Experimental Stress Analysis
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Lecture – 28
Introduction to Strain Gauges

In the last class, we had looked at in detail what is brittle coating test, we have looked at the methodology in conducting brittle coating test. We looked at formation of cracks in direct loading. We have also looked at when you have compressive stresses. What kind of the methodology you need to adopt to reveal the crack patterns and also in low stressed regions, I said, by refrigeration technique, it is possible to reveal the crack patterns.

The moment you know the crack patterns, it is possible for you to identify the (()) (00:51) direction, thereby reducing one strain gauge per point for detailed measurement. I also mentioned the isoentatics what you get in brittle coating test could also be used to find out approximately the magnitude of the stress at that point and I also mentioned how will you handle this isoentatic data.

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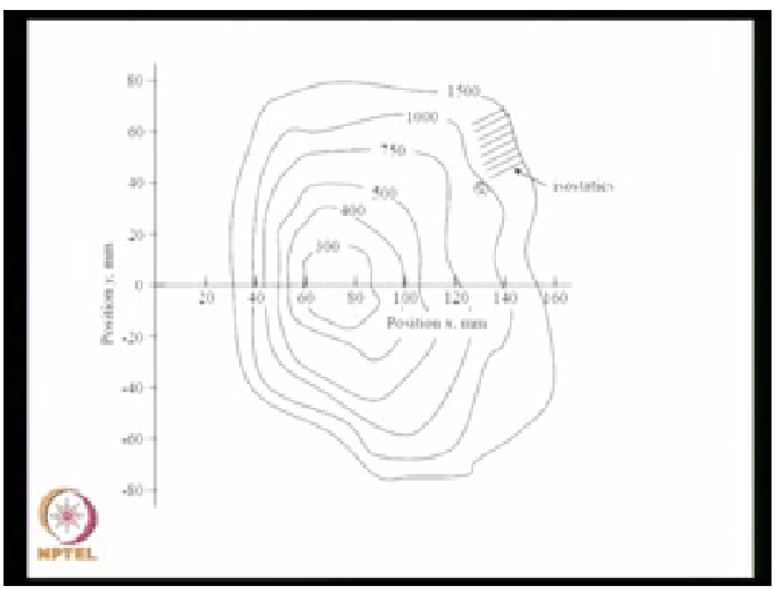

Let us look at a sample, isoentatic data, and what I have here is for different loads from 300 Newtons, 400 Newtons, 500 Newtons, you had these isoentatic curves obtained and these (()) (01:35) and typically you will have a crack pattern like this and you join only the end of this cracks. So the idea is definitely at the end of this cracks, you will have the failure strain of the coating is reached at that point in the specimen but this is obtained for a load of 1500 Newtons and this contour is appended for 300 Newtons and so on.

So the idea is when you conduct a brittle coating test, this is what you will mark. You will load it incrementally. For every incremental loading, you mark the isoentatic and from your calibration test, you also get the failure strain of the coating which could be expressed in many different ways. I can express it as a failure strain or I could see what is the failure stress of the coating or you can also mention it as failure stress corresponding to the specimen stress at that point in time.

So for a given specimen stress value, the coating will fail. So indirectly what you get is, you get the specimen stress at the point of interest. Now the question is, you know we are living in linear elasticity. I can employee principle of superposition. Now how do I interpret this isoentatic data. For example if I want to find out what happens along a line Y=20 millimeter. It will cut several isoentatic curves.

So what you need to do is, you need to find out for each of these curves what is the corresponding stress developed on the specimen and what I had mentioned, it is the initial set of cracks that are very important and obviously what all the stress developed when you have a first isoentatic curve, that would be the maximum value. For all the other loads, you will have less stress developed.

This is what you have to keep in mind because you know by increasing the load applied and you have to report the stress value corresponding to a particular given load. At that point, because it is stressed low, I had to apply a larger specimen stress for me to make the coating at that point to fail and we will look at.

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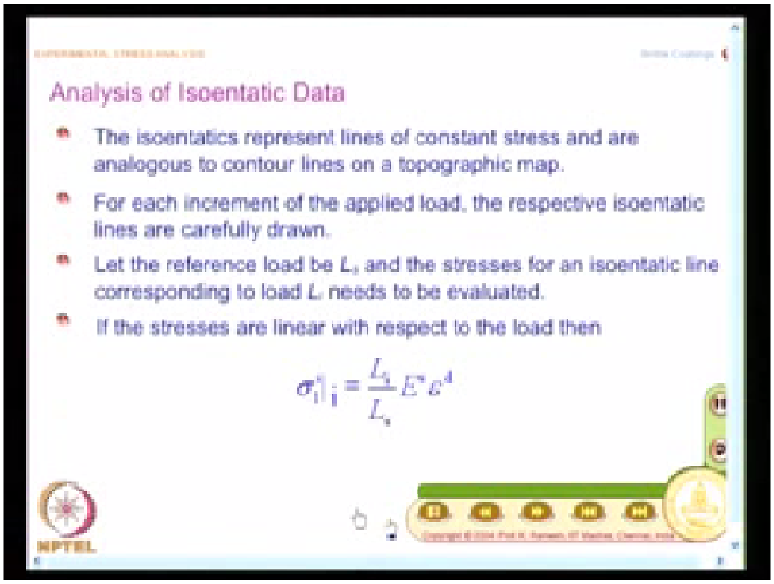

So what you have here is when I want to do the analysis of isoentatic data, let us consider the referenced load be Ls and let us find out for an isoentatic line corresponding to load Li needs to be evaluated and for the reference load, I have the failure strain epsilon d and for the given load, it becomes Li/Ls*Es*epsilon d. So I Get the value of the specimen stress at the isoentatic line given by this expression.

And I mentioned you know even when you do a very careful experimentation, epsilon d can be determined only with +-20% accuracy and here also we are invoking one more approximation, the principle stress value remains approximately constant at the end of the cracks, that is what you joined by isoentatic line. So whatever the estimation of stress that you get is an approximate value good enough from solving an industrial problem.

That is the way you will have look at it. So this brings to a close of our discussion on brittle coating techniques. Now we will take it what are strain gauges, what are the topics that need to look at in strain gauges and we will also look at the historical development and develop pertinent equations for you to carry on with the methodology.

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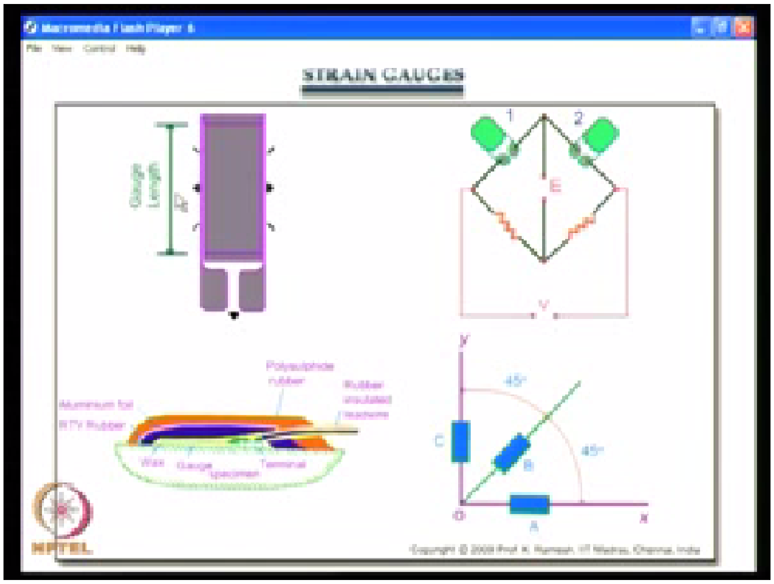

and the moment you take up strain gauges, you need to know that strain gauge has a finite area and you have a definition of what is the gauge length, this is very important, we will discuss that even in the initial lecture today. Then whatever the change in the resistance, you need to measure it by an appropriate circuit. Here I have a Wheatstone bridge shown and this also has 2 strain gauges connected and this is in a half bridge configuration.

