Manufacturing of Composites

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Lecture – 16
Non-destructive testing methods for composite materials

Welcome back, this is lecture number 16. This lecture is predominantly focused on nondestructive testing methods for composite materials. See when you try to manufacture if you cannot characterize the manufactured product or if you cannot test the quality of the manufacture product, then no point in manufacturing. So, it is always better to have a characterization tool to check the developed products quality. It can be contact type, it can be noncontact type.

So, what is a big difference between a composite material checking and normal homogenous material checking? In composites as you know very well there are several ingredients you keep adding to the composite to meet the customer requirement. It can be matrix, it can be fiber, it can be the form of the fiber then it can be fillers, it can be other ingredients which are added to meet the customer requirements. So, in that case it is becoming more complex you have different, different phases of material which is there in a composite material. And the other thing is you should also understand there is a property called as interface, and interface which I have told the difference in the earlier lecture.

So, that also tries to bring in a big difference. And the third one is in composites there is always a possibility of producings defects on the surface, and deep in to the product. So that means, to say along in the core there is a possibility. So, it is always necessary for you to check the composite what you have fabricated is as per your specification.

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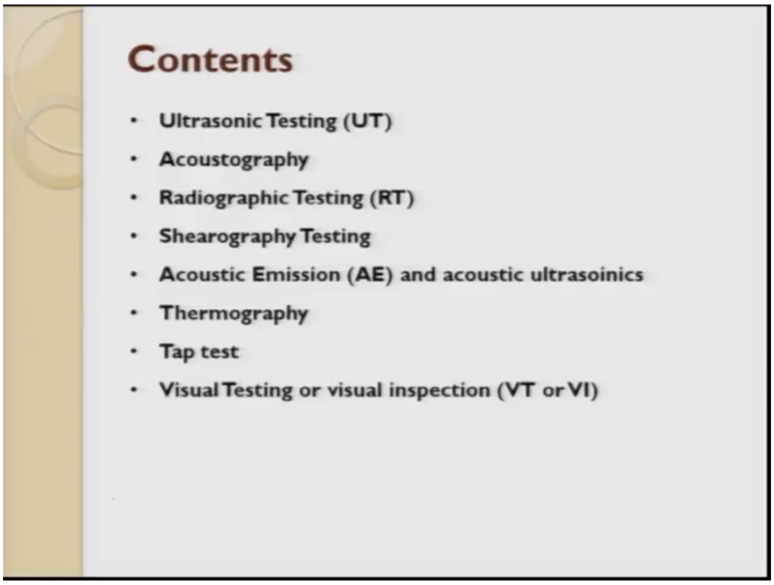

The here now we will see the content of the presentation. So, first you will see ultrasonic testing, then we will see acoustography, then we will see radio graphic testing, then shearographic testing, then acoustic emission thermography tap test and finally, the visual test.

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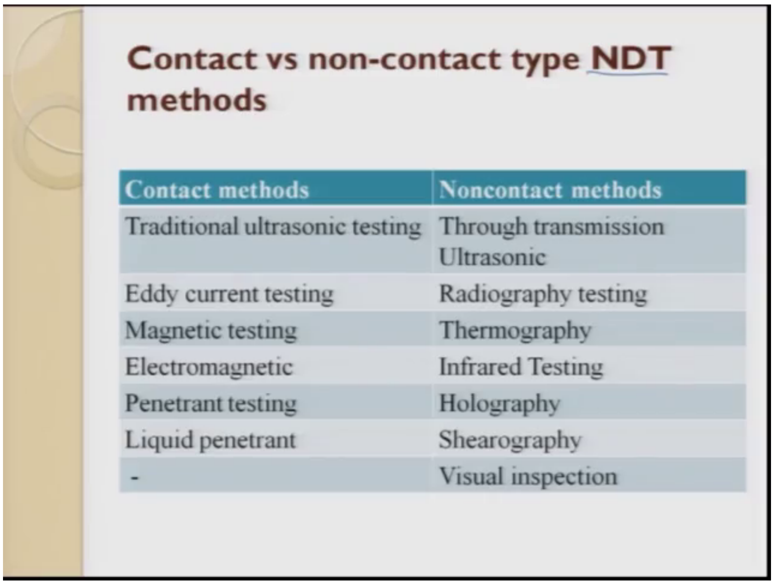

So, composites what are all the possible failures, or what are the possible defects the defects can be in the in the in terms of cracks, in terms of delamination, which is very common when you are talking about polymer matrix composites. So, delamination is one factor. So, here in nondestructive testing. If you see there are 2 methods one is called as contact another one is called as noncontact methods. Today we would prefer to have non-contact methods for 2 reasons. One is while fabrication you would like to assist the quality, after fabrication you would like to assess the quality. And not only that today when you put in service condition we would also try to check the quality of the composite, the how is it performing or if it is deteriorating in performance, how is it deteriorating in it is performance.

So, for that we would like to have non-contact type. There are 2 types of thing one is contact and non-contact. So, we will see what are all the possible contact methods which are in nondestructive testing, and then non-noncontact test ultrasonic can be both in contact as well as in noncontact, we will see that little later. Then eddy current testing is contact, magnetic testing, electromagnetic testing, permanent testing, permanent (Refer Time: 03:45) permanent testing and then you have liquid penetration testing.

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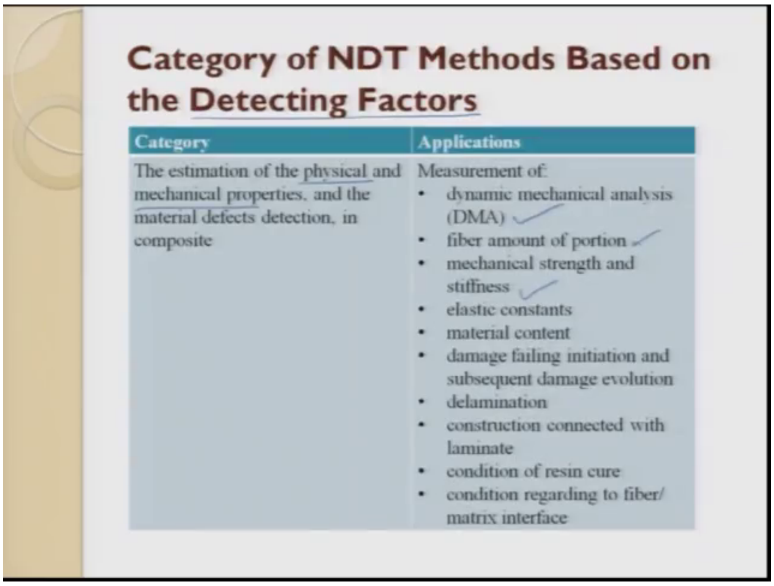

Then we will also try to find out damage failing initiatives and subsequent damage evaluation, delamination, construction connected to the laminate, condition of the resin cure and the condition require to fiber matrix interface. All these things are found out by doing a mechanical analyzing, and then you can try to from there you can try to find out the defects.

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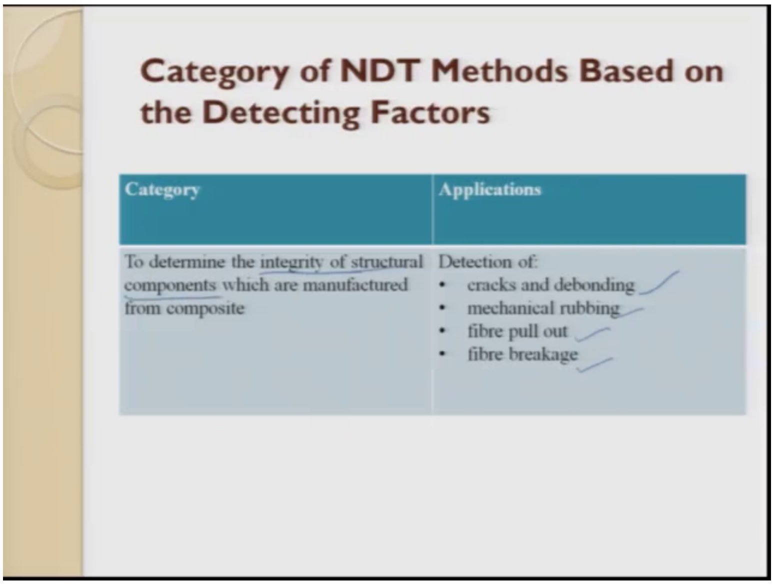

The next one is to determine the integrity of the structural component which are manufactured from composites. We do for detection of cracks, and debondings, mechanical rubbing fiber pullout and fiber breakage. These are some of the things which are very important, where in which we talk in terms of surface integrity or we talk about integrity of the structural component while manufacturing we do we try to do the nondestructive testing, and we try to detect all the other defects whatever is mentioned here.

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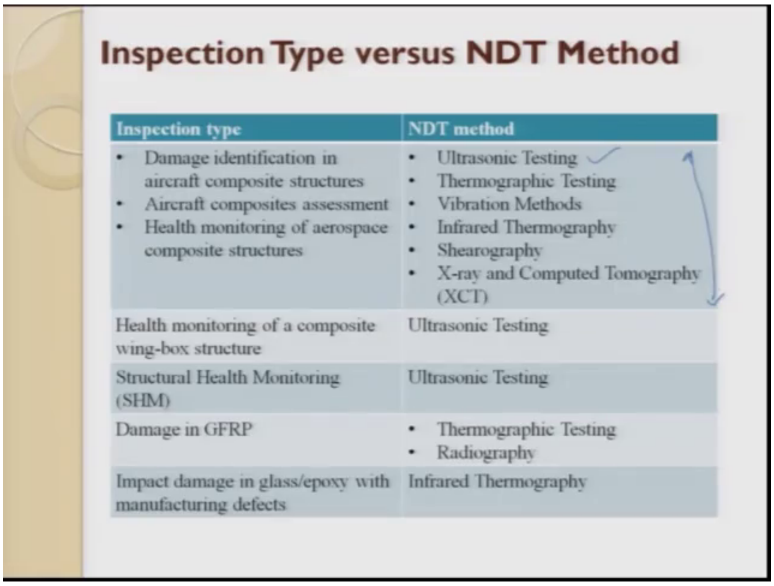

So, the different types of inspection techniques. So, inspection type versus NDT method. So, if you want to inspect the damage identification in air craft composites structures, we can use ultrasonic testing, thermographic testing, vibration methods, infrared methods, shearography and x ray. X ray and computer termography can be used. So, if you want to find out the aircraft composite assessment, you can do it health monitoring you can do it by and large it is your composite is fabricated it is put in service condition, and you have to find out what is a deterioration.

So, it and be found out by all these nondestructive testing methods. So, the next thing is the health of a composite in a wing box structure. So, this can be done by ultrasonic testing, then structural health monitoring of blades of aero profiles again it can be done by ultrasonic testing. Damage in composites can be found out by thermographic testing and radiography, and impact damage can be done by infrared imaging. So, these are some of the inspection types, which you want to do with the application and these are some of the nondestructive testing methods, which are available today.

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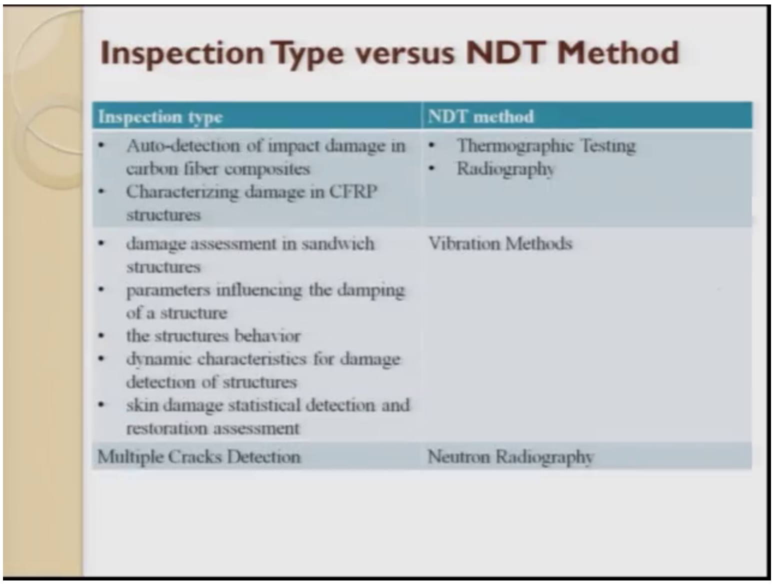
Inspection Type versus NDT Method

Inspection type	NDT method
• Auto-detection of impact damage in carbon fiber composites • Characterizing damage in CFRP structures	• Thermographic Testing • Radiography
• damage assessment in sandwich structures • parameters influencing the damping of a structure • the structures behavior • dynamic characteristics for damage detection of structures • skin damage statistical detection and restoration assessment	Vibration Methods
Multiple Cracks Detection	Neutron Radiography

So, then you wanted to find out the auto detection of impact damage. See in composites 2 things are very important one is while producing while manufacturing you produce defects or when you put in service condition defects happening. The while putting in service condition the defects happening are may be a drop of an impact drop of a heavy item on top of a composite structure, what happens to that? How does the damage grow?

And the other thing is people have smartly cross correlated, that is they have established and indirect way of assessing the damages, if the damage is so much that will be this will be the amount of deterioration in strength properties. They have done cross correlation and found out.

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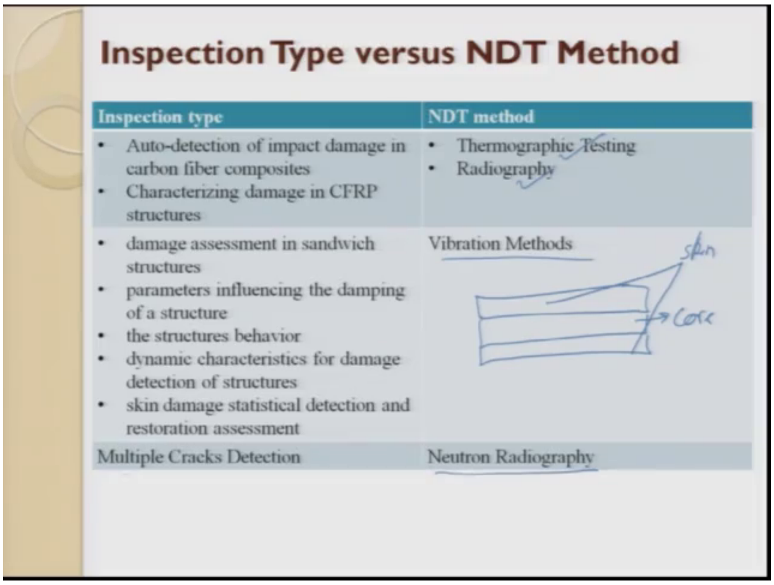

Now, by knowing the defect they can quickly try to assess and tell what will be the deterioration in the mechanical properties. The auto detection of impact damage in carbon fiber composites and characterizing damage in cfro carbon fiber composites it can be done by again thermographic and radiography images. There are other tests test where in which vibration is used damage assessment in sand witch structure what are sand witch structures.

Sand witch means you will have a skin, you will have a core, then you will have a skin. So, these 2 are skin which can be of any composite material. This is core of a lighter weight material basically this tries to mimic the analogy of I beam which is used in normal structures. They take the tensile load and compressive load, and this is giving you the spacing. The parametric influence of damping of a structure structural behavior, dynamic characteristics of a damage detection of structures and skin damage statistical detection and restoration assessment; these are some of the inspection types and the method which is used for is vibration methods can be used.

