Experimental Stress Analysis

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Module No. # 05
Lecture No. # 32
Strain Sensitivity of a Strain Gauge, Bridge Sensitivity, Rosettes

We have started our discussion on the method of strain gauges and we looked at, to measure strain at a point; you do not have a material which has a very high resistance so that I can take a small spec of material, and then, find out what is the strain at a point of interest. I need to have a minimum length of wire for me to give changes that could be measured and when I have a long wire, I cannot paste it on the specimen and make the strain measurement; I have to necessarily make it as the loop, make it as a grid, and then only make a strain measurement and I also cautioned, a single strain gauge provides you only a component of strain along its gauge length.

If you have to measure strain as a tensor, suppose I want to do it on a free surface, I need to find out three independent quantities, so I need at least three strain gauges for me to measure state of strain at a point. So you need to understand these two differences. And in the last class, we had developed what is the strain sensitivity of a single conductor. The idea of that discussion was to understand the role of various parameters. I also mentioned in strain gauge instrumentation, any effect due to thermal influence need to be looked at very carefully and we are measuring very small quantities, so any small changes also can have a significant effect.

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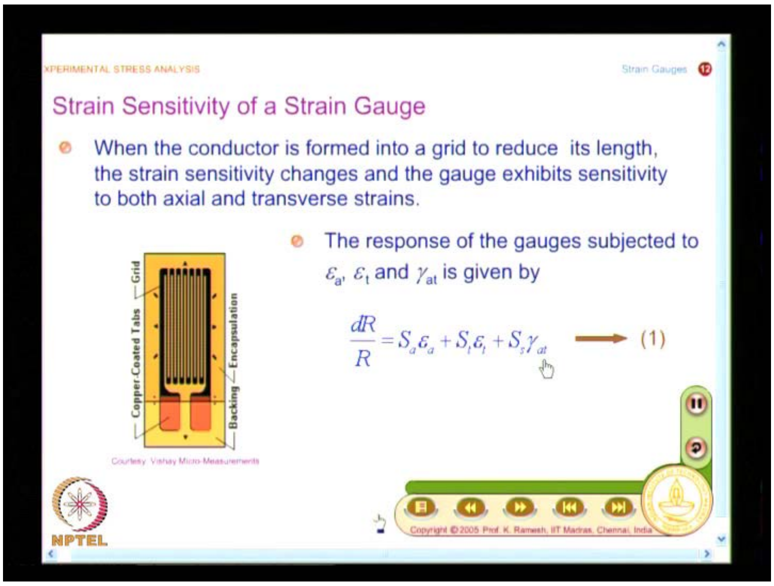

So, now, we look at what is the strain sensitivity of a strain gauge. Because we have looked at, the conductor is formed into a grid to reduce its length, the strain sensitivity changes. Because it is now made into a grid, the gauge exhibits sensitivity to both axial and transverse strains.

And let us look at closely what the strain gauges. You know I have a metal foil gauge shown here, because it is made of a metal foil, I have the luxury when I make a loop, I make this n loop as thick and I had set earlier that when you have this n loop as thick, the reason we why we do this is to reduce its sensitivity to transverse tree. By making the loop wider, we reduce the resistance, so its sensitivity to transverse strain will be minimum and when you look at the strain gauge like this, you have markings like this; these are needed for aligning the strain gauge at the point of interest.

And you also find that there is a backing, the metal foil supported by a backing and you have very large copper coated tabs for soldering and you also find in this strain gauge, you also have a encapsulation; this is needed in certain applications, where the environment has a negative role to play.

You need to protect the gauge from the influence of environment and this provides you one type of improvement over normal strain gauges, there are also other methods. And the advantage of a metal foil is, I can make the metal foil as thin as possible so that I can increase the resistance You have also seen strain gauges are available at 120 ohms, 350 ohms and so on.

So, when you want to go for higher values of resistances, you can do only comfortably in a metal foil gauge; you have a provision to do that. And as engineers, we need to bring in approximations, first observation is, whatever the resistance change dR by R, will now be a function of the axial strain, function of the transverse strain as well as a shear strain.

You know in many problems what we have seen? We will first neglect the sheer effects, because we will always say sheer effect is there, but its influence is quite small. So as a first approximation, let us neglect it and proceed, you will follow the same root here also. In general, dR by R is equal to S a into epsilon a plus S t into epsilon t plus S s into gamma a t and note the way the subscripts are denoted here, I use the small letter a; so the moment I use this, I am talking of a strain gauge and not a conductor. For the conductor, the axial sensitivity is given as S suffix capital A; when I take it as a grid, the axial sensitivity is given as S a, but even this kind of expression is not convenient for users.

Users want a very simple representation of change of resistance to the strain; not only this, many users may not even know how the strain gauge optimization really calculates, they would only see the strain reading, because the instrumentation is so well developed and you connect the strain gauge, you will look at the strain reading, it is all done by the electronics and this is where people mistake that anybody can do and perform an experiment.

And I cautioned, when you are doing a strain measurement, you are talking of micro strain which is 10 power minus 6 and you will also have to measure the change in resistance, which is again 10 power minus 6, it is a very small quantity; first if you recognize this fact, it will go a long way in respecting the procedures given by the manufacturer.

Because many times you do not want to follow a procedure, you want to quickly go and make a measurement that would not do when you want to do strain gauge instrumentation.