In fact this is a most celebrated one because it also has temperature compensation provided when these 2 strain gauges are representing the point at the model of interest and the one which is also kept at the same temperature so that any temperature effect happening at the specimen is compensated by the second strain gauge. Then you have how strain gauges need to be protected in an aggressive environment that is also very important.

You have several layers of coating applied, particularly when you want to do it underwater the piping and anything to do with that kind of aggressive environment, you need well protected strain gauge installation and I have always mentioned that strain gauge gives component of strain along its gauge length. Suppose I have to find out strain at a point, then I need 3 strain gauges.

And here it is shown as a rectangular rosette and you also make an approximation that you pay strain gauges here where it measures the strain at the point O. So there are engineering approximations in the methodology of strain gauges that you will have to appreciate it. Now we will get into the details and I have always been looking at historical development of any of these experimental techniques.

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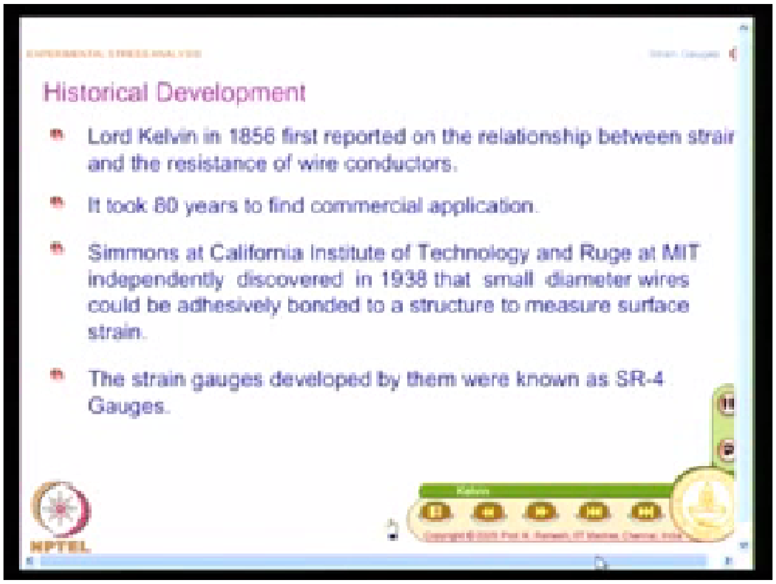

And we have already looked at it was Lord Kelvin in 1856 reported on the relationship between strain and the resistance of wire conductors and you all know it took almost 80 years to find commercial application and one of the earliest strain gauge was developed around 1938 and there have been contributions by Simmons at California Institute of Technology and Ruge at MIT, they have contributed.

And we will see this development a little while later and what are the strain gauge developed by them was famously known as SR-4 strain gauge, we will see, S stands for Simmons and R stands for Ruge and 4 stands for a team of 4 people who have contributed. We will see that development in detail.

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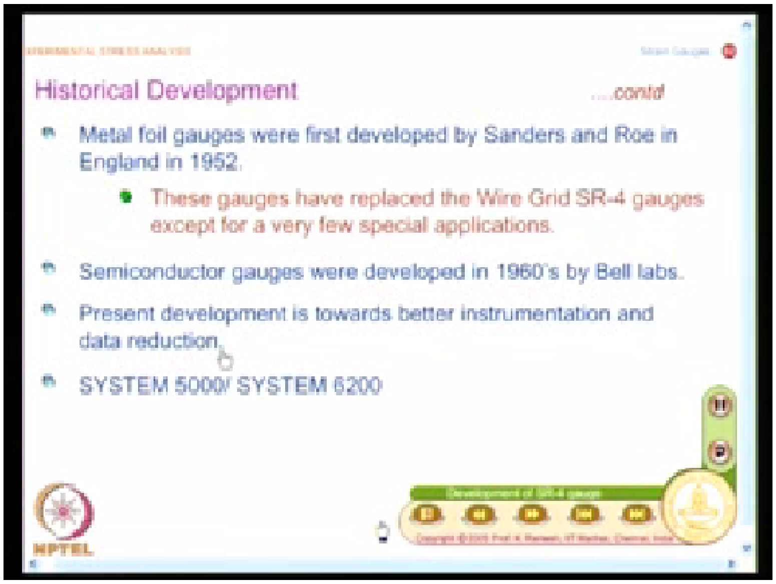

So after the small diameter wire that is used as a strain gauge, people also developed what is known as a metal foil strain gauge that was in 1952 and this was developed by Sanders and Roe and we will also spend time in dealing with metal foil gauges in this course and these gauges have replaced the Wire Grid SR-4 gauge except for a few special applications. You know the metal foil strain gauge has lot of advantages.

I said that if you want to measure the strain at a point, you need to measure the (()) (10:27). I need to evaluate 3 quantities, so I need to have 3 equations, so I need to make 3 measurements, so I need to have strain gauges prealigned and this could be done very comfortably in a metal foil and also the advantages, the metal foil can be very thin so that I can have a varying high resistance for the strain gauge and many advantages and after the development of metal foil gauges, the major development was Semiconductor gauges.

This was developed in 1960s for very special applications and if you look at what is the current focus, it is towards better instrumentation and data reduction. So as the technology is advancing, more refinements come into place. You know with computer technology, I can handle thousand channels comfortably now, which was not possible earlier. You may be able to have few channels to start with and you can also go for dynamic strain measurement.

All that is because of advancements in electronics and you know one of the earliest in the step was by Vishay Measurements Group, they have come out with system 5000, system 6200. Now they have the 7000 also. So these numbers keep improving in terms of the accuracy, in terms of number of channels, in terms for speed. So you see a development on instrumentation.

