length or area changes R will also change.

So, the change in R dR can be written as by simple differentiation this rho dL plus L d rho minus rho L dA divided by A square. It is simple differentiation that we are doing here dL refers to the change in the length of resistor dA refers to the change in the cross stationary of the resistor and d rho is the change in the resistivity. Now, initial volume on the resistor is A into L.

Now, what will be the final volume? Both area and length are changing. So, we can say that change in volume will be equal to A dL plus L dA that is one way, you can calculate this, but there is another way. You can calculate this also, the dV can be written as the difference between the final volume minus initial volume. Now, how much is a final volume, L is the initial length how much is the final length that will be L in to 1 plus epsilon, where epsilon refers to the strain and how much will be the final area. Final area will be A into, can you say what will be the final area for this?.

That will be I am directly writing here, epsilon is the again the linear strain and what is this nu? This is a Poisson's ratio, which gives you the ratio of the change in a length and change in diameter or you probably know it is given as where capital D refers to the diameter of the resistors and L is definitely the length of the resistor. So, once we multiply these with epsilon this portion goes off and it refers to the change in the diameter from there we can calculate the change in the area generally, both epsilon and nu are quite small quantity. So, their product also will be even smaller.

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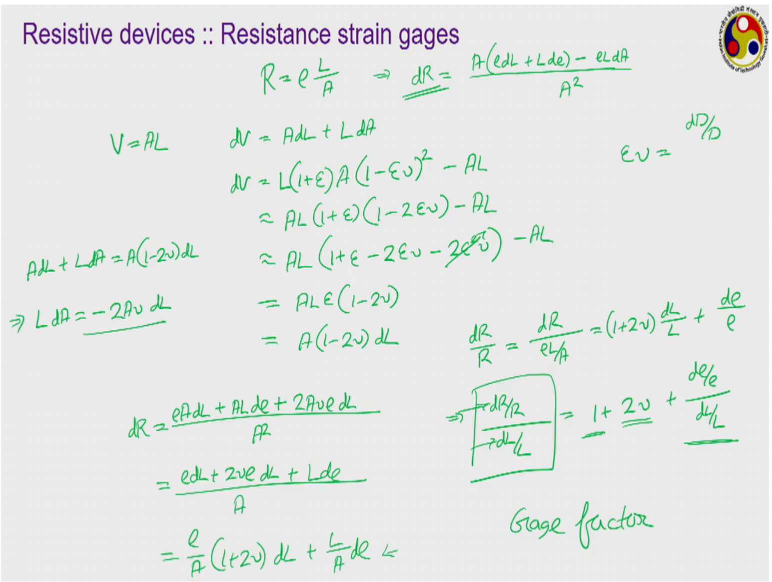

So, accordingly we can write this as AL into 1 plus epsilon and this one can be simplified as 1 minus 2 epsilon nu. We are simplifying this, assuming the product of epsilon nu to be extremely small then we are getting, taking this multiplication sorry, this is the final length and dV will within this minus the initial length minus AL. So, this now now you are taking the products.

So, we have 1 plus epsilon minus 2 cell and nu minus 2 epsilon square nu minus AL. So, this is again a very small quantity. So, we are neglecting this and so, finally, we have AL epsilon into 1 minus 2 nu and L in to epsilon can be written as dL. So, we have A into 1 minus 2 nu dL. So, equating these two expressions of dV, we have a dL plus LdA is equal to a into 1 minus 2 nu dl take everything on one side. So, we have this L dA is equal to minus 2 A nu dL.

So, this is the way we can relate the change in the areas that change in length. Let us put it back into this expression of dR. So, dR will be now we have rho A dL which remains as it is plus A L d rho minus this is where you are going to change, this L dA will be replaced by this. So, we have A plus sign coming into picture and we have 2 A nu rho d L by A square. So, 1 A can be cancelled out from everything and separating that dL and d rho quantities. So, what we have left with let us simplify this instead of writing directly rho dL plus 2 A sorry, A has been cancelled out to nu rho d L plus plus L d rho by A.

