Experimental Stress Analysis

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Module No. # 05

Lecture No. # 31

Introduction to Strain Gauges

In the last class, we had looked at in detail what is brittle coating test; we looked at the methodology in conducting a brittle coating test; we looked at formation of cracks in direct loading; we also look at when you have compressive stresses, what kind of a methodology you need to adopt to reveal the crack patterns and also in low stress regions, I said by a 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 principle stress direction thereby, reducing one strain gauge per point for detail measurement. I also mentioned, the isoentatic what you get in brittle coating test could also be used to find out approximately the magnitude of the stress at the point; I also mentioned how will you handle this isoentatic data.

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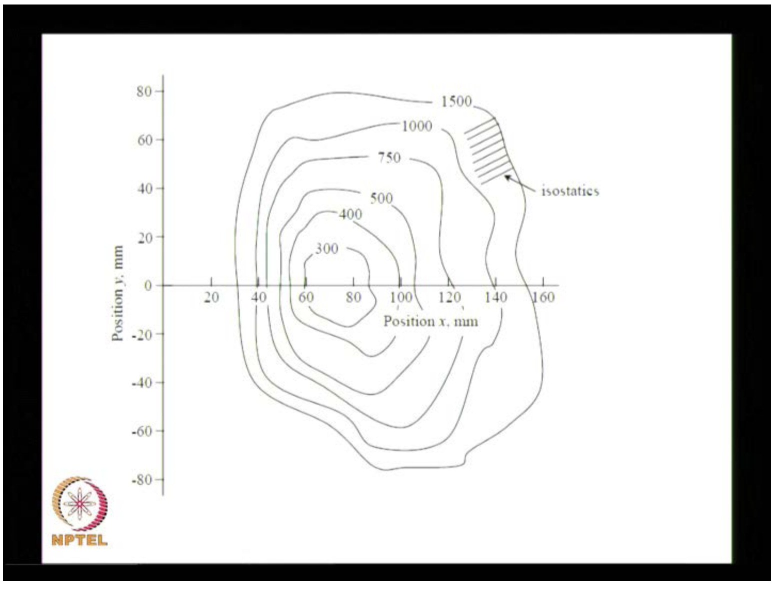

Let us look at a sample isoentatic data and what I have here is, for different loads from 300 Newton's, 400 Newton's, 500 Newton's, you had these isoentatic curves obtained and these are shown.

And typically you will have a crack pattern like this and you join only the end of these cracks. So, the idea is, definitely at the end of these cracks, you will have the failures strain of the coating is reached at that point in the specimen, but this is obtained for a load of 1500 Newton's and this contour is obtained for 300 Newton's and so on.

So, the idea is when you conduct the 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 the 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 super position. Now, how do I interpret the isoentatic data?

For example, if I want to find out what happens along a line y equal to 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 mention? It is the initial set of cracks that are very important and obviously, whatever the stress develop 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, you have to report the stress value corresponding to a particular given load; at that point because it is stresses load, I had apply a large specimen stress for me to make coating at that point to fail and we will look at.

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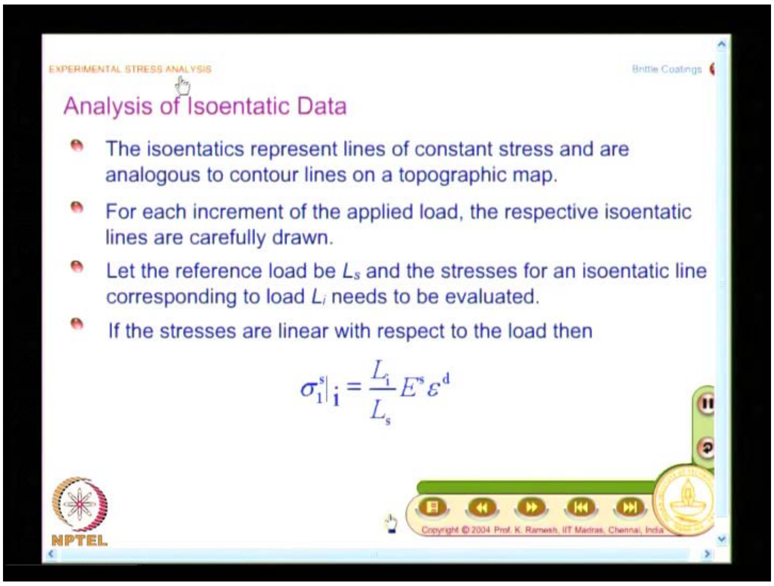

So, what you have here is, when I want to do the analysis of isoentatic data, let us consider the reference load be L s and let us find out for an isoentatic line corresponding to load, L i needs to be evaluated and for the reference load, I have the failure strain epsilon d and for the given load, it become L i divided by L s into E s into 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 determine only with plus or minus twenty percent accuracy and here also we are invoking one more approximation - the principal stress value remains approximately constant at the end of the cracks, that is what you join by isoentatic line.

So, whatever the estimation of stress that you get is an approximate value; good enough from a solving an industrial problem, that is way you will you will have to look at. So, this brings to a close of our discussion on brittle coating techniques. Now, we will take it up what are strain gauges, what are the topics that you need to look at in strain gauges and we will also look at the historical development and develop pertinent equation for you to carry on with the methodology.

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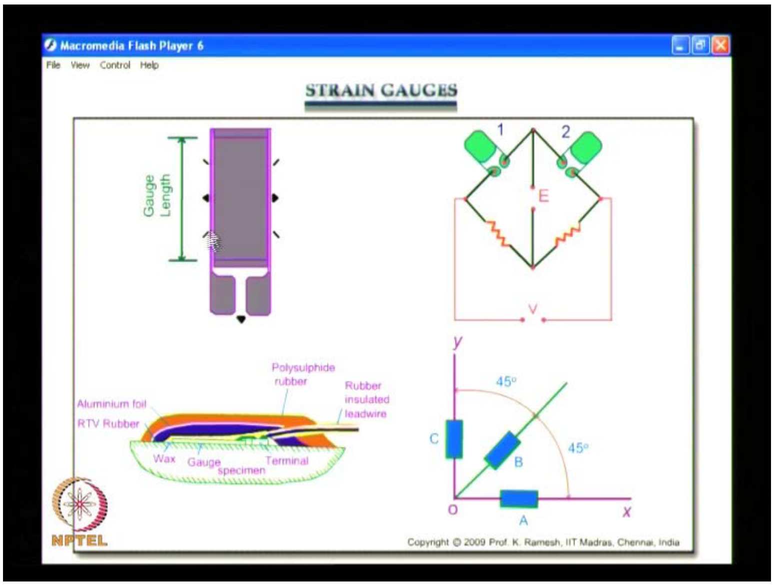

And the moment you take up strain gauges, you need to know that strain gauge has a finite area and you have a definition of what is the gauge length, this is very important; we will discuss that even the initial lecture today.