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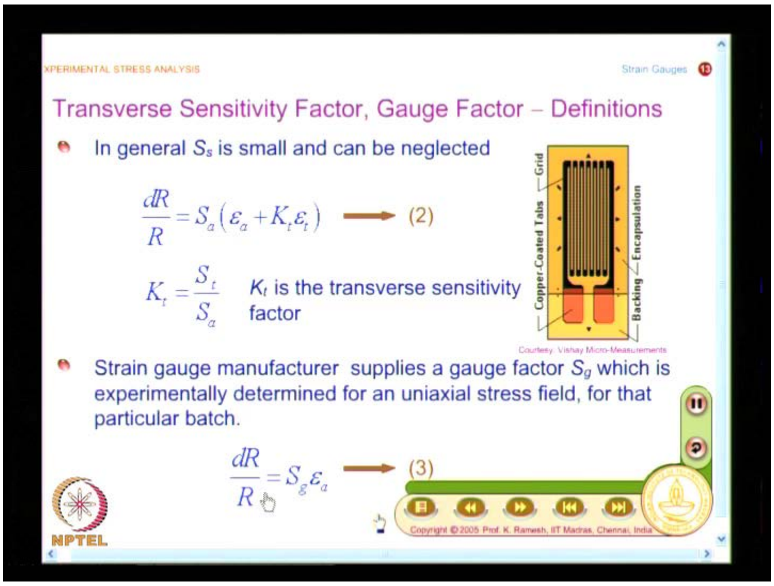

You should know, what is the constrain that you have and now we look at how we simplify the set of expressions. And I said earlier, we will start with the first approximation, that sheer effects are neglected, so S s is small and can be neglected. And we have also done one more modification, we have taken out S a from this and brought in another factor which is called K t, which is defined as S t by S a, this is just out of convenience and what you find here is, the change in the systems to be resistance of the gauge is now equal to S a into epsilon a plus K t epsilon t.

In fact, if you go and look at carefully the specification given by the strain gauge manufacturer, he would provide you what is known as a gauge factor; he will also provide you with the transverse sensitivity factor that is how manufacturers give out their parameters defining the strain gauge and that is where you have what is defined as K t. And typically, we want to keep K t as small as possible while defining the grid and we will also see later by making K t almost equal to the Poisson ratio of the base material, you can have what is known as a stress gauge. See, we already looked at strain gauge, why you call that a strain gauge? Because it primarily gives you strain and when you say stress analysis, there are also occasions where I want to directly get the stress.

So, people looked at, can't we not make a stress gauge so that whatever the electrical signal that I record is proportional to stress measurement. So, there you play with a transverse sensitivity, you want to make it very high. In this case, in a general strain gauge, we would like to have the grid to measure strain primarily along the gauge length that makes our life simple.

So, you have a definition of what is the transverse sensitivity factor and as I said, the user wants to have a much simpler expression and the strain gauge manufacturer supplies what is known as the gauge factor, which is given as S g, and what you have is, you have dR by R is equal to S g into epsilon a and what does the manufacturer do? He performs an experiment and determines what is the value of S g.

Our focus is, we want to find out the component of strain along the gauge length. Suppose I call that as epsilon a, now I have a very simple expression, where change in resistance to original resistance is related by a factor S g to the linear strain. And we have to look at what is the inter relationship between S g and S a. This S a, S t, S s comes directly from our understanding, that we take a conductor, and then, perform an experiment, pull it, and then, determine the strain sensitivity. Now, you adapt the same thing for a grid, the grid is sensitive to axial, transverse as well as shear; so you bring in three factors. But from user point of view, he does not want to look at all these quantities, he wants a much simpler expression and that is also given by the manufacturer, where he simply says dR by R equal to S g into epsilon a and once you have to use this expression, you should know what are the constraints behind it.

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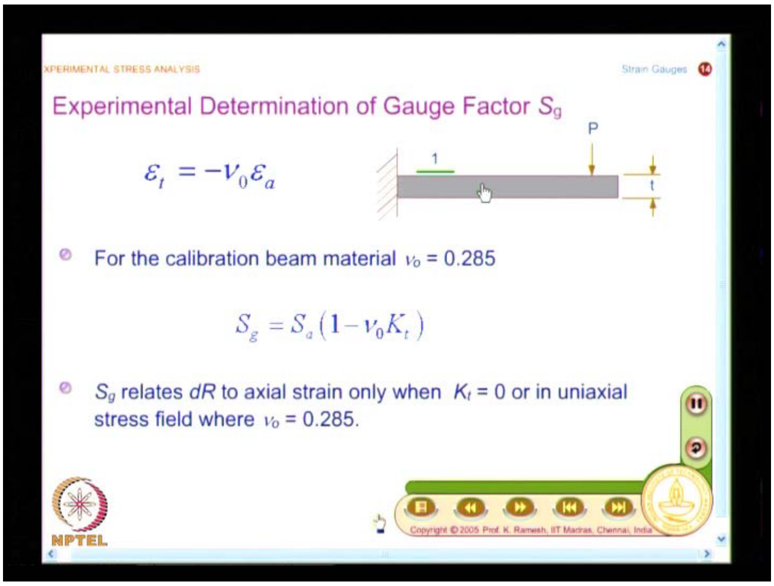

Because I have been saying, Poisson's ratio has a role to play in all the experimental technique and what does the manufacturer do? He takes a cantilever, puts the strain gauge and for a given load or a set of loads, he would find out the strain from the analytical solutions, he would be able to correlate and establish the parameters. When you do an experiment like this, Poisson ratio of the calibration material comes into plane.

Because I have always said, a cantilever beam experiences uniaxial stress, but biaxial strain; you should never forget that and the transverse strain is controlled by the Poisson's ratio. So, without your knowledge, Poisson's ratio enters into your strain gauge instrumentation; it is very important. If you only use the equipment and read the strain, you miss out how the whole technology has developed; you should know the theory behind it. And since I know the axial strain, I can find out the transverse strain simply as epsilon t equal to minus nu naught epsilon a, and for the calibration beam material nu naught is given as 0.285 and you get an expression for S g as a function of axial sensitivity and transverse sensitivity factor.

