Experimental Stress Analysis - An Overview
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Lecture - 3.2
Introduction to Moiré

We are continuing the discussion on Overview of Experimental Stress Analysis. What is a physical principle behind some of the experimental techniques?

First, we saw the method of Strain Gauges, and I said stresses alter the resistance of the conductor. And this was a physical principle used in strain gauges, it is desirable. However, we also found temperature also alters the resistance information. This is the new sense, so you have to be very careful in strain gauge instrumentation to delineate the resistance changes due to strain and that due to temperature.

So, when we see the experimental technique we see both. We look at what is the physical principle behind it, and what is the limitation? Where does a limitation come from? When we go to photo elasticity we said that we get whole field information, whereas strain gauge gives point-by-point information. The photo elasticity requires normal incidence. Normal incidence is a key point; if you have curved models then you have to immerse it in a liquid which has a same refractive index.

Then we had a detailed discussion on Moiré. And moiré you are able to get the displacement. I said moiré is a new sense in some applications. For example, in color printing you do not want to have moiré effects. And secondly, when we all come for this a televised lecture we are advised to where only plain shirts. You can watch in some of the TV programs if they come with striped shirts you will have a sort of color banding, because you have electronic camera which scans the image and that interferes with the frequency of your stripes and you will see a color banding effect.

Like I said, friction is needed in some application; friction is not needed in some application. So moiré is not needed in color printing, moiré is not needed in televised information where you want to take care, may be with high definition television some of these effects are fairly addressed.

But what you will have to understand is for every technique you will have certain kind of limitation. In moiré, what we also saw was I have a grating and which I had shown and what you will have to notice it, when I have this grating I make a rigid body translation and rigid body rotation. I see fringes, we get excited to see fringes but you should implicitly understand this is a new sense in moiré, because moiré I would like to find out what is the effect of stresses or strains introduced in the material not rigid body rotation and rigid body translation.

So you will have to be very careful while performing moiré that you take care of the effect of rigid body translation and rotation. It is very very very important, it is very settle. And we will again go back and look at, because moiré is a very interesting technique we will look at.

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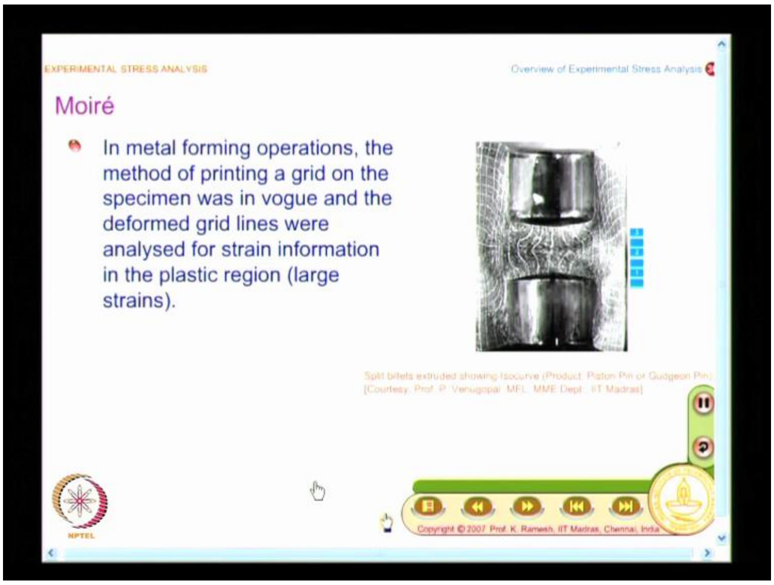

We started moiré by introducing the application of grids in metal forming operations. And what we saw was, we had a billet which is put with a grid, and when you have very high plastic deformation you see this grids visually distorted. This gives you information on what is the level of strain introduced and how the material has flowed and so on and so forth.

