Nature and Properties of Materials
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Lecture 40
Laboratory Demonstration

Now in this particular lecture I am actually going to give you several laboratory demonstration in which I would like to tell you that how you can use various advance systems of measurement for the measurement of the material properties. One such instrument that I am going to show you is a very-very sophisticated instrument, which is known as 3-dimensional Laser Doppler Vibrometer.

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And as you can see here that a 3-dimensional laser Doppler vibrometer had actually 3 axis laser systems and it has a control system here, I will show you how this control system works. Now typically laser comes from each one of these systems and you can see here that the laser is falling here, you can see the drop of the laser okay.

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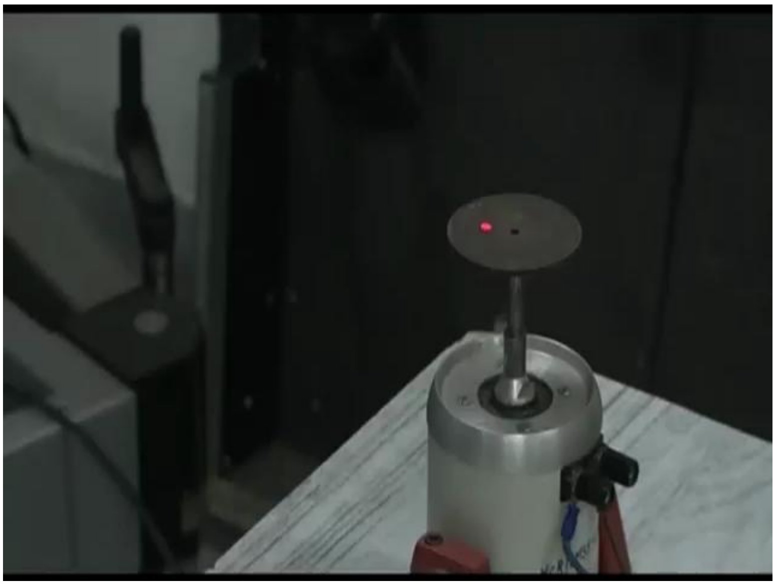

And suppose I am interested to find the material properties of this disc, then what are the properties that I can measure from here? I can measure the modulus of elasticity of this disc if I can find out the natural frequency of this system. And I can also measure the damping properties of this disc. Now, how can we do that? The procedure for doing it is very interesting, as you can see that the plate is fixed here with a small stinger and then what we have here is an exciter. Now we can excite the system, so let us excite this system a little bit and let us vibrate this system.

So what we can do is that there is a monitor and which we can set this particular as you can see the laser is changing its position, but we can also excite this, can we shake this system now. Now, you can see that this plate is actually fixed to the shaker or an exciter and the exciter is connected with a stringer and then we have added just a little bit of glue that this gets fixed to the system and now I can actually excite this system with the help of this shaking machine, so I am going to select a particular frequency, we can select here as you can see that what is the frequency that we are going to choose, pseudorandom okay.

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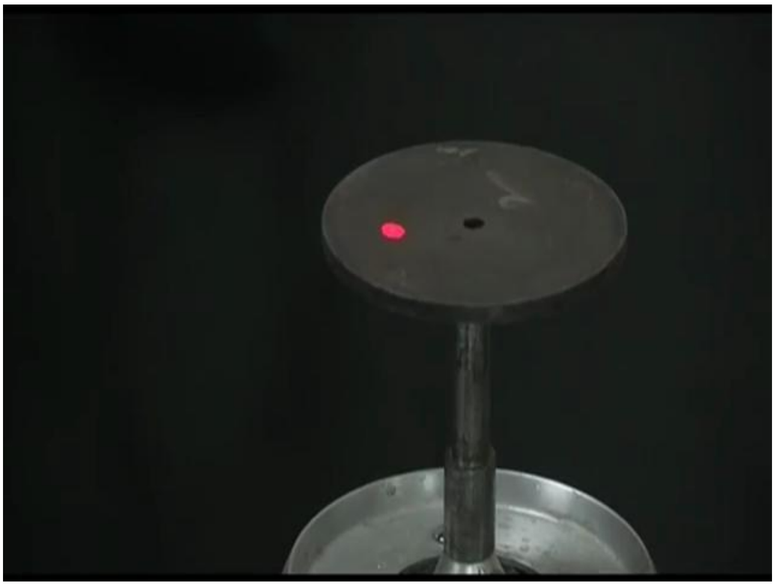

So pseudorandom signal we are applying that means we are choosing the frequency in a random manner and we will see that the shaker accordingly based on the frequency chosen is going actually vibrate in a random manner. So can we increase the amplitude, can we start the process now? Yeah. So you can see it here that the shaker is excited and there is a vibration, we can in fact increase the level of vibration, let us try to increase the level of vibration little more, can you put ones more. So that you can see that the vibration is coming out of the system, now I think you can see, right.

