Experimental Stress Analysis - An Overview
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Lecture - 3.9
Introduction to TSA and DIC

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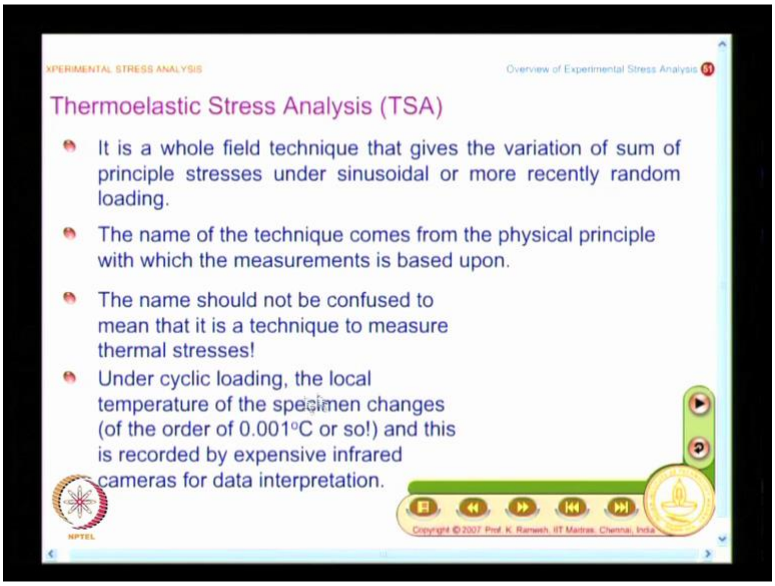

So, we have so far seen quite a few techniques, what is the physical principle? What is the essential difference between them? Now, we move on to another experimental technique which is again a whole field technique, which is known as Thermoelastic Stress Analysis. It is a whole field technique and it gives the variation of sum of principle stresses under sinusoidal or more recently random loading. Because, if you look at the history initially it was developed for sinusoidal loading, once the technique has matured people have found methodology to extract data even for random loading situations. It does not give sigma 1 plus sigma 2 it gives variation of sigma 1 plus sigma 2 that is the difference. So you have to have a cyclical loading on the object, and you find out what happens. Here again you are a employing a physics, we will see what the physics behind this technique.

The name of the technique comes from the physical principle, one common danger is thermoelastic or if I want to find out a stresses due to thermal loading you can directly use the technique, there is a misnomer you cannot do it like that, depends on the principle on which it is based upon. So, that is what is mentioned here, the name should not be confused to mean that it is a technique to measure thermal stresses it is not so. What the physical principle is, under cyclic loading local temperature of the specimen changes and this change is very small, you cannot go and touch and feel it, it is of the order of 0.001 degree centigrade or so. It is a very small measurement from temperature point of view and this is recorded by expensive infrared cameras for data interpretation.

So, people have identified, see as technology has advanced we are able to measure even small changes in temperature, people identified the small changes in temperature takes place and this is exploited to reveal information of the stress field and it gives you a particular kind of stress field. It was originally developed for high temperature application, because you cannot go near and then make any measurement and people wanted to have non-contact measurement and they want to have a technique which could work at high temperatures particularly for gas turbines when they work at high temperature they want to make measurement. What you find here is, the temperature change is very small. We have also looked at while we looked at a strain gauges, we were talking of micro strain and that is 10 power minus 6, you are looking at 10 power minus 6 of change in resistance or change in the strain. When you come temperature you are able to go only to the order of 10 power minus 3, but even this is very, very small.

If you look at moiré or if you look at photoelasticity or hologram interferometry you see the fringe contours, after processing you see the fringe contours. In a technique like this you do not see fringe contours as such it is all plotted from the infrared camera result post processed, that is how you get the result. Here, the technique is also slightly different you have to do post processing for you to look at the kind of information that you have recorded.

