Experimental Stress Analysis
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Lecture – 06
Multi-Scale Analysis in Experimental Mechanics

We are continuing our discussion on overview of experimental stress analysis and what we have done was, we had initially looked at what is the difference between an analytical method, numerical method and experimental method, then we moved on to find out what the experimental methods directly give the information because in each of the experimental technique, we employ a physics; the physics what we employ dictates what is information that it can give directly.

Then, we had a reasonable discussion on what is the physical principle behind each of these techniques. The idea is; if you understand the physics behind it, you will be able to appreciate the technique better and also interpret the results with understanding, the interpretation of results is equally important. In most of the optical techniques, you get the fringe field and we had a reasonable discussion on what is the richness of qualitative information you get.

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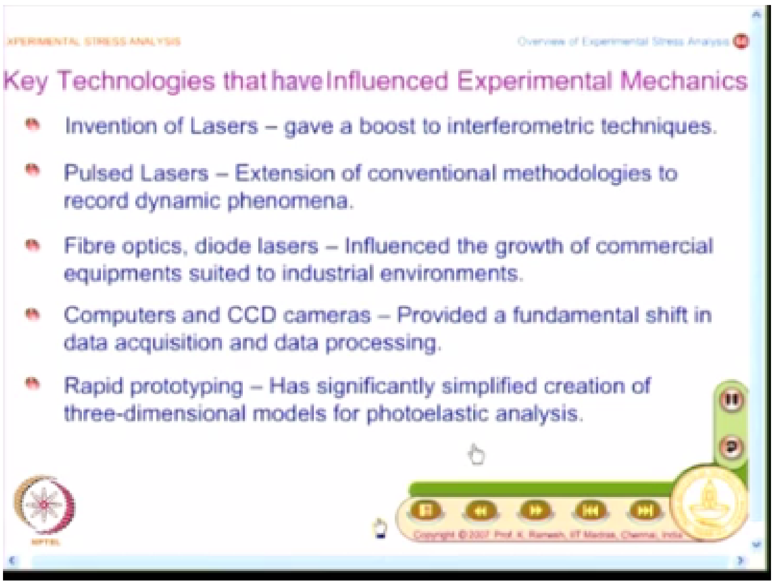

Our ultimate objective is to get quantitative information but certain decisions, which require the immediate attention could also be obtained by looking at qualitative information, then we also discuss that all these techniques have been greatly influenced by technological development.

So, what we saw in the last class was; what are the key technologies that have influenced the experimental mechanics.

We saw that invention of; invention of lasers gave a boost to interferometry techniques, then pulsed lasers; extended method; conventional methods for dynamic phenomena and not only pulsed lasers there are also other methods by which people could record the dynamic phenomena, you had crane shot in camera particularly, for stress wave propagation and we also saw that use of fibre optics and diode lasers helped people to develop equipment to suit industrial environments.

So, with the development of CCD cameras, human eye is replaced by the electronic eye and I said in 1930s, most of the designs have been verified by performing a 3 dimensional photo elastic analysis and for 3 dimensional photo elastic analysis, model making is a crucial step; very involved step and model should be as precise as possible to mimic the 3 dimensional object and with the development of rapid prototyping what you find is a process called stereo lithography provides models that are photo elastically sensitive.

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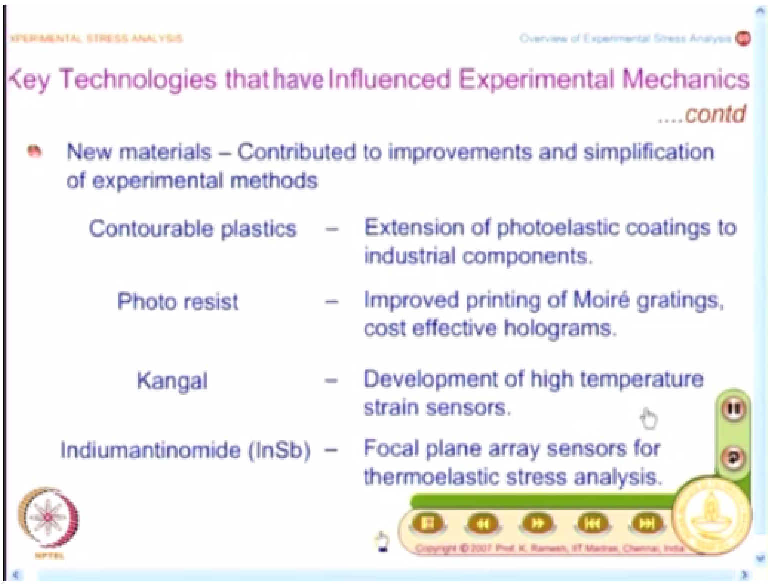

So, rapid prototyping has significantly simplified creation of 3 dimensional models for photo elastic analysis and what I said, if you look at closely the development of science material research as always played a very key role and what you find here is new materials have contributed to improvements and simplification of experimental methods. So, new material development is a key technological advancement for newer and newer designs and simplified approaches.

Earlier you did not have composite aircrafts with the development of composite materials, now Boeing has gone and gone for their fully composite fuselage, so it is a technological advancement reduces the load of the; deadweight load of the aircraft thereby saving fuel and if you look at photo elasticity; the development of contourable plastics really made photo elastic coatings to industrial components.

So, what you find here is the application of reflection photo elasticity was mainly possible for complex objects because of the development of contourable plastics. Here, what you do is you make a polymer that is flexible enough, apply it on the model, it will take the same contour as the model then allow it to cue, so the contourable plastic has helped in industrial use of reflection photo elasticity.

And the development of photoresist has greatly influenced improved printing of Moire gratings and also cost effective holograms, all these hologram stickers have some form of photoresist material, so any material development has always influenced advancement of technology. Then, if you come to high temperature strain measurement development of Kangal has helped and you have high temperature strain gauges.

And finally what you find is Indium Antinomide has helped in the development of focal plane array sensors for thermo elastic stress analysis. See, if you look at one of the earliest method for thermo elastic stress analysis used an equipment called Spade, stress pattern analysis by thermal emission, we choose only a single infrared detector. The technology was at that time was possible to have only a single infrared detector and they had a scanning mechanism to record the phenomena.

Because it was meant for the non-contact special type of experiments, people who are happy whenever you make a development, you start somewhere and once the technology develop, you also bring in more and more features of it, similar to a normal CCD camera the visual range. Now, you have infrared cameras, which has an array of sensors and these array of sensors was possible with the development of Indium Antinomide.

