Machinery Fault Diagnosis and Signal Processing

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Lecture – 10
Practical Examples of Vibration

Well this lecture is on practical examples of vibration, in this week we have studied the basics of vibration, Rotodynamics and so on and then we will see just to give an overview what are the different manifestations of vibration? What are the practical useful as a vibration? Vibration is useful otherwise you know we will we would not be doing condition based maintenance or monitoring using vibration, so in fact to us vibration of machinery is helpful because you know from this vibration we have to tell what is the fault in the machines.

So, in that context I think vibration is good for us, but then vibration in is highly undesirable in many applications human discomfort to begin with; imagine you are going in a vehicle the car seat is vibrating, vibrations would induce fatigue failure and vibrations would induce structural damage ok.

So, we will see different approaches how this vibration is controlled, what are the ways vibration comes about and will see through some examples which we have will see some through some examples.

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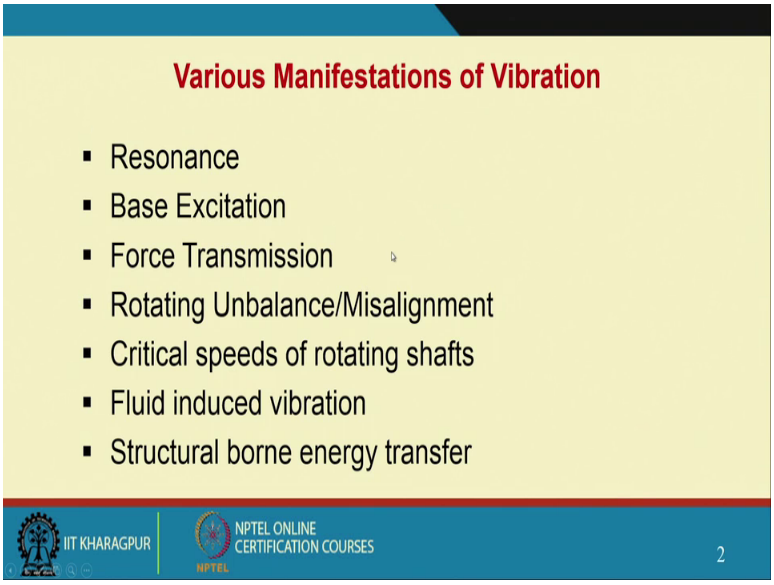

Now, we have an fairly good idea about what this resonance is, resonance the effect of resonance is my amplitude would increase at r is equal to 1; that means, when the forcing frequency is equal to the natural frequency of the system I will have large vibrations, this excitation vibration from the ground is transmitted and in fact this is the idea behind the development of this seismic transducers or accelerometers we measure vibrations at the surface by measuring the relative displacement of the sensing elements, force transmission because of vibration force gets transmitted to the ground or force from another machine comes in to another machine through the ground. So, we had seen how this vibration and shock isolations we have done to reduce either the motion transmitted or the force transmitted.

Another item or which creates vibration is rotating unbalance and misalignment. In fact, these are few of the very common rotating machinery faults being unbalance, in the rotating shaft or the disc being carried by the shaft and the misalignment between 2 shafts which are connected by a coupling or supported on bearings. So, these also give rise to vibrations and we just saw in the lecture on rotor dynamics, how the critical speeds of rotating shafts happens because the shafts are flexible, they will have many natural frequencies and we will avoid operating the machine and their critical speed.

So, that the condition of resonance does not occur, another vibration which occurs is fluid in this vibration and when fluid passes through rough oils there is vibrations and how this will induce and that is dependent on the velocity of the fluid flow and so on and particularly in heat exchanger sub structure this is a very important characteristics aerofoil design and then of course structure one energy transfer, you know vibration of course, requires a medium for transfer. So, even structures transmit energy, so this you know they all this structure bond vibrations which we feel in a vehicle is because of the vibration transfer.

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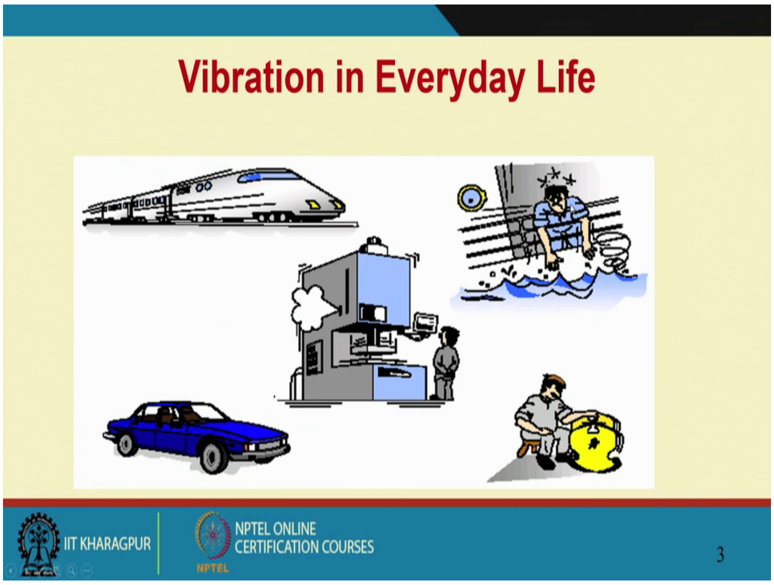

So, with this diagram we will just show you the different aspects of viruses in everyday life, now you have seen the effect of vibrations in an automobile comfort.

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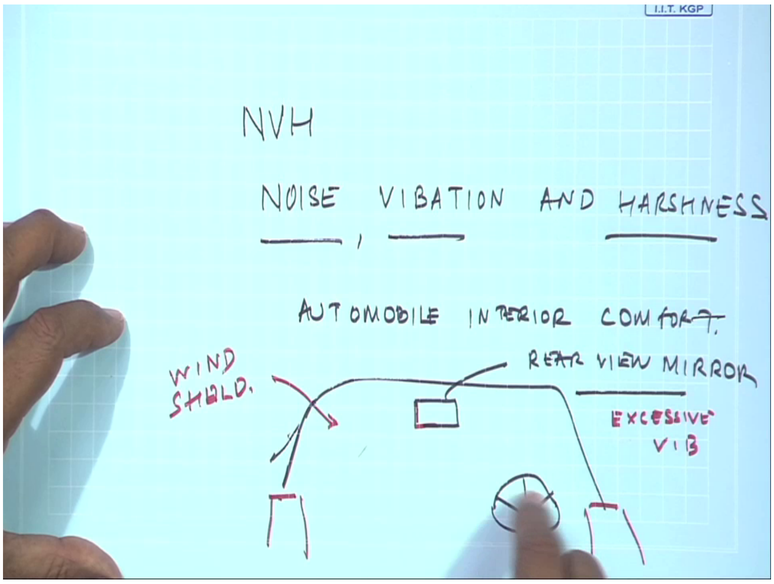

The people nowadays are talking about NVH noise vibration and harshness, these are 3 important parameters which people attribute in product, beet an automobile interior comfort see for example, if you are driving a vehicle apart from being white in the interior imagine, if the will imaginary this is your rear view mirror imagine, if there was excessive vibration of this rear view mirror because your it is attached the windshield and there is vibration in the windshield because it is anchored to the vehicle body and then vehicle body is being having vibration energy because vehicle body is supporting the engine. So, 1 leads to another there is basically energy transfer, but the rear view mirror gets excitation and it starts to vibrate.

So, your passenger or is your driver, who is looking at the rearview mirror will get this comfort or irritated because you cannot focus on what is being shown on the mirror. So, now if you look at the mirror and the mirror is shaking he will he will have a sense of discomfort. So, there are many issues you know you more almost have heard, you know motion sickness while traveling in on ships where there is large rocking motion.