Finally you can also use neutron radiography which is on the higher head, where wherein which multiple cracks detection can be found out by this technique.

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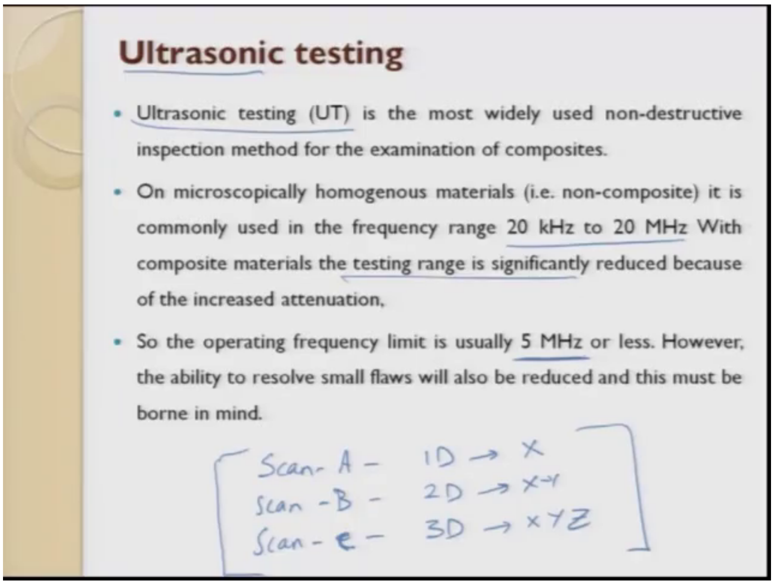

First let us see ultrasonic testing. Ultrasonic is very well known to us ultrasonic means it varies from 20 kilohertz to 20 megahertz. So, what we do is we try to take a material microscope homogeneous material, it is the frequency range of 20 kilohertz to 200 megahertz with composite testing range is taken and from there, what we do is we try to use a pizocrystal vibrate the vibrate and send the signal inside a composite and try to find out if there is any defect in the composite.

So, ultrasonic testing is very, very well used or very widely used nondestructive testing. They can be classified into scan A scan B and scan C. So, basically scan A gives you one dimensional defect scan B gives you 2 dimensional defect scan C gives you 3 dimensional defect. So, one dimensional the 2 dimensional, it is only in x plane. It is only in x y plane. This is in x y and z which also gives you the depth information. So, the scans can fall in any of these regions, and this are the different types of ultrasonic testing which is done. So, the operating frequency is somewhere close to 5 megahertz we use, and we try to detect the defects in the composites.

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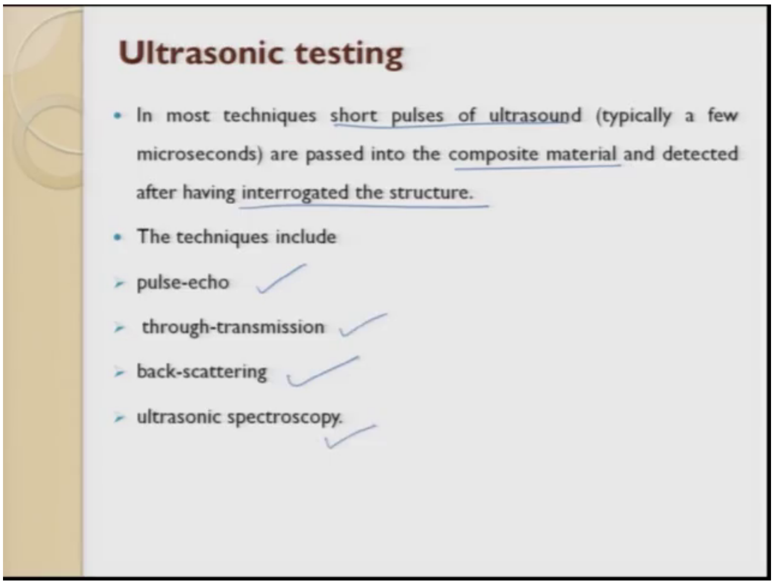

So, here basically short falls of ultrasound is passed through a composite, and it is used to detect the structural defect or it is used to detect the intra it tries to detect if there is any defect in the structure. So, the techniques general used are pulse eco type, through transmission type, backs scattering type and ultrasonic spectroscopy type. So, these are the different techniques which are used in ultrasonic testing. In pulse echo type this is a very, very well established technique.

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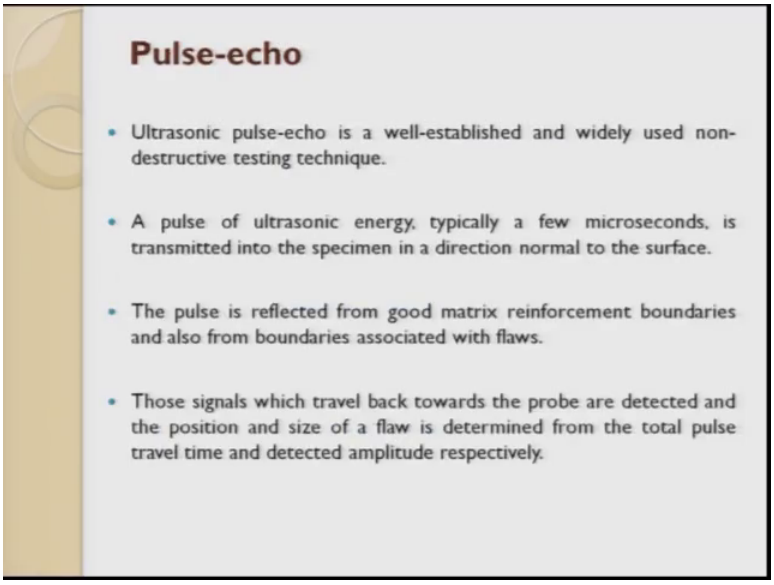

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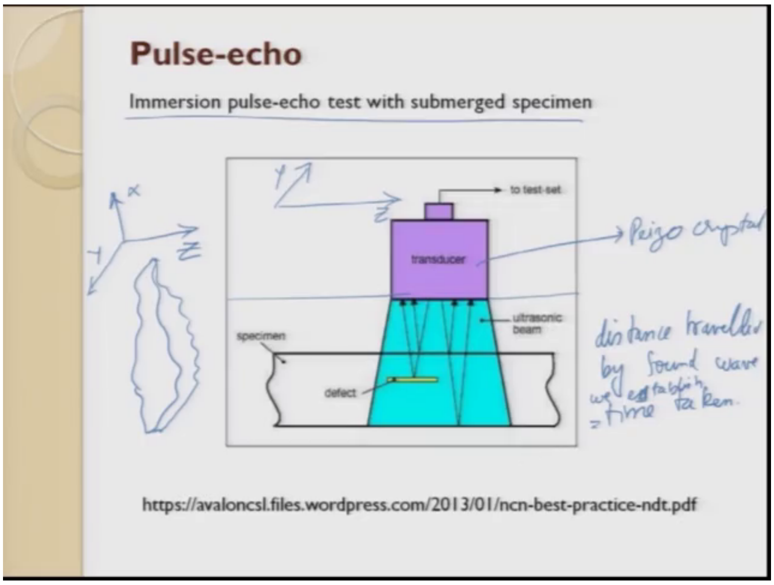

So, this is a pulsed echo type. So, here what we do is we immerse the pulse eco test within a with submerged specimen. So, what we do is we try to have a transducer. This transducer is nothing but a pizocrystal, a pizocrystal which can vibrate in whatever frequency you set. So, here what we do is we have the pizocrystal these pizocrystal vibrates. And when it vibrates it transmits sound waves. And these sound waves are allowed to hit at the surface and then it is allowed to it travels back. So, where ever there is a difference in material or a difference in interface, there are sound waves which gets reflected back.

So, the reflected back sound waves are collected. So now, what we do is based upon the distance travelled, distance traveled by sound wave. We are able to find out the we are able we are we are able to find out the time taken from sound waves we establish, time taken and from the time taken we can try to figure out what is the distance. And from that we can try to figure out why is this sound wave reflecting back, if at all there is a defect and how far is a defect from the interface we can try to find out.

So, here it is theoretically speaking it looks to be very easy, but idealistically speaking there will be a crack which is having something like this a profile, and which might have a depth information like this. So, this is your z direction and this is your x direction and this is your y direction. So, you can have a defect like this. So, if you have a defect like this, then the sound waves getting hit on a surface and getting reflected back will try to give you different velocities. So, it is very hard for you to really find out if you have a complex defect. Idealistically speaking yes, it is easy to figure out the from the travel back of the sound wave we try to figure out, what is the distance time taken time taken to distance we can try to find out what is the defect and where is the defect.

So, where ever there is a change in interface you can do it. So, what happens is when I when I was talking to you about scan A, what we do is we try to take a defect only at a point. Then scan B I try to scan the sensor in both planes in may be if you take in the if I follow the same convention it is x and y plane. So, z and y plane I try to take the complete scan of a of a flat plate. I can get it done. The third one is I was talking to you about the scan C. In scan C what happens? You try to scan over several points which becomes a line, and then several lines it becomes an area. So, when you do a large area you will try to figure out what is the third dimensional defect on the composite.

So, scan A scan B scan C works like this and second thing you should also understand when you keep a specimen and ultrasonic transducer will always be kept very close to the specimen. If you cannot keep it very close to the specimen what we do is we always try to put a coupler here, which is viscoelastic material or it can be water even. And this coupler will try to make sure the sound waves does not get distorted out of the contact area. So, we put a transducer, we put a work piece, and in between these 2 we put something called as a couplant which tries to focus the sound waves on to the workpiece and try to help in getting the data. Is it clear? So, here what happens is it is called as pulsed echo type. So, it is it is or people say it is pitch and catch. So, the sound waves are sent from here it goes to the work piece, and then from the workpiece it gets reflected back it is one way. The same goes here and it gets reflected back. So, varying time difference.

So, if there is a defect from here it goes back and then you try to get the signal.

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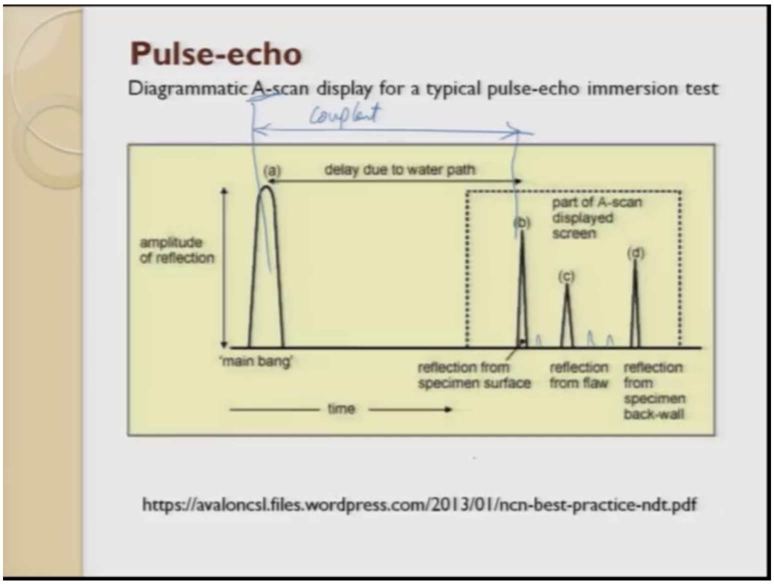

So, you can see how does the signal look like. The signal looks like this here is a amplitude of the signal whatever it has come here is the time. So, whatever distance I said it can be converted into time from here we get it. So, you see here there is a main bang here, and then there are so here is what is delay due to water path. So, what is a water path? Water path is a couplant which I was talking to you about.

So, reflection from the specimen surface. So, this is where is the specimen starts. This is where the specimen this reflection from the specimen surface is B, then there was a defect called c, then there is a reflection from the back backside. So, this part is called as the a scan. So, a scan is nothing but a point scan which we did and then you get it. So, here is a main bank and here is the delay because of water. So, what has happened is still here, whatever got travelled this is what is a couplant which I said we have to use couplant C o u p l a n t. So, this is the couplant. It can be a viscoelastic it can be a viscous material it can be oil it can be water wherever. It tries to focus the sound wave into the specimen ok.

So, this is what is scan A which I was talking to you about. And you get the signals reflecting from the top surface bottom surface if at all there is a defect there is a defect. And again here you can also have many small defects like this, this can this can be due to some small voids which are present interface poor from the distorted interface from the broken fiber there can be several defects also. So, this is only an analogy to do. So, this is from the front this is from the back this is for the defect. So, several small signals are there. And these signals when you do a point scan you have to do repeatable scans and then you have to talk about the answer.

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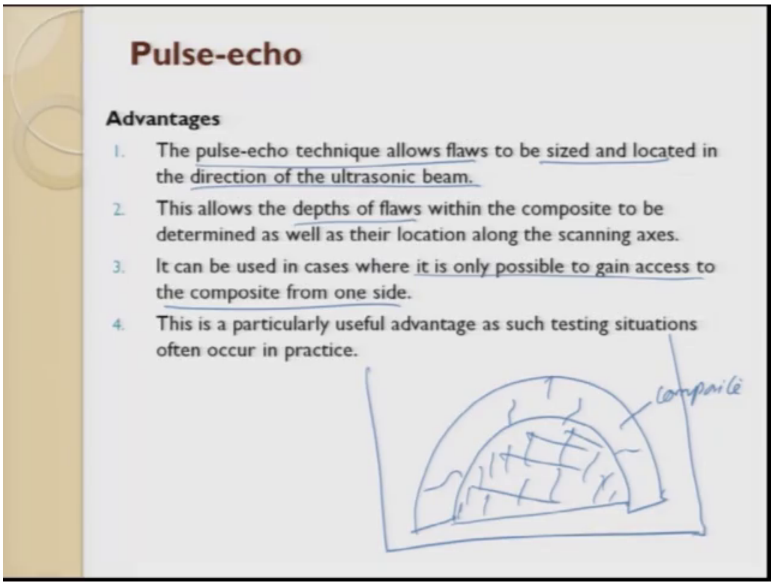

So, what is a big advantage? It the pulse technique allows the flaw to be sized and located, in the direction of the ultrasonic beam. So, I said a scan B scan C scan can be done and you can try to figure out the size as well as the location, which is possible the depth of flaw within the composite can also be determined from the location. It can be used. Where it is not possible to gain access to the composite from one side yes it can do. For example, you have a composite something like this, and assuming that the internal surface you are not having this is the component. So, what we do is I try to put this component, and this portion is non accessible. May be this is kept inside something which is of a different material it is like a clad on the surface.

So, this is a composite surface, and if there are defects if there are defects. So, this is the technique which can be used to find out where the defects is. And here it can it is it can be done by noncontact type. So, since it is done by noncontactive type it is very easy to get the results interpreted.