The reason is that we do not excite it at a very high frequency is because the laser does not need. This laser is a one of the best sophisticated laser actually in fact, its specifications are that this is a helium neon laser and it works with a lambda wavelength of 633 nano meter, its minimum detectable vibration speed is 5 micron meter per second that is why we do not need large amplitude of vibration. Maximum speed is of course 10 meter per second at about 1 hertz frequency and it measures up to 30 megahertz and operating distance has to be greater than half a meter till about 50 meter of a distance.

Now, as you can see here that the laser is coming from one of these sources, there are 3 such sources and it is falling on this system and then it is actually reflected back to that same system. If this particular plate remains stationary, then there will be no phase difference because the speed of light is very-very fast, so the light will come and go back and there will be a reflected another reference source, between the 2 it will compare there will be no phase difference. But the moment this plate starts to vibrate, then when that light will go back, it will have a Doppler shift and that Doppler shift is measured in terms of the phase difference of the system.

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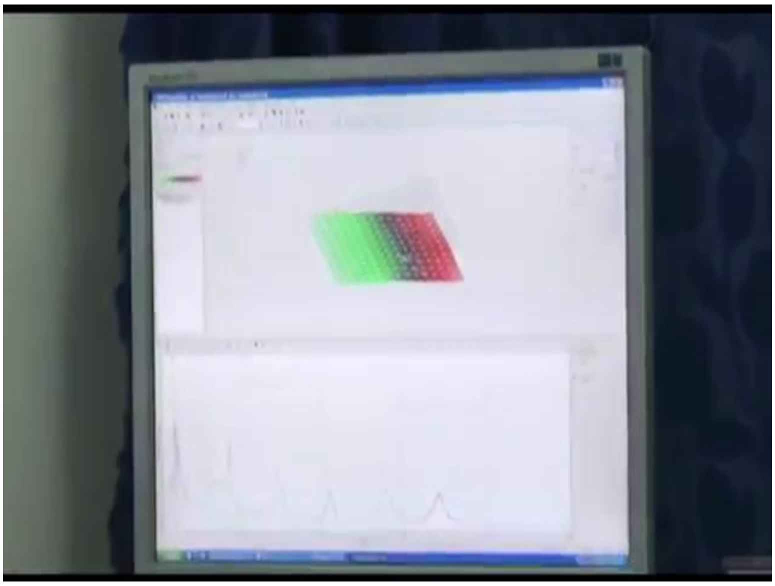

And you can see it now that how we are going to record this Doppler shift as you can see here that this is a particular plate and you can see that various colours on the surface is actually showing how the velocity profile is changing okay. And the red means large velocity, green means smaller velocity and thus the laser can actually go through each of these points and in this case it is a disc, in this example it is a cantilever beam, but the principle is same that in all the cases, the laser scans through each of these points and measure the velocity profile.

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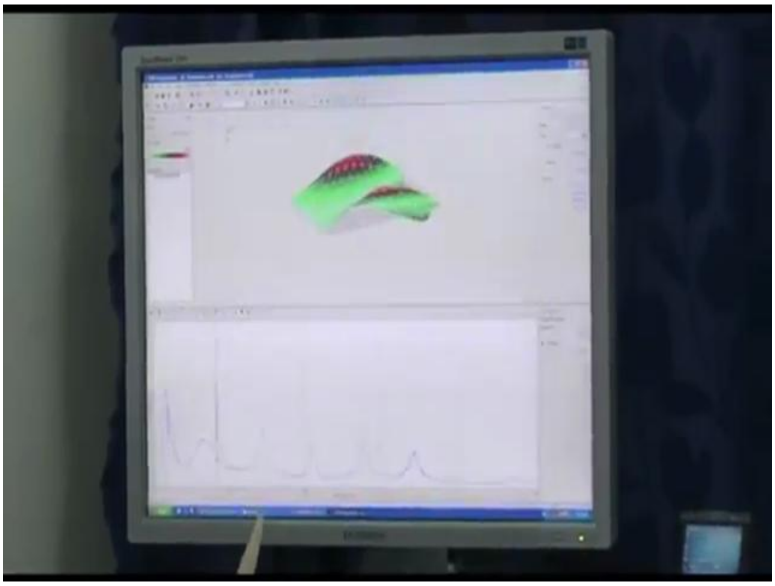

