Mechanical Vibrations

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Module – 1
Introduction
Lecture - 1
Overview of the Course, Practical and Research Trends

From today, we will be starting a new subject that is called mechanical vibration. And this particular topic – before we enter into this topic, let us see what are the things already you have studied regarding this course. You must have studied the engineering mechanics course in which you dealt with a rigid body members, especially the forces associated with them. And then you must have studied the kinematics of machinery course in which we dealt with displacement velocity and acceleration of machines and mechanisms and the basic, because the forces are also associated with… when we are considering the motion of a machine. But, the dynamic aspect of that – that means force analysis and the kinematic analysis of the mechanism – we separate based on the rigid body of the various members of the machines. So, if body of the machines are rigid, there will not be any… We can able to decouple the kinematic analysis and the force analysis separately. And based on this, you have already learnt two courses on kinematics of machinery and dynamics of machinery.

The problem comes when there is a deformation of the various members of the machine. When the deformation is there or the members are flexible, then we cannot decouple the kinematic analysis and the dynamic analysis of machine or mechanisms. In that case, when we are analyzing the motion of that flexible member machines, force also we have to consider simultaneously for the analysis. And this particular… And especially when the member is having flexibility and it has some mass, then they generally start oscillating; oscillations or oscillatory motions take place when they are subjected to the force – especially the dynamic forces. So, in this particular course, we will be seeing this aspect. When there is a time-dependent force in any machinery members, we have oscillations of various members – oscillatory motions.

Oscillatory motion in general you can able to see it is present everywhere; even as a human being, our heart itself it beats; our lungs when we inhale the air or when we take outside the air from our nose, the lungs also have oscillatory motions; when we walk, then also our arms and our legs – they oscillate; and even any other part – means member like any other machines; or, even the earth also oscillate during the earthquake. So, even the planetary motion – you can see they have oscillatory motion, periodic motion. So, every matter or every machines – they have oscillations during their operation. So, these particular oscillations when it takes place? As I have already told that, when we have the elasticity in the members of the machine or structure and they have mass, then they are capable of oscillating it. So, when we design any structure or machine, then we have to consider the vibration aspect or the oscillatory motion aspect of these systems especially in the design stage, so that when we fabricate these structures and machines, there should not be any operational difficulty.

These oscillatory motions can be broadly classified or characterized in two things: one is a linear motion or linear systems and another is the non-linear system. In non-linear system, when the dynamic system is linear, then whatever the methods available for analysis of such dynamic systems are well-developed. And even that theorem of principle of superposition holds; and because of that, most of the cases we can get the solution. And on the other hand, when we talk about the non-linear system; and those systems requires abstract mathematics for solution of third dynamic system. And most of the cases, we may not get the clues from solution and we have to be happy with only approximate solutions especially because the theorem of superposition does not hold for the non-linear system. And because of that the difficulty comes in solution of the non-linear dynamic systems.

Actually there is no as such clear distinction between the linear system and the non-linear system. All the systems are basically non-linear; only the assumption is that, when the oscillations are small – the amplitude of the oscillation is small, then we can consider them as linear. So, that is, a linearization is some kind of approximation in this for the solution of the dynamic system. And there are… If we go more detail on the oscillatory motion, there are two classes of vibration we consider: one is the free vibration and another is the forced vibration. In free vibration, as the name implies, we disturb the system and we let it allow it to oscillate its own; we are not applying any external force to the system. And because of its inherent forces, that is, the elastic force and the damping force and the inertia force, it oscillates its own. So, that is called free vibration.

And another one is the forced vibration in which we apply some external force like there is an unbalanced force in a disc. So, it is continuously it will be applying the force to the rotor. And because of that, it will be having some kind of oscillation or which sometimes we called welding of shaft. So, these…

Also, there are not necessary we will be having simple forces like sinusoidal force; sometimes we can have complicated force in which… Or, I should say the random force can also exerts; like during the earthquake, we have a random vibration of the earth. Or, like in the bridges, because of the air – the wind, it may have oscillations – that also will be random in nature. When we are talking about free vibration, then there is a system property that is called natural frequency, which depends mainly on the stiffness and the mass of the system. And this is the characteristic of the system. And for any dynamic system, our main aim would be to obtain the natural frequency of the system. Especially this is important when we are considering the forced vibration, because in forced vibration, when we have some force, which is having some frequency; if that frequency is coinciding with the natural frequency of the system, then we call that as a resonance condition. And that is very dangerous and that may lead to the failure of any structure; even the bridges and even any other structure can fail if it is getting into the resonance condition.

And, specially, the natural frequency – it depends upon the system property and it can be have different… The natural frequency can be any number; like if there is a single mass, which is attached to a spring, then it will be having single natural frequency. But, if it is having more number of masses, then it may have many natural frequencies. And when it is oscillating in free vibration, then it may contain one or all of the natural frequency; that response may contain all natural frequencies in general. Whereas, when we are talking about the forced vibration; so when the force is having some frequency, the response will always be having the same frequency especially when we are talking about the linear system. So, always the response – the forced response will be of the same frequency as the external force frequency, which we are applying to the system. So, as I told, the main focus of the vibration studies to obtain the natural frequency, so that we are aware that, when can we have the resonance condition.

There is another parameter in the dynamic system that is called damping. Damping – they do not have much effect on the change in the natural frequency. But, they play vital role especially when the resonance condition is there. So, when… Because of damping, the amplitude of vibration, which goes theoretically to infinite when there is no damping is there. But, with damping, generally the vibration of the dynamic system becomes finite. So, that is very crucial at the resonance condition. And since the natural frequency does not depend much on the damping; so in most of the analysis, we will find that, when we obtain the natural frequency, we neglect the damping, because it complicates the calculation of the natural frequency; especially those natural frequency we call as damped natural frequency.

So, now, we have already seen what is the free vibration, what is the forced vibration. Now, gradually, we will be introducing some other terminology like one is the degree of freedom. Degree of freedom is nothing but number of independent variables required to define the motion of a particular dynamic system; like let us consider one – a simple pendulum.

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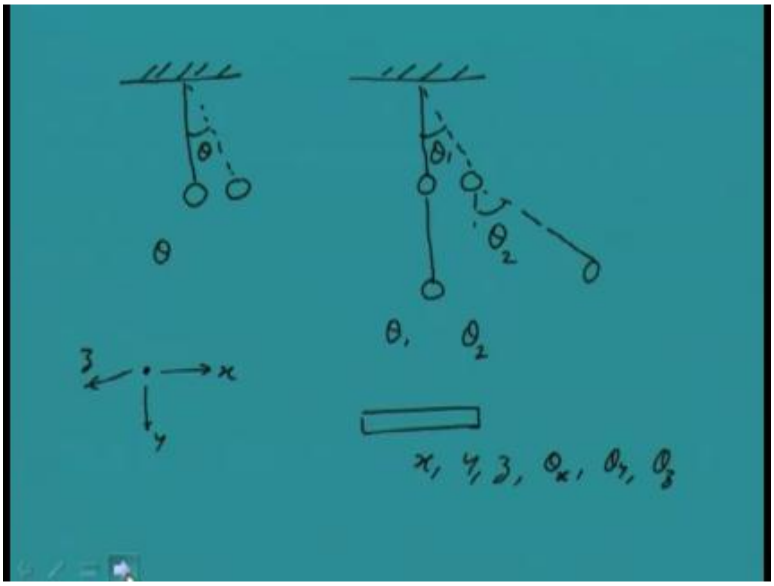

So, this is a simplest mechanical system, which has the oscillatory motion – it is a pendulum. So, when we are giving a small displacement to this; so we can define the position of this particular pendulum with the help of a variable theta. So, is having a single degree of freedom when this particular ball is moving in one plane. So, we are giving a small displacement and we are allowing it to move in a single plane. And same pendulum – if there is another pendulum below that like this; if we disturb this, then maybe it will occupy some position here – let us say theta 1; and this will occupy some another position theta 2. So, you can see that, two variables are required to define the location of the ball. So, is having two degree of freedom. So, like ways we can able to find out a particular system, is having how may degree of freedom. But, in general, if you are talking about a particle, particle will be having three degree of freedom, that is, a particle can have linear motion in x, y, z – three directions. So, a particle is having three degree of freedom.

If we are considering a rigid body, then apart from the linear motion or we can have the rotation – three rotation of the rigid body; let us see this through a figure. So, if a particle is there; so it can have x, y, z – three directions or linear motion. But, if we have a rigid body, then it can have x, y, z rotation – linear motion plus rotation also like theta x, theta y, theta z. So, to define the position of a rigid body, we require six degree of freedom. And if we extend the same analysis for if an elastic or flexible beam… So, in flexible beam, we can consider that, it is consisting of an infinite number of particles. So, each particle is having three degree of freedom. And when infinite particles are there; so effectively a flexible member will be having infinite degree of freedom. So, that is why like a flexible beam can have theoretically infinite number of natural frequencies. But, generally, for the analysis purpose… because we cannot able to do the analysis of a system having infinite degree of freedom… So, what we do – we discretize this kind of members to small number of particles or small number of lump masses, so that we can do the analysis for finding the natural frequency of the system.

