Experimental Stress Analysis - An Overview
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Lecture - 2.5
Overview of Strain Gauge Measurements

Let us continue our discussion on overview of Experimental Stress Analysis.

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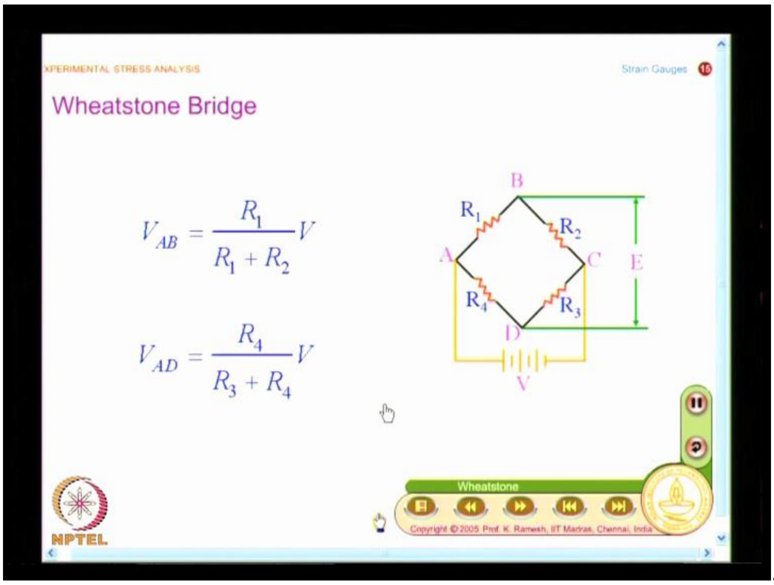

How do you measure the change in resistance? And, in your high school physics, you would have seen about use of Wheatstone bridge; it is a very popular and simple yet robust method of measuring small changes in the resistance. And, what you have here? I have 4 arms of the bridge; I have arm AB, BC, CD and DA. And, what I do is I supply voltage between the points A and C and I measure what is the potential difference in points B and D; that is what I measure. And, in your earlier class, you would have also seen how to find out the voltage AB and voltage AD, and these are given as these expressions. But, our focus is different.

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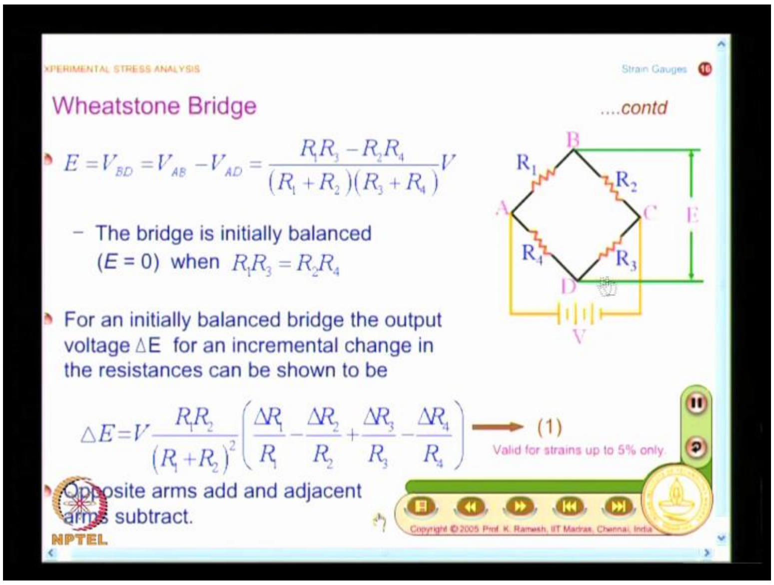

Our focus is what happens when the resistance changes slightly. And, whenever I do any instrumentation, I initially balance the bridge; and, while balancing the bridge, I essentially make E equal to 0, that is, V BD equal to 0; that gives me an expression V BD as R 1 R 3 minus R 2 R 4 divided by R 1 plus R 2 into R 3 plus R 4 into V. When I make E equal to 0, this gives me a condition R 1 R 3 should be equal to R 2 R 4. So, when I construct a Wheatstone bridge, I need to maintain this relationship.

What should be the individual values of R 1, R 3, R 2 and R 4, which would give me an optimal response at the Wheatstone bridge? I would like to have an optimal response, because I am measuring very small quantity. So, I must also look for every single effort to maximize the signal. And, if I have to maximize the signal, I should understand how a Wheatstone bridge functions, and I should also bring in my understanding of solid mechanics in strain gauge instrumentation.

