Experimental Stress Analysis
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Lecture - 33
Strain Gauge Selection

We have looked at in the last class what is the basic aspect of a strain gauge. We have looked at strain sensitivity of a conductor, then strain sensitivity of a strain gauge. Then we also looked at what are the ways that you can make the measurement, the importance of 2-wire and 3-wire circuits. Then we also looked at from the performance of the strain gauge what aspects need to be looked at.

In the process of such discussions, we have also said that you need to understand why you have to select a particular alloy, particular carrier, particular adhesive etc. Now we will move on to discuss formally how do we go and select a strain gauge and then make an installation.

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And when you go for strain gauge selection and installation you have various patterns available and for a plate with a hole you have a strip gauge that is pasted here and this shows what are the accessories that you require for strain gauge bonding and this gives an illustration how do you use a cyanoacrylate cement, what kind of procedure that you need to adopt to effect a bonding.

So you have to move and then put your thumb pressure and thumb pressure itself is sufficient to effect polymerization in the cyanoacrylate cement and you are in a positive to get an installation which is done reasonably fast.

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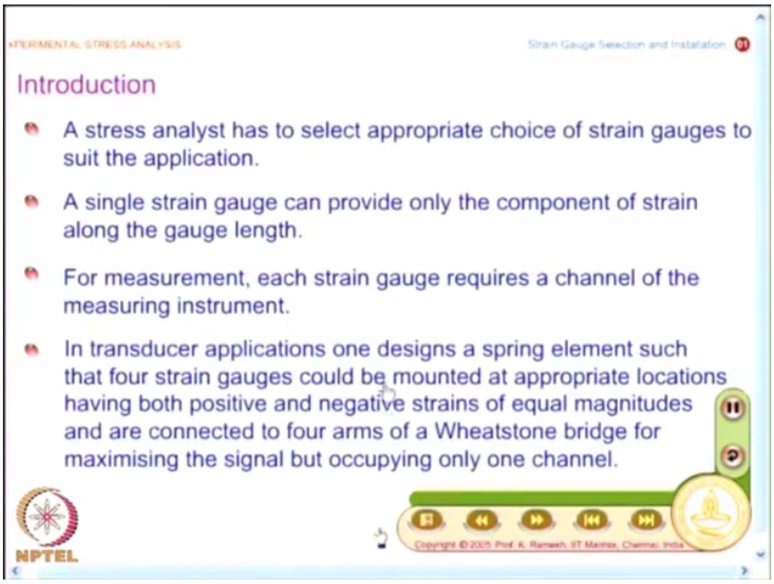

So as a stress analyst, you have to select appropriate strain gauges to suit the application and I have always been mentioning that a single strain gauge can provide only the component of strain along the gauge length and for measurement each strain gauge requires a channel. See from a large installation point of view, you may need to find out strain at several points on the object.

And you may have an instrumentation system which has an upper limit on how many channels that you can employ. This is a very important issue when you are handling complex problems. So you have to effectively utilize the channels available in your measurement system. At the same time, from design point of view you should be able to acquire as much information as possible from the structure.

And I have always seen there is confusion in the minds of the students the distinction between what is a strain gauge and what is a strain gauge channel. See if I have to measure strain at a point completely I need 3 strain gauges. For each one of the strain gauge, you need to have a separate Wheatstone bridge to measure the signal.

So a rosette will have depending on the number of gauges in the rosette whether it is a T-rosette or a delta or rectangular rosette, it will have 2 or 3 channels as the case maybe. So you have to make a distinction between what is the strain measurement and what is the number of channels that you require. That we will have to see back and forth so that you have a clear picture of the distinction between the 2.

See in the case of transducer applications, one designs a spring element such that 4 strain gauges could be mounted at appropriate locations. Why we do this? In transducer application, you want to maximize the signal and you design your own spring, so when you design your own spring, you ensure that you quadruple the signal. So that is what you do by identifying zones where you have tension compression.

And invariably they may be of equal magnitudes, so when you connect them in a full bridge, it gives you 2 advantages, one advantage is it has a self-temperature compensation due to thermal effects. The other advantage is you multiply the signal 4 times. So you have to make a distinction between transducer application and general strain measurement.

So in transducer applications, you have a situation where you maximize the signal by connecting 4 strain gauges but it occupies only one channel of your measurement system. So what decides the channel is how many Wheatstone bridges that you are going to use for measurement. So do not make a mistake if you have a delta or rectangular rosette, connect all of them in one Wheatstone bridge.

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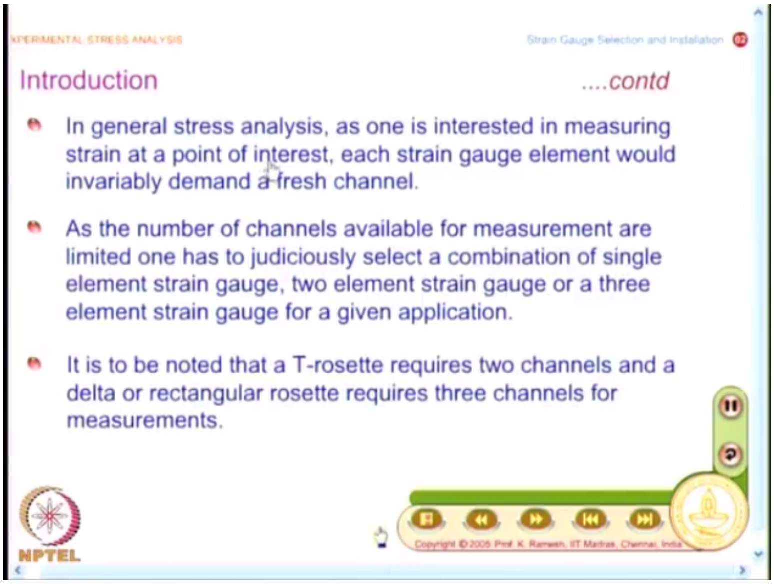

You do not have any interpretation to such type of connection. So the distinction is in general stress analysis, one is interested in measuring strain at a point of interest, that is the focus.

Maximizing the signal is secondary because you may not be in a position to connect 4 strain gauges if you want to maximize the signal you may have to think in terms of increasing your bridge voltage or increasing the resistance of the strain gauge, you may have to take any of those type of measures.

And as I mentioned earlier, in a given instrumentation system you may have an upper limit on number of channels. So before you make a plan for strain gauge instrumentation, you need to select judiciously a combination of single element strain gauge, 2 element strain gauge or a 3 element strain gauge for a given application.

See the idea what is mentioned here is I want to find out strain at a point why not I go and paste at every point, which I want to make measurement a rosette. That means you are demanding 3 channels per point, which may not be required. You may have a knowledge that in a particular zone of a component, you may have only a uniaxial stress, a single element strain gauge is good enough.

And you may also have in certain locations, the principle stress directions are known. Once the principle stress directions are known, it is enough I use a T-rosette because I can align it along one of the principle stress directions and I do not need 3 strain gauges, only in situations where you do not know what is the state of strain or you know in advance that it is a biaxial state of stress, then I need to put a strain gauge rosette for me to measure 3 components of strain.

And this is what is emphasized again you need to know T-rosette requires 2 channels and a rectangular or delta rosette requires 3 channels for measurement, so you should know a distinction between what is that you want to measure and how many channels that you use. It looks very simple but when you ask in the examinations people make mistakes. So have a clarity in this aspect.