Then whatever the change in the resistance, you need to measure it by an appropriate circuit; here, I have Wheatstone bridge shown and this also has two strain gauges connected and this is in a half bridge configuration. In fact, this is the most celebrated one, because it also has temperature compensation provided, when these two 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 aggressive environment, that is also very important. You have several layers of coating applied, particularly when you want to do it under water piping and anything to do with that kind of aggressive environment, you need well protected strain gauge information.

And I have always mentioned that strain gauge gives component of strain along its gauge lines. Suppose I have to find out strain at a point, then I need three strain gauges and here it is shown as a rectangular rosette and you also make an approximation, that you paste strain gauges here, but it measure the strain at the point O. So, there are engineering approximations in the methodology of strain gauge that you will have to appreciate.

Now, we will get in to 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 look at, it was Lord Kelvin in 1856 reported on the relationship between strain and the resistance of wire conductors and you all know, he took almost 80 years to find commercial application.

And one of the earliest strain gauge was developed around 1938 and there have been contribution 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 whatever the strain gauge developed by them was famously known as SR-4 strain gauges; we will see S stands for Simmons and R stands for Ruge and 4 stands for a team of four people who have contributed; we will see that development in detail.

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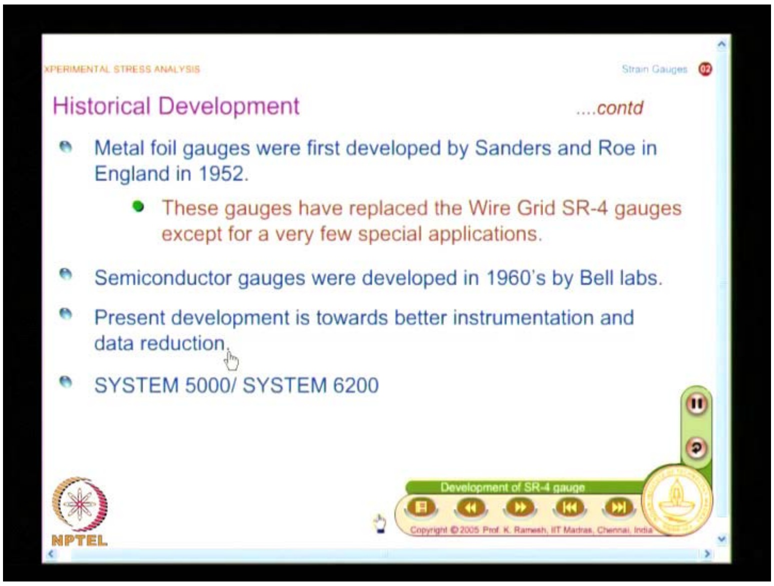

So, after the small diameter wire that is used as a strain gauge, people also developed what is known as a metal foil strain gauge, that was in 1952 and this was developed by Sanders and Roe and we will also spent time in dealing with metal foil gauges in this course.

These gauges have replaced the wire grid SR-4 gauge except for a few special applications. You know the metal foil strain gauges as lot of advantages. I said that if you want to measure strain at a point, you need to measure the sensor; I need to evaluate three quantities, so I need to have three equations; so I need to make three measurements; so I need to have strain gauges pre aligned and this could be done very comfortably in a metal foil.

And also the advantage is, the metal foil can be very thin so that I can have a very high resistance for a strain gauge, many advantages. And after the development of metal foil gauges, the major development was semiconductor gauges, this has developed in 1960's for varies 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 in to place; you know with computer technology, I can handle 1000 channels comfortably now, which was not possible earlier; you may be able to have few channel to start with and you can also go for dynamic strain measurement, all that is because of advancement in electronics. And you know, one of the earliest in the step was by (( )) measurement book, they have come out with system 5000, system 6200; now they have 7000 also. So, these numbers keep improving in terms of accuracy, in terms of number of channels, in terms of speed. So, you see a development on instrumentation and it is worth noting what contributed to the development of SR-4 gauge.

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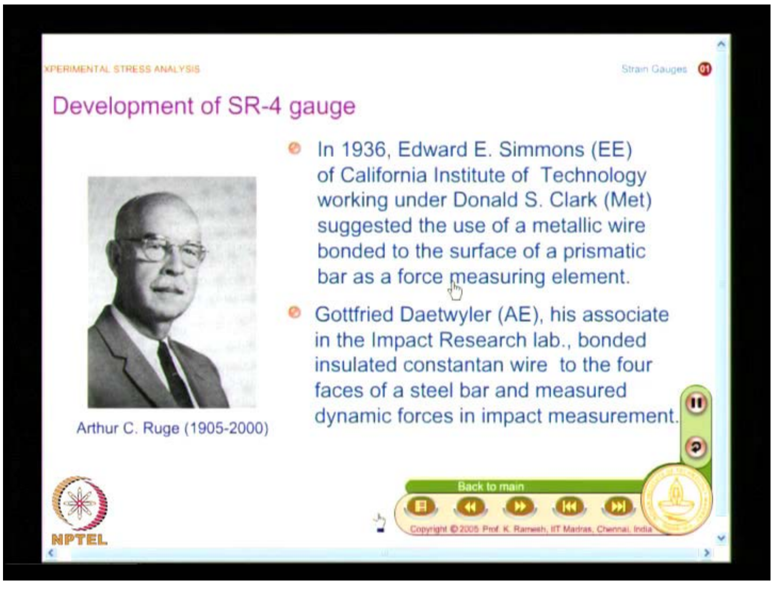

See, you have to note down that no development is done by an individual, that is my interest, that is point number one; point number two is, you also find a team of scientist who work together, it is not from one branch, it is from multiple branches have contributed to the development of the strain gauge 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 contribution was not known to Ruge, who developed and reinvented in 1938. We will see those details and you know, you can listen to this, at least make few salient points; I have detailed 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 a wire for measurement of stresses in an impact test. He was an electrical engineer, he was working under Donald S Clark, who was a material scientist metrologist in material scientist and the person who actually measured the force was an aerospace scientist.

See, only when different minds meet, new idea has developed and Simmons was credited to be very inventive in his approach. So, when they face the problem in impact force measurement, they consulted Simmons, and Simmons suggested why don't you take a wire and bond it.