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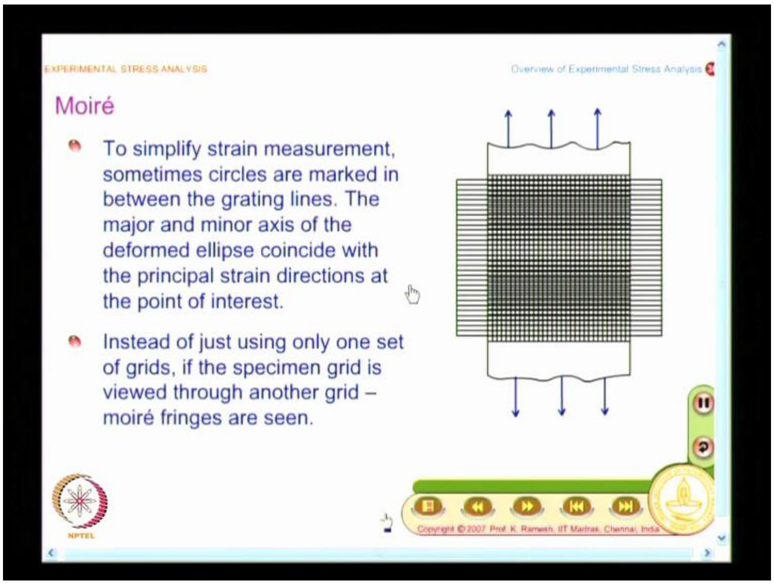

And what we saw was instead of just using a grid, people also had another approach where in along with a grid inside the grid they are put a circle, and when you stretch the member the circle deforms into an ellipse, so you also get the stress direction. Later on what we did was instead of using only one grid we have used two grids, we call one as a master grating and another as a specimen grating. And here the specimen grating is cross hatched and master grating is horizontal lines, and I pull the material, pull this specimen so the specimen elongates as well as contracts because of Poisson effect. And what you see here is, the actual specimen deformation is small, but you see a play of fringes.

So what we find is, instead of using only one set of grids. If the specimen grid is viewed through another grid moiré fringes are seen. And these are very course fringes.

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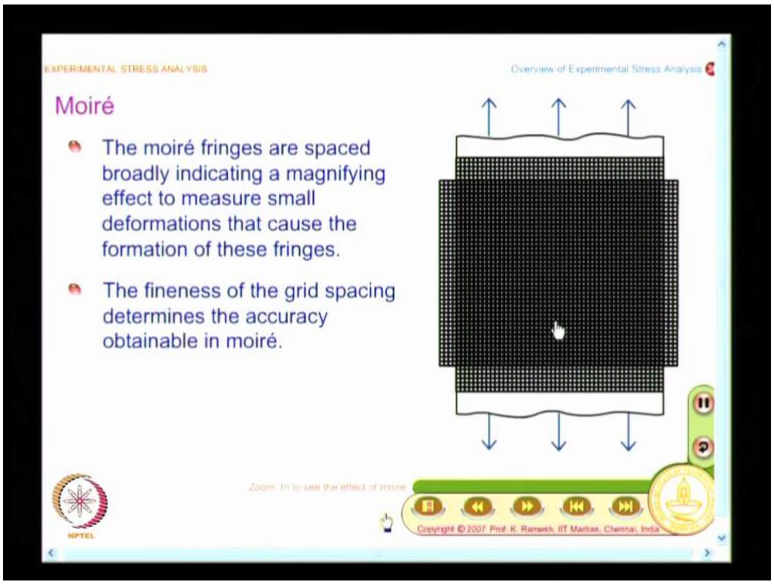

And what we want to see is we want to have fine measurements. You also appreciate that moiré fringes has a magnifying effect to measure small deformations. Because it as a magnifying effect by making measurement on a fringes you are in a position to find out very fine displacements. And what you find here is, the fineness of the grid spacing determines the accuracy obtainable in moiré. Whatever you call it as a pitch, that finer the pitch finer the deformation measurement that you can do. Here, we have situation I have the specimen is width very fine cross hatched pattern and I also have a master which is also having a crossed hatched pattern. So, I get two sets of fringes; one set of fringes horizontal, one set of fringes vertical. See you should not confuse this horizontal and vertical fringe to the grating lines.

We have seen in the problem of a disc, the fringes could be curved. You could get curved fringes, but you interpret whether these fringes belong to u displacement or v displacement by looking at what was the master grating direction. The master grating direction is horizontal then you get displacement in the vertical direction. Here, the problem what have taken is axially loaded member, here you have uniform deformation. The fringes also become horizontal and vertical. So, do not (Refer Time: 07:31) the mental block that horizontal fringes means v displacement, vertical fringes means u displacement do not have that confusion. That confusion is possible by looking at this picture. This is a very special case.

So what we look at here is, I can also get two information from ones experiment. Because I said in some experiments which is time varying you may want to record more than one information, recording both the information simultaneously is better. But simultaneous recording is not always good, so you would like to have information obtained separately. And I also said that in moiré it is possible to identify the displacements easily, we will see that in a few slides later.