So, we can write it from here that is rho upon A into 1 plus 2 nu dL plus L by A d rho. Now, if we take this ratio dR upon R that is dR, this expression that we have got here. This we are dividing with rho L by A, then if we divide it by rho L by A then what we are going to get, we are going to get 1 plus 2 nu into dL by L plus d rho upon rho and now dR by R divided by dL by L. So, what do we have 1 plus 2 nu plus this quantity. This particular factor is called gage factor that is, it refers to the per unit change in resistance to or I should say it relates the per unit change in resistance per unit, the value of the resistor to the strain in the instrument.

And once we know the gage factor then just by measuring the value of this dR, we can get an idea about this dL itself that is the idea or that is the operating principles of this race to strain gages. You can see this gage factor contains three parameters on the right hand side. There are three quantities here the first one; this refers to the change in resistance to the change of length this contains the Poisson's ratio. So, this relates to the change in resistance, because of the change in the cross section area and this is, because of the change in the resistivity.

This is sometimes called a Piezoelectric effect or Piezo resistive effect. So, when this one is significant, the strain gages are piezo electric strain gages, but they are when which is relevant to certain materials, but in several common materials, this one can be quite insignificant, but the other two terms definitely are there.

So, the idea of resistive strain gages that whenever it is subjected to some kind of strain. There will be change in the value of the resistance and if we can measure this resistance or the change in the resistance, then we can get a direct measure of the change in the length or the deflection.

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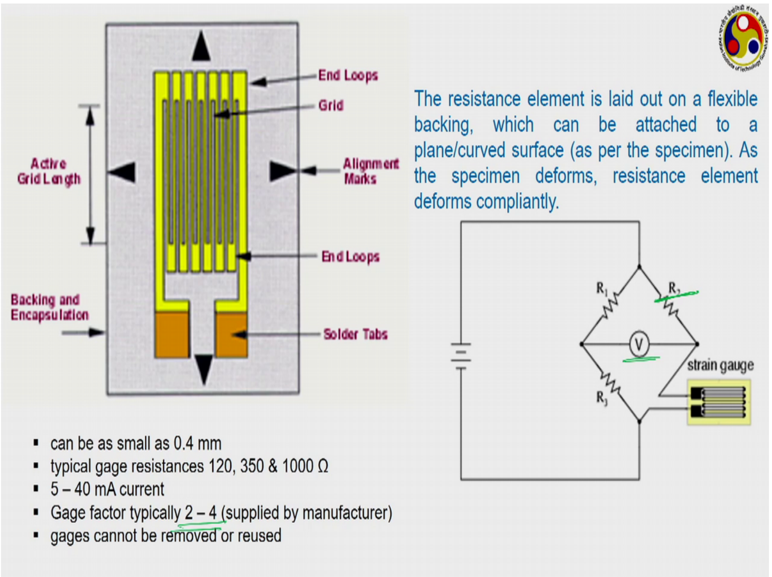

This is how a typical strain gage may look like. Here, we have the resistive wire is connected in or displaced in loops like this the resistance element generally is made led on a flexible backing, which can be attached to any surface either a planar surface or curve surface.

Basically, where you want to get the measurement done the specimen, as the specimen deforms, either under tensile load or comprehensive, compressive load, the strain gage also deforms accordingly, thereby causing a change in the resistance and thereby giving a direct value of the deformation of the original specimen; however, one problem is that once you attach this one to the surface, you cannot remove it.

It becomes a permanent part of the surface itself and therefore, they can be reused for any other measurement and how to get the idea about the change in the resistance. We can easily go for a Wheatstone bridge kind of combination like this where the strain gage forms 1 arm of the four resistors and in normal scenario, when the gage is not under any kind of strain this volt meter will read a 0 value.

But whenever there is some kind of change in the some kind of stress put on to this and then the voltage value will change. We shall be getting a nonzero voltage value and that can directly be calibrated to the deflection. The figure shown here is generally called a quarter gage, but we can also have half or full gage arrangement. Half gage means where we have one strain gage like shown and another strain gage here and when all four are, all four resistors are actually strain gages then we call full arrangement or full quarters strain this is sorry a full strain gage.