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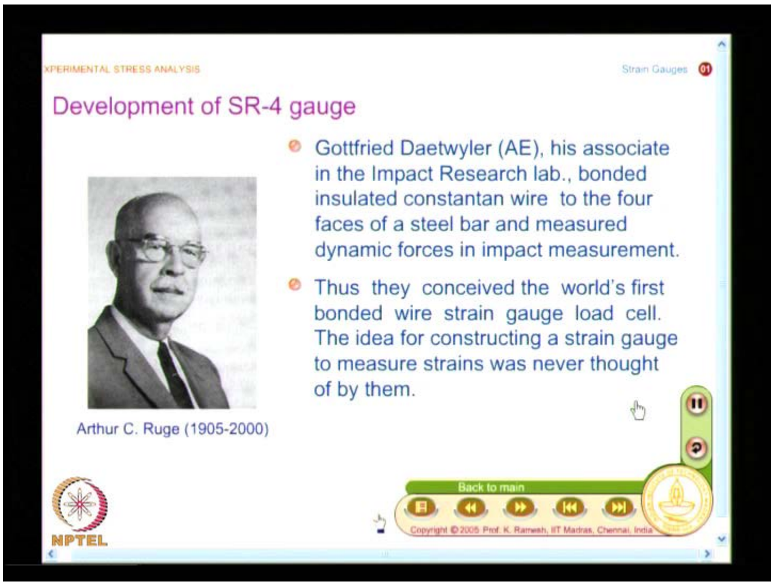

And if you really look at their contribution, they did not know at the time that they are going to develop the strain gauge; their focus is only on measuring the force, but before measuring the force, they took a wire from one of the standard resistors available, they put it on a clocks spring, and then, 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 an initial resistance of 17 ohms, they found after it is flexed, that beam is flexed, you find a change of 0.25 ohms that is what they have measured with worked out 7000 microstrain.

Now, strain gauge technology is so well developed, that I can measure 0.5 microstrains. 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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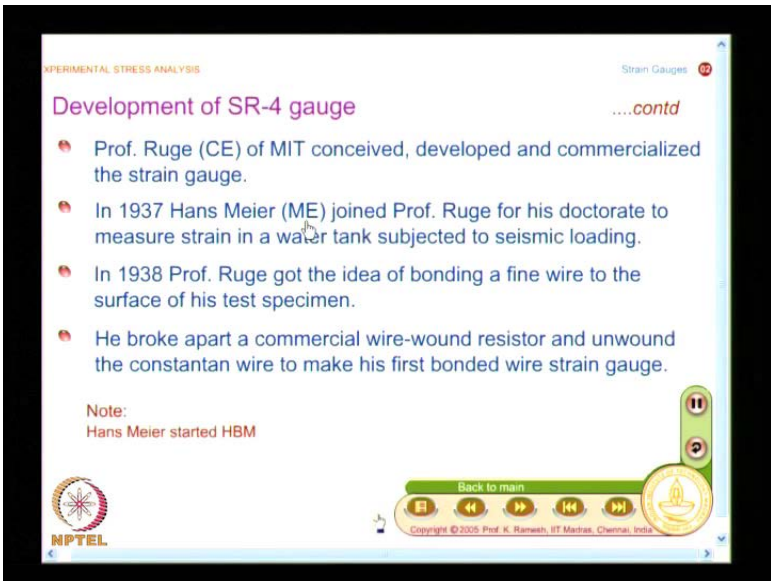

And you know, mean while Ruge is a civil engineer by trainee, he conceived, developed and commercialized the strain gauge, but this happened in 1938. And you should also know, he had student with the mechanical engineering background Hans Meier and he was supposed to work on the problem of analysis of water tank subjected to seismic loading.

And you should also know, you know theses are not designed on the first day when you joined under a professor. If we look at how strain gauge developed, he joined for a particular work and the whole interest got transformed into different work.

Ruge got the idea of bonding a fine wire to the surface of his test specimen and Hans Meier broke a commercial wire-wound resistor and they had also have made this resistor made of constantan wire and he made the first bonded wire strain gauge. And you have a famous company HBM, it was started by Hans Meier and his whole thesis topic is changed.

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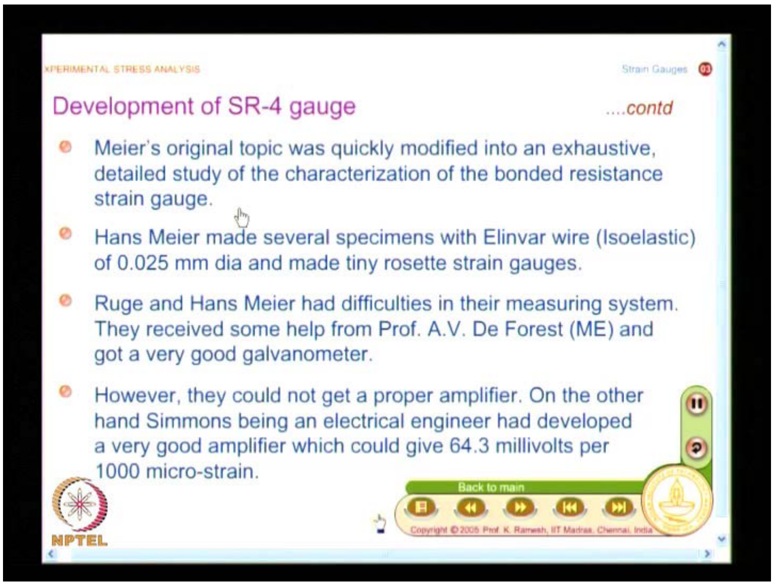

So, original topic was quickly modified into an exhaustive, detailed study of the characterization of the bonded resistance strain gauge. See, that is how any development takes place. Nobody starts working on a thesis by defining what is the thesis and then work of; you work on different ideas and some 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 a good amplifier.

See, electrical engineers know about amplification, and it was Simmons who had developed very good amplifier, so his contributions also look 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 let the basic patent be held by Simmons and any development was done by Ruge, this is also very important. You know, rather than calming who has done first, they joined hands and made strain gauge into a reality, it is very important.

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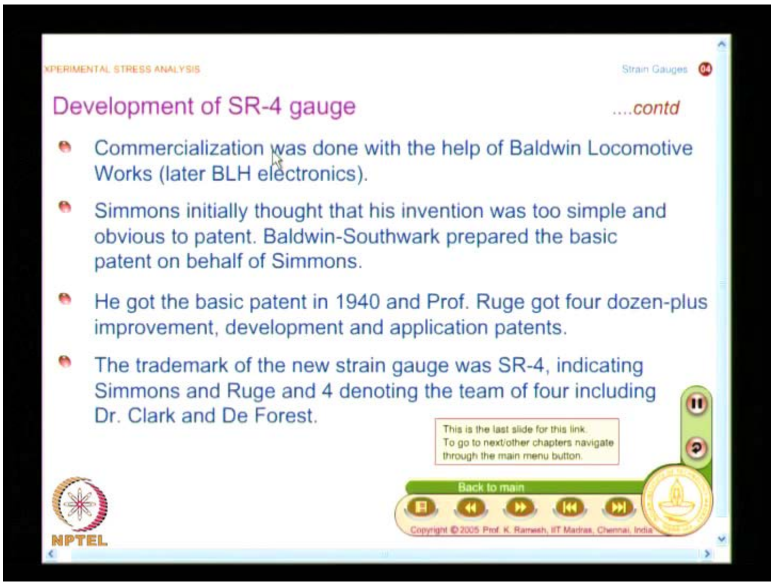

So that is how you have. You have this BLH electronics did the commercialization and Simmons initially thought that his invention was too simple and obvious to patent. So, it was only Ruge, who decided to pattern the work, at that time they found Simmons work and they were disappointed; at the time, De Forest from is experience brought these two teams together.