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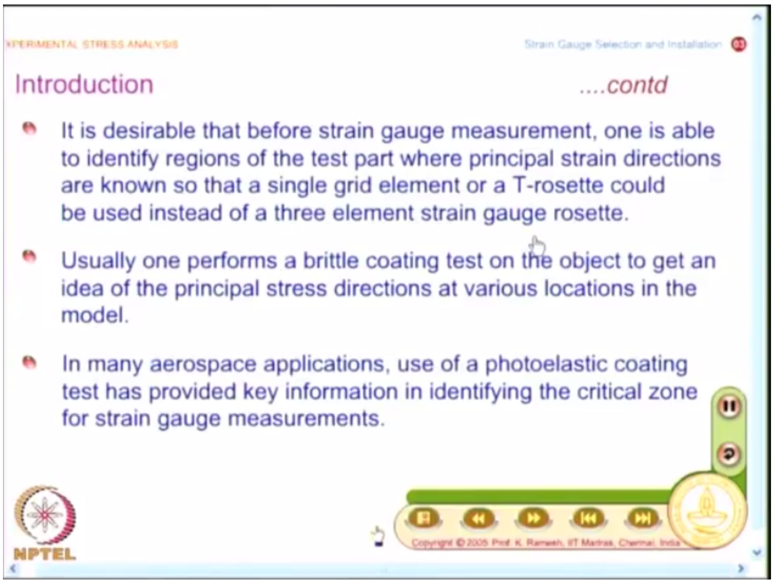

So the recommendation is it is desirable that before strain gauge measurement, one is able to identify regions of the test part where principle strain directions are known, so that a single grid element or a T-rosette could be used instead of a 3 element strain gauge rosette. You know this is the reason why we discussed the method of brittle coatings before strain gauges. Primarily, brittle coating gives you contours of isostatics.

So you can know in advance that these are all the principle strain directions on the component, that knowledge could be well utilized in reducing the number of channels per point. You know that makes a difference so that you are able to utilize your instrumentation system effectively and another aspect is you know strain gauge is a point by point technique.

And if you take a look at any one of the optical techniques like photoelastic coatings that gives you whole field information. So when you get the whole field information, the advantage is you have knowledge of the critical zone where you need to make further study using strain gauge measurements.

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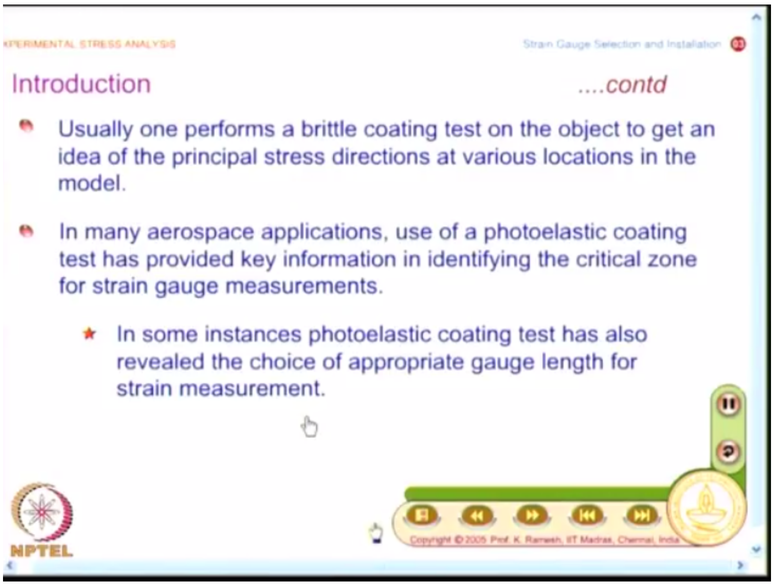

Other aspect is when you are looking at the fringe patterns, the fringe patterns also give an indication of the gradient. If the fringes are very dense then you have a very sharp variation of strain values. So you can also make some assessment on the choice of appropriate gauge length for strain measurement. See this is the general thumb rule.

When you are actually looking at a complex problem, combination of a whole field technique and a point by point technique makes your analysis faster at the same time reasonably accurate because in a complex problem the first identification is which are all critical zones. A whole field technique can give that very easily and in those locations you pay strain gauges and refine your measurement.

So the recommendation is try to use a whole field technique in conjunction with a point by point technique. A point by point technique alone will not be very effective and we have seen some of the examples, some examples where a mere application of strain gauge technique was not sufficient because you pasted it slightly away from the critical zone. So it underestimates the maximum strain.

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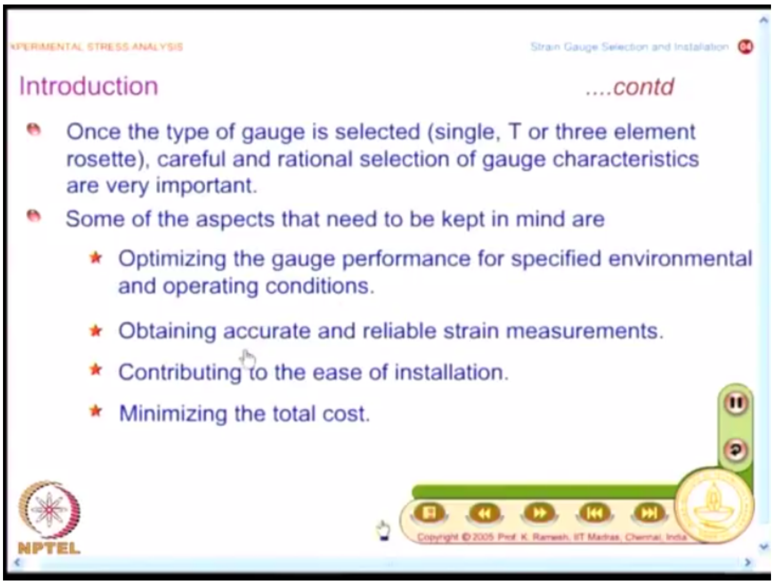

So your design can be way off, so the recommendation is combine the use of whole field technique and a point by point technique. So once you decide yes I need to have in these locations a single strain gauge, a T-rosette or a 3 element rosette, you have to make a careful and rational selection of gauge characteristics for the given application and what are the aspects that you need to keep in mind?

You need to optimize the gauge performance for specified environmental and operating conditions and obviously you want to have accurate and reliable strain measurements that is the basic focus and in certain applications ease of installation also dictates the selection. This is also an aspect which needs to be weighed in rational selection of strain gauge characteristics and finally you would like to have minimizing the total cost.

You do not want to increase the cost of installation that is what I said you do not want to put strain gauge rosette at every point or you do not go and say I will select strain gauges with preattached leadwires, which will reduce my effort but it will also increase the cost. So you need to make these kinds of decisions for you to effectively utilize the strain gauge instrumentation.

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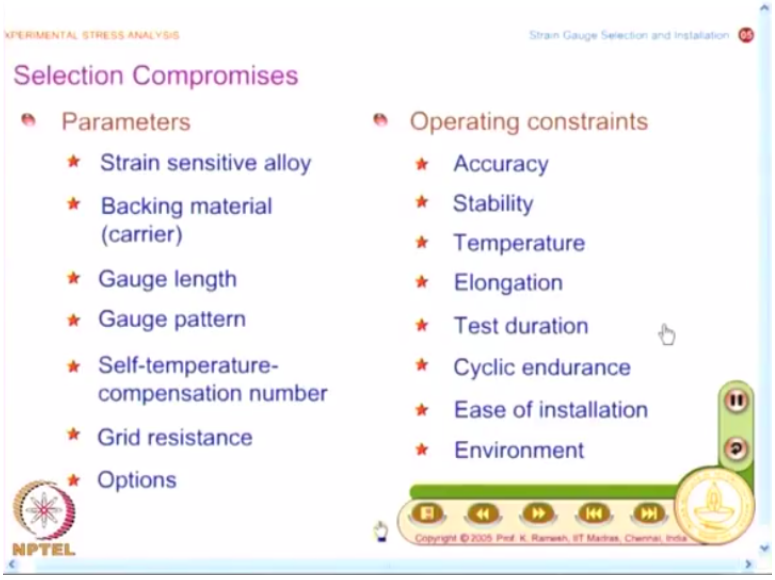

And obviously in any one of these selection approaches, you will have selection compromises. So you will have a set of parameters and set of goals that you need to have and when I look at a strain gauge what all I need to worry about, I need to worry about what is the strain sensitive alloy that I need to select. We have seen in an application where stability was important, we found going from an Advance to Karma has improved the performance.

And in the same application we also saw the selection of backing material from polyimide to epoxy phenolic resin has definitely improved the performance and depending on the strain gradients that you are going to encounter you need to decide the gauge length and gauge pattern is also equally important.

We have looked at from heat dissipation point of view, we have looked at charts, which give you recommendation for a given power density what kind of gauge patters that you can select and we have also said for small temperature variation it is desirable that you go for a self-temperature compensation and depending on the specimen material on which I am going to do the test I need to select this number.

