Experimental Stress Analysis

Prof. K. Ramesh
Department of Applied Mechanics
Indian Institute of Technology, Madras

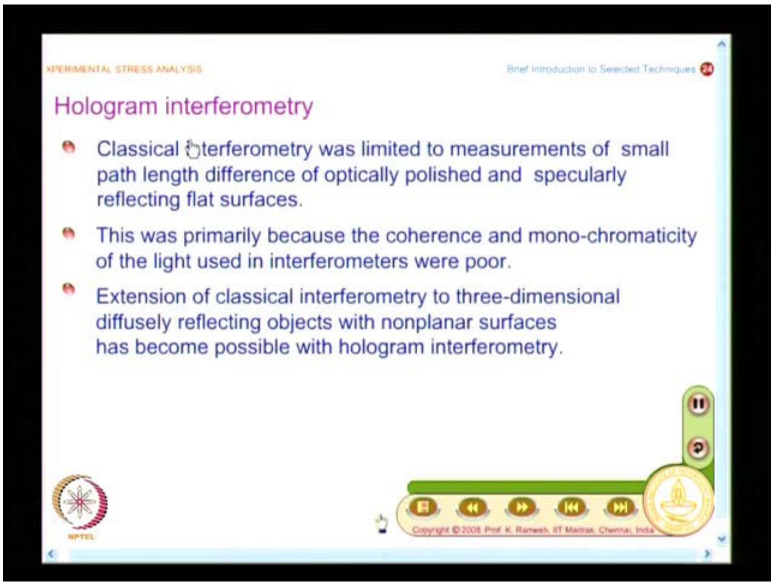
Lecture No. # 06
Hologram Interferometry, Speckle Methods

Let us continue our discussion on overview of experimental stress analysis, the last class we had quickly reviewed what is moiré, then we moved on to the technique of brittle coatings; and in brittle coatings, I emphasized you load the model incrementally, and at every stage of load, you go and record the crack pattern, and also mark the ends of the crack pattern, both give certain kind of information for you to post process the data. And I also mentioned, when you have a very large structure, brittle coating is a ideal approach to identify zones where, you have to concentrate for further investigation. And if you look at combination of brittle coating and strain gauges, makes this stress analysis lot more accurate and fast; because in a last structure, you do not know apriori, which are the zones that needs further attention, which could be identified by brittle coating, followed by a strain gauge technique can give you accurate numbers in zones of importance.

Then, we moved on to holography, and I explained what is the fundamental difference between normal photography and holography; in normal photography, you record only intensity information; in holography, you record intensity as well as, the phase information; and the phase information is recorded in the form of interference fringes; and we also saw the difference what a normal negative looks like, and how does a hologram looks like. A normal negative, you can make code what is recorded with visual inspection; on the other hand when you go to a hologram, you see interference pattern; you do not see anything beyond that. And you need to have a separate optical arrangement to reconstruct, only then, you can see the hologram.

And one of the very common application of hologram is on hologram stickers. You all are familiar where what you find is, if to testif the genuineness of the product, almost every product you name in, they have a hologram sticker. The reason is holograms are difficult to record, but easy to reproduce; and this helps you to make it as a sticker; and only the manufacturer - genuine manufacturer will have the original for him to use it as a sticker, so it acts like a security device. But what we find is, from a stress analysis point of view, we are not interested in only the use of hologram stickers, we want to get quantitative information; for quantitative information, what we have to do? You have to go in for hologram interferometry; and let us look at what is hologram interferometry?

(Refer Slide Time: 03:17)



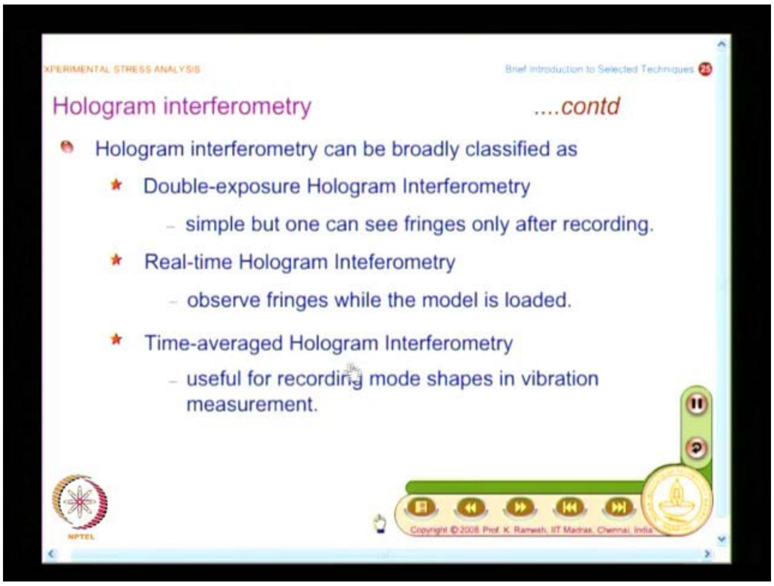
So, what you find here is you know, you will have to look at that, what is the difference between classical interferometry and hologram interferometry. In your schools, I am sure you must have done the exercise on Newton's rings, where you essentially use optically polished surfaces, and find out unevenness by a interferometric technique. So, classical interferometry was limited to measurements of small path length differences of optically polished and specularly reflecting flat surfaces. So, the key point here is you are looking at flat surfaces, they were polished, and you are also confining your attention to small path difference, so even a mercury or clamp is sufficient to reveal that kind of information.

And in fact, when holography was developed in 1948, Gabber had only mercury or clamp. So, the technology was not sufficient to exploit the full potential of holography at that time; it is only after lasers were invented, and were available for common use, the interferometric techniques had a boost. And what we look at as hologram interferometry?

What you find here is, and what we find here is the earlier mercury orchril or mercury arc clamp had mono-chromaticity is not to the extend like what we have in laser; and coherences are also limited, so we were confining only to small path difference. And what happen in hologram interferometry was extension of classical interferometry to three-dimensional diffusely reflecting objects with nonplanar surfaces become possible.