Let us come back again to the periodic motion. We have started with the oscillatory motion. Then, periodic motion – periodic motion is nothing but when the motion repeats after certain time; after its period, again it repeats. So, that is periodic motion. And when we have periodic motion…

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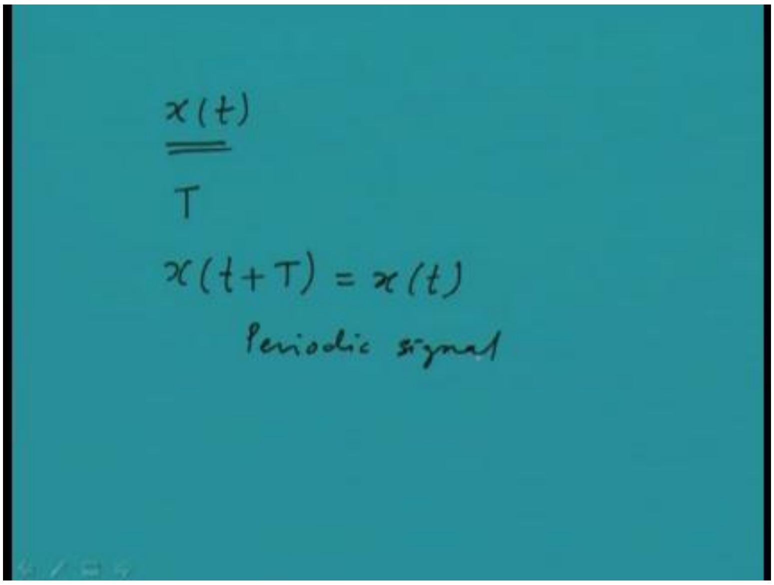

Or, if mathematically if we want to see, a periodic motion is… If a particular motion take place and if period of this motion is capital T, then we have the condition that, at this time, this will be equal to this. So, this is the condition of periodic signal. And when we… This periodic signal… Generally like if we take some example; if we are talking about a violin; then if we are disturbing the chord of the violin, then will be having frequency component, which is we call fundamental frequency; and there are harmonics; that means integer multiple of that fundamental of frequency will also be present when we will disturb the violin. And similarly, when we are talking about many mass or dynamic system, that is, multi mass or multi degree of freedom dynamic system in which the number of variables are more than one to define the motion of that system. So, in that particular system, we will find that, the particular response – the ((Refer Slide Time: 18:04)) response will contain so many natural frequencies simultaneously.

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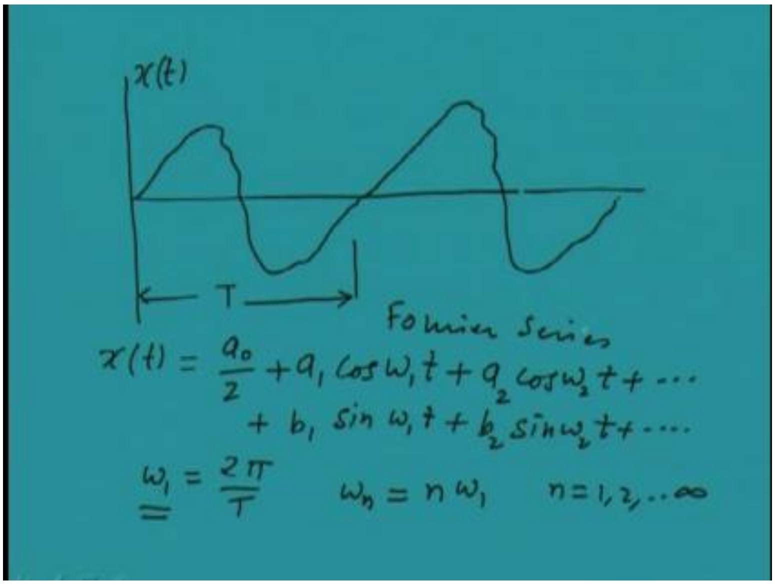

And, this kind of graph can be shown like this. Like this is a periodic signal I am drawing. This is the x t. So, maybe it is having this particular behavior; but, after this time, I will see that, similar pattern will be repeating; exactly same pattern will be repeating. So, this is the time period of a particular signal. But, after that, it repeats. So, this is a periodic signal. And we know that, the French mathematician – Fourier – he explained that this periodic signal can be split in sines and cosines terms and their harmonics. And that is, we call it as Fourier series. So, this periodic signal can be expressed in terms of the sine and cosine terms. Let us see what are those terms. So, if this is the periodic signal x t, we can able to express that signal in terms of some constant term and cos omega 1 t plus a 2 cos omega 2 t . So, like that we can have infinite number of terms, where a naught, a 1, a 2 – these are constants – plus b 1 sin omega 1 t plus b 2 sin omega 2 t plus we can have infinite number of such terms. And here omega 1 is nothing but 2 pi by T; T is the time period of this periodic signal. So, this is the fundamental frequency of this signal. And in general, omega n will be n into omega 1; n is some integer number. So, like 1, 2, 3 up to infinity. So, this is nothing but Fourier series.

And, in general, we will find that, a particular vibration signal will be periodic; most of the time it will be periodic. Or, if it is not periodic, then we assume certain length of such signal. And we assume that is periodic in that region and after that it repeats. And based on that, in subsequent lectures, we will be covering in more detail regarding the signal processing of these signals especially how we can able to transform them into the frequency domain using Fourier transform or discrete Fourier transform or more efficient fast Fourier transform that is called FFT.

So, before going to more detail mathematical treatment of the vibration and what is whether vibration is good for us or bad for us, because it is equally good and equally bad. If we are talking about automobiles; obviously, vibrations will give us some kind of discomfort because of the road undulations will be having lot of jerks during the travel. But, on the other hand, these vibrations – they give some indications regarding the condition of the machine. They give some sound is coming. Sound is also nothing but after effect of the vibrations only. So, if sound is coming from a particular machine, we can able to say that, there is some problem in the machine. So, in that way, vibrations are not good and not bad – both ways they are okay.

Another example I would like to give regarding the vibration, that is, the pulse of the human beings – the heart beat. That gives us the indication about the health of the human being; if there is healthy or not healthy, we can able to get the condition of the human being by using this vibration pulses. So, in that way, on the same analogy, we apply for the machines also, because machine is having so many components; like human beings, heart is there, lungs are there; so many… So, similarly, with the machines also, we have gear rolling element bearings, then we have coupling shaft, shields – so many components are there. And each components are having a unique pulse rate I should say or a unique frequency. So, using these vibration signals – if we can measure them, we can able to point out what is the problem in the machine; especially at very beginning, if some problem is coming, we can able to know what is the problem in the machine. Like in the human beings, if there is a problem of the heart; if we can detect that, there is some problem in the heart at very beginning, we can do some corrective actions, so that the human lives can be saved. Similarly, on the machines also, if we can detect the problem at early stage, we can able to rectify those problems. So, let us see some of the applications of this subject or in practical usage.

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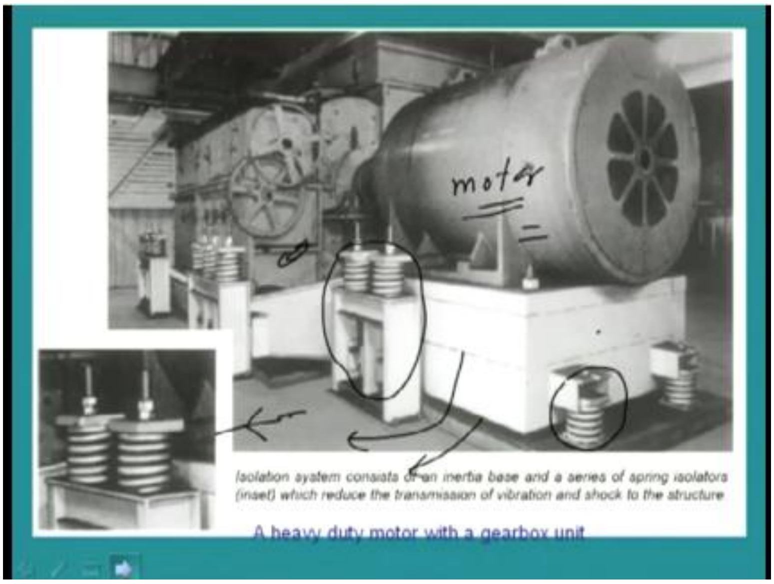

So, now, we will see some of the practical applications, where the vibration can help us in finding the faults or the health of the machine. This is a one unit especially to crush the stone or coal. So, you can see that, there is a big motor here; and gear box is here. This particular box is gear box. And you can see that specially, because it is transmitting very high power – this motor. So, lot of vibration will take place and… So, to reduce the vibration, you can see there are some devices, which has been provided. This is something like shock absorbers, which are there in the automobiles; you can see the springs. And there is some damper inside also, which dissipate the vibration energy of this particular system. And… So, this is one example of a vibratory machinery. You can see here the close view of the oscillatory system. Generally, we have provided this oscillatory system, so that vibration should not go from machine to other foundations, because they may disturb the nearby machines. Also, if lot of vibration is there in the machine itself, then we will be having failure of some of the components due to the fatigue, because it gives cyclic stresses to the members.

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So, let us see another machine. This is also a stone crusher or specially used in the cement factories. So, here you can see there is a motor, is a very high power motor. And this particular component here is gear box. And it is giving power to a crusher unit, which breaks the stone. So, in this also we have a lot of vibrations. And these vibrations... So, whatever the signals are there or the signature – vibration signatures are there – they give us the indication of the condition of the machine, because in machine, various components are there; I will be showing some of the components subsequently.

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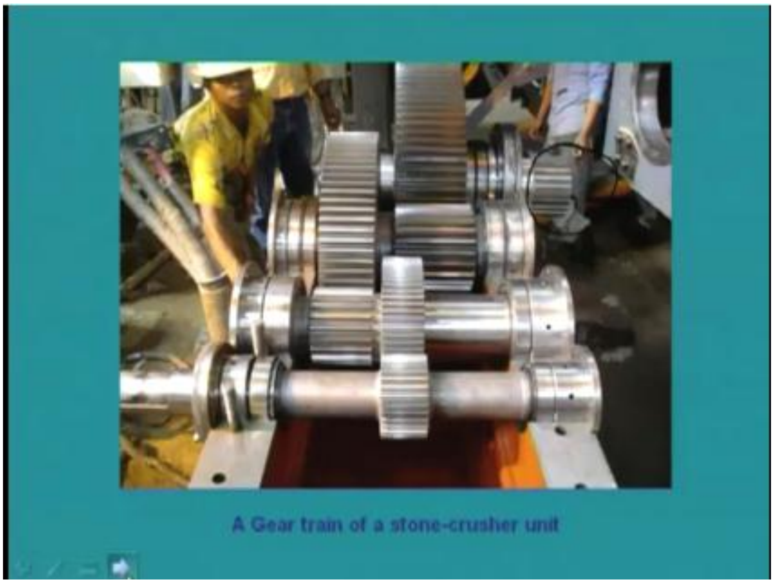

Like this is the gear box, which is… This is the gear train, which in the previous slide was enclosed in a chamber. So, you can see… So, these are the gears. And they are transmitting very high torque. And because of that, their failure may take place. And they are quite large in numbers. So, any of this teeth – if it is broken, we may in trouble, because it will give lot of vibrations; and because of that, other members will also get damaged. So, one of the member, which got damaged; especially this part if you see – spline shaft – that got damaged.