So, finally, you had this new strain gauge which was bond and this is (( )) as SR-4, the S denotes Simmons and R denotes Ruge and team of four, the other two members in the team were Clark and De Forest.

I mean you have to know, it very interesting to see how development take place. So, you have the role of electrical engineering, a metallurgist, a civil engineer, an aerospace engineer, 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 new technology was not a simple task and that is the success of whatever you have as development.

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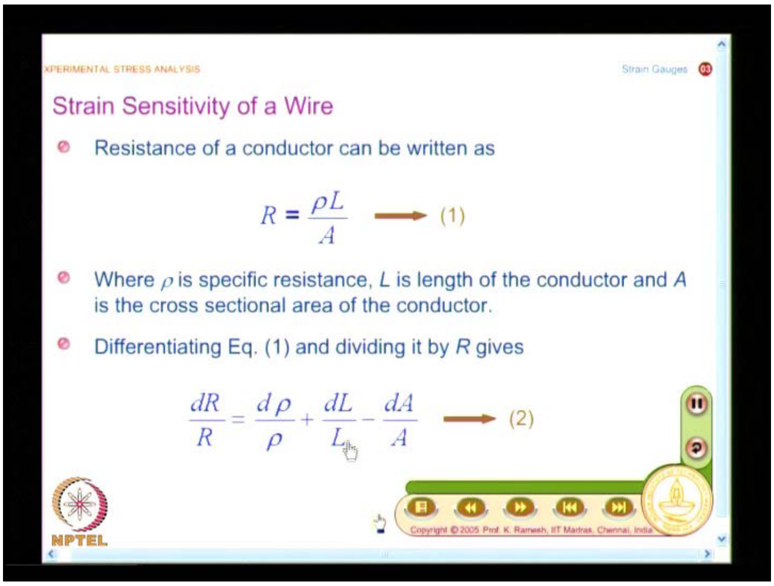
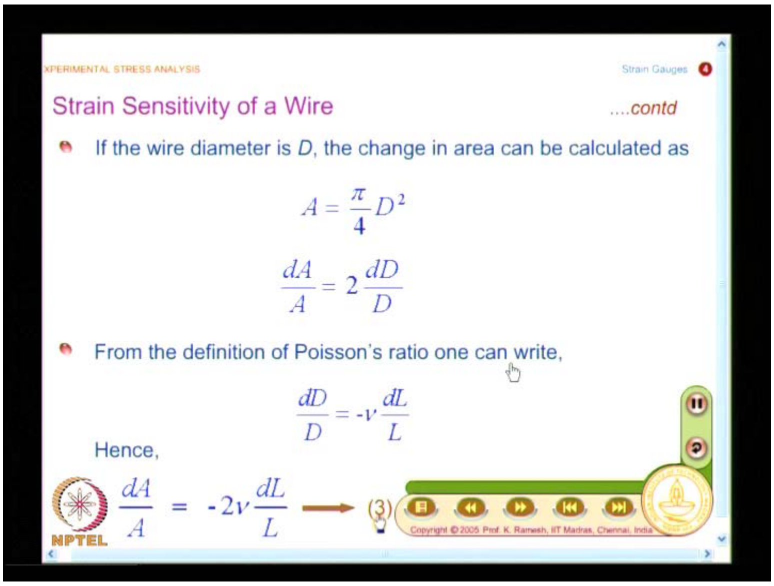


And now, we will have to look at mathematically how do we proceed. You know, this is done in your high school physics, suppose I want to know what is a resistance of a conductor, it is defined as rho L by A, where rho is the specific resistance of the material, L is the length of the conductor, A is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

And what we want to do is, we want to evaluate the strain sensitivity of a wire. So, you will find out, we will differentiate this and find out what is dR by R and it is very simple to write. I have dR by R is given as d rho by rho plus dL by L minus d A by A and why do we do this? We want to focus on the strain sensitivity of a wire; so that is given by dL by L, and dR by R is what I am going to measure. I am going to have a base resistance and I want to find out what is 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 understand the physics and later modify it to suite for your measurement. And from your geometry and also from your Poisson ratio effect, we can write dA by A conveniently that is what I am going to do. Suppose I take wire of diameter d, I have area of cross section is given as pi by 4 D square, then I can simply write d A by A as 2 dD divided by D. From the definition of Poisson's ratio one can write, dD by D equal to minus nu times dL by L. So, I can write dA by A as minus 2 nu times dL by L. See, this is the very basic development of the equations. See, in strain gauge instrumentation, you have to be careful about thermal effects. See, when Kelvin did the experiment, he also found temperature change also change as a resistance.

So, if we understand the physics, stress changes the resistance; temperature also changes the resistance, then you will know in strain gauge technology how the temperature influence is handled and if you understand this, many of the future discussion will become simple and straight forward.

One of the greatest nuisance in strain gauge instrumentation is thermal effects and fortunately you have a very simple circuit 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 minus 6, you should never forget that.

See, because familiarity breeds certain kind of relaxed approach, because you have seen 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 by gold, he has a 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 minus 6, you are really measuring a very small changes, then all the steps that is required and suggested by the manufacturer from the point, where you open the strain gauge until you make measurement, you need to take the advice 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 influence is handled, if you have this alertness, understanding strain gauges is very simple.

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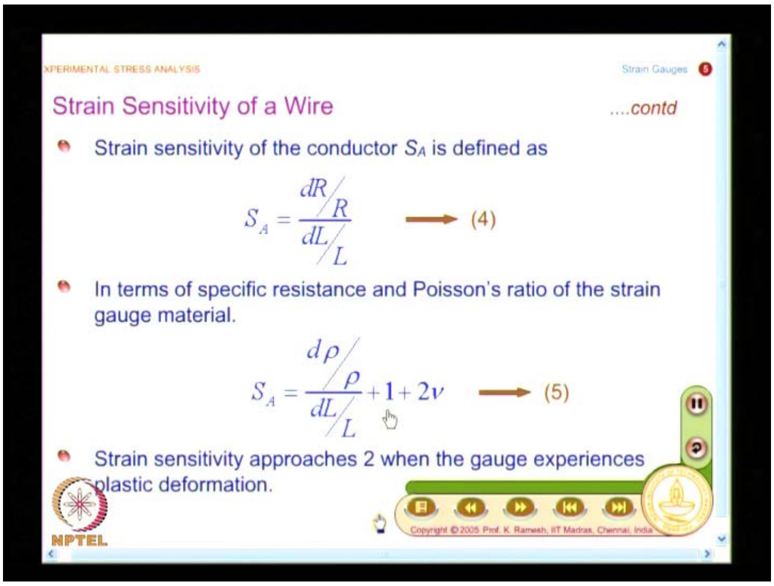

So, you define what is known as strain sensitivity of the conductor S A, you note the way it is is written S suffix capital A and we define S A as ratio of dR by R divided by dL by L.