Now what do I do with the velocity profile? If the velocity profile is known to me, then by going through a frequency based takeoff position of the signals, I get something here which is also called effecting of a signal. And at each point can we come to this peak for example, as you can see that at each such effective position it is actually showing the natural frequency of this particular plate system and how this system is vibrating. Like in this particular case it is vibrating in a way that it is the sides of the place, so it is the one of the width mode of vibration that we are finding here.

Can we come to this mode for example? Yeah. Now you can see that it is a kind of torsion and bending combination that is happening to the system. So like that, I can actually get each one of this system. Now what helps is it for us? One is that we get the frequencies natural frequencies, these natural frequencies are directly correlated with the modulus of elasticity of a material. So thus, we can actually find out the modulus of elasticity of a material, not only that we can also use half power point technique in the FFT.

You see that as for example, he is choosing the band here and then inside this band by using a half power point technique he can actually calculate here that what is the + - 3 dB point and hence what will be the damping that is associated with this system. So both frequency and damping, which are 2 of the most important properties of dynamic application of materials, from that point of view, can be measured through this particular Doppler vibrometer.

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The beauty of the Doppler vibrometer is that it need not work on simple plates or beams, et cetera, it can work on as complicated structure like this as it can see that this is a part of a wheel casing.

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And you can see it here that even for this type of complicated structures, this system works beautifully. And you can see here that how in surface part of it how the vibration pattern and the mobile frequencies are coming out of the system. So thus, you can use this system in terms of developing various load shapes of various types of complex geometries as well.

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The 2nd system that I am going to show you is related to the smart material. As I told you in one of the lectures that I will show you how shape memory alloy based system works, now this is one of the examples, these are for example springs which are not normal springs, but the springs are made of shape memory alloy meaning thereby that even right now if you can see them of this particular shape, you can do anything with these shapes, you can basically squeeze it and put it in any shape, but the moment I will apply a particular temperature you will see that this spring is going to get back to its original memory shape.

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And it is not only available in the spring format, but also in the wire format. Again the wire, it looks like that it is like a very messy wire in fact, you can squeeze it, you can do anything with these wires, but when we actually heat these wires, you will see that it will go back to its memory shape. How we are going to use it? We are going to use both the systems here in this antenna; this is a 5th generation space based antenna, which is actually developed by ISRO from the Satellite Application Centre.

Our collaboration is Dr BS Munjal and as you can see here that this antenna is very-very flexible and this flexibility is actually desirable why because if it is flexible then I can give various shapes and the antenna shape actually determines the signature of the antenna that is, which area you are going to transmit the signal that geography is determined by the shape of the antenna. So what is needed is that suppose you would select 2 geographies, geography A angiography B that means if geography A is for this shape, geography B could be some other bend shape that bend shape you have to go whenever the signals are to be transmitted to that type of a geography.

Now, how do you do that? Well, the system that we have used here is with the help of this SMA wires and springs as you can see here below this, there is this SMA wire line with the insulation, it is coming here like this okay and this SMA wire is connected to one end here and the other end is connected to the source of the power. Now the moment I will apply the power, the SMA wire will go back to its it gets heated that means it will go back to its memorized shape and that memorized shape is going to actually cool this system.

And as it is going to cool as you can see here, with every cooling you are actually bringing this system down okay, so you are deforming it. And, as soon as you are getting a desired deformed shape, you are going to lock it at that location with the help of this locking system. If I release it, you see it is going back to its original location, if I deform it as you are deforming here, it is getting locked.

Now this whole thing I am doing it manually, but now our student is going to show you Mister Shaheen Karla is going to show you how we are going to do this whole thing through a completely computer interfaced system. Shaheen can you start to…

(Student started the demonstration)

I am going to show you with a controller which is right now our (())(12:39) I am going to show it using directly DC supply, which is the voltage of 50 around 50 volt, I will pass it through SMA and then this SMA will cool my antenna, cool one point of antenna towards its own shape. So I am switching only DC power apply and it is supplying power to SMA. So you can see that the pulley is rotating and the antenna can deform up to deflection of 25. And as the (())(13:14) as the less, the position of antenna at that point will get low curing this pulley and (())(13:22).

