Machinery Fault Diagnosis and Signal Processing
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Lecture - 37
Unbalance Detection

In the previous lecture, I had introduced you to the most common faults in rotating machines and in this lecture, I am going to focus on how unbalance can be detected in rotating machines.

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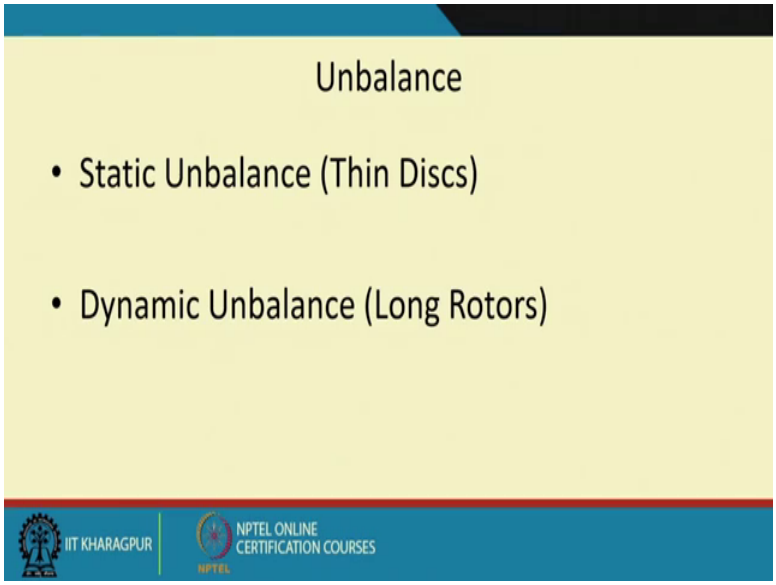

So, what do you mean by unbalance?

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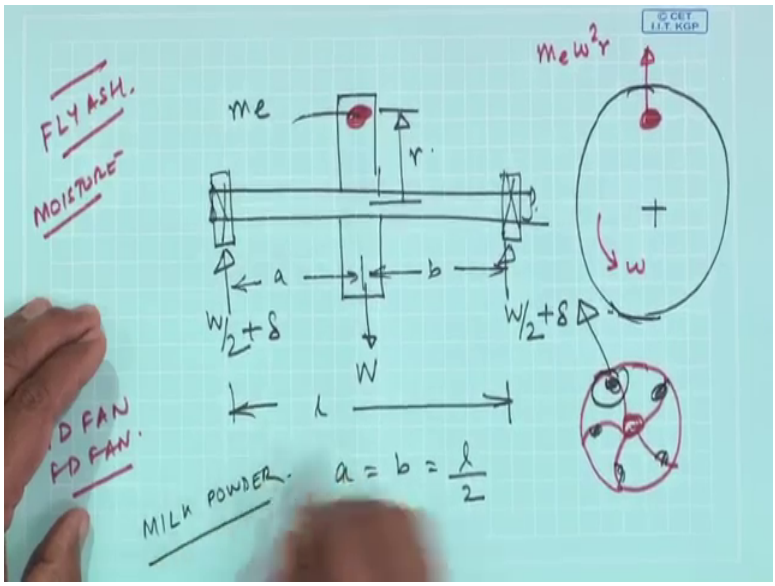

Suppose I have a shaft and this shaft could be carrying a pulley, a gear and if you look at this view here, suppose, there is an unbalance mass here. So, each time this unit is rotating, I will have a radial force me omega square r which is going to come along the periphery. So, if the initial shaft load was w; obviously, at the bearings both the bearings which are getting supported. I will have a reaction w by 2 w by 2, if they are equi-distance may be a b l. So, a is equal to b is equal to l by 2 and this is the radial distance from the center line m is the unbalanced mass omega the seat of rotation.

So, I have such a scenario which can happen and this could be may be set of bades blades in a impeller or fan. So, in any many industrial scenario you will come across such units may be an ID FAN induced draft fan or an FD FAN, etcetera, either to induce in air into the system or expel the exhaust gases from combustion operation etcetera I will give an example for example, in an FD FAN, we have the combustion gases, suppose it is coal combustion, there will be lot of fly ash in this gas. So, this fly ash because of the ambient moisture, it can so happen with time, these ashes may get deposited and the quantities so large that it creates a substantial amount of radial force.