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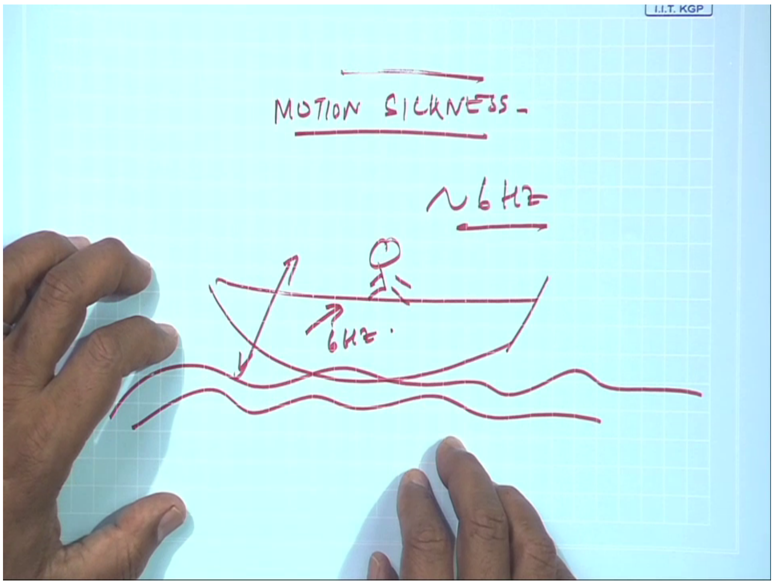

This is another application of resonance in the sense, for example our human body the internal organs are supported in a fluid in the just cavity. So, basically the internal organs have mass and they have certain stiffness. So, they also have a natural frequency and the human organs have natural frequencies around 6 Hertz ok.

Now if you are going on a boat now this is my view of the boat and if there is a large rocking motion and these are because of a choppy wave and the sea rough seas, so there is a lot of rocking motion. So, a person who is standing on the deck, we will have this forcing frequency coming around 6 Hertz and then because there is a resonance you will have large motions in your internal organs you will nociate and vomit and that is what is motion sickness.

So in fact, even you know I have seen cases where people you know have motion sickness while traveling in a vehicle, where the seats are not properly isolated from the floor of the vehicle, so these kinds of issues do happen. So, we have good vibrations bad vibrations these are all examples of bad vibrations, machinery vibrations and then of course, in railway locomotives or even in coaches we have vibrations. So, there are always efforts being made to reduce vibrations.

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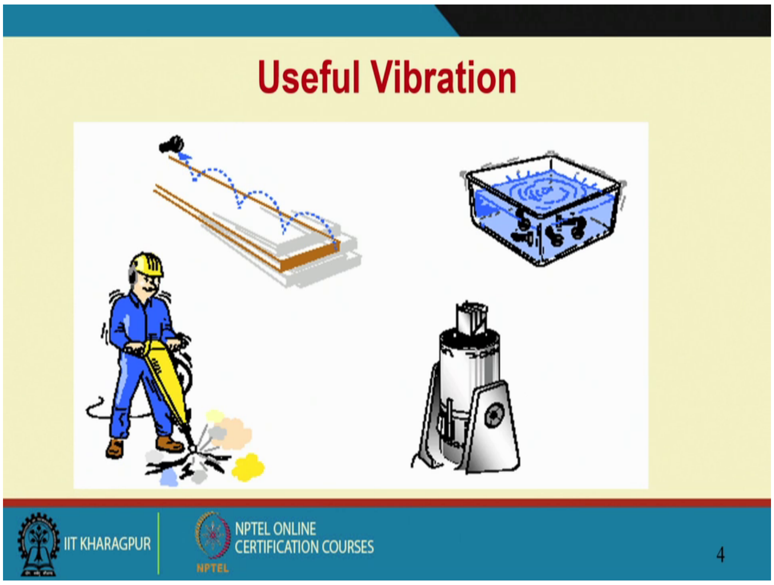

But nevertheless let us see; what is the useful vibration as well as I was telling right, in the beginning of this lecture useful vibration is a machine is vibrating and I can machine could be vibrating because of many reasons.

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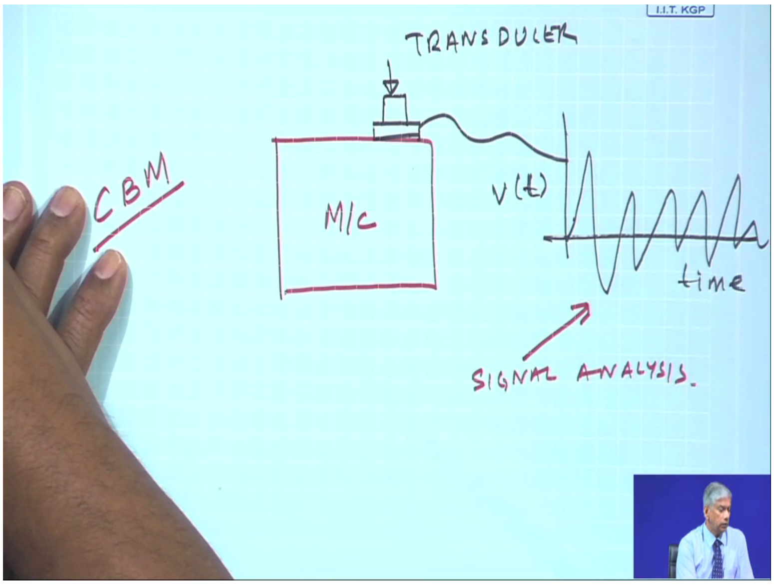

But from a condition monitoring point of view I want to drive on this point, that I put a transducer or many transducers and I will get a signal some vibration signal. So, by analyzing the signal I will know the characteristics of this machine which has created this and imagine if the signals certain artifacts or a certain features change with time, I will know that something is going wrong with this machine and that is what it is helping us in CBM, condition based maintenance condition monitoring; but then this gives you an example of some of these useful vibrations.

Vibrations are used to transport for particles, vibrations like here in an ultrasonic cleaner are used to clean through high frequency ultrasonic waves components, vibration is used to brake concrete rocks etc through what is this jack hammering, but of course, there is an undesirable effect is in which will see, this poor guy who is holding this jackhammer unless his fingers or palms are not protected or isolated he will have excessive exposure to high levels of vibration and that is there are limits to how much human hand can be subjected to the vibrations and we will talk to that talk about that later. Vibrations is used for testing and I test a product in terms of giving in vibrations and see whether there is any resonance and that and so on.

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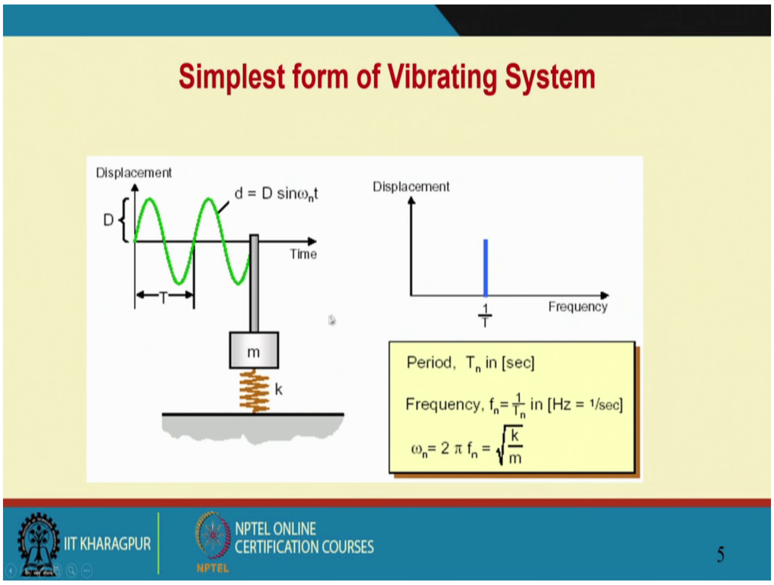

So, I will though we have studied this earlier I thought I would show you the totally, see suppose I have a mass of ma supported tongue stiffness k and if it is given an initial displacement it will have an motion like this, is the displacement amplitude 0 to T and this will repeat if there is no damping this is an ideal system. So, this displacement expression is given by D sine omega and t, where omega and is equal to 2 pi fn root over k by m as the circle of natural frequency and this vibration is going to repeat every time T, where T is the time period of the signal and because this is a single frequency signal the frequency of the signal is nothing but the inverse of the time period.