So, I have S g equal to S a in to 1 minus nu naught a, so what does this signify? Only if you conduct an experiment on a specimen material which has the same Poisson ratio, your expression dR by R equal to S g in to epsilon a is a valid expression; for all other cases, the mismatch of Poisson ratio will influence in some fashion. I had also raised this when we discuss brittle coatings, one of the suggestions I said was, the interplay of Poisson ratio was quite involved.

So, the recommendation is, if I have to do it on a prototype which I am going to do it repeatedly, it is better to take the prototype material, make a calibration specimen and evaluate the failure strain in the case of bridle coating; on similar lines, do the similar exercise and find out S g. What you should remember is S g is experimentally calculated by the manufacture, it is not a theoretical quantity.

And Poisson ratio mismatch can affect all your strain gauge instrumentation; you should never forget that. And again, I want to emphasis in all the coating techniques, you use calibration specimen, you use cantilever beam and in the case of photoelastic coating, you determine the K; in the case of bridle coating, you determine epsilon D; in the case of strain gauge, you do not do the experiment, the manufacturer supplies you. Because he supplies you S g, and then, you will make your life simple and you follow his recommendation in bonding the strain gauge and directly use S g for all your strain gauge instrumentation.

Because normally you do not perform on experiment and determination, because he finds it out for a batch and its reasonably a value which does not change like what you had seen in the case of a polymers, which change their property slowly, so it is mandatory that you perform your own experiment.

So, from batch to batch, the value of S g conveyed; you should know that. So, if I have a transverse sensitivity 0, a very ideal strain gauge, then I have no problem; I can have S g, I will have from this expression S g is directly related to S a when K t is 0, but K t will have some value which is very small. But in critical applications, you may also have to correct for the transverse sensitivity effects; we will also see how we account for transverse sensitivity error later.

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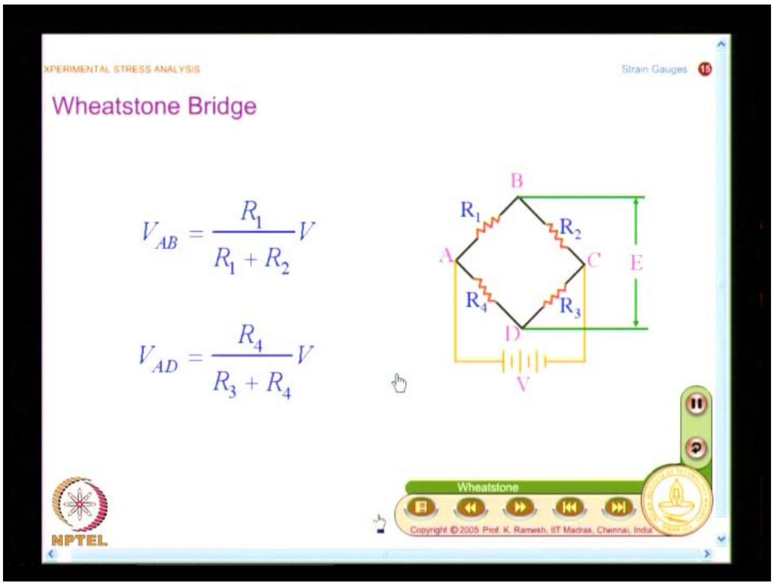

And I have been saying that, you need to measure very small quantities and how do you measure the change in resistance? And in your high school physics, you would have seen about use of this stone bridge, it is a very popular and simple yet robust method of measuring small changes in the resistance and what you have here? I have 4 arms of the bridge; I have arm A B, B C, C D and D A 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 A B and voltage A D and these are given as this expression, but our focus is different.

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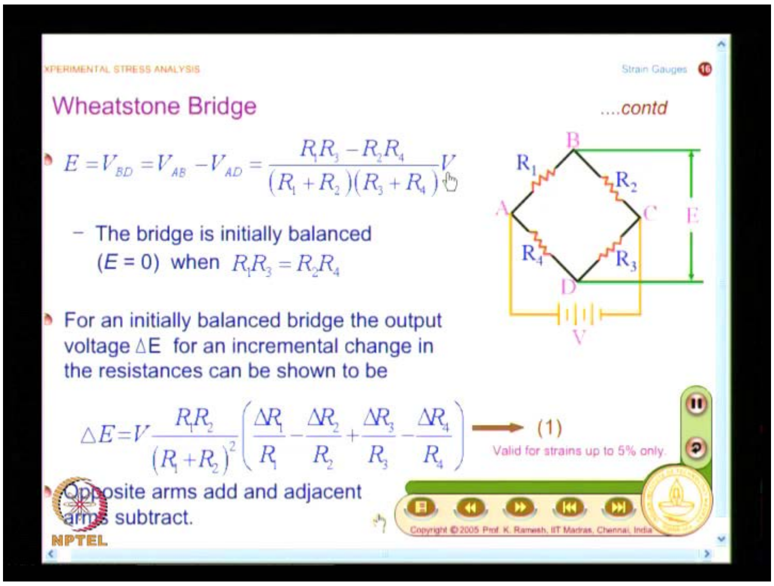

Our focus is, what happens when the resistance changes slightly and whenever I do any instrumentation, I initially balance the bridge and while balancing the bridge, I essentially make E equal to 0, that is, V B D equal to 0 that gives be an expression V B D as R 1 R 3 minus R 2 R 4 divided by R 1 plus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

What should be the individual values of R 1 R 3, R 2 R 4, which would give me an optimal response of 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 my solid mechanics in strain gauge instrumentation.

So, the first condition shows when the bridge is initially balanced, I get a interrelationship between the resistances you 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 and other 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 squared 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 we will have to keep in mind here is, I have labeled it in a cyclical 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 in 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 view. And this if you want to maximize, I can make this minus two 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 requirement. Particularly in transducer design, they would have this bridge factor as 4.