So, we have had a quantum jump, we had a flat surfaces; from flat surfaces, we could go to a three-dimensional objects, and once you come to three-dimensional object, the path length is not small, path length is much larger, and we are also looking at nonplanar surfaces. So, you graduate you graduate from simple experiments on interferometry to go and find out what happens on a three-dimensional object. And in hologram interferometry, you collect so much information, the processing becomes difficult, it is not that the technique is bad, the technique collect so much information, because you are looking at three dimensionality in all its totality. So, this was possible mainly, because of lasers. Lasers have helped this possibility.

(Refer Slide Time: 06:42)



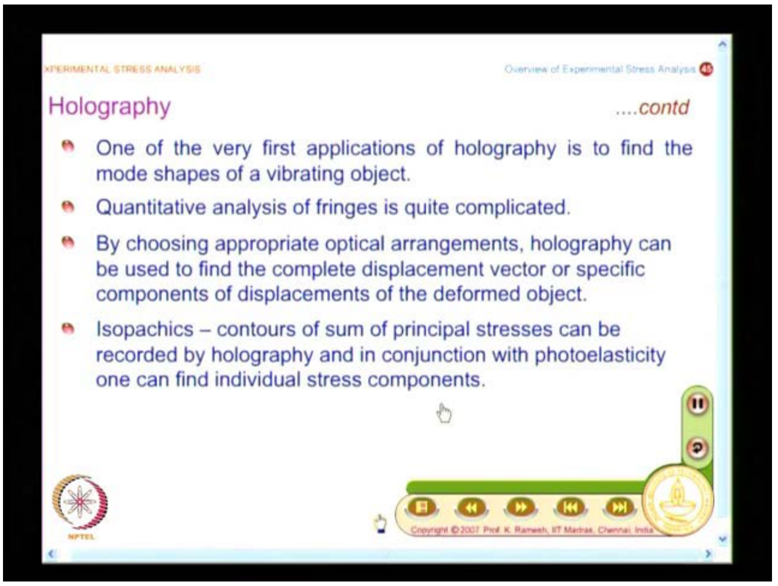
And what you have is you can classify hologram interferometry into various methods; one of the earliest one was double-exposure hologram interferometry; the name itself suggest that you are going to have two exposures. When I going to have two exposures, you will not be able to see the fringes in real time, because you have to post process these exposures, only then you will able to see the fringes in real time. And what we saw in photo elasticity? We could see the fringes as the model was loaded; the similar thing was also there in moiré, when I move the fringe gratings relative to each other, I started seeing fringes, I did not have to have two exposures for me to the see the fringes.

So, what you find here is in double-exposure hologram interferometry, the simple, but one can see fringes only after recording. But what we will have to understand is in holography, we talk in terms of wavelengths. So, I can measure very small displacements. So, it is a very, very fine technique, and later on we will also see, there is also stringent vibration isolation requirement for many of these techniques, why that is so, that also we will have look at it. So, the other category, see once you find a restriction you know, researchers do not keep quiet, researchers find out ways by which, they will circumvent this limitation.

So, what you have is you graduate from double-exposure of hologram interferometry to real time hologram interferometry. The name itself suggests you observe fringes, while the model is loaded, so it is lot for convenient. Real time holography is lot more convenient than double-exposure hologram interferometry; but if you look at the technology, you will have to be very careful in handling it, because you measure in terms of wavelengths, even small misalignments between exposures can spoil your quality of output. So, this is very, very important. So, whenever you find the restriction, researchers and scientist work and circumvent this. So, if you have a problem, do not get worried, you have a scope for research; that is how research problems are coined.

And what is another form of holography is time-averaged hologram interferometry; and this was useful for recording mode shapes in vibration measurement. Time-averaged itself says, you are having a vibration event; and then when the model is vibrating, you have to have some kind of a time post processing so that you get the information without sense of blur; and here you get Bessel fringes and so on and so forth. So, what we find here is hologram interferometry can be broadly classified into three categories: Double-exposure hologram interferometry, real-time hologram interferometry and time-averaged hologram interferometry.

(Refer Slide Time: 10:12)



When you look at the development, what you find here is, hologram interferometry's first application was on finding out the mode shapes of a vibrating object. So, if you look at one of the motivation for hologram interferometry to see as the stress analysis or displacement measurement tool, it was initially used for capturing the mode shapes of turbine blades, and (( )) and others have contributed the significantly in this area. And we have already seen, when you say holography, I look at the depth information. And in the case of vibrating blade, you essentially find out, out of plane displacement.

So, the natural extension of technique for measuring depth information is used for finding out, out of plane displacement that is the natural extension of holography. But interpretation is quite complicated, why it is complicated? Quantitative analysis of fringes is quite complicated, because we record lot of information than what we can handled, because we are looking at from planar surfaces to arbitrary curved geometry, and then you want to find out, so you would essentially find out the displacement vector, it will have a component of u, v and w displacements; it is not that there is deficiency in the technique; it is mainly because the information that is recorded is much more than for you to process; and this we will see again and again; quantitative analysis of fringe is quite complicated, we will keep looking at it as long as we look at hologram interferometry as well as speckle interferometry.

But what is the way that we can circumvent this; if I choose appropriate optical arrangements, holography can be used to find the complete displacement vector or specific components of displacements of the deformed object, so this is what I said. First, identify what is the problem; once you identify this is the problem, then address it and find out what all you can modify, and then how you can use the techniques. So, what you find here is, I can get the complete displacement vector more than complete displacement vector, specific components of displacements of the deformed object could be very interesting, when we want to even understand analytical solution; suppose I want to know what are the displacements in the case of a cantilever, I would like to see only u displacement and v displacement.