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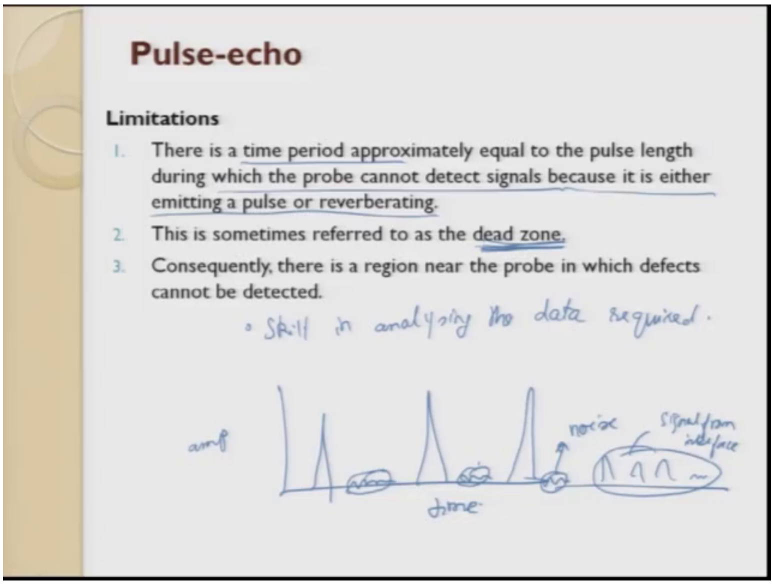

So, you will have to have some calibration done before, and then you can easily calibrate the results. Basically you need to have skill in interpreting the results. The there can be a portion called something like a dead zone where the signal does not even come back.

So, that is that is also possible. So, you have to know very clear. And so, what here you need to have skill. So, skill in interpreting skill in in analyzing the data is required. Because there can be signal, there can be several noise, there can be signal noise and there can be severals and then there can be a noise. So, this is the amplitude this is the time. And then these are these are signals weak signals, these are all this can be signal and this can be noise. So, you need to have skills to find out what is noise and what is the signal the signal from interface or something like interface.

So, if you can find out it is this is very, very important. And this needs lot of skill in interpreting the data. So, today what has happened, there are lot of intelligent systems which have come. So, where in which it has been pre trained with lot of data sets like this. So, it quickly scans the data and it tries to tell you yes there is a possibility of a defect. So, that is what it is done. So, here it is a it is a time period approximately equal to the pulse length during which the prop cannot detect the signal, because it is either emitting a pulse or reverberating.

So, this is the dead zone. So, this defect also can come and you it is very difficult to find out what is this and then interpret.

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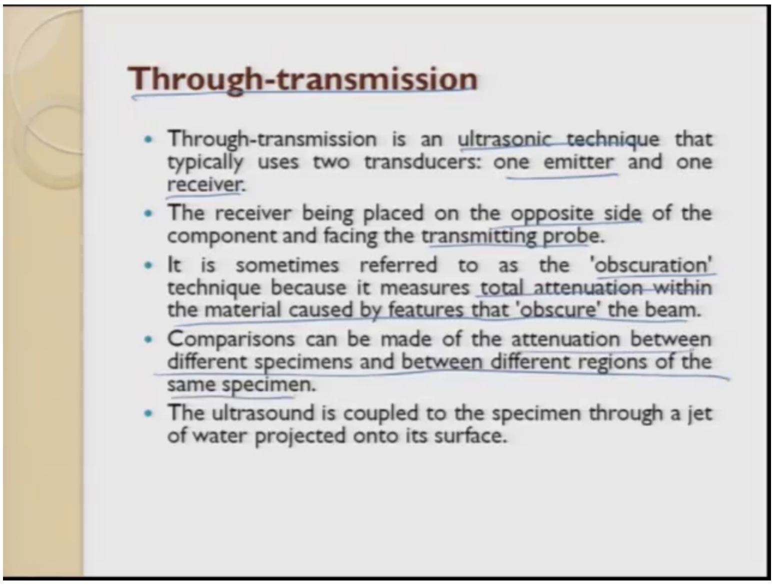

The next one in the same ultra sonic is called as through transmission system. Through transmission system means you will have something like a pitch and a catcher.

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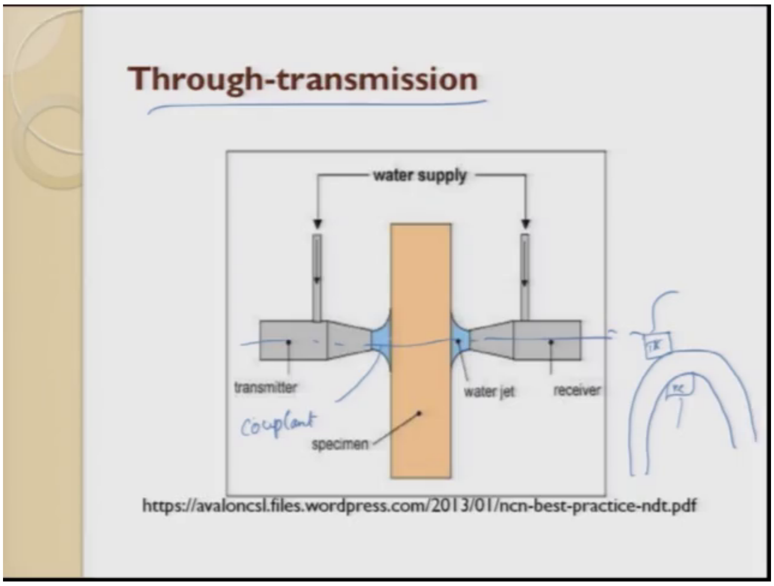

So, the pitch and catcher if it is there in the same side, then it is pulsed eco. If the transmitter is on one side and the receiver is on the other side, if the transmitter on one side other side. So, this type of ultrasonic sensors are also used. So, where in which this gives a better results as compare to that of pulsed echo. But the only problem is it should have the access to the on the other side. So, that you try to get the data correctly and again suppose you have something like a complicated surface. So, what happens is the way you keep here and suppose if it is offsetted by a small distance a sensor. So, then you will have this is through this is receive, or this is transmit this is receive. If you have this then there is a small offset between the 2 sensors, and then it will give you a fictitious result wherein which it is very hard for you to find out whether it is a defect, or it is because of the offset whatever is there.

So, that is the advantage is more clarity in the signal the disadvantage is the access has to be their second thing these 2 fellows should be almost in the same axis. If they are offsetted then that gives you a different result. So, it is an ultrasonic technique where in which we have we use 2 transducers, one is called as emitter the other one is called as receiver. The receiver is placed on the opposite side of the transmitting probe. It is sometime refers as obscuration technique, because it measures total attenuation within the material caused by the feature that obscures the beam. And the comparison made by the attenuation between the difference specimens, and different regions of the same sample can be compared ok.

So, it can be compared, and you can try to get it. And here again, why did I use this water jet? Whatever we are talking about this is nothing but a couplant. So, you couplant to make sure that this sound signal does not get distorted. And second thing is if I know the velocity with which the sound travels in the water media, then I can easily find out where exactly is the signal getting reflected from the specimen; because this velocity is directly proportional to the time taken.

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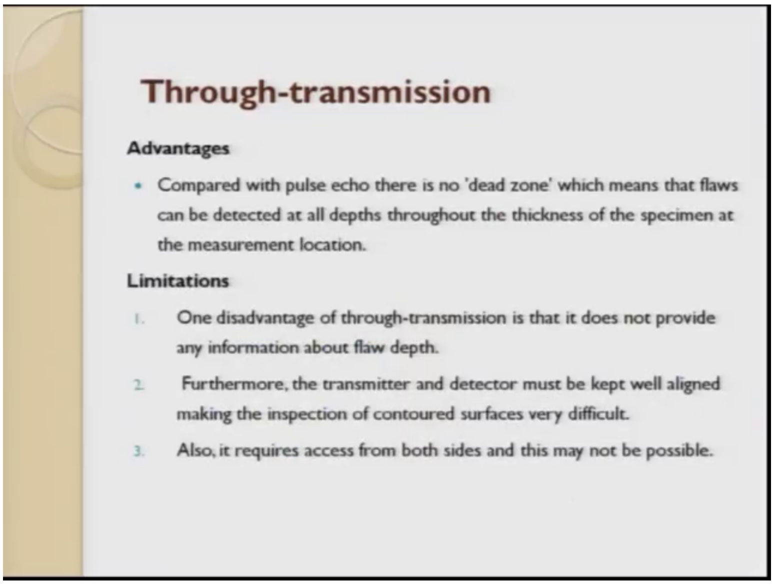

So, in the signal what I have amplitude versus time plot I can quickly find out what is that. So, what is the advantage? The here there is nothing called as a dead zone which was there earlier. And here it is giving much more perfect signals or reliable signals. And even a small variation in thickness can be quickly figure out by this tooth transition. Interestingly when I was discussing all the processes, I was trying to talk about one parameter which is called as surface roughness. I was saying that the surface both side surface roughness is very good, or the surface finish is smooth. When I use these composite materials, if I have a rough surface and I if I use ultrasonic techniques, then there is a problem with my signal interpretation.

So, only to avoid this we always try to have on both surfaces, smooth surfaces. When you are looking at structural applications primary strength applications in aerospace industry or in automobile industry we are more particular about finish on both surfaces. Why because the characterization technique, the nondestructive technique which is used can like if you use ultra sonic the roughness plays an important role in the interpretation of the results. The disadvantage is you should try to have access; you should try to maintain the access on the other side. Second thing is there has to be a provision for you to put the transmitter on the dead and the receiver on both sides.

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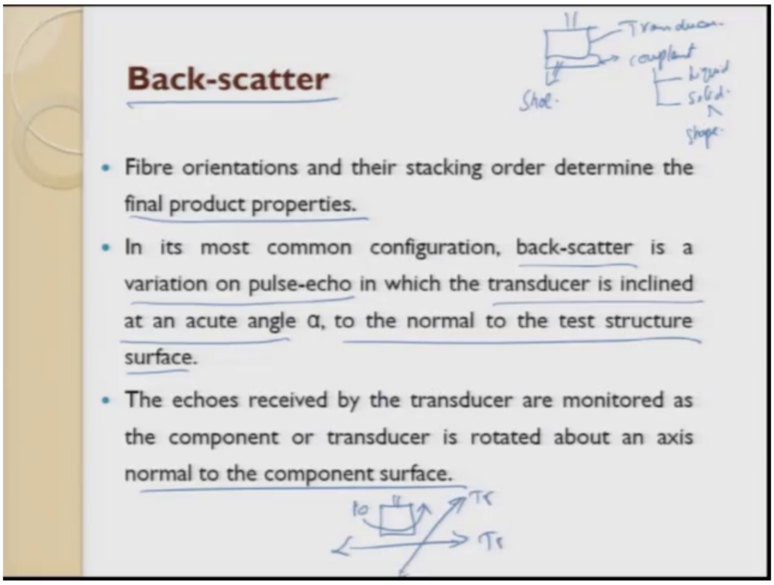

So, this is the limitation. There is something called as back scatter. If you are very much interested in the orientation of the fiber, we are talking about the orientation of the fiber for example, 0 degrees, 45 degrees, 90 degrees did we place according to that? And if at if we place it according to that and between the 2 laminates is there a defect. So, how do we find out that is done by this back scatter? So, the fiber orientation and the stacking order can be can determine the final property of the product. The most common configuration is backscatter in the it is a variation of pulsed echo type in which the transducer is inclined at an attenuating angle alpha to the normal of the test surface.

So, for so what we do is now we have this transducer. This is a transducer whatever we have transducer, ultrasonic transducer. And then what we do is we try to make a shoe a shoe can be a solid shoe. See basically the couplant whatever I was talking to you about, it can be liquid it can be a solid. And again in solid what it can happen is it can have. You can have liquid, you can have a solid. When I have a solid, then what I can do is I can give shape. Moment I give shape what I do is, I try to make something called as a shoe. And this shoe can be made at any angle in order to make sure that I get this acute angle alpha.

So, moment I have this acute angle alpha, then I can quickly figure out what is the stacking sequence which you have used in the composite. By the way it is really skilled, but still there is a technique which can be used. The echo received by the traducer as monitored of the component or transducer is rotated about an axis normal to the composite. So, that means, to say I keep a transducer and then I try to rotate the transducer and translate the transducer in this is translation, translation and then I also rotate to make sure the data what I get is perfect.

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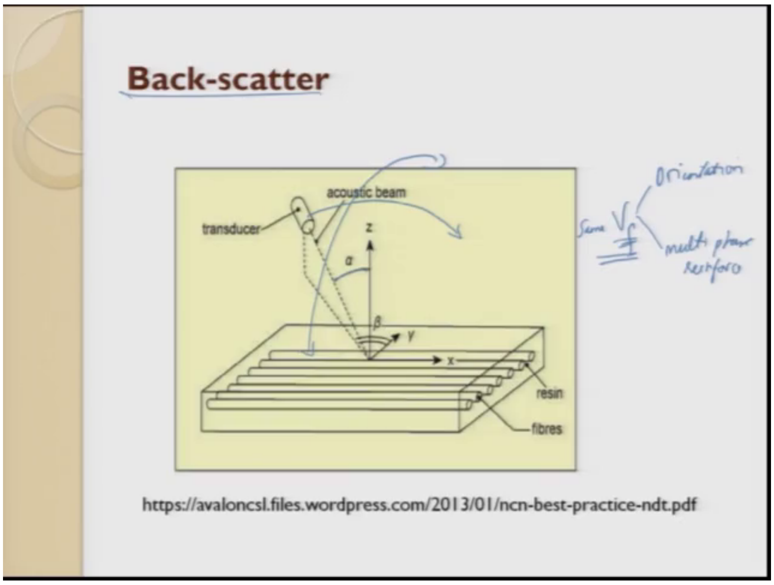

So, this is what is a technique. So, here is a transducer and here is the angle alpha, I and angle alpha, I was trying the I mean this is the x axis this is the y axis. So, what I mean to say is I will make a shoe, and then what I will do is I will try to move the transducer from here to here, or from here to here whatever angle. So, I try to do it. So, that I try to get the fiber orientation. So, this technique is called as back scatter technique. In the ultra sonic testing, if you are only trying to find out the defect, then we can use it either in the pulse echo mode or in the through a transmission and receiving type. If you are interested to find out the orientation of the fiber. This is very important because, if a composite of varying orientation does not perform to your expectation. Then the next thing which immediately comes to your mind is how sure is my orientation.

So, moment I know my orientation, then I am pretty sure that yes the composite is it is because of something else. And on top of it in composites the volume fraction keeps changing. See you can have 2 composites with the same volume fraction, same volume fraction 2 types it can be all orientation variation. You can have you can also have multiple phase multiple phase variation multiple phase reinforcement. So, the volume fraction if you see of the glass fiber will be constant, but the performance is completely different. So, this can be found out by the back scatter technique.

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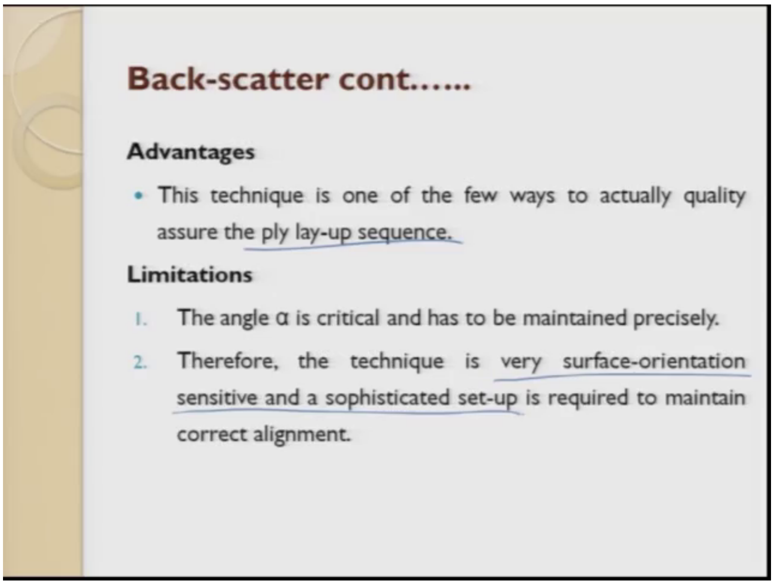

So, I have told you the ply layup sequence can be figure it out, but really you need to have true skill because the surface orientation sensitivity, and the sophistication of a setup required is really, really, really high.