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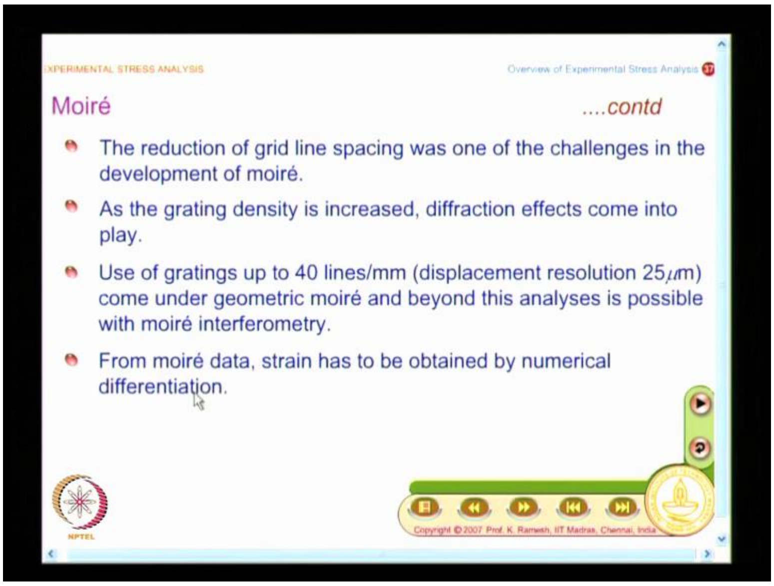

Now we also looked at, the reduction of grid line spacing was the challenge and many scientists have contributed to it. And we have also seen as the grating density is increased. What you find was, the fringes become finer and finer. I said a thumb rule which says up to 40 lines per millimeter, you can call it as geometric moiré. Even these 40 lines per millimeter are fairly small and you are able to get a displacement resolution of 25 micro meters. Moiré gives you only displacement, and from moiré data strain has to be obtained by numerical differentiation. We have seen that the numerical differentiation is erroneous, so unless you have very fine information it is not worth doing the numerical differentiation.

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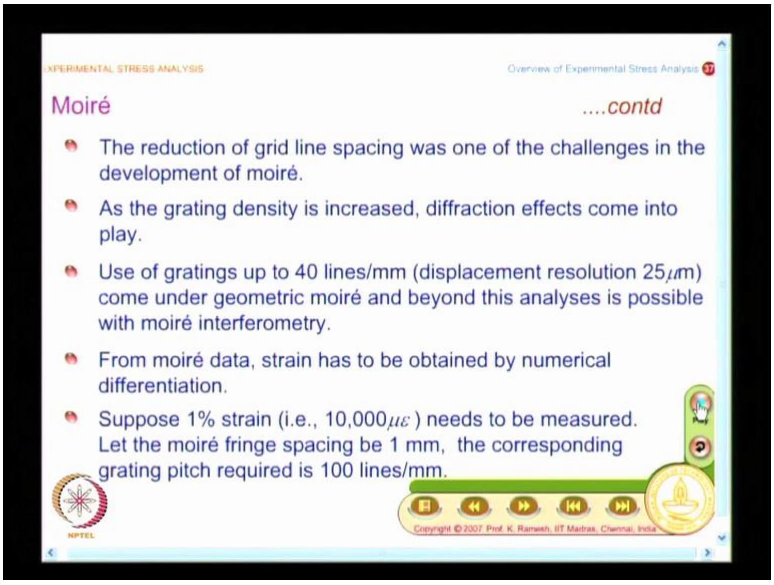

We have also looked at efforts have been aimed at increasing the density of the gratings. And I pause the problem, I want to measure 1 percent of strain and here it is clearly shown as 10000 micro strains, obviously it is a very large value. Even when you want to measure very large strain what you find here is, you require 100 lines per millimeter. So from 40 lines per millimeter if you go to 100 lines per millimeter which is very very fine from pitch point of view, but what you find here is the strain value is still very high. So what you need to understand is moiré is applicable for large strain problems comfortably.