So, what is going to happen is this is going to load this system and then what happens if the shaft is not designed to carry substance and excessive load it may fail if the bearings because they are running for a certain life the extra load which comes because of the

unbalance mass is going to reduce the dynamic load capacity of the bearing. So, bearings will fail at a time which is much less than the life of the bearing.

So, all this scenarios happen. So, and then of course, you know one leads the another in machinery condition monitoring if an unbalance was led to grow undetected what is going to happen is this will lead to a bearing failure and then you will be investigating the earring bearing failure without actually going into the failure because of this unbalance. So, these are some of the scenario, if you do not do a production plant of where they make a milk powder or we have an agitator or mixing tank on mixing tank.

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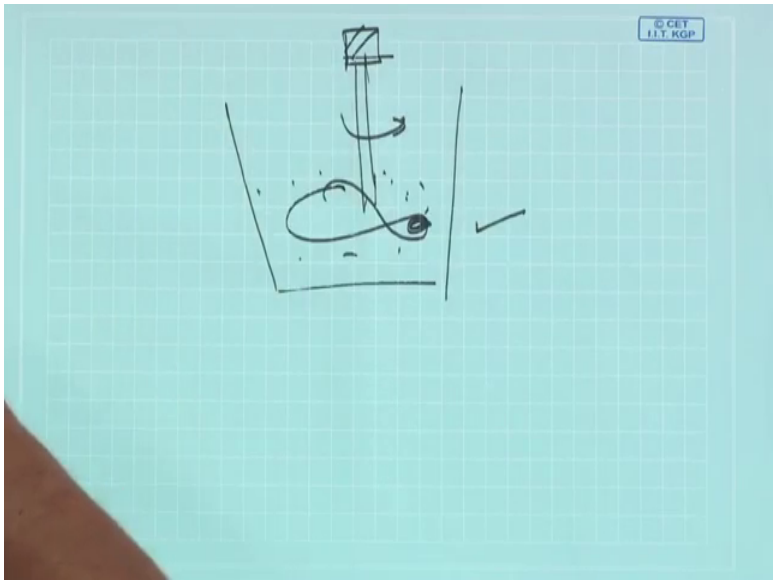

And we have large fan which is rotating supported lung bearings and there is some liquid here what happens something get stuck here the loads will come and there will be wobbling, etcetera. So, one will lead to the another such kind of faults occur and if I was to classify this one in to the static unbalance, another is known as dynamic unbalance for example, if the shaft is very small.

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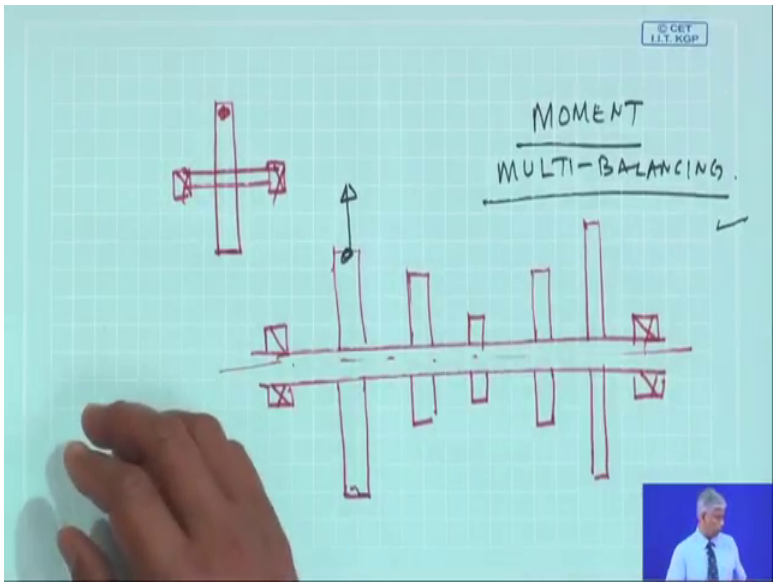

And I have just significant force in the radial plane, this a good example of static unbalance. So, it is unbalance in one plane as opposed to think of a large turbine in a power plant, I have a long shaft where there are stacks of blades and heavy, these are all stacks of blade later on I will show you photographs of you know gas turbine were you will see how closely this blades are there and.