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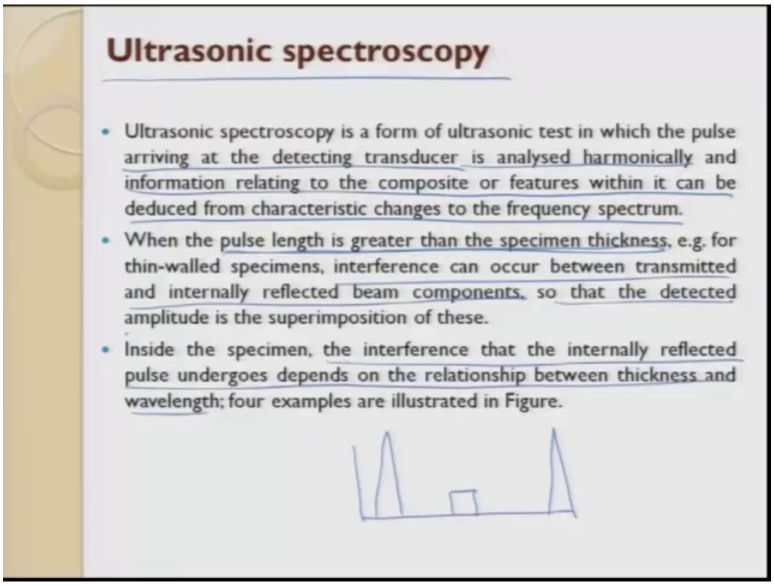

The next one is ultra sonic spectroscopy. So, ultrasonic spectroscopy is in the form of ultrasonic test in which the pulse arriving at the detector detecting transducer is analyzed harmonically and the information related to the composite or features within it can be deduced for the characteristic change in the frequency spectrum. So, what do we do is we try to take the ultra sonic signal, and we what we do is we after taking the signal we try to do as spectroscopy analysis. So, spectroscopy analysis in terms of frequency. And then we try to figure out what is the damage. So, that is what we said the form of ultrasonic test in which the pulse arriving at the detecting transducer. It can pulsed echo or it can be transition receiving is analyzed harmonically the information relating to the composite or the feature within it can deduce for the characteristics change, if the pulse length is greater than the specimen thickness when can it happen the pulsed length whatever you are taking this is one pulse, this is other pulse, if the sample fall somewhere here. Then it is very, very difficult.

So, when the pulse length is greater than the specimen thickness. For example, for thin walled samples the interference can occur between the transmitter and the internal reflected beam component. So, that the detected amplitude is super imposed on this. So, this is very important, for thin walled specimen. The interference can occur between the transmitted and the internally reflected beam components. So, here what we do is we detect the amplitude and then we do super impose them and try to find out.

So, inside the specimen the interference that has internal reflected pulse undergoes dependent relationship between the thickness and the wavelength.

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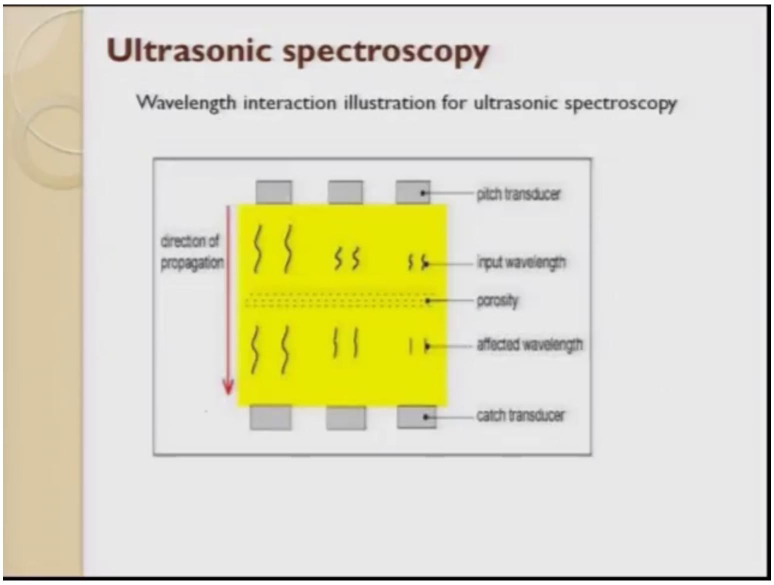

So, you can see the from the example. So, this is the pitch transducer, this is the catch transducer. This is the transmitter type, this is the receiver type. I have given different names, because you should be aware all are same pitch and catch right. Pitch and catch on same pulse record type. So, transmission receiven, and then you have input wavelength which are there. So, here are some porosities, here are the affected wavelength which comes back. This is the direction of propagation of the wave which goes inside. So, from here it goes here it receives, and then what we do is we do an ultrasonic spectroscopy analysis to find out what is the defect in a much more clarity way, is it clear?

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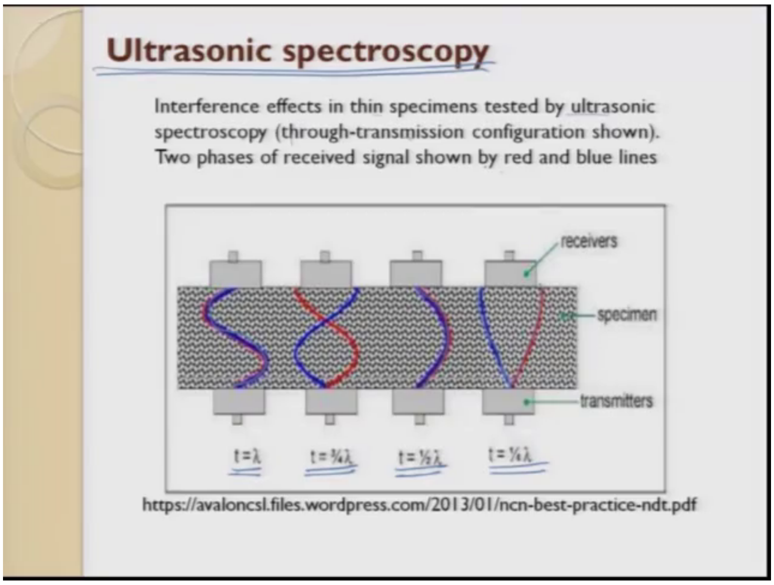

So, you can also have a ultrasonic trans ultrasonic spectroscopy. The interference effect in thin specimen tested by ultrasonic spectroscopy through transmission configuration which we studied. 2 phases of signals received show shown by the red and blue lines. You can see the transmission can be something like (Refer Time: 30:59) it can be t equal to lambda, t equal to 3 4th lambda, t equal to half lambda, t equal to quarter lambda. So, you see the signal how does it pitch and catch goes ok.

So, this is the for a thin specimen, this ultrasonic spectroscopy analysis is used to find out the results.

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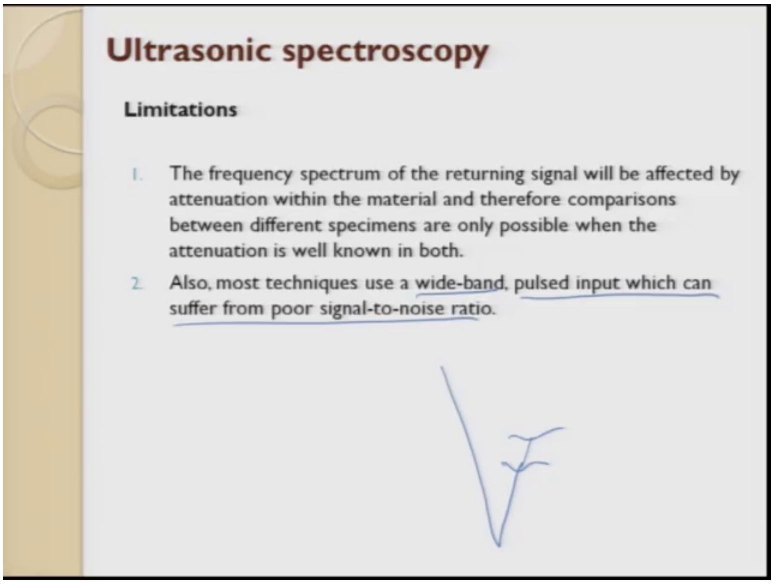

So, here as we discussed the ultrasonic spectroscopy can be better than pulsed echo type for transmitting the for thickness of the thin specimens, and all ultrasonic spectroscopy is used this is because a specimens can be it may be difficult to resolve pulses reflected from the front and the back wall. So, we always use this ultrasonic spectroscopy to find out this. Limitation is the returned signal has more influence on the and it can also get attenuated suppose while returning back it has a defect and then one more defect. The signal can get attenuate it need not go back also.

So, that is what is a major problem. So, here and the technique is used for wide band pulsed input which can suffer a poor signal to noise ratio. So, this one of the biggest limitation of the ultrasonic spectroscopy.

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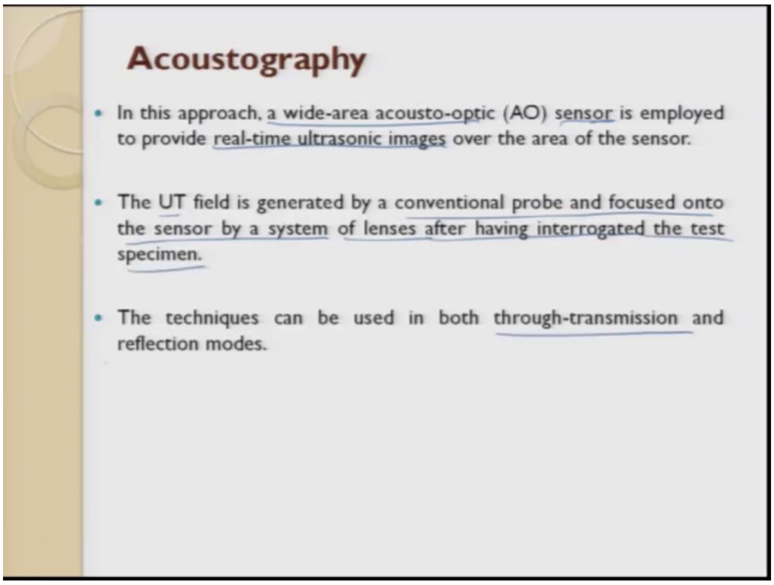

Next one is called as acoustography. This is an approach which is a wide area of accousto optic sensors are employed to measure the real time ultrasonic image over the area of the sensor. The ultrasonic technique field is generated by the conventional probe and focused on to the sensor by a system of lenses, after having interrogated into the test specimen.

So, what we do we try to put some lenses in the system so that you would try to get the best result out. The technique can be used both in transmission through transmission and reflection mode type.

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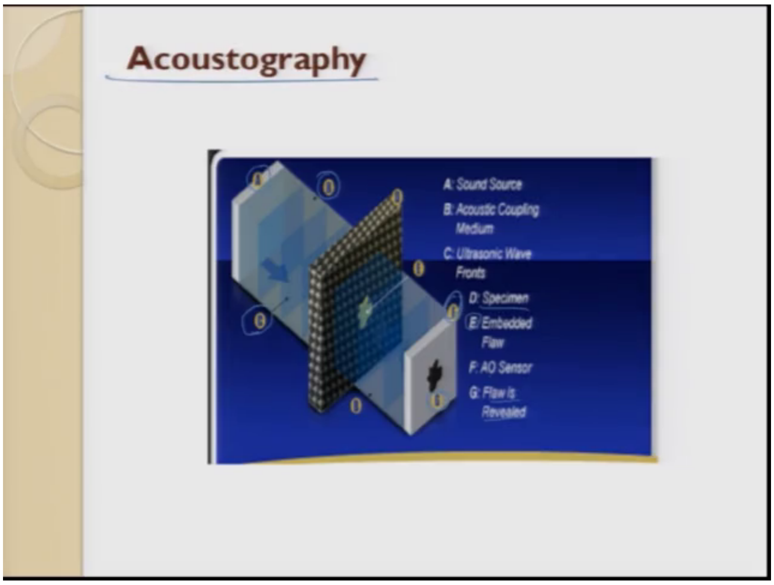

So, this is what it is. So, you see the specimen here. So, sound wave a sound wave sound source A is there. Then you see a sound acoustic coupling media which is B. Then we have ultrasonic wave front is C right. And then you have specimen as D. Then you have embedded a flaw or there is a flaw which is called as E. F is the octo accousto optical sensor. So, it is a o sensor which is F. So, this is F, and then G is the flaw is received on a plane which is called G.

So, this is the complete setup of acoustography, which is ultrasonic testing where in which accousto optical lenses are used to find out the defects. So, that is what I said it is accousto optic sensors is employed to provide a real time ultrasonic image over the area of the sensor. So, here the ut ultrasonic testing field is generated by a conventional probe, and focused on to on to the sensor by a system of lenses, that having interrogating the test specimen. So, what we say is this. So, test specimen what you get in AO sensor last ok.

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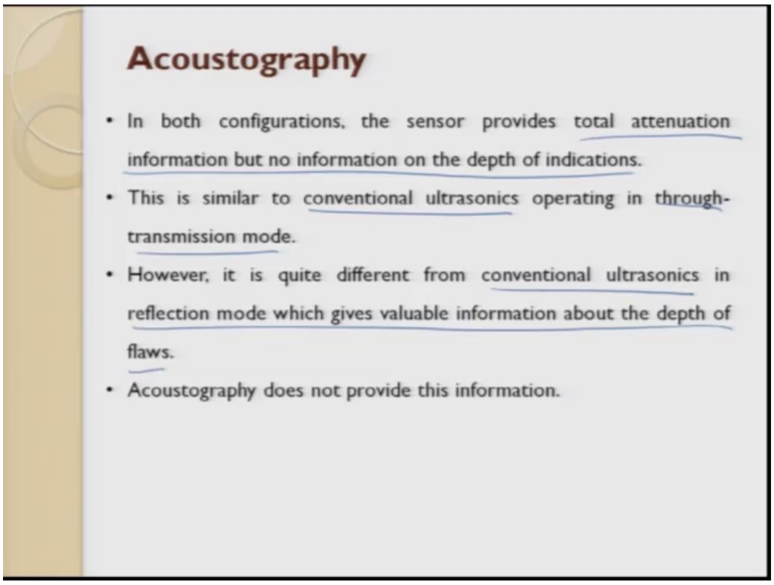

So, in both the configuration the senor provides total attenuation information, but no information about the depth of indication.

So, this is similar to that of conventional ultrasonic technique in through type mode it is used. It is quite different from the conventional ultrasonic in reflection mode, which gives valuable information about the depth. So, here you have no information about the depth, but you have information about the area does not provide the information about the depth. So, this is what, you get only areas. So, here if you are smart what happens? You get a one area then if you can if you can take all the change the orientation change the location of the work piece or change the location of the sensor. Now I get different in 1 plane I get different differently informations. Now what I do is I change the depth and I can reconstruct the object and get the 3 dimensional way of doing it.