So, I will have one optical arrangement to get u displacement, another optical arrangement to get v displacement, then I can compare it with my analytical solution, and see that these two match; whereas, in moiré you had a very simple process, wherein the grating direction dictated your data interpretation, here you have to provide some constraint on the way you do the optics; and some constraint on the specimen deformation, because we are not bringing in a three-dimensional object, and then extracting u, v, w, extracting only u displacement; in a three-dimensional object, then it is deforms, you will get u, v, w in general. Here you would take a two-dimensional problem, and then deform it, and extract only v displacement or v displacement as the case may be.

So, you have to know while doing this experiment, what are all the restrictions in the way you have to do the experiment. And what we have been looking at is they have also looked at, how some of these techniques can be combined? We have looked at brittle coating can be combined with strain gauges, so that I get information on the entire surface, and also detailed precise information in regions of interest. On similar lines, I can use a variation of holography; I choose an appropritical optical arrangement to get only the lateral displacement; and you all know, the lateral displacement what you have as lateral displacement; if I have this as a specimen, and because of Poisson effect, the specimen has lateral displacement in this direction; if I look at this, that could be related to in a planar problem to sigma 1 plus sigma 2 that is all the whole things comes.

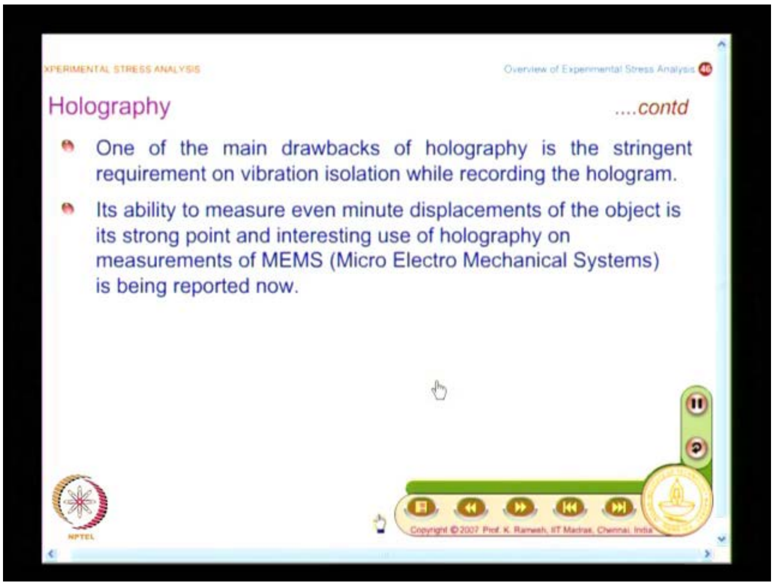
Holography essentially gives you the depth information; suppose I have this as the specimen, when I deform it, when I pull it and deform it, you will have thickness variation; thickness variation could be related to sigma 1 plus sigma 2. So, when I record that as whole field information, I call those contours as isopachics, so this is where holography comes. Holography essentially measures the thickness information, depth information can find out; here, I find out the change in the depth, because of in plane stress; I call those whole field contours as isopachics, they are nothing but sigma 1 plus sigma 2 contours. And what photo elasticity gives? Photo elasticity gives you sigma 1 minus sigma 2, so now I have, I have said individually it will give you only a particular contour or a contour, which has combination of stress components, but if you want to post process, I can extract them individually also. So, that is what it summarizes here, isopachics - contours of sum of principal stresses can be recorded by holography, and in conjunction with photo elasticity, one can find individual stress components.

Actually, in holography you told about the isopachics that is sigma 1 plus sigma 2, I like understand the concept between how sigma 1 plus sigma 2 is (( )) of thickness.

See in the case of photo elasticity, essentially we deal with the planar models, and subjected to in plane (( )). So, when you have that kind of situation, when I have a planar model, suppose consider my hand is the model then I pull it, what happens is, because of Poisson ratio effect, the thickness changes. And if you look at the thickness change, it is proportional to minus nu time sigma x plus sigma y divided by e, and sigma x plus sigma y is the first invariant, and sigma 1 plus sigma 2 is also first invariant. So, from there, you get sigma 1 plus sigma 2, simple; it is straight forward; I get sigma 1 minus sigma 2 from photo elasticity, I combine these two and get sigma 1 and sigma 2 separately (( ))

The basic question here is, do you require individual stress component for the problem on hand? If you required it, then go to the circus, because holography is not a simple exercise, any interferometric technique is not a simple exercise. So, this is where I said, I also showed you the picture of Athena, Goddess of wisdom. So, you should be wise enough to tackle your problem, not blindly use one technique, another technique collect volume of information, and do not know what to do with. So, this is where wisdom is required.

(Refer Slide Time: 17:51)

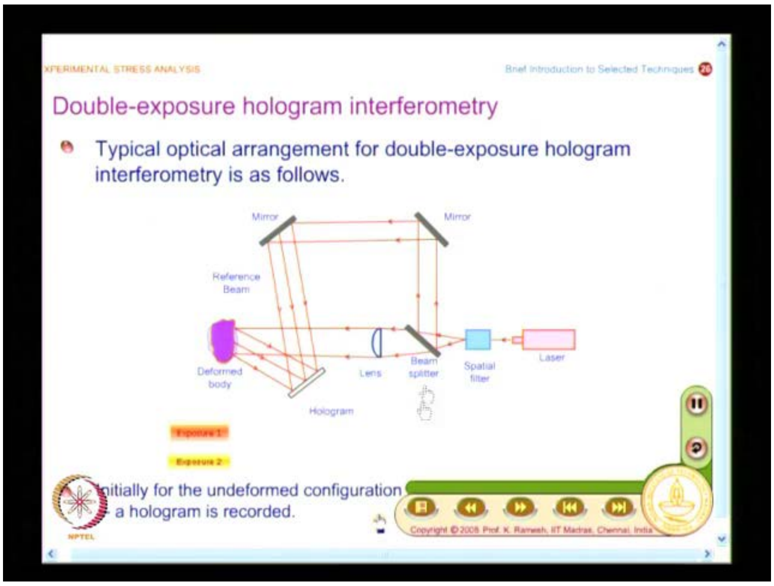


And, what is the restriction in holography? Holography demands vibration isolation. So, we will have to have a look at, what is the optics that I use, and why it dictates vibration isolation. If we just look at how the double-exposure of hologram is made, you will be able to appreciate, why in holography we talk of vibration isolation. We are never spoken about vibration isolation in photo elasticity. On the other hand, I caution in moiré, you will have to worry about digit body displacement and rotation, translation and rotation, you have to worry about, because that can give you spurious fringes. So, there also the alignment becomes important.