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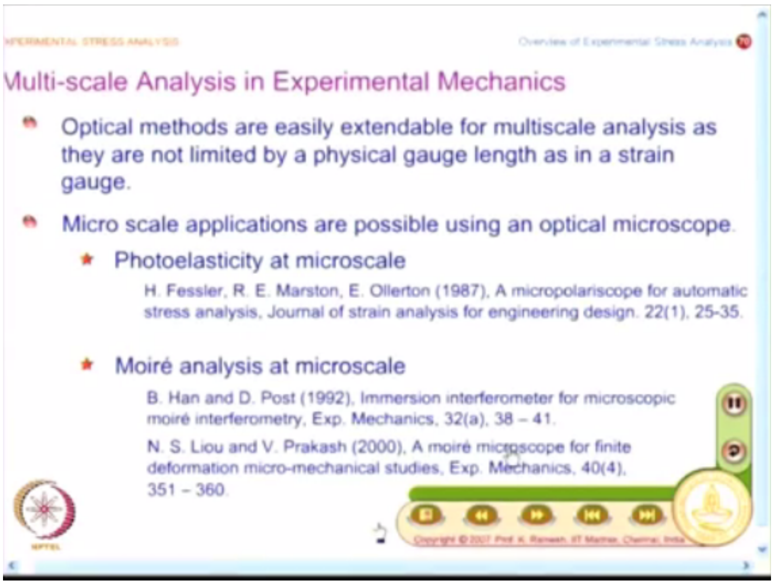

So, what do you find material research has contributed to the advancement of methodologies for experimental evaluation and what we will also look at is; another important aspect whether you could do multi scale analysis in experimental mechanics. This is also very, very important because now miniaturization is the order of the day, people would like to make it as small as possible.

And you will also like to find out, whether from a stress analysis point of view these miniaturized components are stable and whether they will do the intended service, whether they will come for the life that you talked about so, multi scale analysis becomes important. Suppose, you take a strain gauge technique, what happens? The physical gauge length determines the size on which I can operate.

I want to do it for a single point, so I want to have the gauge length as small as possible and for very miniatures components strain gauge itself. When you paste it, it will reinforce the specimen. So, we do not want to use; we will not be in a position to use in such applications. On the other hand, when you come to optical methods, it is the optics which dictates what is the scale in which I can operate and once you get into this, researchers have developed specific equipments.

And you have that available in the literature and it is very important that you need to have some of these in your notes, so that you know how these are used. So, what I am going to give you is; for each of the technique what is a key paper that will give you an idea that this is also applied at a different scale and in order to save time, what you could do is rather than writing the journal name completely, you can write it as an abbreviation.

And also write the first author and put et al for you to access it, so photo elasticity at micro scale you have H. Fessler et al, it was published in 1987 and you have a micro-polariscope for automatic stress analysis. This was published in Journal of strain analysis for engineering design, you just write it as JSA and the issue number and page numbers are noted, so you abbreviate this reference.

And this also gives you an idea what are the journals that you should look at for you to get additional information on experimental mechanics. So, that information also you get indirectly from the list of references you have and you should also know photo elasticity is applied at micro scale, we have already seen Moire, we have already seen holography being applied at micro scale.

And these are all very important information for you to know how experimental mechanics can be applied. So, Moire analysis at micro scale you have Han and Post in 1992 and they have come out with an immersion interferometer for microscopic Moire interferometry, this has been published in experimental mechanics, write it as EM that is good enough, so what you could do is; you could just write the author, year, journal and the page reference.

With this, it is possible for you to access information in the library and you could have a look at those papers and N. S. Liou and V. Prakash in 2000, they have come out with a Moire microscope for finite deformation micromechanical studies, again in experimental mechanics and you have the page numbers. So, just write the first author, year, abbreviated the name of the journal and the page number.

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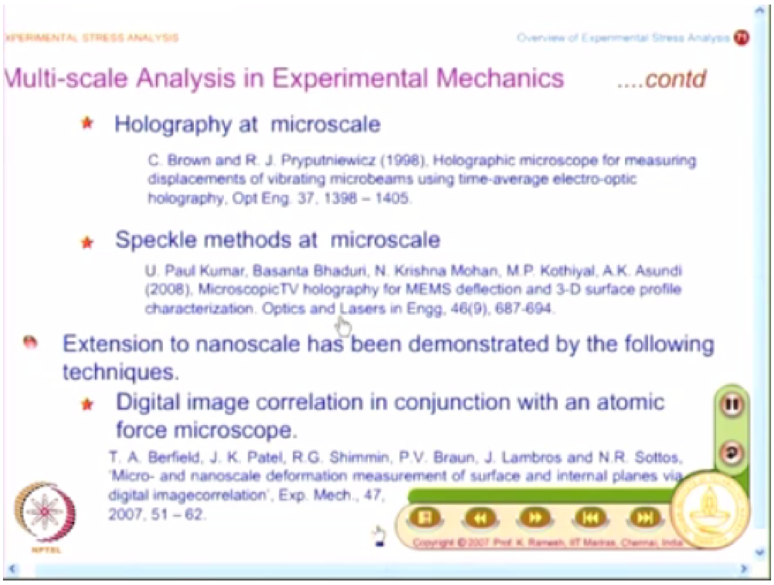

This information is sufficient for you to look for these journal papers later and likewise, we are going to do it for each of the technique; each of the technique what is the available reference; some of the key references, you will have several references given in the end of the paper that will also give you an idea, what they can go. Then you come to holography, you have a paper by C Brown and R. J. Pryputniewicz in 1998, publish in optical engineering you can put it as OE.

And this was for holographic microscope for measuring displacements of vibrating micro beams using time averaged electro optic holography. So, micro beams, all these have become important from nano level studies now, people are going in for miniaturization, so you have to find out whether these components are stable at those skills and speckle methods; you have U. Paul Kumar and others published in 2008.

It is published in optics and lasers in engineering, you could abbreviate it as OLEN, so it is published in OLEN and these are all the page reference and this we had seen when we looked at speckle methods, we were getting the pressure sensor; it is a rectangular pressure sensor and you have this out of plane displacement was recorded by speckle methodology and some MEMS application.

Then we move on to nano scale studies have been done and digital image correlation in conjunction with an atomic force microscope that is what I have been saying digital image correlation is an emerging technique. The greatest advantage is; if you are able to control the size of the speckles and also improve your optics, you could conveniently study at different scales.