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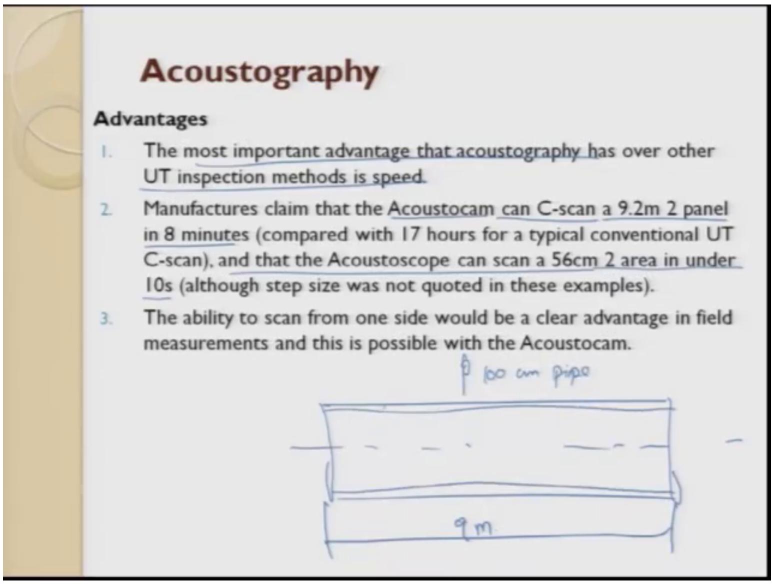

So, this is today the latest things are acoustography. People talk about 3 dimensional where in which the surface depth also, can be measured by talking a combination of several things. So, the advantage of has to is this speed in the method is very good the manufacture claims accoustocam can C scan 9.2 meter to 2 panel in 8 minutes, and the accousto can do a 56, 2 areas under 10 seconds. So, this technique I much faster as compared to that of your C scan. The C scan what I told A scan, B scan, C scan. His can be much faster and you try to get the results today if you have long pipes which are made, and if you want to find out the health of it. So, then acoustic graphic techniques cab be used for detecting. So, here you have 9 meter long pipe. So, and a diameter is 100 centimeter pipe.

So, you try to get through acoustics signal, acoustography you can try to get the signals much faster.

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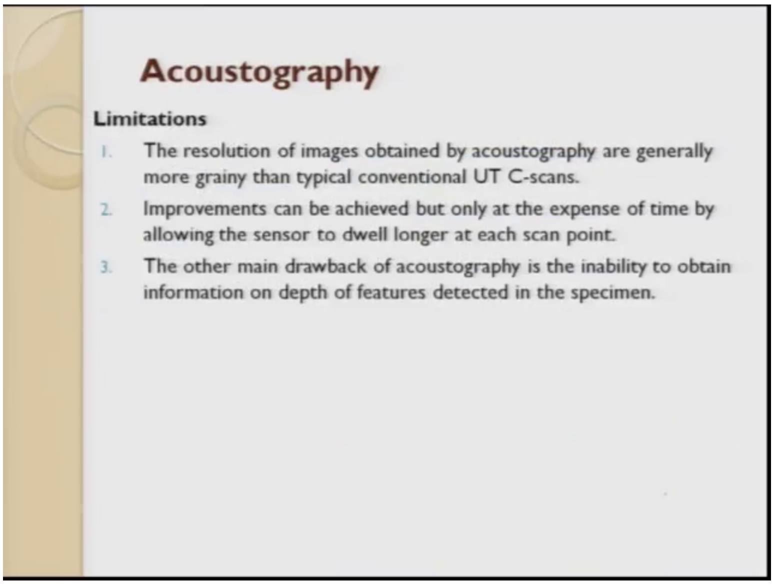

Limitation of course, though it is said very easy. The image the resolution of the image which is very important so that also tries to talk about the result, then you then the improvement in the results can be got above the sensors can be changed and other things which needs lot of skill to get it done. So, it is here the depth information is not got only the x y. So, it is almost like your or surface data only you get. So, depth details you do not get it in acoustic, but today to get out of this there are people have made it lot of software interface, and then they are trying to do it.

The next technique. So, till now what we studied was using ultrasonic sensor for trying to find out defects.

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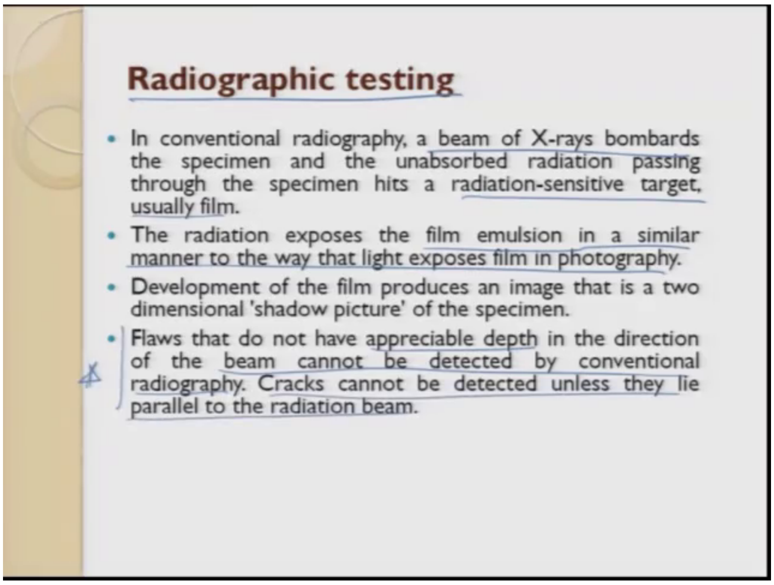

So, where we saw it can be pulsed echo type it can be a transmission and the receive type. It can be through acoustographic test, and then the other thing what we studied was the spectroscopy, ultrasonic spectroscopy. Where in which you got results like this, you try to get the results the next one for the discussion is a radiography test. Radiography is a beam of x ray is bombarded, a beam of x ray is bombarded on the specimen. And the unabsorbed radiation passes through the specimen hit a radiation sensitive target which is usually a film. Which was earlier a film nowadays it is has gone to digital mode. So, x ray source is used to find out the defect.

So, the radiation exposed film, emulsion is in the similar manner to that of light exposed to a photograph. Today this technique is no more. The flaws the that do not have appreciable depth in the direction of the beam, cannot be detected by the conventional radiography. The cracks cannot be detected unless the lie parallel to the radiation beam, these points are very important. If the cracks are not parallel to the radiation beam you will not be able to find out anything through this defect.

So, this is a x source, here are the here is a test specimen.

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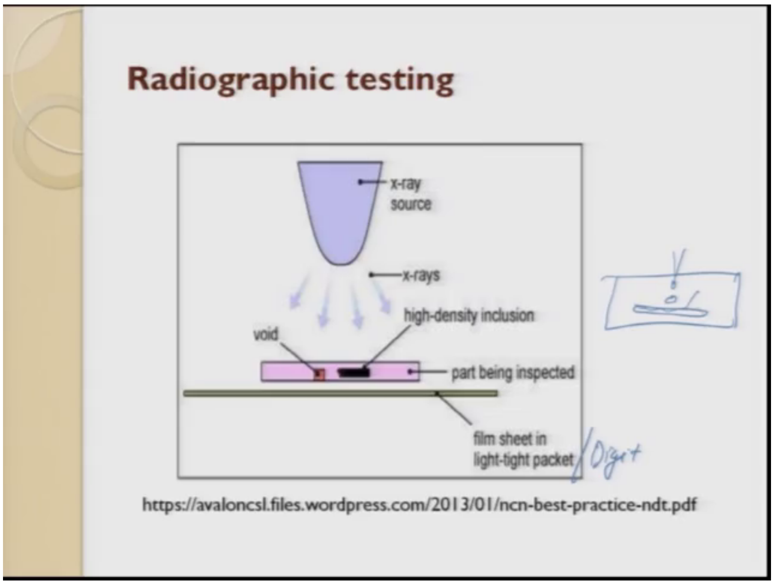

So, here are the defects whatever it is, and then you have a film. So, today it has gone to digital. So, you do not have to thick of the film, it directly you have a exposure made and you can try to find out the defects. Suppose if there are defects on for example, if there are defects like this. So, these 2 defects will not be able to be found out. Because there is nothing called it reflects back. And second thing is suppose if this defect is very large all the small defects can be nullified and if this defect crack grows in a 3 dimensional plane. So, then also it is very difficult to use these radiography technique together results.

So, compared to a transition test the radiography resolution of the image is good. Because shorter for x ray than the ultrasonic.

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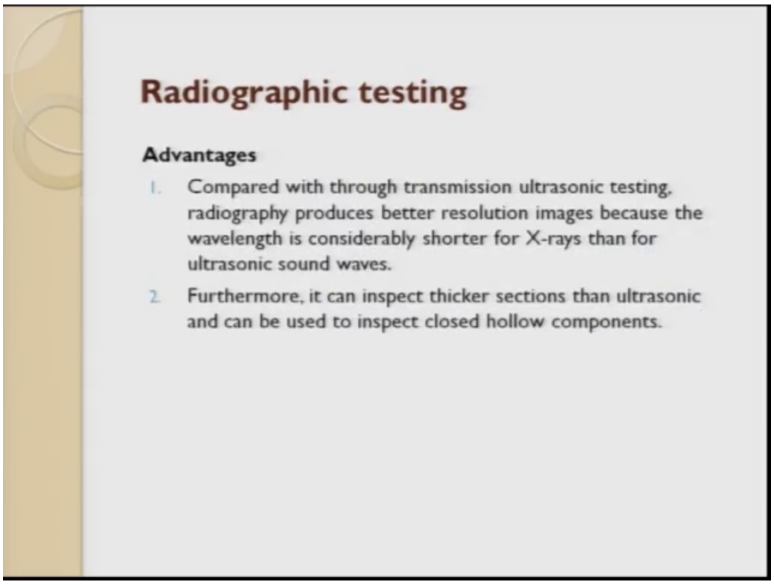

So, because of the wave length it is good. So, you get and here thick samples can be done, provided the cracks the defects are not patched up one over each other.

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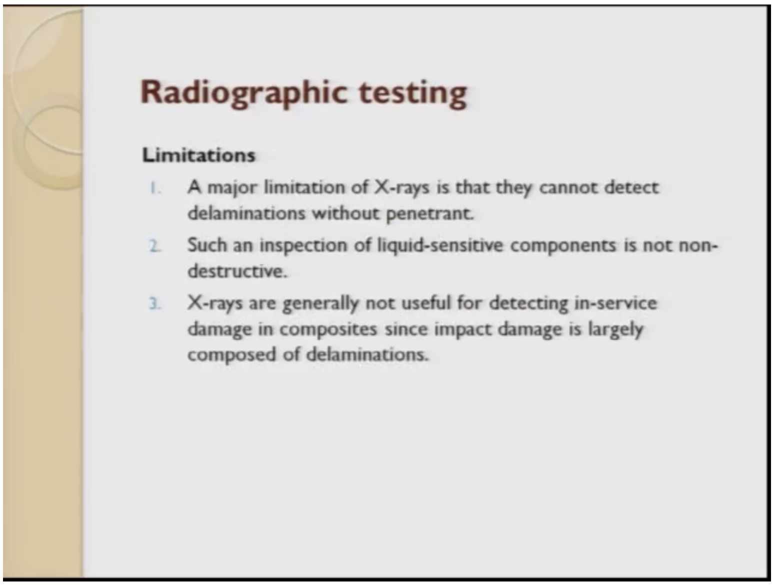

So, it can be done on this. So, a limitation as I said parallel direction perpendicular direction is one. And second thing is if the defects are slightly larger, it can even try to attenuate the signal. So, you will not get any signal out.

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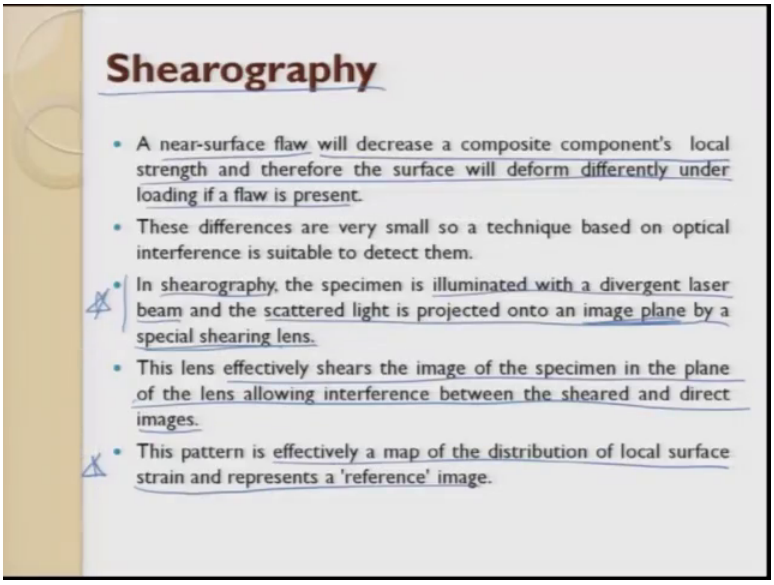

The next technique is called as shearography. So, shearography is a technique where in which a near surface flaw. So, all these 2 ultrasonic and the radiography we were trying to talk about defects. If we have defects slightly far away from the from the surface top surface. Slightly away from the top surface yes these techniques can be used. If there is a defect on the surface or very close to the surface, then we always go for shear shearography which decreases the component the composite components local strength and therefore, the results can deform directly on the load.

So, the surface defects also play a very, very important role. In shearography the specimen is illuminated with the divergent laser beam. And the scattered light is projected on to an image plane by a special shearing lens. So, this point is very important. So, here what we do is we try to use a divergent laser, a divergent laser beam which falls on the surface.

And once it falls on the surface it scatters light, and these light I try to collect these light on a on a image plane by using some shear lens. So, the lens effectively shears the image of the specimen in the plane of the lens allowing interference between the shear and the direct image. The pattern is effectively a map of distribution of the local surface strains and represented a reference image.

So, this one is an important point. So, here what we do is we try to take a work piece then we try to take a divergent beam laser beam, try to expose the light on the beam, light on the work piece and then the light gets scattered it goes back, on the image plane I put on the light gets scattered on to the image plane, I put some shear lens in between to get it done.

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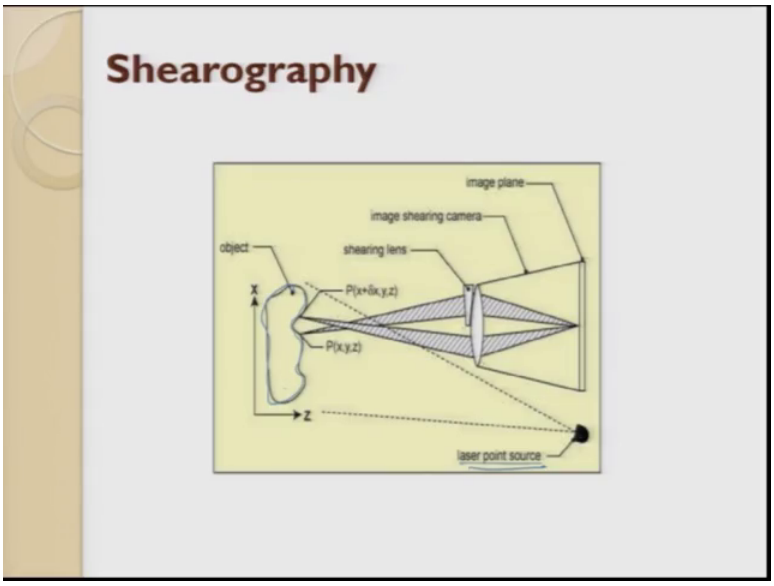

So, this is how it is this is an object this is the image plane here is the here is the shear lens and here is a laser. So, you see a laser is from here. So, the laser hits the workpiece where it is having a complex surface this is the object, which is a complex surface the object is complex, inside this object also you a have complex phenomena happening.