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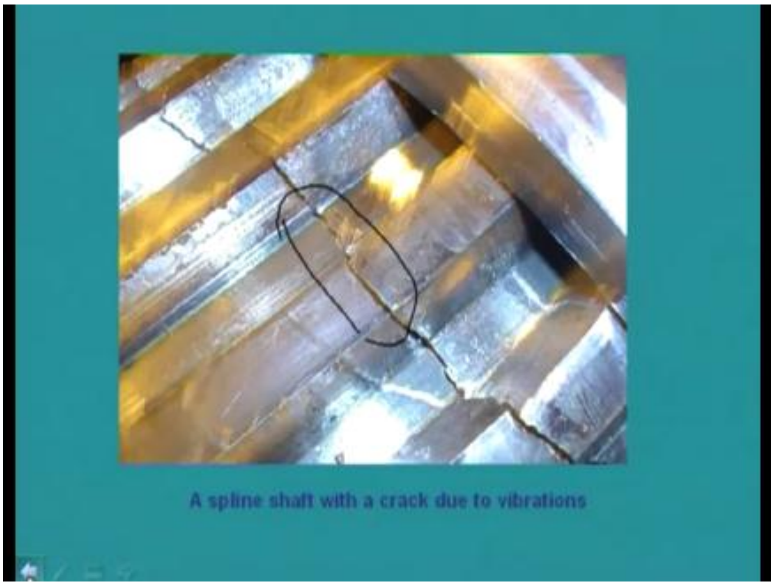

That view is in the next slide. You can see there in that spline shaft, these are the cracks developed. So, these are through cracks you can see. So, these kinds of failures we can able to detect by measuring the vibration outside the casing of the gear box.

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Like these kind of failures – if we put, accelerometer may be here; or, here to measure the vibrations, we can know when this particular fault is appearing in the machine. Just by observing the vibration from outside we can know the condition of the machine from inside. So, this is one of the application, where we can have the advantage of the vibration signature for health monitoring of the machinery.

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This is another power plant machinery. You can see that is a big machine and these are the various stages of the turbines. These are various stages of the turbines. And you can see so many components are involved. And if any of the components is getting failed, the whole train of these turbines shafts will get stopped or they may get damaged. So, condition monitoring of these kind of machinery through vibration is very important, because they carry large power. So, the dynamics whatever is taking places inside the machinery reflects the condition of the machine. And that is nothing but the after effect of that is vibration. And that gives us how good or how bad or which component is behaving nicely or which is not functioning properly.

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So, another slide is this one you can see. These are the very heavy machinery and they are very complicated. And when they are in operation, the noise is so much we cannot able to find out is whether there is some problem inside or not unless otherwise you have some are very sophisticated instrument to measure the vibration and then to analyze those vibrations, because vibration signatures are also quite complicated. Or if we take the measurements of such big systems, they are very complicated. But, in this course, whatever the study we will be doing; with that as a background, a person can able to find out or he can able to see the signature or a vibration signature or signal; and he can able to pin point what kind of problems are there in that particular machinery. Is similar to the ECG of a human being through which a doctor finds whether the heart is having some problem or not. So, it is identical to that.

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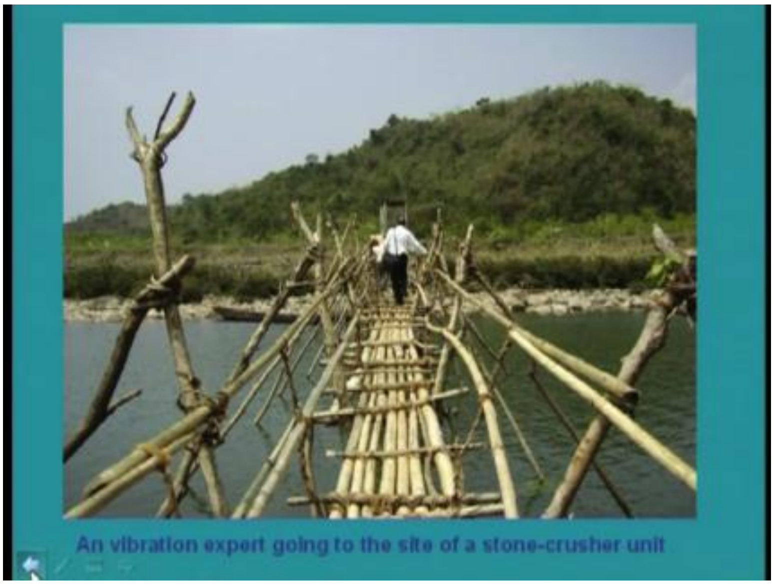

One problem with this kind of… Let us come back again. One problem with these kind of vibration signature analysis is most of these machinery will be placed in a remote place. So, if someone – some expert need to get the access to these data; obviously, he has to visit that remote place like this, because most of the machineries – they will be in such a remote place, where the accessibility is a problem.

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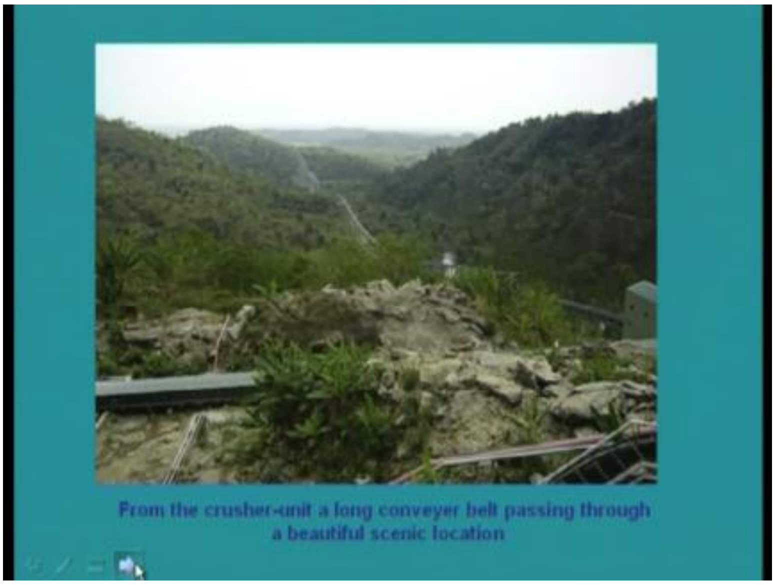

Or, maybe the scenes or the beauty will be… The scenery beauty will be good, but an expert – vibration expert – he cannot visit several time. Or, whenever there is a failure in the machine, always he cannot go or he cannot be there continuously there, because that is a remote place. And maybe the failure is taking place in three months or after one year. So, there has to be some system by which these experts can have access to these data continuously throughout. So, we will see what are the possibilities and how through this computer age can help us in analyzing this data when an expert is sitting in a single city and he is getting these data from various places from the remote place.

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So, let us… So, this is one particular unit in which some of the experts have visited the site. They are measuring the vibrations at various places. You can see the environment is not good, because the noise level is very high. These experts may get fatigue. So, they may not think properly how to analyze those data. So, maybe they will just store the data; come back to their places and then they will analyze.

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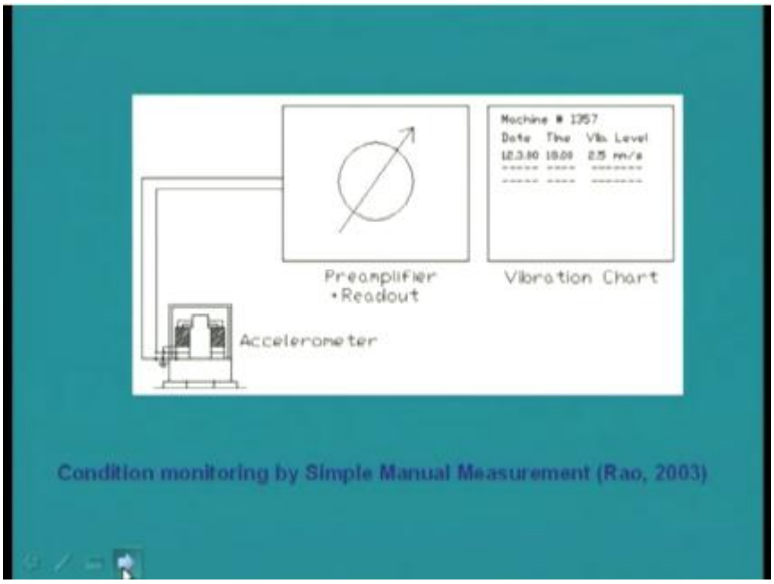

So, this is the conventional way of analyzing the data. So, in which… This is a pictorial view of the overall – how we can able to find out the condition of machine. This you can see the accelerometer, which measures the acceleration of a machine surface. And this instrument, which gives the read out maybe after amplification, how much is the acceleration or displacement is there. And manually if we want to find out the condition of the machine, manually maybe you can ((Refer Time: 33:49)) Every day we can record this with time and details. And these charts can be prepared, which will help us in the diagnostic of the machine fault. These are the conventional way of doing it in which we are just using the raw data; just we are bothered about the RMS or the peak to peak value of the vibration and we are recording that.

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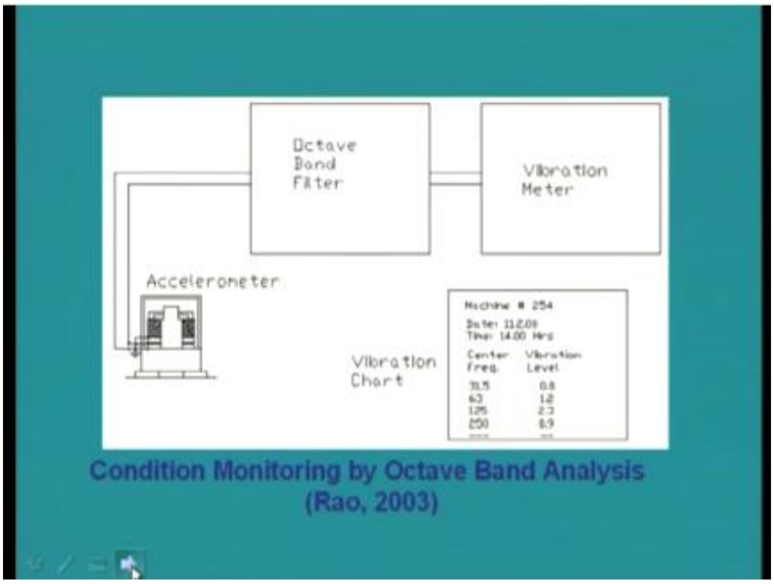

Then, there is some more sophistication can be done if we use some kind of filters. This is an octave filter, which is slightly broadband filter; and it gives the vibration. In this we can have certain range of frequencies, where we are taking the measurements. Other frequencies we are eliminating them, because as I already told, various machine elements – they give different frequencies; like rolling element bearings – they give… If there is a fault in the rolling element bearing, they give frequencies much higher as compared to gears. So, if we are measuring the vibration at different frequencies. And at those frequencies, if some of the level of vibration is high; so we will be having some idea – which member is getting failed.

