

**Experimental Stress Analysis**  
**Prof. K. Ramesh**  
**Department of Applied Mechanics**  
**Indian Institute of Technology, Madras**

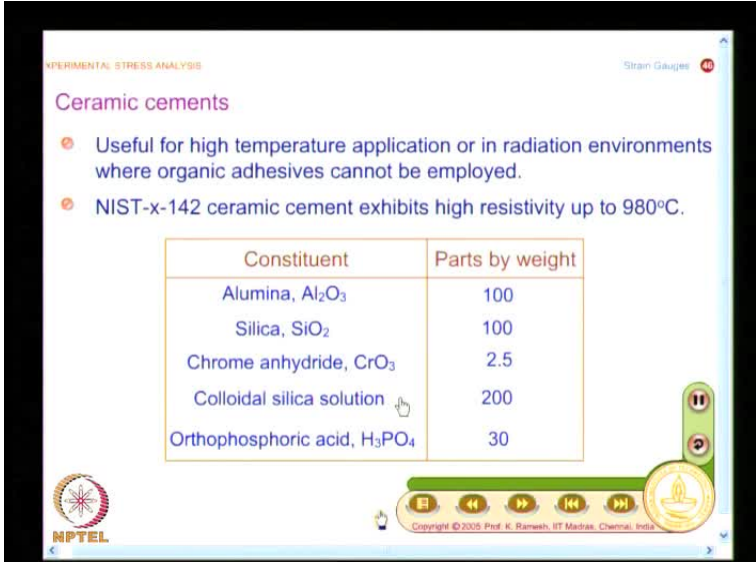
**Module No. # 05**

**Lecture No. # 34**

**Performance of Strain Gauge System**

Let us continue our discussion on strain gauges. We have looked at in the last class, strain gauge as a system consisting of the metallic grid supported by a carrier and which is bonded to the specimen by a suitable adhesive. We have looked at quick setting adhesive like **cyanoacrylate**; then, we looked at epoxy, which is meant for sophisticated installations like in transducers, where you need to provide a very thin bond line, and also, it should come for longer periods of operation; then, we looked at polyester adhesive.

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The slide is titled "Ceramic cements" and is part of a presentation on "EXPERIMENTAL STRESS ANALYSIS". It contains two bullet points and a table. The first bullet point states that ceramic cements are useful for high temperature applications or radiation environments where organic adhesives cannot be used. The second bullet point mentions that NIST-x-142 ceramic cement has a high resistivity up to 980°C. The table lists the constituents and their parts by weight: Alumina (Al<sub>2</sub>O<sub>3</sub>) at 100, Silica (SiO<sub>2</sub>) at 100, Chrome anhydride (CrO<sub>3</sub>) at 2.5, Colloidal silica solution at 200, and Orthophosphoric acid (H<sub>3</sub>PO<sub>4</sub>) at 30. The slide also features the NPTEL logo and navigation controls.

Constituent	Parts by weight
Alumina, Al <sub>2</sub> O <sub>3</sub>	100
Silica, SiO <sub>2</sub>	100
Chrome anhydride, CrO <sub>3</sub>	2.5
Colloidal silica solution	200
Orthophosphoric acid, H <sub>3</sub> PO <sub>4</sub>	30

Now, let us look at the ceramic cements; and when you look at ceramic cements, they are useful for high temperature application or in radiation environments. See, now nuclear power is becoming very, very important; so you need to live with radiation environments in such installations. And in such applications, organic adhesives cannot be employed; so

you need to necessarily go for ceramic cements; and one of the popular ceramic cement is NIST-x-142, which exhibits high resistivity up to 980 degree centigrade.

We have earlier looked at some of these common alloys, advance and **karma**, they can go up to 260 degree centigrade, that is only their metal foil and the associated carrier we will look at was polyamide or epoxy or any such carrier. For any one of the high temperature application, you need to find a suitable metallic foil, as well as an adhesive. Now, we are looking at the adhesive. We will also look at the special type of strain gauge, and also the special process by which you could spray the ceramic cement.

And what you have here is, the constituents of NIST-x-142 is listed here: you have alumina, you have silica, you have chrome anhydride, and you have a colloidal silica solution, and you also have orthophosphoric acid.

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EXPERIMENTAL STRESS ANALYSIS

Strain Gauges

Ceramic cements ....contd

- Blend of ceramic powders such as alumina and silica combined with a phosphoric acid is mixed with a solvent such as isopropyl alcohol and an organic binder to form a liquid.
- A pre coat of the ceramic cement is applied and fired to form a thin layer between the gauge grid and the component.
- Carrier of the gauge is removed and placed on the thin layer of ceramic and a second layer of ceramic cement is then applied to bond the gauge.
- Gauge resistance to ground exceeds 6 MΩ.

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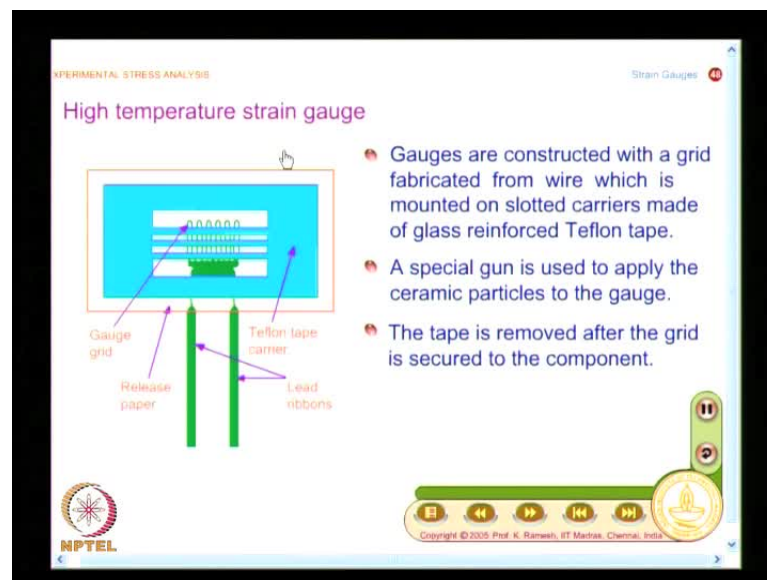
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So, what you have here is, you have the blend of ceramic powders such as alumina and silica, combined with the phosphoric acid is mixed with a solvent such as isopropyl alcohol and an organic binder to form a liquid. So essentially, you have the ceramics available as a liquid, so that it is easy for you to apply it by a spraying process.

And what you do is, on the specimen, you provide a pre coat of the ceramic cement. After application, it is fired to form a thin layer between the gauge grid and the component. So, it is a very elaborate process; you need to have a proper training to

handle this kind of special cements. So, once you form a thin ceramic cement layer on the specimen, you place the gauge; and the gauge is also very special, we will have a look at it a little while later, and what you have is, you have to remove the **carrier** of the gauge and place it on the thin layer of ceramic and a second layer of ceramic cement is then applied. So, you have initial layer of ceramic on the specimen; your normal carrier of the gauge will not withstand such high temperature. So, the **carrier** of the gauge needs to be removed and you put a second layer of ceramic cement to bond the gauge. And when you do something like this, gauge resistance to ground will be only about 6 meg ohms; it is much smaller, but that is the best that you could get when you use these kind of ceramic cements. So, what you see here is, you need to have a strain gauge such that its carrier can be removed.

