Experimental Stress Analysis

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Module No. # 02
Lecture No. # 19
Tardy's Method of Compensation

In the last class, we had seen the ways to find out fringe order and theta at any arbitrary point. What you need to keep in mind is all the optical techniques provide you whole field information. The whole field information, you can make certain general appreciation of the stress field or the displacement field from the way the fringes are arranged; the density of the fringes give one kind of information, the thickness of the band gives another kind of information.

So, you can make certain assessment about the problem by visually looking at the fringe patterns, this is one aspect of it. The other aspect is you need to make quantitative evaluation of the parameters involved, only then you will be able to compare whatever the numerical values that you get from an experiment to a parallel analytical or a numerical comparison.

So, you need to also know how to get these quantities quantitatively and what we saw was finding out theta at any arbitrary point is very simple. You go to a plane polariscope, keep rotating polarise analyzer combination, and when an isoclinic passes through the point of interest, you find out what is the value of isoclinic. The only key difficulty there was the isoclinic fringes are very broad, because they are very broad, unless you casually stop your polarizer analyzer combination at the point of minimum intensity, there could be error introduced.

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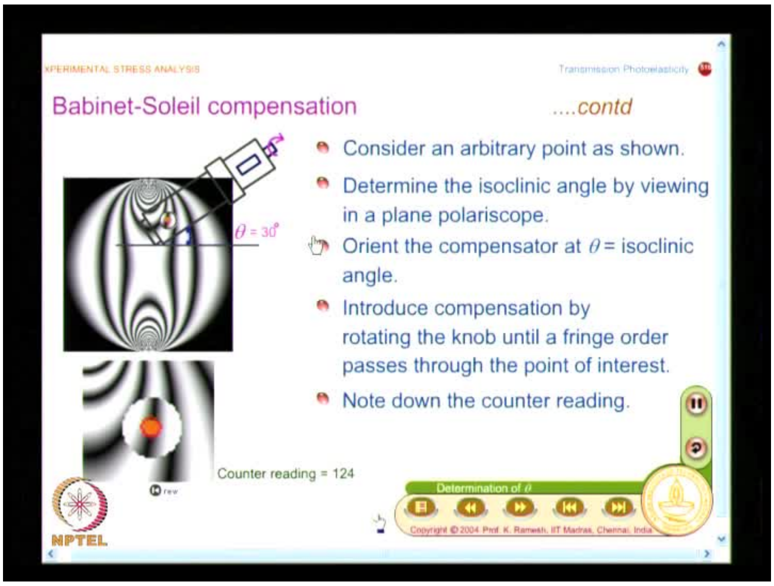

The moment you come to finding out fringe order n, a simple way is take a photograph, and then process the data by collecting points along the particular line, and if your point of interest does not lie exactly on the fringe order by plotting the graph, you can get the fringe order; however, this is time consuming. So, we also need to have techniques which help you to find out the fringe order at the point of interest quickly.

What we said was these are all compensation techniques; though your interest is to find out only the fringe order n, even to find out the fringe order n, the first step is to identify the isoclinic at the point of interest. This is the key point, once you understand this, you can also appreciate what we do in digital photo elasticity later.

And what you saw was we had Babinet-Soleil compensation, in this, you had an external compensator, you had a gadget and this was aligned by finding out the isoclinic angle. In this case, it was 30 degrees, and then this was kept, and what you did was then you rotated the knob until a fringe order passes through the point of interest (Refer Slide Time: 03:13). And I caution that, this is the field of u within the compensator, within this, whatever the modification that you have done is valid only for the point of interest from the point of u of data interpretation.

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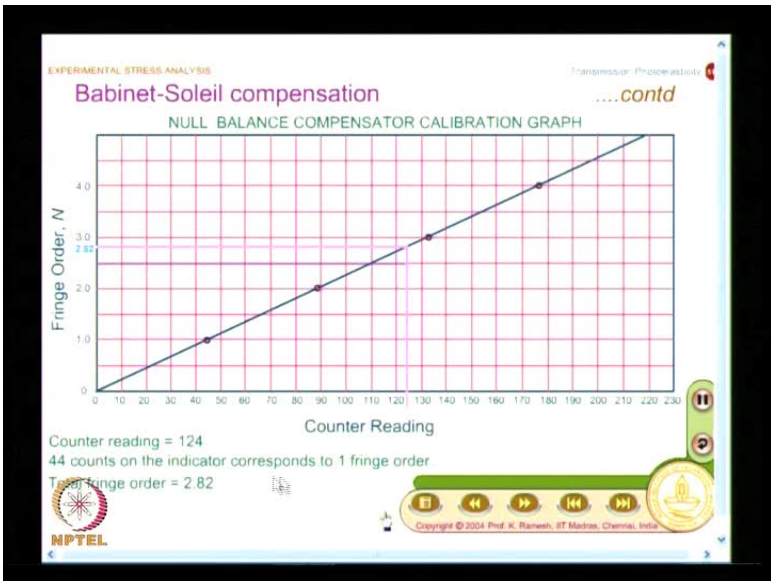

I also said that, you need to find out whether the higher fringe order comes and coincides with the point of interest or a lower fringe order comes and coincides with the point of interest. In this case, it is the higher fringe order that has come and coincide with the point of interest and we manufacturers give it in various ways. In this case, the manufacturers has given directly; note down the counter reading, then he has also supplied you a graph and based on the graph, you can find out the fringe order at the point of interest (Refer Slide Time: 04:04).

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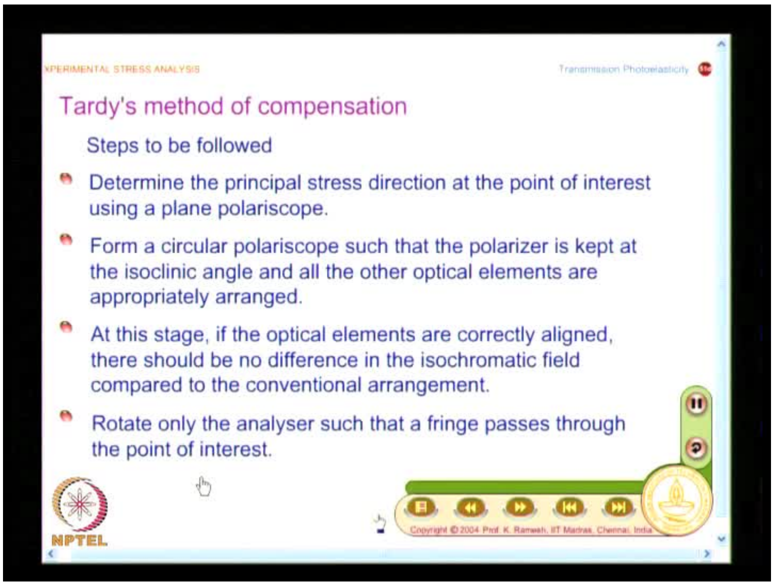

Then we moved on to what is known as Tardy's method of compensation. The focus here is instead of using an external compensator, can one of the elements in the polariscope itself could be used as a compensator. In this case it is the analyzer, which is to be rotated to an appropriate angle to function as a compensator.

And what we will do is we will see the procedure first, then we will go and develop the mathematical analysis and convince our self, whatever the procedure that we have stated indeed coincides with our analytical development, that is a way we will proceed. As in any compensation technique, you will have to find out the principle stress direction at the point of interest using a plane polariscope.