So, the first condition shows when the bridge is initially balanced, I get interrelationship between the resistances. We will see further what way R 1, R 3, R 2, R 4 should be, by looking at the performance of the bridge. What we have seen when I put a strain gauge as one of the arms, under the application of the load the resistance of the strain gauge will change slightly. And, what you have here? The expression is suppose I have four strain gauges connected and each one is measuring the respective strain, there would be changes in R 1, R 2, R 3, R 4, which would be measured as delta E. And, you have this expression as delta E equal to V into R 1 R 2 divided by R 1 plus R 2 square delta R 1 by R 1 minus delta R 2 by R 2 plus delta R 3 by R 3 minus delta R 4 by R 4. what you will have to keep in mind here is I have labeled it in a cyclically fashion – R 1, R 2, R 3, R 4. This sequence has to be maintained in this expression also.

And, what I find here? Mathematically, I see a minus sign and plus sign. But, how we will look at is R 1 and R 2 are adjacent arms; and, I have a minus sign in between. What way we will look at is similar strains and adjacent arms cancel each other. So, this is one of the principles used when I want to remove the thermal influence. And, what you find? R 1 and R 3, they are opposite arms; opposite arms add each other. That is how we look at this expression from solid mechanics point of you. And, this if you want to maximize, I can make this minus to positive. If I have opposite strains on adjacent terms, I can make this quantity equal to 4.

So, that way I will amplify my signal. So, the idea is you are measuring very small quantity and we should always look for ways to increase the signal output. This is also one of the requirements. Particularly in transducer design, they would have this bridge factor as 4.

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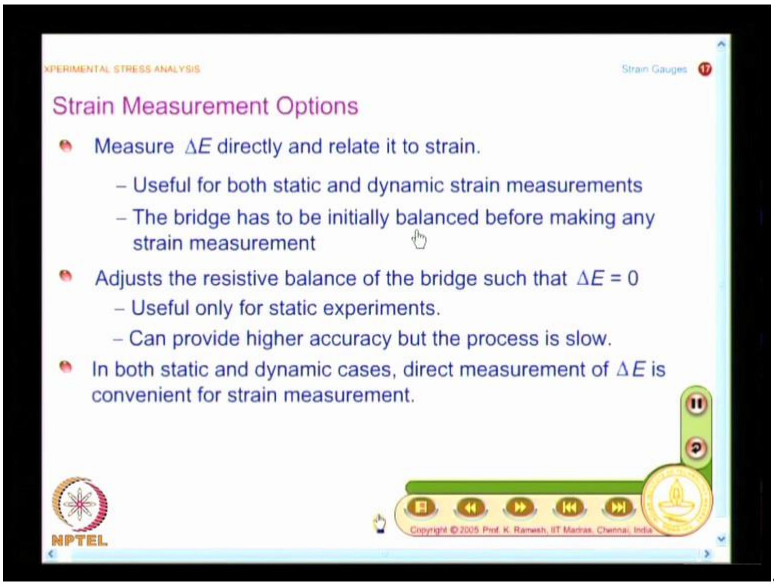

So, now, we will look at the performance of the bridge. So, before we go into that, we look at what are the strain measurement options and then we will go and optimize the bridge. What way we can do? I can measure the change in EMF directly and relate it to strain. And, this is useful for both static and dynamic strain measurements; absolutely no difficulty. But, for me to do that, the bridge has to be initially balanced before making any strain measurement. So, this is very important. So, initial balance of the bridge is a very important criterion. And, this becomes very significant when I have thousands of channels; you know I must have electronics and multiplexing type of situation, where I am able to balance and then start doing a measurement. So, that is where the instrumentation is now focusing on.

The other approach is adjust the resistive balance of the bridge such that delta equal to 0; but, it is slow; it will take some finite time for you to do. This is good for static experiments, but it can provide higher accuracy. Nevertheless for both static and dynamic cases, direct measurement of delta is convenient from practical view point. And, that is what we will try to do.