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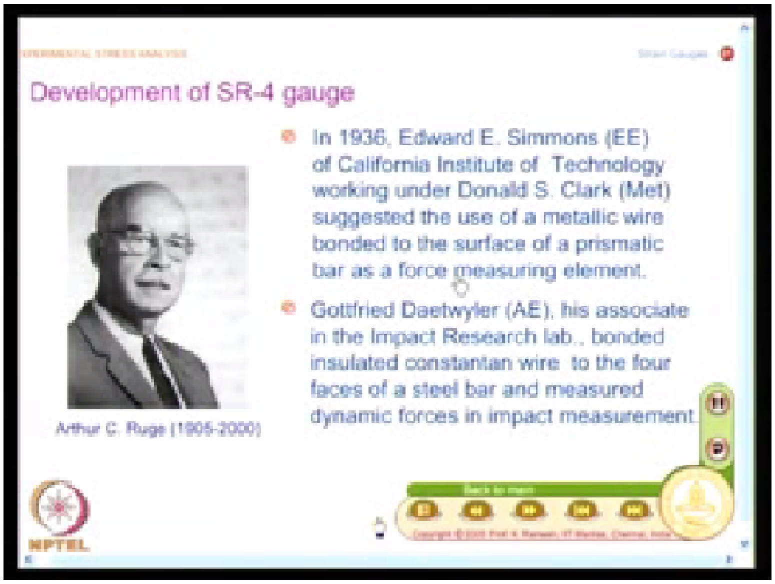

And you know it is worth noting what contributed to the development of SR-4 gauge. See you how to note down that no development is done by an individual, that is my interest, that is point number 1. Point number 2 is, you also find a team of scientists who work together. It is not from 1 branch, it is from multiple branches have contributed to the development of the strain gauge technology and another interesting feature is, you know it was developed during a time where there was not much communication.

You had Simmons was developing strain gauge in a different context. His contributions were not known to Ruge who developed and reinvented in 1938. We will see those details and you know you can just listen to this, at least make few salient points, I have detailed the set of points. You do not have to write all of them. The focus here is, in 1936, marked as a very important year for strain gauge development and it was Simmons who suggested to bond wire for measurement of stresses in an impact test and he was an electrical engineer.

He was working under Donald S. Clark who was the material scientist, metallurgy and material scientist and the person who actually measured the force was aerospace scientist. See only when different minds meet, new ideas develop and Simmons was credited to be very inventive in his approach. So when they faced the problem in impact force measurement, they consulted Simmons and Simmons suggested why do you take a wire and bond it.

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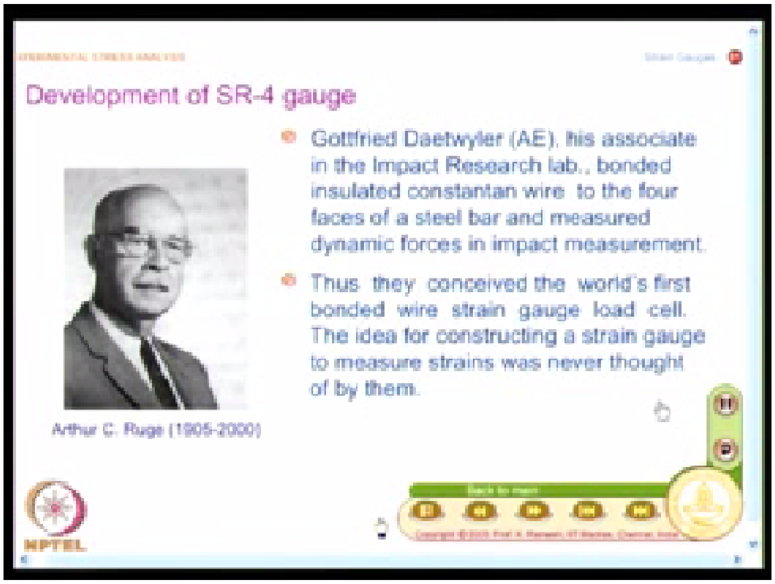

And if you really look at their contribution, they did not know at that time that they are going to develop a strain gauge. They focused only on measuring the force but before measuring the force, they took a wire from one of the standard resistance, resistors available, they put it on clocks spring and then flexed it and the first strain measurement they made was for 7000 microstrain. Imagine it is well beyond elastic limit. So large quantities you can measure and they also had a strain gauge which had initial resistance of 17 ohms.

They found after it is the flexed, that beam is flexed, you find a change of 0.25 ohms, that is what they had measured which worked out to 7000 microstrain. Now strain gauge technology is so well developed that I can measure 0.5 microstrain but if you look at the development, they were not really focusing on measuring strain. They actually conceived the world's first bonded wire strain gauge load cell, though they used this phenomena of bonding a wire and measuring the strain, it was actually for a load cell.

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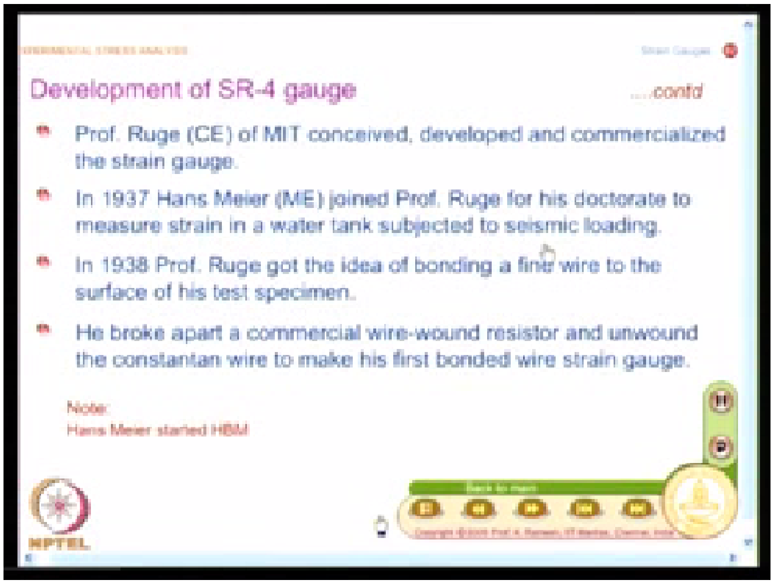

And you know meanwhile Ruge is a civil engineer by training, he conceived, developed and commercialised the strain gauge but this happened in 1938 and you should also know you know he had a student with a mechanical engineering background, Hans Meier and he was supposed to work on the problem of analysing a water tank subjected to seismic loading and you should also know, you know, theses are not designed on the first day when you join under a professor.

If you look at how strain gauges develop, he joined for a particular work and the whole interest got transformed into a different work. Ruge got the idea of bonding a fine wire to the surface of the test specimen and Hans Meier broke a commercial wire bond resistor and they had also made this resistor made of constantan wire and he made the fast bonded wire strain gauge and you have a famous company HBM, it was started by Hans Meier and his whole thesis topic changed.

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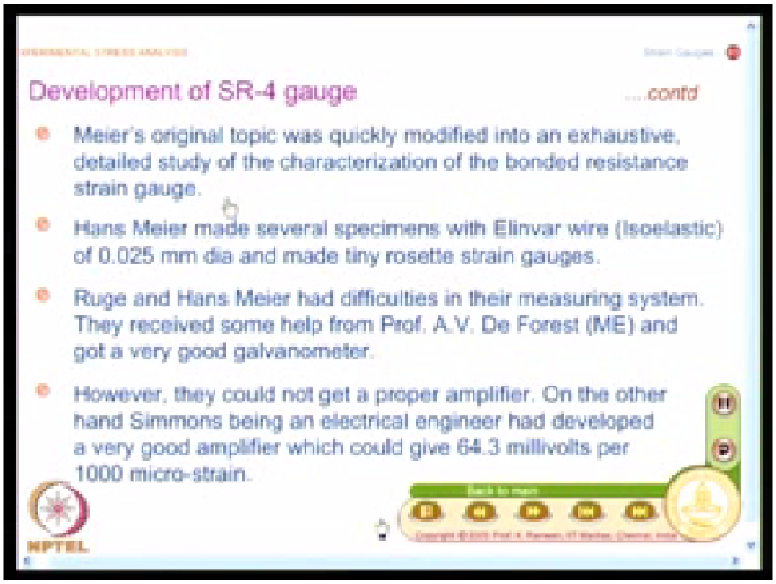

So original topic was quickly modified into an exhaustive detail study of the characterisation of the bonded resistance strain gauge. See that is how any development takes place. Nobody starts working on a thesis by defining what is a thesis and then work on. You work on different ideas and some ideas develop into interesting final results and the whole course of action gets shifted and what is important is, they had difficulty in measurement system because you are measuring small change in resistances.