These are certain typical features for strain gage, they can be extremely small often much-much smaller than a millimeter also depending on what value you want to measure typical gage resistances are pne 2350 ohms or 1 kilo ohm depending upon. Again what ranges of deflection you would like to measure 5 to 40 million per level of current. It has most of the common gage factors, gages have factors in the value of 2 to 4 and this value comes directly from the supplier and as I mentioned gages can be cannot be removed or reused.

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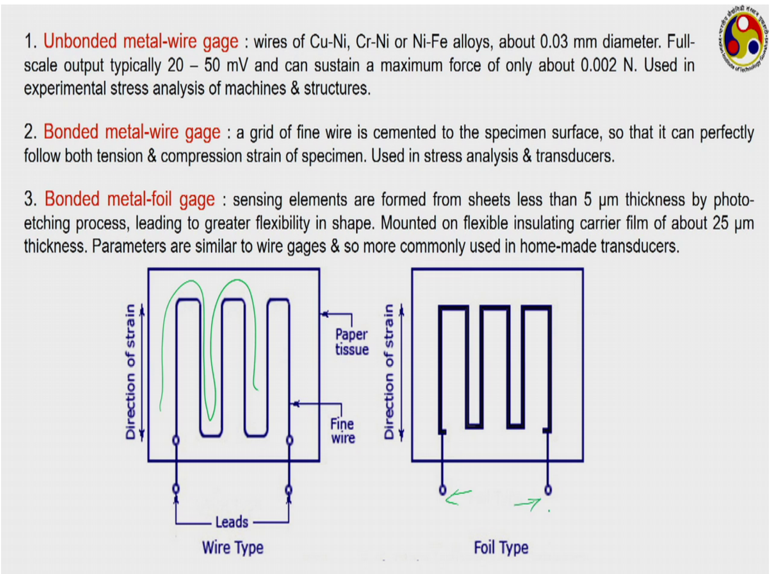

Now, strain gages can be of different types commonly we can define such strain gages into 7 different categories; the first one is the unbounded metal wire gages, just a one that we have seen there.

Here, we you can use wires of copper, nickel or chromium nickel or maybe nickel iron wires typically having a 0.03 (Refer Time:61:23) 2.04 millimeter diameter full scale output voltage typically varies in the range of 20 to 50 mille volt and it can sustain a maximum force of only about 2 mille Newton's. these are the kinds of instruments which are used in experimental stress analysis of machines or structures. These are unbounded and other variation of the same is the bounded one, where fine wire grade is cemented on the specimen surface ever making it a permanent fixture or permanent part of the element. Unbounded bonds are fixed are fixed with flexibility kind of arrangement whereas, the bounded ones are permanently cemented there.

So, it can perfectly follow both tensile and compressive loads and they are typically used in stress analysis just like the unbounded one and also part of the transducers, then we can have bounded metal foil gages. The bonded metal wire gages have now, mostly been replaced by this bonded metal foil gages here, the sensing elements are formed from sheets less than 5 microns thickness by photo etching process. there by you can have much greater flexibility and control over the shape of the gage that we want depending on the nature of the surface of the contour of the surface, where you want to have the measurement.

We can have different shapes for these gages., the bounded metal foil gages are mounted on flexible insulating carrier flame of very small thickness of in the range of a few microns, but their parameters levels are very similar to the wire gages and again that is why they are generally very popular for as, the first level solution as for homemade transducers or several other instruments also. All these three can have gage factors in the range of this 2 to 4 that we have mentioned these are the typical structure like wire gage, wire type, where we have the wire which or placed like this.

Whereas, in case of foil type, it is by photo etching kind of procedure, it is just drawn on the surface itself like shown here, only the two lids which comes out from the surface.