But once you come to holography, you find vibration isolation is very, very important requirement. And even this you know, with advancements people are coming out and making techniques, which are the reasonably robust; you know, that is also research is going on. And what you find is, because you talk in terms of wavelengths, you can record minute displacements, and such tiny components as MEMS, a nothing but Micro Electro Mechanical Systems. So, you have even the actual component is very, very small insides, and if you want to find out the displacement on the daily much smaller than this, and because hologram or holography helps you to measure s of the order of wavelengths, you can measure those small quantities comfortably.

If I have a very small component, I cannot go and place the strain gauge; though strain gauge gives me one micro strain, the strain gauge will go and reinforce the small components. So, I should go for a noncontact measurement. So, when I have to go for a non contact measurement, holography is good. So, what you find is its ability to measure even minute displacements of the object is its strong point and interesting use of holography on measurements of MEMS is being reported; we will also see one example in the course of the lecture.

(Refer Slide Time: 20:35)



And what we have now is we will go and look at, what are the steps in a double-exposure hologram interferometry; because I said vibration isolation is very, very important; and when you say vibration isolation is very important, you will have to know what are all the components in a general holographic recording, and you will have a look at, we will also have a enlarge portion of it. So, what I have here is, I have a light source, I have a next component as spatial filter, this spatial filter has a pin hole and also a lens; then I have a beam filter, then I have a another lens, I have two mirrors, and I have a object to be recorded for the hologram.

And I have a holographic plate, you need to sketch this; you need to sketch this; and we will see the optical diagram, what we will do is I will do, I will have to do two exposures, I will make exposure one, I will also show exposure two. So, you need to have a decent sketch of it, it will take you few minutes for you do it, take your time, because this is important, and I am going to show this in a slow motion; in the sense, you know light travels at a very high speed, so I am going to draw the diagram, and then I am going to show as if light moves, but it certain very, very slow movement.

And what I will do is, I will make on exposure path, just look at what what happens - light comes, hits the beam splitter, and goes the mirror arrangement, and comes to the hologram and this is the reference beam. And from the beam splitter, another set of rays go and illuminate the body, and this also comes to the hologram; and both happens simultaneously; for the purpose of understanding, I have shown how the reference beam falls on the hologram, and how the light reflected from the object falls on the holographic plate; after you develop the holographic plate it becomes hologram, you can see the hologram.

So, what you have here is, you have the laser light source, you have a spatial filter, you have a beam beam beam splitter. So, beam splitter sends one set of beam to the hologram directly - the holographic plate directly, you call that as a reference beam; and the necessity of the reference beam brings in the restriction of vibration isolation; if I do not require a reference beam, then I do not have to worry about vibration isolation; because of the reference beam, I need to conduct experiment as carefully as possible. See the one of the requirement is even a normal running AC can alter the vibration characteristic. So, people keep the also AC away from the holographic table, you do not keep it nearer. So, you have to take here of that.

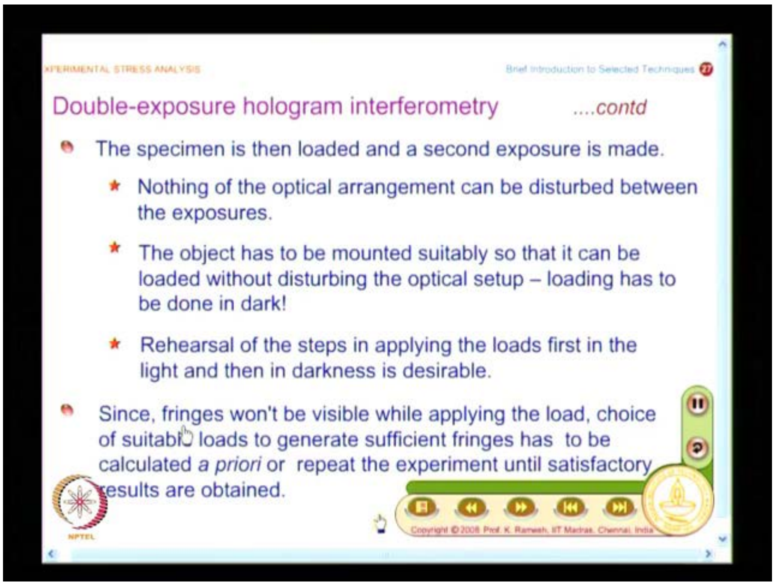
And I will repeat the exposure one, you can just have a look at it, how the whole exposure takes place. So, you have a reference beam, and you also have a beam reflected from the undeformed body. So, these two waves interfere, and then I get this pattern, so if I see this pattern, what I will see? I will see this three-dimensional object; if I record this as hologram, developed it, and then reconstructed, I will see the three-dimensional object. And here, I am not interested knowing the methodology of the three-dimensional object, I am not interested in the depth measurement or shape measurement of that object. I am interested, because of loads applied, what is the deformation introduced in the model, that is what my interest. So, that is why you need a double-exposure.

So, what we do is, in the first exposure, you capture this. Now what I do is let me see whether I can do the second exposure, I have a button below, I will carefully press it. So, when I do a second exposure, you would have noticed, I have not change the reference beam, the body is deformed, and the deformation how I obtained I have not shown it in the figure; I have only shown that this is the deformed body. So, you have the light reflected on the deformed body is also recorded the same hologram, same holographic plate. Now, when I develop this plate, I will be able to get the fringes, which is representative of complete deformation of the three-dimensional object that is the advantage of holography, because you record so much information, interpretation becomes involved; once you find it is involved, there are enough number of research students and research scientist across the world would try to crack this problem so that work is going on. They are large extern we have achieved, in certain issues you have to have certain complicated calculation that is fine.