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And for unlocking, we are using SMA springs and this ratchet will be unmatched with the pulley and the antenna will get back to its original shape. So now we are developing a control system to control it directly using our controller that is DC for NIA card,

(Demonstration by student ends here at 13:56)

Okay so thank you Shaheen, so this is how we have just shown, you how shape memory alloy wire based system can work and how you can control the shape of it okay.

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With this setup, I am going to show you several non-mechanical properties that come into picture through this particular setup like the optical property and the magnetic property of the system and the setup is known as the magnetic levitation system. As you can see here that there is an LED here, a white light is coming, so it is a light limiting diode okay, so this uses electro-optical property of the system and this LED light is coming to this direction and what you have here is a magnet.

Now what happens, we are basically generating a magnetic levitation system, so I am going to put an object at this location, the moment I put it the magnet and the system is on, you will be able to see in this scope that the magnetic field is going up and there is a controller that we have designed that will come into action and you will see that this particular object is going to remain at this particular location. Now there, one interesting thing will happen is that the moment I will keep an object at this location, because of the gravity the object will try to fall down so it will have a downward acceleration, but the magnetic field will try to take it up.

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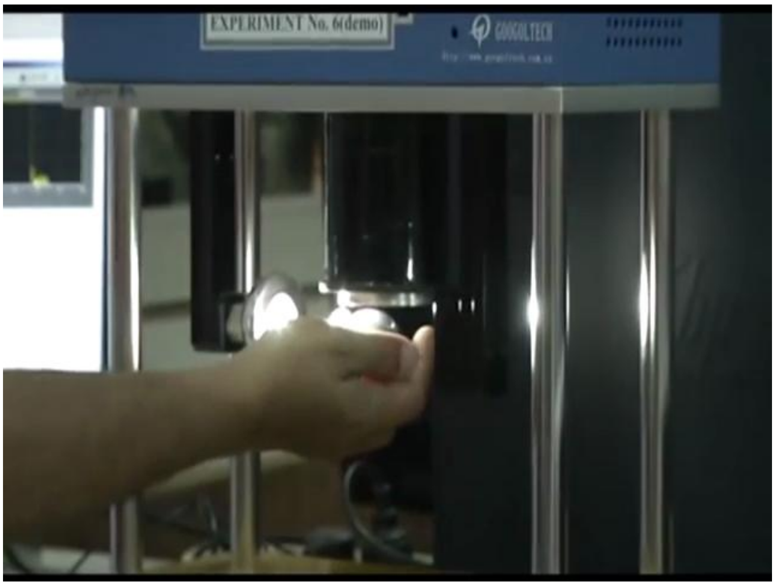

And the moment these 2 will be balanced as you can see here that the controller the job of the controller is to balance these 2, we will be going to have the levitation. Now we have an object here. This is a magnetic object and I am going to keep it here. As you can see if I keep it very close, the magnet is going to catch it and the light is falling on this so the shadow is coming here, through the shadow it knows that how much of object is within its radii and how much object is not, so that shadow is going to vary. So now I am going to float this object.

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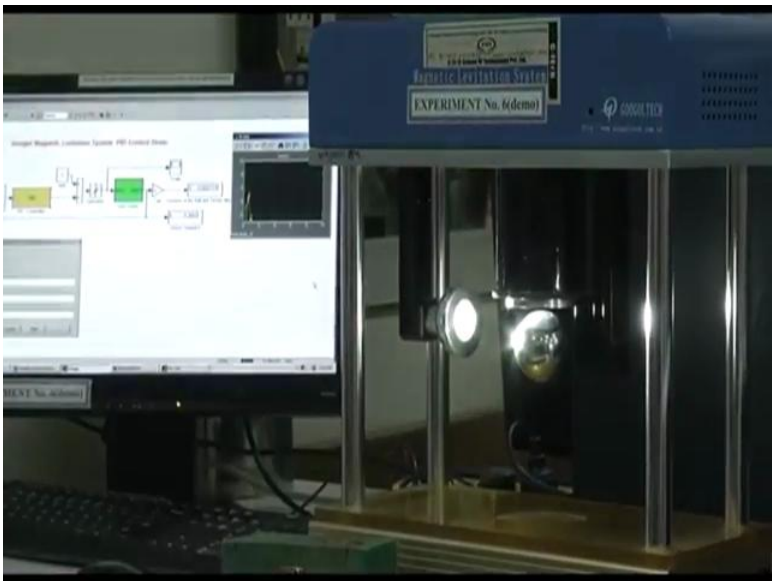