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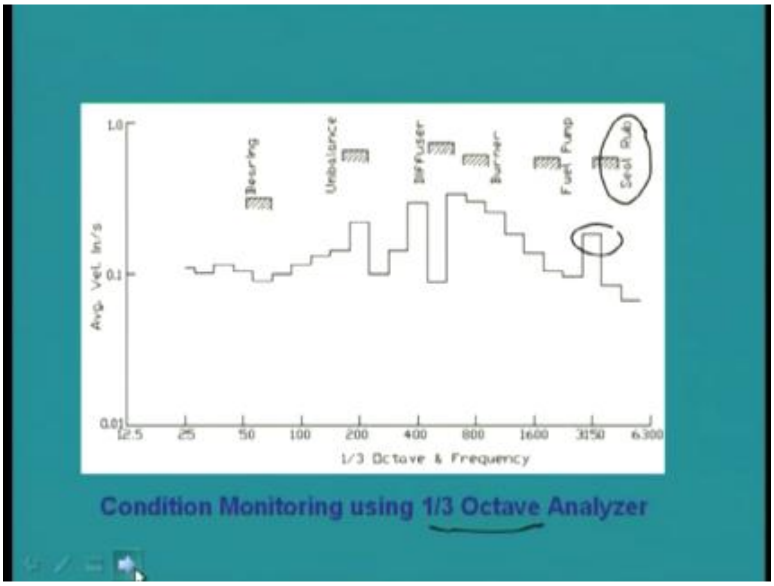

So, this is another slightly improved filter, that is, one-third octave in which we can have narrow band pass filter. So, you can see that, here various amplitudes of various frequencies are plotted. This is frequency and this is the amplitude. So, some kind of a variation at various frequencies – how the amplitude of vibration is changing. So, you can see that, here this is an amplitude is high and that is related to the sealed rub. So, we have some correlation between the frequency and the various components of the machine like seals. This is the pump – fan pump; this is burners. So, various members are there and they are giving different frequencies. So, this is one way of finding the faults in the machine.

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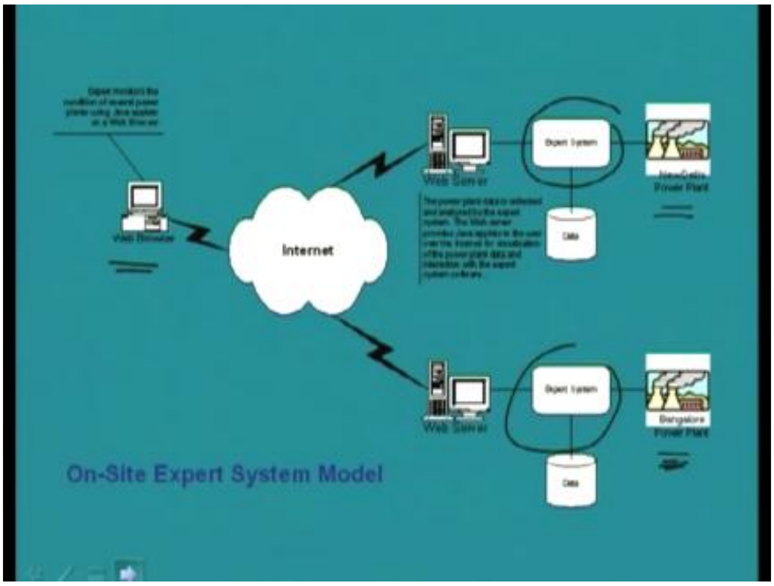

More sophistication now we can able to do through the internet and the expert systems. So, in this particular scene, you can see that, there are plants at various places; maybe one is in New Delhi and other is in Bangalore. And here we are extracting the data; giving it to the expert system. And this expert system is based on the prior faults, which has occurred; based on that, it has some sets of rules and some knowledge in the form of data. And whatever the information is getting recently, it compares with the previous data; and then indicates – if there is some problem, then it indicates that there is a fault in some member. And these data can be fed to computer and it can be send through internet to other places also. So, another improvement in this is instead of expert system at various locations, we can have expert system in one location.

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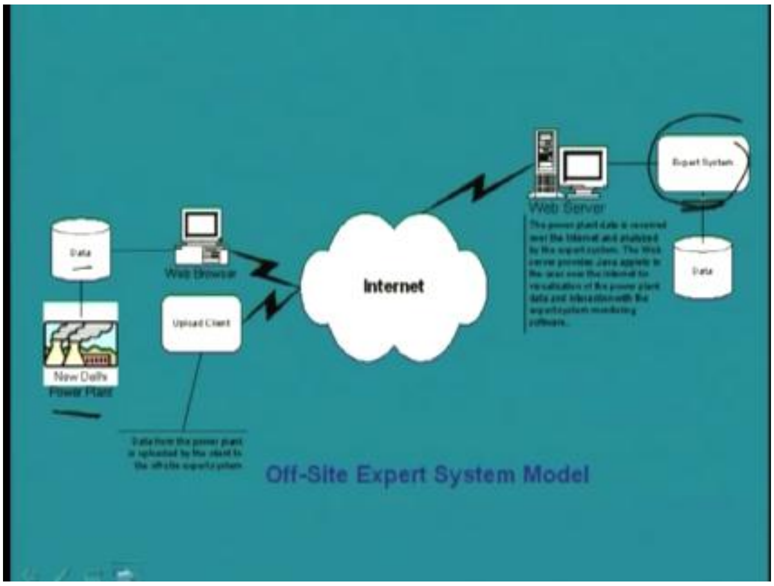

That is, here. So, in New Delhi, some plant is there. They are capturing the data and they are sending it through internet to a central place. There one place expert is sitting and he is analyzing the data; and he is then sending the information back that, there is a fault in the machine or not; the condition on the machine he can mention. So, there is no need to visit of an expert to the site; it takes time to reach there. Also the problem is to carry all the instruments. And so these problems can be sorted out if we use internet based expert systems.

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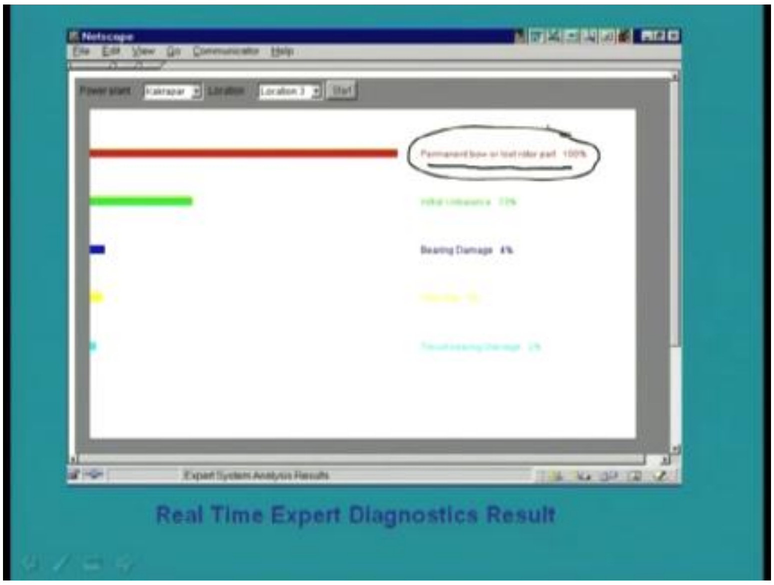

This is a typical plot from an expert system. You can see that, based on the recent data captured from the machinery, the expert system is predicting the probability of various kind of faults in the machinery. And you can see that, the maximum probability it has assigned to the permanent bow or loss of rotor part in a particular machine. And others are having less probability. So, you can able to see that… We can look for this particular fault in the machine and we will try to rectify it, so that it should not damage the other component of the machine. So, we have already seen what is the vibration and how it can help us in diagnosing the fault in the machinery. So, now, let us see in just brief outlined of what are the different kind of measuring instruments and the analyzing instruments, which we have, so that when we will be going into more detail mathematical background of the vibration, we will keep these in mind that. Finally, we have to use these instruments properly and analyze the signal, which we are getting properly; so that we can have a better understanding of the vibration signal and the fault associated with the machinery.

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So, these are the various sensors, which we use for measuring the vibration. First one is the displacement sensor. This is the displacement sensor. This is a non-contacting type sensor; we keep gap a between the rotor and this sensor certain amount. And when the shaft is having vibration, this gap changes; and that is proportional to the voltage which it generates. And that we can able to convert in the form of – there is displacement. There are other kinds of sensors; these are the accelerometers, which are mainly piezoelectric based. And these are various kinds of accelerometer depending upon applications how to choose them; due course we will learn, because none of them is universal accelerometer; depending upon the application, we have to choose them. This is another instrument, that is, a sound level meter by which we can able to measure the sound level.

There is another – some kind of pocket vibration meter I should say. This gives all displacement velocity, acceleration components maybe RMS or peak to peak value of that. And this is the microphones, which… These are also we can see that, variety of microphones are there and you can see there this tiny one – they are having very high frequency component; even the sonic boom. Those frequencies – they can able to capture very accurately. So, these are the various vibration and sound measuring sensors.