And here you have a paper published in 2007 by T. A. Berfield in experimental mechanics; you can put it as EM. This is on micro and nano scale deformation measurement of surface and internal planes via digital image correlation. As I mentioned earlier, you need the lead author, name of the journal and page reference, this should be sufficient for you to go and search for the paper.

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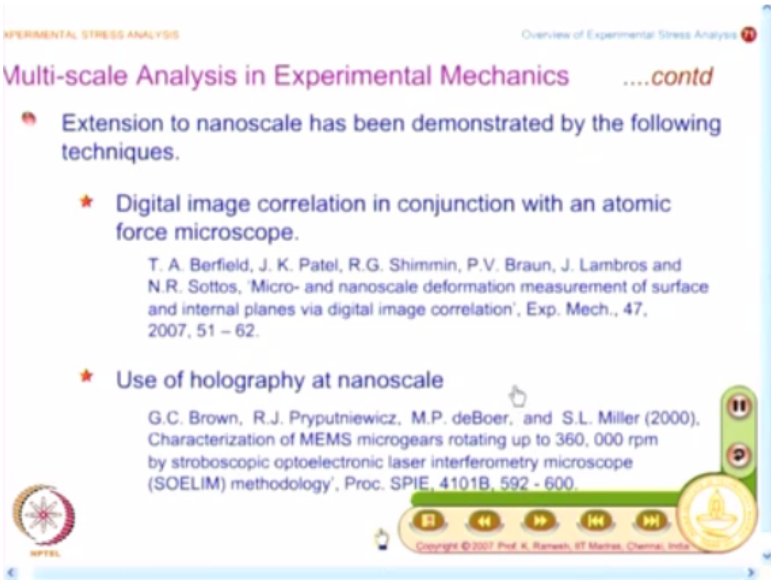

So, you have seen; you have to look at experimental mechanics, optics and lasers and engineering, journal of strain analysis and you have; you can add to this list experimental techniques; these are all the journals that you would be finding it useful from the point of view of looking for additional and recent information and you also have holography at nano scale, this is essentially a group led by Pryputniewicz.

They have done extensive studies on MEMS and mind you, this is about 3, 60, 00 rpm, you have a micro gears rotating at 3, 60,000 lakhs rpm, people have done experiments on such miniaturized and such high speed applications and this is done by stroboscopic optoelectronic laser interferometry microscope, so very very sophisticated methodology, only very people in the world could achieve such high level of precise experimentation.

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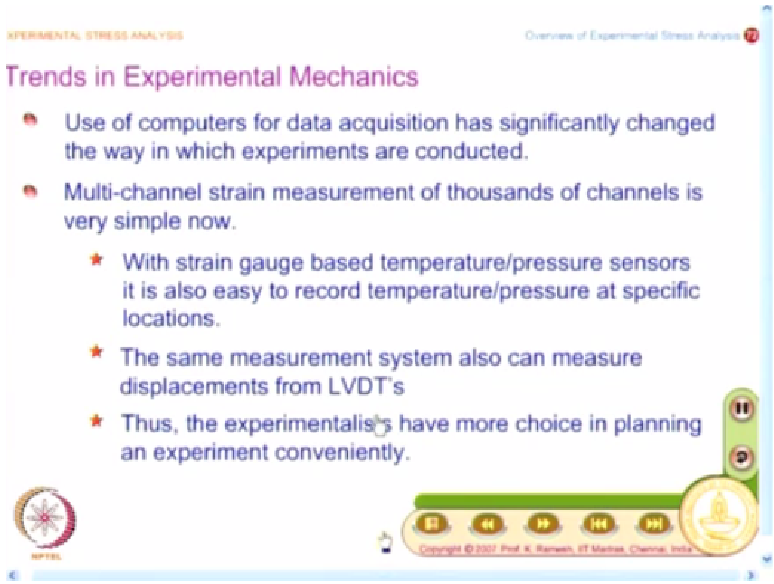

So, it is very interesting, I thought that you should know it is not few thousand rpms; 3, 60,000 lakhs rpm, very high speed rotating gears. So, here again, this is in proceedings of SPIE, so you write that 4101B, these are all online accessible, so write the lead author, year and then go in for the reference. Now, the other aspect what we will have to look at is; what are the trends in experimental mechanics?

So, one of it; once computers are developed, numerical techniques became very popular and if you do not use computers in an experimentation, you will also fall back, so computers are also been employed in experimentation and what you find is they have been used extensively for data acquisition and also has significantly changed the way in which experiments are conducted. This is a very important aspect.

Earlier people have to go and wet their hands, now it is all press of a button, so what you find here is when you have experiments on large scale structures collecting data by strain gauge was a nightmarish experience, it is no longer so, with computer data acquisition multi-channel strain measurement of thousands of channels is very simple now. The technology has so well developed, electronics are so well developed.

Because the switching and then scanning all this need to be very carefully done when you are having thousands of channels It is one story to have 4 channels and make measurement, it is totally another story when you have more and more channels at it, the technology is different and it has to be precise and another advantage is; it is not only you measure strain, you also need to measure temperature, you may also have to measure in a system, pressure.

So, what you have is; with strain gauge based temperature, pressure sensors it is also easy to record temperature pressure at specific locations. So, what you have is; you measure strain, you also in a position to measure temperature, you are also in a position to measure pressure and some of these will always come in a combination, you may have to; if you are really looking at a structure how it behaves, you may have to have this data.

So, now I can have one data acquisition system which could record in some points temperature, some points strain, some points pressure, so I need to identify which are all the locations where I want to do and what was possible? What has made this possible? Technology, electronics and you can also measure displacement using LVDTs; they can also be combined to the multi-channel strain measurement.

So, experimentalists now have more choice in planning and experiment conveniently. I have always been mentioning experiments are planned and executed, you anticipate values unless you anticipate values, you will not know what instrumentation to use, an anticipation of values also helps you to look for surprises, you need to have an open mind when you do an experiment, you will have to have and take the surprises find out why you have a surprise information?

In most cases, it may be because of certain approximations you would have done in your analytical or numerical methods, which would have escaped reality, it has several times happen; experimental measurements or truth raw data is very, very important but you should record raw data as accurately as possible. When I say the raw data is important, you should find out how an experimental technique has to be carried out, follow all the steps and record raw data as accurately as possible.