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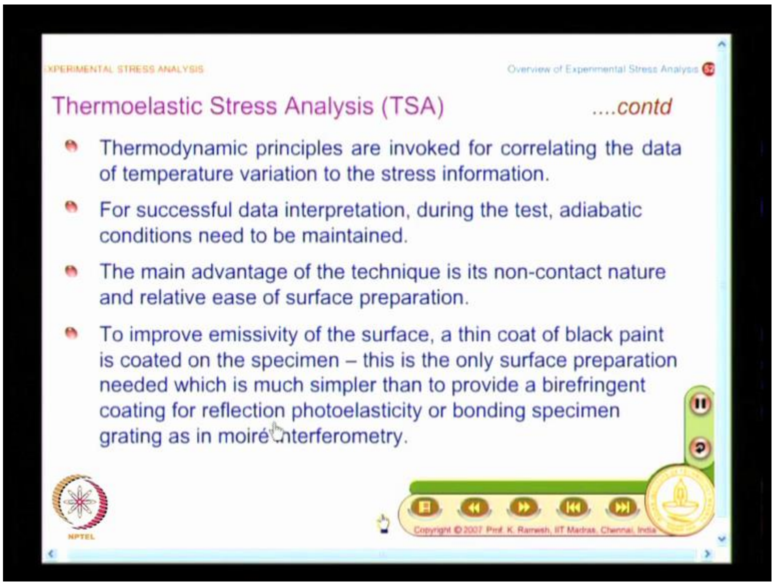

Another important aspect here is, you use Thermodynamical principle for data interpretation. So as you go advanced you also have more complicated mathematical development for you to interpret experimental data. You have to be very careful in conducting the experimental method, you should be worried about other thermal sources, you should suppress that information because you are essentially recording a emissivity of the surface whatever the emissive characteristics. If you have other sources of thermal disturbance they have to be suppressed, so the experiment has to be conducted very carefully.

You need to maintain adiabatic conditions for successful data interpretation, and this adiabatic condition comes in the form of what is the frequency of loading. There is a recommendation, what is the minimum frequency of loading you have to maintain, so you have to look at this so the requirement of adiabatic conditions imposes certain restrictions on how you do the experiment.

The main advantage here is, the technique is non-contact. And again you know when there is a small advantage you should take note of it, it has a relative ease of surface preparation. It is again a relative term. Here, what is the kind of surface preparation you do? You have to improve the emissivity of the surface; a thin coat of black paint is coated on the specimen. It is not white paint like in speckles, but it is a thin coat of black paint. And again it is a comparison that is what is summarized here. This is the only surface preparation needed which is much simpler than to provide a birefringent coating for reflection photoelasticity or bonding specimen grating as in moiré interferometry so on and so forth. You can sight many such comparisons that is not something difficult

So what you find here is, you have to apply a thin coat of black paint and as I have said earlier even to get a thin uniform coat you need to develop skill. Though it is simply said it is a comparatively less difficult, but even this you will have to do it with care. Unless you do it with care you will not be able to do it, you will not be able to get reliable experimental results. People have combined thermoelastics stress analysis with photoelasticty and try to find out stress separation in all those exercises I have done. It is desirable that you have a look at what is the measurement scheme employed here. I will give an idea how you go about.

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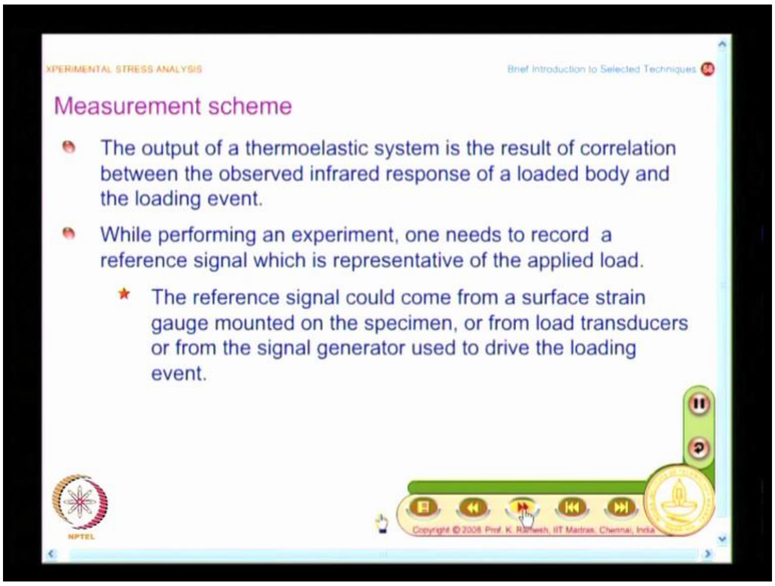

As I said you do not see the information directly, the output of a thermoelastic system is the result of correlation between observed infrared response of a loaded body and the loading event. So you have to make a correlation and you have to do post processing of it then display the result. I need a signal to record how the body is loaded, so you need a reference signal. While performing an experiment one needs to record a reference signal which is representative of the applied load. This can be done in various ways that is what is listed below. What I find here is, the reference signal could from a surface strain gauge mounted on the specimen, or from load transducers or from the signal generator used to drive the loading event.