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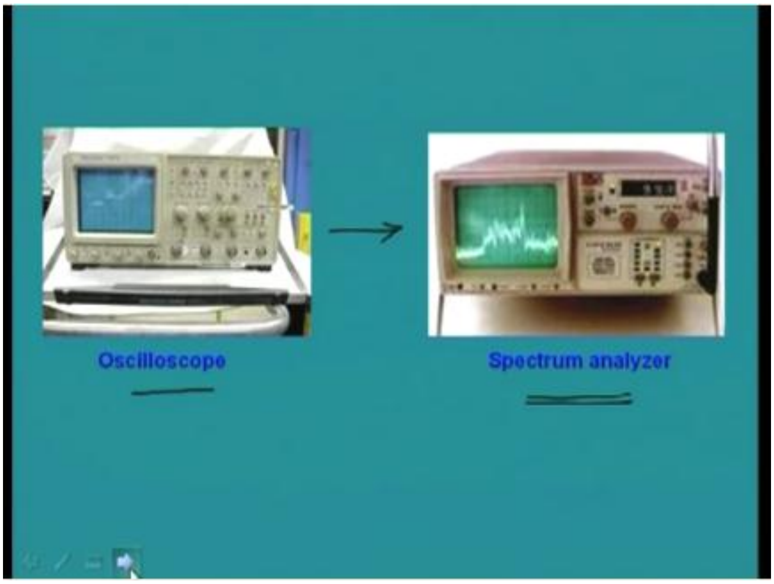

This is the oscilloscope, which gives the signal, that is, the vibration signal with respect to time. So, horizontal axis will be time, and vertical will be the magnitude of the signal that can be either displacement velocity or acceleration or voltage. And this is the spectrum analyzer, which converts this particular time domain data into the frequency domain. So, various frequency components as we have seen that, a periodic signal through Fourier series, we can able to convert into sine and cosine terms. So, it is similar to that it is doing it – this spectrum analysis. It does digitally and you can see various frequency components of a particular random signal.

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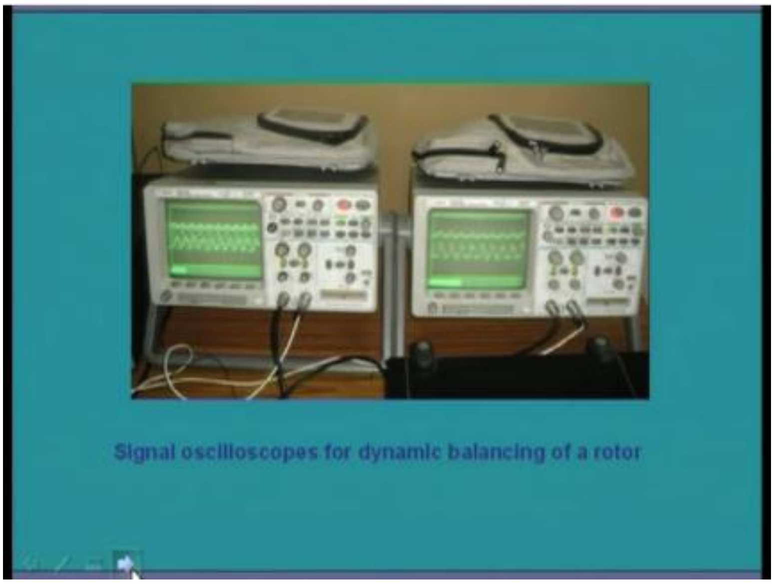

These are… This is again, you can see the oscilloscope in which we are having two signals simultaneously in a particular oscilloscope. There are two oscilloscopes. Especially during the dynamic balancing of rotors, we measure the vertical and horizontal displacements. And we need to obtain their amplitude and phase with respect to some reference mark on to the shaft. So, the upper one is the reference signal and the lower one is the actual signal. So, the upper one is used to obtain the phase of the vibration signal.

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This is another device that is called impact hammer. Any dynamic system if you want to excite and want to see what are the various natural frequency of system is there; we use this hammer. As name implies, is not literally hammered, but we have to just tap the dynamic system or the structure or the machine. Just tap and then it has… If you see here, there is a force transducers. So, how much force we are imparting to the structure – it can give us in time domain. Here you can see various kind of the tip of the hammer is there. So, it varies from rubber, aluminum to steel depending upon what kind of frequency we want to impart to the structure. These are the force transducers, which gives us the force; you can see the chord here. So, from this, we can take it to the instruments and we can display those forces with respect to time.

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This is another kind of exciter. These are mechanical… These are the electromagnetic exciters. We can place any object here and we can able to give the excitation to this particular object. We can vary the amplitude, frequency, phase and we can able to find out the dynamic characteristics of any particular object. So, they also have different sizes depending upon their capacity.

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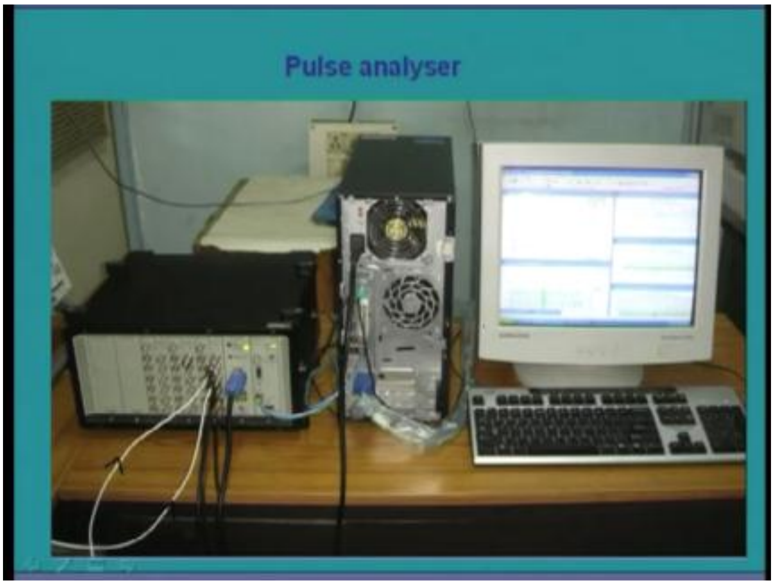

Once we have captured the signal from the various instruments, then it goes to the analyzers. This is an analyzer, which… because whatever the signal we get from the sensors, they are analog in form. So, we… If we want to further process those data, we need to digitize them. So, for digitization of that, it would be converter; and apart from that, it condition the signal, because some noise is there. So, those unnecessary noises it eliminates and then it digitizes in a computer hardware. And there are softwares also available through which we can able to display this data directly on to the computer. So, we can able to see the signal directly and we can able to find out various frequency component of the signal. So, it indicates what kind of faults are there in the machine.

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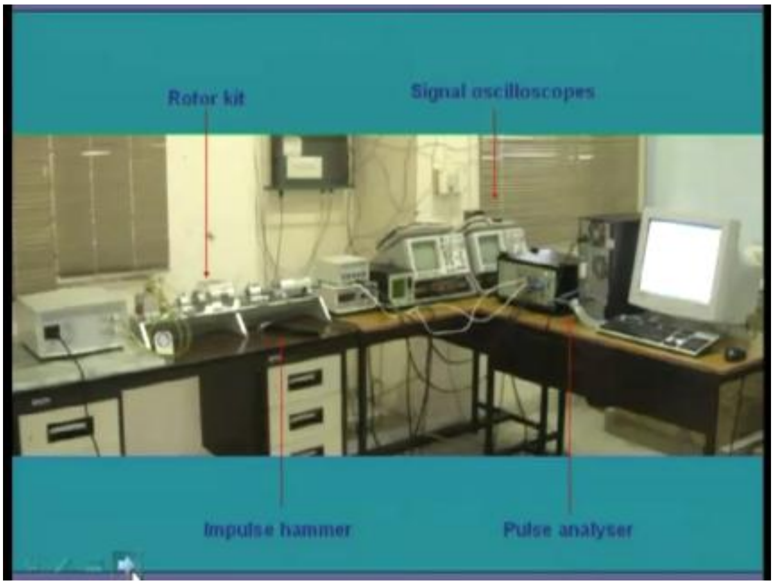

Then, this is another laboratory setup. You can see a typical laboratory in which this particular is a rotor kit, which is having all the inbuilt sensors to measure the vibration of a rotor or bearing and even the control of the motor of… Means through motor, we can able give a constant speed to the rotor or we can able to give some kind of acceleration to the rotor, so that it goes from one speed to another speed with some acceleration. And various instruments like oscilloscopes – these three are already shown. This is digitizer and software related to the processing of the signal.

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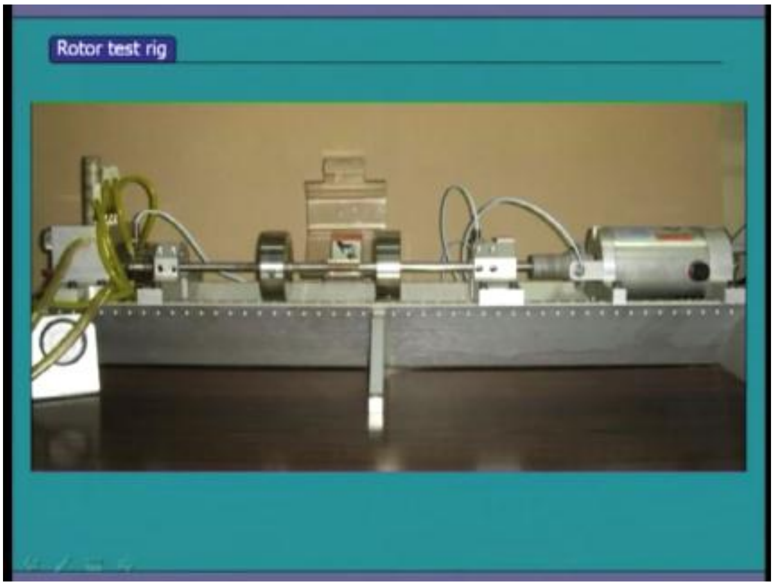

This is the close view of a rotor system. You can see that, these are the discs. This is a shaft motor is here. And these are the sensing probes.