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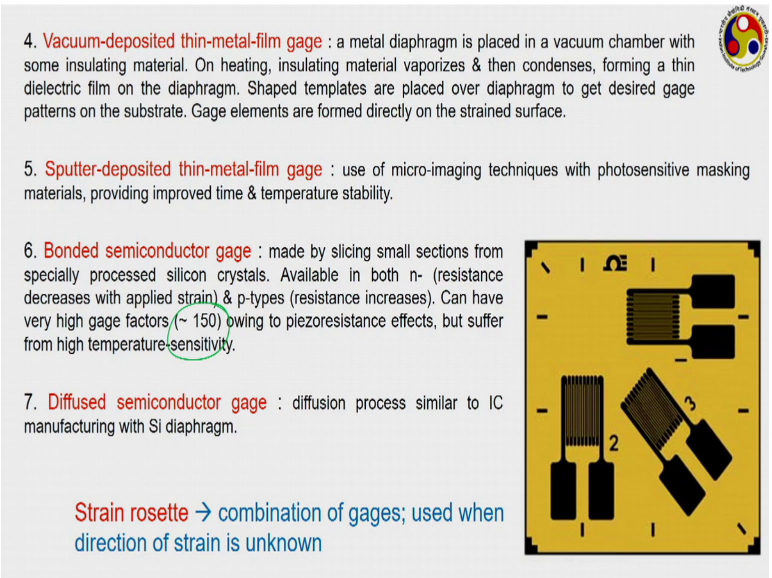

Then we can have thin metal frame gages. Thin metal frame gages can be of two types either vacuum deposited or sputter deposited. In case of vacuum deposited metal diaphragm is placed in a vacuum chamber with some insulating material. Now, once we supply the heat, the insulting material first evaporates and they on removal of heat that condenses thereby forming a very thin flame of dielectric on the diaphragm, then we use shaped templates to get gages of desired shape and the gage elements are then directly deposited on the strain surfaces.

They can be very accurate though they are parameter level can be typical to the wire gages or the metal foil gages. The sputter deposited thin film gage are the improvement of the vacuum deposition wire use the IC manufacturing technology and micro imaging techniques with photosensitive masking materials. They can provide excellent time sustainability and also temperature stability. The biggest problem with any kind of strain gage is a change in resistance with the temperature. Therefore, this temperature stability is very important.

And some of these metal film gages have much better temperature stability compared to the wire gages and the final two categories relate to the semiconductor gages. We can have the bounded semiconductor gages were, small semiconducting materials like silicons are processed into small sections. We can have both n and p type versions. In case of p type versions, a resistance keeps on increasing on application of strain whereas, the resistance decreases in case of n type versions they can have very high sensitivity, and they can give very-very high gage factors compared to the metal fin gages oe, the wire gages it can be even in the range of this 150, which is extremely high compared to the metal wire gages; however, they are they are very sensitive to the temperatures as well with small change in temperature.

Their resistivity can change very-very significantly thereby, causing large era in the instruments. The other version, a very new variation you can say is the diffused semiconductor gage, where the IC manufacturing technologies are used rather than slicing semiconductor material into small sections but their working principle and their character parameters or characteristics all remain similar to the bounded semiconductor gages.

So, you can say there are three broad category of gages; one is the metal wire or metal foil gages, second we can have thin metal film gages and third the newer addition, the semiconductor gages, but practically one type of gage may not be sufficient or just 1 gage may not be sufficient in a particular instrument, specifically when we do not know the direction of the strain application.

Therefore, then we go for this strain rosette like one example shown here, where there are three gages have been combined into one structure. They are 45 degree apart and therefore, depending on the direction of strain, one of the gages can be applicable and one of the gages can give much improved results. similarly several other rosette structure can also be found you can search on net about the pictures of different rosette structures about this.

So, that is it for the resistive semiconductor gages or I should say the resistive strain gages, the main idea is to know the operating principles without go into detail of different categories and I hope you have been able to understand the operating principle of potentiometer and strain gages. If and if you have any further questions on any of them, please write back to me.

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So, today we have talked about the displacement measurement. You started with the unit of that we talked about the gage blocks, which are the industrial standards, then we have learned about two instruments both based upon the change of resistance to displacement; one is a potentiometer, other is the strain gage. So, that is it for the day.

In the next lecture we shall be talking about the other kind of electromechanical transducers used for displacement measurement like the induction based instruments or capacitance, capacitance based instruments and maybe a few other kinds of transducers also. So, thank, you have a nice day and let us see you very soon.