So what I need is, I need a reference signal, I need to have a correlation between the loading event and the recording phenomena. So for recording the loading event we need a reference signal, that could come from a surface strain gauge, or that could come from low transducers or from the signal generators. This idea would become clear if you have a look at how the whole arrangement is made ready for a thermoelastic measurement. What we will see is, these ideas will become clear if you look at how a thermoelastic test is done.

This is depicted in the line sketch here.

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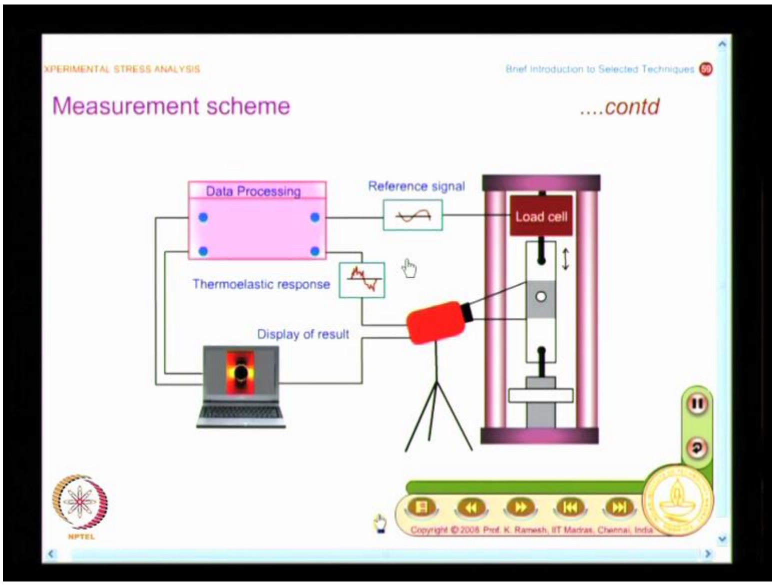

Let us look at path by path I will also give you sufficient time for you to take down this sketch. You make your sketches little brief you do not have to put these pillars with lot of effort minimize that. The essence here is, I have a specimen the region of interest is painted black, and this arrow shows that I am applying a cyclical loading. I do up and down I do a cyclical loading, so the model is subjected to a cyclical loading. This event is recorded by a thermoelastic camera.

And mind you thermoelastic cameras are very expensive it is not like visual range cameras, in a thermoelastic even the lens is very, very expensive. The other restriction is you need to have better cooling systems for you to cool down the thermoelastic camera, because the temperature generated because of that can give spurious signal. In fact, they have a specific engines for a cooling this camera, you have certain cycles are used for cool this camera.

So what I have is, I have a specimen mounted on a loading frame which is cyclically loaded, and the region of interest is painted black and you have a thermoelastic camera which focuses on this, and you get a response from the thermoelastic camera. It could be a response something like this. And from the load cell of the testing equipment you also get a reference signal. So what you need to do is, in thermoelastic stress analysis you need a reference signal how the system is loaded, you want to correlate whatever the results that you get with respect to a reference signal.

The camera by itself does not give you any information for you to visually look at. So it has to be post processed and then displayed appropriately. So what I have, I is have a data processing unit which takes the reference signal and which gives you the output, once you take into the computer you could display this result in a fashion which is convenient for you to interpret.

What elements you have? You have a loading system, you have a thermoelastic camera, this is taken to the data processing unit, you also have a reference signal and you post process this data and display the result. So you have a plate with a hole with sigma 1 plus sigma 2 contours, they appear like this. You can also have a larger picture of this, this is how you have the display and it is a post processed display. This is the case when you go to the next technique here again you do not see the fringe patterns visually. You have to post process the data and display it in a fashion convenient for you to understand.

So what you find here is, more and more computers are used in experiments that becomes evident in some of this sophisticated techniques and if you go and look at the price, it is exorbitant cost, because of the thermoelastic camera and also the whatever the lens system that is used. If you look at the resolution not as comparable as what you get from a visual range optical system it is in operating at infrared region, very expensive. So unless you have very high level of funding you would not be able to do a test of thermoelastic stress analysis.