Your interest is only to find out fringe order n, but you also have to find out theta. The second step is I have to form a circular polariscope such that, the polarizer is kept at the isoclinic angle and all the other optical elements are appropriately arranged. If you do not align the elements properly, there would be distortion in the isochromatic field. So, one of the indirect check is if the optical elements are correctly aligned, there should be no difference in the isochromatic field compared to the conventional arrangement.

So, this is how you verify whether you have followed the second step correctly. Identify the isoclinic, second step is reorient your polariscope such that, the reference axis at the point of interest namely the principle stress direction is the reference axis for formation of your circular polariscope. This makes your analysis simple; see once you make the reference axis as the reference axis for your polariscope, what is the value of theta that you need to substitute? When I have to analyze the model, we always say gives a retardation delta it has the orientation theta. Suppose, I take the reference axis as the principle stress direction at the point of interest, theta becomes 0.

This makes your calculation very simple and fast. So, the implication of making a circular polariscope also helps you in your mathematical analysis, the theta becomes 0. So, this is the important step that you need to understand then finally, you rotate only the analyzer such that a fringe passes through the point of interest.

So, from this axis, I should find out what is the angle by which analyzer is rotated. I should know what the reference axis is, before I start rotating the analyzer that becomes a reference axis. Then I start rotating it until a fringe passes through it, what are the possibilities, I can rotate the analyzer clockwise as well as anticlockwise. So, both will give some numbers.

So, we need to know how to interpret this, there is no preferred orientation that you should always rotate clockwise or you should always rotate anticlockwise, you have to do it depending on the problem on hand. And in experimentation, we always want to do some kind of an averaging; so, you better do one measurement by anticlockwise, another measurement by clockwise. So, you take the average of these two and find out the actual fractional fringe order, then the total fringe order.

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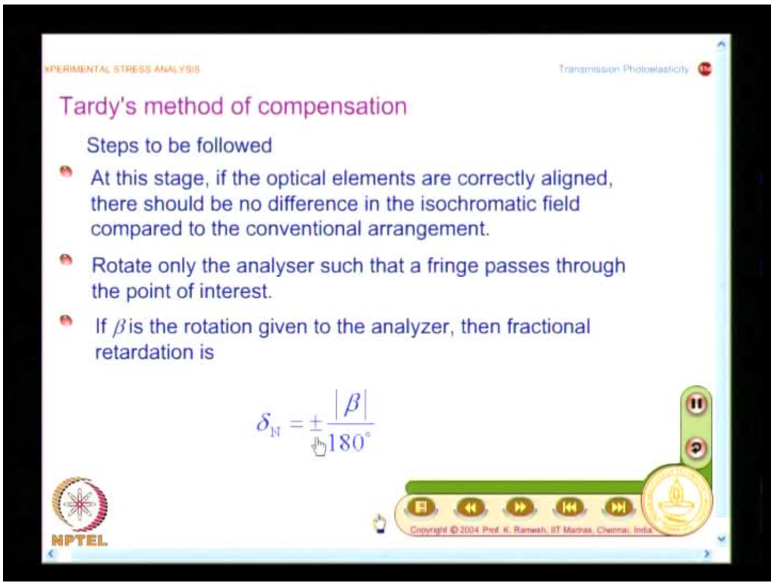

What I said was suppose beta is the rotation given to the analyzer then, fractional retardation is given as in terms of fringe orders. When I write it as simply delta it is in radians, if I write it delta suffix n it is in fringe orders and this is given as beta by 180 degrees and I have this as sign has to be fixed based on heuristic information; sign does not come from your mathematical analysis, sign comes from your observation whether the higher fringe order comes and occupies this point of interest or a lower fringe order moves and occupies the point of interest.

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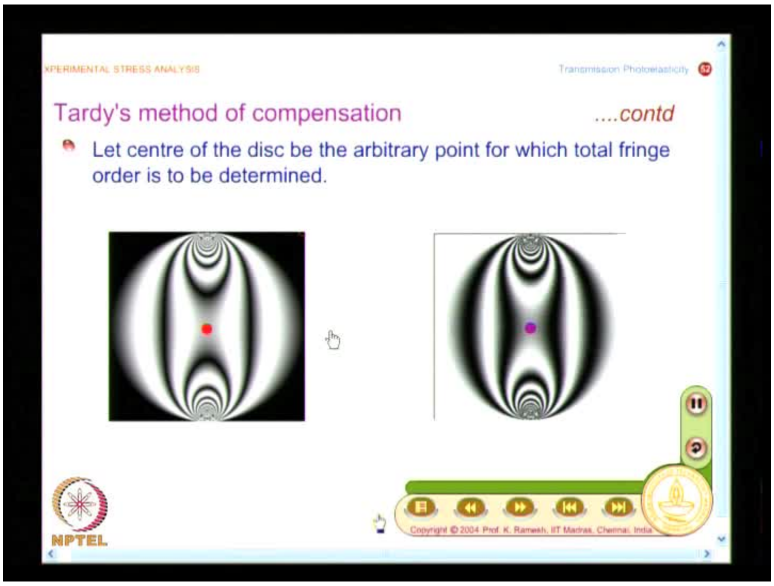

I have also caution, whatever I do in a compensation technique it pertains to the point of interest from the point of u of data interpretation that will become clearer when you look at tardy method of compensation. And what we are going to do is rather than taking an arbitrary point, we will take a very convenient point for finding out the total fringe order. And what I have taken is, I have taken a disc and diametral compression, there is a particular reason behind it because the next topic we are going to discuss is how to find out material stress fringe value f sigma.

I would use circular disc under diametral compression as the basic model to be used for finding out f sigma and we will use tardy method of compensation to find out the fringe order accurately. And what we are going to look at, we are going to look at the center of the disc and I have taken the loading in such a manner f, either a full fringe or half fringe (Refer Slide Time: 10:25). That is here it is 0, 1 and 2 the fringe order lies between 1 and 2 and fringe order lies between 0.5, 1.5, 2.5 that is a way the fringes increase. So, it lies between 1.5 and 2.5.

So, both in the dark field as well as the bright field, a fringe order does not pass through the point of interest. So, I need to find out the exact fringe order only by a compensation technique. In some of the polariscope is built several years earlier, they use to have a control on loading the model, they use to have water tank to load the model. So, they will adjust the level of water until a fringe occupies the center, there are also polariscope is like that. So, we do not need that kind of a loading arrangement, if how to employ tardy method of compensation. I can find out the fringe order very accurately, with the existing loading frame, without much difficulty in adjusting the load so that a fringe passes through the point of interest.