So, if I am going to have strain and S A is around 2, so you are also going to measure changes in resistance of the order of micro ohms. 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 recast this expression in terms of the specific resistance as well as the Poisson's ratio.

So, what I have is S A equal to d rho by rho divided by dL by L plus 1 plus 2 nu and what you have here is, this gives an indication that strain sensitivity approaches 2 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 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.

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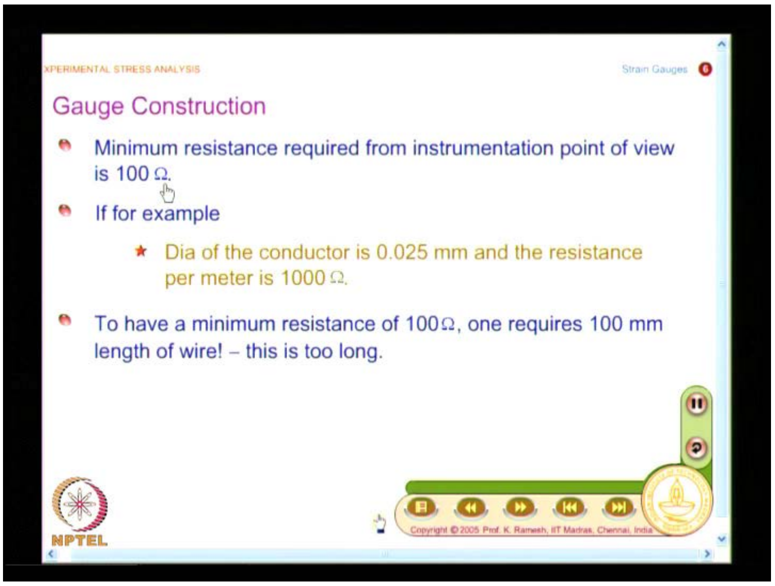

What is the difficulty? We need to know how strain gauges have to be constructed. See, what you have here is, I said that you are going to measure very small quantities, we are going to make changes that are very small and from measurement of point of view, if I have base resistance as 100 ohms, any 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 a 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 two years only, people coated 0.5 microstrain, earlier they where coating one microstrain, but 100 microstrain is comfortable to measure, that is how you will have to have a thumb rule, when you designing the experiment, at least 100 microstrain should be develop 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 that 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 a kind of resistors that they had at that time.

And also take for example, the resistance per meter is about 1000 ohm, if you have to meet this requirement of 100 ohms, one requires 100 millimeter 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 form a reasonably thin wire, I need 100 millimeter length to make a measurement.

With 100 millimeter how can a measure it 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? Behavior is different when I bring in approximation. So, you have to appreciate approximations also, but if you appreciate the approximation and also you are measuring a very small quantity, and the nuisance from thermal influence, you have understood strain gauge technology.

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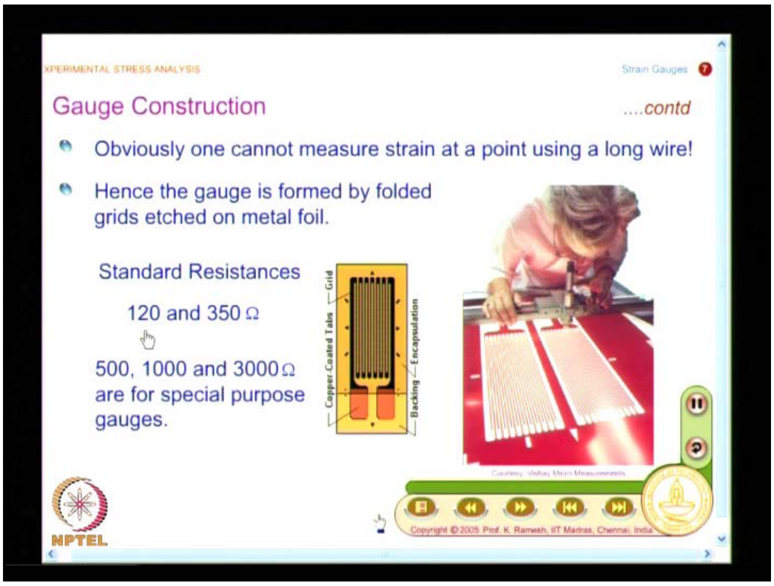

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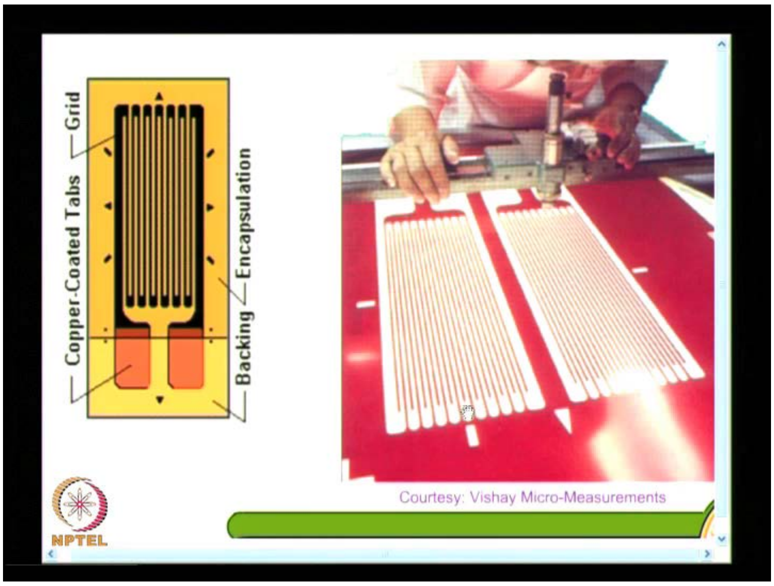

Now, let us see how we make the gauge and you have very nice etched foils that they make and we are going to focus on metal foil regions and this is the advantage that they have, you have the pattern well engraved and then optically reduce it and make a strain gauge like this.

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 have 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 millimeter 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 the low resistance, it is an approximation; it would have some sensitivity for strain along the transfer 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 one speck, put it in the point of interest and solder it, there is nothing equal to it. We do not have one speck of material to give you strain at a point of interest; we have to necessarily put 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 resistance is available. See, if you go to a shop, you can ask for resistors of any magnitude.

On the 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 comfortable. 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 mu in how to handle the strain gauge. You cannot say I am not handing a plastic, I am handling only metal, but metal is too thin; so needs to be supported by backing. So, you have to handle and taking it out very carefully from backing otherwise, a metal foil will break and you will have discontinuity in the circuit and it also has to be bounded very well and the difference here is, in photo-elastic coating we saw its 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 much thinner than any of those measurement, but the difference is, here you are pasting metallic foil where your pasting plastics and (( )) those thickness of permissible.

Here also have a 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 measure experimentally for photo-elastic analysis. The moment you come to photo-elastic 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 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 procedure 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 resistances that is available.