Then raw data is sacrosanct, if you take a very casual attitude in doing the experiment, raw data is no longer sacrosanct, so if you record the raw data and you find surprises, first thing you go and find out have you made any approximation in your analytical modelling or numerical modelling which could be improved, so that those results will match with experiment. In fact, if you take a simple cantilever and put an end load and if the cantilever has sufficient depth, your experimental measurement will definitely be different from your PL cube/ 3EI approximation.

Because you ignore sheared deformation in that formulation, so you cannot go and say the experiment is wrong, you are not accommodated shear deformation in your formulation and your experiment as revealed there is a slight variation; the variation will be small, if the depth of the beam is more, if shear effects are the predominant then the deviation will be more and it again depends on the sensitivity of your measuring system.

If the measurement system is accurate enough, you will be able to see the difference, so that is how you have to look at it and now what you have; when you have a complex situation because you have one multi-channel strain measurement can accommodate temperature, pressure and displacement sensors in one platform, it makes your life lot more convenient and help you to plan your experiment much more intelligently.

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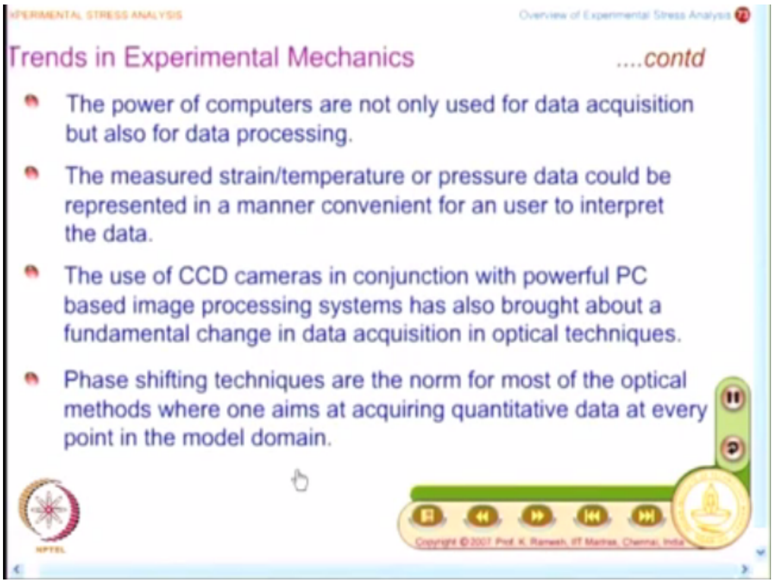

Then what are all the other development that has influenced and what you have here is there are 2 aspects; data processing is now very fast for example, double exposure techniques you can make it appear more as real time, when you do computer processing because we are processing of computers is very fast in handling large scale images. This is not the only advantage, if you go and look at thermo elastic stress analysis.

Or if you look at digital image correlation and you can post process the measured data; temperature, strain or pressure, they could be represented in a manner convenient for an user to interpret the data. This is not only for the techniques like the image correlation even strain data when I have; suppose, I have a multi-channel system I have strain data developed at several places. I would like to see a visual representation even at point information, if I get.

So, the colours; if you put it in colour, you are able to react better this, which you have been doing only in numerical techniques which can also be done in experimental technique with the availability of computer processing. Then what you have? I have already said the CCD cameras have replaced human eye, you know all the optical methods, so what you find is it has brought about a fundamental change in data acquisition in optical techniques.

The advantage here is I could record intensity information using CCD cameras at several frames per second. This has modified the experimental approach developers to find out new ways of processing this intense information. So, what do you find now is; you have techniques known as phase shifting techniques have come into place and they are the norm for most of the optical methods where one aim set acquiring quantitative data at every point in the model domain.

This was unthinkable earlier, if they have to record intensity, they had a photomultiplier cube and it has to be moved over the model domain and you have to process data, it is time consuming. Now, with CCD cameras, I get intensity data over the field at several frames per second, so I could also record slowly varying time phenomena with high speed cameras.

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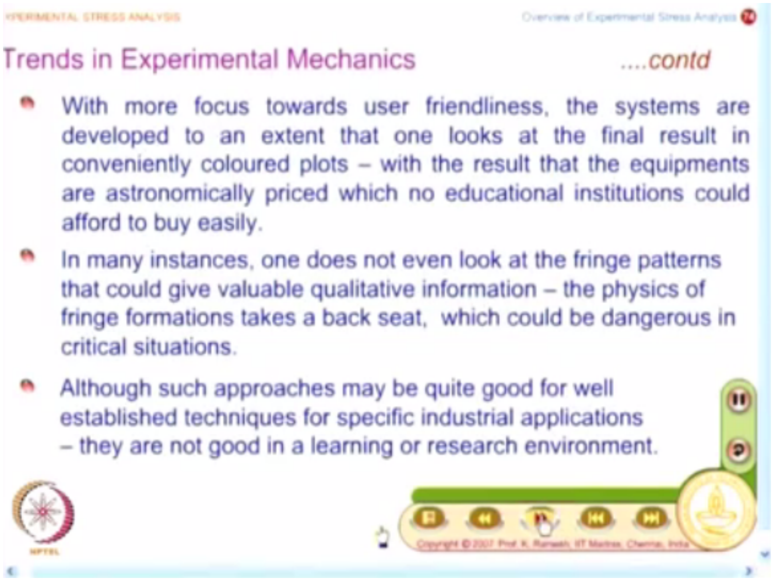

It is also possible to record dynamic events with appropriate optics, you could record multiple images, so technology has really advanced with the development of computers and experimental methods have taken full advantage of it, so this is the positive side of it. What is the other aspect and you know people want to have user friendly equipment, so when they have goal as user friendly equipments, the systems are developed to an extent that one looks at the final result in conveniently coloured plots.

What is the outcome of this? The equipments are astronomically priced with no educational institutions could afford to buy easily, that is becoming the trend, this is one aspect of it. The other aspect is; now, I have always been saying there is joy in looking at fringe pattern and fringe pattern has lot of information. When we have this information, you can make certain judgment based on looking at the appearance of fringes.

And with modern developments, what has happened? One does not even look at the fringe patterns that could give valuable qualitative information and in the process; the physics of fringe formation takes a back seat, which could be dangerous in critical situations. A similar thing happened in development of numerical techniques also. Once finite element got stabilized, so what they found was now, we have very good software which can do all problems, so no engineers are required.