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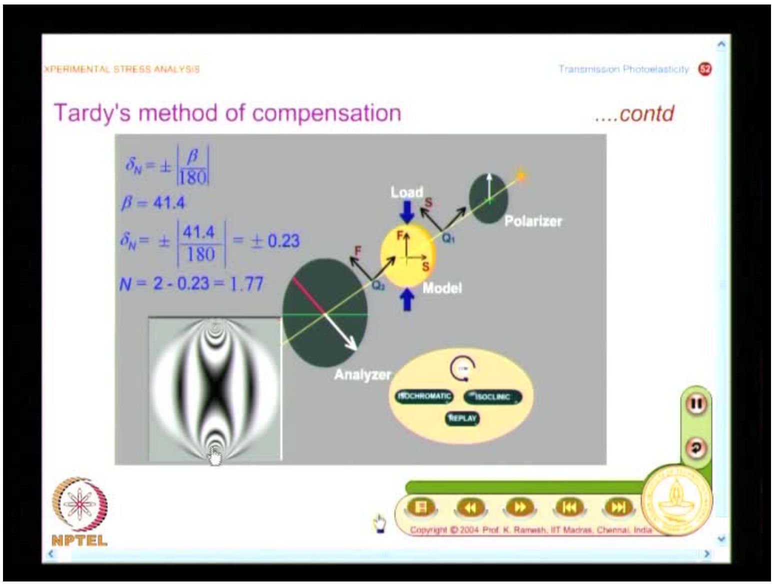

Here, we have deliberately taken the center from your knowledge of solid mechanics and you have also looked at the analytical expression for the stress field. What is the principle stress direction at the point of interest? This is exactly at the point of symmetry. So, the x and y axis themselves function as principle stress direction, we will verify.

We will also see the isoclinic because in any compensation technique, my first step is to find out the isoclinic at the point of interest. Once I have the isoclinic determine, the polarizer analyzer is aligned to this as the base angle, quarter wave plates are appropriately rotated. So, that you form a circular polariscope with the reference axis at the point of interest as x and y. Let us go and see how I getting it. So, what I find here is I have been able to get a fringe order passing through the point of interest, this we will see this animation we will see quite a few times.

You should also look at what is the shape when it passes through the point of interest, I am moving the cursor what is its shape; it is like figure of 8. So, if you are able to observe this, is it necessary to mark the point at the center? It is not necessary, see if I want to do any evaluation quantitatively at a point of interest, I must mark the point and then find out the fringe order, if I take the center because the fringe occupies a position as 8, it is easy to identify that I have got the fringe order at the center. This is one of the advantages, when I want to go and find out f sigma, I have to simply take a circular disc make it as a figure of 8 by rotating the analyzer.

You find out the fringe order accurately, you do not even have to mark the point. So, it eliminates one more step in finding out comparison between experimental calculation and analytical comparison because the focus is to find out f sigma, focus is not to find out the fringe order; fringe order you need to know and based on your analytical computation, find out what is the material stress fringe value. So, this eliminates one more step in your evaluation of material stress fringe value. So, note down in the earlier slide what we saw was, both the bright and dark field fringes were not passing through the center.

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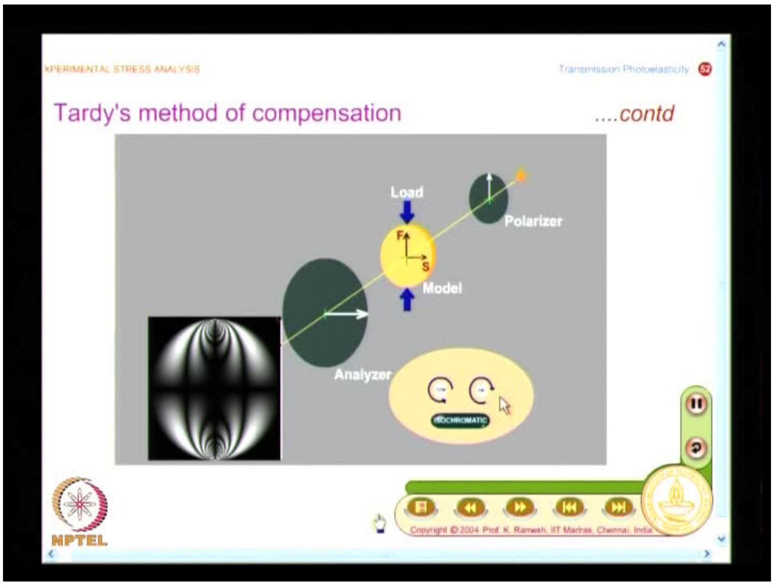

Now, I have rotated the analyzer and I have made this fringe passes through this point of interest and I have made an observation that this forms a figure of 8. And just to convince you, we will see the isoclinic, isoclinic at the point of interest is 0 degree isoclinic, I have a plane polariscope because I have to go to a plane polariscope and then do it, I have the source of light, then I have the polarizer, I have the model and this is what I said the at the point of interest the reference axis itself is the base reference axis for the final circular polariscope also.

In this case, the point is selected as a center of the disc. The horizontal and vertical axis themselves are principle stress directions. So, I have the polarizer, analyzer coincide with this and normally we also make a polariscope with polarizer vertical and analyzer horizontal. So, another advantage why I use circular disc as a model for f sigma calculation, I do not have to do anything for the polariscope. Even if I want to find out fringe order with second decimal place accuracy, it is enough I keep the model properly loaded and simply rotate the analyzer.

Though in a generic tardy method of compensation, my first step is to find out isoclinic at the point of interest, second step is rotating all the optical elements such that you form a circular polariscope with the reference axis at the point of interest. So, these two steps are redundant when I want to use circular disc and use the center to find out the f sigma calculation. So, you are learning both tardy method of compensation, as well as why circular disc is so popular in photo elastic analysis.

Because I said when you are learning strength of materials you are taught from a simple tension member, then you go to bending and you never touch circular disc whereas, in photo elasticity you touch only circular disc because unless you do a course in theory of elasticity, you cannot find out the stress field in a circular disc, but circular disc has very simple fringe contours, you can illustrate both isoclinics and isochromatics in a plane polariscope and also helps you in finding out material stress fringe value very comfortably.

So, I can develop how to identify fringes using circular disc also use it to find f sigma that is why circular disc is very popular. So, the first step is I need to find out the isoclinic angle at the point of interest and we find that in a plane polariscope, you find the zeroth degree isoclinic passes through the center and if I look at the isochromatic to convince yourself that, I have this as a dark field, I have fringe order 0, fringe order 1 and fringe order 2.

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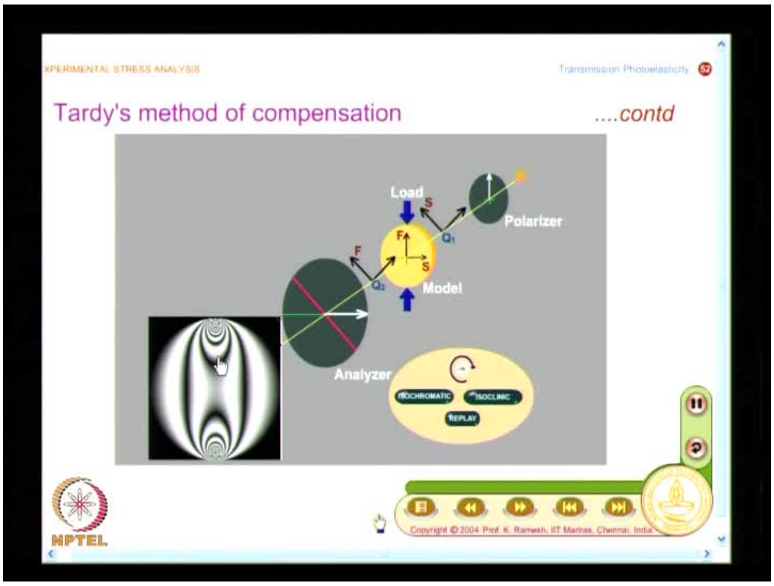

So, you can say the fringe order at the center is between 1 and 2. So, I need to find out the fractional part and I have already said I can rotate the analyzer clockwise or anticlockwise, while doing so, I should also see which fringe moves and occupies the center.