And again the heat dissipation brings in what is a grid resistant that I should select. If I have a higher resistance, I minimize I squared R loss thereby minimizing the heat generation. This may be necessary when I go on work on composites or poor conductors of heat as specimen material and finally I will also have to select options. See we said in one of our earlier applications, we used a Karma alloy for improving the stability.

And one of the basic difficulty in Karma alloy is it is difficult to solder the leadwire so that you can go for the option of preattached leadwires from the manufacturer and let us look at what are the operating constraints. So we have to focus on accuracy, the measurement should be stable for long durations of time and at what temperature I need to make the strain gauge measurement.

And what is the level of strain I am looking at. That is dictated by the elongation and the test duration am I doing a dynamic test or am I doing a test on in-situ measurements, which requires monitoring over months and years and particularly in transducer applications I need to ensure cyclic endurance and you should not ignore the difficulties in installation that is why you have ease of installation is also one of the operating constraints.

And finally what is environment? Am I working at room temperature or am I working at aggressive environment like exposure to sea water.

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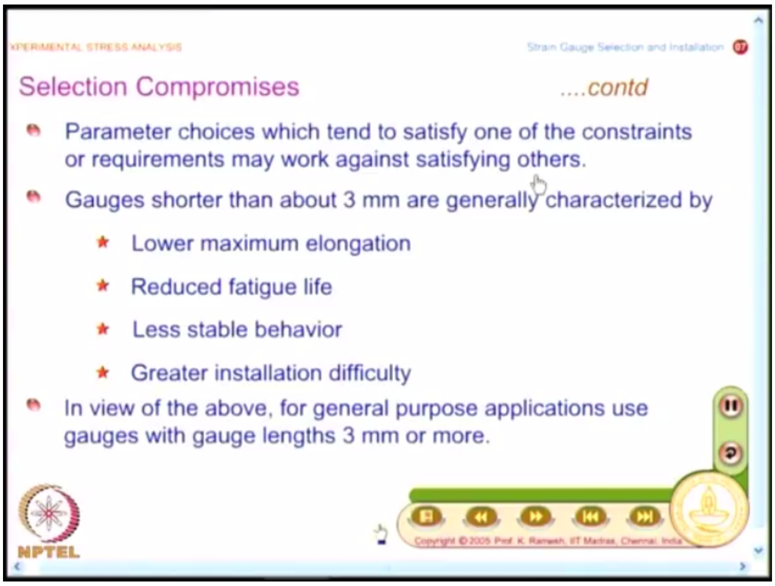

And obviously when you have a selection parameter choice, which tend to satisfy one of the constraints or requirements may work against satisfying others. This is there in any selection. So when you have to make a selection, you have to strike a compromise that is why even the discussion is mentioned as selection compromises.

So you compromise it scientifically. See I have always been saying the general purpose strain gauges have a gauge length of 3 millimeters. Suppose I go and try to use the strain gauge shorter than 3 millimeter what is the kind of problem that I may have to encounter? It may have lower maximum elongation, it will have a reduced fatigue life and it will have a less stable behavior and finally it will have greater installation difficulty.

See before you take up the discussion on strain gauges, you would have heard that strain gauge is a point by point technique and you would have imagined I can find out what happens at a point precisely. What we saw was from the way we have to make a strain gauge. I do not have a material which has very high resistance wherein I can put a spec of material and measure what happens at a point of interest, I need to essentially make a grid.

So it is not point by point technique, it is only measuring over a small finite area in bringing certain approximations. So from that point of view you may want to simply go for the shortest gauge length possible. So what is the recommendation here is when you go for smaller gauge length than required, then you need to face these kinds of difficulties. So the thumb rule is for general purpose applications, use gauges with gauge lengths 3 millimeter or more.

This is the thumb rule and if it works be happy with it, do not go and emphasize that you need to go for smaller gauge lengths.

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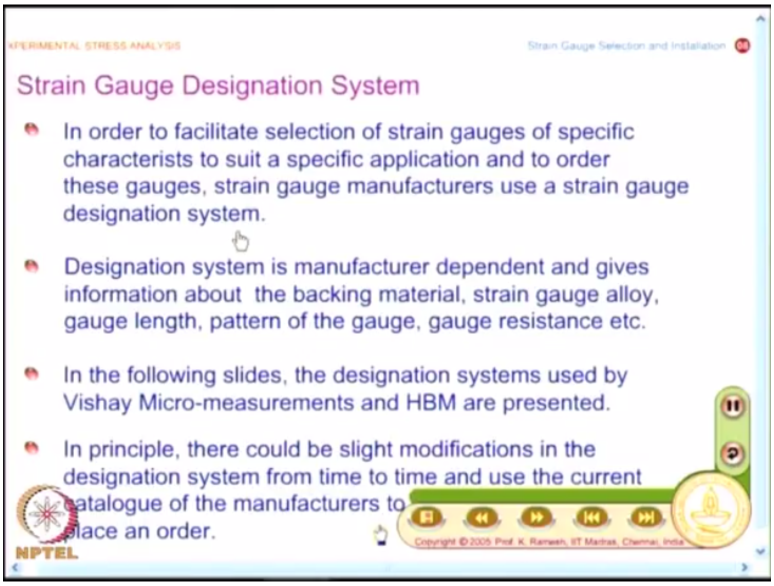

And you know if I have to select a strain gauge of suitable characteristics and also to order these gauges, strain gauge manufacturers use a strain gauge designation system. So it does 2 jobs, one is to facilitate selection of strain gauges or specific characteristics and also to order these gauges and obviously the designation system is manufacturer dependent and gives information about the backing material, strain gauge alloy, gauge length, pattern of the gauge, gauge resistance etc.

See we have looked at various aspects of the strain gauge alloy, backing and also the adhesive to facilitate our current discussion on selection for a given application. So what way we will go and look at is what way your strain gauge is designated and provide general guidelines on how to go about in selecting these parameters. We may not take a specific problem to select a strain gauge.

But we will provide you general guidelines on how to go about and for these discussions, I have the designation system from Vishay Micro-measurements and HBM and you can also look at other manufacturers. You have a manufacturer from Japan and you should also keep in mind these are discussions to give you an idea of what way you can go about and there could be slight modifications in the designation system from time to time.

And use the current catalogue of the manufacturers to place an order. So here we are looking at what aspects are important, that also gives you an idea how do you go about in deciding what strain gauge you want.

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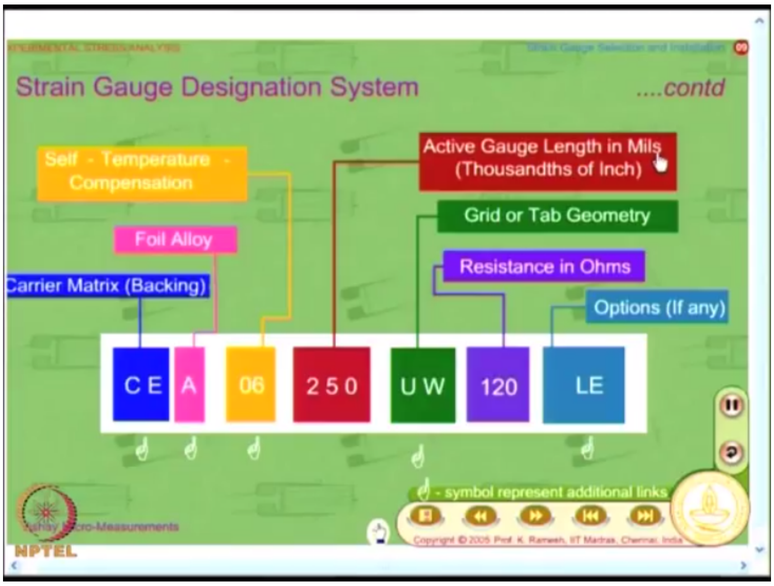

And you have a very elaborate strain gauge designation system, so I have 1, 2, 3, 4, 5, 6, 7 items are mentioned in the designation system used by Vishay Micro-measurements. So the first set of symbols tells you what is the carrier matrix, then the second one tells you about foil alloy, the third one gives you the self-temperature compensation number and the 4th one gives you active gauge length in Mils.