Science graduates who know how to run the computer program are sufficient and that way the industries can bring down the cost of analysis then they burnt the fringes. They found that boundary conditions are very very important. The science graduates know how to operate the program but they do not know what to feed to the program, then they had a scenario where you will have a team leader as a doctoral candidate with a background in engineering who would decide on boundary condition and you will have set of people who will run the software.

And a similar situation is also lurking on experimental mechanics, so you need to have user friendly equipments fine, but it should not go to the extent that physics of the fringe formations takes a backseat; the physics or the methodology takes a backseat and you press only buttons. So, that is not the way the exponent mechanic should go and the caution here is for well-established techniques for specific industrial applications.

Particularly, if you go and look at glass manufacturing, they employ photo elasticity and when they employ photo elasticity what they do is; they have to control glass process parameters. For this, they have well developed equipment, where you have to press few buttons and then keep monitoring the process. That is a specific application where you need some level of automation, some level of fast response.

For such industrial applications, this kind of user friendliness may be alright but they are not good in a learning or research environment, so you need to find out a make a difference when I am in a research and learning environment, I want to know everything about the experimental technique, I want to know its advantages, I want to know its limitations because in a real scenario, I may invent a new methodology to extract information in the way I want it.

I do not want to go and use it as a black box, press some buttons and report the results that is not the way learning and teaching environment should be. So, in this course we would focus more on physics behind the experimental techniques and that will give you certain level of confidence although, phase shifting methods are norm of the day in optical methods. We would focus on the conventional approach of looking at fringes.

So, that you gain insight into experimental method as well as improve your understanding of solid mechanics because many of those things would have just seen it in the books as equations and when you see them as fringe patterns, you also have an appreciation how the values are at different points on the model, it will also reinforce your understanding of solid mechanics, so that is what we look at.

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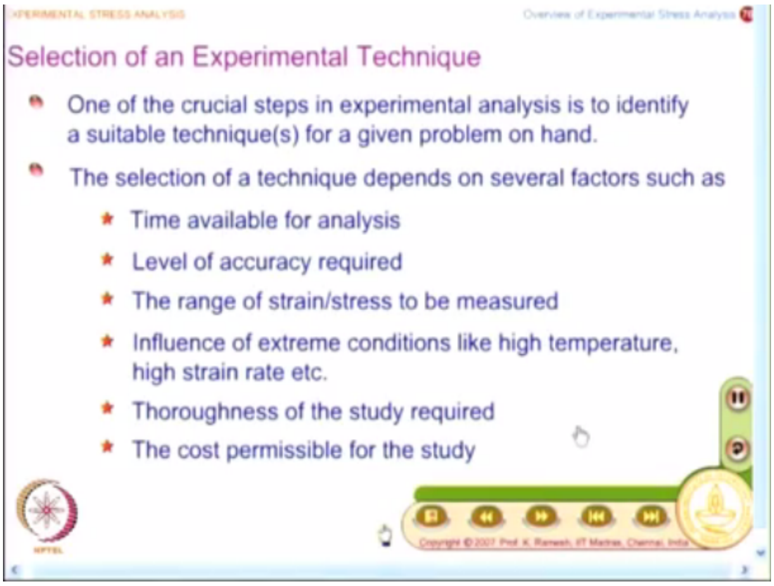

And now, we move on to a very important topic, how to select an experimental technique for a given problem? And this is one of the crucial steps, whether I can choose one technique or combination of techniques to solve a problem on hand and you have reasonable information now though, we are discussing only overview, you already know what are the information an experimental technique can give directly and you also know the physics behind the technique.

Now, when you are confronted with the actual problem, so you will have to find out, if we want to get strain information, you will definitely go to strain gauges; if your focus is on displacement information, you will go and choose among the many displacement methods which one you would like to select for a given application and in all this you know; you could give certain guidelines.

These are only guidelines, these are not like you know definitive steps that this is the way you will go about and we will have a look at some of these guidelines systematically and what you should understand is; selection of a technique depends on several factors. One of the first factors which you; what is the time available for analysis. If you have time at your disposal, you can take your most elaborate method and then accurate method and find out the values.

But if the time available is short, then you will have find out which technique is appropriate, so time available for you to do the analysis is one of the very important steps that you should consider. Then, you have level of accuracy that is what I said. If you want higher level of accuracy, then you will require more time for you to do it. If you want to get picked results, suppose I want to go and look at an industrial component.

And I want to find out approximately which are all the stress concentration zone, I would apply a brittle coating technique and then find out where the cracks have formed, so that gives me quickly in a huge structure where to identify but if I want refined quantitative information, then I have to pay strain gauges and strain gauges you know, it will take some time for you to cure and then make the measurement.

And on the other hand, if you want to do online monitoring, then even the pasting of strain gauges will require more time for you to do it but you may allow the strain gauge to remain on the structure for months together particularly, in civil engineering bridges they do such type of studies over a period of time what happens, so time available, level of accuracy required both are important.

Then the range of strain or stress to be measured and in any measurement technique, range is very important because that dictates suppose, I work on large deformation then I will choose a technique of a particular kind but on the other hand, if I have to look at small strain levels then I will have to look at for a different type of experimental technique. So, the range is very important and extreme conditions like high temperature, high strain rate etc.

Suppose, somebody wants to analyse re-entry vehicles, which is becoming very common these days, several countries are trying to develop such technologies and you need to find out what is an appropriate technique? People have attempted digital image correlation for such applications and suppose somebody wants to find out what happens in an offshore platform, which is in a very aggressive corrosive environment, you have the seawater.

So, when you have that, you have to select a technique like strain gauges obviously and what is the thoroughness of the study required and what is the cost permissible for the study? See for the conventional; you know industry which is doing the consumer goods, you will look at cost permissible in a particular fashion you will factor it in a manner. On the other hand, high tech applications cost is not a consideration, there safety is the main consideration.