So, unbalance here in any plane is giving going to give rise to a couple it is going to give rise to a moment. So, if I put an unbalance mass here, this also will give rise to a radial moment. So, this has to be done what is known as multi plane balancing and those of few done balancing on multi cylinder long engines or multi plane turbines, we can do it by such methods, but this will give rise to moments as opposed to this giving rise to reaction forces at the bearing locations and we will particularly focus on small machines were we are talking about static unbalance.

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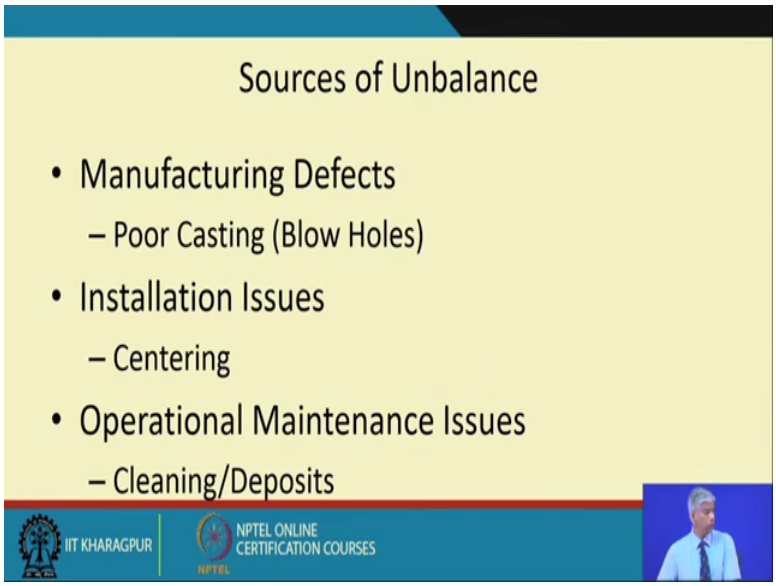

Now, question is in a first place why did this unbalance occur it could be poor casting imagine a pulley which is mounted on a shaft if there are blow holes because pulleys are usually cast.

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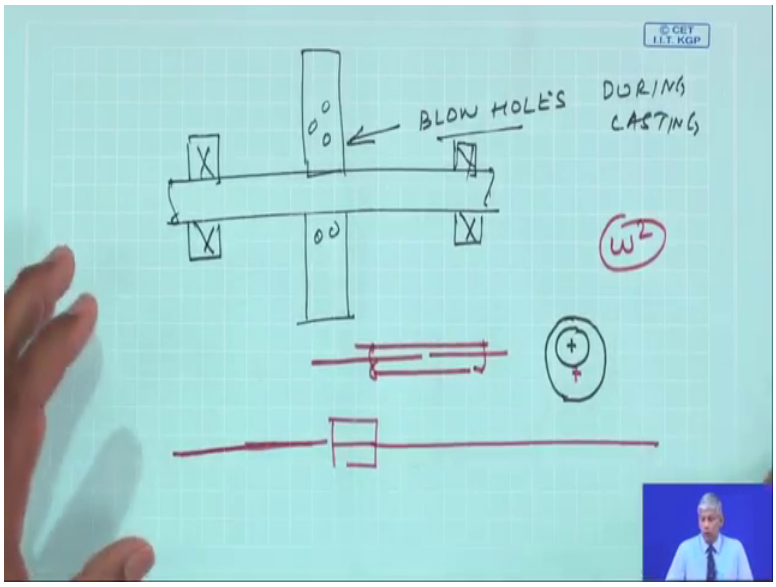

So, blow holes during casting for once twice operation this is, but with lot of with time this forces will induce stresses in these and they are having a little problem installation issues centering.

If I have a shaft with supported on bearings I have exaggerated this shaft center and because of uneven clearances, I have what is known as the centering issues and particularly this happens when they install large machines where the shafts of the 2 machines have to meet and this because of incorrect centering this issues could happen.

So, I have a mass which is not in center and this will give rise to another and of course, the other one is operational maintenance issues like I was saying the fly ash deposits in the FD FAN or the you know milk powder deposit in a food processing plant, etcetera. So, these are the reasons why unbalance occurs in shaft we cannot avoid it, but you know to know if a good periodic inspection of the unit we might as well reduce it.