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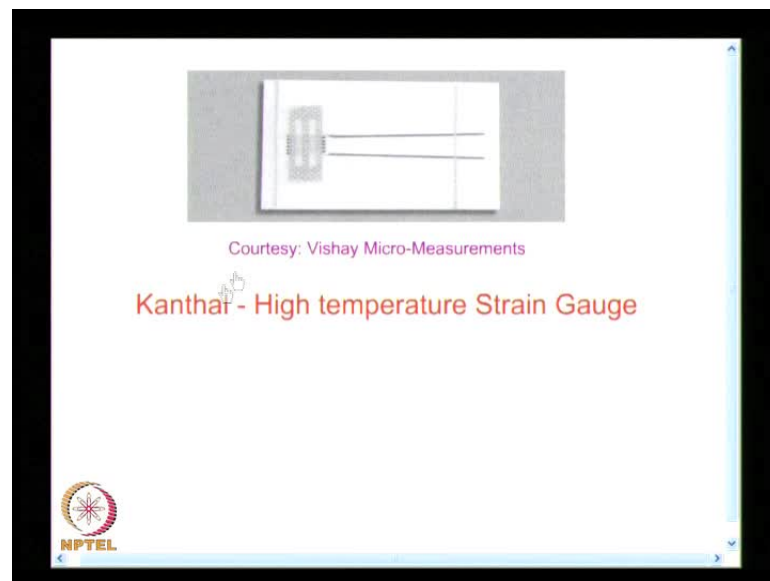


And you have an example of a how such a gauge can be constructed. I have a sketch here. I essentially have a wire type strain gauge, and you have a Teflon tape carrier, which could be peeled off, and you make a decent sketch of this. So, what you have here is, gauges are constructed with a grid fabricated from wire, which is mounted on slotted carriers made of glass reinforced Teflon tape. So, why you have slotted type is, you put a layer of ceramic, then the strain gauge would be bonded, at the time you can remove this Teflon tape; then again do a code and complete your installation.

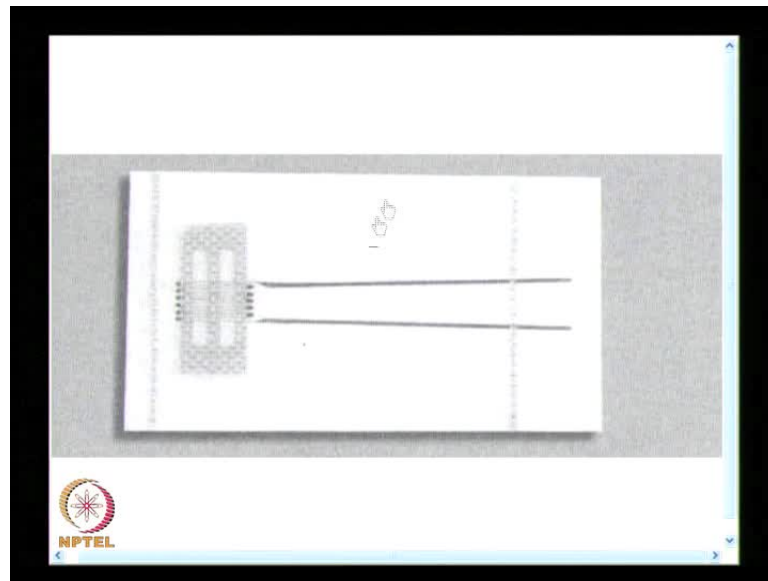
And in order to apply the ceramic, you need to have a special gun, and as I mentioned earlier, the tape is removed after the grid is secured to the component. So, it is a very involved process. You know it is not like simple strain gauge bonding, since you have to work at very high temperatures, you need to have a systematic procedure. Here we look at one family of strain gauges, which could be used for high temperature. There are also **weldable** strain gauges, which we are not paying attention now, but you should know, that for high temperature application, you also have another form of strain gauge, which could be welded to the base material.

Here we only look at forming a layer of ceramic, and remove the carrier, and again put another layer of ceramic, so that the gauge is properly bonded. And you have such gauges available commercially; and this is given by a **(( ))** micro measurements.

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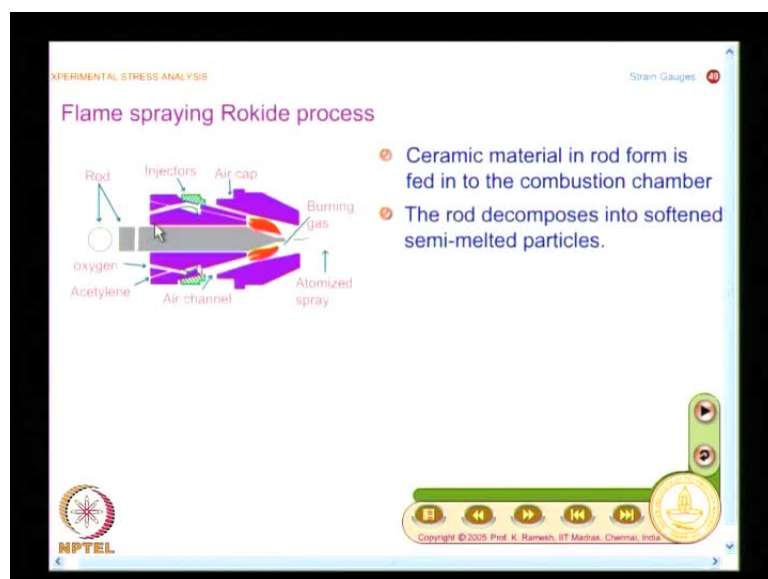


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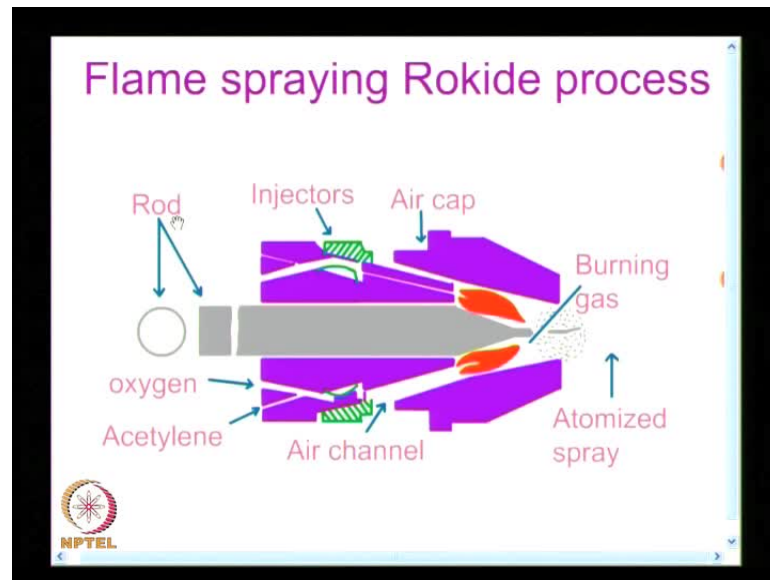
And they have what is known as Kanthal - is meant for high temperature strain gauge, and you could see the slotted Teflon tape carrier, and you have the strain gauge available like this; so this can be used to put the ceramic cement, and remove the carrier, and put another layer. So essentially, you will have only a ceramic base and you have a metallic foil. There is nothing like a polymer that comes in between; so at such high temperatures, they will not withstand that, they will **disintegrate**. So in order to make sure that your instrumentation is good at that high temperature, you form a ceramic layer.