See though you have SI units, this is the kind of system that they use in the USA, so you have a USA manufacturer gives you only in terms of Mils and then you have grid or tab geometry. So this becomes important when you look at a particular installation you need to have the tabs at a particular orientation. Then you have resistance in ohms. So when you look at the designation you will know whether you are talking about 120 ohms or 350 ohms.

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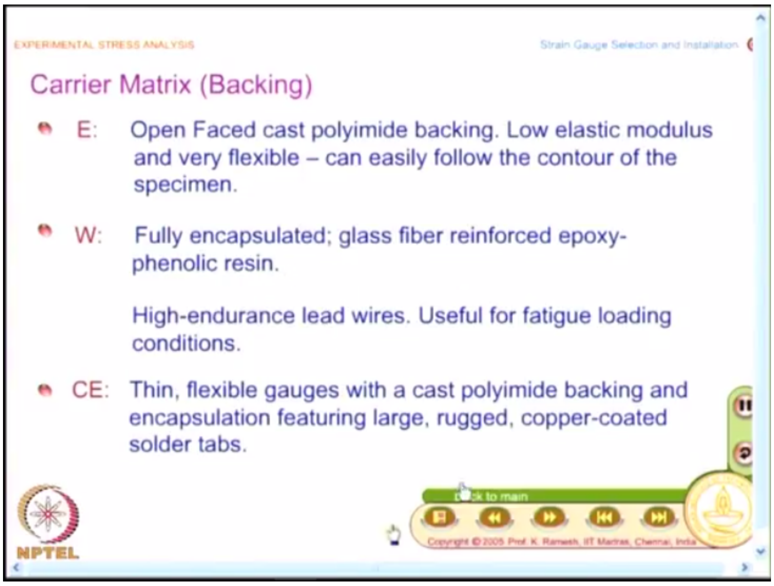

And finally you will have options and we will see some of these parameters and when I go to carrier matrix or backing, you know I have a list, I have a list of symbols, the idea is to give a flavor that when I have a symbol E, symbol W, symbol CE what happens. So when I have E it is simply open faced cast polyimide backing and when I say W it is fully encapsulated, you use a glass fiber reinforced epoxy phenolic resin.

And C denotes thin, flexible gauges with a cast polyimide backing and encapsulation. So this is a polyimide with encapsulation, W is glass fiber reinforced epoxy phenolic resin and if you go to foil alloy you know you will have symbols for Advance, Constantan because I am going to show you some strain gauges from Vishay Micro-measurements.

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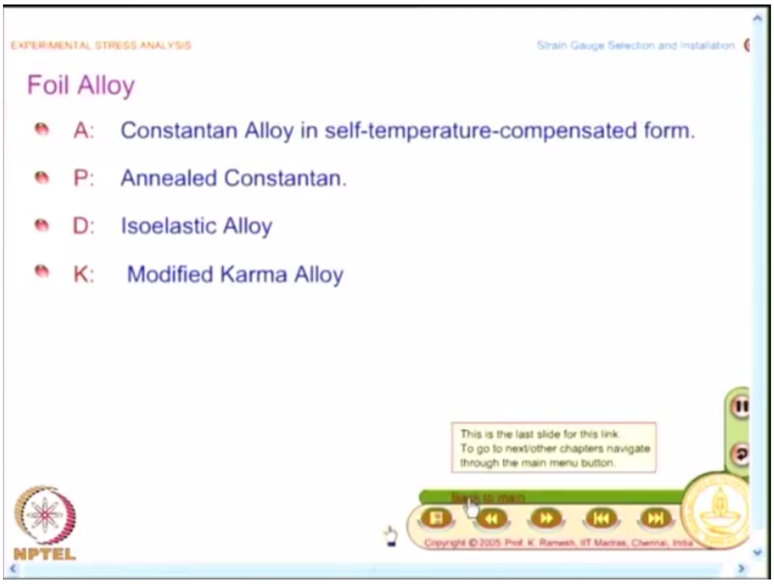

You should be able to find out what these strain gauges are in reality and A denotes Advance, it is a Constantan alloy in self-temperature compensated form, P is annealed Constantan, D is Isoelastic alloy and K is modified Karma alloy so by looking at this we will also know what is the foil alloy I am using and you have already noted you know what is the self-temperature compensation number for various specimen materials.

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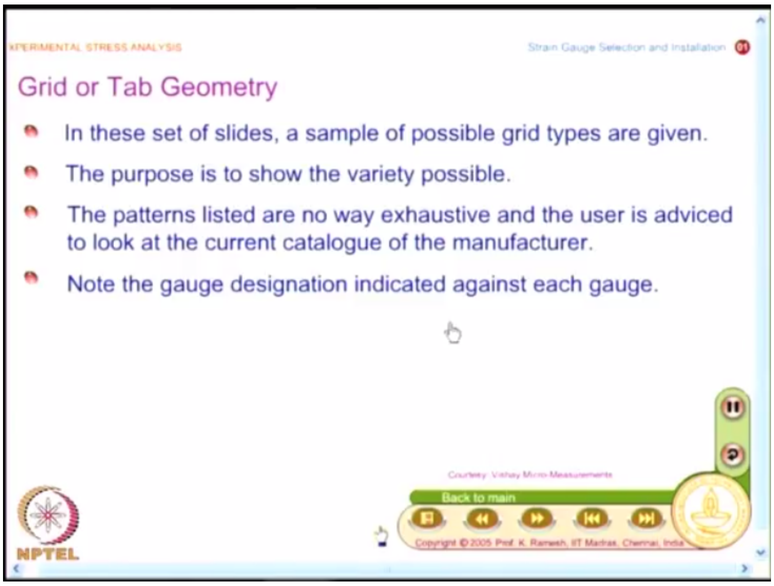

So now we focus our attention on what are the grid and tab geometry available. So what I tried to provide in these set of slides is only a sample of possible grid types because you need to know what is the variety possible? A strain gauge is not just a single set of loops. The patterns listed are no way exhaustive and as an user you have to look at the current catalog of the manufacturer.

And the idea what I want to show is when you look at these grid patterns, also note the gauge designation system indicated against each gauge. So you have a number assigned to it, you will be able to quickly find out what kind of a strain gauge am I looking at.

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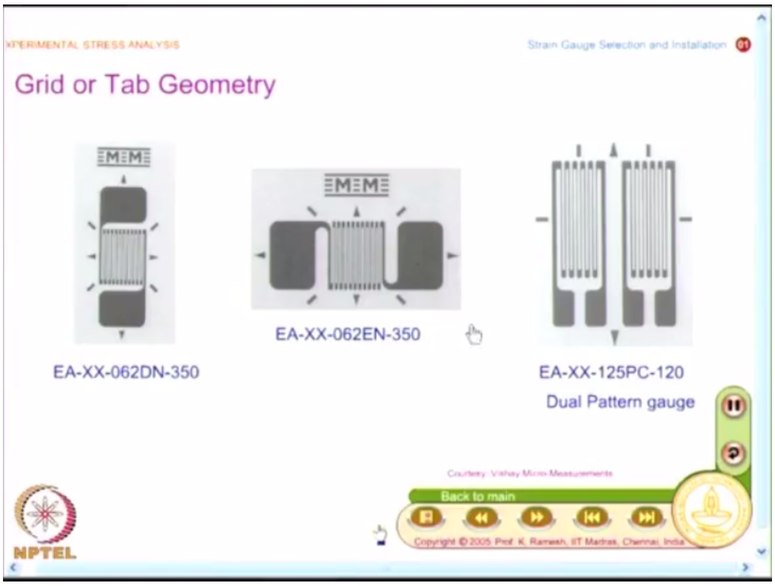

And obviously the simple strain gauge what you have is a simple loop like this and what I shown here is you have the tabs on either end and for this the particular manufacturer gives this as DN. So E denotes the carrier backing, A denotes Advance alloy and XX denotes depending on the specimen material I will have to select my self-temperature compensation number that is why this is not listed.