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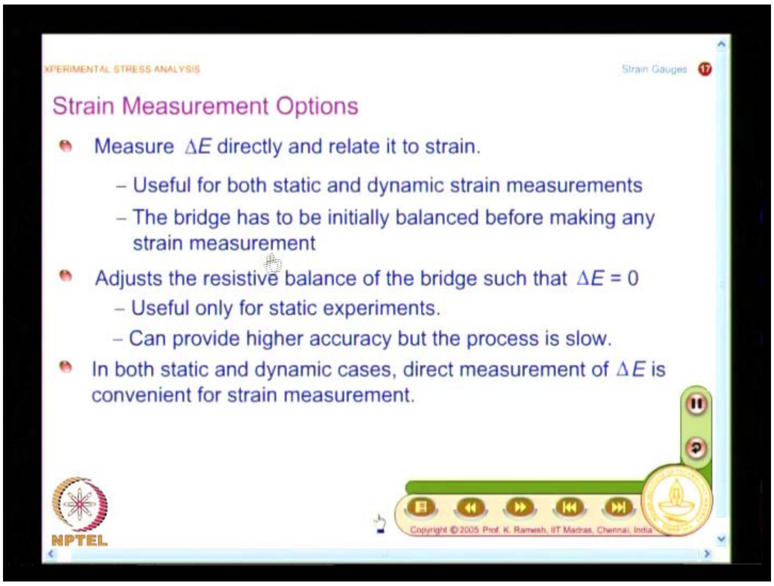

Now, we will look at the performance of the bridge. So, before we go into that, we look at, what are the strain measurement options, and then, we will go and optimize the bridge; what way we can do? I can measure the change in EMF directly and related it to strain and this is useful for both static and 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 criteria and this becomes very significant when I have 1000’s of channels. You know, I must have a electronics and multiplexing type of situation, where I am able to balance, and then, start doing my 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, direst measurement of delta is convenient from practical view point and that is what we will write to do. So, now, we will go and look at, how I can improve the signal from my Wheatstone bridge.

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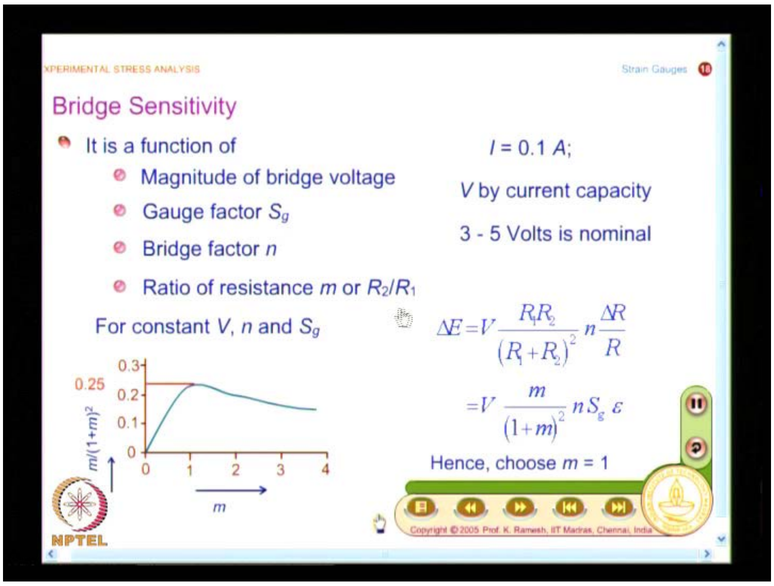

So, I have the bridge sensitivity, it is the function of magnitude of bridge voltage, gauge factor S g, bridge factor n and the ratio of resistance R 2 by R 1. See, what we want to look at is, your initial balance only gave me a condition between the resistances; now I will find out for maximum sensitivity 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 replace S g into epsilon.

So, if I have to maximize my delta E, one can also say I will also have a very large value of S g, this is one of the focuses in semi-conductor 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 the 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 we 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.

Now, what I will have to do is, with these constrains, I must maximize this term m by 1 plus m whole squared. So, if I look at its variation, how does it appear? (Refer Slide Time: 27:34) 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 4 arms of the bridge to have equal magnitude of resistances. So, that is how we will construct the 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 you want to have a better sensitivity for the bridge, ensure that each arm of the bridge has same resistance to start with them.

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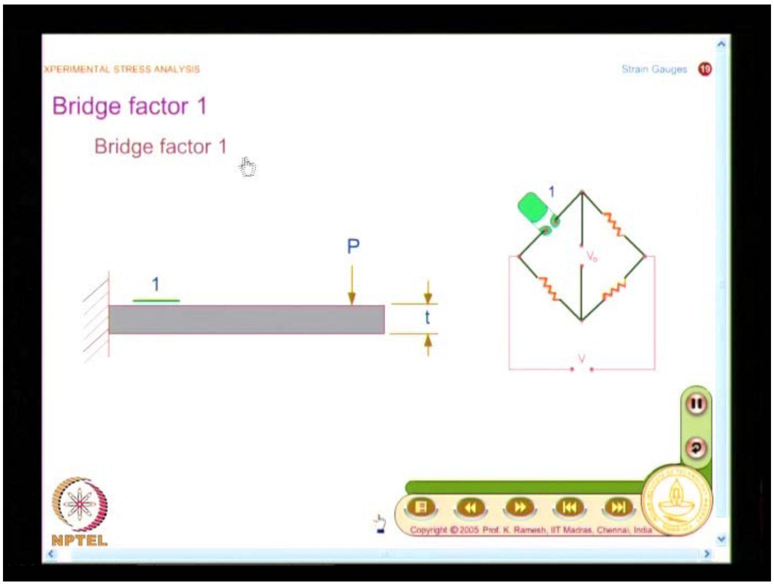