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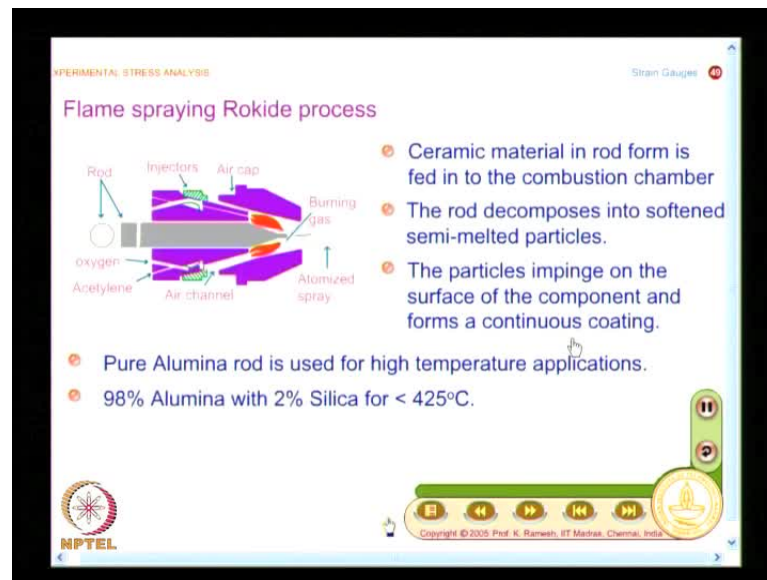
And how do you do this application of ceramics? So you have a special gun, this is the modification of your gas gun, and you feed the alumina as a rod. So you have a ceramic material in rod form is fed into the combustion chamber. And because of the high temperature, the rod decomposes into softened semi-melted particles.

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And you can actually have a closer look of this. So you have the ceramic rod, you have oxygen and acetylene, and at the outlet of the gun you have an **atomized** spray of ceramic particle. That is what you get. The idea is to get a fine spray, and spray it on the specimen; and by changing the rod, you could apply it for different temperature gauges; that also we will see. The material that will use for the rod, if you change it, you can work for different temperature gauges.

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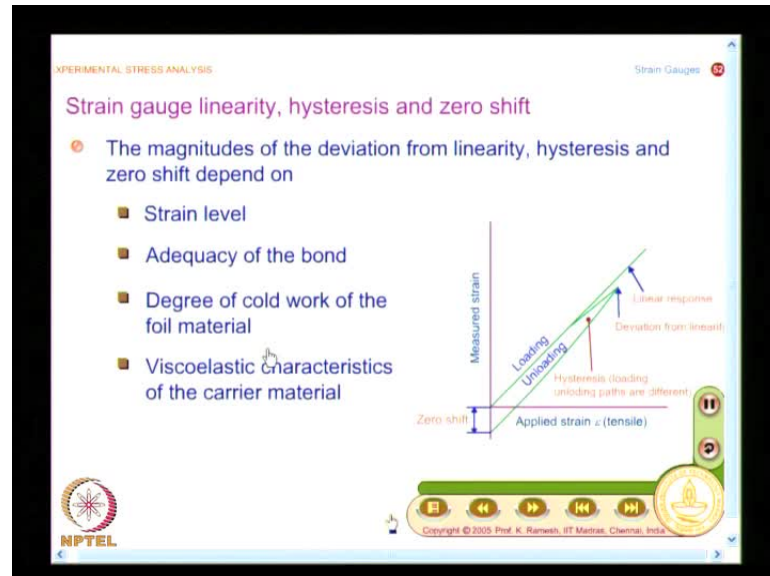
And what you find here is, you use a pure alumina rod for high temperature applications; on the other hand, if you use a rod which has 98 percent alumina with 2 percent silica, you could use it for applications below 425 degree centigrade.

So, what you have in this process is, the ceramic material in rod form is fed, and you have an atomized spray of these particles, and the particles impinge on the surface of the surface of the component and forms a continuous coating. Again, a very special process; it is not a simple spray gun, you have to handle it carefully for you to form a thin layer of ceramic.

Now, what we had looked at is, we had looked at the strain gauge system: system consisting of the metal foil, carrier and the adhesive. Now, we will have to look at how this system functions in actual practice, what considerations that we need to look at while selecting the constitutions of the system. Depending on the application, I will select the suitable alloy, suitable carrier and also a suitable adhesive. For high temperature, the selection is very simple: you know that you cannot use epoxy or polyester as an adhesive, you need to go for ceramic cement. But even from stability or hysteresis or linearity point of view, the constitutions play a role. You know that is what you have to look at. And I said strain gauge selection is the very, very important aspect that you need to learn, and for strain gauge selection, you need to have a background - what is the role of each of the constitutions. Though this information is descriptive, that information is

also needed from the point of view of selecting the appropriate system for your measurement.

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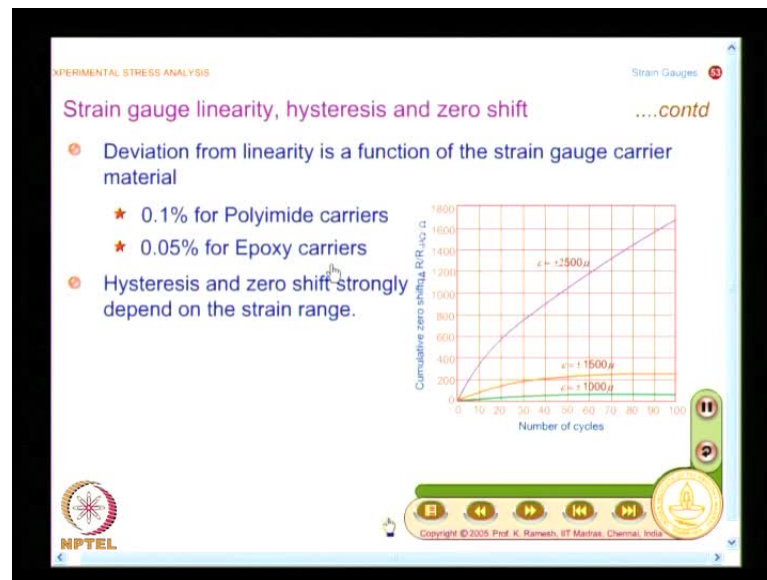


And we have already look at... you need to worry about strain gauge linearity, hysteresis and zero shift in any strain measurement application. And, what happens to the magnitudes of these like deviation from linearity, hysteresis and zero shift - they all depend on various factors: what is the strain level that which I operate, whether the bond is adequate, so that strain transferred from the specimen to the strain gauge is effectively carried out; and if you look at the property of the alloy, what is the degree of cold work or the foil material, and naturally, the viscoelastic characteristics of the carrier material.

Because we say that deviation from linearity, hysteresis - they all become very important in transducer applications, and you will find by changing the suitable carrier, it is possible for you to improve some of these aspects. That is why I said, you should view strain gauge as a system consisting of the alloy for the strain gauge metal foil, then you have the carrier, then you have the adhesive. Selection of all these three are interrelated; depending on the application, you should select it appropriately.



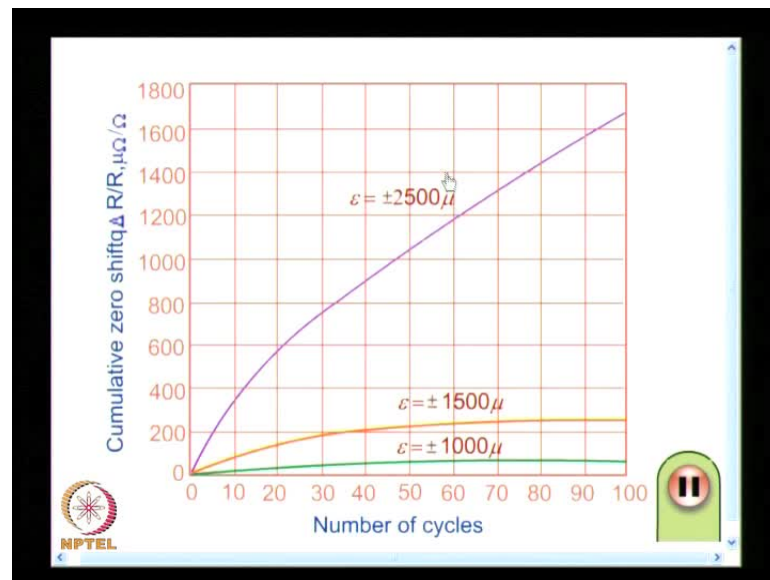
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And what I have here: suppose I want to minimize deviation from linearity, then choose an appropriate carrier. What you find is polyamide carriers the deviation is about 0.1 percent. On the other hand, if I go for epoxy carriers, this just half off it - is about 0.05 percent. But you know very well, polyamide is easy to handle. It is a plastic, even a beginner can handle this polyamide carrier. We have already looked at epoxies bridge; that is recommended for transducer applications. So what you find is, when I want to improve linearity, hysteresis, zero shift, I need to go for sophistication. It comes with the price; it does not come freely.