So, in the displacement was the frequency curve, I see this curve f n is equal to 1 by T and this amplitude is going to be D. So, this is the simplest form of a vibrating system. As I was telling you vibrations can either be represent it as displacement or velocity or accelerations.

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So, I will give you another example; so this is a tractor wheel steering wheel and the problem with this kind of tractor wheel was you know as long as soon as they started the engine, this steering wheel had an excessive vibration. So, our efforts at idea were how to reduce these vibration levels.

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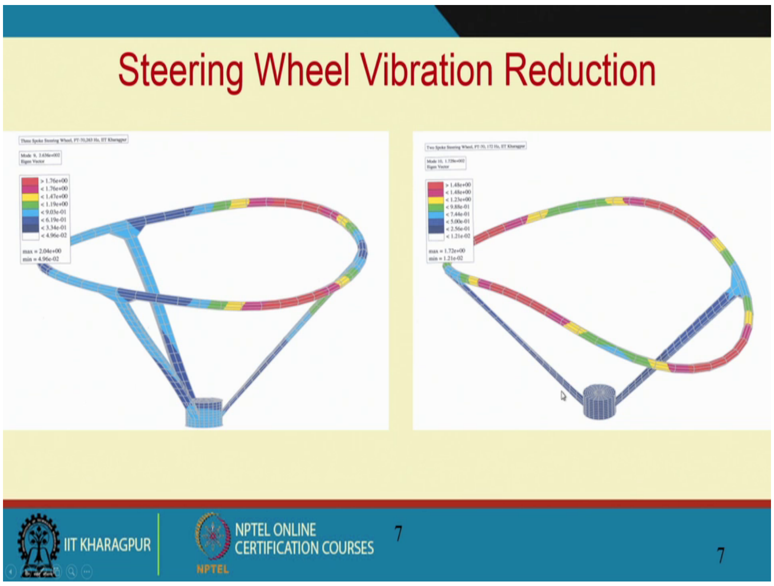

And then we studied this thorough a finite element model and found out the natural frequencies of the steering wheel, and we found out that the natural frequencies of the steering wheel was equal to the engine firing frequency.

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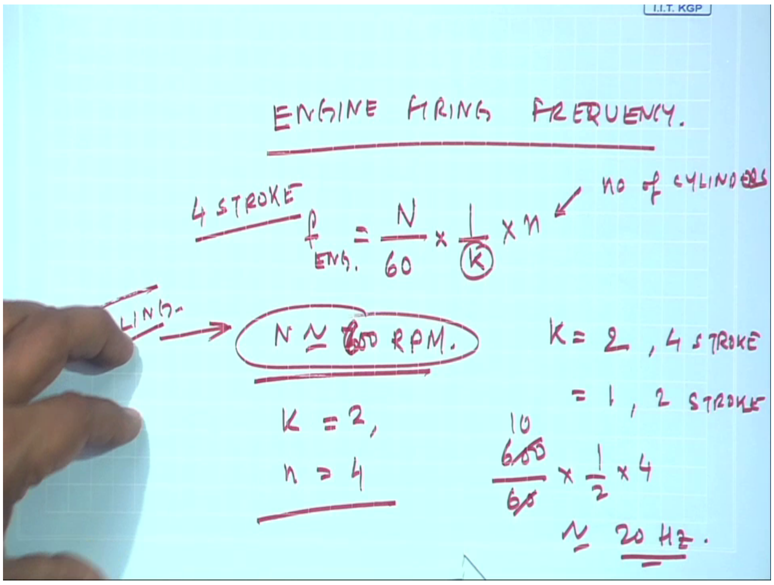

So, what is this engine firing frequency, in a nice engine suppose it is 4 stroke; that means, for every 2 revolutions I have 1 a power stroke. So, if they RPM of the engine is n so N by 60 is RPS divided by 1 by k, k is a factor k is equal to 2 which if it is 4 stroke and k is equal to 1 if it is 2 stroke times n, where n is number of cylinders and that engine.

So, this is the firing frequency of the engine. So, in this case this firing frequency was very close to the natural frequency, so at idle and the idle RPM was close to about 700 RPM I believe and k was 2 and n was 4. So, you will work out what the natural frequency is in even if I take it for the sake of discussion here, if we try taking it 600, 600 by 60 times 1 by 2 times 4, so this becomes 10. So, this was around of about 20 Hertz this was a little higher than 20 hertz, it was somewhere around 28 Hertz that this RPM was a little higher.

So, the engine firing frequency at 600 RPM when the engine was idling, there is a slow speed diesel engine particularly used in tractors. So, the natural frequency of the steering wheel was very close to the idling firing frequency. So, through a design modifications of this stiffness of the steering wheel, the natural frequency of the steering wheel was shifted away from these frequencies and they are not idling the steering will did not have excessive vibrations.

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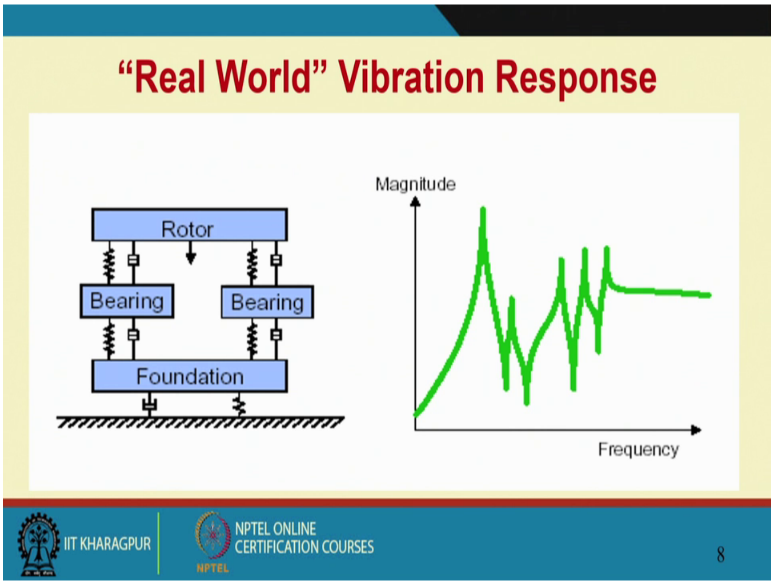

So, this is how one can play around with the natural frequencies designed to change the occurrence of resonance.

Now, that was just a single frequency example of the harmonic oscillator, but if you see in practical examples real world there will be a rotor which is nothing, but the shaft carrying at this support around 2 bearings which is supported and anchored to the foundation. So, if you look at the frequency response of such systems from the signal acquired by a transistor kept on the bearings, I will see many natural frequencies and the best part about condition monitoring is every frequency here corresponds to a mechanical element in your machine. So, if a corresponding element in the machine has gone wrong, there will be change in the amplitudes at that corresponding frequencies and that is the genesis why CBM is so popular using vibration monitoring.

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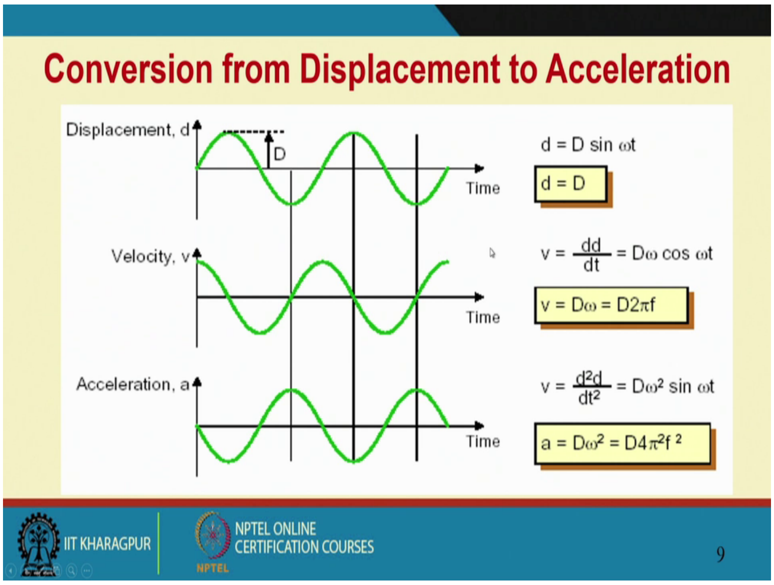

So, continuing our discussions on the simple harmonic oscillator, say if I look at the amplitude of the vibration is d and the velocity is the D omega cosine omega t and then again I differentiate the velocity, by the way there will be minus sign here; but if you look at the amplitude it will becomes just so.