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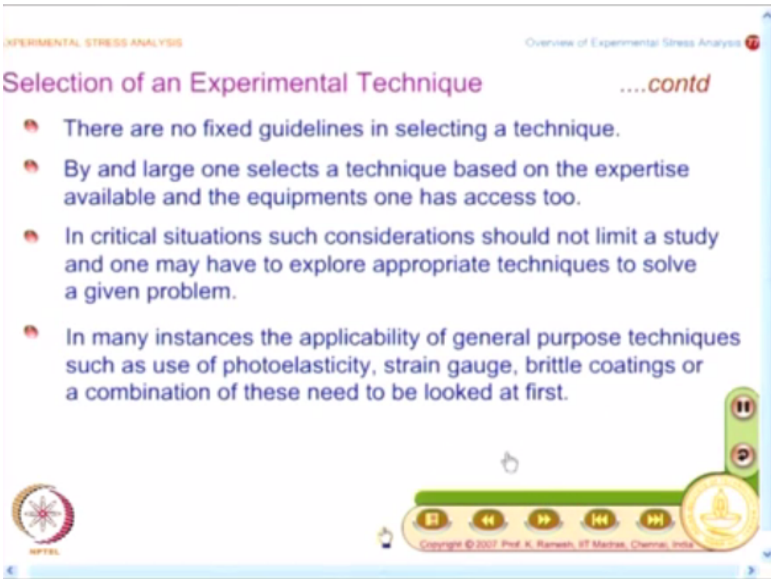

In a nuclear power plant, if you want to find out what could happen? Then cost is calculated in a different way, what is the damage is going to create and what is the kind of human suffering, so there you have to look at it differently. So, all these factors are very important and when you have looked at these factors, what way should be go about? And as I mentioned earlier there are no fixed guidelines in selecting an experimental technique.

And by and large what will you do? You will select a technique based on the expertise available and the equipments one has success too. So, this also indirectly dictates, you may have several techniques that are suitable for a given problem on hand but you would definitely choose those techniques that you have access to and also you have personnel trained in employing those techniques.

See one common drawback what I find in the minds of people is people think anybody can go and do experiments, it is not so; you need to have proper training and you need to be very sensitive right at the beginning of the experiment. You have 5 steps in an experimental analysis, each of these steps you should do it very carefully only then you are guaranteed with accurate information at the end of the experiment.

You cannot suddenly wake up at the stage 4 or stage 5 from now onwards, I will make the measurements accurately. If you have not followed the steps for example, in the case of speckles if you do not have good characteristic of speckles whatever the measurement that you do later will be erroneous depends on the quality and similarly, if you are not pasting the strain gauge then anything you measure is what you want.

It is not what the system says that this is the strain value I am experiencing, so you have to have an approach that you need to have an expertise to do an experiment, keep that in mind when you become managers, you train your people to acquire this expertise and what you have to look at is; I have already mentioned in critical situations, you should not limit a study based on what we have or what is the expertise we have.

One has to explore appropriate techniques to solve the given problem, so that is always the case and in many instances, the applicability of general purpose techniques such as photo elasticity, strain gauges, brittle coatings or a combination of these need to be looked at first. In fact, for many of the industries, several day to day problems can be conveniently handled by these tools. These are essentially tools you have to use your human intelligence to innovatively combine aspects of these techniques and try to attack the problem.

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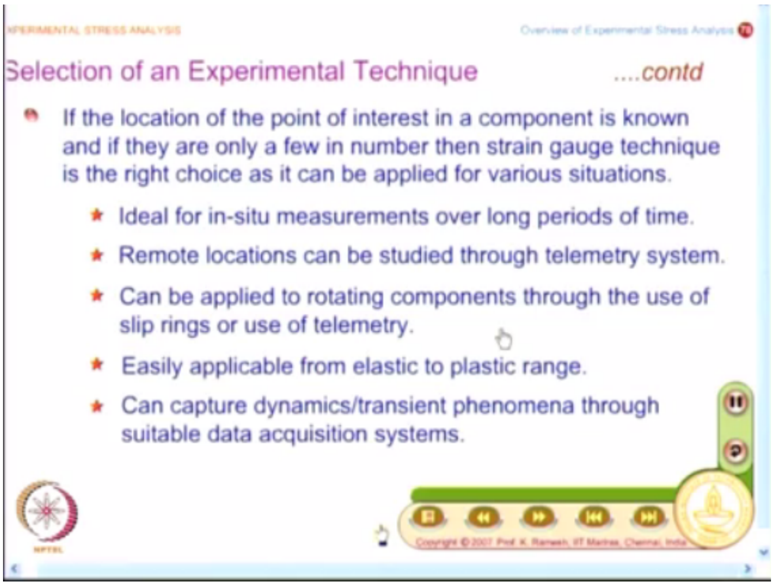

They are also very fast very simple to do and you have reasonable expertise available for you to employ these techniques comfortably. So, the first step in the general guidelines is look for general purpose techniques whether they could be employed to solve your problem and then let us look at what are all the class of problems that they can do and if you know a priori, the point of interest where you have to get quantitative data and these are only a few in number.

Then strain gauge technique is a right choice as it can be applied to various situations in many instances, identifying which are all the point that I need to do, you may have to have a priori knowledge. If there is a failure that indicates where you have to analyse more and you can take some clue from brittle coatings and so on and so forth. The beauty of strain gauges; they are ideal for in-situ measurements over long periods of time.

Suppose, I want to monitor what happens in a bridge, I could do it as a function of time and remote locations that is what I said, suppose I want to find out what happens on the top of the TV tower because you have wind loads and you want your tower to be safe and you want to find out some measurements there, I can have telemetry to do this and you know you always want to study rotating components, you have compressors, you have turbines, you have many rotating components which require thorough study.

I can use strain gauges by the use of slip rings or use of telemetry; I can mount them on rotating components. Here the accessibility is very crucial unless you take special steps, you cannot employ optical methods here and strain gauges are ideal choice when disability is not there when it is interior and you know fairly well. See the problem becomes complex, it is also becoming expensive.

One simple example what I would suggest is anything hidden, it is always a difficult problem. If some portion of the components are visible for optical analysis, then well and good. If anything is hidden, it is always much more complex to do, residual stresses not seen outside, so you have to have special methods to reveal it and similarly, when you have a component, the interior assembly has a problem then you have to put a strain gauge and take it out and do the analysis comfortably.

And another one I have also said, we have to look at the range, some problems you will be able to assess that I live within the elastic region but in some experiments, you may want to go up to the failure, so you may also get into the plastic range, so you should know the range. If you have to go from elastic to plastic range, then strain gauge is ideal and another advantage is it can also capture dynamics and transient phenomena through suitable data acquisition systems.

So, what this slide shows are; what are all the special features of the strain gauge instrumentation, you can do it for dynamic studies, you can do it for rotating components, you can do it on in-situ measurements, you can do it on remote locations, you can do it on locations where you have aggressive environment, so all these cases you are able to get. So, that is why it is a general purpose technique.