Now, we look at what is the bridge factor. It is a very simple one; I have a single strain gauge connected and when I do this, only one arm of the bridge is connected to the strain gauge and from our earlier understanding what these resistances should be? They should be equal to the strain gauge resistance, never forget that. Because you know, you may have a strain gauge meter, which has the provision to connect default 120 ohms or 350 ohms, may be with a modern development you may also have selection for 500 ohms and 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, we will also have a discussion later connecting only one strain gauge possess lot of difficulties. So, it is better to avoid a quarter bridge configurations from minimizing the role of thermal impedance; we will see that in detail later. And there is also a via media, if I have to use only a quarter bridge, how do I reduce the errors? We will look at a two wire circuit and the three wire circuit; a three wire circuit will minimize the thermal influence significantly.

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 kind of errors that come, 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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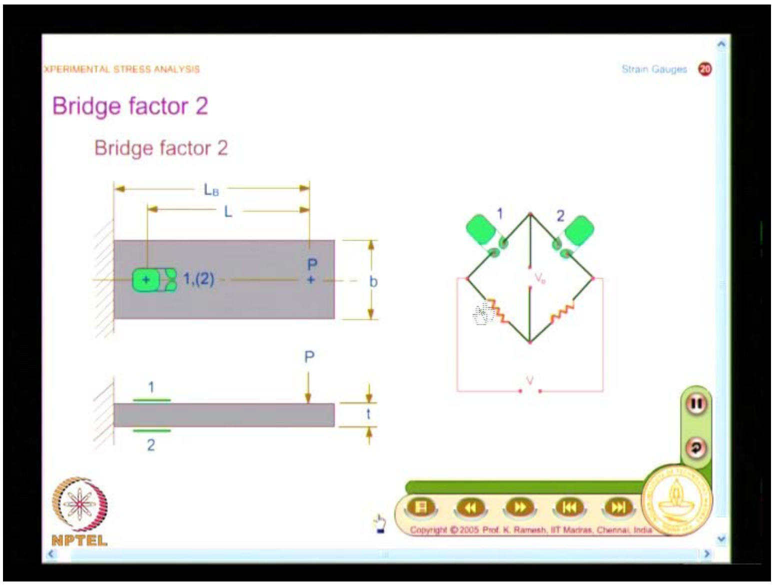

But when I go for transducer application, I always go for a full bridge for me to find out the maximum signal and here, I have it for a bridge factor 2 and you bring in your understanding of solid mechanics here, what is done here? Suppose I connect strain gauges on the top surface and bottom surface to opposite arms what would happen? For any load, I will have 0 strains; you should not think that my strain meter as 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 you paste the strain gauge, how they are connected in a Wheatstone bridge, both are important.

See, in most of the strain in a measurement scenario what you do you? You decide that this is the critical location, so I invariably put a one single strain gauge and connect it to my Wheatstone bridge, you may essentially use a quarter bridge. Only in situations, where the signal is so low, you want to amplify, you may find out methodologies to amplify the signal and suppose once such application, you 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 cancelled by the thermal strain introduced in this gauge. So, you have a 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, how you can manage the thermal influence. And suppose I want to use bridge factor as 4 with same cantilever, how can I go and do it?

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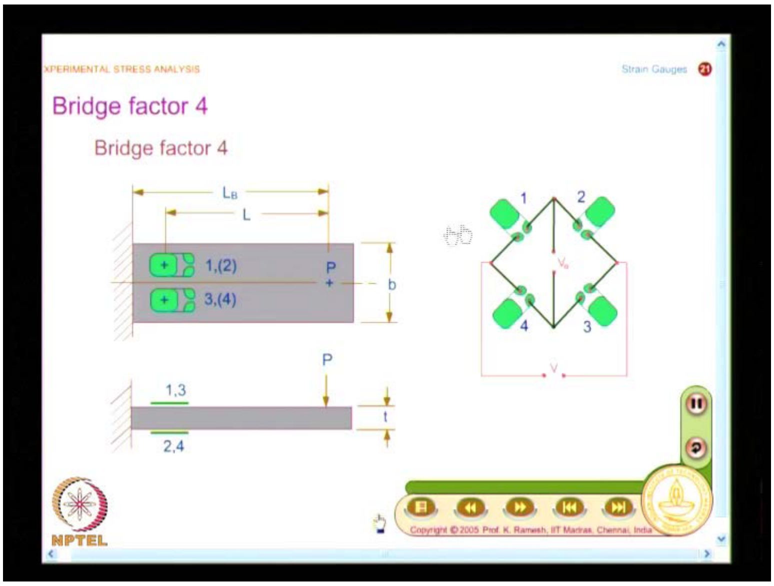

I can paste instead of one strain gauge on the top surface, I can go and paste two strain gauges on the top surface and connect them appropriately, this is very important and you will be tested in the examination on this aspect. Because pasting the strain gauge, you need to apply principles of solid mechanics, because you should know how a beam behaves; you should know when the beam bends, top fiber will be in one state of stress and bottom fiber will be in a opposite state of stress that you should know and how they are connected, this is a very important and subtle information in strain gauge instrumentation.