And as I am changing, you can see there is a rapid fluctuation that is happening in the magnetic field, so now I am going to levitate the object. And you can see that the object has beautifully levitated in its position, the magnetic field as you will see now soon that it is it will gradually process and it will show you that how this magnetic field it is maintaining. In fact, if we just little bit shift it or oscillate it, then the magnetic field also will automatically adjust itself and thus the electromagnetic will maintain just an up force which is required so that this whole thing will not fall down, so that is how this magnetic levitation system is based on, thank you.

Here, we are going to show you an optical fibre-based system as I told you that that is based on total internal reflection and if you remember, I also told you that there are 3 areas in an optical fibre-based system. One is the core, and then there is cladding and then there is the 3rd layer which is the protective coating of the system. Now the beauty of total internal reflection we will be able to see that if I put light on one point, you will see it will be totally transferred and here this is an optical microscope.

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So as I am putting the light here, you will be seeing that the light is actually coming out from many of these locations as you can see now okay. So there is a total internal reflection, none of the light is going out of the cladding and you are going to see beautifully all those locations, which are showing the light and this is happening because light is taken by the optical fibre which is a multimodal optical fibre system and each one of them is carrying out the light signal and it is coming out of this system as you can see it here okay. So such a system is used for developing various types of this kind of LED-based microscopic systems.

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We are now going to show you another very interesting smart material which will show you both the concept of smart material as well as the composite system. This particular smart material is known as macro-fibre composite. It is a composite system; I am going to explain you the system in a minute and this is used both as sensors I will show you that how you can use it both as sensing as well as for generating vibration for actuation, so it can work both for sensing vibration and strain sensing as well as for generating vibration in the system.

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This particular system is developed in NASA in 1996 and is commercialized by Smart Material Corporation. This is composed of these piezo ceramic rods, which are like sandwiched between the layers of adhesive electrodes and polyimide films. This yellow colour is coming from the polyimide films and then there are piezo electric rods there, you may see that there are very fine rods here okay, which are interconnected between the 2 electrodes, so there are many such and then there is this polyimide film.

Now as I apply the voltage on this okay, so through a voltage source I am going to do that. In this particular application you will see that as I apply voltage, it is going to bend. If I change the direction of the voltage, it will bend in the reverse direction thus you can generate a vibration in the system, so can actually use it in 3 modes for expanding, for bending and for torsion. The blocking force of this particular system generally varies between 28 Newton to 1 kilo Newton, it depends on actually the width of the MFC and the operating voltage is actually - 500 to 1500 volts.

And the current is about 50 milliampere and the amplification here is about 200 folds per volt. The maximum operating frequency up to which I can generate vibration in the systems is about 10 kilo hertz however, as a sensor it can sense much-much higher excitation close to about 3 megahertz. The thickness of such a system is about 300 micro meter and as actuators, it survives about 10 to the power 8 cycles, as sensor about 10 to the power 11 cycles and as energy harvester, this can also be used for harvesting energy and for storing energy and that mode it will serve about 10 to the power 10 cycles.

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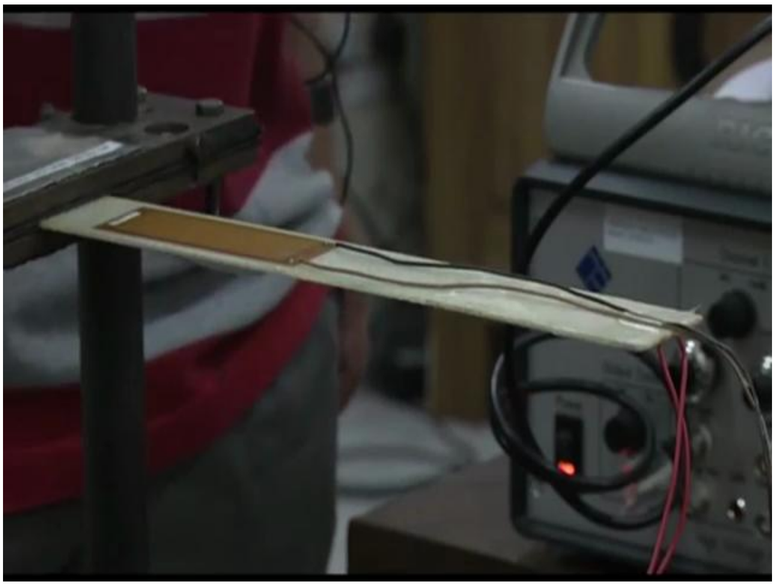