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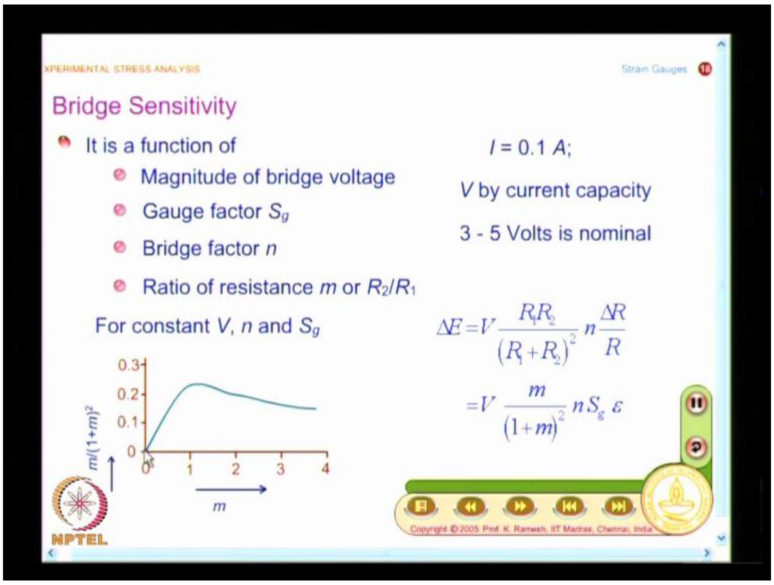

So, now, we will go and look at how I can improve the signal from my Wheatstone bridge. So, I have the bridge sensitivity. It is a function of magnitude of bridge voltage, gauge factor S g, bridge factor n and the ratio of resistance R 2 by R 1. See what we want to look at is your initially balance only gave me condition between the resistance. Now, I will find out for maximum sensitivity, what should be the value of the ratio R 2 by R 1. And, we write this expression delta E in a much convenient fashion. I have this as V into R 1 R 2 divided by R 1 plus R 2 square. And, the long expression is replaced by n, which I call it as a bridge factor. And, you are essentially measuring delta R by R. And, delta R by R can be replaced by S g into epsilon. So, if I have to maximize my delta E, one can also say I will have a very large value of S g.

This is one of the focuses in semiconductor gauges. But, if I want to measure strain both in elastic and plastic regions without altering the instrumentation, we have seen it is desirable that gauge factor is around 2. So, most of the problems whatever the strain gauge that you have, you will find the gauge factor is around 2, 2.1; that is how you will have it. And so, we will not have much change in the value of S g when you are using the metal foil strain gauges.

I can play with maximizing m by 1 plus m square and n. And, I can also look at what way I can change a voltage. So, you should know the relative parameters that we can modify to improve the bridge sensitivity. And, if you look at, the current capacity is very small; we are only sending 0.1 Ampere; and then, the voltage that you are going to energize the bridge is only between 3 to 5 volts. You are not supplying a very high voltage. So, it is a very small voltage. So, now, what I will have to do is, with these constraints, I must maximize this term m by 1 plus m whole square. So, if I look at its variation, how does it appear?

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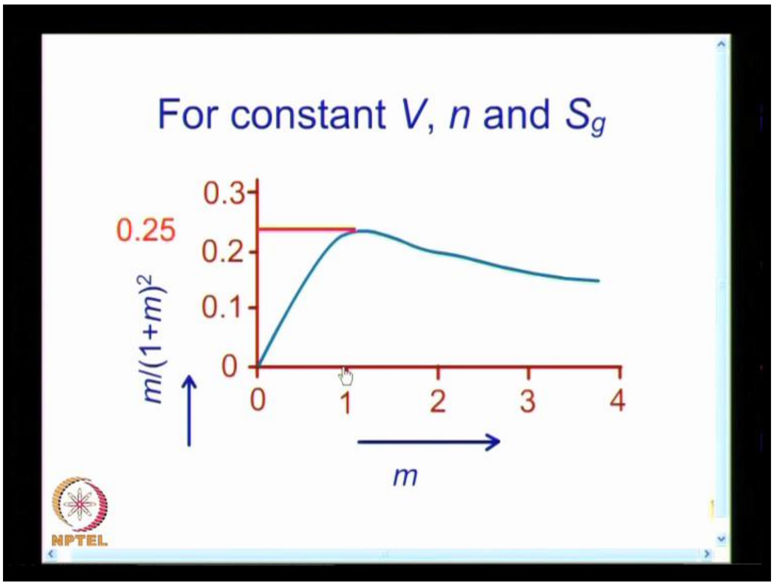

So, what I have here is for constant voltage and bridge factor n and the gauge factor S g, you find the ratio m by 1 plus m whole square reaches the value of 0.25 when m equal to 1. So, what does it translate to? You want four arms of the bridge to have equal magnitude of resistances. So, that is how we will construct a Wheatstone bridge. And, we also have configuration, where I will just use only one strain gauge or I use two strain gauges or I use four strain gauges. That is how I will make the bridge depending on the requirement. So, when I do that, I will be essentially playing with the factor n. So, if we want to have a better sensitivity for the bridge, ensure that each arm of the bridge has same resistance to start with.