And let us now repeat the exposure two; then we will see the entire animation again. So, in the exposure two, I have a reference beam that is not altered; I deformed the body, and I record another set of light rays on the holographic plate; and if we go in the sequence, we will see the exposure one. So, only during exposure, I have a reference beam, which falls on the holographic plate that is not disturbed, when I go for the exposure two. So, in between the exposure, I have to deform the body, there are certain aspects that we will have to note down, how do you deform; and what is that you need to practice; all that we will see. Right now you look at the optical diagram, and find out how the whole aspect is done.

So, this illustrates that you have a reference beam, and you have a un deformed body, and then you have this second exposure second exposure, second exposure is done where I have this light rays comes from the deformed body. Now we will look at what are all the restrictions that you will have to look at when you are loading the model.

(Refer Slide Time: 27:38)

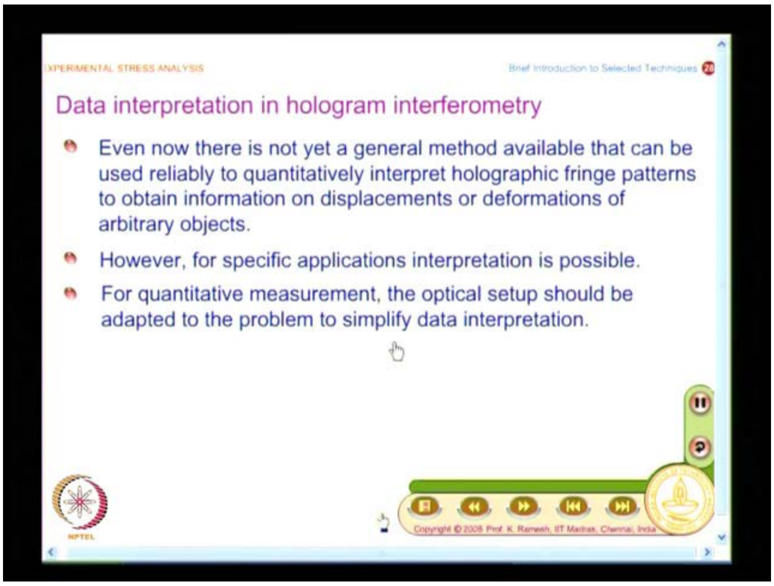


See, the specimen is loaded and a second exposure in made, that you have well understood; and this is to be done what? This is to be done in darkness - total darkness; and you have to ensure nothing of the optical arrangement can be disturbed between the exposures. So, it is not that is simply move your hand, and then I mean disturbed the alignment of any of the optical elements. So, this has to done very carefully. So, that is what I always being saying, experiments are planned and executed; it is not that you go, quickly make some measurement, and come and interpret the way do it; experiments have to be carefully planned, also you anticipate what is the type of result approximately, you may, there may be an error in judgment, but still you want to know the range that is how you want to do the experiment.

So, you cannot disturb optical arrangement, and what are the other finer points? The object has to be mounted suitably, so that it can be loaded without disturbing the optical setup, and loading has to be done in dark, even this you can the practice. The other difficult point here is since, you do not do not know apriori, how the fringes are formed. You will have to have appropriate calculation to find out what is the extend of load that we should apply; and what is advised is you have to do rehearsal of the steps in applying the loads first, in the light, and then in darkness is desirable. So, you have to do some practice. So, when you want to record the hologram, you have to do this practice; and from loading point of view, since the fringes will not be visible while applying the load, choice of suitable loads to generate sufficient fringes has to be calculated a priori or repeat the experiment until satisfactory results are obtained.

So, you understand experiments are not that easy, it is backbreaking that is why people want to minimize the number of experiments that they want to do; the numerical simulation have to be looked at more in the light of reduce in the number of experiments, because experiment is truth, ultimately any design that you want to release for the pubic, where any design deficiency can have see this consequences, you have to testify the results verified by experimental measurement. But experiments are have to be done systematically, it takes time until you get satisfactory results you may have to get; this is where people found that why do you go and do this kind of double-exposure with advancement in computer technology, people are able to solve and address this issues reasonably well, and even now though there are restrictions, digital holography is also catching up.

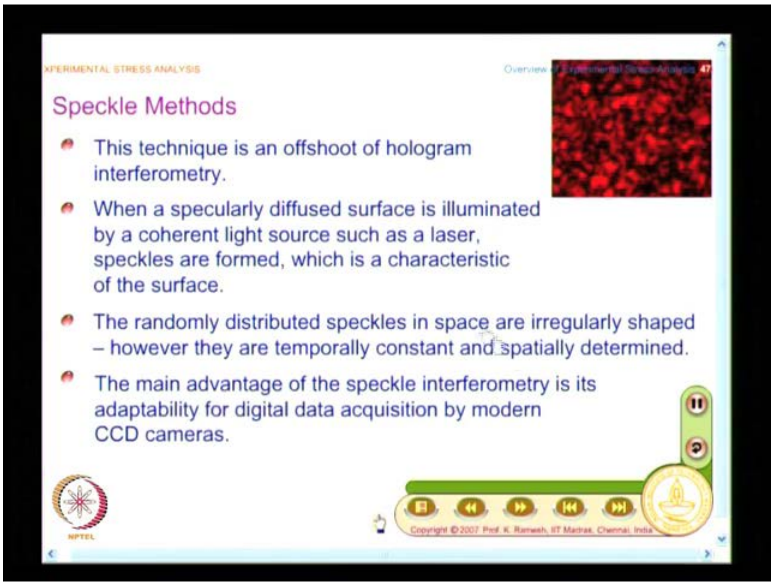
(Refer Slide Time: 31:11)



And what are the other things that will have to look at? Because I said you are recording more information, reliable quantitative interpretation of holographic fringes is still difficult. There is no general method; but for specific applications, interpretation is possible. See, one of the emphasize on many of this optical methods is people would like to minimize human intervention; what they want is they want to press the button, and then finally, say that this is the displacement, deformation and so on and so forth. In fact, I do not subscribe to that kind of a view, you know you need to use computers more for doing the routine job, but intelligence, human intelligent has to be used; human intelligent replacing human intelligence totally by any of the automated methods can result in observed answers many times, and also the effort involved is quite high.