And we have also looked at strain level plays a role, and what is observed is, hysteresis and zero shift strongly depend on the strain gauge. And that is what is illustrated in this graph, you can have a look at it.

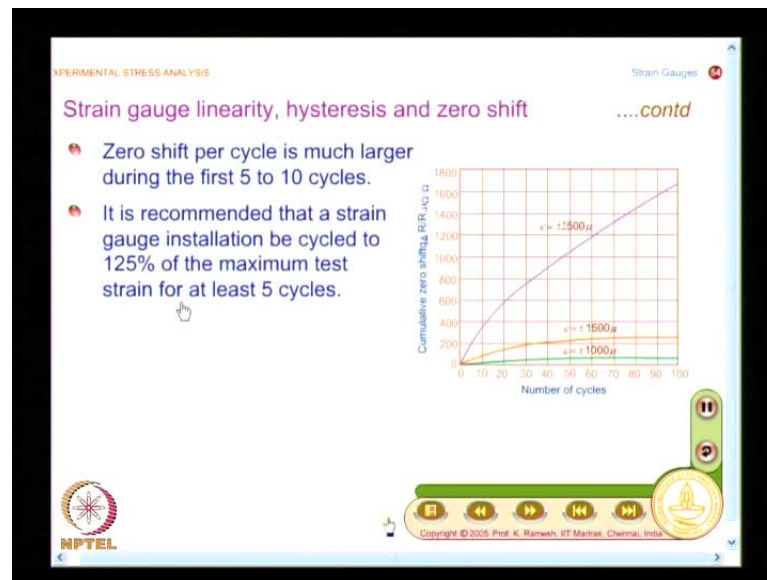
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So, what I have here is, on the x-axis I have number of cycles, and the y-axis you have cumulative zero shift, and the graph is plotted for a strain range of plus or minus 1000 micro strain; and another graph for 1500 micro strain, and the third graph for plus or minus 2500 micro strain. It is very high, it is going beyond elastic region; plus 2000 micro strain is the strain range at which you have the plastic deformation take place.

So what you find if you closely look at, you know there is the initial slope; as the number of cycles increased you have a radiant, and then it becomes horizontal - make a note of it. How do you use this information for strain gauge instrumentation, what is the recommendation - that will see now.

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The recommendation is, define that the zero shift changes the initial few cycles; so you have zero shift **per** cycle is much larger during the first 5 to 10 cycles, that is what the graph shows. So what you do is, it is recommended let us strain gauge installation be cycle to 125 percent of the maximum test strain, for at least 5 cycles. So you do not go and make the measurement as soon as you paste it, and the strain gauge is ready for measurement. You find that adhesives completely cured, you do not go **and do the make and the measurements.**

The advice is you do a strain cyclic; particularly when I making a transducer, I will do the calibration at the factory itself, where in you will load it, and beyond 125 percent, do a few cycles, and then ensure that the system as the whole is stabilized, then release it for actual measurement. Even in your regular test conditions, it is recommended that you do a strain measurement, before you make final measurement. From where thus knowledge **comes**? You find the zero shift is the function of the cycle. Initially, the zero shift is more; after about 10 or 15 cycles, it stabilizes. So the recommendation is, at least do 5 to 10 cycles. If you can do more, that is well and good enough. So that is what you get from looking at your observation on zero shift as the function of the strain range.

(Refer Slide Time: 20:02)

EXPERIMENTAL STRESS ANALYSIS

Strain Gauges

### Stability

- In certain applications it may be necessary to record strains over a period of months or years.
- Further, there may not be an opportunity to unload the specimen and recheck the zero drift.
- In such applications it is essential to choose the proper alloying material of the strain gauge, the type of carrier as well as the adhesive.
- Thus stability of the strain gauge system as a whole has to be looked into.

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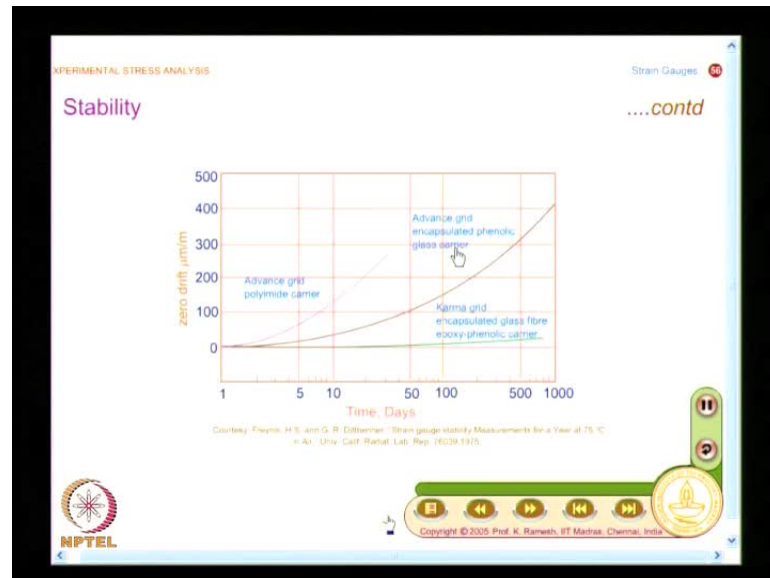
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Now we get on to another important issue in all strain gauge installation, **add its** stability. This become very important in applications, when you have to record the strains over a period of months or years - is not just that you do the strain measurement for immediate requirement, and forget about it. Suppose I want to monitor structures like dams and bridges, we may have to do it for long periods of time.

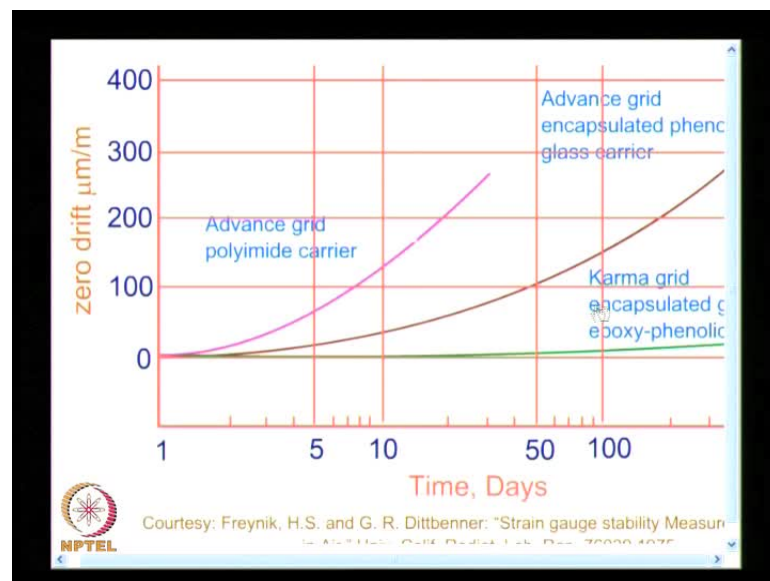
And in such applications, there may not be an opportunity to unload the specimen, and recheck the zero drift. So in such applications, it is better that you select a system that is stable for such applications. And when I say the strain gauge system have already set, you have to choose the proper alloying material of the strain gauge, the type of carrier, as well as the adhesive; all three go together. We will see a nice example where people have conducted experimentally for a long period of time, different alloy as well as the backing in the adhesive. When I change one after another, you find there is significant improvement.