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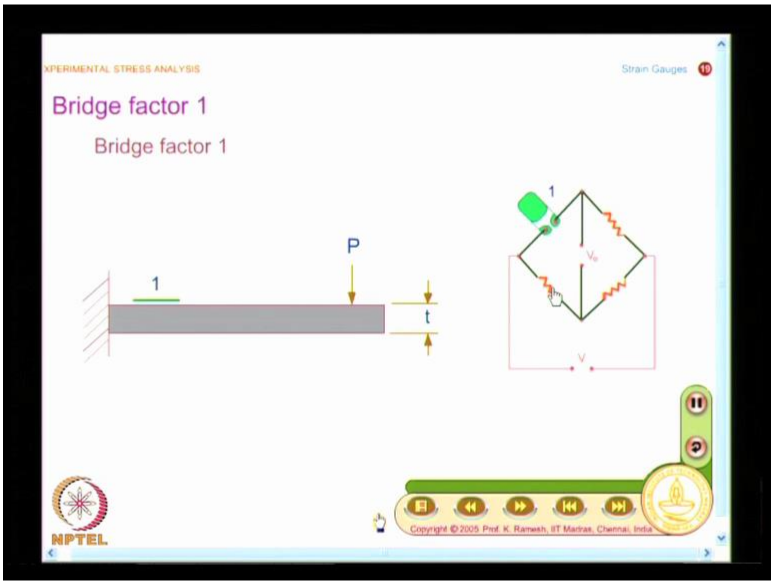

Now, we will look at what is a bridge factor. It is a very simple one. I have a single strain gauge connected; and when I do this, only one arm of the bridge is connected to the strain gauge. And, from our earlier understanding, what these resistances should be? They should be equal to the strain gauge resistance; never forget that, because you know you may have a strain gauge meter, which has a provision to connect default 120 ohms or 350 ohms. Maybe with the modern development, you may also have selection for 500 ohms or 1000 ohms. If the bridge is configured for a particular strain gauge, you must ensure that you put the balance resistance equal to the strain gauge resistance. You should not miss this fact. Then, your calibration everything will not match for the strain meter.

And, another caution is connecting only one strain gauge poses lot of difficulties; it is better to avoid a quarter bridge configurations from minimizing the role of thermal influence. See you will have to look at each aspect; each aspect has to be looked at very closely and find out how you can improve the sensitivity, what are the kinds of errors that come. So, that understanding is very much needed. When I have only one strain gauge, what happens? The bridge factor is only one. And, this is good enough for strain measurement.

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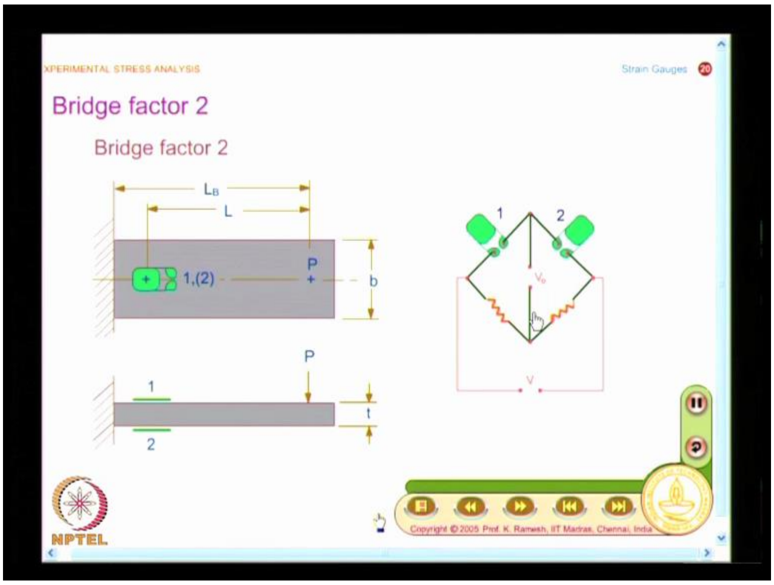

But, when I go for transducer application, I always go for a full bridge for me to find out the maximum signal. And, here I have it for a bridge factor 2. And, you bring in your understanding of solid mechanics here. What is done here? Suppose I connect strain gauges on the top surface and bottom surface to opposite arms, what would happen? For any load, I will have zero strain. You should not think that my strain meter has gone bad; it is not so. It is how you have connected the strain gauge to the Wheatstone bridge. It is also equally important. See, in strain gauge instrumentation, how do you pace the strain gauge, how they are connected in a Wheatstone bridge; both are important.