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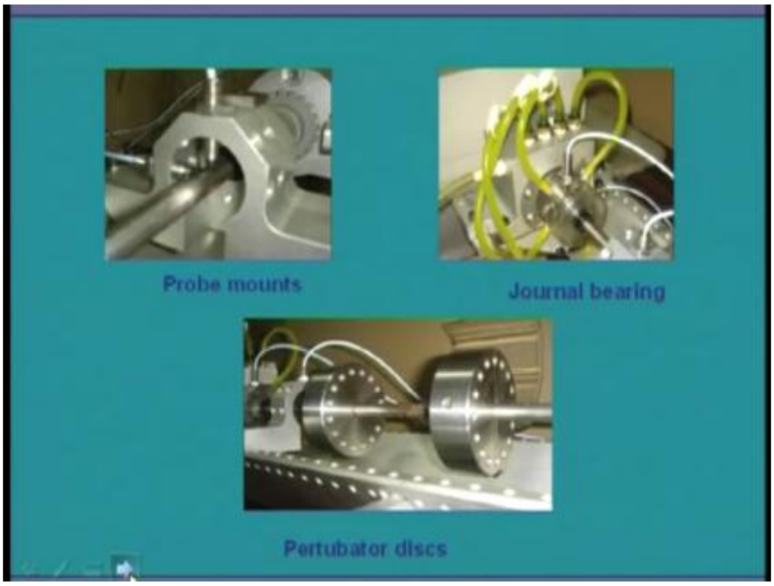

We will show the close view of that how to mount these sensors. This is a proximity sensor. So, there is a gap between these sensors and the shaft. And when shaft is having some displacement, they give the displacements in the horizontal direction and the vertical direction. This is a fluid film bearing. You can see various taps are there through which we can able to measure the pressure variation along the circumference of the bearing. These are the displacement probes, which is measuring the displacement of the bearing. This is the close view of the disc. You can see that, there are holes on that; we can able to put some kind of known unbalanced force in that to simulate some kind of force vibration in the machinery.

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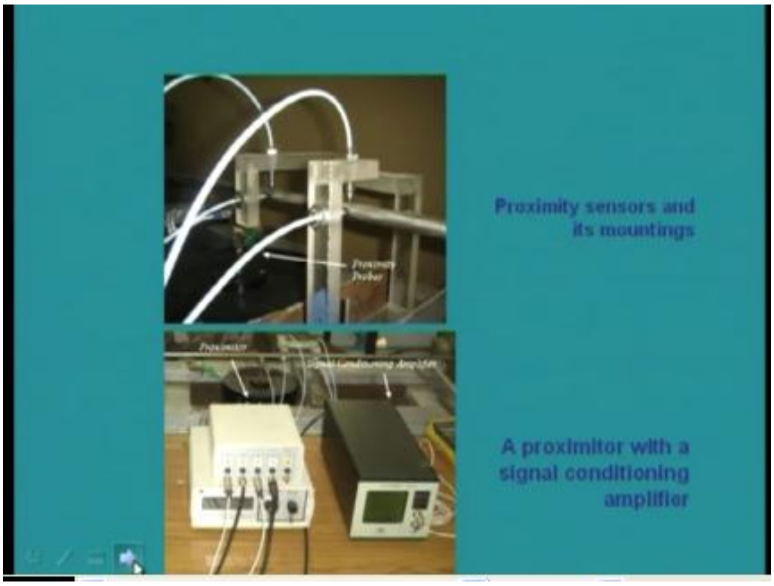

This is a close view of the proximity stand – vertical and horizontal, is measuring the vibration of a beam. These are the amplifiers, because these signals, which are generated in the voltage form – it has to be amplified and then we can able to display them.

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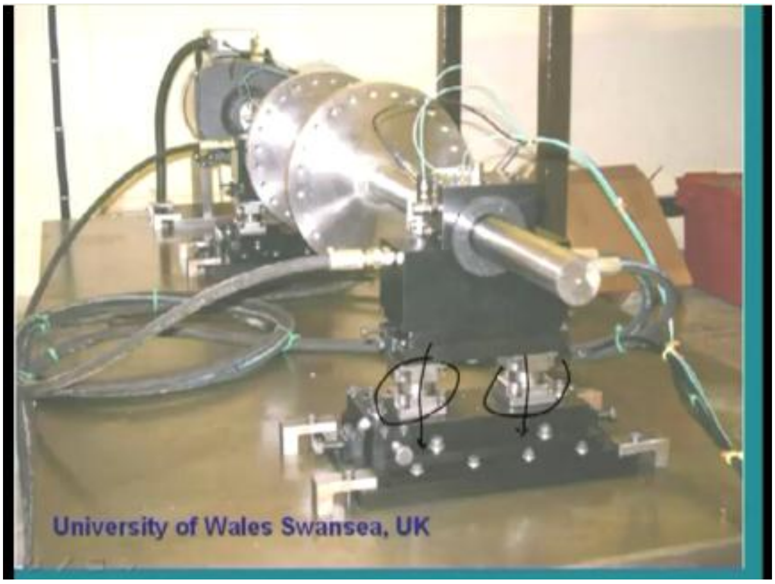

This is another view of another rotor in which some more sensors. We would like to say this particular… You can see these are the force transducers, which are there in between the bearing block and the foundation. So, basically, it is measuring how much force is getting transmitted from the rotor to the foundation. So, they can be measured. Apart from that, other sensors are there – accelerometers…

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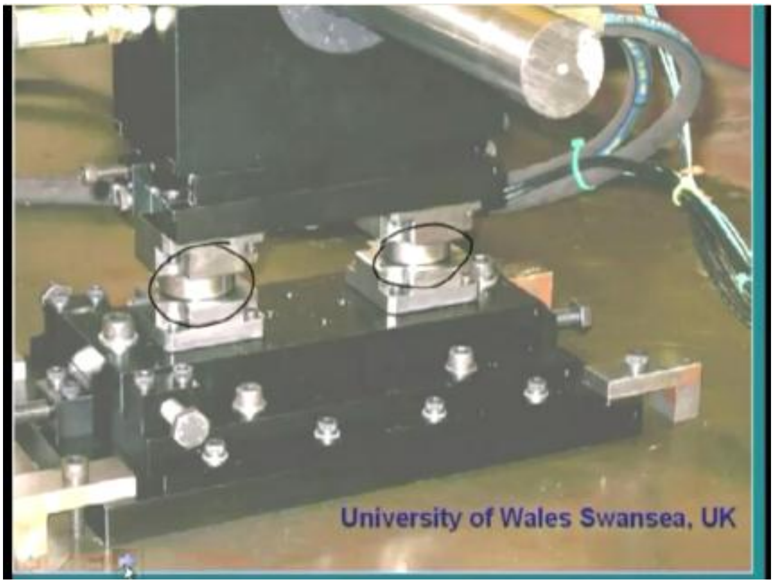

This is a close view the force transducer, which is measuring how much force is being transmitted to the foundation through bearing.

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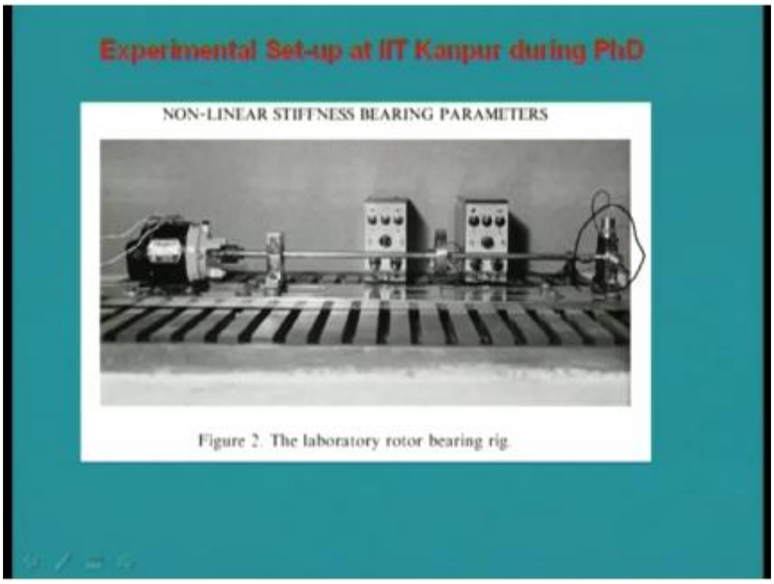

This is another setup. You can see there is a solid foundation. Generally, we need that when we conduct the experiment, so that whatever the vibration we are having here; it should not go to the other instrument, which is nearby. And here you can see this is a motor, which is rotating a shaft, which is mounted on two bearings. And this bearing is having measurement or accelerometer.

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Other view that we can see here.

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Or, here is more closely we can see. So, this is the vibration of the bearing we can able to measure using these accelerometers and we can analyze those for finding the condition of the bearing.

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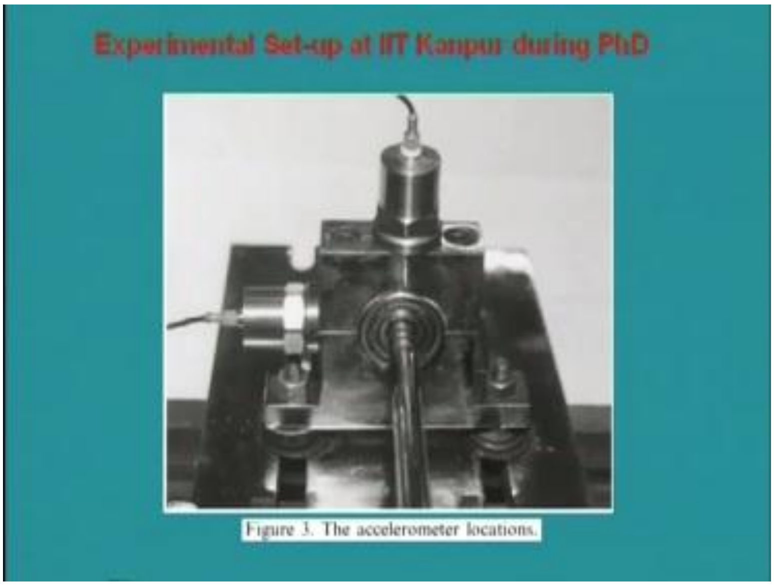

This another view of the same bearing block.

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This another setup; you can see that this particular support is having springs. So, these are laboratory setups, so that we can simulate the real life turbines, because any method for finding the fault in the machinery can be checked in these small setups. And then it can be applied to the real machineries.