So in applications where you have to record strain over a period of months or years, the stability of the strain gauge system as the whole has to be looked in to. So when I say a system as the whole, you should pay attention on selection of proper alloying material, type of carrier, as well as the adhesive. And you will have a nice example.

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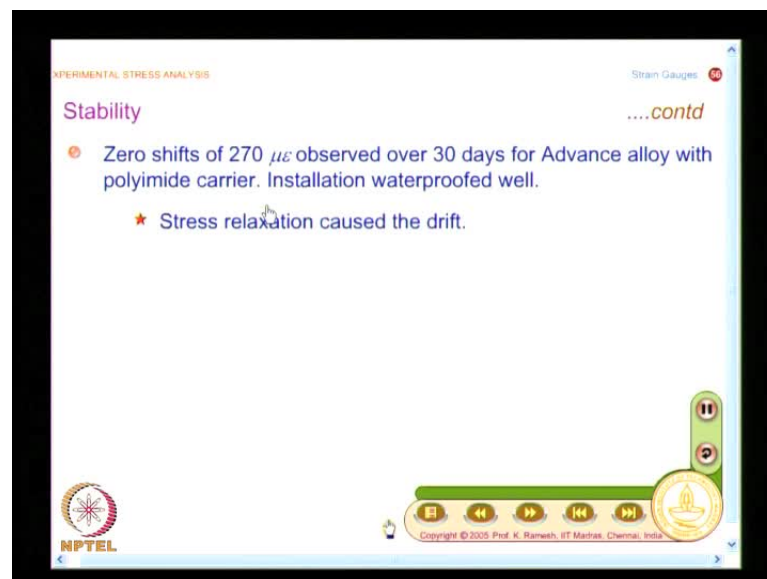
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I have a graph, which shows time versus zero shift; time is plotted in a log scale; I have 10 days, 100 days and 1000 days. And I have three graphs - I have one graph for strain gauge alloy, its advanced grid and polyamide carrier; and the second graph is the grid material is same - it is again advanced grid, encapsulated phenolic glass carrier, the carrier is made different, you have the encapsulation and you have the phenolic glass carrier, it is much better than the polyamide carrier. So what you find, you see a very significant zero shift in a simple advance with polyamide carrier, which is substantially reduced when I just change the carrier material.

And the third graph, which is almost close to 0, that you get from karma grid encapsulated with glass fiber epoxy phenolic carrier. So what you find here is, by changing the strain gauge alloy, what you find finally, the system as the whole has improved. From the first graph to second graph, you found that the carrier as indeed improved. A further improvement is possible by changing the alloy itself. So that is where I said, you need to look at strain gauge as a system. And you have a summary of the observation of the graph which is available in the next slide.

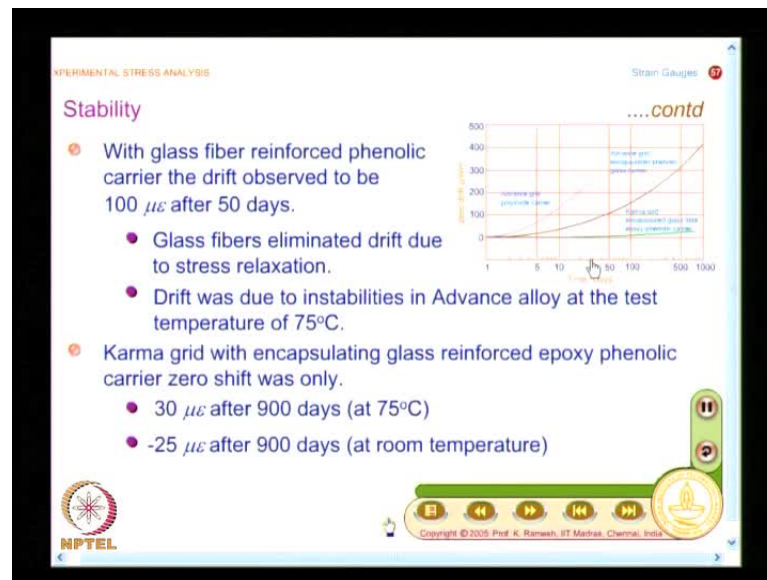
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And what you find here is, a zero shift of the order of 270 micro strain is observed after 30 days for advance alloy with polyamide carrier. And if you look at the installation, installation was water proofed well - there was no difficulty of moisture entering into it, and **deteriorating** the strain gauge bonding. And what people found was, the carrier is not taking the load properly, so there was stress relaxation, which just caused the drift.

And when you are making a measurement, 270 micro strain is very high; if the zero shift itself is 270 micro strain, then what level of confidence you will have in the final measurement. So for a given application, you need to find out, have you selected the right combination of strain gauge alloy, carrier, as well as the disk. And you see in stages - initially we saw 270 micro strain, which is very bad.

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Now I go and improve the carrier instead of polyamide; if I use the glass fiber reinforced phenolic carrier, the drift has reduced from 270 micro strain to 100 micro strain, even after 50 days. In fact, that is what is listed in this graph. This is about 270 micro strain. This you see at the end of 30 days; and at the end of 50 days, you find only a 100 micro strain, by just changing the carrier for the strain gauge.

So whatever the stress relaxation, the glass fibers eliminated that effect. And also the whole test was done at 75 degree centigrade. See we have already noted that advance alloy is the good strain gauge alloy for room temperature applications; and they also noticed, that drift was due to instabilities in advance alloy, at the test temperature of 75 degree centigrade. So, once you notice this, change the strain gauge alloy to karma grid, by retaining the same carrier with encapsulating glass reinforce epoxy phenolic carrier. Zero shift was only 30 micro **second** after 900 days, so that means so almost like 3 years 2 and half years.

For two and half years absolutely no problem in your strain measurement. But when I take a karma grid, what happens - it is difficult to solve the taps. So, you need to go for factory supplied lead wires. Strain gauge also comes with three attached lead wire systems. So, you need to go for that kind of a strain gauge, for you to use in such applications. So all that is expensive. See if you go and solder your own lead wire, the costs are less. But, if you have to get the pre attached lead wire, cost is high; and glass

reinforced epoxy phenolic carrier is again expensive. So when you find your application demands high stability, **then** it is what is spending money for such applications. So you need to select, you cannot take things for granted - stability is an issue.

So you need to worry about what temperature that you are working at, and what backing that you are using, and what adhesive. Here the adhesive role is not emphasis that much, and what **we** find is karma grid as work, as 75 degree centigrade quite well - even at room temperature, instead of positive drift, it has a negative drift of minus 25 micro epsilon.

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EXPERIMENTAL STRESS ANALYSIS

Strain Gauges

Stability

....contd

- For long term measurements Karma grids with glass fiber reinforced epoxy phenolic carriers with a well cured epoxy adhesive system is recommended.
- The gauge installation should be waterproofed to minimize moisture penetration.
- Bridge completion resistors should be hermetically sealed to ensure stability of the bridge.

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See what you have here is for long term measurements, karma grids with glass fiber reinforced epoxy phenolic carriers, with a well cured epoxy adhesive system is recommended. I said that adhesive as not be mentioned, but what you find here is for any sophisticated applications, people go for epoxy adhesive.

And you should also ensure that the gauge installation is water proofed well. You do this to minimize moisture penetration. Not only this, see we have already seen in a strain measuring instrument, I need to have completion resistors. The bridge completion resistors should be hermetically sealed to ensure stability of the bridge. See the idea is, you have taken care of the strain gauge installation: you **have** selected the right type of the alloy, carrier, as well as the adhesive. But now you have to make the measurement using a (( )) stone bridge, and (( )) stone bridge has completion resistors - because in



many applications we may do only a quarter bridge, the other three resistors are there in the (( )) stone bridge, and these have also to be waterproofed well - because you are trying to make the measurement for long durations.