See, in most of the strain measurements scenario, what do you do? You desire that, this is the critical location; so, I invariably put one single strain gauge and connect it to my Wheatstone bridge. You may essentially use a quarter bridges. Only in situations where the signal is so low, you want to amplify; you may find out methodologies to amplify the signal.

And, suppose one such application, you have put two strain gauges on the top of the cantilever and bottom of the cantilever; you know from solid mechanics for the kind of loading that is applied, the top fiber is subjected to tension and bottom fiber is subjected to compression and you connect them appropriately on the Wheatstone bridge. So, here the focus is more on amplifying the strain signal. And, this also has an advantage that, whatever the thermal induced apparent strain in this gauge is canceled by the thermal strain introduced in this gauge. So, you have better thermal management when you have a half bridge. But, you may not be able to use half bridge in many of your applications. In transducer application, yes; in strain measurement application, it may not happen. So, you will have to find out what application you are looking at and how you can manage the thermal influence.

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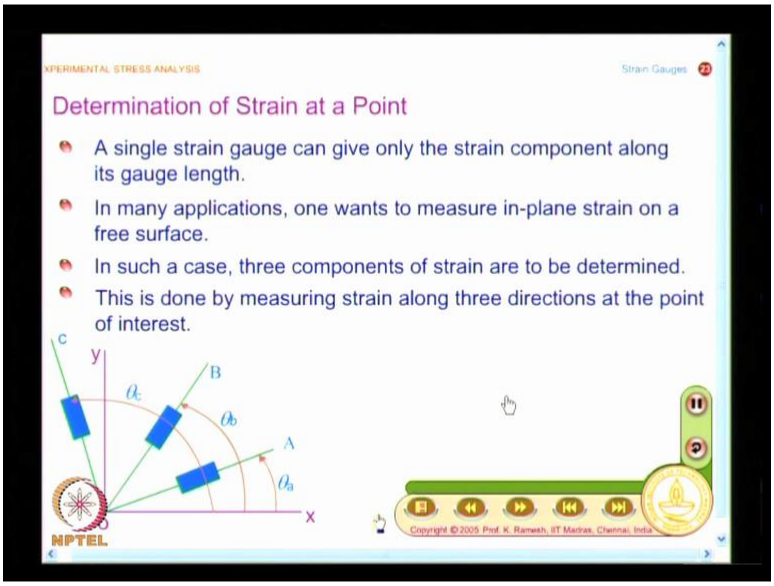

So, we want to find out in plane strain and I need three components of strains to be determined. And now, here only you look at strain is a tensor of rank 2 and you bring in the tensorial transformation law. So, what I have? I need to find out three components of strain. So, I need to have three strain gauges oriented at angles A – theta a, theta b and theta c. And, you have to bring back your old memories; how do you write strain along a given direction in terms of the tensorial components. And, that is a very famous expression that you have. You can take a minute to recall that expression and try to write.

See strain tensor and stress tensor share commonality. The Tensorial transformation law is similar. And, if you know how to write this transformation law, your Rosette analysis becomes child’s play; it no longer Greek and Latin because there the angles are wellknown. You are not taking arbitrary angles, you take certain fixed angles. So, finding out how to get the strain at a point using a Rosette becomes very simple if you know the strain transformation law. I think some of you have written it.