So you had another person A. V. De Forest, a mechanical engineer, he gave a good galvanometer but they did not have good amplifier. See electrical engineers know about the amplification and it was Simmons who had developed very good amplifier. So his contributions also looked at. In fact, when the MIT team decided to patent the work, they came to know of the work by Simmons and they were disappointed that whatever they have done.

Somebody has already conceived it and it was De Forest who you know suggested that the basic patent be held by Simmons and any development was done by Ruge. This is also very important rather than claiming who has done first, they joined hands and made strain gauge into a reality. It is very important.

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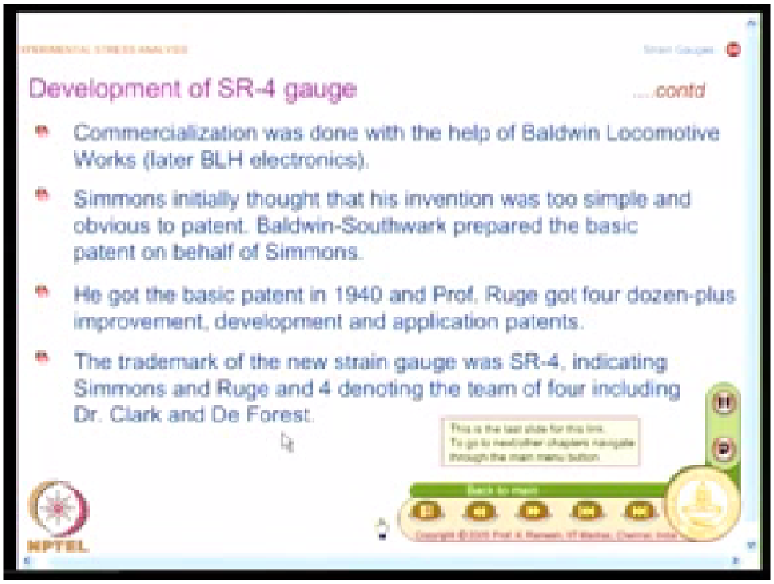

So that is how you have. You have this BLH electronics who did the commercialisation and Simmons initially thought that his invention was too simple and obvious to patent. So it was only Ruge who decided to patent the work. At that time, they found Simmons work and they were disappointed. At the time, De Forest from his experience brought these 2 teams together. so finally you had this new strain gauge which was born and which is christened as SR-4.

The S denotes Simmons and R denotes Ruge and team of 4, the 2 2 members in the team were Clark and De Forest. I mean you have to know it is very interesting to see how developments take place. So you had the role of electrical engineer, a metallurgist, a civil engineer, an aerospace engineer, they have all contributed to the development of strain gauge as a technology. Now people understand what is strain gauge.

Imagine in those days, arriving at this kind of a new technology was not a simple task and that is a success of whatever you have as development.

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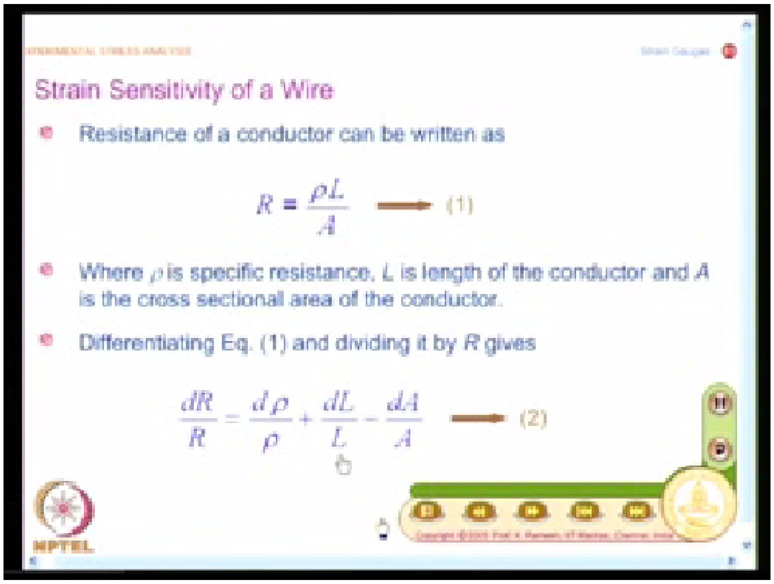

And now we have to look at mathematically how do we proceed. You know this is done in your high school physics, suppose I want to know what is the resistance of a conductor, it is defined as rho L/A where rho is the specific resistance of the material, L is the length of the conductor and A is the cross-sectional area and what we want to do is, we want to evaluate the strain sensitivity of a wire.

So we will find out, we will differentiate this and find out what is dR/R and it is very simple to write. I have dR/R is given as d rho/rho+dL/L-dA/A and why do we do this, we want to focus on the strain sensitivity of the wire. So that is given by dL/L and dR/R is what I am going to measure. I am going to have a base resistance and I want to find out what is the change in the resistance and I would like to relate this to the strain quantity, that is the interest.

And mind you for this exercise, we simply take a wire because that is how you have to understand the physics and later modify it to suit for your measurement and from your geometry and also your Poisson's ratio effect, I can write dA/A conveniently. That is what I am going to do.

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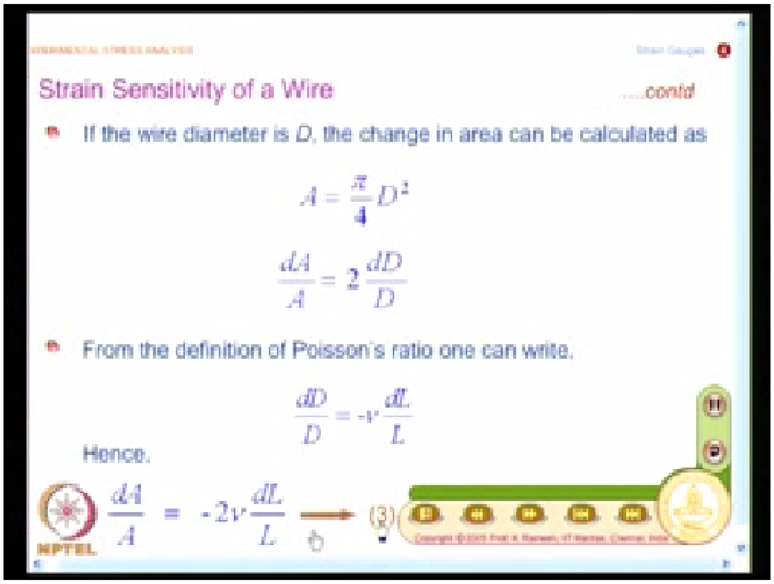

Suppose I take a wire of diameter D. I have area of cross-section is given as pi/4D square. Then I can simply write dA/A as 2dD/D and from the definition of Poisson's ratio, one can write dD/D=-nu*dL/L. So I can write dA/A=-2nu*dL/L. See this is the very basic development of the equations. See in strain gauge instrumentation, you have to be very careful about thermal effects. See when Kelvin did that experiment, he also found temperature change also changes the resistance.