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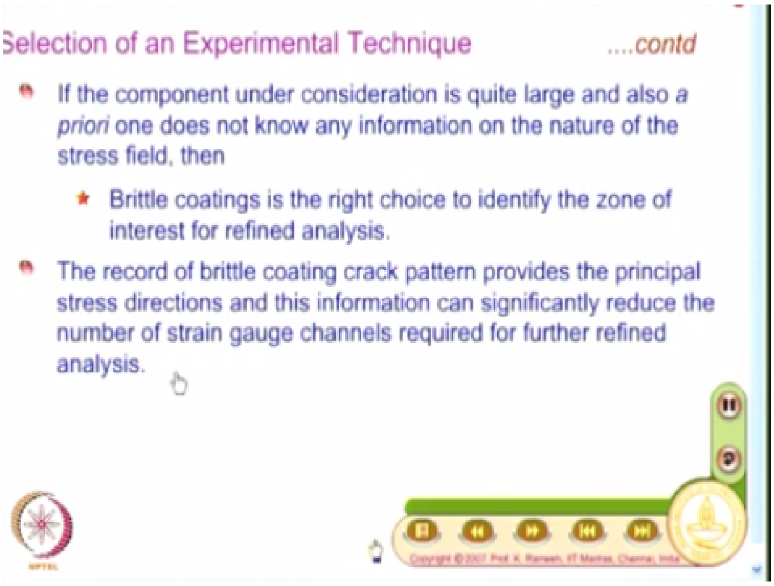

So, look for whether this could be employed for your problem on hand. On the other hand, if the component under consideration is quite large and also a priori one does not know any information on the nature of the stress field, then combine brittle coatings, identify iron strain gauges, so use brittle coatings to identify zones of interest for refined analysis, continue the refined analysis based on strain gauges.

And there is also another advantage; the record of brittle coating crack pattern provides the principal stress directions and this information can significantly reduce the number of strain gauge channels required for further refined analysis and this is used in large structures, people take the advantage of knowing the principle stress direction on a free surface, if the principle stress directions are known instead of 3 strain gauges, I paste only 2 strain gauges.

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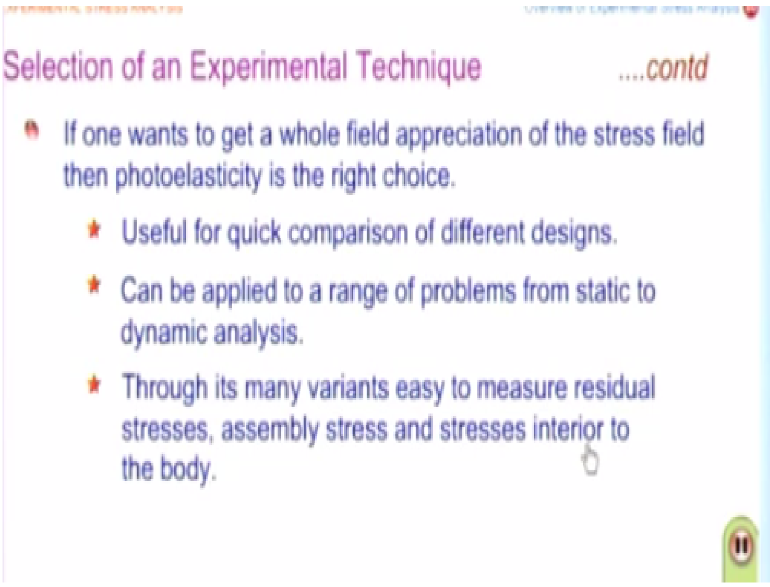

So, instead of 3 channels, I need only 2 channels per point, so that way if my measurement system has only 1000 channels, I can now handle 500 points rather than around 300 points, if I have to use 3 strain gauges. So, you take advantage of an optical technique, the brittle coating provides a whole field information you visually inspect, here the optics is nothing but visual inspection and the choice is very clear.

If one wants to get a whole field appreciation of the stress field, then photo elasticity is the right choice. If I use photo elasticity, I get sigma 1 - sigma 2 contours. In facts, we have looked at for different problems of stress concentration, how do the fringe field look like? We could see for a circular hole, elliptical hole in a crack and we could quickly appreciate crack is more dangerous it gives you that information you get a feeling for it.

And we have also seen it is useful for quick comparison of different designs, which we have looked at. We have taken the example of stream line fillet, I introduced a concept that when you are looking at castings or forgings, I do not have the restriction of only circular fillet, I could relax that and go in for non-circular fillets and this is one example when I have to compare designs, a technical photo elasticity, if it is possible for you to apply, it is a very good candidate.

I do not have; even have to do a quantitative analysis, even a qualitative picture can help you to quickly identify among various options, which option is better and we have also seen with different methods of photo elasticity, you can go from static to dynamic analysis and throw its many variants easy to measure residual stresses, assembly stresses and stresses interior to the body.

In fact, among the various experimental techniques, it is only photo elasticity that has been successfully used for a variety of problems to find out stresses interior to the body through its unique process of stress freezing and slicing, which we will see when we discuss on photo elasticity but from the point of view of selection, if my problem on hand demands stress analysis interior to the body, then I would find out whether I could go for 3 dimensional photo elastic analysis.

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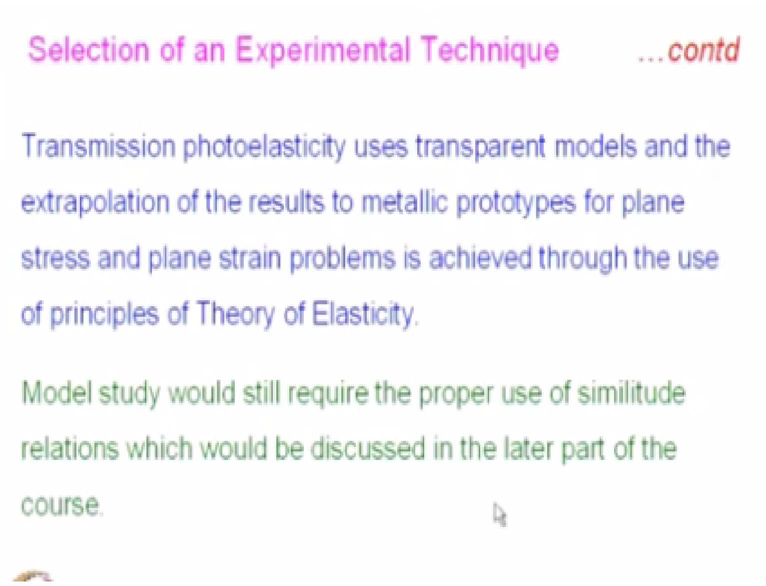

The certain class of problems they can handle certain class of problems you will not be in a position to handle. Transmission photo elasticity uses transparent models and the extrapolation of the results to metallic prototypes for plane stress and plane strain problems is achieved through the use of principles of theory of elasticity. You are actually using a model and model study would still require the proper use of similitude relations, which would be discussed in the later part of the course.