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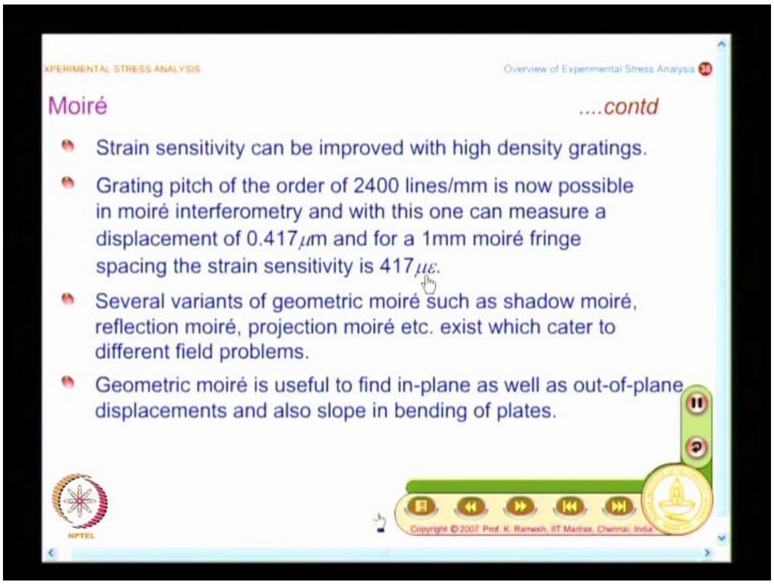

We have also looked at what is the level of grating pitch that they could reduce. People have gone up to 2400 lines per millimeter. And what you find here, if you have 2400 lines per millimeter the displacement accuracies of the order of 0.417 micrometer. Suppose, you find that you are able to see a moiré fringe at a spacing of 1 millimeter, it is a reasonable assumption the strain sensitivity is only 417 micro strains.

It still large, because I said we live much below 2000 micro strain for most of our practical requirements and we may operate around 500 micro strain for many of our strategically important components. If moiré is sensitivity cannot go below that, so measurement in those regions you have to look for other techniques. We have already seen strain gauges you are able to measure up to 1 micro strain, now even 0.5 micro strain reliable measurements is possible. So when you go for very fine small strain measurement, strain gauge is good but it is point-by-point information. The advantage of moiré, is I get a whole field information and what we have seen is I also see the fringes in real time and I also find the rigid body rotation and translation you have to be careful about in moiré

And I said that once you take any technique you have a several variants exist. So in geometric moiré, you have shadow moiré, you have reflection moiré; you have projection moiré which cater to different field problems. And geometric moiré is useful in in-plane as well as out-of-plane displacement and also slope in bending of plates. We have already seen that reflection moiré was used to find out the curvature, and you could find out of plane displacement by shadow moiré and geometric moiré can give in plane displacement. The method of putting the specimen grating is slightly different from shadow moiré, reflection moiré and projection moiré etcetera.

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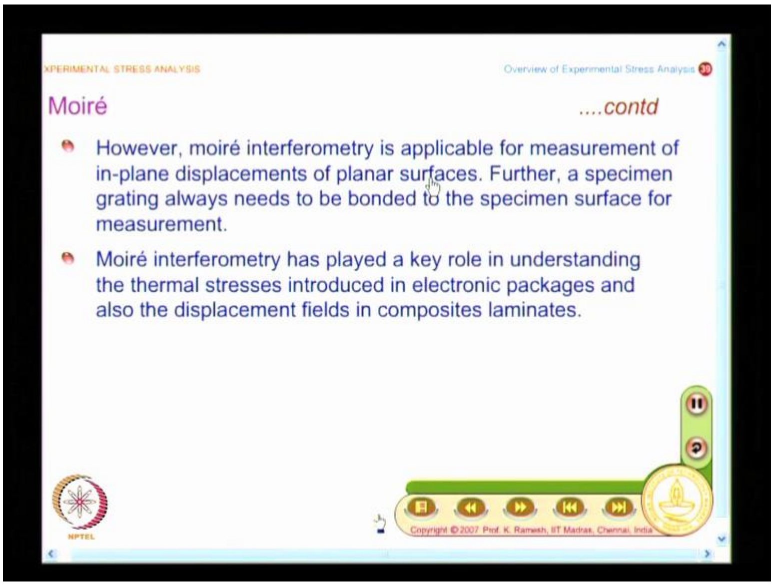

We have also seen that moiré interferometry is to improve the accuracy. And what you find here is, primarily it is applicable for in-plane displacements of planer surfaces. This is a very key point. If you have curved surfaces whether it is photo elasticity or moiré or any other experimental technique will have problem. So we are happy from simple geometry to complex shapes, but once you come to complex shapes if it is curved then you will get information but interpretation becomes difficult. The greatest advantage of moiré interferometry is whatever the equations that you have developed for geometric moiré equally applicable. Here, you have to have a specimen grating always needs to be bonded to the specimen, which is not the case in geometry moiré I can project that grating on the specimen, I can look at the shadow of the grating on the specimen and then do the interferometry.