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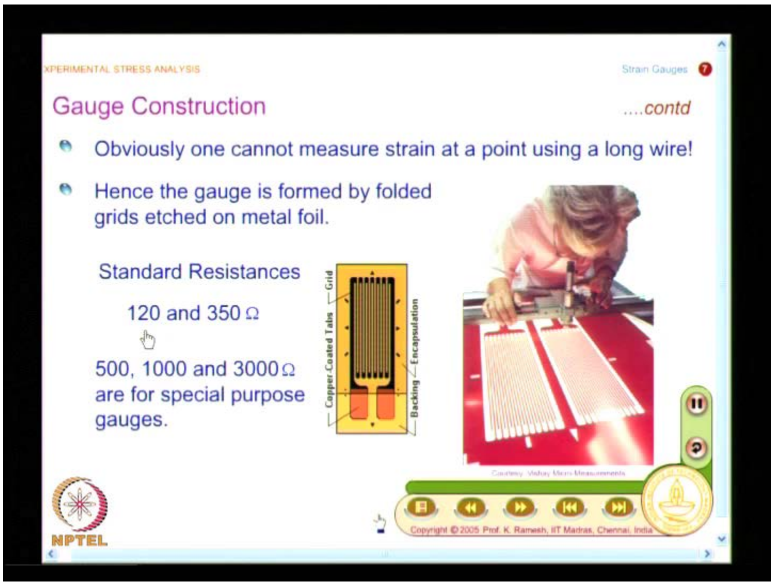

So, you do not have it as 100 ohms, the base is 120 ohms. You know, this is from measurement consideration, for our discussion to alert that you need a long wire, I said let us start with 100 ohms, but the least resistance that is commercially available now is 120 ohms, then you have 350 ohms. With the advancement 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 expansive and the moment you paste it, strain gauge is lost, you cannot reuse it. So, you have to be very careful in designing strain gauge instrumentation; it is a very expensive propagation.

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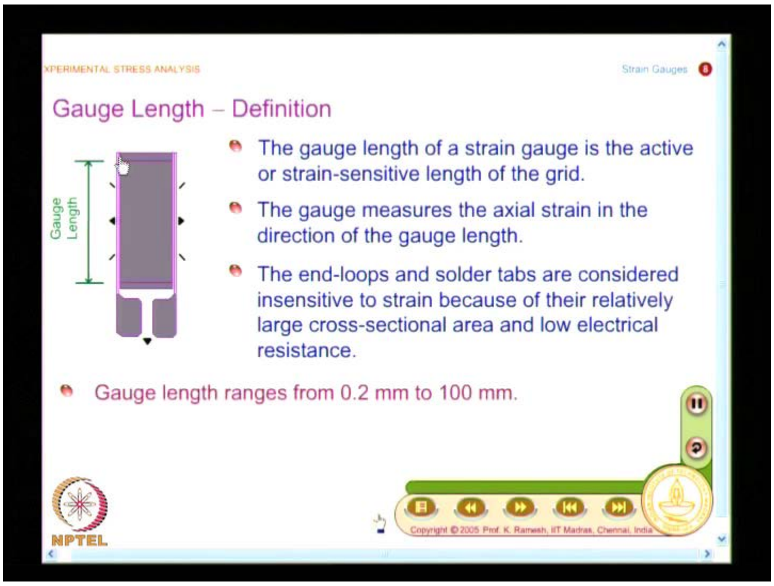

And let us understand what is the gauge length, because this is a very important aspect. Because I said you do not have magic material which as a (( )) of material is able to measure strain I need to have finite length and this is put an grid form and the way it is manufactured, you ensure that it is primarily responsible for measurement of strain along the gauge length.

Because you make the wire thin enough of 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 you have already noted. You are seen in the enlarge picture that end loops are made deliberately thick so that they have low resistance and they will be relatively insensitive to strain measurement and the transpose 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 gauge. Because we have already seen, you need 100 millimeter for you to develop 100 ohms in normal resistance wires; you need to take special effects to reduce the length.

And most common strain gauges general purpose strain gauges have a gauge length of 3 millimeter that is good enough for a variety of problems; only special applications you need to select smaller gauge lengths or longer gauge lengths in which class of a material, you will look for longer gauge lengths. Suppose I have a hydrogenous material like concrete, I would definitely go for longer gauge lengths for most of your metallic application, 3 millimeter strain gauges good enough; at 0.2 millimeter is only for very special applications.

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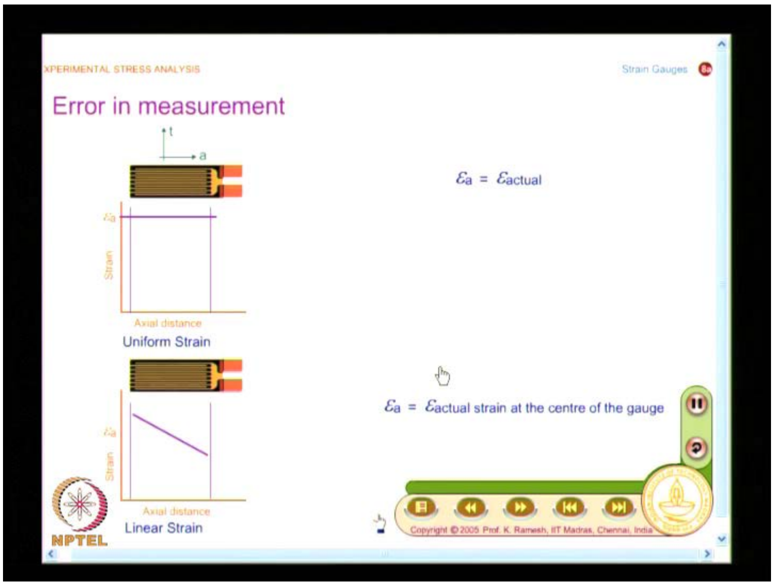

And let us also look at what are the errors that would come when gauge length is not chosen appropriately. Suppose I have constant stress thus gauge length has any influence does not influence whatever the strain as measure is equal to the actual strain.

Suppose I have a strain varying linearly, this happens when you take a cantilever, 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 it not having any influence, because whatever the average strain that you measure at the center is as same as your actual strain.