You know sometimes you may ignore this, you may take it for granted that the instrumentation will automatically take care; so you need to go for properly shield completion resistors for such long term applications. It is very important and this completes. So what you find is for stability, go for karma grids with glass fiber reinforce epoxy phenolic carrier with well cured epoxy adhesive, and also ensure in your bridge completion resistors to be hermetically see.

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EXPERIMENTAL STRESS ANALYSIS

Strain Gauges

### Heat dissipation

- Local heating takes place in the strain gauge due to  $I^2R$  loss. This causes a change in temperature.
- A change in temperature also causes a change in the resistance of the strain gauge, thereby, spurious strain signals would be produced.
- One of the most challenging aspect of strain gauge instrumentation is to carefully account for the temperature changes.
- Thus, heat dissipation assumes importance.

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Now we move on to one of the other important aspect in strain gauge instrumentation, namely, heat dissipation. See when you come to thermal effects, you need to dealing two effects: one is I worked at moderately high temperature than the room temperature. Suppose I want to measure strains on a IC engines, then I may have to put it at the IC engine block, and find out that temperature will be higher than the room temperature.

So in such applications, I should measure the temperature by a thermo couple, and then either look at thermally induced apparent strain and subtract it; or put another strain gauge which is at the similar temperature and make it as a half bridge, and handle the thermal effect. This is one type of thermal influence.

The other type of thermal influence what you need to worry about, is heat generation due to  $I^2R$  loss. This is very **subtle**. See in many applications, if you have working at high temperature, compensating for that you may do it more by a routine, because that is very obvious. What is **subtle** is, because current flows through the conductor, the strain gauge itself get heated. This is a very subtle issue and you need to find out what parameter at influence, given the selection of the grid size can make; and what is the voltage that I applied to be stone bridge for making my measurements that also can influence. So here again you have to look at system as a whole, and find out a remedy.

And why we need to worry about this, whatever is the  $I^2R$  loss, this causes a change in the temperature, which in turn causes the change in the resistance of the strain gauge; thereby spurious strain signals would be produced. So I need to eliminate this spurious signals. And this is the most challenging aspect of strain gauge instrumentation. And from this point of view, heat dissipation assumes importance. Whether you like it or not, strain gauge get heated, and you need to look for how to dissipate this heat generated. What are all the parameters that I have to look at, so that I minimize any temperature raise, because of buildup of heat **due** to  $I^2R$  loss. That is the focus.

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EXPERIMENTAL STRESS ANALYSIS

Heat dissipation

Factors influencing heat dissipation are

- ★ Gauge size (width and length)
- ★ Grid configuration, spacing and size of conducting elements.
- ★ Carrier, type of polymer and thickness.
- ★ Adhesive, type of polymer and thickness.
- ★ Specimen material, thermal diffusivity.
- ★ Specimen volume in the local area of the gauge.
- ★ Type and thickness of weathering coat used.
- ★ Velocity of the air flowing over the installation.

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And it depends on various factors. The first factor is, what is the gauge size - if you look at the catalog of strain gauge by the manufacturers, you will find gauges of various width and length to **suit** different applications.

The second aspect is, what is the configuration of the grid and what is the spacing and size of the conducting elements? See, when you say the configuration, I had already mention, I can have a row set with (( )) strain gauges separately aligned, and I can also have them as tract. And from measurement point of view, the approximations involve in idealizing the point on which you make the measurement, stack row sets are better. But stack row sets bring in another problem - the heat generation will be much more in a stacked row set than the normal rectangular row set, where they are kept slightly away from the point of interest. They meet at a point of interest; they are not exactly on the point of interest for which you want to make the strain measurement.

So grid configuration matters, and what is the type of carrier, and what is the type of polymer, and what is its thickness. You can also say the similar thing for the adhesive; and if you look at the specimen material, that also plays a role. Am I working on copper, or am I working on steel, or am I working on plastics - the specimen material matters. Not only this - I may work on copper, or I may work on steel, but even the specimen volume at the point of interest matters. If you have a very thick block of copper, then heat dissipation is not at all a problem. So apart from specimen material, specimen volume also plays a role.

And we have always been saying, whenever you do a strain gauge installation, we must provide a proper coating, so that changes in weather does not affect your installation. That is good from one point of view - it prevents moisture absorption. From heat dissipation point of view, what is the type of weathering is used, and what is its thickness also plays a role. Because if I put a very thick weathering coat, you are not allowing heat to dissipate. On the other hand, if I have a high velocity of the air flowing over the installation, it is well and good.

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EXPERIMENTAL STRESS ANALYSIS

Strain Gauges

### Allowable power density

- Power density  $P_D = P/A$
- $P$  is the power to be dissipated ( $I^2R$  Loss)
- $A$  is the grid area.

Allowable Power densities

Power density		Specimen conditions
(W/in <sup>2</sup> )	(W/mm <sup>2</sup> )	
5 - 10	0.008 - 0.016	Heavy aluminum or copper section
2 - 5	0.003 - 0.008	Heavy steel sections
1 - 2	0.0015 - 0.003	Thin steel sections
0.2 - 0.5	0.0003 - 0.0008	Fiber glass, glass, ceramics
0.02 - 0.05	0.00003 - 0.00008	Unfilled plastics

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So the manufacturer also looks at it differently. They recommend what is the allowable power density; that is the way they look at it. So you have a power density defined as  $P$  by  $A$ .  $P$  is the power to be dissipated, that you can also calculate from  $I^2R$  loss, and  $A$  is the grid area.

See, later we will also go and see selection of strain gauge, where will see a variety of patterns, and you will find, you get gauges of different grid area. Why such grids are available, you will know from charts that say for a given application, and a given power density, what kind of grid patterns I can select. So I need to look at and approach the problem scientifically; so I have a parameter for a given type of specimen material and for the thickness what is mention - this is the power density that it can safely operate.

And what you find here is, if I have a heavy aluminum or copper section, the power density permissible in watts per millimeter squared ranges from 0.008 to 0.016. And when I go for heavy steel sections, the power density value reduces; and when I go for thin steel sections, it reduces further. And when I go for poor conductors like fiber glass, glass, ceramics, unfilled plastics the power density permissible is almost close to 0. It is very, very small - so you need to have very efficient heat dissipation. And that is the reason I said, if you have to work on composites, which are becoming very important structural members, you need to go for higher strain gauge resistances. And mind you, when you go for higher strain gauge resistances, they are also very expensive and not

cheap. Because we have already looked at making a small strain gauge with even 100 ohms, you needed a longer wire. So if I want to have 1000 ohms at the same place, unless I improve my technology, is not possible. And when improvement technology also demands high cost. So if you want to go for sophisticated applications, you need to go in for higher cost; has no other way that is available for you.

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EXPERIMENTAL STRESS ANALYSIS

Strain Gauges

### Allowable power density

#### Allowable Power densities

Power density		Specimen conditions
(W/in <sup>2</sup> )	(W/mm <sup>2</sup> )	
5 - 10	0.008 - 0.016	Heavy aluminum or copper section
2 - 5	0.003 - 0.008	Heavy steel sections
1 - 2	0.0015 - 0.003	Thin steel sections
0.2 - 0.5	0.0003 - 0.0008	Fiber glass, glass, ceramics
0.02 - 0.05	0.00003 - 0.00008	Unfilled plastics

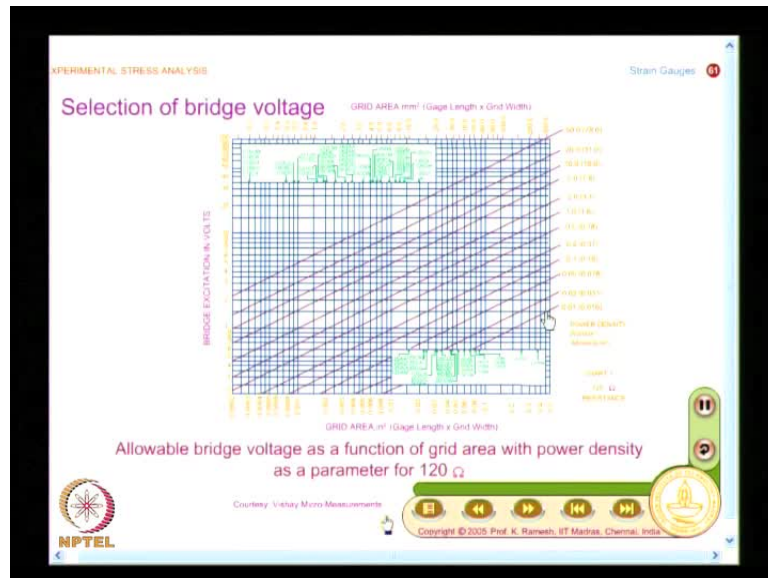
- Allowable power densities are strongly related to the specimen.