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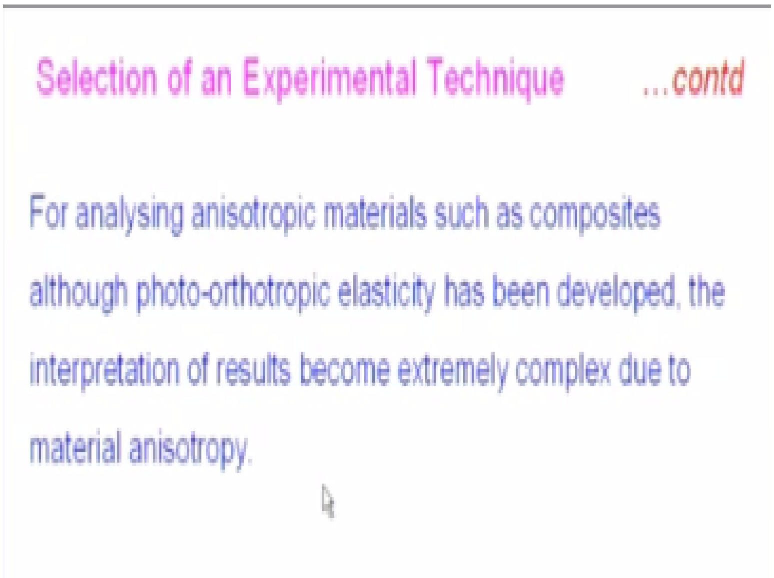

For analysing isotropic materials such as composites although photo orthotropic elasticity has been developed, the interpretation of results become extremely complex due to material anisotropy.

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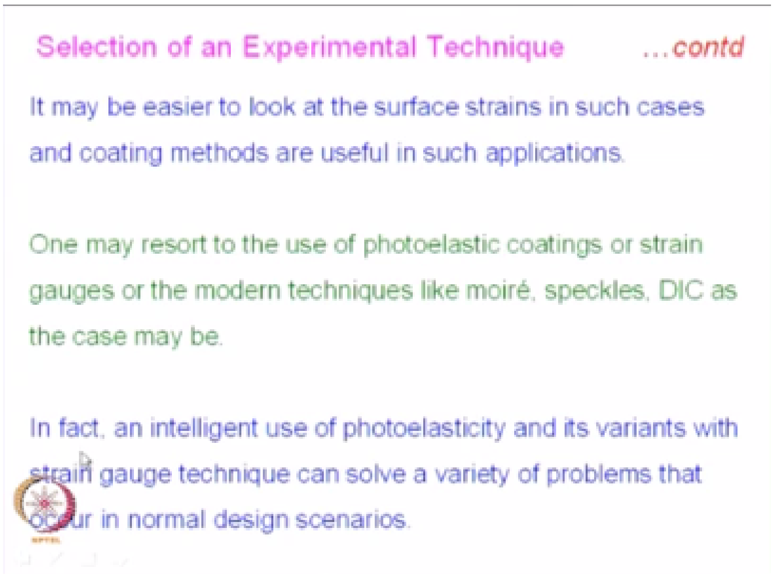

It may be easier to look at the surface strains in such cases and coating methods are useful in such applications. One may resort to the use of photo elastic coatings or strain gauges or the modern techniques like Moire speckles, digital image correlation as the case may be. In fact, an intelligent use of photo elasticity and its variants with strain gauge technique can solve a variety of problems that occur in normal design scenarios.

That is a reason why in this course, we would focus more on photo elasticity and strain gauges because it is a general purpose technique and the overview looked at variety of techniques. So, with this background, you can do a self-study and if you have to look at any one of those particular techniques, you will be able to appreciate what is the physics, how to exploit the physics, how to go about and so on and so forth.

So, what you find here is selection of an experimental technique is a very important step although; we are only looking at overview of experimental stress analysis. Since, you have looked at what each technique can give directly right now, you are in a position to at least look at which technique you may want to use. They use, interpret and improve data you need to know the experimental technique completely that we have to look at the details.

And if you actually look at when we were introducing many of these techniques, I have mentioned these techniques are applicable for certain class of problems like I said in the case of Moire, for electronic packaging you find Moire was very extensively used, so some of this you have to keep remembering it, so that when you confront with the problem situation you would be able to find out which technique to adopt.

In fact, I have set of questions which gives certain specific situations and which will prompt you to find out how to identify an experimental technique, say in normal books on experimental stress analysis people only discuss the details of each of the experimental technique, they do not go about and explain you how to select a technique because what is the purpose of this course? The purpose of this course is when you confront with the problem, you should be able to go and tackle the problem with the knowledge that you have gained.

And it is not that you learn what is strain gauges but you do not know which class of problems you will select and apply if that knowledge is not gained whatever the knowledge that you have on strain gauges will not be used optimally and this comes only from experience, you know people will burn their fingers in the field, you know there are problems where when they had to find out interference fit, what is the level of stresses develop, people use strain gauges.

And in the process of interference introduction itself strain gauge peeled off, so you will have to use a different technique and you have to have a care in finding out how the stresses are developed. It is not that any industry should have all the methods available to their R&D group, they need to have at least the basic techniques like photo elasticity and strain gauges and if there are special requirements they can always consult organizations which have these capabilities.

And you need to have an appreciation how to select an experimental technique that does not come on one day, you will have to look at, listen to this and then have this background while looking at the technique and when we get into the details of the technique, you reflect Oh! This is the physical principle behind it, this is the physics is exploited and in which class of problems this could be advantageously used.

This kind of thought process should be there in your minds that is the reason why I thought that I would have some discussion on overview of experimental mechanics in which we also had a brief discussion on selection of an experimental technique and we will continue with selection of experimental technique in the next class also because you have to listen to this quite a few times and also apply your engineering acumen.

It is not that you need always newer tools, existing tools if they are intelligently employed you can solve the problem, so you need to develop engineering equipment and that comes only by application of your thinking faculty. Thank you.