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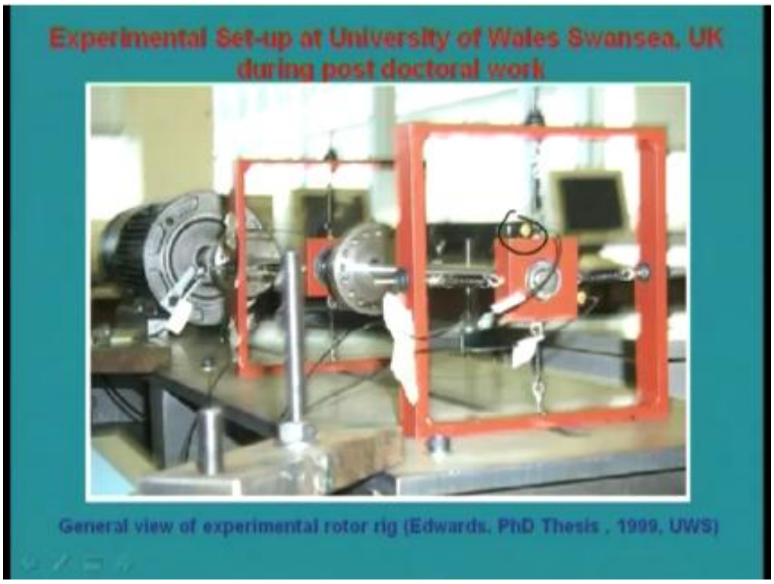

So, here also you can see various sensors closely. So, here there is accelerometer on the bearing block; they are measuring the vibration of the bearing.

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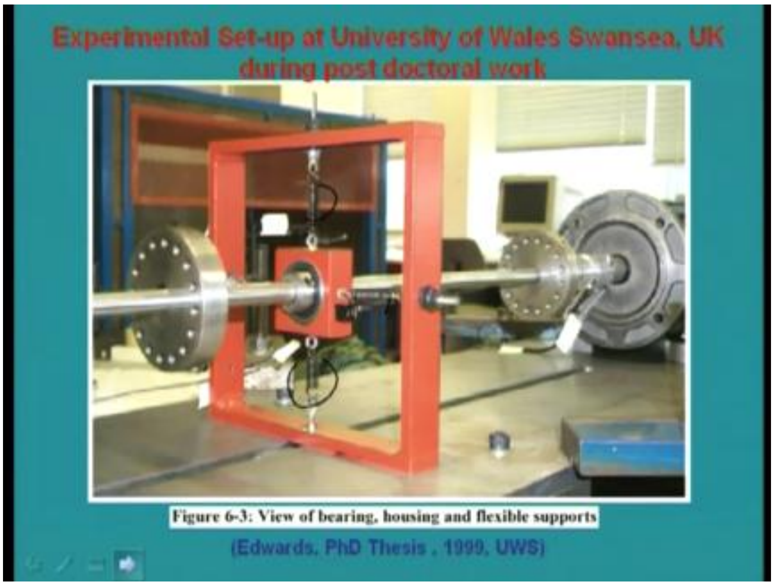

Here this – you can see this bearing block itself is mounted on springs, so that it can have more vibrations, which we can able to observe clearly.

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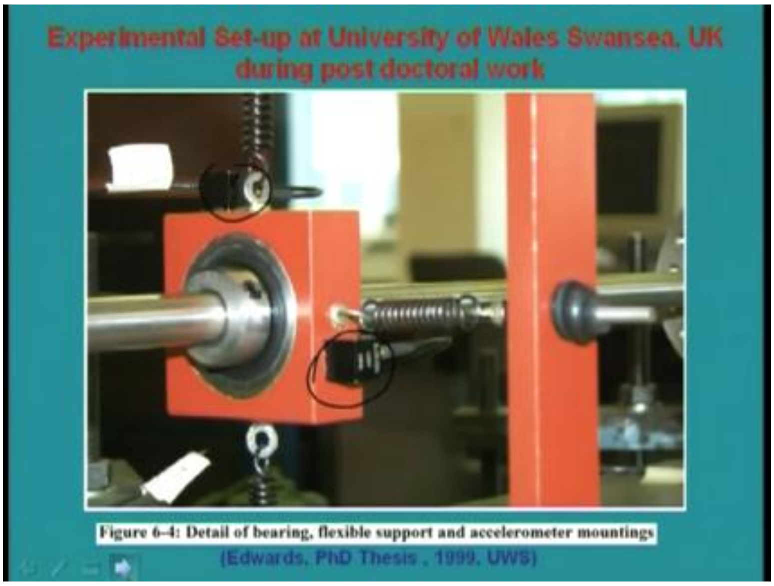

A close view of the bearing block; these are the springs; this is the accelerometer – two sides; here also. So, they are measuring the acceleration in the horizontal direction and vertical direction of the bearing block.

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Is the close view of this coupling. This is spiral cut is there in this particular aluminum block. So, it gives torsional flexibility. So, when the motor is rotating the rotor; if there is some disturbance in the motor; due to this torsional flexibility, it will not transmit to the rotor. So, these cuts are spiral in nature. And here you can see there is another proximity probe, which is giving… We can have one under cut on this, so that whenever this comes here; we will get a pulse. And that can be used to obtain what is the speed of this particular rotor. Or, even it can be used for phase reference of other signal. So, now, we have already seen various kind of measuring instruments and analyzing instruments. Let us see what is the typical vibration signal, which we get from these machineries; and that will give us some idea – how they look like and what we should seek during the measurement, so that we are aware that, these are the kind of information we should look when we are trying to measure vibrations in a particular machinery.

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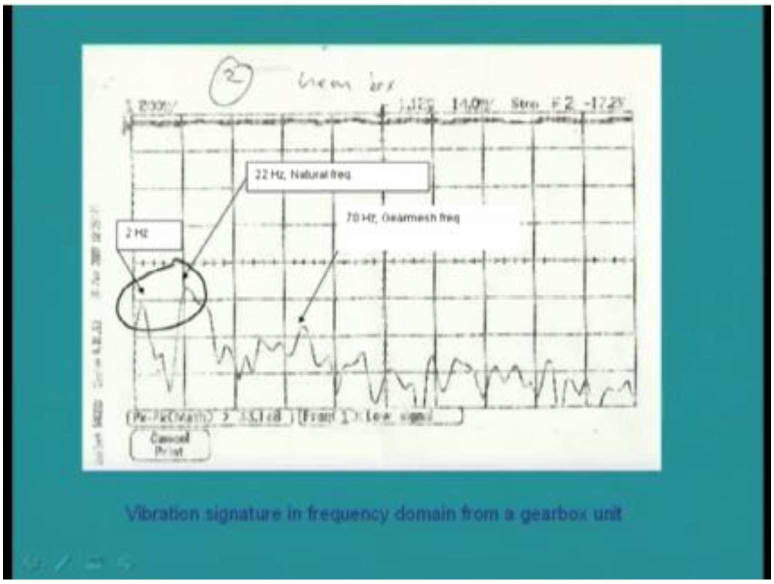

So, first one is generally in the oscilloscope, you will find that, the upper one – especially this one is a time domain signal. You can see that, it is very iritic; nothing you can be able to make out from this. And the lower one – this one is the FFT of the above time signal. So, this is the frequency domain signal. You can see that, this is having some peaks, that is, the vibration amplitude in these frequencies. Some of the frequencies are very high. So, these are of our concern why they are happening; why these peaks are coming in the signal – they are of our concern, because a particular frequency – if it is coming high; like if you are measuring the human heart beat; and we know what should be the heart beat of frequency of the heart beat. And if we get the amplitude very high corresponding to that, we will be worrying what is happening to the heart.

Similarly, in the machinery, we will be having several machine components; every machine components will be having unique frequency. And if a particular frequency is having very high amplitude; then we will be worried what is happening to that particular component. So, you can see that, this particular signal, which is frequency domain is contains lot of information. And it is the expertise of us to find out what is representing what. So, to understand these signals, we should have the sufficient knowledge of the vibration theories; also, what kind of… that is… and how to obtain them; means once you have knowledge and how to calculate them – this particular component will give what frequency; how to estimate them. That is the expertise of this course through which we can able to… After the end of the course, maybe you will be having sufficient expertise to have understanding of these kind of signals. You can see that, especially the time domain signal – they are not periodic; they are very random. So, we need to find out what are the information they carry, so that we can able to focus our attention towards the condition of the machine.

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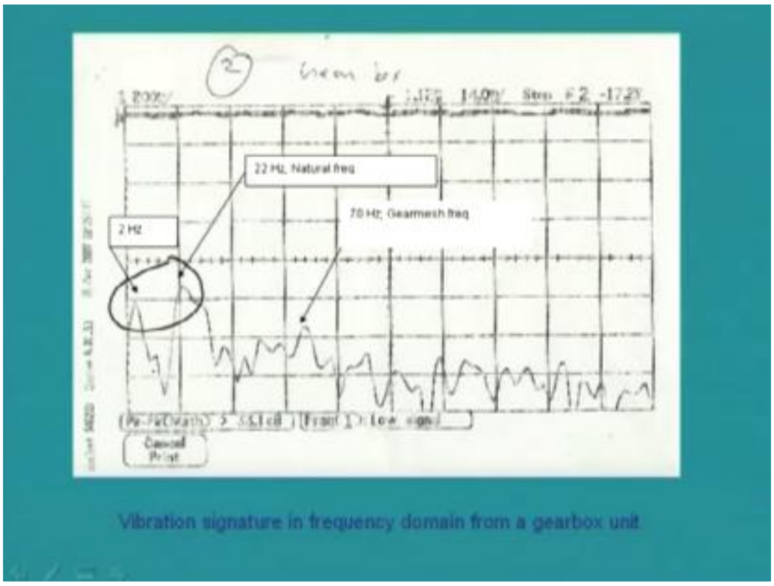

Vibration signature in frequency domain from a gearbox unit

So, another signal is you can see in this particular, these peaks are more predominant. They are more high in amplitude. And these are the signal – actual signal, which have been taken from a stone crusher unit just one week before the failure of that. I have showed in the previous slides, the crack was developed in a particular crusher unit. And these are the indicators, which we measured one week before the failure. And it is very difficult to find out a priori what is the design. But, once it got failed, then we could able to understand what was the problem. So, that is the difficulty. That information is there in the signal. But, it takes time to analyze that. So, because of that, that failure took place.