Because I have a very good animation, I can show you repeatedly either clockwise or anticlockwise and observe, first observe then make a note of it, I will also give you sufficient time for you to make a sketch of it because, the concept you will have to understand. You have to form a figure of 8 mainly because even without marking the point, you can ensure that you find out the fringe order in the center.

So, that is why I identified because when you rotate the optical elements you have to visually check whether you have reached the minimum intensity. So, one check is it forms a figure of 8, even if you rotate the element slightly this way, that way the figure of 8 will get disturb, there is one indirect check.

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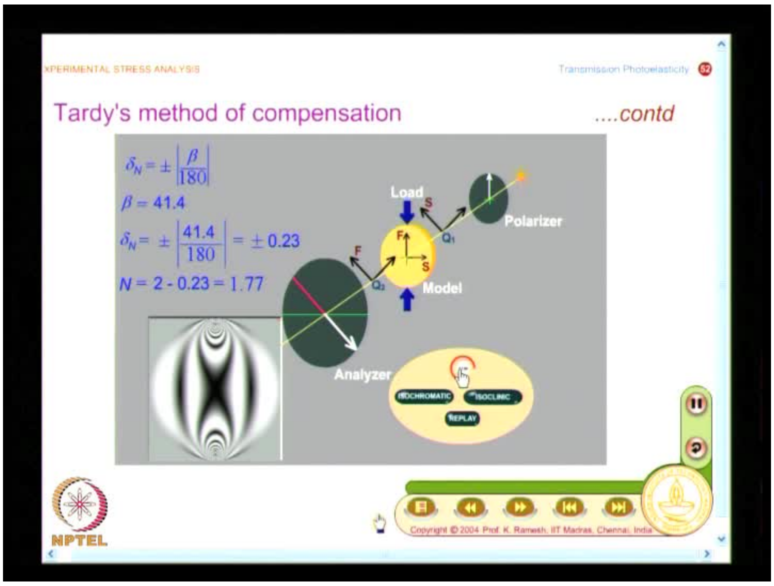

So, what we will do is we will rotate it in a clockwise direction; I rotate it in a clockwise direction, what happens? You may not have noted all aspects it has form the figure of 8 now look at, i will replay this, look at which fringe order has moved and occupied the position, only now look at which fringe order has moved and occupied the position.

So, what we find is the fringe order 2 has moved and occupied this position. So, I need to have this information for me to assign the sign. I need to note down 2 things: I need to find out by what angle I have rotated, I need to find out that angle, the second one is which fringe order has moved and occupied the position. And we have said the fringe order is nothing but, the fractional fringe order is nothing but, beta by 180 degrees.

So, now I have that information. So, what I have here is I have delta N equal to plus or minus beta by 180 and this angle is like 41.4 degrees. I could do this because my horizontal axis itself is a reference; see in some other point in the disc, you may find some other angle will be the reference. So, you must start from that reference, you should not always start from 0, the isoclinic angle at the point of interest forms the reference because in this case, the center horizontal and vertical coincides, I measure from horizontal. So, there is the possibility that you may misinterpret find out the angle from horizontal it is not so, find out the angle from the reference axis at the point of interest.

So, I have beta equal to 41.4. So, I can find out what is delta N I have still not attach the sign, I still say it is plus or minus 41. 4 by 180 degrees and that give you plus or minus 0.23. Now, I know the fringe order was between 1 and 2. So, I do this as 2 minus 0.23 equal to 1.77. So, I can find out the fringe order at the point of interest very precisely, it depends on your skill because if you are using a human eye to stop your analyzer rotation, you need to see it without error of parallax and have sensitivity in stopping it at the point of minimum intensity, all that you have to take the precaution and also note down the angle correctly.

Then you attach the sign, let me ask a question. Suppose I rotate it in anticlockwise direction, I will get some angle from that also, can you find the relationship between the rotation I do it in clockwise and the rotation I do it in anticlockwise? Suppose I have beta 1 as a rotation in clockwise and beta 2 as the angle rotated in anticlockwise, can you anticipate what would be the final relation, beta 1 plus beta 2 will be 180.

So, that is another check, but you do not have to make it as 180, you have to make the experimental measurement. So that, if I take 2 measurements because the fringe order at the point of interest is only one unique value, whether I rotate the analyzer clockwise or anticlockwise, it should reflect the same value, but because of experimental uncertainties you may find out one degree error this way that way.

So, you take both the measurements and take an average. So, you also have the advantage of applying statistical principle in data process. So, let us look at now, that I will rotate it by anticlockwise. I rotate it anticlockwise so, I find that I have to rotate by a longer angle, number one and I will replay and then ensure which fringe order has moved and occupied the position.

So, which fringe order has moved, fringe order 1; in the earlier case, we saw fringe order 2 came and occupied the position, in the second case, fringe order 1 has moved and occupied this is a very important information. In fact, this is the advantage in a conventional photo elastic analysis you get the heuristic information in fixing the sign of the fractional retardation.

In fact, this was the very difficult task in digital photo elasticity; fixing the sign of the fractional fringe order was not a simple task, it took almost a decade for people to figure out completely all aspects related to this, it was not a simple problem.

So, what I find I find the angle as 138.6 degrees, then I am able to calculate delta N this is plus or minus 0.77, because the fringe order 1 has moved, I attach the sign plus. So, I make it as n as 1 plus 0.77 equal to 1.77.

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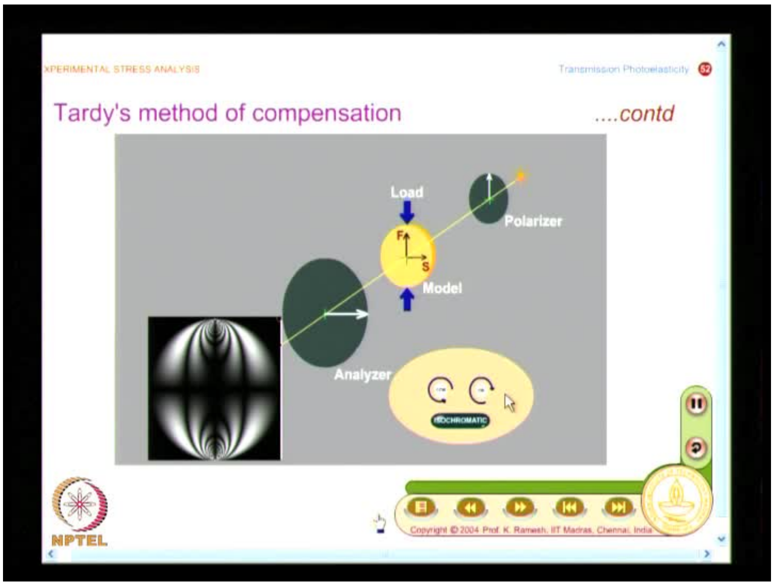