But once you come to moiré interferometry, I will have to have the specimen grating firmly bonded to the specimen. There are many techniques that had been developed. Newer materials have contributed to the improvement and many techniques and these are all very fine grid lines. See the fineness makes the process delicate. I have also identified that moiré interferometry has made a key role in understanding the thermal stresses introduced in electronic packages and also the displacement fields in composite laminates. Because composites are becoming very important for structural applications and because of their material anisotropy analytical modeling is extremely (Refer Time: 14:51) and at least you get surface information by using techniques like moiré interferometry.

So what is important here is, each technique has a particular domain where it has served it is purpose fully. The moment you think of moiré interferometry electronic packaging you cannot forget, they go together. Very interesting problems in electronic packaging have been solved by moiré interferometry.

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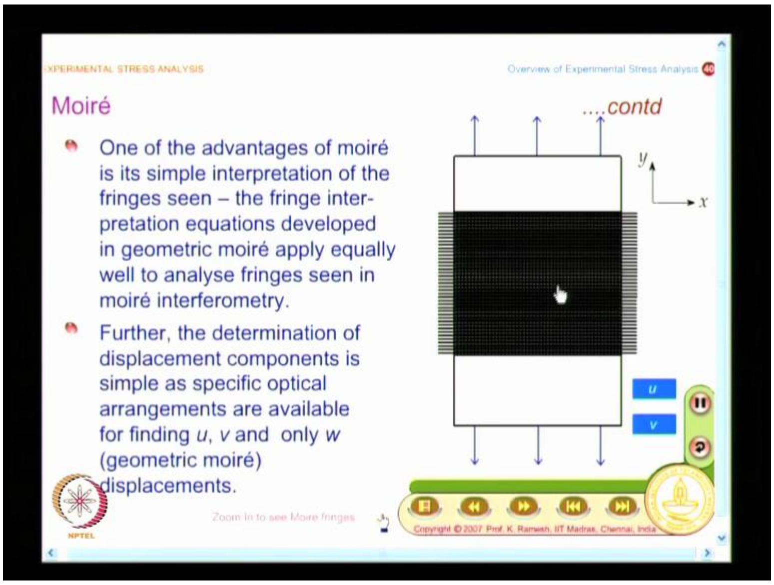

Other concepts which I wanted to say was that you are able to get the displacement information comfortably separated in moiré analysis. And purposely this is taken like this I have a specimen with a crossed grating, but I view this specimen with the horizontal grating. So, what is the displacement I get? We have already seen, once we have horizontal grating what is the displacement you get.

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You get the displacement perpendicular to that. So the fringes what you have here show the v displacement. Suppose, I want to see u displacement I will change my grating, I will change my master grating to have vertical lines, so I will have a u displacement. What I have is, on the specimen I bond only one grating which has a crossed lines. But I view this with a horizontal grating or a vertical grating, so I can comfortably switch over from u displacement to v displacement. Data interpretation is not difficult, it is a very key important because the next technique we going to take it up is holography. In holography you will get displacement vector; it will give you u v as well as w bundle together separation becomes difficult.

In the case of moiré by choosing the master grating appropriately I can look at u displacement separately, I can look at v displacement separately. All this contours when you look at them all have special names. You know we have seen in photoelasticity isochromatics, we have seen isoclinics. In moiré these contours are called as isostatics, u displacement isostatics, v displacement isostatic, r displacement isostatics, theta displacement isostatics all those terminologies you will come across.

So what you find here, the determination of displacement components is simple as specific optical arrangements are available for finding u v and only w displacements that is possible from geometric moiré. Moiré interferometry gives you only u and v displacement. When you go to geometric moiré it is variation like, shadow moiré, reflection moiré, projection moiré, you get out of plane displacement, you get slope, you get curvature and each case you need to have a specific optical arrangement. Though it appears specific arrangement is a new sense in some instances data interpretation is lot simpler if you have specific optical arrangement.

In this lecture, we have looked at the physical principle behind moiré. We have also looked at several variants of moiré and their applications. Limitations or experimental technique were also highlighted during the lecture.

Thank you.