So, this is the laser which hits the workpiece, and here what happens? You have the light which is getting reflected from this, and here is a shearing lens. So, this shearing lens what it does is it tries to focus the image on to a plane. So, the image shearing camera is used, and then this is the image plane it hits the image plane and you try to note down. So, this is a point p of X Y Z. This is a point which is p of delta X Y Z. So, this is p of delta. So, you are offsetted in the x direction. So, this is a laser. So, this one is called as shearography. So, this is also used for measuring the surface defects, the surface defects on the composite ok.

So, this is used for surface defect the previous one which we saw about the spectroscopy. The spectroscopy acoustography is also same for the surface, here the spectrography is also used for surface.

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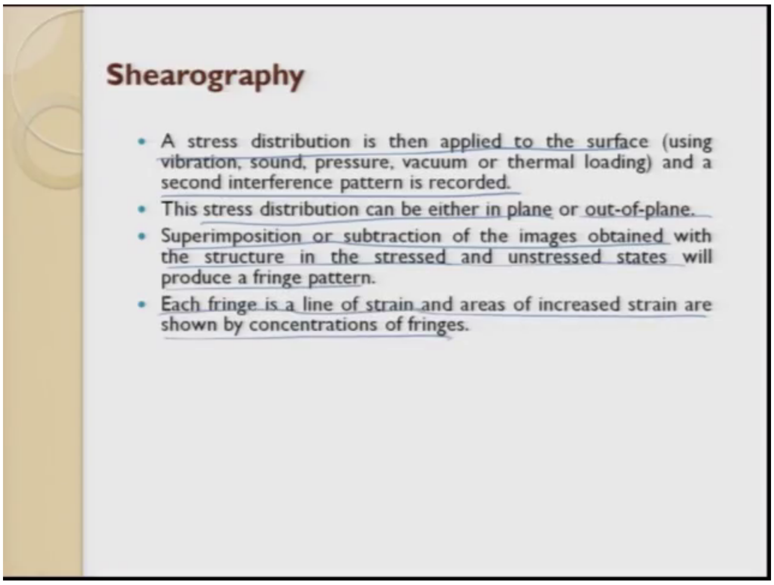

So, a is a stress distribution is applied on to the surface, and a second interference pattern is recorded, using vibration sound pressure vacuum or any thermal load it is one. So, the stress distribution is then applied to the surface. So, we get this this test distribution can be in plane or out of plane. The super imposition or subtraction of the image obtained from the structure is in the stressed or the unstressed state produces a fringe pattern. Each fringe pattern is a line of strain and the area increased strain are shown in the concentration of the fringe pattern so of the fringes. So, this is what it is.

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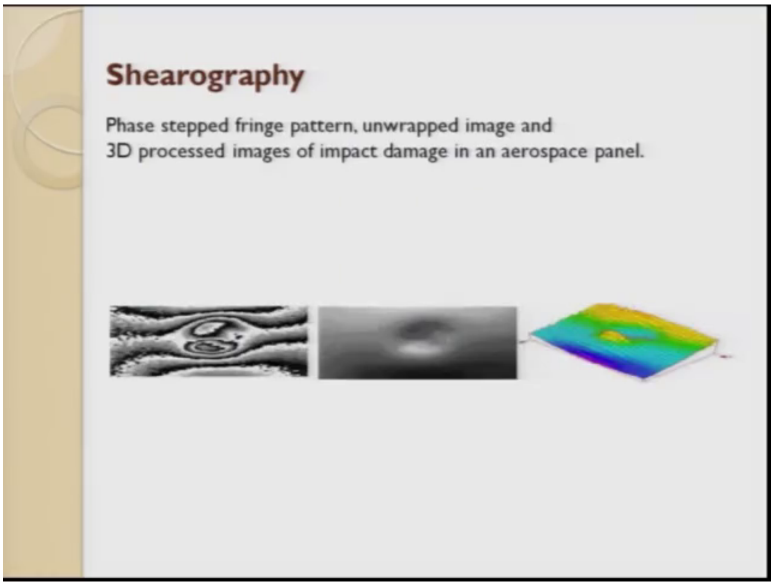

So, this is a phase stepped fringe pattern unwrapped image. So, the 3 dimensional 3 D process image of the impact damage on a aerospace panel is done. So, that you get to know what is the defect. So, if you look at it I repeat the stress distribution is then applied on the surface using the vibration sound, pressure, vacuum or thermal load. The second interference pattern is recorded, first interference second interface. The stress distribution can be can be either in a plane or out of plane in this direction. The super impose or subtraction of the image obtained from the structure is stressed and unstressed state with which produces the fringe pattern, and with this fringe pattern you are able to record such defects.

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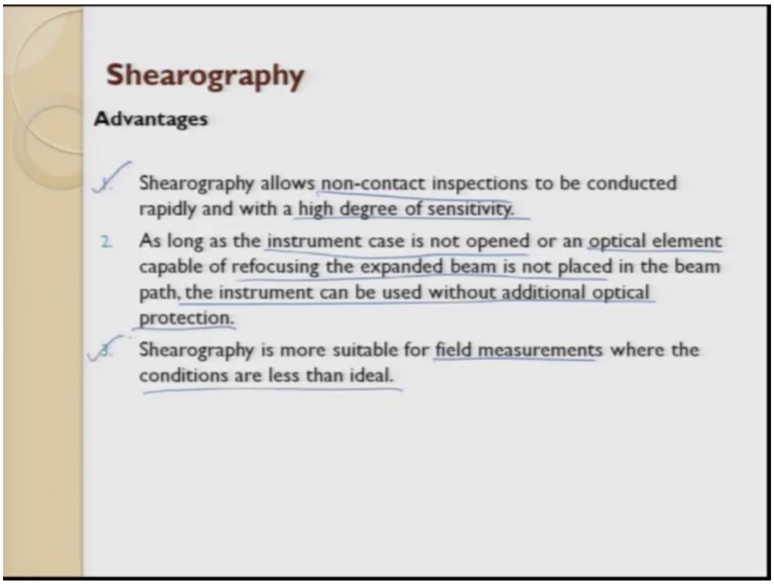

So, this is used for surface defects in a in a big way. It is a non contact type, it is it is very fast and it is highly sensitive. So, the loaded instrument is not open or an optical element capable of refocusing the expanded beam into a small place in the beam laser. The instrument can be used without any additional optical projection it is used. So, it is used suitable for field measurements where the conditions are less than ideal. So, this is a noncontact technique and this is used in the field also. Limitations I have put very clearly and you also know limitations.

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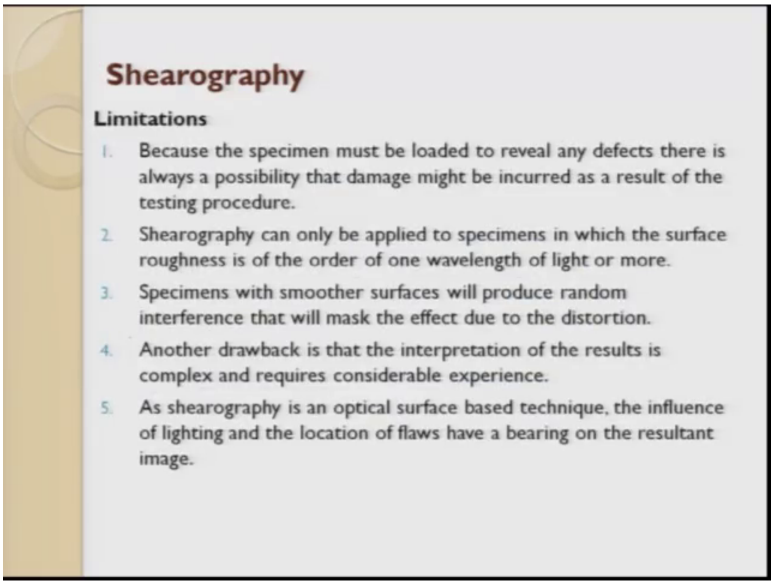

So, the specimen must be loaded to reveal any defect that is always a possibility that the damage might be incurred as the result of the testing procedure.

So, you have to load so load in the sense bend apply high weight or give pressure and other things. So, there can be a possibility of failure. The shearography can be can also be applied to a specimen in which the surface roughness is in the order of the wavelength one wavelength of light. This specimen with smooth surfaces which produce a random interference pattern which may, which will mask the effect of a effect due to distortion this is another important point.

Another drawback is that the interpretation of the result is complex and request considerable experience the as shearography is an optical surface base technique, the influence of light and the location of the flaw have a bearing on the resultant image. So, this are some of the defects of shearography which is used. Shearography going back to the basics, this is the basic. You have a laser light which is trying to hit on a on a composite material. This composite material is complex in shape. So, the laser light hits, and then the light gets reflected. So, you use a shearing lens and this shearing lens tries to make an image on the image plane, the shearing image camera is used. With this camera you take a image on the shearing plane. So, you try to get the output.

So, this is also used very well for surface defects.

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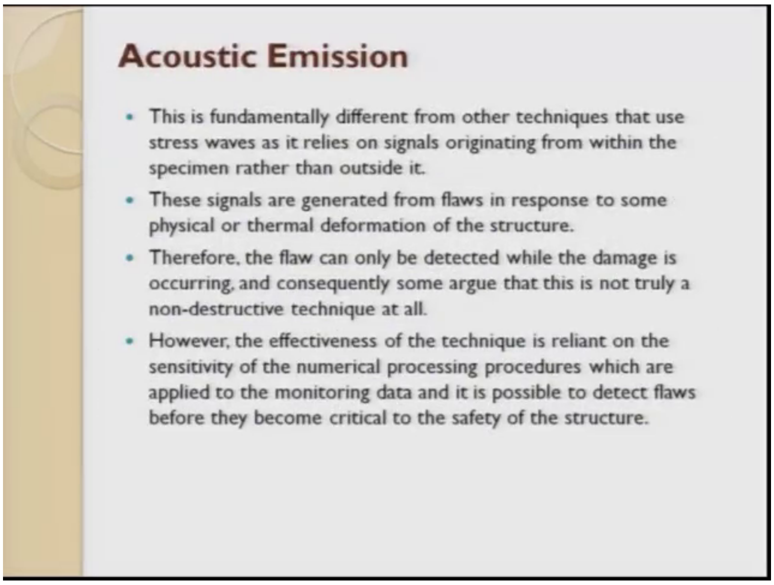

The next technique is acoustic emission. Acoustic emission is a is also a non contact type nondestructive testing. So, here what happens is what I try to measure the stress waves which are getting released from the sample. For example, you take any plastic cover. This plastic cover when you start folding it or unfolding it tries to produce some sound. And this sound is called as the stress waves. If I put a sensor and if I can capture all the stress waves. Now I will be in a position to interpret and say what is the defect or what is happening to the material.

So, that is called as acoustic emission. Acoustic means, hearing emission means sound signal which comes out of it. So, acoustic emission is used so here the material stress waves are captured by the sensor. So, here again sensor is a pizocrystal sensor like ultrasonic sensor, this is also one more sensor. So, these sensor are generated from flaws in response to some of the physical or thermal deformation on the structure. Therefore, the flaw can only be detected when while the damage is occurring or consequently some argues that it is not truly a nondestructive testing at all. So, what happens is it is a because I want some event to happen. If the event is happening then it is already becoming destructive.

So, but here leaving all those arguments, if I can record the signal which is getting coming out the stress waves which are coming out of the event happening, then I call this as acoustic sensor. It is reliant on the sensitivity of the numerical process procedure which are applied to the monitoring of data and it is also possible to detect flaws before they can be critical to the safety of the structure. So that means, to say online monitoring if you are trying to do, or if you are trying to maintain the health of a composite we can always use acoustic emission sensors.

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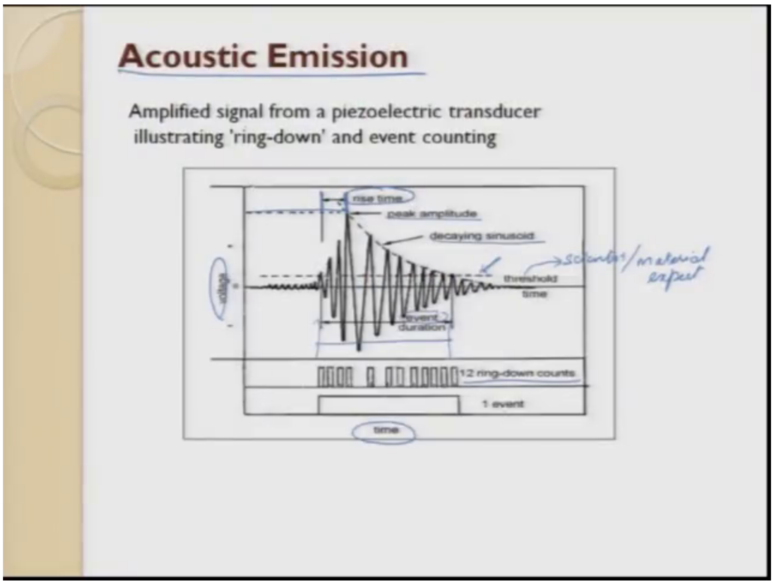

So, acoustic emission sensors this is the typical signal what we get. So, what we get is this is the magnitude this is with respect to time, same whatever we got with respect to ultra sonic we also get the same signal here. The only difference between ultrasonic sensor and acoustic sensor is the frequency range. So, vibration signals and acoustic signals ultrasonic signals the difference is only the range of the frequency. So, here if you see a typically a signal when you get. So, the first point is called as a rising time. Rising time means the time taken for an event to happen. So, that is called as a rights rising time.

So, after the rising time is there, then what happens? This these signal starts slowing decaying. So, that is called as the decaying sinusoidal response. So, the entire episode whatever has happened is called as a event. So, the duration of the event is given here. You can also fix thresholds, this is the threshold. And who fixes it the scientist or the measurement taking fellow or the materials expert, he fixes it. And he says that I have fixed a threshold anything above this threshold will be called as a defect. So, this is a threshold and the threshold time is also the threshold and the rise time is also noted down from here. So, here is a rise time, this is the peak amplitude. So, you see here this is the peak which we get right. So, here is the peak which we get. And this peak this is the highest peak.

So, we try this is the peak amplitude we get. And the time between this peak amplitude and the start of the event is called as a rise time. Then any event decays. So, that is called as decaying sinusoidal. And then we have the total event which is happening this duration. So, during this duration how many times this has touched the decaying sinusoidal is called as the ring down count. So, these are some of the parameters which we try to evaluate while doing acoustic emission testing on a composite material. So, rise time, peak time, decay, threshold, event ring, down count all these things play a very, very important role.

So, the amplified signal from the prezo piezoelectric transducer illustrates the ring down count and the event count.

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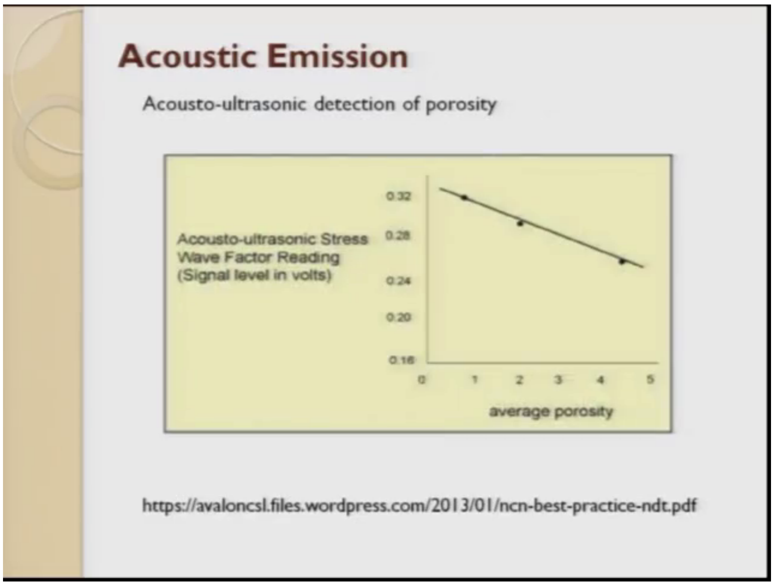

So, you can see here the acoustic emission signals, the average porosity with respect to the acousto ultra sonic signals. You see that this is how the signal you get.