So if you understand the physics, stress changes the resistance, temperature also changes the resistance, then you will know in strain gauge technology, how the temperature influences handle and if you understand this, many of the future discussion will become simple and straightforward. One of the greatest nuisance in strain gauge instrumentation is thermal effects and fortunately you have a very simple circle which can remove it and another important aspect is, you are talking of measuring very small quantity.

See you are talking about strain, you are talking in terms of microstrain. So you are really talking in terms of changes of the order of 10 power -6. You should never forget that. See because familiarity breeds certain kind of relaxed approach because you see strain gauge everywhere, you think that you can simply paste it and make the measurement but if you understand even if you go to a shop, if you want to buy a gold, he has the balance with an enclosure.

He does not even allow the air current from the fan to disturb the measurement, only then he can measure small quantity and when you are measuring 10 power -6, you are really measuring very small changes, then all the steps that is required and suggested that by the manufacturer from the point where you open the strain gauge until you make measurement you need to take that place very seriously.

If you do not follow any one of those procedures carefully, you are not guaranteed with accuracy of measurement. So this is very important. One is you are measuring very small quantity and second, whenever we discuss, look at how temperature influences handle. If you have this alertness, understanding strain gauge is very very simple.

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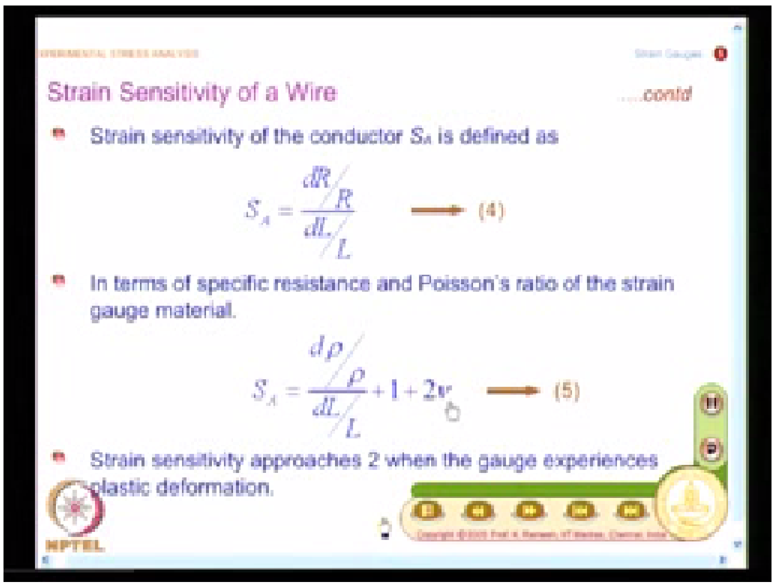

So you define what is known as strain sensitivity of the conductor SA. Yes note the way it is written, S suffix A and we define SA as ratio of dR/R/dL/L. So if I am going to have strain and SA is around 2, so you are also going to measure changes in resistance of the order of microohms. So you are really looking at very small changes, never forget that. Then you will attach the necessary importance to strain gauge instrumentation, that is the catch and I can read as this expression in terms of the specific resistance as well as the Poisson's ratio.

So what I have is SA=d rho/rho/dL/L+1+2 nu and what you have here is, this gives an indication that strain sensitivity approaches to when the gauge experiences plastic deformation, the change in specific resistance goes to 0 and your Poisson ratio approaches 0.5. So that means if I have a strain gauge which has strain sensitivity closer to 2, from elastic to plastic region, I do not need to do any modification in my interpretation. It becomes linear. So I can read out from the strain gauge, both elastic strain as well as plastic strain and now let us look at how we have to make a strain gauge. What is the difficulty.

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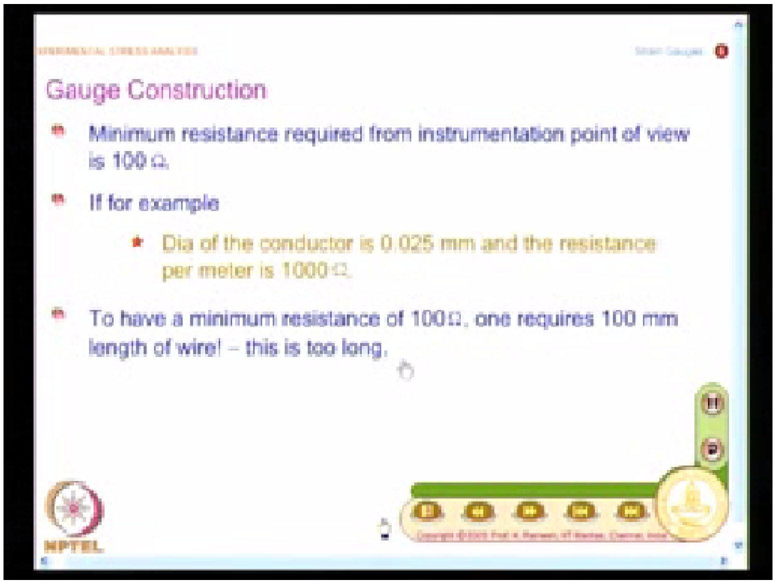

We need to know how strain gauge have to be constructed. See what you have here is, I said that you are going to measure very small quantities. We are going to make changes that are very small and some measurement point of view if I have a base resistance as 100 ohms, any change that you look at, will be significant for you to measure, that is the focus here. See the initial strain gauge when Simmons did very preliminary experiment, it was about 17 ohms and they were measuring well beyond the plastic strain limit.

Now the technology is so well-developed that I can measure 0.5 microstrain, that is very recent. In the last 2 years only, people quoted 0.5 microstrain. Earlier they were quoting 1 microstrain but 100 microstrain is comfortable to measure that is how you will have to have a thumb rule. When you are designing an experiment, at least 100 microstrain should be developed at the point of interest for you to reliably measure.

So what you have is from the instrumentation point of view, what is the minimum resistance you have reasonable to assume that you need about 100 ohms and if you want to have 100 ohms and if you have a diameter of the conductor as 0.025 millimeter, this was the kind of resistors that they had at that time and also take for example the resistance per metre is about 1000 ohms. If you have to meet this requirement of 100 ohms, one requires 100 millimetre length of wire.

See we want to measure strain at a point and we said from measurement point of view since we have to look at small changes, it is better that I have a larger base value to start with and you said I need minimum of 100 ohms and if I have to have 100 ohms even from a reasonably thin wire, I need 100 millimetre length to make a measurement. With 100 millimetre how can I measure at a point. So obviously I have to make this wire go back and forth and then make a grid out of it.

When I make a grid out of it, what happens. Its behaviour is different. Then I bring in approximation. So you want to appreciate approximations also but if you appreciate the approximations and also you are measuring very small quantity and the nuisance from thermal influence, you have understood strain gauge technology.