So, what we find here is data interpretation is an issue; and what will have to do is when I want to use for specific applications, I said already the specific application is determining isopachics. The optical setup should be adapted to the problem to simplify data interpretation. So finally, what you come down to planar surfaces are easier to handle; so though you start with three-dimensional surfaces, three-dimensional displacement, I can record the information; but interpretation becomes difficult. But I will also say when I have three-dimensional information is very rich, and we will also see a separate lecture on how to extract as much information as possible by looking at fringe patterns alone; we will have a lecture on that. But once you come to any one of these experimental methods, the optical setup should be adapted to the problem to simplify data interpretation. A generic approach is still illusive and difficult; specific applications are possible; and you adapt the optical arrangement to simplify data interpretation.

(Refer Slide Time: 33:53)

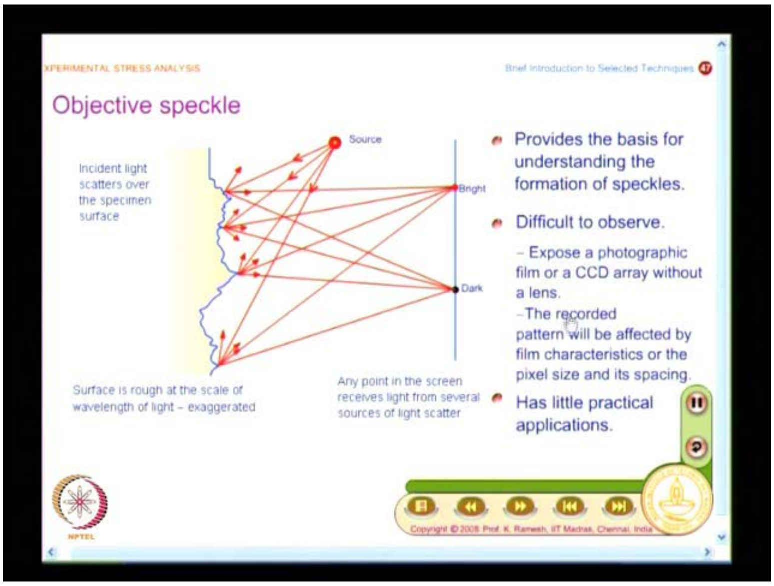


Now, what we do is we move on to another technique that is speckle methods. And this is where yet is you have a very nice illustration of the method, you just see the speckles first; and these are largely laser speckles; and this is just give you a feel of what the speckles are; I have shown in this animation; and obviously, this is an offshoot of hologram interferometry. And we have already seen whenever you have a coherent elimination, you have formation of speckles, we have seen if I use it with white light Athena Goddess was looking nice, the moment I illuminate with laser, you saw speckles on the phase on the entire picture.

And this is used as a technique to reveal displacement information. And what you find here is the speckle distribution is random; but the advantage here is they are temporally constant and are spatially determined; this will see again and again. We will emphasize these two aspects, that is, this is why we are able to use it as a technique; if they are totally random and changes as the function of time and space, we will not have speckle interferometry. What we find here is you have randomly distributed speckles in space, they are irregularly shaped; however, they are temporally constant and spatially determined. And why is speckle interferometry advantageous? The main advantage of the speckle interferometry is its adaptability for digital data acquisition by modern CCD cameras.

So, a speckle method is an offshoot of hologram interferometry, and speckles are random irregularly shaped, but they are temporally constant and spatially determined. This is the very important characteristic, which we use it to, are advantage; and also you will have at lot of debate in literature between the methods will look very similar, there is the still debate whether to call it as speckle interferometry or TV holography, this kind of discussions are going on among a academic circles. And then, you know this such discussion will continuity exist. So, we will see certain category as holography in our own judgment, certain category as speckle methods. And what we need at look at is we need to look at what these speckles are. So, what I am going to do is, I am going to look at how speckles are formed.

(Refer Slide Time: 37:04)



And one of the thing, one of the important aspect in all this category is you have formation of object is speckled, and what I want show here is surface is rough at the scale of wavelength of light exaggerated, so make a sketch of the surface. This surface for all practical purposes will be very smooth and straight; but if you look at, at the wavelength of the light, surface is rough at the scale of wavelength of light, so it is the highly exaggerated picture; it is a very highly exaggerated picture of the surface to illustrate how speckles are formed, and it is very interesting, this will open up deeper understanding on how you have these methods.

So, and what I have is I have a source of light, and then is going to impeach on this, and you can observe it very carefully that is what I said all these animations are very slow, it is not at the speed of light, this is just to understand the sequence of steps in the formation and let us see that. So, what I see here is, what I see here is as the light hits, you have light scattered at each of these points. So, what I have is we can also see this little enlarged. Incident light scatters over the specimen surface, so when it hits the specimen, the light get scattered in all direction; and this will see again; we will see the animation; the light will hit other places on the object, what you need to notice is the light ray comes and immediately you have scattered light, you have scattered light do not stay here, they travelled to the screen, I have not shown that portion, I am showing the sequence of happening in stages, for you to understand.

And what I have here? The light ray comes here, then you have immediately scattering of light, immediately here, you have scattering of light; and this is what happens. Now, what I am going to do is, I am going to put a screen; and this screen is sensitive to what are the light that falls on it or I should have a CCD camera with its lens removed; I do not have a lens in this process; I do not have a I do not keep a lens here. And what will happen is… And this is what you will have to look at. See, this is again very important point; any point in the screen receives light from several sources of light scatter, this I want you to observe.