So the same kind of pattern will be available for a set of base specimen material and EN is a kind of gauge where I have this is horizontal and you know in the case of maximizing the strain reading in one of the classes I said you can also paste 2 strain gauges adjacent to each other. Instead of you make the alignment; you have that available as a pre-aligned gauge.

So that has a specific designation by the manufacturer and in all these cases you also have the last digit indicating the resistance. I have 350 ohms, I have 120 ohms here and there are no special options.

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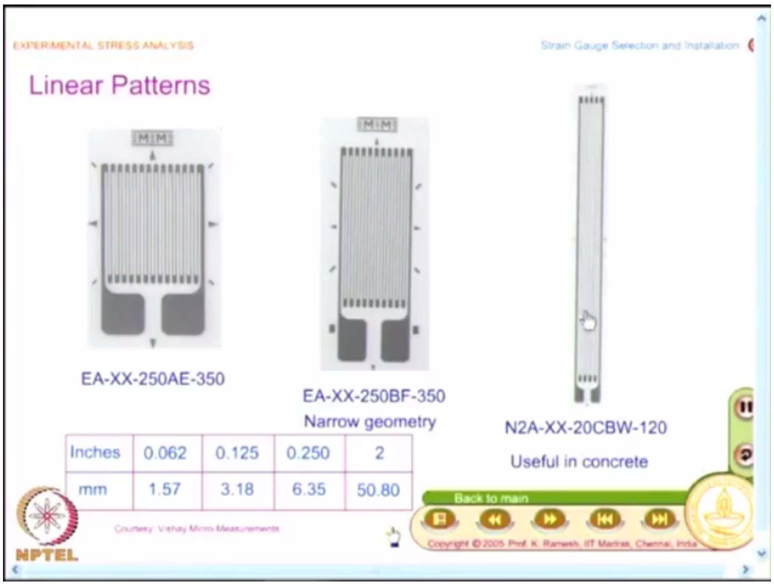

And the idea here is to show a variety, you know I can have a very wide grid pattern. Why do you have the wide grid pattern? For heat dissipation. A heat dissipation is an issue then go for a wide grid. Otherwise go for a narrow grid and this is other extreme, you have a very long strain gauge. You have to know that such strain gauges are really available and this is about 50.80 millimeter.

These are very long and useful in concrete and in all these cases we have separate symbols for indicating the pattern.

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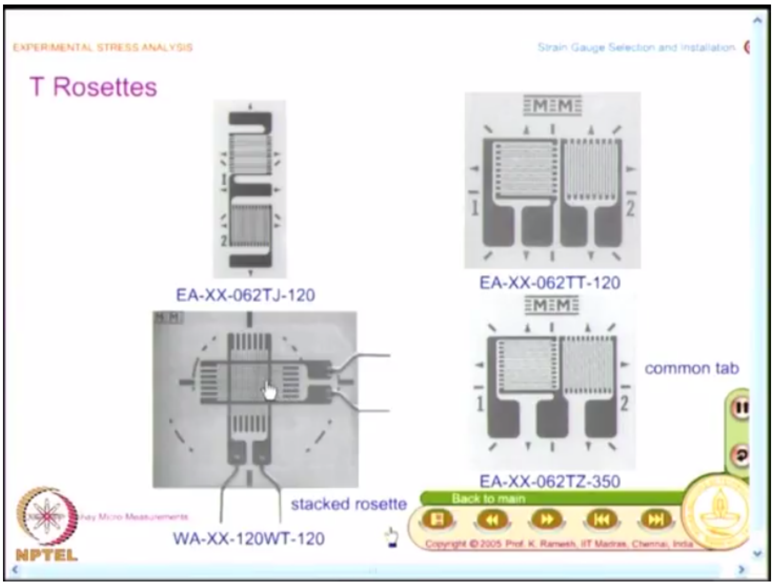

And I said that you have T-rosettes where 2 strain gauges are available and if you note very carefully the elements are mutually perpendicular. So I will measure strain at 2 perpendicular directions and I have also mentioned you also have stacked rosettes available because you should see that stacked rosette then only you will find out if I want to get the strain at this point.

Stacked rosette is very good from that point of view because the approximations involved are less and in this you have variety of patterns available.

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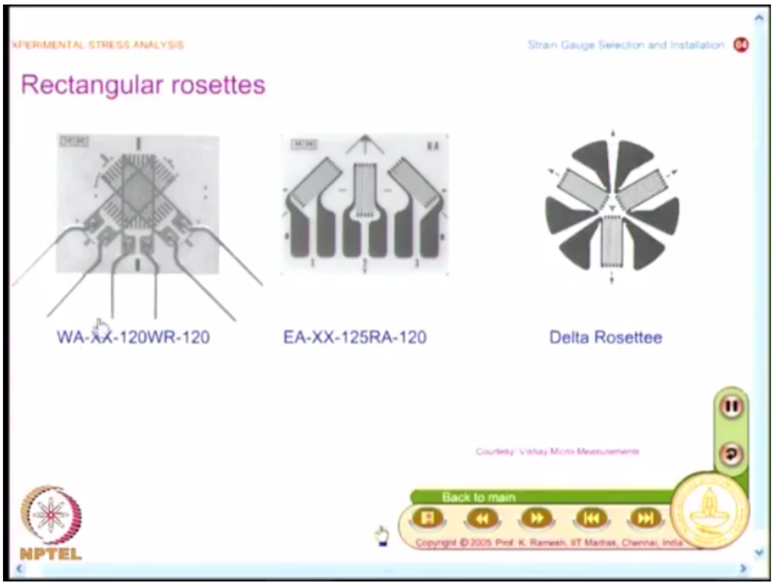

See one of the simple examinations I will have is I will give you a few patterns and you should be able to distinguish what class of strain gauge it is. That familiarity you need to develop that is why these patterns are shown and you have this as stacked rectangular rosette and the moment you have this as W then you can imagine that it is an encapsulated epoxy phenolic and A denotes it is a self-temperature compensator Advance alloy.

And you have the same rectangular rosette in the conventional form here. This rectangular rosette is expected to measure strain at this point where these 3 strain gauges meet. On the other hand, this is good from analytical thinking point of view but there is a practical difficulty. It is going to generate lot of heat and particularly in bending application this is not recommended.

And you also have another variation that this is a delta rosette, which is better than a rectangular rosette when you want to find out what happens at the point of interest because that is enclosed by all the 3 strain gauges. So this again selection of delta or rectangular dictated by your strain field, you need to select appropriately, also the installation considerations can also decide one way or the other.

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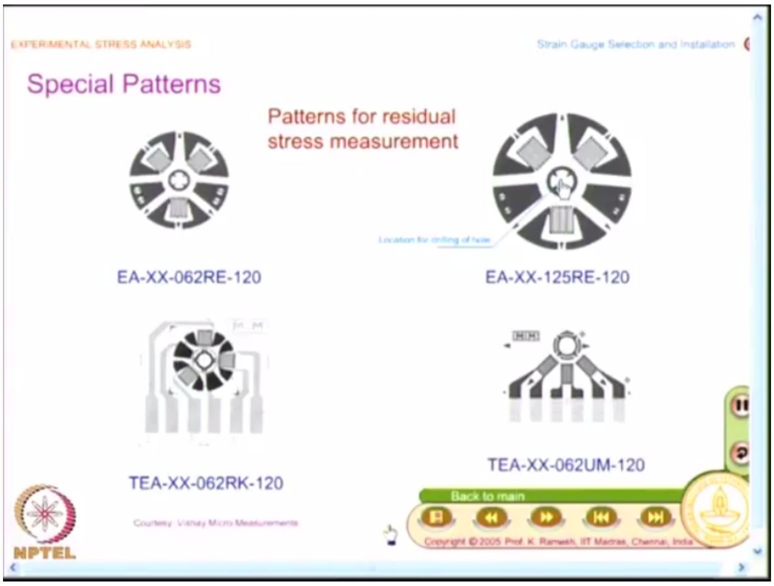

Then you have very special patterns. You have special patterns for residual stress measurement. See if you look at it causally, it will look like a delta rosette. I will magnify this you make a sketch of one such strain gauge.