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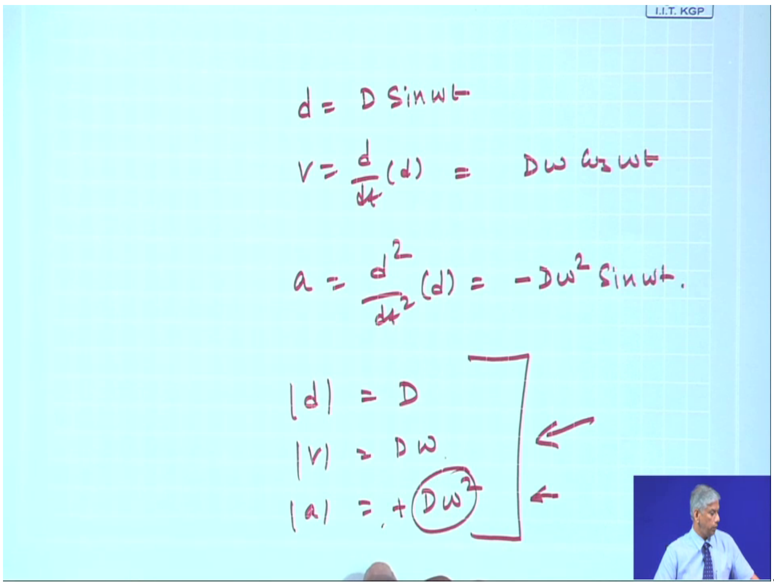

If I have our displacement d as D sine omega t, velocity is nothing but d by dt of d which is nothing but D omega cosine omega t and acceleration is assembled d square of d and then this will be minus D omega square sin omega t.

So, if you look at the amplitudes of d it is d amplitude v it is D omega and amplitude of a it is minus D omega square. So, they are always related, I can if I know the frequency I can either divide velocity by omega to get displacement or sorry or if I may because I have given modules here.

So, if I and divide acceleration by omega I will get velocity, from multiply velocity with omega I will get acceleration; I invariably get ask this question what is the best parameter to measure once we are doing CBM. So, my first answer to anybody is enough at high frequencies we have to measure acceleration because, omega squared omega being large this is a large quantity. So, signal to noise ratios are pretty good when you measure acceleration and of course at low amplitude or displacement is good enough, but somebody you know some standard say you know measure velocity and then you can.

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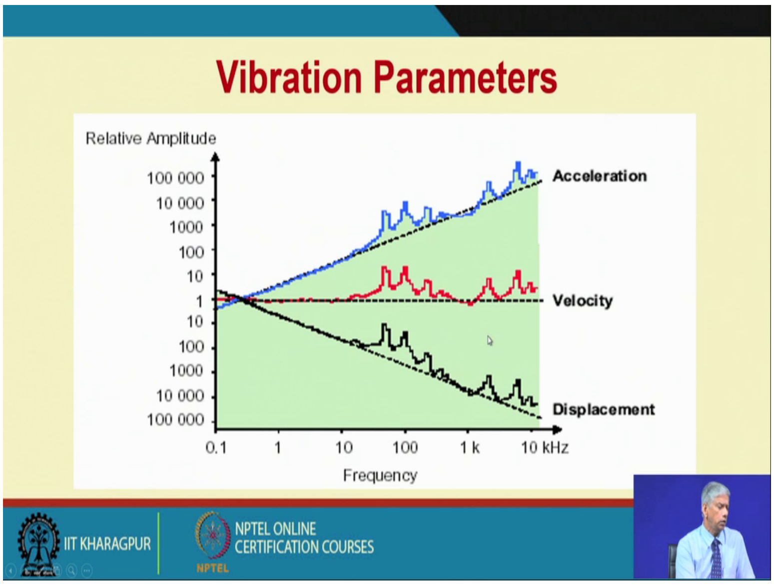

You are somewhere in between, but to answer this question is the relative velocity is all most linear in the log scale, I am displacement has high amplitudes at low frequencies ok.

So, this is obtaining a individual, but a nowadays of course the piezoelectric accelerometers are available to measure axial ration, where by knowing 1 you can measure the other.

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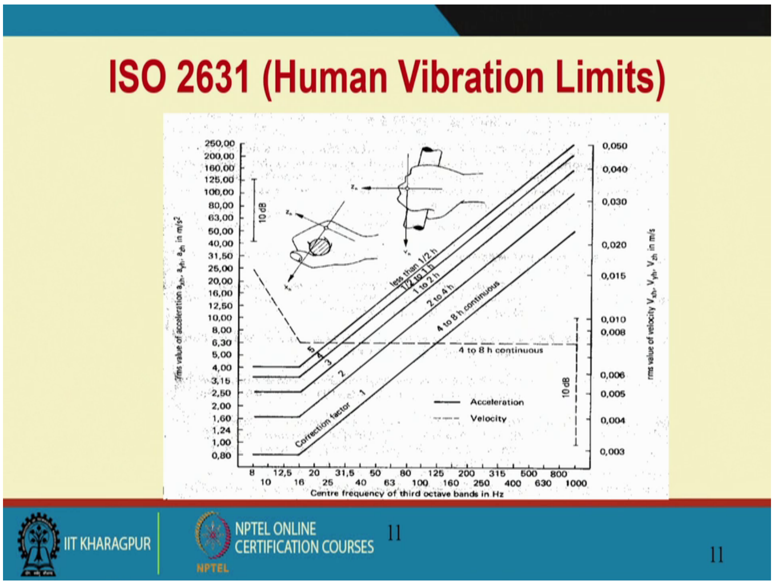

I was mentioning about that a jackhammer. So, there is an excuse me ISO 2631 human vibration limit standards as to at different frequencies, if somebody is having an exposure to 4 to 8 hours of less than half an hour, what is the permissible level in terms of velocity or in terms of acceleration ok.

So, this standard people can look up to. So, as a designer there is a certain limit, what is the maximum level 1 can be subjected to at different frequencies, different duration of exposure. So, this governs the designing of any equipment where human beings are to be used, for example anything were at holding like a steering wheel like a jackhammer or In fact even the human seat.

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This is a seat accelerometer, this just to show you seat accelerometer can be strapped onto the seat and basically this has a accelerometer in between it and somebody's made to sit on it. So, if the seat is having excessive vibration this exposure limits can be measured on this human vibration analyzer. So, you can get the vibrations in the x y z and whether they are within the limits ok.

Particularly in vehicles so know this is a standard nowadays, that your human vibrations are the human hand arm seat vibrations are within the ISO limits. So, manufacturers are putting a lot of efforts to have good isolators and so on.

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Another case here is hand armors this is you know hand operating tool and then this is an accelerometer voltage will be put here to measure the vibrations faced at the handle, I am sure all of you must have experienced even just holding a hand drill and imagine this was fine you know when we do hand drilling operation for in this driving home 1 screw or 1 nail and so on. But imagine operator who is day in and day out you know holding a pneumatic hammer or drilling machine and for 8 hours of operations, what kind of levels is exposed to. So, these are certain rules which have been put in place nowadays, so that you know people do not have overexposure to vibration because it gives rise to lot of disorders.