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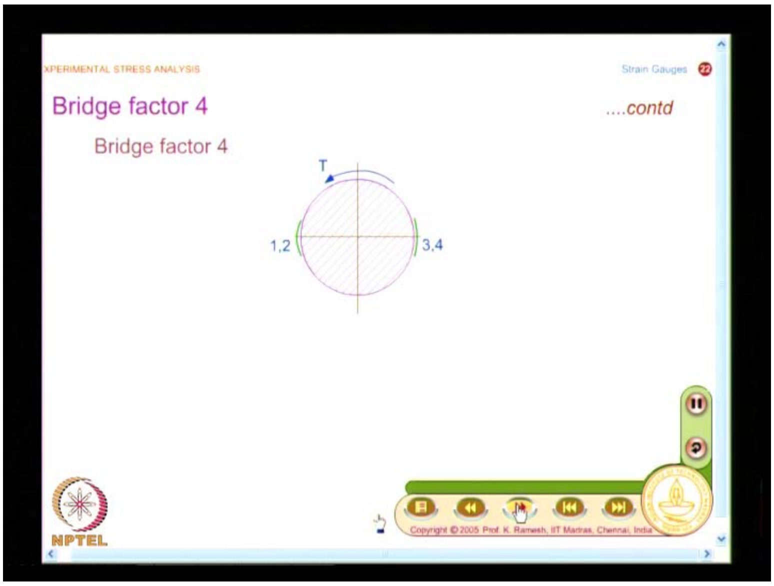

And you know, I am going to give you one more example which I leave it as a home exercise. You know, I have taken a shaft under torsion and what I want you to do is, I want you to identify how do I paste the strain gauge 1 and 2, how do I paste the strain gauge 3 and 4, and how do I connect them into Wheatstone bridge for me to measure the torque.

See, you will have to notice a strain gauge measures strain along its gauge length. So, when I have to decide how to identify the strain gauge to measure torque, you should also look at what is the alignment that I should paste. So, all this knowledge you have to get from your basic understanding of mechanics of solids; you should understand how a pure state can be expressed; you have to use that knowledge, identify the orientation for pasting; not only this, how do I connect. See, it is very tricky; you know, people can make this take in this, how do I align the strain gauge and how do I connect it on the Wheatstone bridge. So, I leave this as a home exercise and we will see in the next class what way you have got the answer.

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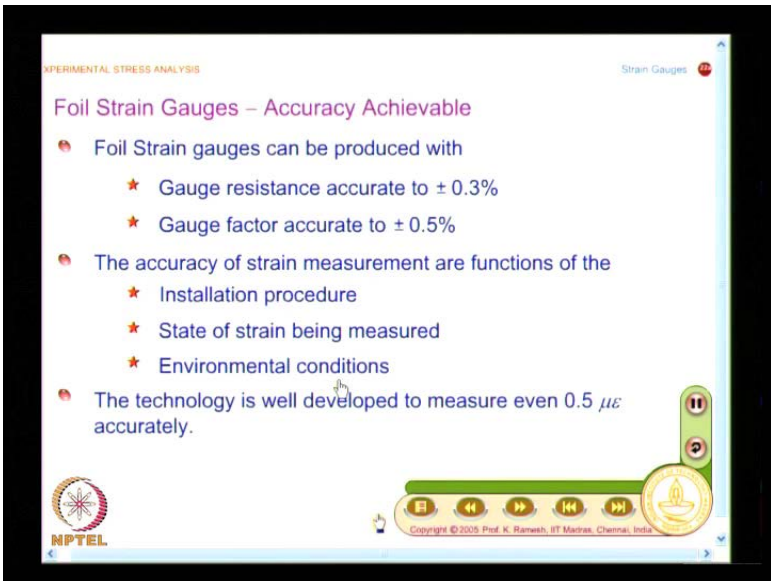

See, what I have been mentioning is, strain gauge instrumentation, we are looking for measuring small quantities. So, we have to pay attention for every minute detail. We looked at strain sensitivity of a conductor, then we graduated and looked at strain sensitivity of grid, and then, we also looked at bridge sensitivity in bridge sensitivity.

In bridge sensitivity we understood, if I do strain gauge instrumentation, each arm of the bridge should have same resistance to start and using the principles of solid mechanics, I can have bridge factor up to 4; this may be good enough in the case of transducer applications; in normal strain measurement, you may paste just one strain gauge.

And what is the level of accuracy that we can think of? It depends on what way we get individual accuracies of the various factors influencing in the strain gauge instrumentation. And what is the accuracy achievable possible? Foil strain gauges can be produced with gauge resistance accurate to plus or minus 0.3 percent.

And one of the first steps in strain gauge instrumentation is, you would measure the resistance of the gauge and you also need gauge factor measurement, because you may have to set the knob of your strain gauge instrumentation to the gauge factor. Because gauge factor essentially works like a multiplication factor and if you do not set the knob properly, you will not be able to interpret the strain and gauge factor can be obtained with an accuracy of plus or minus 0.5 percent, reasonably good. See, we saw in the case of bridle coating, the failure strain accuracy is only plus or minus 20 percent; so strain gauge instrumentation the accuracy levels are much higher.

And the strain measurement accuracy depends on what factors? Though I get the gauge resistance and gauge factor very accurate, if I do not do the installation properly, my entire strain gauge instrumentation can be faulty and installation is the very important step and you need trained technicians should to do that; so this is one factor. The second factor is what is the state of strain being measured. We will also see different types of strain gauge patterns that will give you on an indication how problem becomes complex when I have to find out what I should do. Suppose I have a bending scenario, what type of gauge configuration I should use, I have to select.

And finally your environmental conditions, you have to take special precautions in aggressive environments and what you will have to keep in mind is, accuracy in measurement is closely related to technology. You should be happy that technology is now very well develop to measure even 0.5 micro strain accurately that is an achievement.