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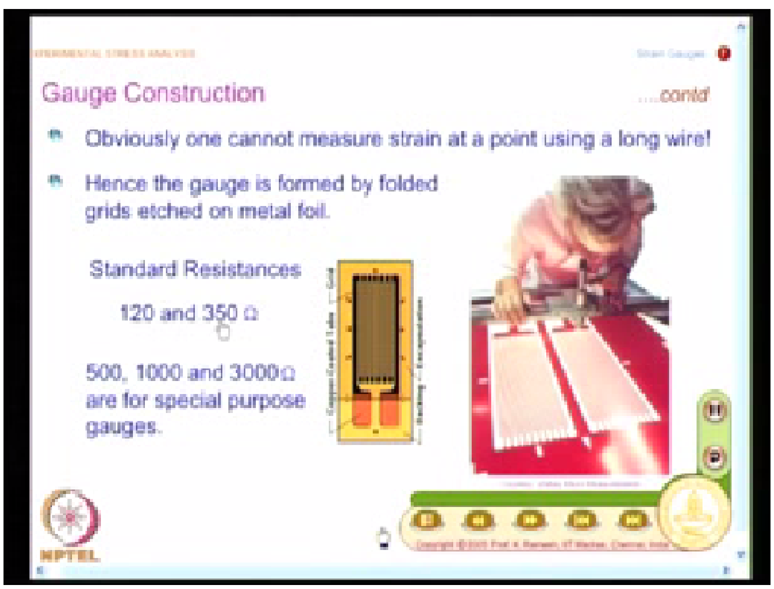

Now let us see how we make the gauge and you have very nice etched foils that they make and we are going to focus on metal foil gauges and this is the advantage that they have. You have the pattern well engraved and then optically reduce it and make a strain gauge like this and if you look at here, you have loops and wherever the loop turns, you have a very broad end and why do you have these ends as broad from your simple understanding of what is resistance, if the area of cross-section is large, resistance is less.

If the area of cross-section is very small, resistance is very high and I had earlier mentioned that you measure strain along the gauge length. You measure the component of strain along the gauge length and because I have loop, I have 2 4 6 8 10 12 loops I have here and typically you will have about 3 mm gauge length. So I actually have 36 millimeter of wire which is compacted into a grid and I make the end loops thick enough so that it has a low resistance.

It is an approximation. It would have some sensitivity for strain along the transverse direction too. So we have to bring in the engineering approximation. See if I have a wire or if I have a magic material, I just take 1 spec, put it at the point of interest and solder it. There is nothing equal to it. We do not have 1 spec of material to give you strain at a point of interest. We have necessarily put the wire in this zig-zag fashion and then make it as a grid and then only use it.

So we have to look at very closely how this grid behaves, that also we have to look at and we will also have to look at what are all the standard resistances available. See if you go to a shop, you can ask for resistors of any magnitude. On other hand, strain gauge is also a resistor but it is available only at certain discrete values. We have right now seen making a resistance of 100 ohms is very difficult, it is not so simple. It requires technology.

If I go to metal foil gauges, I can make the foil as thin as possible. So I can increase the resistance comfortably and remember when you look at the foil like this, see this is the metallic foil but when I am going to have a very thin foil, even a metal thin foil is fragile. So handling becomes very sensitive. See if you understand the construction and also what is the level of measurement that you are going to make, it brings in automatically a sensitivity in you in how to handle the strain gauge.

You cannot say I am not handling a plastic, I am handling only a metal but metal is too thin. So it is to be supported by a backing, So you have to handle and take it out very carefully from your backing; otherwise, the metal foil will break and you will have a discontinuity in the circuit and it also has to be bonded very well and the difference here is, in photoelastic coating, we saw it is about 3 millimeter as a coating thickness.

The moment we came to brittle coating, it was about 0.1 millimeter. The moment you come to strain gauge, it is again a coating, it is much thinner than any of those measurements but the difference is, here you are pasting a metallic foil, there you are pasting plastics and resins. So those thicknesses were permissible. Here also I have another problem. Many people do not know that you have to make certain calibration constant even for strain gauge measured experimentally.

See you know F sigma has to be measured experimentally for photoelastic analysis. The moment you come to photoelastic coatings, you measure K, strain optic coefficient or strain coefficient. The moment you come to brittle coatings, you measure the failure strain. In strain gauge, you have to measure what is known as a gauge factor experimentally, then you will again see interplay of Poisson ratio mismatch.

Strain gauge is a very good technique. I can take a strain gauge, put it, versatile and if I have a technician who knows all the details of how to handle it, it is very well-developed technology but you will also have to respect the procedures involved. So all that you understand when you look at how the strain gauge is manufactured and advantage of when I have metal foil is with integrated circuits, I can have different types of grid pattern, could be very precisely developed and etched and we will now see what are all the resistances that is available.

So you do not have it as 100 ohms, the base is 120 ohms. You know this is from measurement consideration. For our discussion to alert that you need a long wire, I said, let us start with 100 ohms but the least resistance that is commercially available now is 120 ohms. Then you have 350 ohms. With the advancements in composites, now you have 500 ohms, 1000 ohms, as well as 3000 ohms have been developed and mind you they are very difficult.

It is not simple, it is very expensive. Strain gauge is also very expensive and the moment you paste it, strain gauge is lost, you cannot reuse it. So you have to be very careful in designing your strain gauge instrumentation. It is a very expensive proposition.

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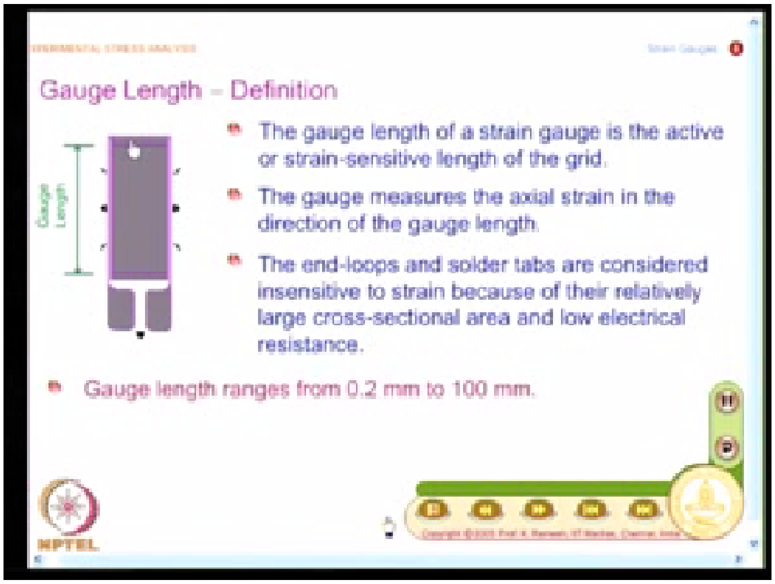

And let us understand what is the gauge length because this is a very important aspect because I said you do not have a magic material which as a speck of material is able to measure strain. I need to have a finite length and this is put on a grid form and the way are it is manufactured, will ensure that it is primarily responsible for measurement of strain along the gauge length because you make the wire thin enough in the direction and you define effective measurement length here as gauge length.

And I have already indicated the end loops and solder tabs are considered insensitive to strain because of their relatively large cross-sectional area that we have already noted. You had seen in that enlarged picture that end loops are made deliberately thick so that they have low resistance and they will be relatively insensitive to strain measurement in the transverse direction and another aspect is what is the length of the gauge length ranges.