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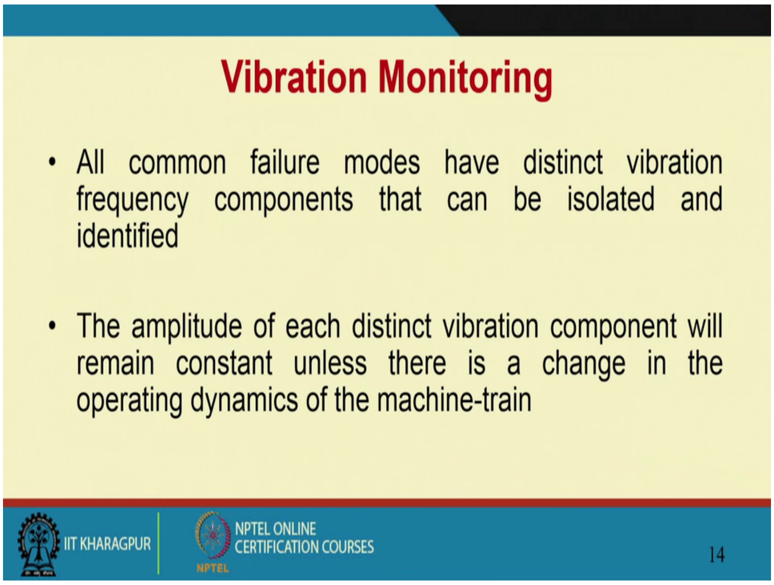

But then why do we do vibration monitoring because, all common training modes have distinct vibration frequency components that can be isolated and identified and that was the preamble wise vibration monitoring is so popular in CBM and in the next 1 is the amplitude of each distinct vibration component will remain constant; unless there is a change in the operating dynamics of the machine train, so you know if the there is no change.

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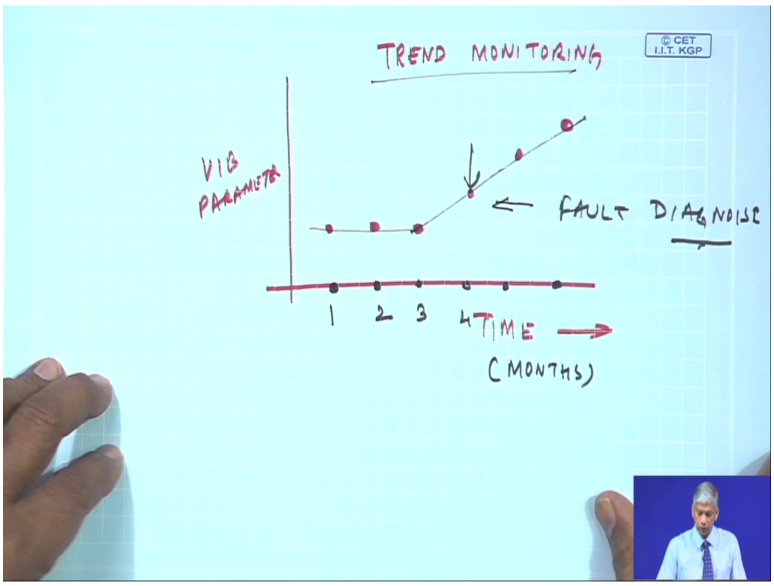

Now, that that is whatever people do in CBM, they do what is on this train monitoring with time and then this see the vibration parameter, this frequency is dependent you know for example, you know for the sake of discussions say every month time is in month and so on. If a certain parameter which are monitoring is almost constant, but then I see so this obviously, means that something has gone wrong; the amplitude of each distinct variation component will remain constant unless that is changing the operating dynamics of the system.

So, this gives us an indicator well something has gone wrong with this machine. So, this is where even a simple trend monitoring will give you an idea as to something is perhaps wrong with your machine and this is what an of course and then you can measure and do an actual fault diagnosis by measuring the vibrations and doing an analysis which we will discuss later on.

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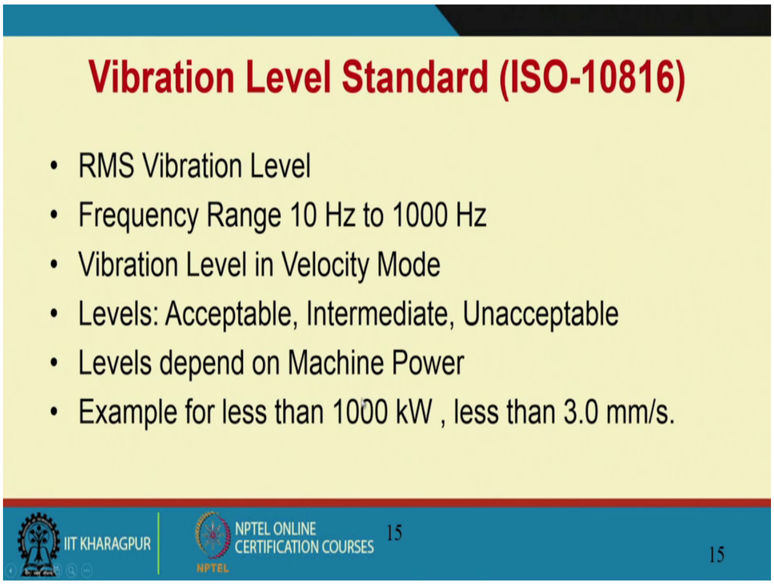

So, by the way when we are talking about this monitoring, there is an ISO standard ISO 10816, which says this that a vibration level in RMS that is the root mean square level has to be measured, the frequency range of measurements is from 10 Hertz 2000 hertz, where some level is measured in the velocity mode and if you look at the standard there are 3 levels for a particular machine power, which says whether it is acceptable intermediate or unacceptable by the way this is standard this chart is also to some extent given in the appendix of my book. So for example, if a machine is less than 1000 kilowatt it is maximum RMS level at any point should be less than 3 millimeters per second. So, the standard lists out and it has in different parts depending on what kind of machine and so on.

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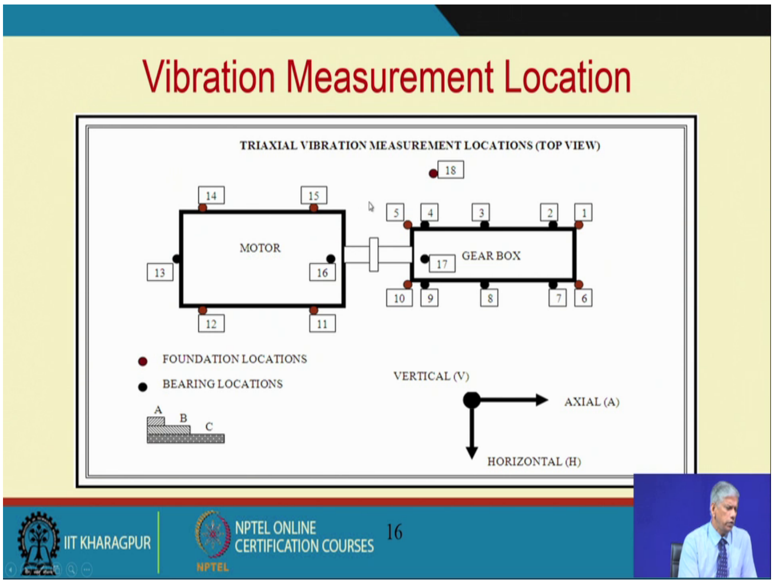

So, this is just to give you an example where this vibration measurement can be done. So, this is a motor gearbox with a coupling and these are the red ones are the foundation locations and then the all these are remaining black of the bearing locations, attentive every foundations there are certain levels of a material may be you know concrete steel and the frame and so on and at every point you can measure in 3 directions because, I was telling you vibration is directional. So, such a survey can be done and then so for example, for such a systems you measure all the values and keep it with you and then measure after another month and so on and if there is a change you can get alarm that something wrong with this machine ok.

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And this is just to give an example of on a conveyor system, there is a coupling here and this is on the concrete foundation or frame and the machine formation and this gearbox being driven by a motor driving the conveyer system.