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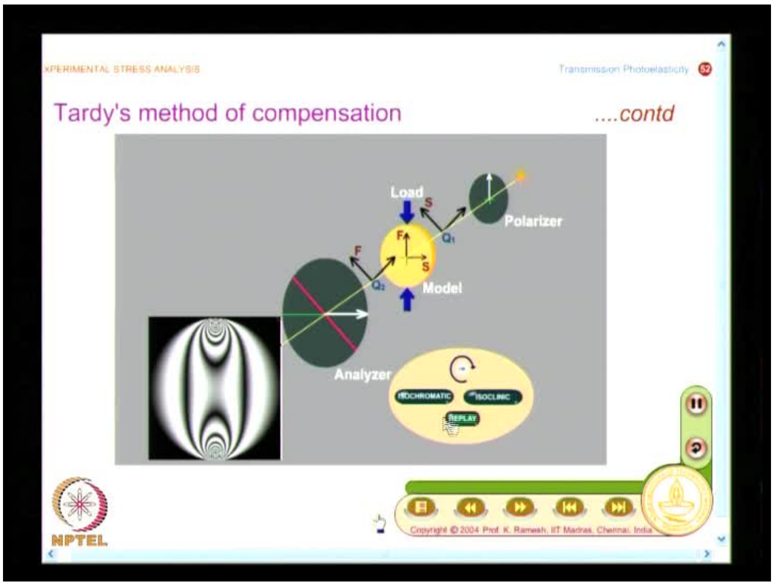

So, now what we will do is we will look at the complete procedure. The first step what I need to do is, I need to find out the isoclinic. So, I find out the isoclinic in a plane polariscope even though while starting the discussion, I said because it is at the point of symmetry the axis coincide with the principle stress direction, the reference axis themselves are principle stress direction, you also verify experimentally wherein I put polarizer, analyzer and I ensure that I have a 0 to be isoclinic passing through the point of interest. Then we have also seen that, at the point of interest in the dark field no fringe actually passes through and we get information, it is between 1 and 2 and I rotate the analyzer, I am able to directly rotate the analyzer, why? Because the basic polariscope arrangement is with respect to the horizontal and vertical, I do not have to do the step of orienting the polariscope to the reference axis, the basic polariscope itself is oriented towards that.

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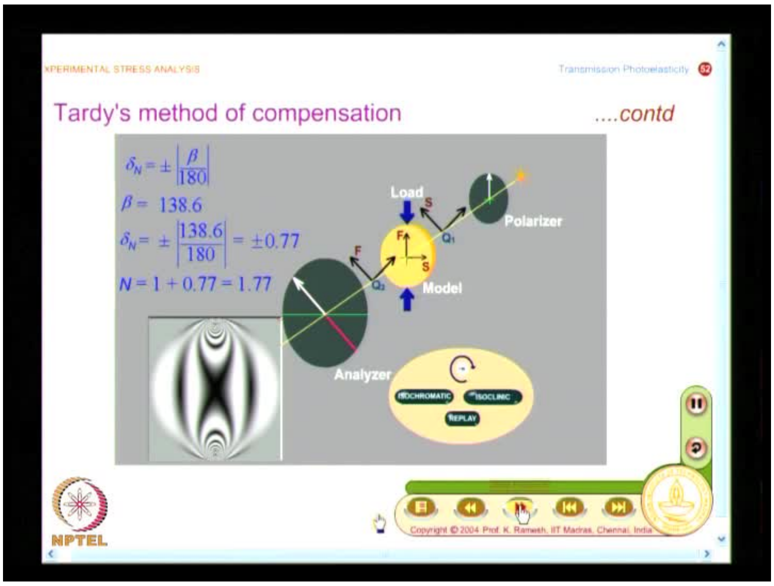

Now, when I rotate it clockwise what happens, I am able to make the intensity transmitted at the point of interest as 0, this is another way of looking at it. I have a fringe with shape of 8; other way of looking at is intensity passing through the point of interest is 0. Fine, I also see somnolence fringe pattern elsewhere when I rotate the analyzer, I see the complete model. Can you attach any physical interpretation to those fringe branches because I see a fringe, you cannot assign any interpretation to those points in conventional photo elasticity. The interpretation is valid only at the point of interest where we have done the compensation; this was not very clear when you looked at Babinets-Solliel compensator because the field of view itself was very small, here the field of view is the complete model you can see, what happens when the analyzer is rotated arbitrarily.

So, do not make a wrong understanding that you can interpret I rotate the analyzer and find out what happens at every other point, it is valid only for the point of interest. So, what I have here is I find out what is the angle by which I have rotated, and then I find out what is delta N. I finally, attach the sign depending on which fringe order has moved and occupied, that is the key point and we rotate it counter clockwise, I have a fringe order one and moving and occupying.

So, now we have fairly understood what is the way the fringe orders move and how analyzer helps in making the intensity at the point of interest 0 because we always may looking, you have some intensity at the point of interest mainly because the model has not behave like a full wave plate. So, for it to behave like a full wave plate, I need to add some retardation or subtract some retardation depending on which way I want to proceed.

So, that whatever the additional retardation which I introduce is now done by the role of analyzer, it is very interesting because I will also have a brief discussion what has been the philosophy of digital photo elasticity, how people utilize this aspect in devising various algorithms. So, now you have a fairly good idea on how to proceed from jones calculus point of view, because when I want to go out the jones calculus, I need to represent the retardation matrix at the point of interest because the model behaves like a retarder and that matrix becomes very simple because I take that as the reference axis, I simply make theta equal to 0.

We have seen the procedure, now we have to validate yes that procedure was convenient to find out the fractional retardation. So, my interest in jones calculus analysis is what? I need to establish a relationship between delta and beta; beta is the angle of rotation by which I rotate the analyzer, I must establish the relationship between beta and delta that is our focus. And mathematics also fortunately becomes simple, essentially are go analyze circular polariscope and very well, when I go from plain polariscope to circular polariscope the mathematics involved is quite lengthy.

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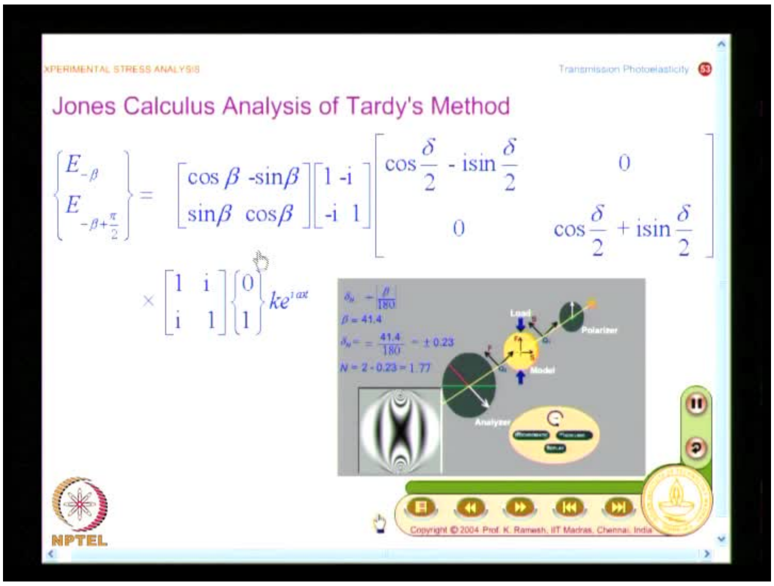

But if you have theta equal to 0, that retardation matrix is very simple then multiplication becomes lot more simple and I would expect you to do that multiplication right in the class. So, we will also look at the jones calculus representation. So, my interest is to find out what happens along the analyzer axis and perpendicular to the analyzer axis and I think we will see this one after another, I will replay the animation.

So, what I am going to do is I want to find out this (Refer Slide Time: 31:11). So, I have what is the light that is coming out of the polarizer, then after the polarizer I have the first quarter wave plate, I have the model, I have the second quarter wave plate, and then I have the analyzer. Here I also bring in the analyzer and I also made one more statement when a fringe passes through the point of interest, we are essentially saying intensity goes to 0.