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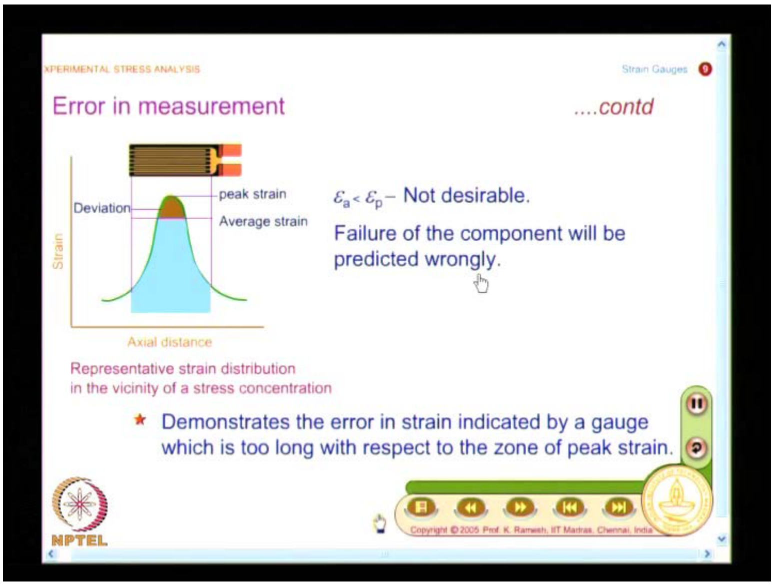

Suppose I have a non-linear variation which happens in stress concentration zone, then I have to be very careful. Suppose I have a very sharp change in the strain magnitude, my peak strain is mismatched, but strain gauge will measure only an average strain, which is much below the peak strain.

So, when you have a stress concentration 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, we have to be careful.

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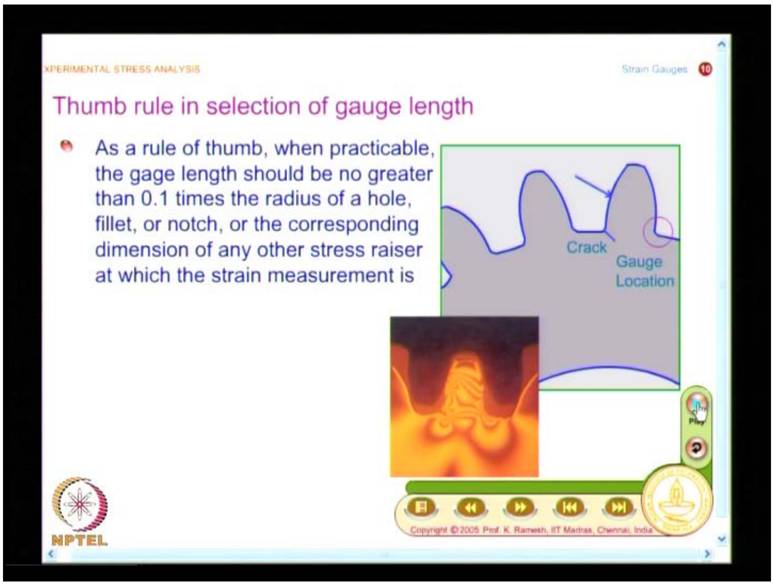

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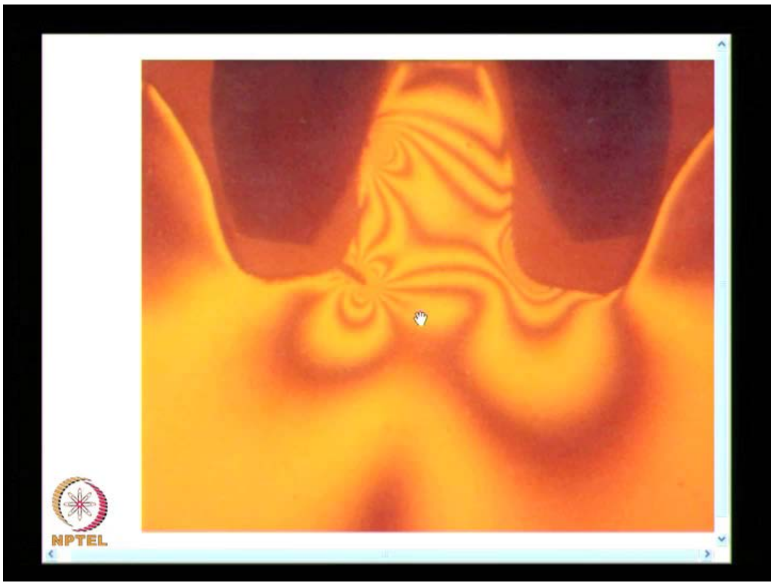

And let us look at two example problems and look at thumb rule on what I am going to look at. See, I am going to look at the strain field in the case of a spurge here and you have all done course in experimental stress analysis, where you have already seen what is photo-elasticity.

And this is a (( )) and you have this as loaded, this is the epoxy model and on the tensile side, you have a crack developed, you have a crack stress field and suppose for example, I need to measure strain on this pillar, you could see many fringes tensely 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 the general purpose strain gauge of length 3 millimeter; I need to use a strain gauge smaller than that.

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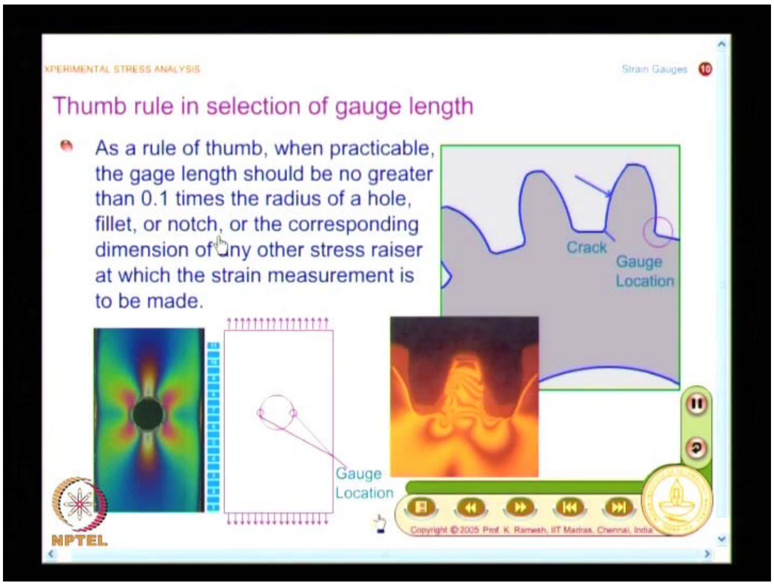

So, you have a thumb rule, what is the thumb rule? We look at the thumb rule and what did say is, it is about 0.1 times the radius of a hole fillet or notch; here we are talking about fillet, so you take only 0.1 times of that; it may not be practically feasible sometimes, but you have to have a trade off in your selection.