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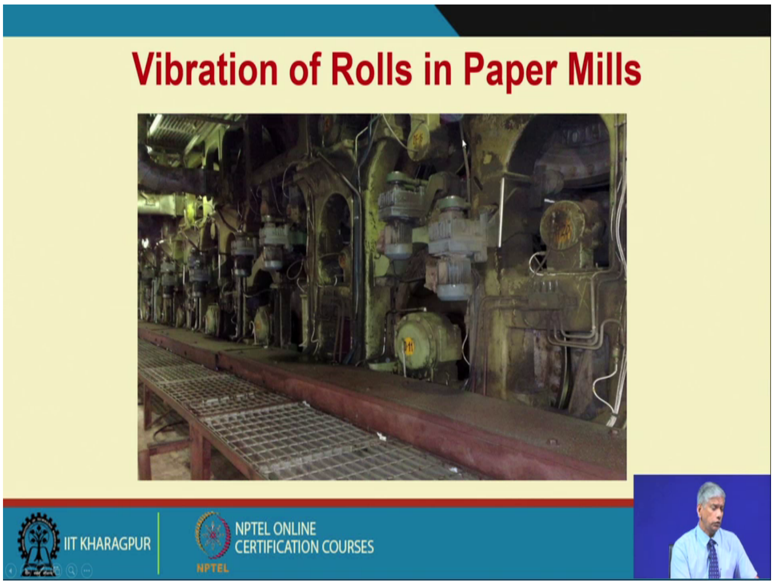

So, vibrations of roles in paper mills are a very important problem.

So, you can see all these cable here, they are monitoring the bearing condition ok.

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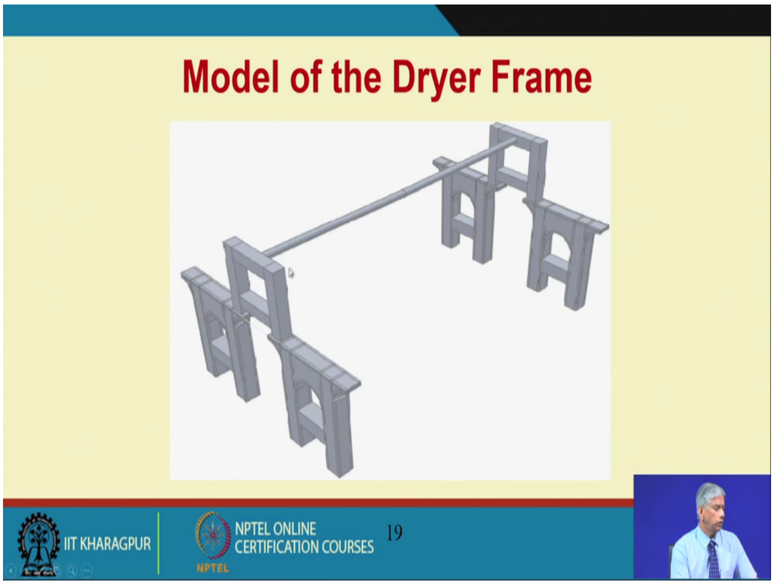

And we can do 4 because, if you look at the frame of the dryer and a paper mill there is a frame and the frames must not have resonance equal to the rotating speed of the paper mill rolls.

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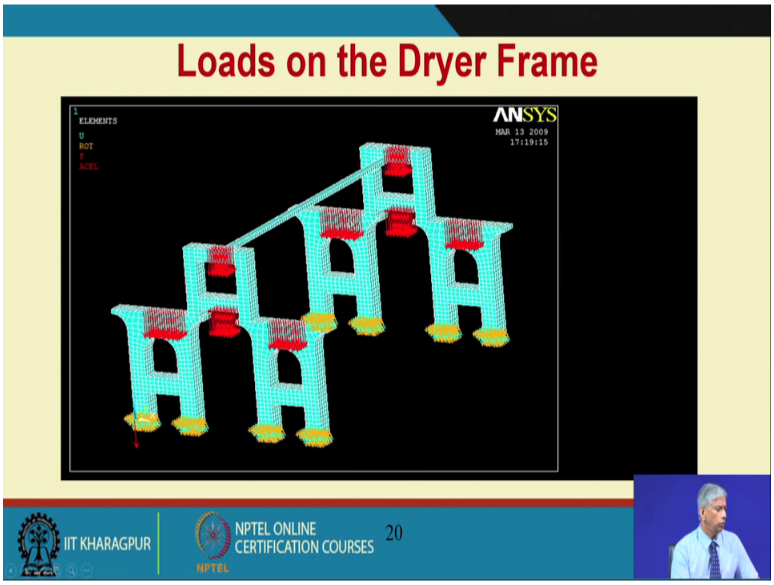

And we have done an find elements study to understand the loads on the frame. So, that in the vibrations called because of this dynamic loads are within the limits, other than the structural damage to the component.

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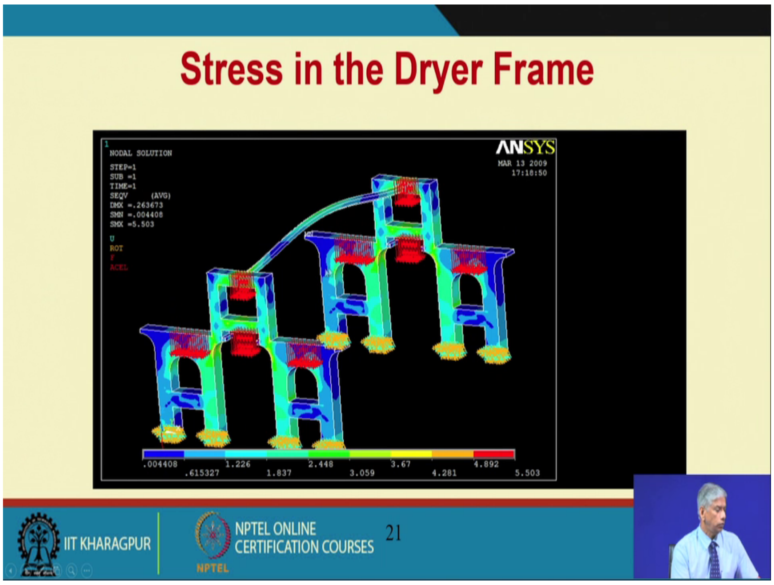

And then the stresses were determined using such finite element analysis, you can find out the dynamic stresses ok.

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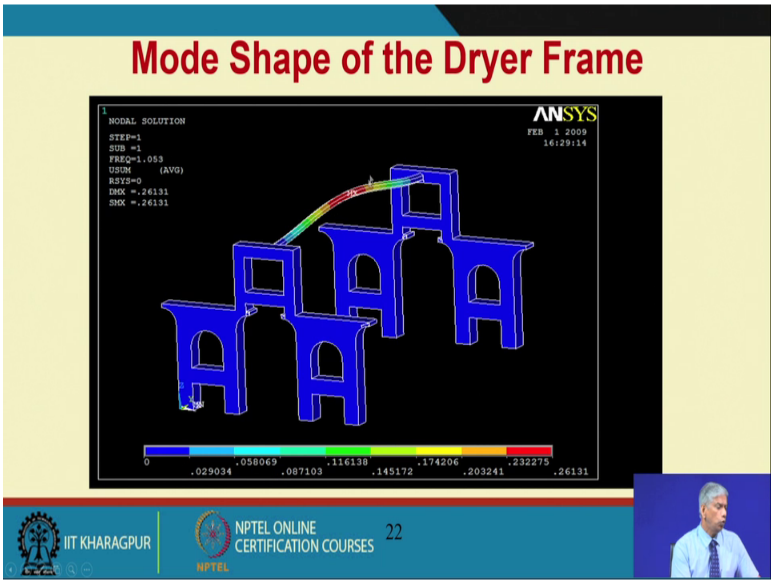

And then mode shapes of the dryer frame because this is an elastic model. So, we can find out the natural frequency of such systems and then you can find out that you need to avoid the natural frequency of this while you are in operations.