So, that is the condition I will use for me to establish a relationship between beta and delta; that is what I am going to do. See in all our earlier calculations, we stop before the analyzer because I said that, when I keep the analyzer horizontal and vertical, I can analyze for dark field and bright field. So I let it is advantages to stop the calculations just before the analyzer, but here my interest is to find out a relationship between beta and delta, so I go up to the analyzer.

After the analyzer only I look at it, now I write the matrices for each of the optical elements and you know very well what is the optical the jones matrix for the first quarter wave plate, very simple and the model because theta is 0 this matrix is very simple. I simply have cos delta by 2 minus I sin delta by 2 and these two terms go to 0 and I have cos delta by 2 plus I sin delta by 2. Now, you have the second quarter wave plate and what is the different between the first quarter wave plate and second quarter wave plate.

I have not written 1 by root 2 here because I will write it finally, for both the quarter wave plates, product of 1 by root 2 as 1 by 2, now I will write the second quarter wave plate. That is nothing but, 1 minus I minus I 1 and I also put the rotation matrix for me to find out the component of light vector along the analyzer axis and perpendicular to the analyzer axis and I know I have taken this as clockwise. So, I use this angle itself as a referential like this and what I am going to do here? I am going to multiply all the elements, find out the component of light and what we are going to see is the light along the analyzer axis is 0.

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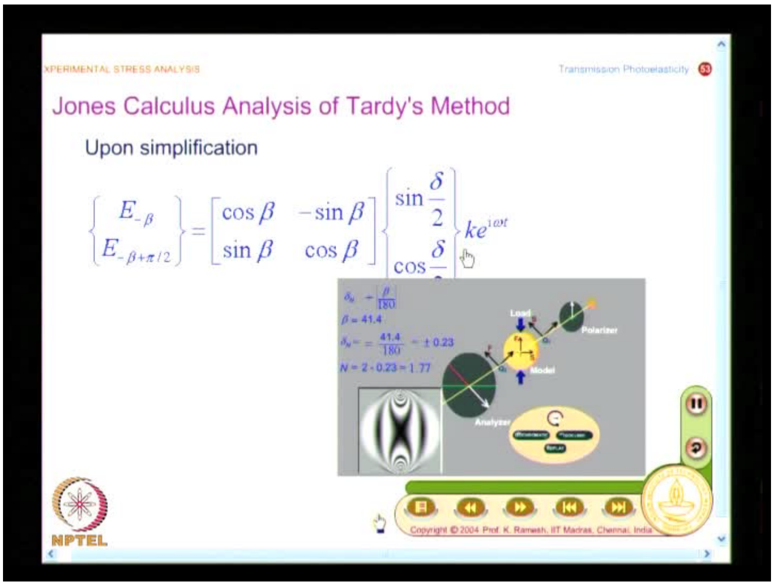

So, that is the condition I am going to enforce; now I want you to do the product of these matrices and try to get the expression, I will give you few minutes of time for you to do this, that would help for you to revise the notes comfortably. I am sure the mathematics is fairly simple and some of you have got the results reasonably and I will proceed to the next step and when I do the simplification, I get the final expression in this fashion. I am not multiplied this rotation matrix, the rest of the matrices reduced to sin delta by 2 and cos delta by 2 k e power I omega t, you can verify your calculation and this is how you get the expression.

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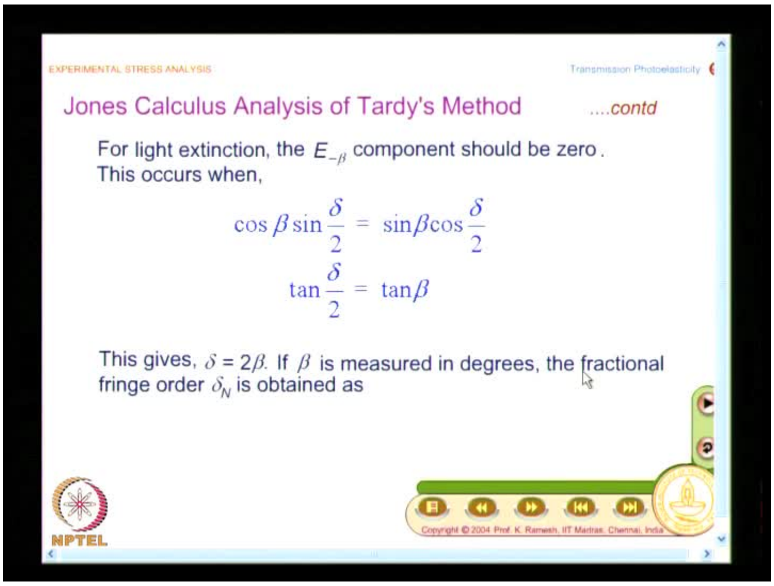

Now, I am going to say that horizontal component goes to 0 and finding out that is fairly simple. That is fairly simple, that you can work it out and when I do this, I have it like this. So, what I have here is for light extinction, the e minus beta component should be 0; this occurs when this identity is satisfied, I get this as cos beta sin delta by 2 equal to sin beta cos delta by 2 (Refer Slide Time: 35:30). So, I get this as tan delta by 2 equal to tan beta. Now I find, the rotation of the analyzer is link to the retardation, fractional retardation introduce at the point of interest. Though in all your expressions this can be in radiance, when you physically measure you measure beta in degrees and I can express fractional fringe order simply as beta by 180.

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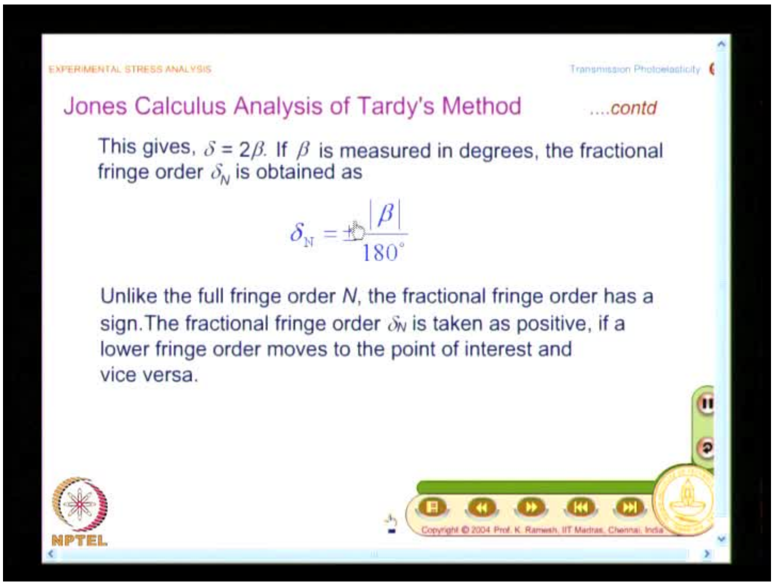

I can simply do this as beta by 180 degrees, what we have seen is we get delta equal to 2 beta and since beta is usually measured in degrees which is very convenient, I get the fractional fringe order as beta by 180 degrees and I do not attach the sign. The sign has to be attached based on whether a higher fringe order has moved to the point of interest or lower fringe order has moved to the point of interest and this has made conventional analysis very simple.