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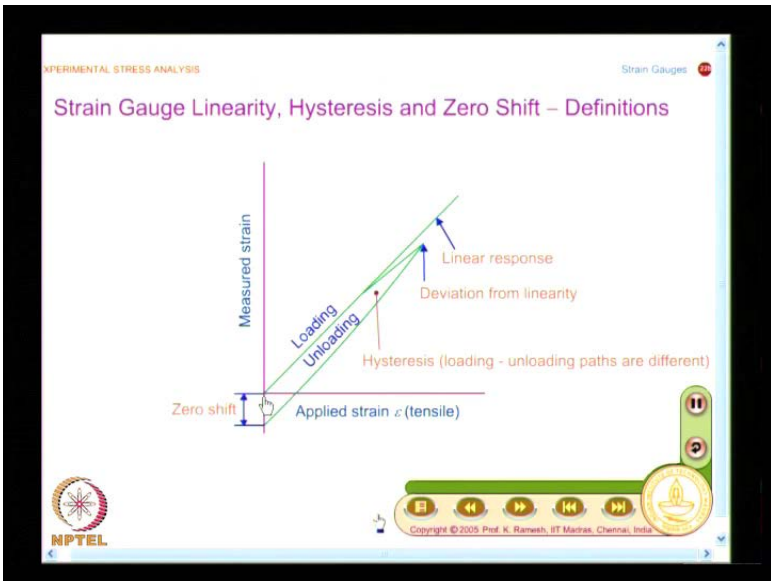

For you to get that, you need to be very careful about insulation and all the other recommendations that the manufacturer ask you to do that and there is also another aspect which will have to look at, what is the strain gauge linearity, what is hysteresis and what is the zero shift. See, you would like the loading and unloading path to be same, but in reality the loading and unloading path can be different. So, this constitutes what is known as hysteresis and when the load is reduced to 0, you may have some apparent strain, it may not necessarily compressive and this is called a zero shift.

You need to make a decent sketch of it, because when we go and discuss various strain gauge materials, the backing and also the adhesive we would say certain comments about how does this influence linearity or hysteresis or zero shift, and zero shift is a nuisance in strain gauge instrumentation. In fact, before the development of SR 4 strain gauges, they had also painted carbon, and then, they had (( )) type of strain gauges, which had very difficult problem about hysteresis and zero shift.

I also mentioned, if you have to make a measurement on plastics because current flows through the strain gauge, you have small heat is generated; plastic being a poor conductor of a heat, it will not dissipate the heat energy and the heat energy will build up. And we have also seen, resistance can also change as a function of temperature, so you would find as a function of time, the strain meter will keep on drifting if you do not take care of thermal effects; do not think that your component is behaving that strain is keep on increasing, it is not so; it is the zero shift and that is the nuisance that has to be addressed very carefully.

Particularly when you are going to make measurements for long durations of time, for months and years, you have to worry about zero shift and what we will see later is, choice of the backing, choice of the adhesive and choice are the alive for the strain gauge grid, everything has an influence. See, the advantage of strain gauge is, its versatility; it can be applied to a range of problems, but for each class of problems, you should select an appropriate strain gauge and all the other associated features - what (( )) you should use, what backing you should use these are all not trivial things, but to an extended look boring. Because you know, you should collect facts; it is not explaining a concept, collection of facts is also important and that is also part and parcel of your learning.

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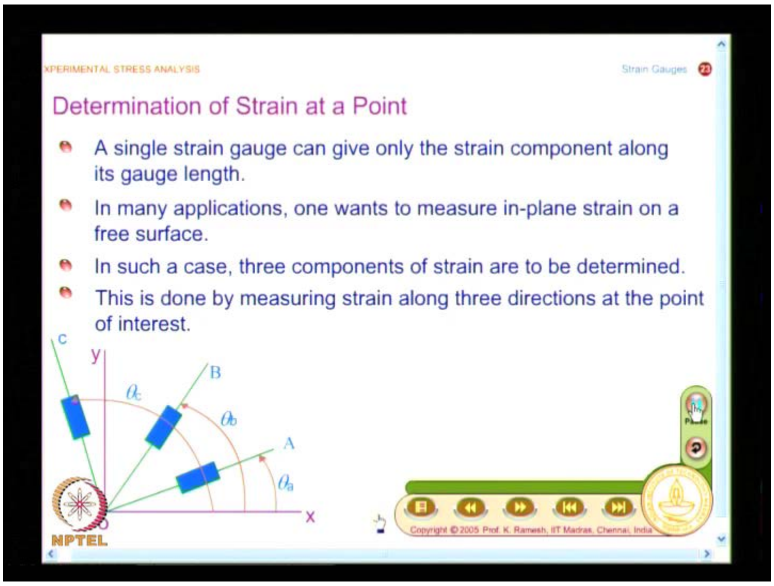

Now, we come to the very important aspect, how I measure strain at a point. This I have been mentioning it many times, a single strain gauge can give only the strain component along its gauge. In many applications, one wants to measure in-plane strain or a free surface. Mind you, suppose I want to go and paste a strain gauge inside a pressure vessel, I want to know what is the way the inner surface is stressed, and then I need to bring in certain correction factor, what happens there? When I paste a strain gauge, you have fluid pressure acting on it.

So, we will postpone how to analyze strain data in those class of problems later; first we are looking at, suppose I have a beam that is bend, it has a free surface; I paste a strain gauge and find out what is the strain on the surface. So, the strain gauge as such is not loaded externally; whatever the strain of the base component is faithfully transferred through adhesive backing system to the strain gauge.

So, we want to find out in plane strain and I need three components of strains to be determined. And you know, here only you look at strain is a tensor of rank 2 and you bring in the tonsorial 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 the given direction in terms of the tonsorial 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 sensor share commonality. Tonsorial transformation law is similar and if you know how to write this transformation law, your rosette analysis becomes child's play; it is not, no longer Greek and Latin, because there the angles are well known; 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 determined.