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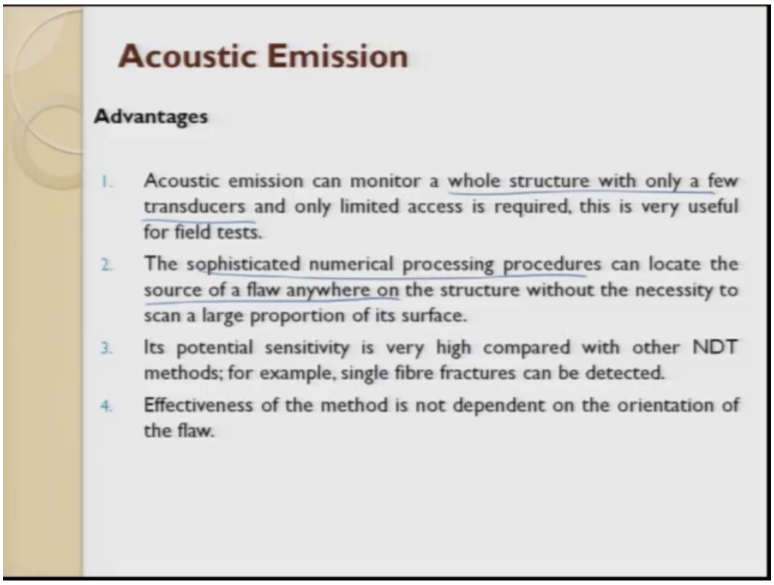

So, what are the advantages? Advantages are the whole structure with only a few transducers. You can measure the sophisticated numerical processing procedure, can be can be can locate the source of the flaw anywhere in this structure. This can be done this is a potential sensitive nondestructive evaluation technique. The effectiveness of this method is not dependent on the orientation of the flaw.

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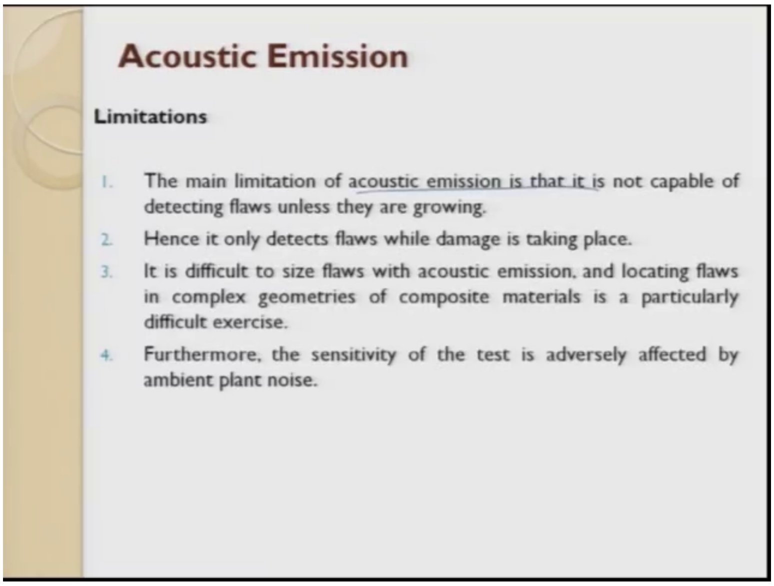

Limitations, the acoustic emission is not capable of finding out. Where exactly is the location of the flaw they can only tell whether the flaw is growing or not. So, the only when the damage takes place there is a release of elastic or the stress waves. So, you capture those stress waves and then from there you try to find out. So, the sensitivity of the test is adversely affected by the ambient plant noise. For example, if the ambient is also producing noise and this fellow is also there. Then because of these 2 the accoustic emission signals might be lost.

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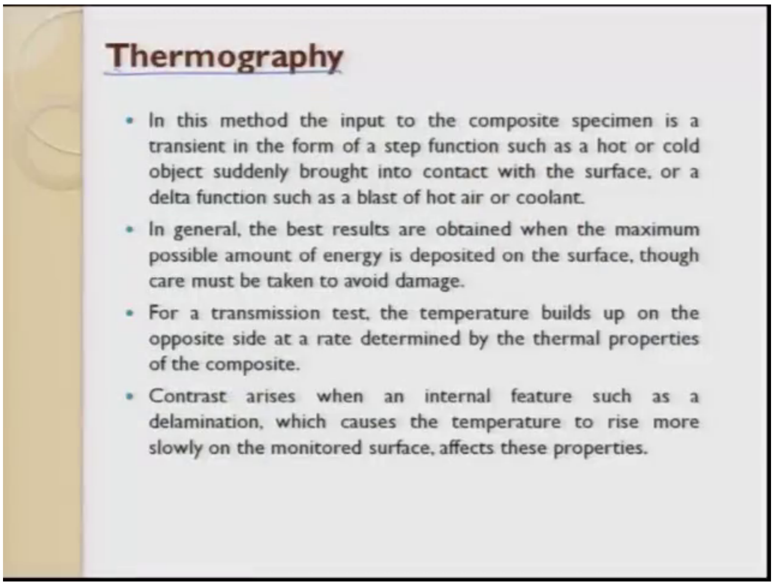

The next technique for discussion is going to be thermography. Thermography is the most commonly used technique, where have we used for example, today when you go to airports they try to see when the passenger enters into the country they always try to see the temperature whether you are running with fever. So, they try to measure your temperature this is done by noncontact. So, how do they do? They just try to have a infrared camera. And this infrared camera tries to find out what is the temperature distribution between your body and the surrounding. So, wherever there is a gradient it maps and it gives you a figure.

So, this technique is nowadays becoming very commonly used. So, thermography, thermography is also used in composites. So, what happens here in thermography is when you try to emit when you try to hit infrared on a on a surface or when you try to load the surface with some heart waves, and then if you start recording the temperature distribution over a period of time. What will happen there? Will be a decline which happens with respect to time. Once the decline happens wherever there was a cold zone the decline does not happen in the same uniform way, or the heat gets stuck to that spots. So, with that what we can try to find out is we can try to of out whether there is a defect or not ok.

So, this is what is a technique used in thermography techniques what we do is we try to take a composite specimen. And there is a heat source heat source which we apply which we forced air or a light is thrown on top of a surface, and then we try to record the decline in the heat loss. So, the method the input of the composites specimen is a transient in the form of a step function such as a hot or a cold objects suddenly brought in contact with a surface, and then the delta function of the of the air. So, whatever it is the hot blast air which is coming out it is slowly recorded. The best results are obtained when the maximum possible amount of energy is deposited on the surface, and it should make sure that with the heat whatever you apply should not damage the surface.

A transmission test the temperature built up on the opposite side I at a rate determined by the thermal properties of the composite, and then what happens is here if there are any internal flaws there will be a difference in heat loss. So, that is what whatever I have explained here we have put here. So, this is what it is. So, you have an IR camera, infrared camera though this is a flash light.

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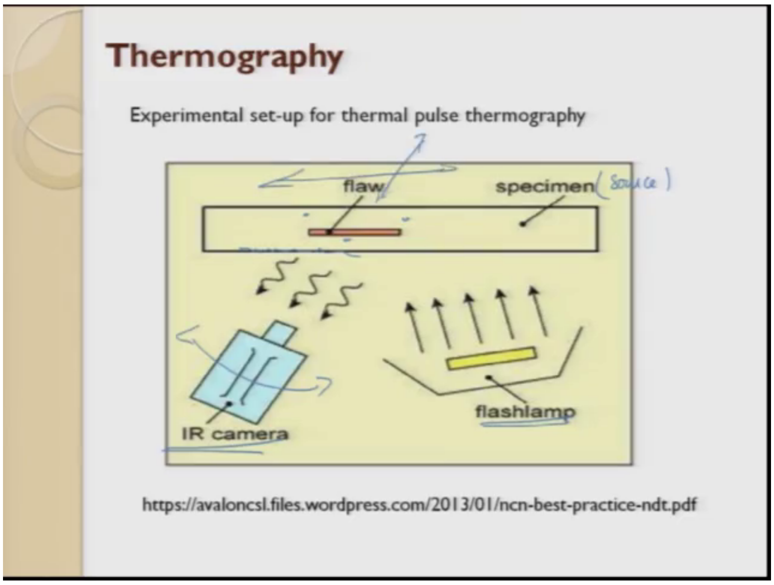

So, the example what I gave in terms of human being in the airport is we have our own the specimen has it is own source, but here in a composite it will not have it is own source.

So, what do we do is I try to hit with the same heat or by issuing a flash lamp or infrared whatever it is I try to hit it on top of a composite. And when there is a flaw there is a difference in cooling rate. So, I record this on the surface and then I try to figure out the presence of a flaw. If there are surface roughness yes there will be a problem if, and then if there are multiple flaws in varying direction yes, this will have a problem. So, this needs lot of skills and it does not easy to get only one spot. We try to move this in this angle and or we try to move the sample in almost all the axises so that we get a proper information about the defect.

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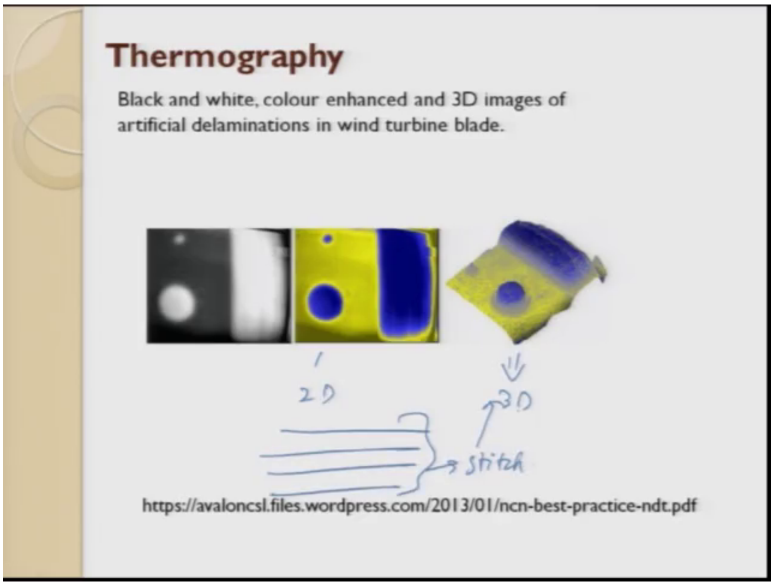

So, a blank and white image looks like this, a colored image look like this. And here what this is this is a 2 D plot, this is a 3 D plot. So, if I have several planes of information and if I can stretch the information I get a 3 D information.

So, this is a 3 D information which is got. And people can find out the surface defects or internal defects generally for surface defects it is easy internal defects you need to have skills to find out the results. So, advantage we have discussed.

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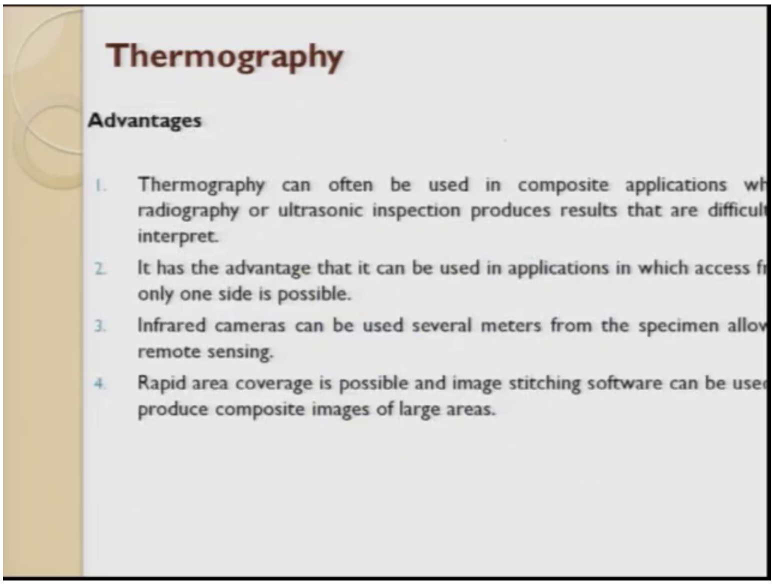

So, this is also having a similar advantage like ultrasonic, but compared to ultrasonic infrared camera, this thermography images are much easier to interpret. Because you get the full data image ultra sonic what do you get is only a signal. So, you have to reconstruct it. So, if there is an anisotropic nature. So, then the thermal conductive properties vary from different directions. So, it becomes very difficult.

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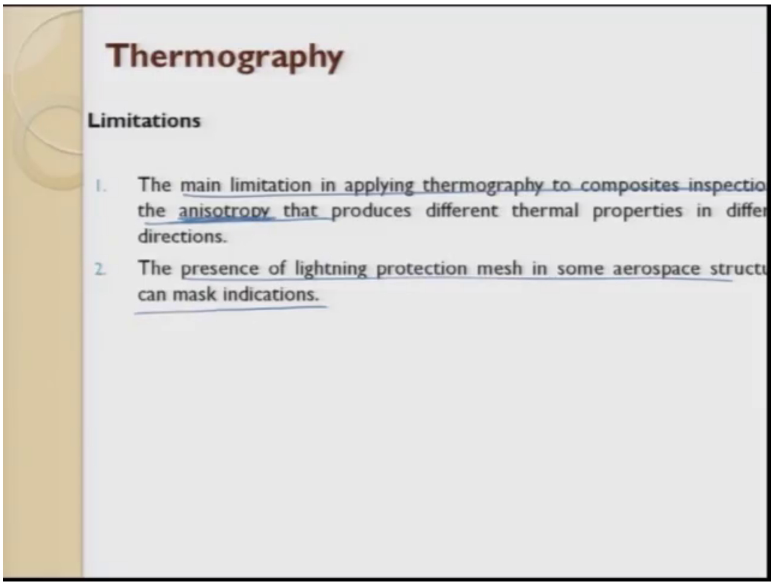

So, the presence of lightning protection mesh in the aerospace structure is will try to bring in difference in thermal gradient. So, you can try to figure out. So, the most important point is if there is an anisotropic property it is very difficult for you to find out what is it.