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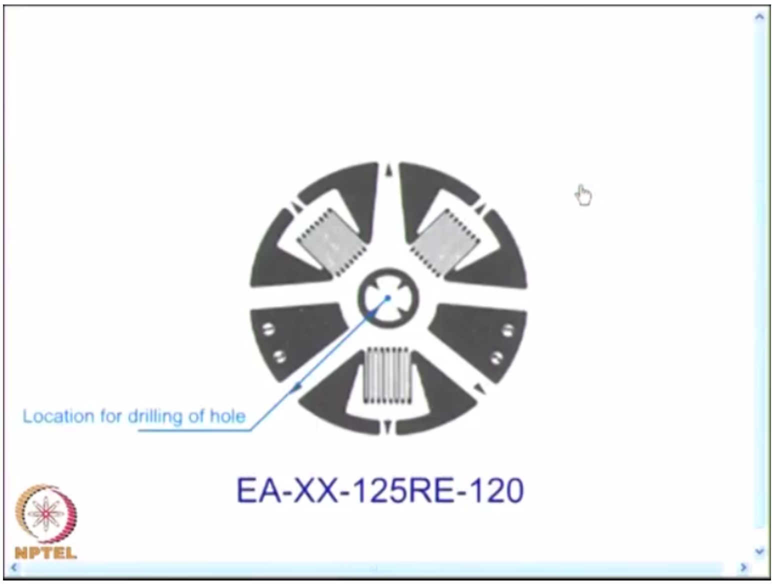

It will look like a delta rosette but it is not a delta rosette. You have a provision to drill a hole at the center and you have very sophisticated drilling gadget that comes along with this. So the idea here is when you drill the hole, the stresses get relieved and those relieved stresses are sensed by these strain gauges and you have expressions available from the manufacturer how to interpret and find out the residual stress.

See residual stress is a very difficult problem to handle with and this is a semi destructive type of approach you need to remove material, it is not like x-ray diffraction where you do not do any destructive analysis but where you can find out residual stress only up to very small depths, here you can go up to 2 to 3 millimeter depth and it will look very similar to your delta rosette.

But because I have provisioned to drill a hole here, you must distinguish that this is a strain gauge meant for residual stress measurement and what you have in the slide is the different ways the tabs are provided to facilitate ease of installation. So ease of installation dictates this. Then you have another interesting pattern.

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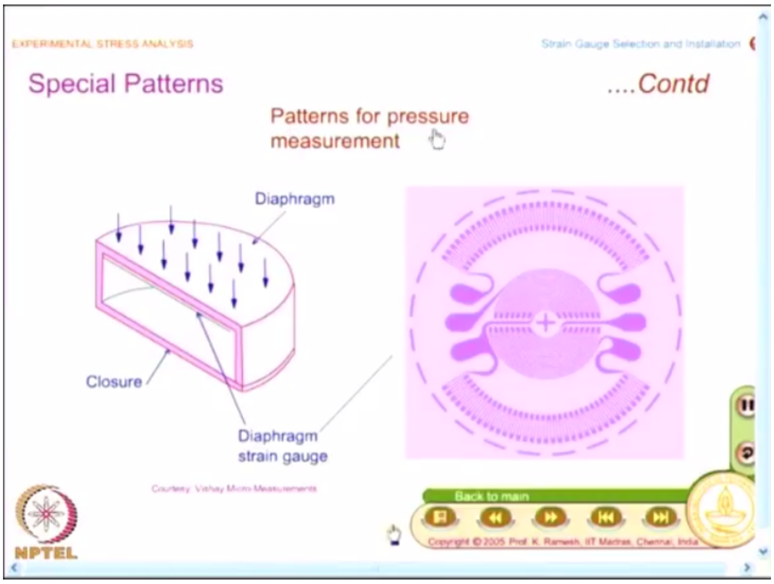

You have a special pattern for pressure measurement. I have a thin diaphragm and I have a strain gauge, which is shaped in this manner. Because I use a metal foil and then I do an etching process, I can put any complicated pattern for me to do the etching and you have one set of patterns, which are radial like this. What is a component of strain that this will sense? It will sense the radial strain because it measures only strain along the gauge length.

You have another set of patterns, which are circular. So this will measure the tangential strain, circumferential strain or tangential strain. So you have a special pattern meant for measuring pressure.

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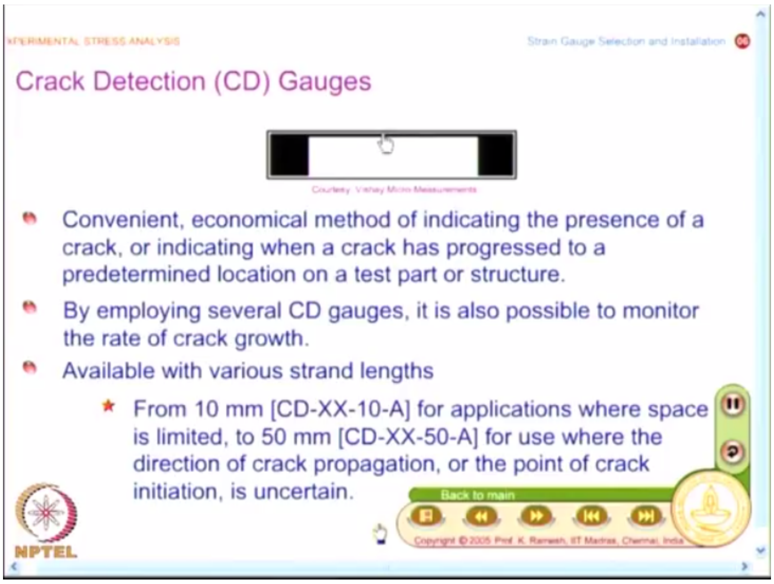

And you also have because you have an etching process, you also have special gauges. These are not essentially meant for strain measurement because fracture mechanics is becoming very, very important. You also have what are known as crack detection or CD gauges. The principle of operation is simple. Suppose I have a crack and this crack crosses the strain gauge, it will cut the element.

Because when the crack passes through, the connectivity of this conductor is lost. So that is detected to know the crack has crossed a particular point of interest. So this is a very interesting application of metal foil gauges. So they are convenient and provide an economical method of indicating the presence of a crack and we also have another variation of this which is meant for measuring the velocity of crack propagation.

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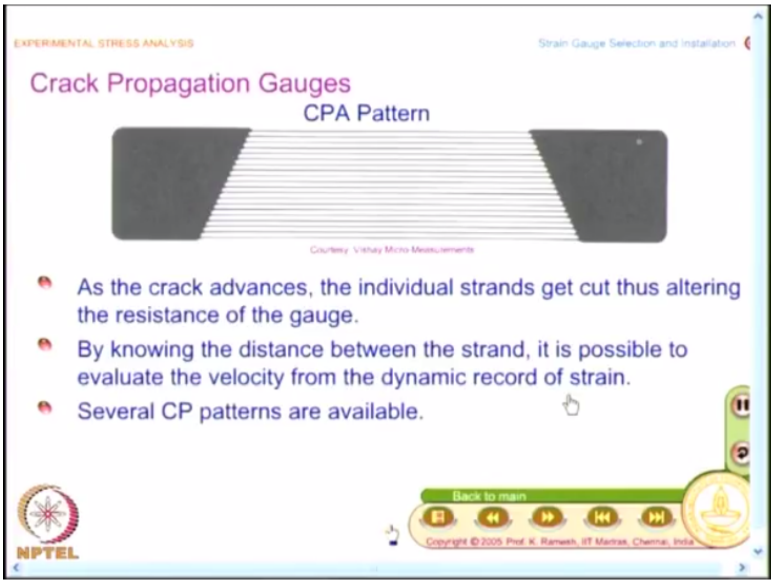

So what do you have here, in one foil I have several strands shown here. So what will happen? As a crack advances, the individual strands get cut thus altering the resistance of the gauge. So use the same principle, you are not measuring strain but you are measuring crack propagation, very interesting because I know that distance between the strings. So I can also find out the velocity.

Since I know the distance between the strands, it is possible to evaluate the velocity from the dynamic record of strain, see we have to look at fracture mechanics. This is becoming very, very important from design point of view and once you look at strain gauge development, we will also look at if time permits towards the end of the course how to measure stress intensity factor from strain gauge measurement.