So with that now I am going to show you how the system will work once I will excite the system. Now in this setup, we are going to show how you can use a macro fibre composite MFC to generate vibration in a flexible beam, so this is a flexible beam and a MFC we have attached here. And we are right now applying a frequency of 3 hertz, so an alternating voltage of 3 hertz frequency is getting applied and it is applying a kind of a oscillatory force on the system.

You will not be able to see that the vibration is happening, if I increase this frequency a little more, we will go close to one of the natural frequency of the beam and then you will be able to see how beautifully this macro fibre composite is able to actually vibrate the system. So I am gradually increasing the frequency, this is at 6 hertz, 7 hertz, you can see it is increasing the amplitude as we are going closer to the natural frequency. Now it is 8 hertz, 9 hertz, it is certainly now it is perceptible to you that yes this is doing something, 10 hertz.

You can now see that we are very close one of the resonating modes of the system okay. In fact, we have several constraints here otherwise you would have seen much larger amplitude of the vibration. Maybe we can try up to 11 hertz, but you can see that as we have approached 11 hertz, now the amplitude is coming down. If I go further 12 hertz, you can see the amplitude is coming down, so which means if I go back to 10 hertz or so, close to 10 hertz it is one of the natural frequencies of the system is there.

And at that frequency the MFC is able to excite this flexible beam. So thus through this we are demonstrating that how you can use this macro fibre composite to generate dynamic actuation forces on a flexible beam and to generate vibration as a result of it. The same system wonderfully enough can be also used for sensing purposes in fact, the signal is also we are splitting that signal and you can see that signal here now.

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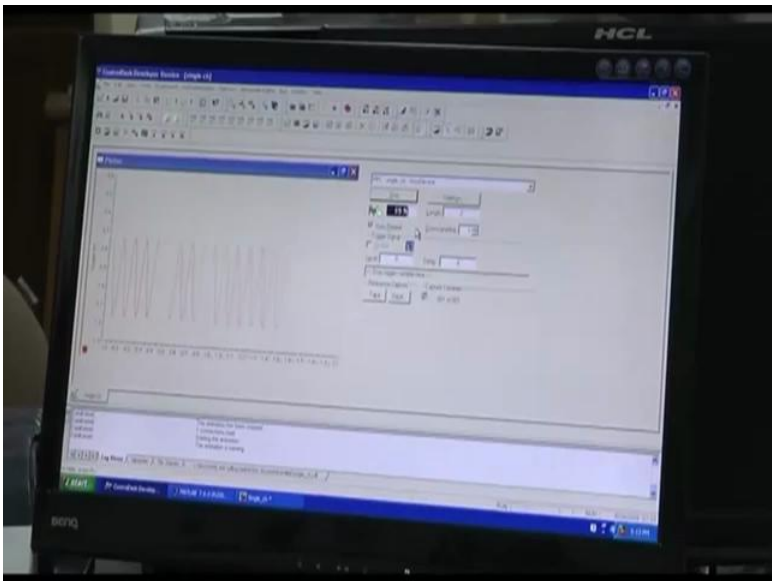

We have used a similar macro fibre sensor here and this macro fibre sensor is taking the signal of the vibration and as you can see it is getting in the computer there and you can see that how the vibration is taking place in the system, so this is going to give you an idea of how this system is getting excited at 10 hertz level. As we change the frequency, we will see that this amplitude is going to slightly come down because we are below the resonating point.

And also if I hold it constrain it, we will see that it is coming down as you can see that the sensor will immediately sense that there is something which is holding the vibration and hence, this signal will actually come down. So this is how you can use the MFC both as actuators as well as a sensing system, thank you.

Dear students now we have reached the fag end of our lecture series, so I hope you have enjoyed this lecture series. I am just going to summarize them, what we have covered in this journey with you. In the first week, we had 6 lectures and these were mostly introductory lectures, where we have 1st covered about the history and evolution of materials and then we have talked about classification of materials into the groups, various groups. For example, into polymers, into ceramics, metals, glasses, composites, et cetera.