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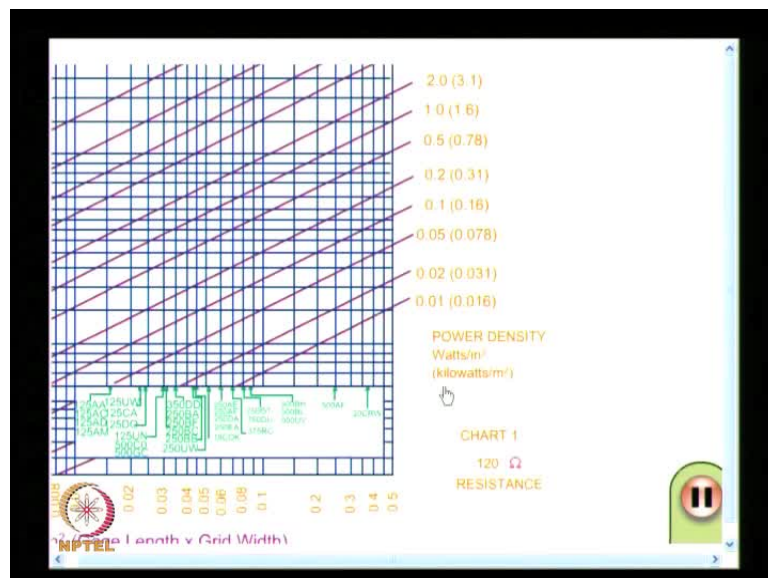
So this is what you have to look at: allowable power densities are strongly related to the specimen. That is what this table essentially brings out. So in a strain gauge installation, I said strain gauge as the system consisting of grid alloy, carrier, and adhesive - now you find from the heat dissipation point of view, even the specimen material decrease.

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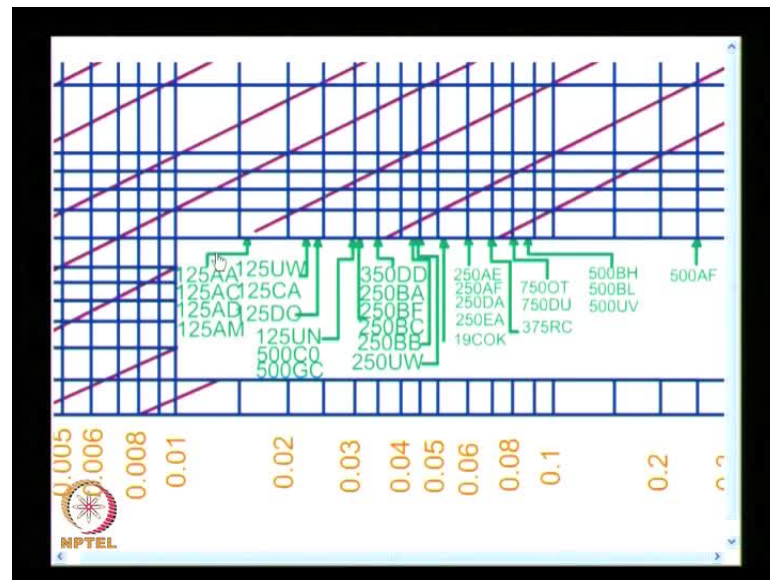
And the manufacturer supplies you with the such complicated graphs. I will try to explain it with the very simple fashion. So, on the x-axis, you have a grid area. I will also enlarge it a little while later. First on the x-axis, note that you have a grid area; on the y axis, you have the bridge excitation voltage. So my idea is to find out the excitation voltage, so that I satisfy the power density requirement. And what you have here is, on the graph you find slanted lines - these lines indicate different values of power density.

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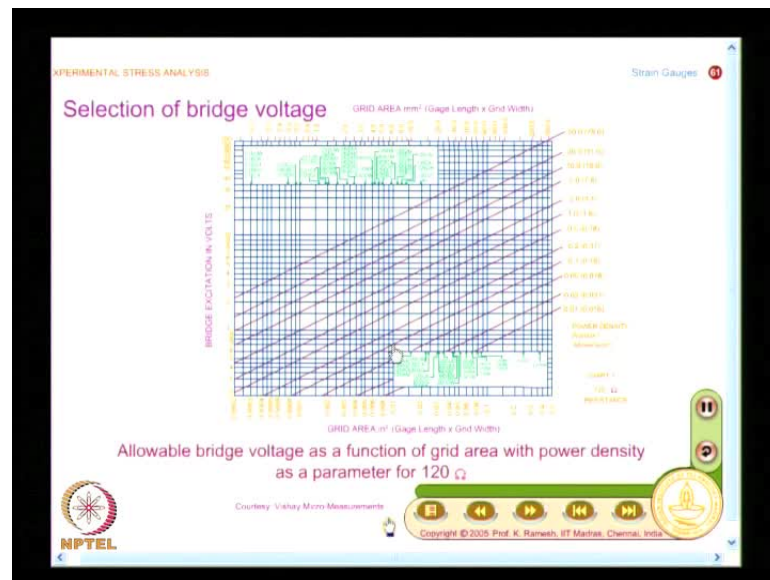
So if you look at it zoom - so what I find here is, I have a line for 0.01 watts per inch squared, or it is 0.016 kilowatt per meter square, and the power density increases in this fashion. So if I know for a particular specimen material, only a particular power density is permitted, then this tells me what kind of great patterns which I can choose.

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I suppose you are able to see this letters, is have not able to enlarge it, and what you find here as 250AE, 250AF - they indicate, first is the length of the gauge length, expressed in mills, and AE, AF, DA, EA - all this pertain to particular strain gauge manufacturers classification of the grid pattern. You have so many grid patterns - you know they shown out many different grid patterns, and for each one of the manufacturer will provide you a graph like this, for you to select the suitable grid pattern, and also decide on the selection of bridge excitation voltage.

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And if you look at the graph, you have a cluster of gauge grid identification here. You have another cluster of gauge grid identification here. This is essentially grid area. You could have a wider grid, you could have a narrow grid - you have different types of pattern. You know your measurement application you decide whether you need a wide grid, or narrow grid - all that decisions you will have to take

And if you also look at this graph, is available for 120 ohms - and this is the particular graph for 120 ohm strain gauges. Suppose I go for a 350-ohm strain gauges, these power density graphs get shifted. So, that means, I can offer to apply a higher voltage for the same power density if I use a higher resistance of the strain gauge. And you have also have another graph for 1000 ohms, this is just to give you an idea such selection graphs are available from the manufacturer.



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EXPERIMENTAL STRESS ANALYSIS

Strain Gauges

....contd

**Selection of bridge voltage**

- Most commercial strain indicators use bridge voltage between 3 to 5 V.
- Small gauges mounted on a poor heat sink result in lower allowable bridge voltage.
  - ★  $P_D < 1 \text{ W/in}^2$  or  $0.0015 \text{ W/mm}^2$
  - ★ Use a higher resistance gauge or a gauge with a larger grid area.