This is going to make your utility of strain gauge for a variety of practical problems of current interest and you also have several such patterns available. I have shown one such pattern here.

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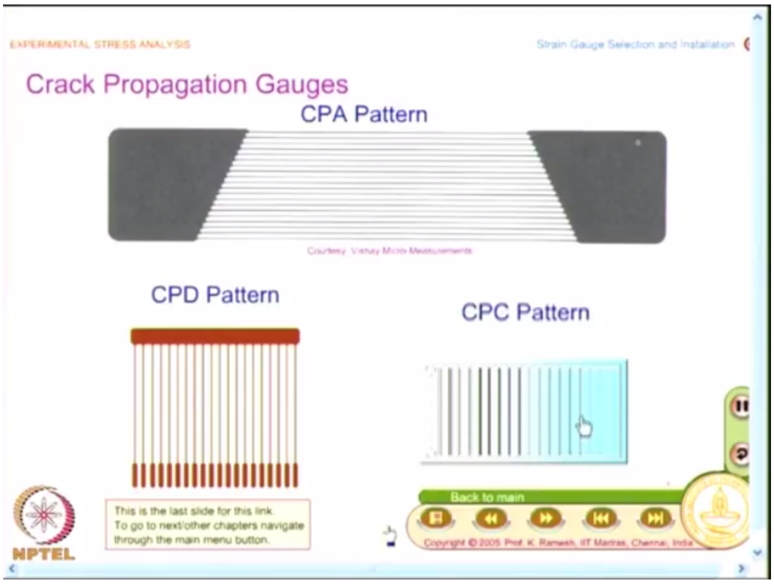

And you have another 2 set of patterns, which are like this. This is designated as CPD and then you have another pattern called CPC pattern. In this case, the grids are aligned like this and this is also used for finding out the crack propagation and eventually its velocity.

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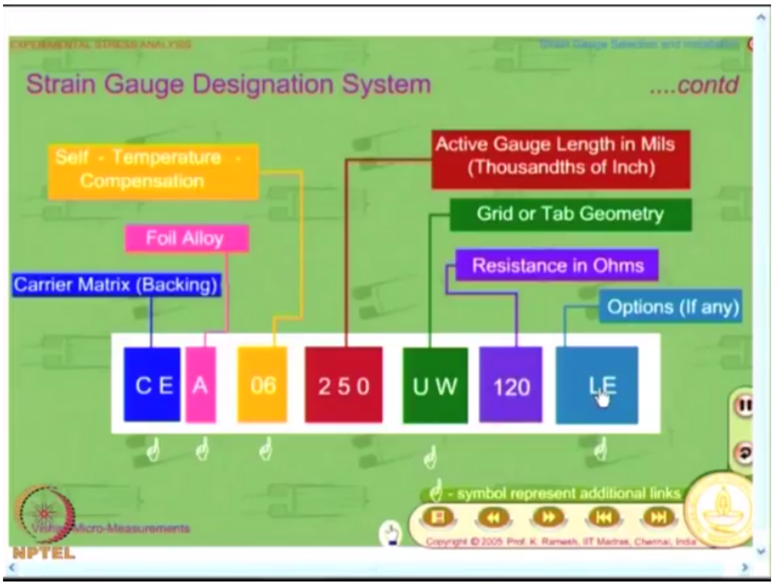

And finally we will look at what are all the options available. We have looked at carrier matrix, we have looked at foil alloy, you have already seen what is self-temperature compensation. Then you have the gauge length, grid pattern we have seen, the idea is to show a variety of strain gauges possible. Then you have resistance in ohms and what are the options.

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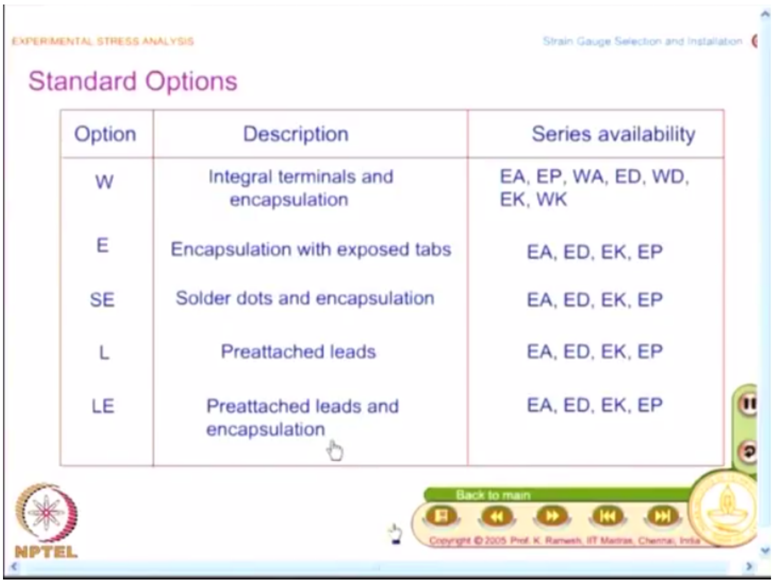

Option	Description	Series availability
W	Integral terminals and encapsulation	EA, EP, WA, ED, WD, EK, WK
E	Encapsulation with exposed tabs	EA, ED, EK, EP
SE	Solder dots and encapsulation	EA, ED, EK, EP
L	Preattached leads	EA, ED, EK, EP
LE	Preattached leads and encapsulation	EA, ED, EK, EP

So when you look at the options, you know I have W which is integral terminals and encapsulation and when I have L it is like preattached leadwires and if I put LE it is preattached leads and encapsulation. So the idea is to emphasize for special applications, look for suitable options to minimize your effort in installing the strain gauge. So that is what we have looked at.

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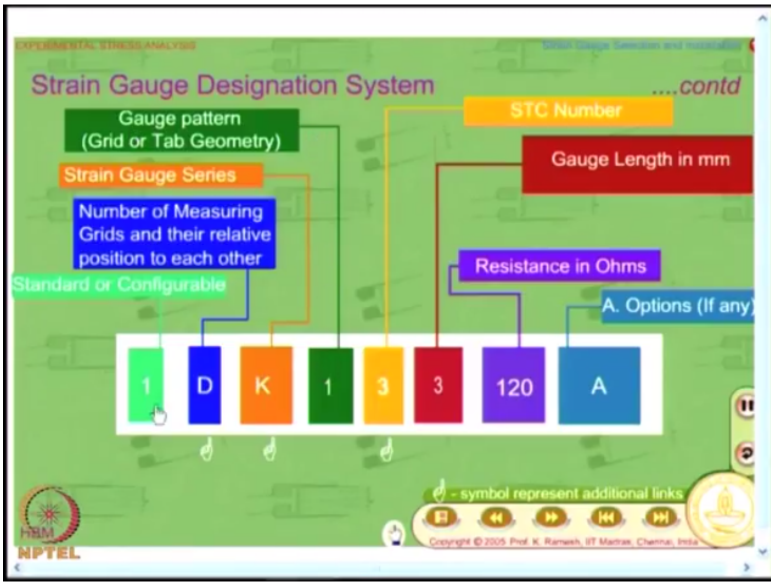

And now what we will do is we will go and see the designation system adopted by HBM and I have tried to use the same color code for similar parameters. Obviously, the order is diffident here. He has first code as standard or configurable and the second one is number of measuring grades and the relative positions to each other, then he classifies this as strain gauge series, then you also have a gauge pattern.

I wanted to make a note of this. You need to know that I have 1, 2, 3, 4, 5, 6, 7, 8 parameters are necessary and the common ones are you have a gauge pattern, he may have a different designation but gauge pattern is forming part of the designation system. The designation system also gives you STC number and mind you the classification of STC number by this manufacturer is different, so it is manufacturer dependent.

Then by looking at the designation, you can also look at the gauge length and he gives you SI units, this gauge length is given in millimeters and in both the designation systems, you have a resistance in ohms. So by looking at the designation, you will know what is the gauge length, what is the resistance, what is the specimen material it is meant for directly. The other ones are manufacturer dependent very closely.