It ranges from 0.2 millimeter to 100 millimeter. So you cannot simply jump and say I will always go and use a 0.2 millimeter strain gauge. Unless it is warranted, you should not go for such sophisticated strain gauges because we have already seen you need 100 millimetre for you to develop 100 ohms in normal resistance wires, you need to take special efforts to reduce the length and most common strain gauges, general-purpose strain gauges, have a gauge length of 3 mm, that is good enough for a variety of problems.

Only in special applications, you need to select smaller gauge length or longer gauge lengths. In which class of material you will look for longer gauge length? Suppose I have a heterogeneous material like concrete, I would definitely go for longer gauge lengths. For most of your metallic application, 3 mm strain gauge is good enough and 0.2 millimeter is only for very special applications.

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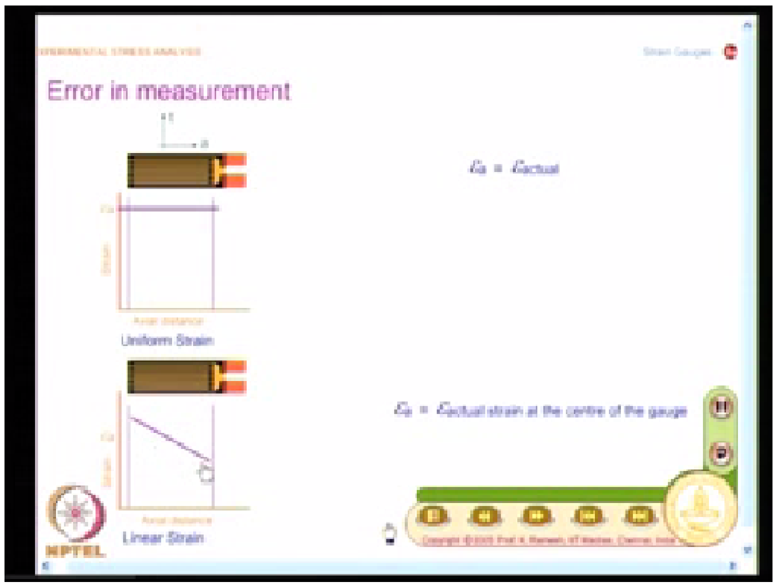

And let us also look at what are the errors that could come when gauge length is not chosen appropriately. Suppose I have constant stress, does gauge length has any influence? There is no influence. Whatever the strain I measure is equal to the actual strain. Suppose I have a strain varying linearly. This happens when you take a cantilever beam, you put a strain gauge on top of it.

Strain varies linearly because the bending moment varies linearly, strain also varies linearly. So in a problem where you have strain varies linearly, does the gauge length has any influence. Again does not having any influence because whatever the average strain that you measured at the centre is same as for actual strain.

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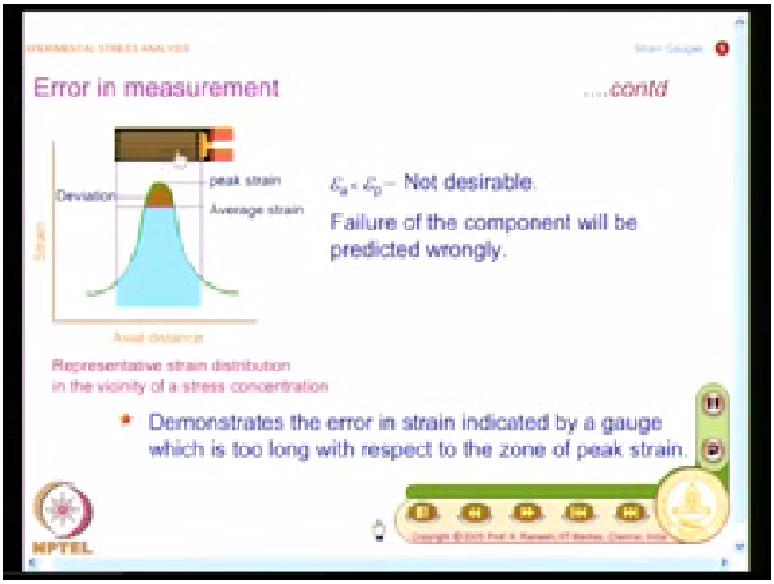

Suppose I have a non-linear radiation which happens in stress concentrations zone, then I have to be very careful. Suppose I have a very sharp change in the strain magnitude, my peak strain is this much but strain gauge will measure only an average strain which is much below the peak strain. So when you have a stress concentrations zone, failure of the component will be predicted wrongly if you have a longer gauge length.

Suppose I take a small gauge length which is only of this length, then I would measure the peak strain reasonably well. So you understand why gauge length selection is important. You cannot take gauge length selection arbitrarily. There are thumb rules available. For different class of problems, how do you go about and select the gauge length. So what you find here is when you have a non-linear variation of strain, the gauge length has an influence on the measurement and you have to be careful.

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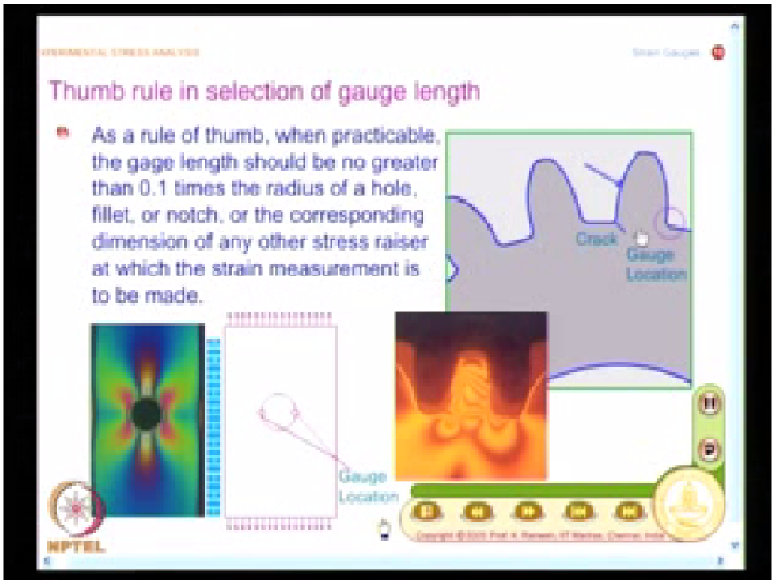

And let us look at the 2 example problems and look at the thumb rule on what I am going to look at. See I am going to look at the strain field in the case of spur gear and you have all done course in (()) (43:51) analysis where you have already seen what is photoelasticity and this is a spur gear tooth and you have this as loaded. This is the epoxy model and on the tensile side, you have a crack developed.

You have that crack dips stress field and suppose for example I need to measure strain on this fillet, you could see there are many fringes densely packed in this corner so that indicates obviously you have a stress concentration zone and if I have to measure strain in those locations, I cannot use that general-purpose strain gauge of length 3 millimeter. I need to use a strain gauge smaller then that. So you have a thumb rule.