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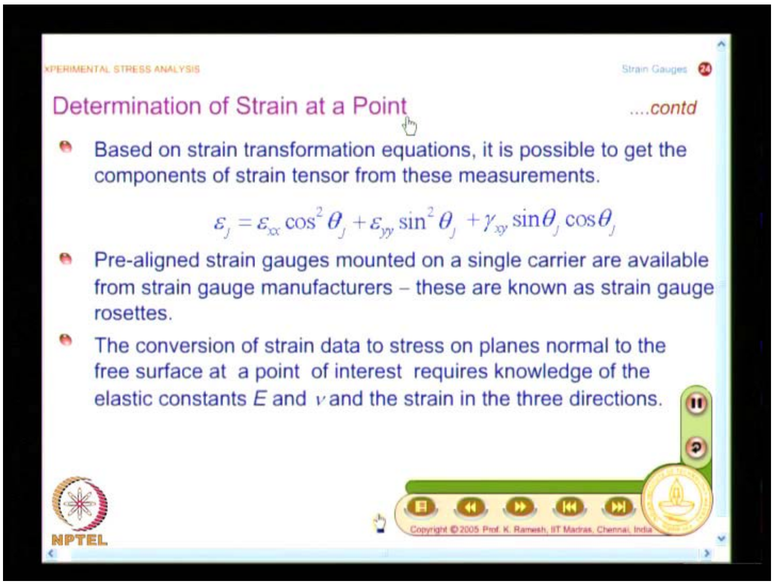

And the strain transformation law is very simple that is what you have here; I can write it as epsilon j equal to epsilon xx cos square theta j plus epsilon yy by sin square theta j plus gamma xy sin theta j cos theta j. I have written the engineering shear strain component; if you write it in terms of tonsorial components, so this is epsilon xy divided by 2 and when I go to different row sets, 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 the 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 employ 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 conference 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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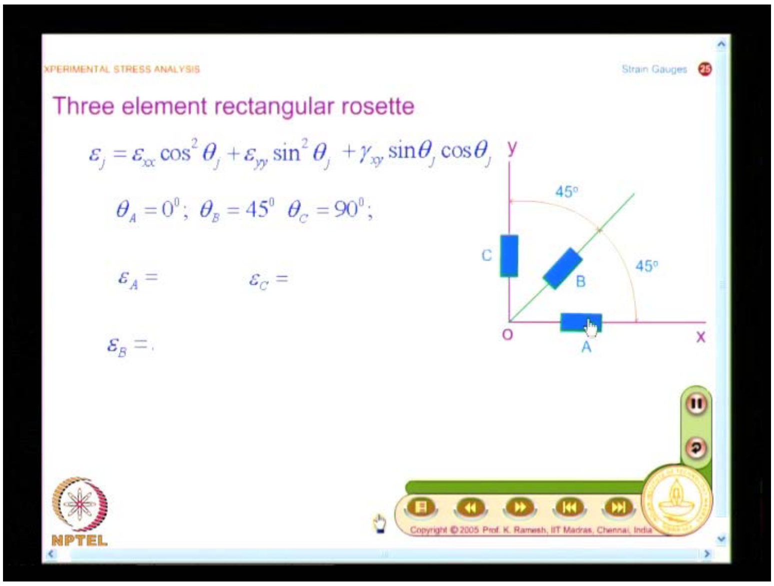

And let us see two famous configurations of the rosettes. And one of the rosette is called a rectangular rosette is primarily because I have a strain gauge along the X axis and the second strain gauge at 45 degrees and the third strain gauge is along the Y axis. So, what is the strain measured by the strain gauge A? If I have this as my reference axis, I could simply say its equivalent to epsilon X and strain measured by the strain gauge C is epsilon Y.

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. See, you have to look at the certain subtle things when I developed the definition of gauge factor S g, I also cautioned that you have a sensitivity in the transverse direction, which is given by a transverse sensitivity factor K t. The moment I go to rosette analysis, I assume that K t equal to 0 and then write this strain transformation law and find out what is the strain at the point of interest. Later, we will also see you can bring in correction due to transverse sensitivity effect to the rosette also; in that case, the equations will become very complex and that is given by the manufacturer.

The manufacturer provides you all this information also and what will have to look at? Another issue is, from measurement of strain by a strain gauge A, B and C, I say that I measure strain at point O; that is a point, where the strain gauges meet. If I have to offset this, one way of doing this is, I put this strain gauge move it, and then, have it here; move this also, have it here; move this also, have it here, then I will have three strain gauges stack over the other, this is good enough for axial problem.

Suppose I go to a bending problem, the stacking height also can affect your area. Another aspect is what is its thermal influence. When I stack it, I am going to have high thermal influence because of current flowing through all the three strain gauges. I can probably do it on a thick metallic specimen, where heat is dissipated, so this is where the selection comes. See, strain gauge selection is a very big topic by itself, rather than postponing our discussion on strain gauge selection as and when we learn certain aspects of strain gauge, how this aspect influences strain gauge selection and you should also know what kind of approximation that we do.

First approximation is, I have a finite grid; we have looked at how the gauge length is going to affect your strain measurement. Now, you find in a rosette I have to be careful about how this strain gauges are aligned with respect to the point O. So, keep thinking about these issues; these are very important. Because strain gauges is so versatile, people think that I paste a strain gauge, connect to the strain meter, they had look at the reading and they go and make the fast conclusions. You know, if you do not know the (( )) in strain gauge instrumentation, you can be way of and I will show you some example, where if I am not accounted certain parameters, a simple calculation can result in 20 percent error.

So, you have to know on which kind of component that you are pasting the strain gauge. And in this class, we have started what is the strain sensitivity of a strain gauge, then we moved on to how to measure 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 is the rosette and in the next class when you come, get the shear strain in the case of the rectangular rosette. Thank you.