Also we have talked about a few advance and exotic materials. And then we have introduced you to some of the very basic concepts like stress-strain concept, Hooke's law, ductility, resilience, impact properties and hardness creep and damping. Although, there are many mechanical properties, but the reason of choosing the mechanical properties set in these 3 sets is because this is what you would mostly need for in general any product design, so that was our venture in the week 1 which was introductory nature.

Week 2, we said that we will go slightly deeper inside the mystery of these mechanical properties. So hence, week 2 we started with the atomic bonding, we have discussed about primary and secondary bonding. Then we have discussed about crystal structures in depth, we have talked about structure of the Crystal, Miller indices, crystal defects like point defect, Scott Key defect, Frankel defect, dislocation, et cetera, and that was our journey in the week 2.

Week 3, we started to explore the 1st material which is the most popular material group that is the metals, so week 3 was for metals and for ceramics. 1st we talked about metals in which we have talked about ferrous alloy, nonferrous alloy and strengthening and degradation of these alloys. Then we went to the ceramics, we have talked about the classification and crystal structure, what is the uniqueness of the ceramic crystal structure and what are the mechanical properties of the ceramics, then that was our journey in the week 3.

Week 4, we started to talk about the polymers. So we have started with the introduction and classification of polymers and then with the polymeric structure, effect of important or very important property of polymer, which is called Glass transition temperature and then the mechanical properties and parameter models. Now once we have completed metals, ceramics and polymers, what is left for us is to tackle 2 advance sets of these; the 1st one is the composites.

So week 5 we devoted to the study of composites in which in the very 1st lecture we have talked about classification, properties, longitudinal and transverse modulus of elasticity of composites and then following lectures we have talked about fibre reinforced composites like polymer matrix composites, ceramics matrix composites and the metal matrix composites, et cetera. We have also shown you that the hand layup, spray layup technique, Pultrusion,

(())(29:05) how exactly composites are made using transfer moulding, pressure and vacuum bag composite manufacturing technique, et cetera, that is our journey in week 5.

Next we came to the very last set of advanced materials, which are the smart materials. In that series, I 1st discussed with you that what the smart materials are, what are various types of smart materials, what are the properties, what are the advantages of smart materials. Then I have talked about piezo electricity, I have talked about magnetostriction, I have talked about smart polymers and shape memory alloys, with that we have concluded the week 6 and in which we have obtained the very good glimpse of some of the very widely used smart materials.

Then the week 7, we started to do some amount of design process. The design process that is mostly relevant for us was inspired from Ashby and that is material selection for mechanical design. So, we have 1st given an introduction to this material selection, what is this design process, what is an eco-efficient way of selecting materials, what are the Ashby charts, etc and then we have started to solve some problems which needs your knowledge of this course as well as a bit of basic background of the strength of material.

So in the case study section in week 7, we have studied how we need to choose the material for a cantilever which has a high stiffness and lightweight, and then in the next how to choose a material for a cantilever which has high strength and lightweight. Then we also talked about connecting rod problem, when fatigue and buckling load both comes into picture, so in a sense it is a multi-objective problem. And also we have talked about a cantilever for scanning probe microscope, which is from the dynamic application point of view is very relevant, so that was our journey in week 7.

Week 8, we have concentrated on properties which are not mechanical but are associated with mechanical design. In that non-mechanical property set, we have 1st talked about the optical properties, then we have talked about the optical fibre and this is followed by thermal properties, we have done once again a material selection study, a numerical work on material for heat exchanger based on Ashby approach and this was followed by electrical properties in which we have 1st talked about the conductivity and conducting materials, then we have gone through the dielectric material and materials for heat sink.

In the final set, I have talked about the magnetic properties of materials. These are the most essential non-mechanical properties that are always associated in a mechanical design.

Finally, I thought that I will show you that how to use an advance laboratory in order to determine some of the mechanical properties and demonstrate also some of the advanced materials like smart materials, how they are used for sensing and actuation. So towards that direction and the very last lecture, I have shown you the laser Doppler Hydro meter, the macro fibre composite, the antenna shape control using SMA, optical fibres and magnetic levitation.

So this is where we have completed our journey in the nature and properties of materials, I hope that you have enjoyed this course and I will be very much interested to get feedback from you with anything you want to know. And if you want to pursue a career in this direction, please do it and touch with me. Thank you very much and I wish you all the best, by.