I am looking at objectives speckle, and one of the key points here is any point in the screen any point in the screen receives light from several sources of light scatter; and that you see the animation; and I am looking at point like this here, so I have a light coming from this scatter, another ray coming from this scatter, another ray coming from this scatter, another ray coming from this scatter. And it is so happened, I have selected point, so happened that these rays do a constructive interference, and I see this as a bright spot. And I take another illustrative point, where again I will have light rays from all these scattered points. This is the key point; any point in the screen receives light from several sources of light scatter is a important characteristic of objectives speckle.

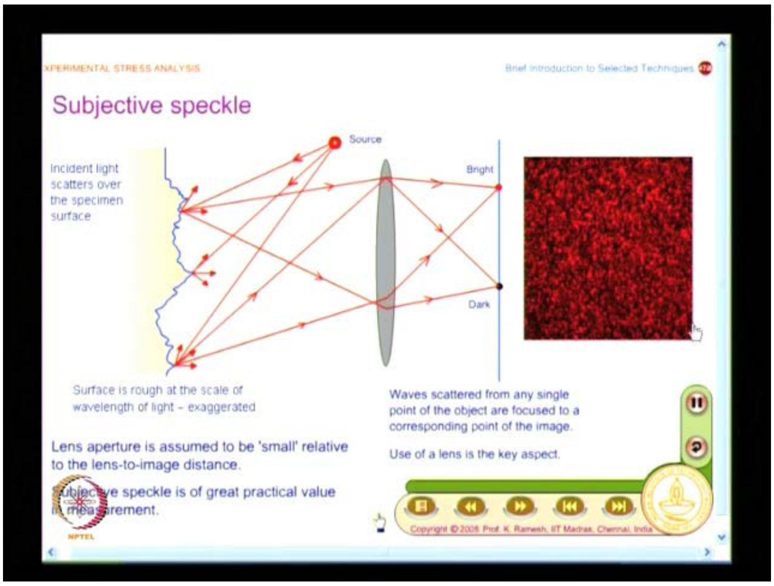
So, what I do is, I see the second set of rays meeting at a point, and I have selected this point in such a manner for illustration that these rays interfere and gives you dark fringe - dark point. So, I have a bright point, and I have a dark point; have you been able to reasonable sketch of the final ray diagram of the whole thing, because you need to have this, we have seen how this formation of lines actually happened; the light rays go and hit the model; on the surface of the model, it gets scattered, and from the scattered all the any point on the screen receives light from several points of scatter, and that is why we have to read the picture, you may finally have the picture like this, but how this picture came into the existence, these are the sequence of operations, and if you want I can repeat the repeat the animation once for the clarity, you just see only animation.

I have a light source, light comes and hits it, we have scattered from each of these points where it makes the model, then I put a screen, and each point on the screen receives light from several sources of scatter; 1, 2, 3, 4 from all these, we get a ray; and this is the characteristic of objectives speckle. I will also go and see the another formation of speckle, I call that as subjective speckle, it is known as subjective speckle, where the story is different. And what is the advantage of this; provides the basis for understanding the formation of speckles, and it is difficult to observe; why it is difficult to observe? All of us have a eye, which has a lens; the moment I have a lens, I always observe only subjective speckle, we will see that also; because I have the lens, my eye eyes have lens. So, the moment I put a lens, though I record something, whatever the specular reflecting object if I look at directly, I would be recording only objective subjective speckle; but only on a photographic plate or you have take special effort to record objective speckle; so it is difficult to observe.

And this is what the methodology is given what way I can do a expose of photographic film or a CCD array without a lens. The recorded pattern will be affected by the film characteristics or the pixel size and its spacing, has little practical applications, but the importance here is it provides the basis for understanding the formation of speckles; but it is difficult to observe, so you need to have a photographic film exposed; and that is what you have to do it. And this shows how the whole as speckle get formed, and this shows the animation again; because you know, if you understand this, then your appreciation of speckle methods become not more clear.

So, I have a dark fringe form, I have a bright fringe form, and I get lights from all points of scatter, and the points are summarized, one after another; you understand that it helps you to understand the formation of speckles, difficult to observe, and we finally say that it has little practical applications. Now we will see what is subjective speckle? And what we are going to look at is, we will just make one small modification in this, rest of it is same; the first procedure is same; in fact, you can even have another sketch here, wherein you modify it, you do not have to repeat the full sketch.

(Refer Slide Time: 46:09)

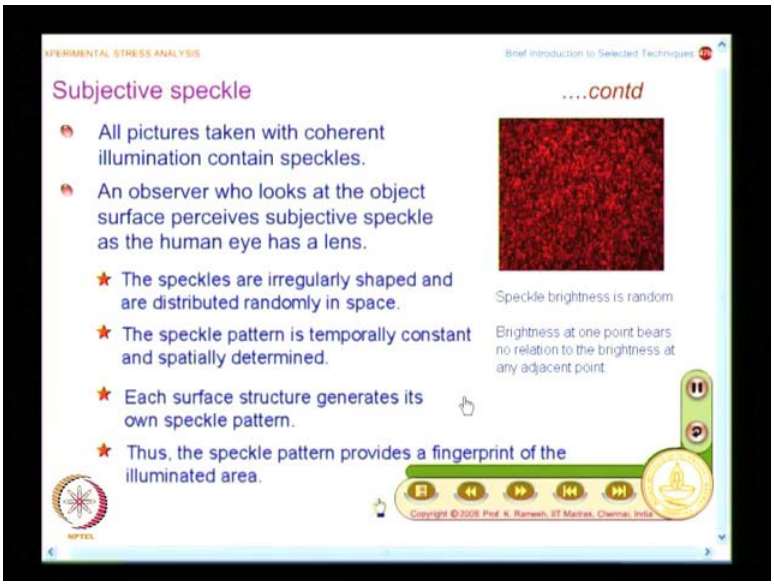


The moment I go to subjective speckle, the difference is in between the screen, I put a lens; lens is the key aspect; what happens on the surface, it is same like what was seen in objective speckle; but what is recorded there is a suttle, but important difference. And subjective speckles are very useful, we want subjective speckle, we speckle interferometry uses only subjective speckles, and we have an advantage. And let us see how the formation of speckles here. Because of the lens what happens; because of the lens, what is the key point here is suppose I have a point on the object, it is mapped on to another point on the screen that, is what the lens does. In the case of objective speckle, this point will receive light from all points of the scatter, because I put a lens, this will receive light from corresponding point on the object.