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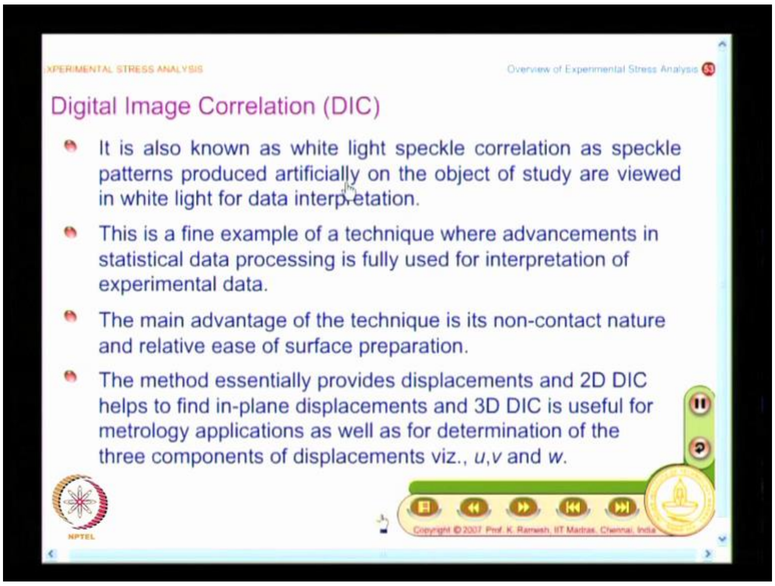

The next technique what we will go and look at is one of the very new and emerging technique called Digital Image Correlation. You know the name itself is very interesting it is the image correlation, we have seen in the previous a methodology. There is also some other type of correlation was taking place between the reference signal and your thermoelastic response. This uses speckles and these are called white light speckle. In the speckle method what we did was, we had a laser beam impinging on the model and you had speckles develop naturally. It was not artificially created, if you have specularly reflecting surface you had speckles because of laser illumination and that was used for all the measurement. This is the off shoot of that kind of an approach. Here, you have this speckles arbitrarily done, it is done externally on the specimen under consideration artificially it is done and you use white light for data interpretation. So you can really cover large areas comfortably.

And you have to look at; this is the fine example of a technique where advancements in statistical data processing is fully used for interpretation of experimental data. I always felt that it is more of computer processing and less of seeing the joy of looking at fringe patterns in real time. You will not see fringe patterns in real time in this, you will only see dots speckles on the surface they have to be post processed and they have to be plotted in a fashion convenient for you to interpret. But this is becoming a very, very important technique because of development of newer materials. There are certain materials you will not be able to do experiments otherwise.

As again, this is an optical technique, all optical techniques are by and large non-contact in nature. Here again, you do not need a complicated surface preparation, but I should caution the speckle formation is not simple. You have to have randomness, you have to have particular characteristics and formation of speckles again you have to develop skill and size of the speckle matters, because you can do for multi scale analysis depending on the scale on which you operate you need to have that correct size of the speckle.

So, though it is said surface preparation is simple in relation to strain gauge where you will have several steps for surface preparation compare to that here you have to only put the speckle by a spray gun, but that requires again skill. What is the information it gives? It provide displacement you have 2D DIC which helps to find in plane displacements and you also have 3 dimensional DIC which is useful metrology applications, as well as for determination of the three components of displacements u v and w. So, you are directly getting displacement information. It uses quite a bit of data processing which is not seen in other experimental techniques here more of number crunching is done. When you go to 3D DIC you have stereoscopic images recorded with two cameras, calibration is very, very intensive and people have developed proprietary software how to do the calibration. So, the technique is a emerging that is a way you have to look at it.

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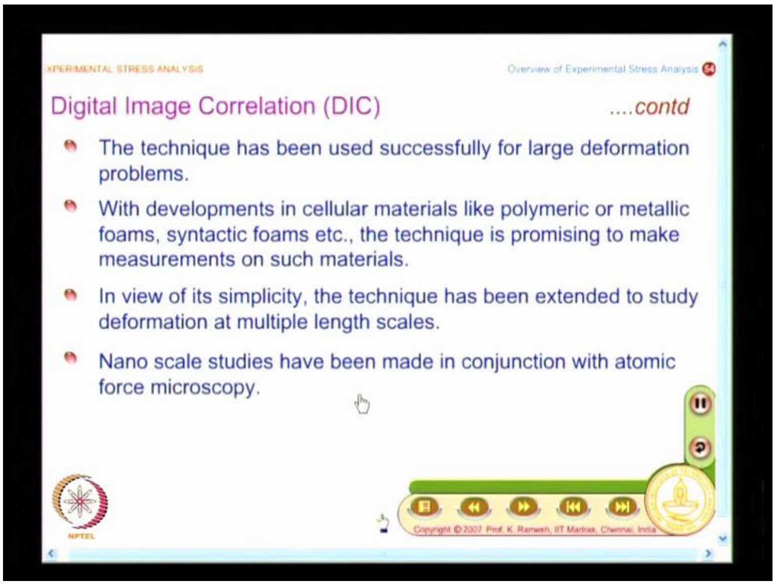

And what I have here is, for large deformation problems the technique has been used successfully. That is how people start. We have seen when we looked at moiré people had grid methods, and then from the grid method they graduated to having the grid put a circle inside look at the stress direction, then they refined it by putting two grids one over the other that is how moiré was developed. Then if I am geometric moiré they graduated to moiré interferometry where they could go for finer and finer displacements and digital image correlation has successfully applied for large deformation problems.