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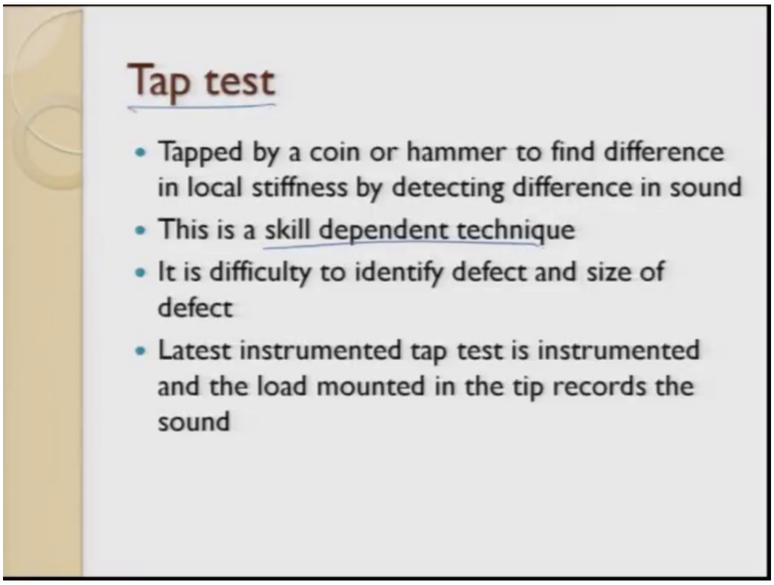

The next test is going to be something called as a tap test which is very common. Which we always try to do. It a tap test is nothing but you take a coin, or you take a hammer or you take any source heavy metal and try to hit at the work peace you make sure when you hit you do not damage the work piece.

So, when you try to hit at different locations. If you get a same sound or if then it is said to be a consistent composite. If you try to get a varying sound if there because of the local stiffness there is a variation. So, what will happen is there will be a difference in sound. So, from the difference in sound you can try to figure out that there is a defect presence. So, there is a resin rich region work matrix risk region you can on. So, it predominantly depends upon the skill, and here it is very difficult for you to identify the location and the size of the defect.

So, latest instrumentation what has happened is even the tap test they have tried to put they have taken a coin. Or they have taken a hammer and on the hammer they have put a load cell. This load cell when it hits the work piece they try to record the signal and try to interpret the health or the quality for the composite.

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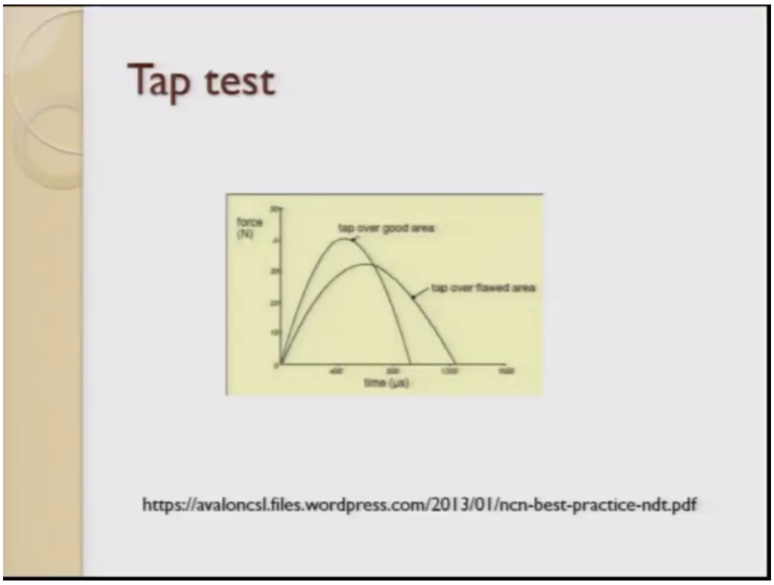

So, if you see here a force whatever it is there and you see time, you see a tap over a good area and a tap over a bad area. So, this is a good area signal, this is a bad area signal. So, which is respect to time with respect to force you get, and you can interpret whether the composite is good or not.

So, this is what we can conventionally do it for ceramics composite also when we have when we try to buy a pot, or when we try to take a brick and then find out the quality of the brick what we take is we take 2 bricks and tap against each other and we try to get a shrilling sound. If you moment you get a shrieking sound or a shrilling sound what happens we say yes, the quality of the brick is good. If it is not so, then we try to say if you get a sound which is of not shrieking noise, then we say there are pores there are defects. So, this is a defective component.

So, this though it is said to be a semi unskilled test or something today we are trying to instrument it. But still this is the most common test which is done on small workpieces and on large workpieces people use sometimes tuning fork also going around hitting it and then trying to figure it out.

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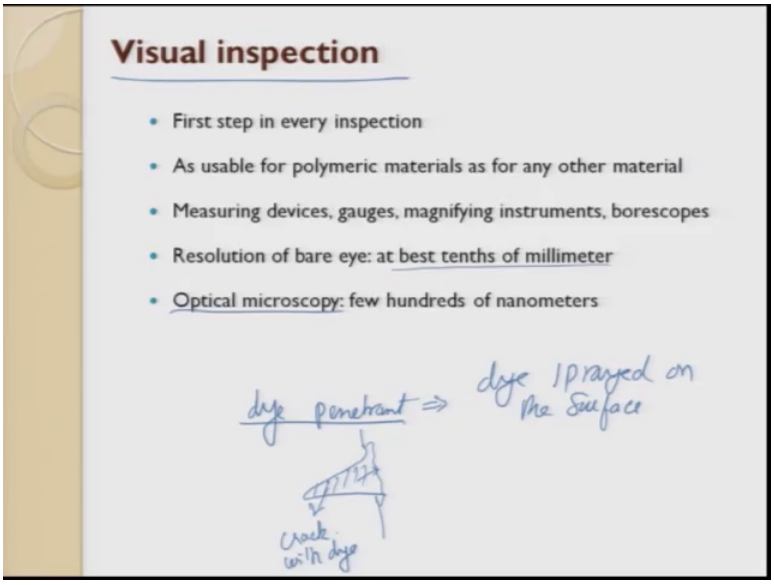

The next one is going to be visual inspection. Visual inspection is the most common thing which is done as soon as the manufactured composite is made. People go for visually they try to find out whether there is any defects. So, this is more focused towards the surface defects only.

So, here what we do is, we try to in visual defects we try to use a dye penetrant dye penetrant. So, here what we do is, we either by visual we do or what we do is we try to put a we try to throw a lights heavy source of light and see whether there is any reflection which is coming out. And then if there is any glittery or glare which comes out that we see from there we try to figure out there is a defect. So, human eye cannot go less than few 10’s of or 100’s of microns.

So, once we wanted to go less than that if the defect is smaller than that we go for a higher scale we try to magnify the eyes. So, we go into a microscope. Suppose if there are defects which is still not visible what we do is we used to go for a dye penetrant test here dye is sprayed on the surface. And then what we do is try to add a developer on top of this dye, and try to clean the dye. And wherever there was there is a defect. So, what happens is this dye go sits inside and when the developer is hit. So, this is a composite. So, this is a crack. So, the crack with dye. So, when we try to spray dye if this dye go inside, and then what happens? We try to hit the developer we try to clean the surface.

Then this dye over a period of time this dye starts whooshing it out and they share difference in color.

So, that is our dye penetrant test works this is more focused towards surface defects here in complex internal external surfaces can be done.

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The next one is called as borescope, if you have a high aspect to l by D ratio high. So that means, to say diameter is very less length is very long. So, aspect ratio we always go for a borescope in borescope what happens here. You have a camera, you have a light which is thrown here you have a camera this is an optical fiber this optical fiber transmits information and through this screen you try to see what is the crack within the surface.

So, this is used for a aero planes for example, the blades if you want to have more information of the blade non-accessible regions from the surface. So, then what they use they use a borescope and we try to get the information. Again, this tries to tell the surface information, the visual inspection surface borescope also surface. This is what is a dye penetrant test which I was trying to tell you along with the visual.

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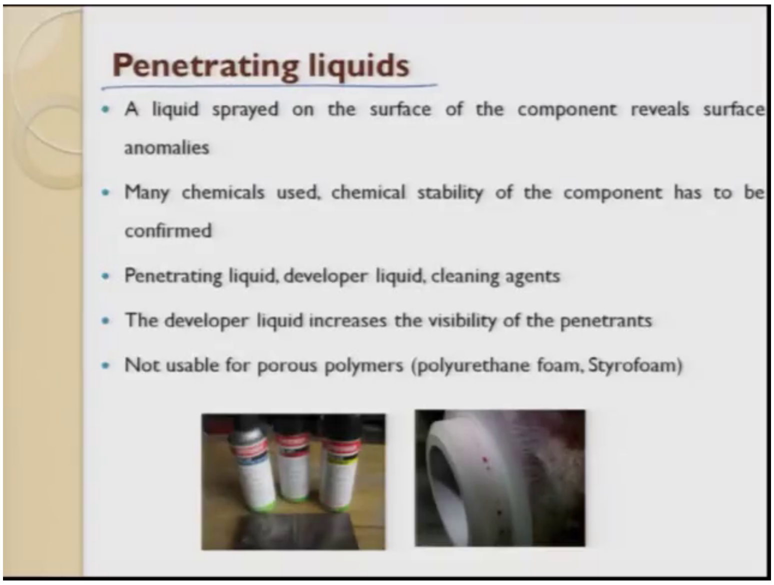

So, here I have told everything penetrating liquid is there a developer is hit the developer hit liquid is done. Then a cleaning agent is done. So, then what happens after this whatever gets wussed out you will see the dye. From this we can try to figure out yes there is a surface defect. And here we should make sure whatever the developer we use the dye we use should not bring in a hygroscopic defect for the composite.

So, this is the liquid dye penetration test.

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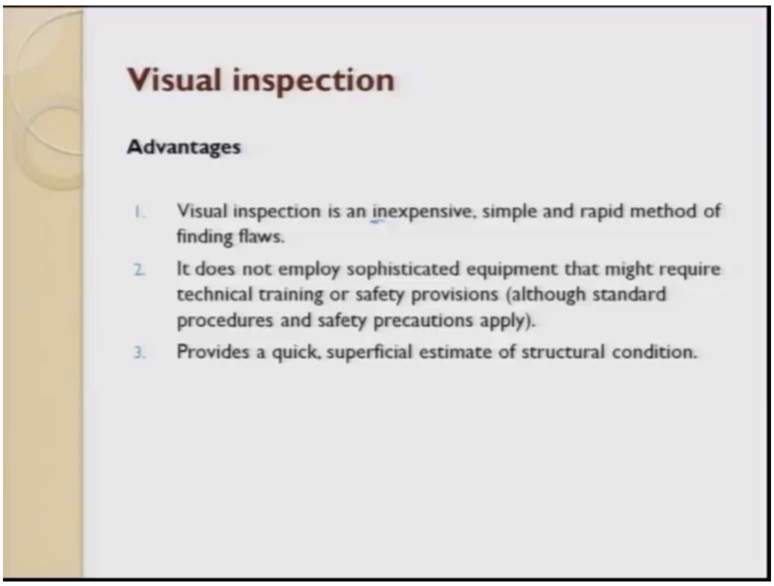

So, advantages it is very inexpensive very simple, very fast, they do not need any sophisticated equipments. And any complex surfaces can be done through visual inspection.

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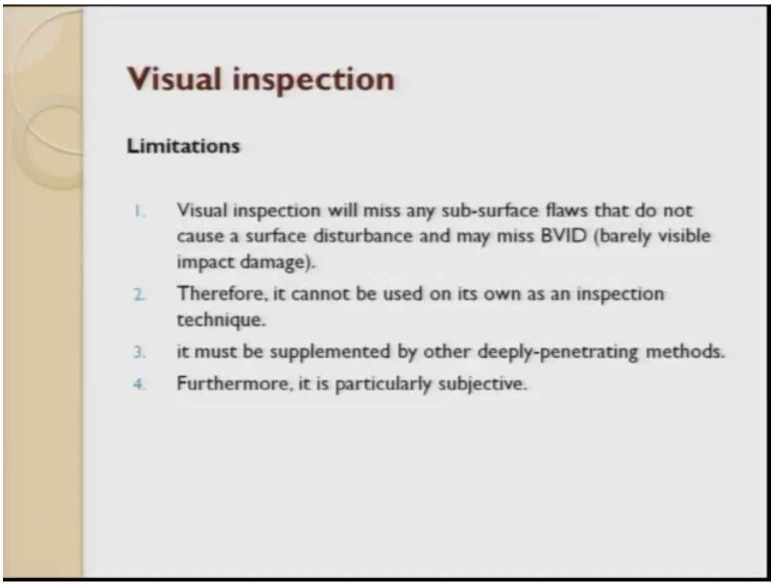

Limitation if there is a blur or if there is no light in the particular location and you want to do it, then this becomes very difficult and very small cracks on the surface and if the cracks are below the surface then visual inspections cannot be used for finding out this. With this we come to the end of this lecture on nondestructive evaluation of composite materials.

So, here we studied about the contact measurement, non-contact measurements. And we predominantly looked into only on contact measurements we started with ultrasonic. Then we moved into acoustics. Then from acoustics we went into tap test, we went into visual inspection, we were doing looking for dye penetration test. And we were trying to interpret the results. In acoustics the big challenge is the surface can have a defect the from the surface deep you can the core you can have defects. So, when you talk about defects, 2 things are there the size of the defect and the depth of the defect has to be found out. And no defect is exactly along a straight line it is random in nature. So, we are supposed to find out what is the area of the defect present.

So, this the nondestructive testing evaluation is done for 2 things. One to see the quality of the manufactured product to see the deterioration of the product when you put it on service condition that is called as health monitoring we do.

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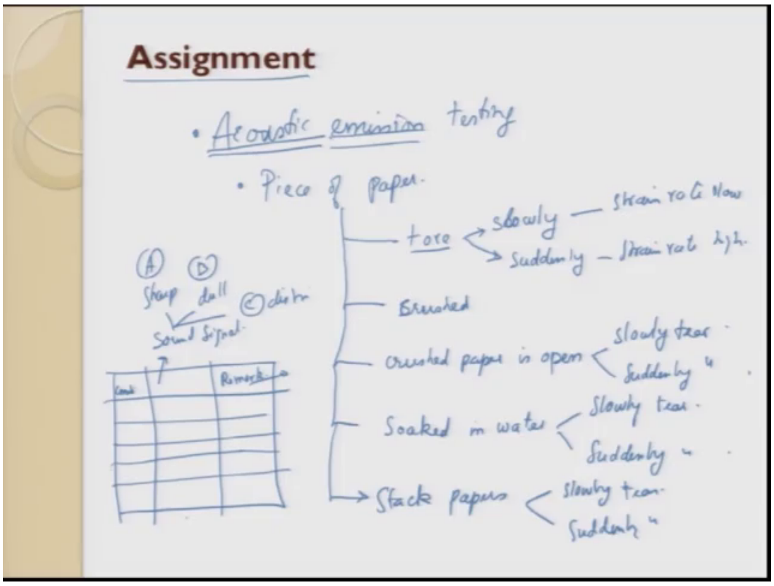

So, today assignment is more focused towards acoustic emission. Acoustic emission testing. Let us take a piece of paper. This the piece of paper is tore. This is slowly and suddenly or fast tore. Next is the paper is crushed. The third one is the crushed paper is opened and then slowly tored, and it is suddenly tored.

The paper is soaked in water and slowly tored and suddenly torn. So, these are the different experiments. So, what I would want you is put a table. Right down here the condition. Whatever you have done and here you try to note down the sound signal. And then you write your remarks. Now you will see based upon see slowly and these are nothing but a strain rates, if you convert into engineering’s strain rate slow strain rate high. And the last one is you try to stack papers, and then you slowly tear I will convert all these things into tear all these things in to tear; it is all these things slowly tear suddenly tear.

So, please note down the signal. Whether the signal is sharp, whether it is dull or is there anything else. So, you can make A category B category and you also have C category disturbed signal or something like that. What is disturbed there are lot of noise getting imbibed into the signal? So, if you can do this experiment. So, then what you will do is you will try to see human hear as an acoustic emissions sensor where in which you record all the stress waves which are getting released, and now you can interpret what is happening to the workpiece in different service conditions.

Thank you very much.