Conventional analysis becomes very simple because, you have a way of finding out the sign of the fractional retardation. And let me also give a few ideas on digital photo elasticity here, see if you look at one of the focus in digital photo elasticity was rather than finding out fringe order at an arbitrary point, they wanted to find out fringe order at every point in the model domain.

There are two issues: one issue is we have seen in a dark field arrangement whether it is 0, 2 pi, 4 pi, 6 pi you will not be able to find out any distinction on how to order the fringes, you will have fringes at these discrete location whether it is 0, 1, 2, 3 so this is one issue. Another issue is between fringe order 1 and 2 or 0 1, how to add the additional fractional fringe order. So, these are the two issues they have to find out the fractional fringe order and they will also have to find out, how to resolve adding the integer part because you are all trigonometric relations, all trigonometric inverse trigonometric relations are multi valued.

When you do inverse trigonometric calculation, you get multi valued functions. Fixing up the integer part is always been difficult, this is called unwrapping and this electrical engineers were doing it for a very long time and they were doing phase unwrapping. So, you need to borrow those concepts into photo elasticity and then do the unwrapping of the phase. The other issue was how to find out the fractional fringe order and if you look at many of the interferometric techniques, we have looked at for example, double exposure methodology and hologram interferometry.

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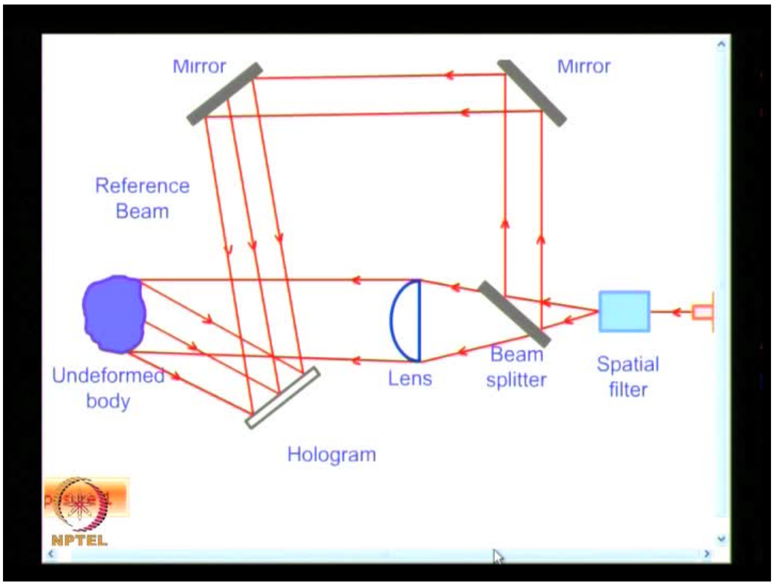

We'll just have a look at it, we will just have a look at that double interferon double exposure method and what we had was, we had one beam falling on the model, another beam goes to the mirror and then gets reflected and you call this as a reference beam, you call this as a reference beam.

So, one of the techniques what people did was they wanted to record multiple images with known phase shifts because in order to resolve the ambiguity in fixing the sign, fixing the integer fringe order, they had recorded multiple images and the whole approach was processing intensity information. The approach is not just looking at fringe order and then assigning it, you have to look at what is intensity at the point of interest. By processing the intensity information, they were trying to find out fringe order at every location and in all those experiments, you have only one phase that is the phase difference because of deformation and in order to get multiple images, the usual procedure was move this mirror at known steps and they also use fizzo electric actuators to do this. So that means, I will have one set of images with the reference beam and the actual model deformed and then I repeat the same thing by changing the reference beam alone with known phase shifts with this information I am taking multiple images, people were able to fix the total fringe order in and also automate the procedure.

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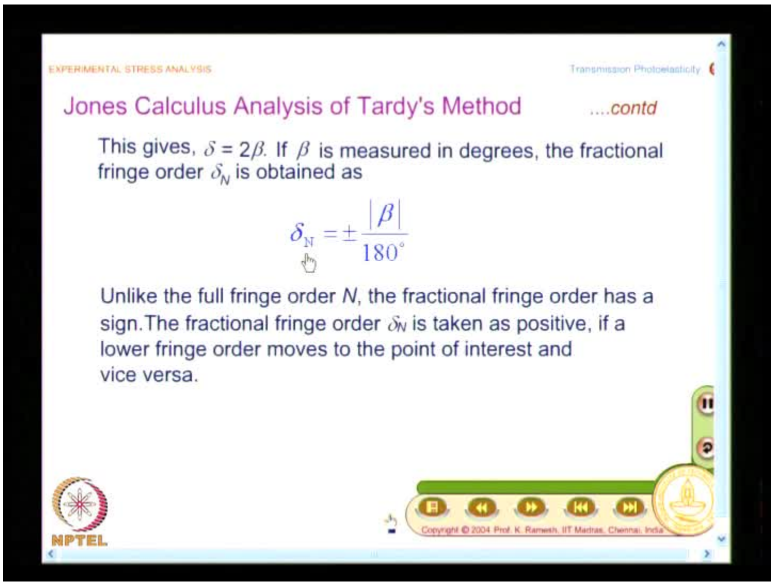

Because I do this shift, they also call this as phase shifting techniques. And what is the parallelism in photo elasticity? Photo elasticity we saw one ray becomes two because it behaves like a crystal and you have a temporary by reference. So, whatever happens to one ray happens to the other ray also and this is where tardy method of compensation opened up a new perspective.

So, in other interferometric techniques, they had external gadgets to introduce the shift in phase. In the case of photo elasticity what I have is, I have established by rotating the analyzer, I am able to introduce a phase shift. See how a rotation of element is (()) to giving a phase shift comes from understanding tardy method of compensation. So, this photo took it immediately then, they said I will not rotate only the analyzer, I will rotate other optical elements also and many algorithms got developed.

So, this is the basics behind it, even if you want to go and understand digital photo elasticity, in digital photo elasticity people essentially process intensity information and for them to get phase shifted images, the via media was rotating the optical elements appropriately provided something equivalent to the phase shift which was externally obtain in other interferometric techniques.

So, understanding tardy method of compensation will also help you to understand digital photo elasticity and also to verify digital photo elasticity because you have algorithms to fix the fractional fringe order sign because those algorithms are developed based on certain assumption, certain approximation, and certain conditions. Some of these may get violated in an actual experimentation and when you compare it with tardy method of compensation, there is a variation you could use this as an input and improve your algorithm to find out the fringe order precisely, now that is achieved.

If you look at in the last 20 years digital photo elasticity has now matured to find out total fringe order at every point in the domain, no problems. People have solve this, but the genesis has come from understanding tardy method of compensation and initially if you look at professor Asundi he has only found out, I have been saying when I use tardy method of compensation, I find out the fringe order only at the point of interest. He came up with the digital photo elastic technique; he would find out the fringe order on all the iso, all the points lying in the isoclinic.

See when you are looking at the isoclinic at the point of interest, rather than only at the point of interest, when you rotated the optical elements, he extended the first method was to find out the fractional fringe order at all points lying in the same isoclinic. So, from one point they have gone to multiple points, now they have gone to the complete domain. So, for all that tardy method of compensation is useful, this gives an indication that rotation of an optical element is (( )) to introducing a phase shift, that we have proved. Because we are now proved there is a relationship between delta and two beta and we have been able to convincingly show by jones calculus analysis, what we have been suggesting as a procedure is indeed correct.