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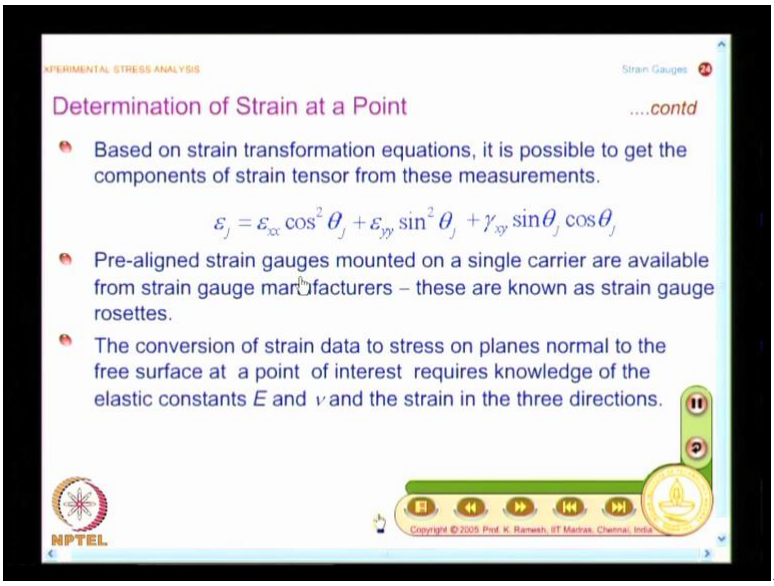

And, the strain transformation law is very simple. That is what you have here. I can write it as epsilon j equal to epsilon x x cos square theta j plus epsilon y y sin square theta j plus gamma x y sin theta j cos theta j. I have written the engineering shear-strain component. If you write it in terms of tensorial components, it is epsilon x y divided by 2. And, when I go to different rosettes, the theta j will change; that is all the difference. So, what I do? I get strain from this expression. And, if I use the elastic constants, I can also get the stress information.

And, the theta measurement becomes very critical. That is a reason why you have pre-aligned strain gauges. They are mounted on a single carrier and they are called by a special name called rosettes. And, you need these strain gauge rosettes for finding out the strain tensor at a point of interest. The greatest advantage is they are pre-aligned; and because you are having a metal foil, it is easy to do this very precisely. And, I have always been saying – the basic information given by experimental techniques is dictated by the physics that we exploit. So, in a strain gauge, you essentially employee change of stress modifies the resistance of the conductor.

And, I essentially measure a component of strain. Once I measure the component of strain, if i know the elastic constants of the base material, it is possible for me to find out the stress on the specimen by invoking equations from mechanics of solids.

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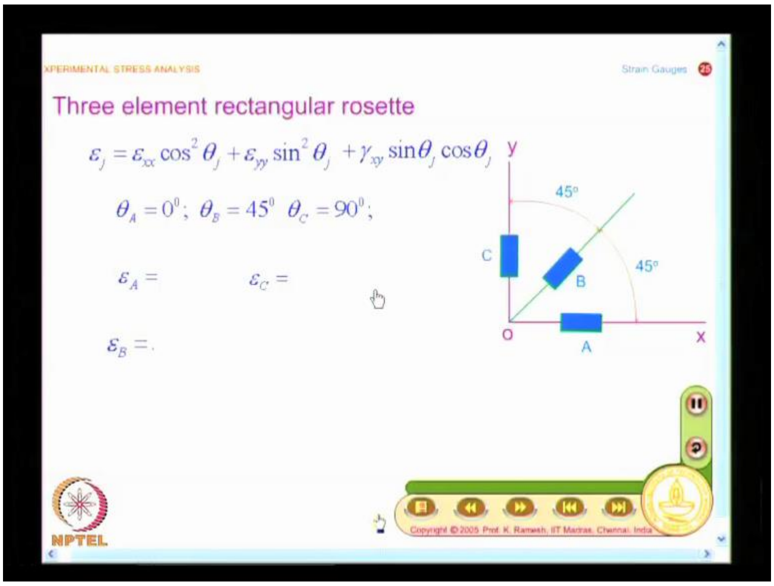

And, let us see two famous configurations of the rosettes. And, one of the rosettes is called a rectangular rosette. It is primarily because I have a strain gauge along the x-axis and the second strain gauge at 45 degrees and the third strain gauge is along the y-axis. So, what is the strain measured by the strain gauge A? If I have this as my reference axis, I could simply say it is equivalent to epsilon x. And, strain measured by the strain gauge C is epsilon y. So, now, you use this strain transformation law and find out what is the shear strain.

So, I will have epsilon A, epsilon B, epsilon C measured from the actual strain gauge. Use it and find out what is the state of strain at a point. Then, we moved on to how to measure the change of resistance. We said Wheatstone bridge is the most celebrated type of measuring approach. Then, we looked at what is the accuracy achievable in strain gauge instrumentation. And finally, we had a brief discussion on how do you find out state of strain at a point. And, we have also seen what a rosette is. And, as an exercise, I would like you to get the shear strain in the rectangular rosette, which we have seen.

Thank you.