And in this case, I have taken that, these two rays interfere in the manner that you have a dark fringe, dark point; I would call it as fringe; I would call it as a dark point. Similarly for this another point, if I take it what I am going to have is, I am going to have, I choose the point in a manner that there is constructive interference, and I have a bright point. So, this is the fundamental difference, and what is important here is waves scattered from any single point of the object are focused to a corresponding point of the image, that is the fundamental difference between objective and subjective speckle.

So, when I come to subjective speckle, use of lens is the key aspect use of lens is the key aspect; and let us see, now what I am saying is I said that objective speckle was difficult to observe, and subjective to speckle is nice to see, and if I have a film, what I will have is, I will have this formed here, I have this speckle beautifully formed here, I have the speckle beautifully formed, because I have a lens, and we have already seen that it is temporally constant as a function of time, it does not change and spatially determined; it is like a fingerprint; the same concept, I will again reinforce, we will have look at this in the next slide as well. So, the key point here is waves scattered from any single point of the object are focused to a corresponding point of the image that is the key difference between objective and subjective speckle. So, I have beautifully formed subjective speckle pattern.

(Refer Slide Time: 49:49)



And when I go and look at the finer aspect of this like this. So, what we summarized here is all pictures taken with coherent illumination contain speckles; this is a fundamental point that we have been looking at. An observer who looks at the object surface perceives subjective to speckle as the human eye has the lens; this what I have mentioned it earlier; and you have this speckle, and what is put here is speckle brightness is random, and what you find is brightness at one point bears no relation to the brightness at any adjacent point. So, speckle brightness is random, these are all the characteristics of it.

And what I find here is, it is put in slightly different words, set of words this thing, because you know this is very important characteristics. So, repetitions are always advantageous for you to remember speckles are irregularly shaped, and are distributed randomly in space, temporally constant and spatially determined, and also I find each surface structure generates its own speckle pattern; suppose I have a if I change the structure, the speckle patterns also will be different. Thus the speckle pattern provides a finger print of the illuminated area; this is like a finger print. In the case of moiré, we put a grid on it, which is regular, in the case of speckle, you have the speckles formed that act like a finger print, that is why we also said speckle provides you fringes, which are not very smooth; we saw that, when we looked at, out of plane displacement of a plate clamed all around the boundary with a central load. When we have a plate all around the boundary, and put a central load, when we looked at, we looked at out of plane displacement, the experimental fringe pattern, which I showed was from speckle interferometry, it was not as smooth as what I saw in photo elasticity, it had only points.

So, this is they are called correlation fringes, different from interferometric fringes, and there is also a reason, why we looked at moiré first, and then look at holography and speckle interferometry; because speckle interferometry has certain ideas share with moiré; you have a random pattern, which is naturally produced, because of specular reflection.

Can speckle methods be used for surface phase measurement?

Definitely, see all this techniques optical techniques like holography and speckle, they are all used for metrology applications; metrology application is happening parallelly, and what we are interested in this course is to look at under the given application of loads, what is the deformation introduced on the object, and in fact, if you look at the feature, you are going to have a 3D facts, the concept there is you will have on object, you will have a facility like your micro wave oven, you will have a facility, you keep the object, the object will rotate, and you will have a light rays scanning the object, and pick out the coordinate information; and this will be available in a file that will be transferred over internet or any type of data transfer mechanism.

At your end you will have a rapid prototype information, which will understand these signals, and you will have the object on hand, when you print it, you will have the object on hand, and this is what people say that is going to the future of manufacturing, and will also reduce your inventory, and developing nations they would like to concentrate more on design, and make the under developed or developing nations to do the manufacturing.

And you know, in this lecture, what we started was we looked at what is holography? We focus more on holographic interferometry, because holographic interferometry is necessary for you to make the displacement measurements, and we graduate from planar surfaces to three-dimensional objects, but when we graduate, there is also a difficulty comes and crossed, because I record more information, data interpretation becomes more challenging, but for simple planar surfaces, it is possible for you to do the data interpretation by appropriately constraining the model and also looking at the way the model is loaded.

Then we moved on to speckle interferometry, in speckles we understood that you have when you have coherent illumination, speckles are formed. And the when I say speckles, the two aspects people look at it; what are known as objective speckle and subjective speckle. We saw the difference between objective and subjective speckles. And now we have to go and see what do I get in speckle interferometry, and then what is the variation of speckle interferometry, which is adapted to an industry, which we call it as sherography; and why it is advantageous to an industrial environment? We have looked at in hologram interferometry, when we do a double-exposure, you have a reference beam, the necessity of reference beam demands vibration isolation; when I come to speckle interferometry also, we will see you need a reference beam, but on the other hand, when I go for sherography, I do not need a reference beam. So, it is robust from an industrial point of view.

And entity people have quickly taken this for inspecting honey comb panels. So, what will have to appreciate is when you develop any of this techniques, whatever that is convenient for industrial use, automatically comes up. People identify that, and that becomes a very popular technique; and people are able to use in day in day out, because that technique that you want to use to be a robust, you should not be sensitive to the person, who conducts the experiment; and vibration isolation in the very, very key aspect, and if do not have vibration isolation, you will not able to record holograms, thank you.