The key point here is how to find out the sign. For finding out the sign in conventional photo elasticity, you have the luxury of looking at the fringe pattern and seeing whether higher fringe order moves and occupies or lower fringe order moves and occupies, but in digital photo elasticity, you record only intense information. And this also shows they had flexibility in finding out which optical arrangement is suitable because I said in a conventional photo elasticity, you use circular polariscope bright field and dark field;

plane polariscope, dark field and there even the association of whether the real fast and slow access of the quarter wave plate is considered, even that was not critical as long as quarter wave plates are kept crossed, your job of conventional photo elasticity is done, but once you come to digital photo elasticity, all these issues have to be looked at very closely. In fact, if time permits, I will also give one lecture on what is the bird's eye view of what digital photo elasticity is and you have some advantage by understanding tardy method of compensation in that light.

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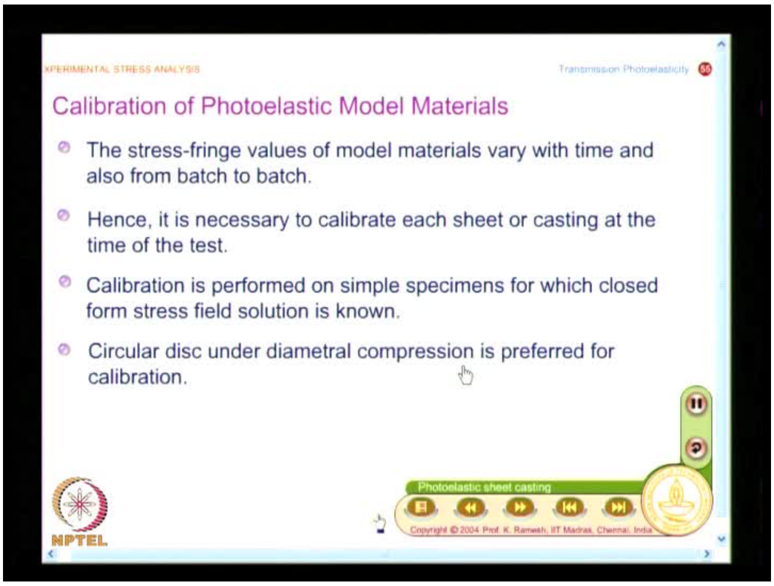

It can also verify your digital photo elastic algorithm because, if I want to find out the fractional fringe order and then if I find out from my conventional approach that should match with the digital algorithm. Now having determined the fringe order, what is a next step? The very important step for me to do the photo elastic analysis is I need to have calibration of photo elastic model materials. Why I had to do that, because I use only polymers and when I use polymers, the stress fringe values vary with time and also from batch to batch.

They do not remain same. So, I need to find out at the time of experiment, what is the material stress fringe value for the model material that I have selected? So, you need to calibrate each sheet or casting at the time of the test and what is the thumb rule when I have to do this, my focus is on finding out f sigma. So, I need to do it on a model for which closed form stress field solution is known, because I should conduct the experiment as accurately as possible. So, that I follow all the restrictions on loading and I find out what is the fringe order at the point of interest, I use that information to compare it with my analytical solution and find out the material stress fringe value and mind you the material stress fringe value has to be evaluated with sufficient accuracy. If you do not follow the step carefully, then comparison of any one of your quantitative information from a photo elastic analysis to the numerical or analytical approach would be erroneous. So, it is very crucial step.

When it is a very crucial step, I should perform a very careful experiment to find out f sigma and for which to do that what is preferred? Circular disc and a diametral compression is preferred for calibration; it is only said it is preferred you can also do it by other methods, but this gives the least amount of error. And when you look at this, we will find out only one data point by a conventional approach later on because I use a whole field methodology, I will also extend, I will collect as much data as possible from the field and find out what is the f sigma value.

That also opens up how people started employing computers in experimental mechanics you will have a bird's eye view of that, because experimental is wanted to get information quickly and they would be comfortable if I process one data point. In fact, in fracture mechanics, Aravind was very intelligent to identify one data point to find out k and sigma naught x. So, in experiment mechanics if you look at, you have on one hand finding out the data from the field by sophisticated statistical methods; on the other extreme, people also find out by using only one data point or few data points for you to quickly assess what is happening. You need to have both, you need to have quick solution as well as an elaborate methodology and in this case, we will look at both the quick solution as well as the elaborate methodology.

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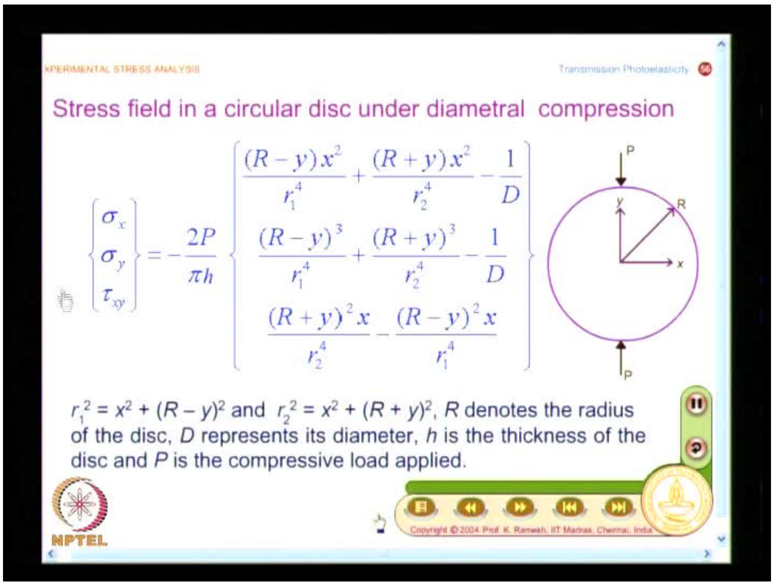

This is just to brush your old memories; we have already seen this set of stress field equation. So, what you could do is I have sigma x, sigma y and tau x y expressions are given, where you have h is the thickness of the model, P is the diamteral load applied and once I have the expression for sigma x sigma y and tau x y it is possible for you to find out sigma 1 minus sigma 2; in photo elasticity in use only sigma 1 minus sigma 2.

So, what I would appreciate is since you have this expressions go back work it out in your rooms, find out the expression for sigma 1 minus sigma 2 represent it as a function of x,y then, later on we will do it for what happens at the center and we will also use it for whole field determination for various values of x comma y.

So, the home exercise is to find out what is the principle stress difference for a circular disc under diametral compression analytically. So, in this class what we had looked at was, we started with what are compensation techniques; we looked at briefly Babinet-Solliel compensation. Then we looked at elaborately what is tardy method of compensation, what are the steps involved, then we said these steps involve need to be verified by analytical development; we did the analysis by jones calculus and established a relationship between rotation of the analyzer to the fractional retardation introduced.

And I pointed out tardy method of compensation as indirectly help development of digital photo elasticity, because people found (( )) to shifting a phase which is done external means in our interferometric techniques could be done in digital photo elasticity by appropriately rotating the optical element and people developed many different algorithms. And towards the end, we saw that we need to find out the material stress fringe value because if I want to do quantitative analysis, I need to know the fringe order at the point of interest as well as material stress fringe value. And we have looked at how to find out fringe order at any arbitrary point and we have we will also look at how to find out the material stress fringe value and I caution that this has to be determined with sufficient accuracy, all these details we would see in the next class.