What is a thumb rule, we will look at the thumb rule and what it says is, it is about 0.1 times the radius of a hole fillet or notch. Here you are talking about a fillet. So you take only 0.1 times of that. It may not be practically feasible in sometimes but you have to have a trade-off in your selection and this is another example which you all know. You have done how to find out the stress concentration factor by photoelastic analysis.

You simply measure the maximum fringe order at the boundary of the hole. Find out the average fringe order, take the ratio, you get the stress concentration. Suppose I want to use a strain gauge, then what happens. Because it is a stress concentrations zone, gauge length matters. Not only the gauge length matters, when you put it in this zig-zag fashion, it also acquires a finite width, okay. Because it acquires a finite width, the transverse strain which is also varying very sharply that will also affect your result.

So one way of supplementing that problem is, do not paste the strain gauge on this face but paste the strain gauge on the inner wall. All these are difficult proposition. If the hole is very small, what will you do. So you appreciate a point by point technique, how difficult it is to apply in stress concentration zones. I had also mentioned that rudder of Concorde was failing, they used a strain gauge, they found that the strain gauge was measuring strains lower than what is actual and a photoelastic coating test revealed that maximum strain was at slight distance away and they had corrected it.

So now this is an example which you have already done as part of your photoelastic analysis, how to find out the stress concentration factor. In strain gauge, it becomes involved and complicated. It is not simple and the thumb rule is you use the gauge length which is small enough. It is about 0.1 times the radius of a hole and to illustrate the stress concentration better, I have shown you this photoelastic fringes. Now you know how to interpret the photoelastic fringes better.

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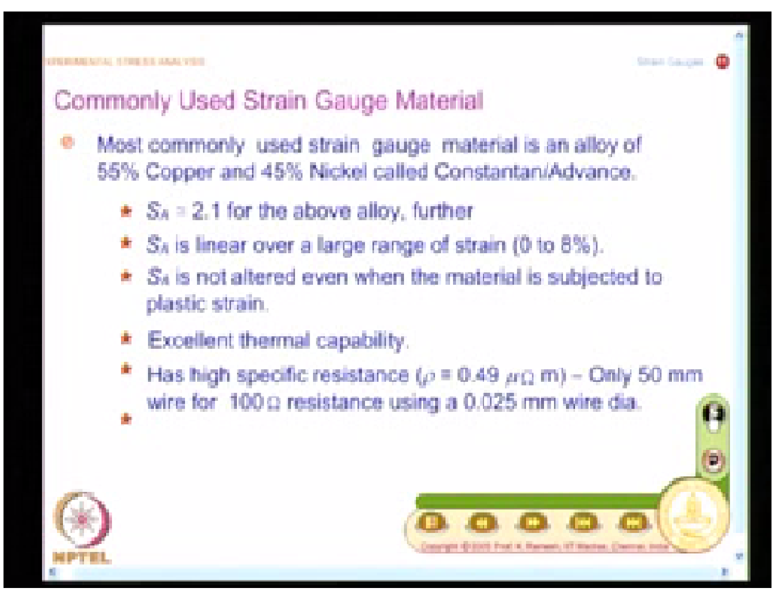

And what is the commonly used strain gauge material. You know for most of the resistors that were available at that time, they had only constantan or Advance. It is a very good strain gauge material and it is an alloy of 55% Copper and 45% Nickel and the advantage is the strain sensitivity of the conductor, A means conductor, you have still not looked at strain sensitivity of a strain gauge. We will take it up and look at the various aspects of it later. It is about 2 and SA linear from 0 to 8% and we have already seen 0.2% is the value at which yielding takes place.

So 8 is a very large strain magnitude and we have already seen from the expression for strain sensitivity of the conductor that it approaches 2 when the material is subjected to plastic strain and this is the reason why we want 2 because it reduces to 1+2 nu, that is the reason why we choose the material which has SA closer to 2 and you also have a statement excellent thermal capability. See this is the relative comparison.

We have to see another popular strain gauge material iso-elastic compared to that, this has a better thermal capability and also it has a very high specific resistance, rho is given as 0.49 micro-ohm meter and resistance is given by rho L/A. So you will also have to bring in the area of cross-section and this says that 50 millimeter wire is enough for getting a 100 ohm resistance because of its high specific resistance and we have already seen that even in that small strain gauge which we saw, we had at least 12 loops.

So it was, if I have a 3 millimeter gauge length, it was about 36 millimeter long and because I have a small gauge, but I can also have a high resistance. For a given voltage supplied, the current passing through the conductor will be less. So I will have I squared R loss is less. See I said in all strain gauge instrumentation, you will have to keep looking at the thermal influence. When current passes through the conductor, what happens.

The conductor gets heated up and you call that as I square R loss and if you have looked at my statement very carefully, I had said with the advancements in composites, people have developed 350 ohms, 500 ohms, 1000 ohms, 3000 ohms, etc. and whatever the heat generated on the strain gauge has to be dissipated. If I put a strain gauge on a metallic surface, metal surface will dissipate the heat generation very fast.

On the other hand, when I have a composite, it will not dissipate the heat that effectively. So in those applications, go for a strain gauge with a higher resistance so that you pass less current and you minimize the heat generation. These are very subtle issues. You will be able to appreciate and then faithfully adopted it in your measurement only when you keep at the back of your mind, you are trying to measure very small quantities in strain gauge instrumentation compared to any other measurement scenario that you are used to.

So this makes the technological aspects very very stringent and also the procedures to paste the strain gauge and make measurement, you have to follow the recommendations by the manufacturer very systematically. So what we have seen in today's class was, we looked at how to handle isoentatic data and how to find out approximately the specimen stress at those points and brittle coating and strain gauge go hand-in-hand.

You know they were also developed almost at the similar time and brittle coating was very useful to identify zones of importance. Since you know the principles of direction at zones of importance, you are able to reduce one strain gauge channel too. So that is the advantage and that is the reason why we looked at brittle coatings first, then we took up what is strain gauges and in strain gauges, you will have to appreciate resistance changes because of temperature change also.

If you keep this in mind and identify it at every stage, how this thermal influence is handled, like I said, normally you do not recognise when current passes through, the conductor gets heated. The heat generation maybe small but since I am measuring very small quantity, this small change also affects. What you say is small is significant in, it is not like your room heater. See you all have a room heater in winter where you put the room heater, the room gets heated up.

When you put a strain gauge, it is not going to heat your room. It generates very small amount of heat. Since I am measuring very small changes in resistance, even that small change becomes significant. That is the way you have to look at it and if you understand this right from the beginning, whichever way we are developing the strain gauge methodology.

Even from instrumentation point of view, we will invoke certain very good methodologies where there is self temperature compensation in the bridge itself in the measurement system or you modify the impurities in the metal foil and bring in some self-temperature compensation. You have to address temperature compensation in strain gauge instrumentation. There is no escape. Only if you do that satisfactorily, your measurement is accurate because resistant change also is influenced by stress change or temperature change.

Both temperature as well as load change can affect the resistance. So if you understand that, the technological aspect would become meaningful; otherwise, you know, many are descriptive in nature. At times, you may get little bored that you have to note down several minute details but that is part and parcel of in any learning. The physics behind the strain gauge technique is very simple but the details are equally important.

So I will try to organise my lectures in such a way, we will try to make it as interesting as possible because you also need to know the details and we will also look at how the grid patterns are arrived at for various problem, that will make your appreciation more interesting.

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