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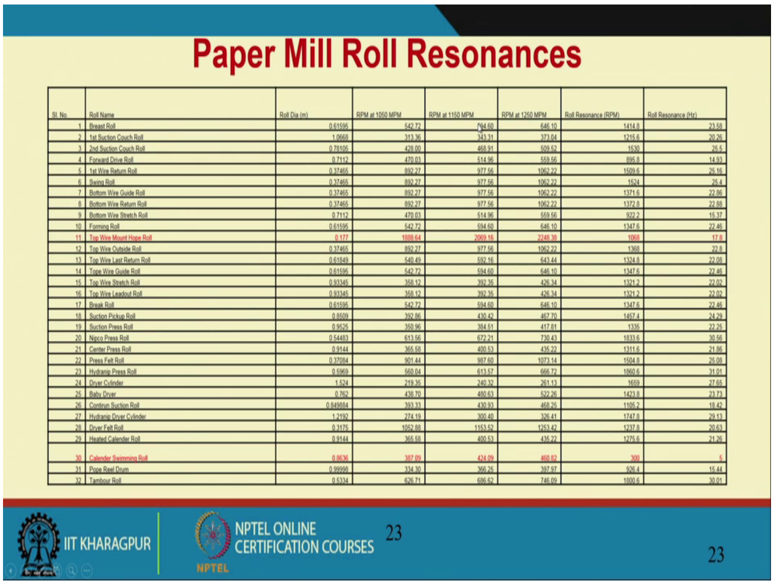

Sl. No.	Roll Name	Roll Dia (m)	RPM at 1050 MPM	RPM at 1150 MPM	RPM at 1250 MPM	Roll Resonance (RPM)	Roll Resonance (Hz)
1	Breast Roll	0.61595	542.72	594.60	646.10	1414.8	23.58
2	1st Suction Couch Roll	1.0668	313.36	343.31	373.04	1215.6	20.26
3	2nd Suction Couch Roll	0.78105	428.00	468.91	509.52	1530	25.5
4	Forward Drive Roll	0.7112	470.03	514.96	559.56	895.8	14.93
5	1st Wire Return Roll	0.37465	892.27	977.56	1062.22	1509.6	25.16
6	Swing Roll	0.37465	892.27	977.56	1062.22	1524	25.4
7	Bottom Wire Guide Roll	0.37465	892.27	977.56	1062.22	1371.6	22.86
8	Bottom Wire Return Roll	0.37465	892.27	977.56	1062.22	1372.8	22.88
9	Bottom Wire Stretch Roll	0.7112	470.03	514.96	559.56	922.2	15.37
10	Forming Roll	0.61595	542.72	594.60	646.10	1347.6	22.46
11	Top Wire Mount Hope Roll	0.177	1888.64	2069.16	2248.38	1068	17.8
12	Top Wire Outside Roll	0.37465	892.27	977.56	1062.22	1368	22.8
13	Top Wire Last Return Roll	0.61849	540.49	592.16	643.44	1324.8	22.08
14	Tope Wire Guide Roll	0.61595	542.72	594.60	646.10	1347.6	22.46
15	Top Wire Stretch Roll	0.93345	358.12	392.35	426.34	1321.2	22.02
16	Top Wire Leadout Roll	0.93345	358.12	392.35	426.34	1321.2	22.02
17	Break Roll	0.61595	542.72	594.60	646.10	1347.6	22.46
18	Suction Pickup Roll	0.8509	392.86	430.42	467.70	1457.4	24.29
19	Suction Press Roll	0.9525	350.96	384.51	417.81	1335	22.25
20	Nipco Press Roll	0.54483	613.56	672.21	730.43	1833.6	30.56
21	Center Press Roll	0.9144	365.58	400.53	435.22	1311.6	21.86
22	Press Felt Roll	0.37084	901.44	987.60	1073.14	1504.8	25.08
23	Hydranip Press Roll	0.5969	560.04	613.57	666.72	1860.6	31.01
24	Dryer Cylinder	1.524	219.35	240.32	261.13	1659	27.65
25	Baby Dryer	0.762	438.70	480.63	522.26	1423.8	23.73
26	Contiun Suction Roll	0.849884	393.33	430.93	468.25	1105.2	18.42
27	Hydranip Dryer Cylinder	1.2192	274.19	300.40	326.41	1747.8	29.13
28	Dryer Felt Roll	0.3175	1052.88	1153.52	1253.42	1237.8	20.63
29	Heated Calender Roll	0.9144	365.58	400.53	435.22	1275.6	21.26
30	Calender Swimming Roll	0.8636	387.09	424.09	460.82	300	5
31	Pope Reel Drum	0.99998	334.30	366.25	397.97	926.4	15.44
32	Tambour Roll	0.5334	626.71	686.62	746.09	1800.6	30.01

So, if you look at a paper mill we just had a class on rotor dynamics, there are many rolls and then these are the roll diameters given in millimeters and these are the different RPMs. And if I have the speed you know paper mill speed comes out at different RPMs. So, we have increased the peppermill speed from 1050 meters per minute to 1150 to 1250 and then we have measure the roll resonances.

So, once you are operating the plants at different speeds; that means, when you operate at a higher speed the rolls are running at higher or rotational speeds, but some of these rolls could be under resonance. So, 1 has to avoid and particularly in paper mills when there are many, 1 has to individually find out the critical speeds of each of the roles and ensure that none of them undergo resonance otherwise they will be premature failure.

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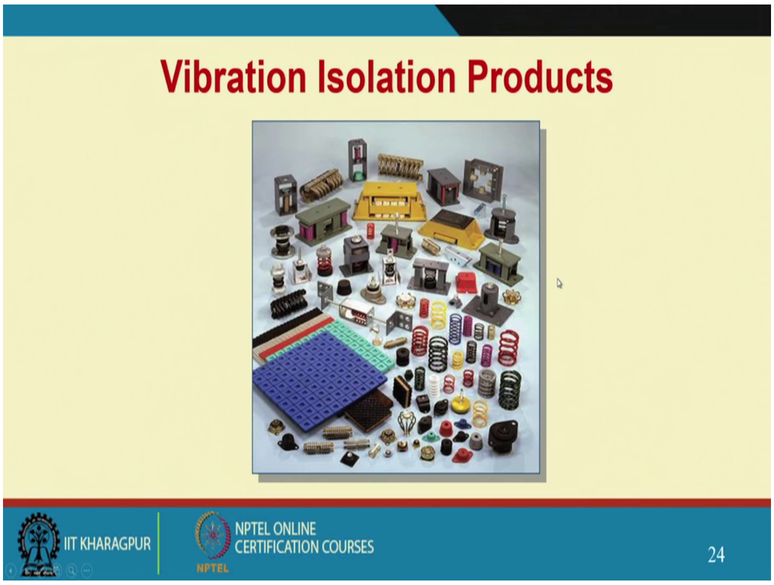

I had covered this earlier in the class on vibration and isolation products.

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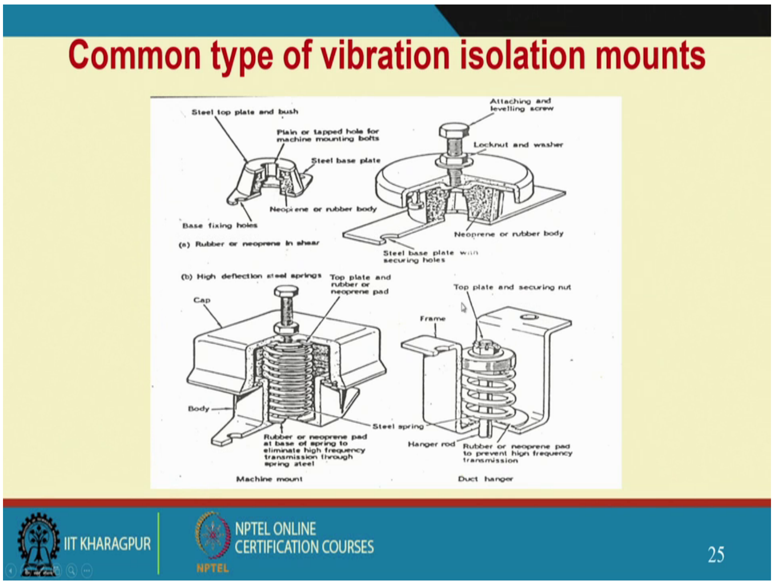

So, there are many types of isolators available in the market.