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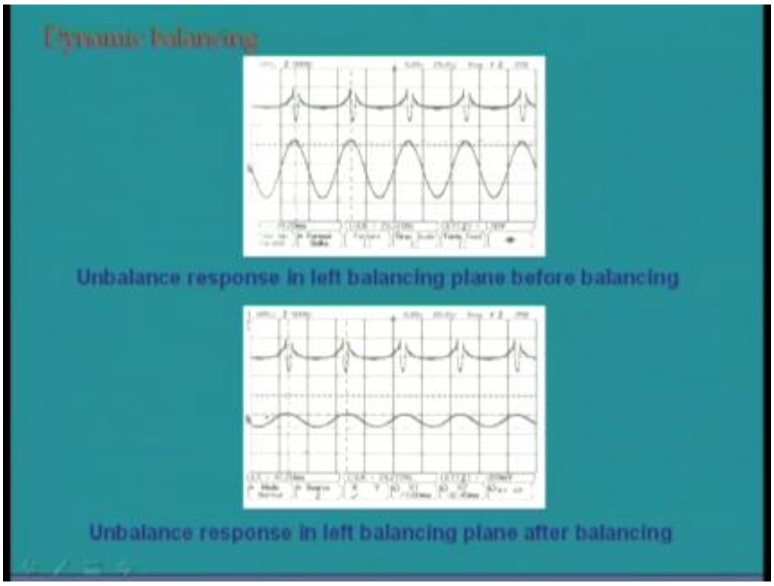

This is another signal especially, which is used in the balancing of machine. You can see that, this particular signal is the vibration signal of a shaft. This is the reference signal, which I showed earlier; that is used to measure the phase of this particular signal. What we did; we did the balancing of this machine. And then again we measured the vibration of the shaft. You can see that, quite decrease in the amplitude of the vibration took place when we dynamically balanced the rotor. You can see these are the actual measured signal from the rotor kit, which I showed earlier. So, there are drastic decrease in the amplitude; that means the force which was coming from the unbalance, got reduced drastically.

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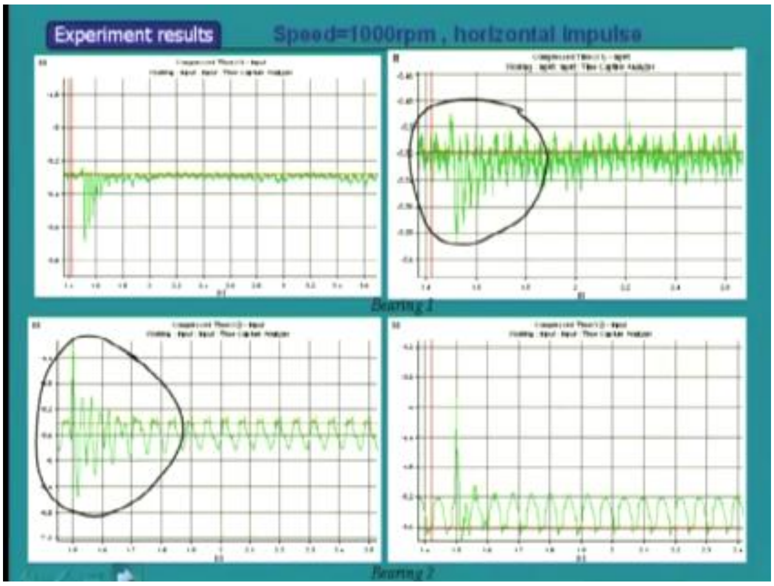

Then, this is a typical time domain signals especially when we have the… Especially this one if you see; we have given impact to the rotor through impact hammer. So, you can see there is this impact and straight decay of the signal take place and then the usual periodic signal. But, in this region, because of the impact, there is the transient components. So, this we are using for finding the damping in the system using the impact hammer. You can see this also; these are at various bearings and various places. But, rest of the things are remains finite. But, here it shoots up. So, this is one another typical signal.

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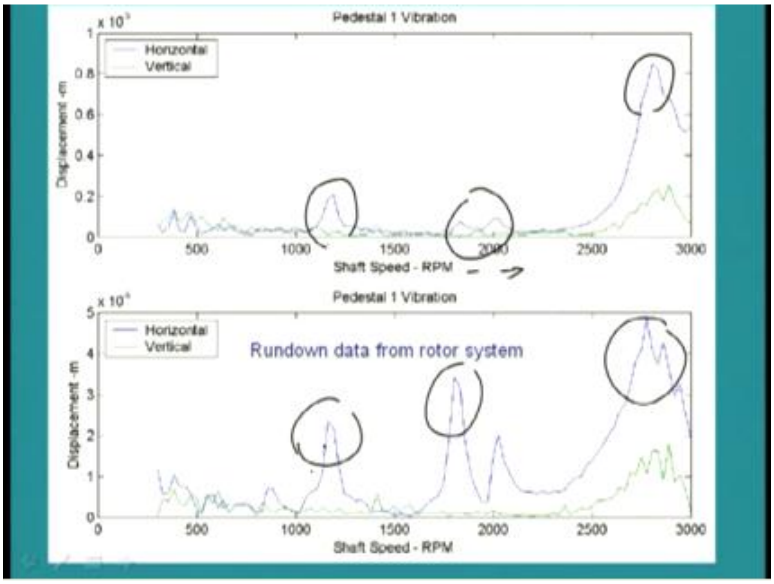

This is another signal from a rotor; when we change the speed of the rotor from low speed to the upper speed. And we are doing some kind of run up of the rotor and we are trying to find out the amplitude of that how it increases. So, you can see some peaks are appearing there – the natural frequency of the system or the resonance conditions are there here. Here also you can see some resonance conditions; you can see there one to one matching is there. These are the critical speed of the rotor.

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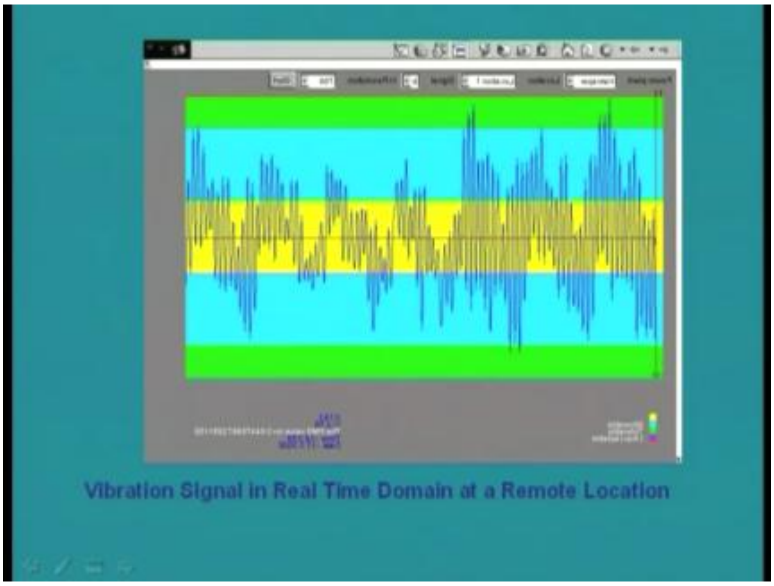

This is another typical time domain data. You can see that it is quite random. Especially in time domain, it is very difficult to find out what kind of information it has unless we go into the frequency domain.

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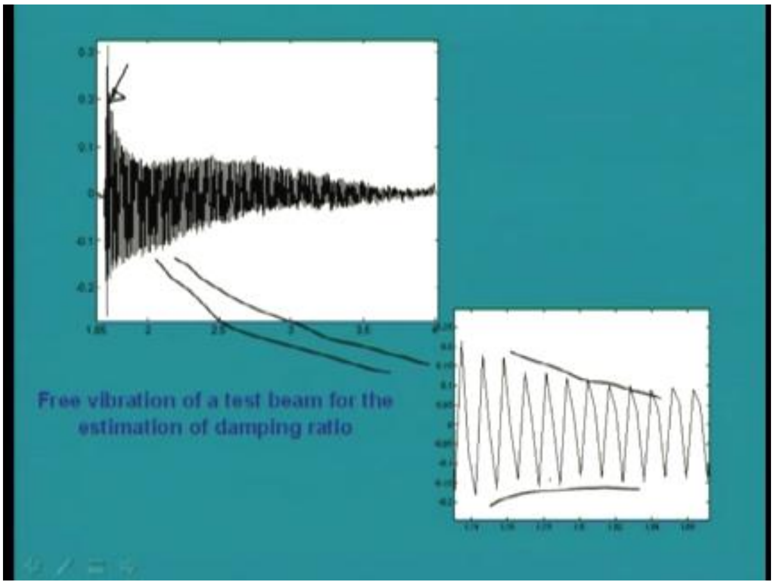

There is another typical data, which we have captured especially when we gave the tap or the impacting to a beam – simply supported beam; and we measured the decay of the vibration. So, you can see here we gave the tap or the hammering to the beam and then gradually the vibration is decaying. The close view of some part maybe up to this has been blown up here. You can see there is the decay. And based on this decay, this amplitude we can able to find out what is the damping in the system. Why… These are nothing but the amplitude of the vibration and it is decaying gradually; that means some energy is getting dissipated in some form; and that we generally call it as a damping. So, today we try to introduce the subject of mechanical vibration, because we have already seen that, vibration is nothing but the oscillatory motion of dynamic system, which is having some elasticity and some inertia. So, it is having some kind of a to and fro motion.

And, gradually, we introduce some terminologies and characteristics of the vibration like free vibration, force vibration the natural frequency resonance conditions. Even we solve some of the practical applications, where we can able to use the vibration; whatever theories there behind that – how we can able to use them in practical situation. Especially when we are talking about the condition of the machine, these vibration signatures help us in finding what kind of faults are there in the machine. But, the main problem is understanding those complicated signal or requires the background behind the signal processing. Also, the basic theory of vibration should be clear how to calculate the natural frequency of a system, so that we can able to locate them especially in this vibration signal. Or, even as a designer, we must first find out the natural frequency of the system. And when we are designing any system, we should see that, whatever the operational speed of that particular system is there – they should be well away from this natural frequency of the system, so that we should not land up in the resonance condition and the background. And the more detail fundamentals we will be studying in this particular vibration course.