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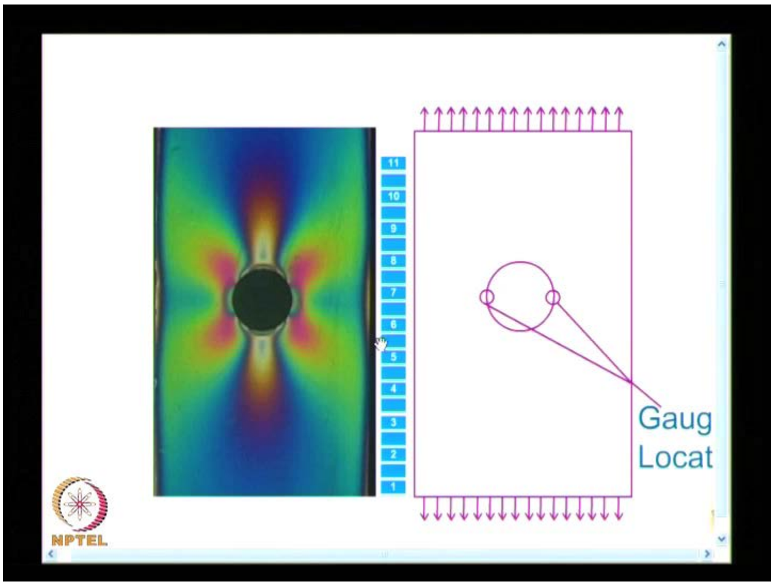

And this is another example, which you all know, you have done how to find out stress concentration factor by photo-elastic analysis; you simply measure the maximum fringe order at the boundary of the hole, find out the average fringe order, take the ratio, you get the stress concentration.

Suppose I want to use a strain gauge, then what happens, because it is a stress concentration zone, gauge length matters; not only the gauge length matters, when you put it in this zig-zag fashion, it also acquires the finite width; because it acquires the finite width, a transverse strain which is also varying very sharply that will also affect your result.

So, one way of circumventing that problem is do not paste the strain gauge on this phase, but paste the strain gauge on the inner wall. All this is in a difficult propagation, if the whole 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 redder of concede was failing by using a strain gauge; they also found that the strain gauge was measuring strains lower than what is actual and a photo-elastic coating revealed that maximum strain was at slight distance away and they had corrected.

So, now, this is an example which you have already done as part of your photo-elastic analysis, how to find out the stress concentration factor. In strain gauge it becomes involved and complicate; it is not simple. And the thumb rule is if you use the gauge length which is small enough, it is about 0.1 times the radius of the whole and to illustrate the stress concentration better, I had shown you these photo-elastic fringes; now you know how to interpret the photo-elastic fringes better.

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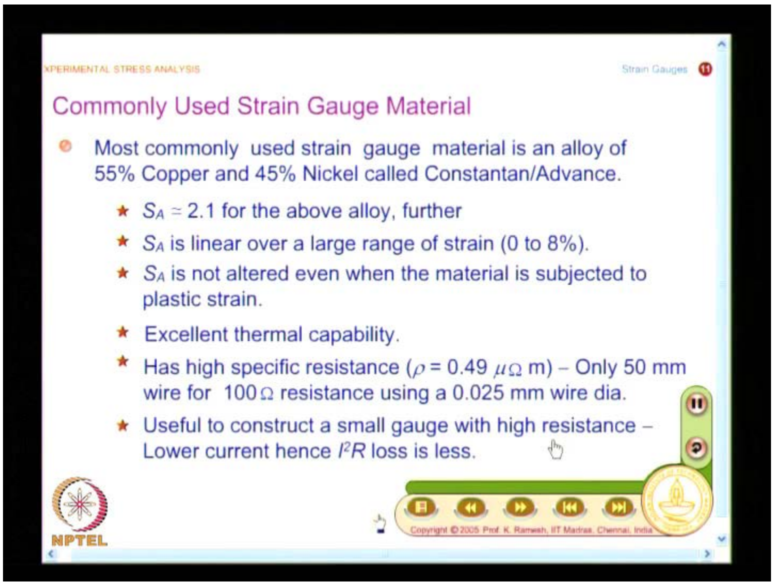

And what is the commonly used strain gauge material? You know for most of the resistors that were available at that time, they had only constantan or advanced, it is a very good strain gauge material and it is an alloy of 55 percent copper and 45 percent nickel. And the advantage is, the strain sensitivity of the conductor, A means conductor, we 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 S A is linear from 0 to 8 percent and we have already seen 0.2 percent is the value at which yielding takes place. So, 8 is the 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 to… because that deduces to 1 plus 2 nu, that is the reason why we choose a material which has S A 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 isoelastic compared to that, this has the better thermal capability and also it has a very high specific resistance, row is given as 0.49 micro ohm meter and the resistance is given by rho L by 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 our 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 pass through the conductor what happens, the conductor gets heated up and you call that as I squared R loss and if you have looked at my statement very carefully, I had set with the advancements in composites, people have developed 300, 350 ohms, 500 ohms, 1000 ohms, 3000 ohms etcetera.

And whatever the heat generated on the strain gauge has to be dissipated away; 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 the higher resistance so that you pass less current and you minimize the heat generation, these are very shuttle issues. You will be able to appreciate, and then, faithfully adapt 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 the measurement scenario that you are used to.

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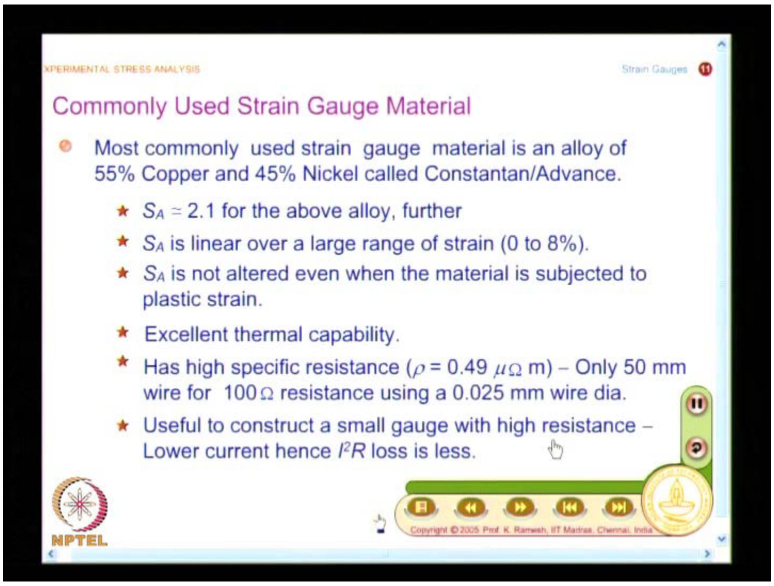

So, this makes the technological aspects very stringent and also the procedures to paste the strain gauge and make measurement, you have to follow the recommendations by the manufacturer very systematically.

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 bridle coating and strain gauge go handle in hand; you know, they were also developed almost at the similar time and bridle coating was very useful to identify zones of importance. Since you know the principle stress 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 bridle 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 at every stage, how this thermal influence is handled.

Like I said, normally you do not recognize when current passes through the conductor gets heated; the heat generation may be small, but since I am measuring very small quantity, this small change also affects. What you say a small is significant in…, it is not like your room heater. See, you all have a room keeper in winter, where you put the room heater, the room gets heated up; when you put a strain gauge 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 become significant that is the way we will have to look at it. And if you understand this write from the beginning, whichever way we are developing the strain gauge technology, 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 measurements 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 resistance 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 any learning. The physics behind the strain gauge technique is very simple, but the details are equally important.

So, I will try to organize 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.

Thank you.