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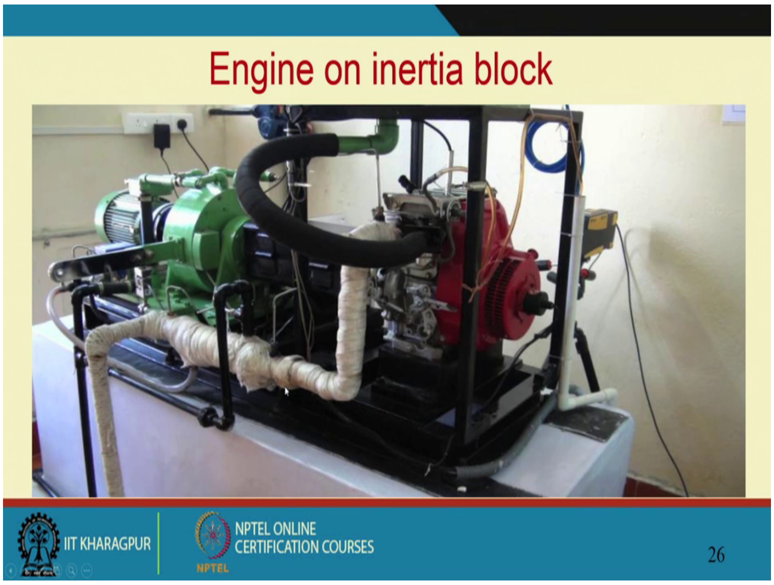

Another example is this inertia block because the objective is to reduce vibration, which is either getting transmitted or getting transmitted into the machine in a backhoe loader also again in the tractor.

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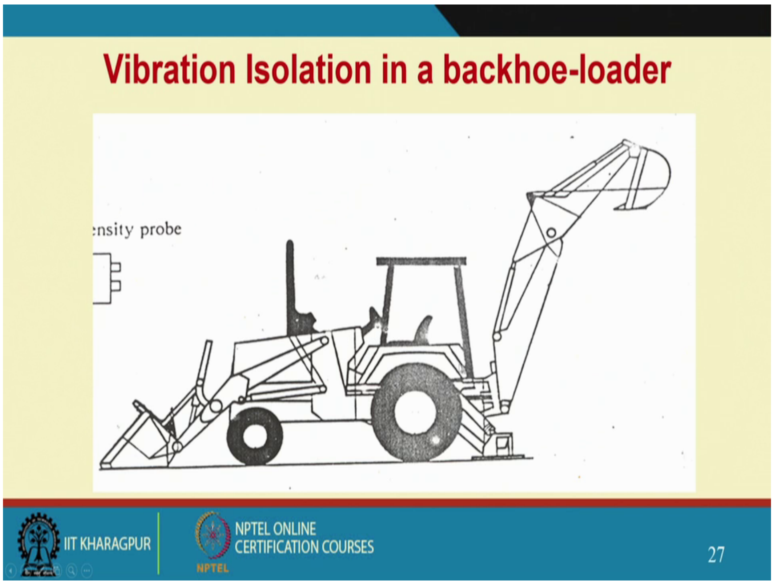

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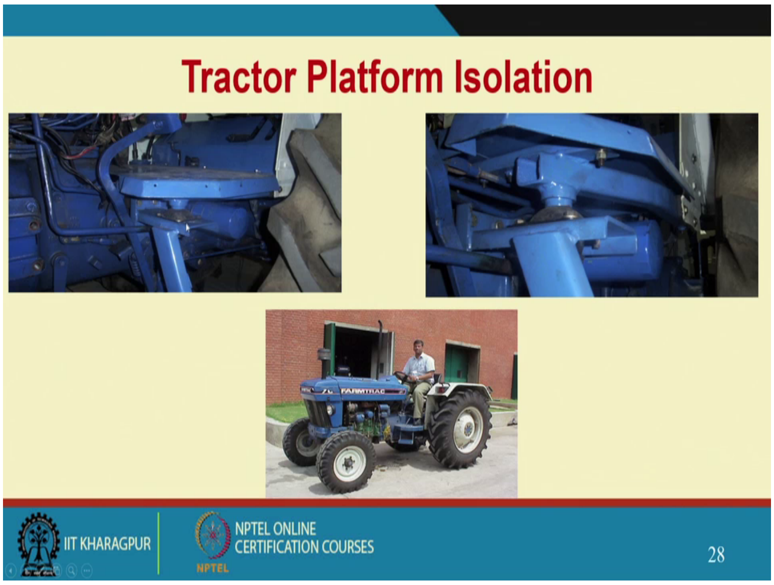

I had told you about this isolators being put.

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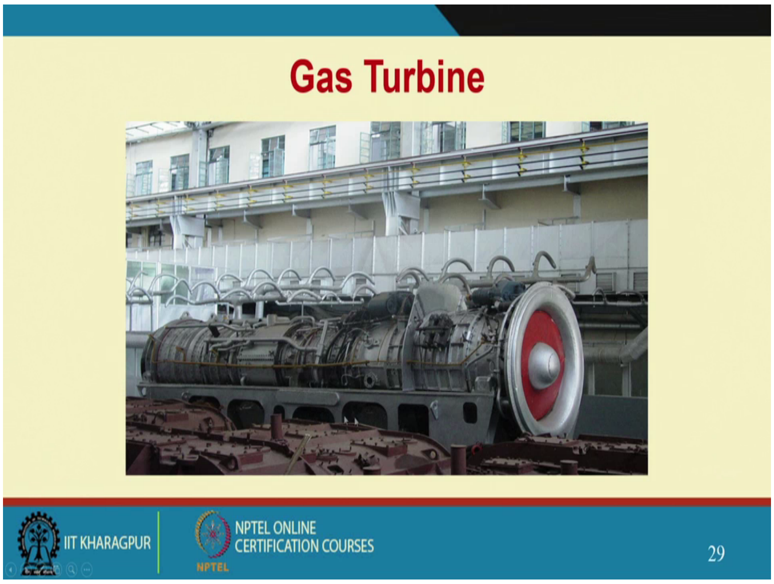

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Gas turbines isolators are insured so that there is no large rocking motions and these are another isolators which have been put here.

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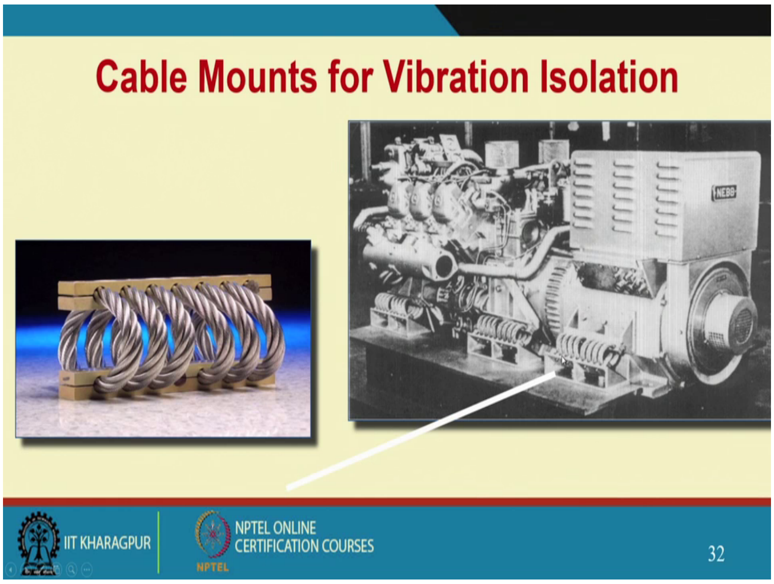

Cable mounts we discussed, cable mounts used in missile launchers ok.

Thank you.