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So how I go about and select the bridge voltage? If we look at most common strain indicators, use bridge voltage between 3 to 5 volts. Small gauges mounted on a poor heat sink result in lower allowable bridge voltage. So there is the reason, when we had a discussion on selection of gauge length, we saw if the strain is varying linearly. Length of the gauge length do not matter in interpreting the strain at the center of the strain gauge; only when there is the non-linear variation, when I need to worry about selecting a suitable gauge length. I will also caution, when you select a smaller gauge length - is expensive, difficult to make - and in addition, you need to worry about what is the bridge excitation voltage that you can select; and also make special provisions for heat dissipation. You must allow a stream of air for you to cool the strain gauge installations or some such special attention you need to pay.

And suppose you are unable to improve your heat dissipation so the external means, you can at least think of using a higher resistance gauge, or a gauge with the larger grid area. This is the kind of selection compromise: see if I have a larger grid area, then I am deviating from idealizing measurement of strain at a point. I am measuring it only through area. This is possible only then the strain variations are small as a function of distances. So selection compromises always exist - without compromises, you will not be able to handle a problem.

(Refer Slide Time: 47:15)

EXPERIMENTAL STRESS ANALYSIS

Strain Gauges

### Sensitivity of gauge to temperature

- When the ambient temperature changes
  - The strain sensitivity ( $S_A$ ) of the metal alloy used for the grid changes.
  - Variation in  $S_A$  for  $\pm 10^\circ\text{C}$  is usually neglected.
  - The gauge grid either elongates or contracts.
  - The specimen either elongates or contracts.
  - The resistance of the gauge changes.

$$\Delta R/R = S_T \Delta T$$

Where  $S_T$  is sensitivity of gauge to temperature

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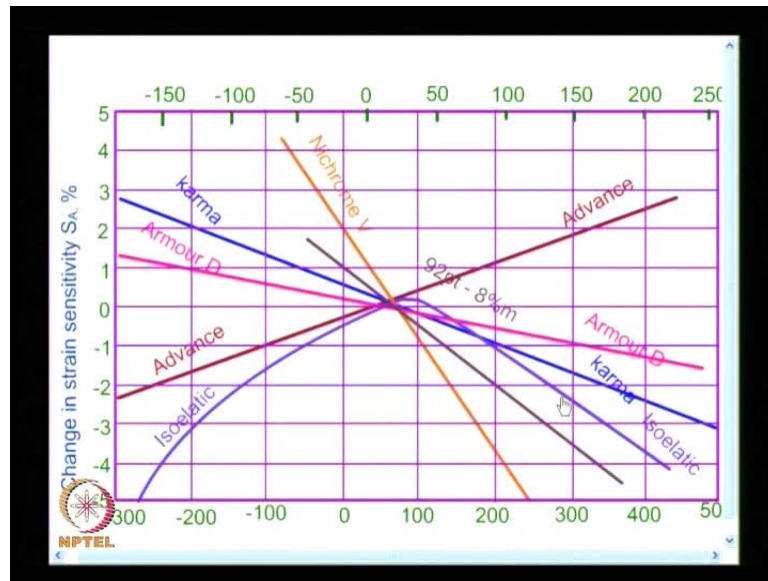
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Now we have talked about influences of temperature. In some form, you should also look at what is the sensitivity of the gauged temperature - what happens when the temperature ... The strain sensitivity  $S_A$  of the metal alloy used for the grid changes. We will have to see how does it change - that is the question.

And for simplification, for a change of plus or minus 10 degree centigrade, the variation of  $S_A$  is usually neglected. And it is obvious, depending on the coefficient of expansion; when the temperature changes, the gauge grid either elongates or contracts; specimen either elongates or contracts, depending on the delta T. And you also find, the resistance of the gauge changes, because we have earlier written, the change of resistance original resistance has  $S_T$  in to epsilon. On similar lines, you write the expression  $S_T$  into delta T. And you label  $S_T$  as, sensitivity of gauge to temperature.  $S_T$  is the gauge factor which is used in interpretation of change in resistance to axial strain. When I bring in effect of temperature, I bring in another parameter called  $S_T$ , which has to be evaluated again experimental.

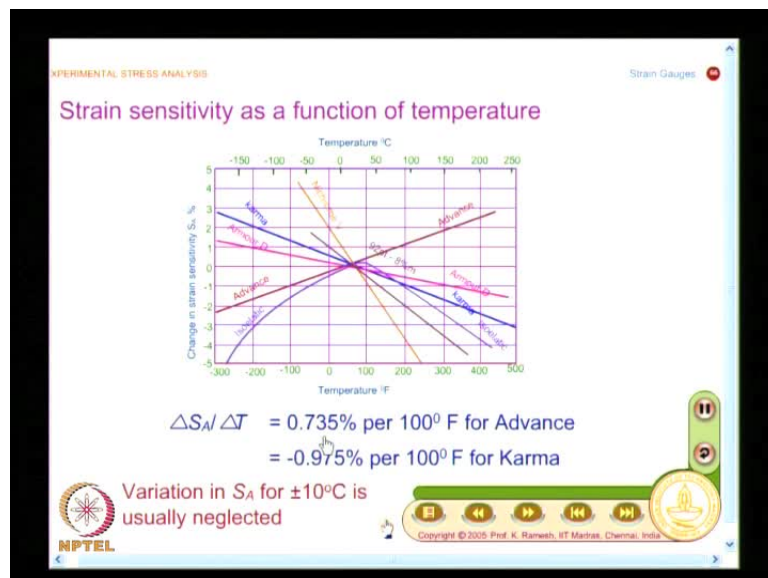
How does this  $S_A$  change as the function of temperature?

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And what you find is, fortunately it is the linear graph, for the popular strain gauge material like advance karma, as well as high temperature applications like nichrome, armour D, as well as the platinum constraint type of strain gauge alloy. Only for isoelastic, it is non-linear. So if it is linear, it is good enough. So you just make to note, that advance and karma it is varying linearly, that is what you need to worry about, itself variation is linear; fortunately, it is linear. So we can do some kind of a correction in that.

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So what you find in quantitative terms is, change in the strain sensitivity of the conductor as the function of change in temperature is 0.735 percent per 100 degree Fahrenheit for advance. It is minus 0.95 percent per 100 degree Fahrenheit for karma. So you have this data: it is possible because strain gauge is constructed based on a conductor, so I need to know the conductor property. Then I need to look at, when I make it as the loop, how does this changes. So what we will look at is, handling temperature information and segregating the change in resistance you to stress applied, and temperature change is the most challenging aspect in strain gauge instrumentation.

So in today's class, what we saw was we will looked at how to use ceramic cements and what is the kind of strain gauge that you need to use for high temperature application. Then we moved on to performance analysis of the strain gauge system. I said you need to worry about deviation from linearity, hysteresis, as well as zero shift. And we found the constitutions forming a strain gauge influence these aspects. We saw selection of the carrier influences the linearity; selection of the alloy as well as the carrier, and an appropriate adhesive can improve stability for a very long duration - for selection is very important. Then we moved on to another subtle issue - how does temperature changes occur.

One of the subtle changes is current flowing through the strain gauge itself can heat it up, and you find the heat dissipation is the function of the specimen material. Not only the strain gauge system, you should also consider on which material we want to operate, which decides selection of the bridge voltage also indirectly decides the selection of the resistance of the strain gauge alloy, and also the type of grid - whether you want to go for a wider grid or smaller grid or whether you want to go for stack rows is possible or whether you need to go for un stack row sets only - possible for this kind of heat dissipation. All those decisions are dictated by the heat dissipation capacity of the specimen material. So, this takes you a step ahead on how to do effective strain gauge instrumentation.