These days we do encounter in our design large deformation being allowed. So, you need to have techniques which do this. And you also have several new materials, cellular materials like polymeric or metallic foams. In auto mobile manufacture they want to put metallic foam in your structure so that it absorbs the energy when you have a collision. See in earlier days when steam engines were developed 15 kilometers per hour was considered terrific, now you travel at 350 kilo meters per hour, and when you increase the speed any collision becomes dangerous. So, you need to have protective mechanism for you to have it. And people are thinking of using metallic foams, syntactic foams and all these materials are very peculiar, even to find out the material property they cannot do a conventional test and they depend on digital image correlation to find out even the material properties.

So, the development of new material have force also the development of newer techniques for data gathering and interpretation and the technique is very simple. If you go from one scale to another scale the methodology is essentially same, only thing is your optics has to be sensitive enough and your speckle size should be adjusted suitably. In view of that the technique has been extended to study deformation at multiple lengths.

Today, I mean these days we talk of nano mechanics. So, nano scale studies have been made in conjunction with atomic force microscopy. Where you have whatever the beam that you use inside if you want to make measurement people have used digital image correlation, and you are able to do even nano scale studies. Holography is also applied for nano scale studies. The advantage here is, once you have the software developed for image correlation by varying the size of the speckle and also your optical arrangement it is possible for you to go to smaller and smaller scales or even large scales.

People also use image correlation for finding out the buckling behavior of windmills. You have huge windmills. Now, renewable sources of energy people are playing attention, you have very large windmills have come and for that those blades are sensitive for buckling, and you have a very large area and you need to find out the buckling whether buckling takes place are not and people use image correlation.

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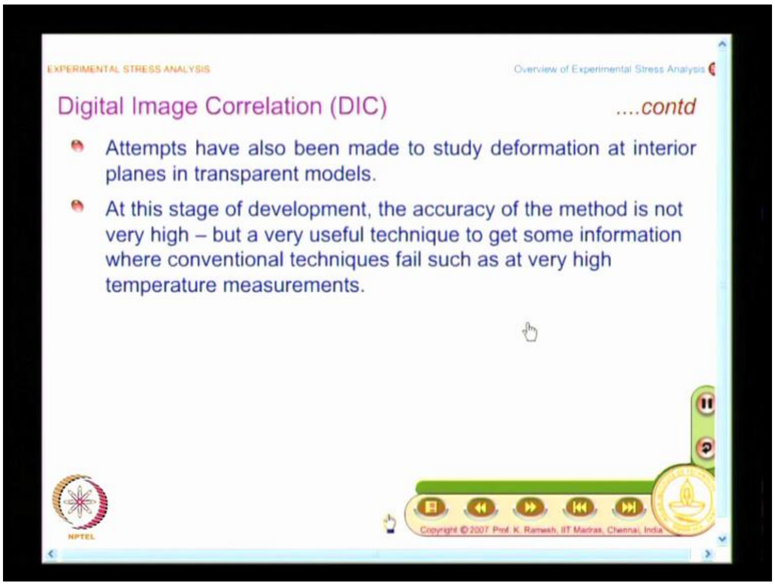

Being an optical technique they also find out, how to find out information at interior planes in transparent models? You should also accept at this stage of development the accuracy method is not very high, so that is the scope for research. If the accuracy is not high this is the ideal area where people can refine. It is a very useful technique to get some information where conventional techniques fail, such as at very high temperature measurements. People have done at very high temperature whatever is the particularly when you are looking at a reentry vehicle systems. In space technology, they look at reentry vehicle system; they all subject to very high temperatures and you need to have some measurement. People have attempted a using image correlation because of non-contact nature and they have been able to get useful information for that design.

So, in this class we have looked at Thermoelastic Stress Analysis. I cautioned that you should not interpret that this is meant for finding out stresses due to thermal loading. It exploits a temperature change and finds out the information of variation of sums of principle stress. Then we looked at image correlation. I said it is one of the very nice emerging techniques it is also becoming a general purpose a tool like strain gauges and photoelasticity. As of now the equipments are little expensive and also the software is proprietary in nature, people have developed their own a software they are becoming cost effective.