Because you need to select the grid pattern and then you will have to look at what kind of backing and alloys, these are different.

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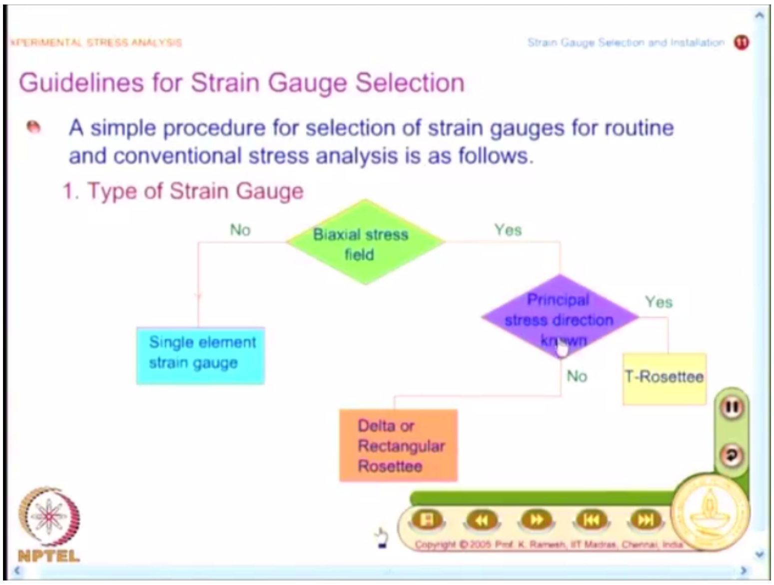

And now we will look at a generic recommendation on how to select a strain gauge for a given application. What is a first step? The first step is what is a type of strain gauge that I need at a point of interest. I have to as the question, am I working on a biaxial stress field? If the answer is no, it tells me it is enough I use a single element strain gauge.

On the other hand, if the answer is yes then I need to ask the other question do I know the principle stress direction. If I know the principle stress direction from a brittle coating test, I can use a T-rosette, 2 strain gauges are sufficient and you are going to occupy 2 channels. After looking at transducer application where you connect 4 strain gauges to one Wheatstone bridge, do not go and connect 2 strain gauges of the rosette in one Wheatstone bridge.

It does not make any interpretation possible, you need to measure strain at 2 perpendicular directions from your measurement point of view and suppose I have a situation where the principle stress directions are not known and I am in a biaxial stress field, I need to have a delta or rectangular rosette. So you first decide whether you want a single element, T-rosette or a delta R rectangular rosette.

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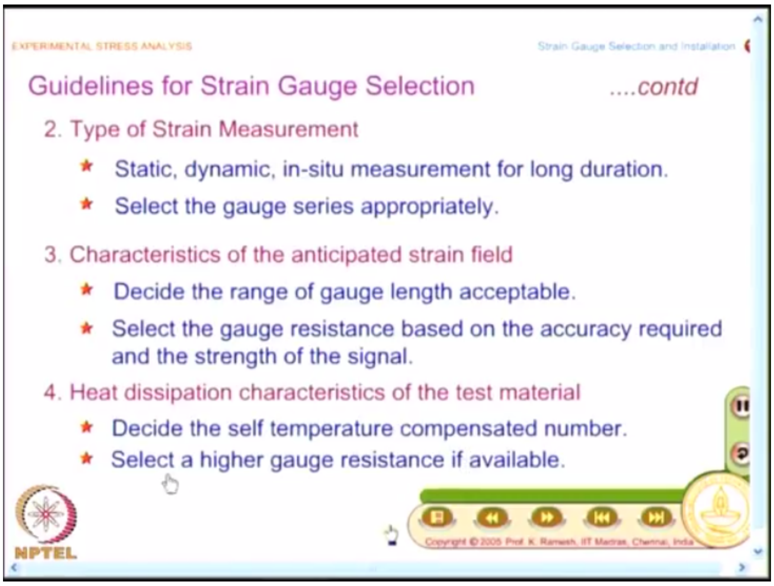

And what is the second step? What is the type of strain measurement? Am I going to make a static strain measurement or dynamic stain measurement or in-situ measurement for long duration. So this helps me to select what, what is the strain gauge series appropriately. Because you have different types of series for static, dynamic and in-situ. When I go for dynamic I can go for Isoelastic alloy.

When I go for in-situ measurements, you may go for a Karma alloy. So you need to decide the type of strain measurement and what are the characteristics of the anticipated strain field is a third step. So if I know the strain field, I can decide the range of gauge length acceptable. Because if I am going to have a very sharp changes in strain levels, I need to go for the smaller gauge length.

And this also gives me an indication what is a gauge resistance that I need to have based on the accuracy required and the strength of the signal so this is where I said when I am talking about strength of the signal when you are designing a loading grid for you to test your component, you select the load in such a manner at the point of interest you should be able to get at least 100 microstrain.

Because we have seen many of the installation aspects like if you do not connect the leadwires as a 3-wire circuit, if you do only a 2-wire circuit, a small temperature change itself can give you an error of 156 microstrain. So many of the installation and other associated aspects of strain gauge measurement can make so much variation on the measurement, it is desirable that you have a situation where if possible load it to an extent that I get 100 microstrain at least.

Suppose I do not have that luxury then what I have to look at is I must find ways to increase the signal strength by modifying the gauge resistance and you have to look at heat dissipation characteristic of the test material. So this decides the self-temperature compensation number and here again if necessary select the higher gauge resistance. So what we have looked at is first decide the number of strain gauges you need to do.

Then decide whether you want to do for static, dynamic or in-situ measurements. Then look at the characteristics of the anticipated strain field, look at what gauge length is appropriate, this gives some indication on the gauge resistance possible, then address the issue of heat dissipation, which helps you to determine the self-temperature compensated number.

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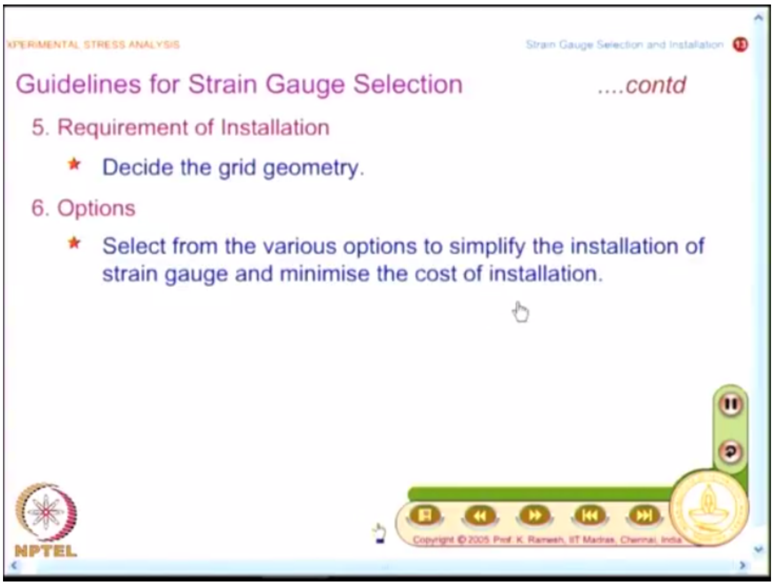

And you will also have to look at requirement of installation. See this you may ignore, many times you say I am not going and installing, only my technician is going to install. Let him face the music of difficulties in installation. If you leave it, you do not have a confidence on the strain measurement. You will also have to look at difficulties in installation as an issue and decide the grid geometry.

So finally you select the set of options that would help you to simplify the installation of strain gauge and minimize the cost of installation and this is what I said if you are using a Karma alloy, it is better to go for a preattached leadwires rather than you struggle in trying to solder it. So in this class what we looked at was what are the nuances in the selection of a strain gauge for a particular application and we have also looked at a typical strain designation system by 2 manufactures.

So that gives you an idea by looking at the designation of a strain gauge, you look at the gauge alloy, you look at the backing, you also get an identification of what is the grid pattern, what is the self-temperature compensated number, what is the resistance and also options if any and finally we looked at a sort of a general guideline how do you go about in a step-by-step fashion to decide on a particular strain gauge for a given application. Thank you.