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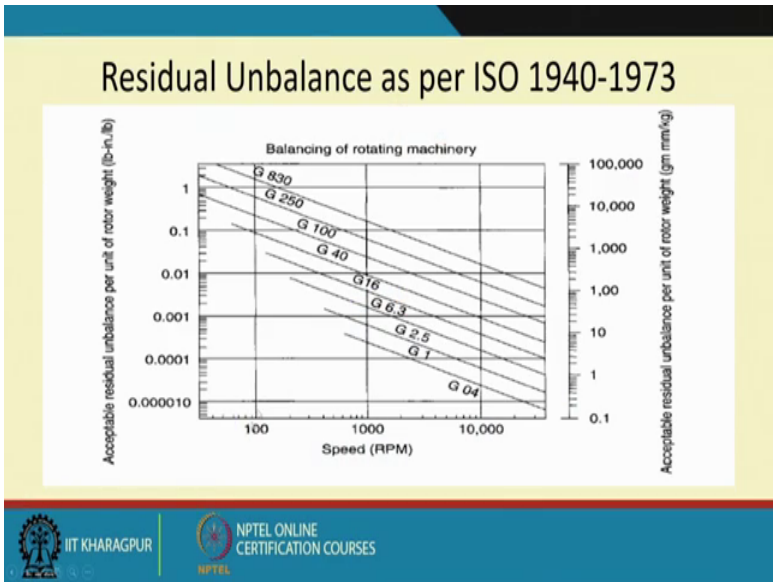

So, if a shaft is rotating and there will be some amount of unbalance mass per unit weight of the shaft and as a function of speed and this is given by this residual unbalance as per ISO 1940-1973, there are grades of balancing 004 being very precision and you will see these are for very very high speed machine the tolerances are very very low and for slowly moving machines. I can have a little higher grade of unbalance left because it is all function of omega square. So, you will see this surface finish does matter for high speed machines now we are talking about cryo engines you know running at 70,000 rpm, 80,000 rpm these are very very difficult rotators to balance to machine.

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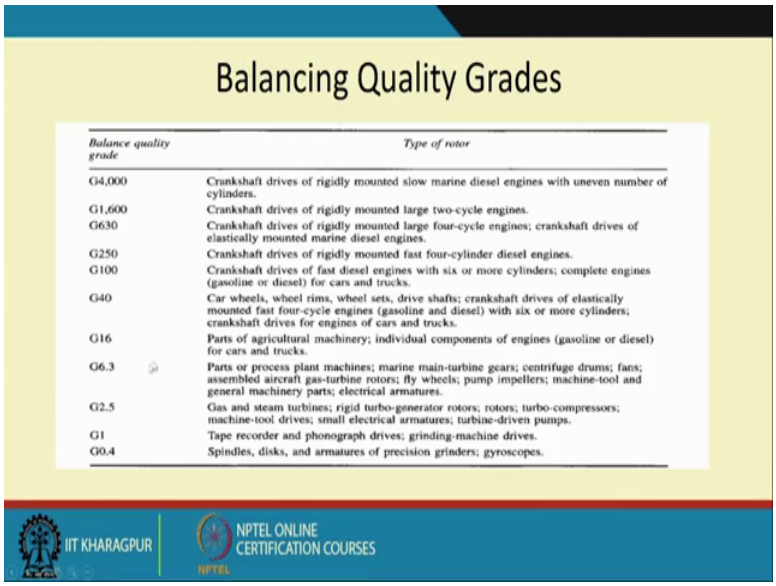

So, we can understand the tolerances I will give you a list of the balancing quality grades which are as per the tires of standard if we look at here 00.4 spindles disk and armatures of precision grinders and gyroscope G 1 for tape recorders ok.

These are for G 2.5 for gas and steam turbines, you know gas and steam turbines usually steam turbines are 5000, gas turbine are on 30,000 rpm as opposed to G4000, a slowly moving marine diesel engine this could be you know may be five hundred rpm. So, you can see once the speed increases here balancing grade has to improve I will just give you an example may be in some of the later classes, I will show you the pictures see if you go to a paper mill.

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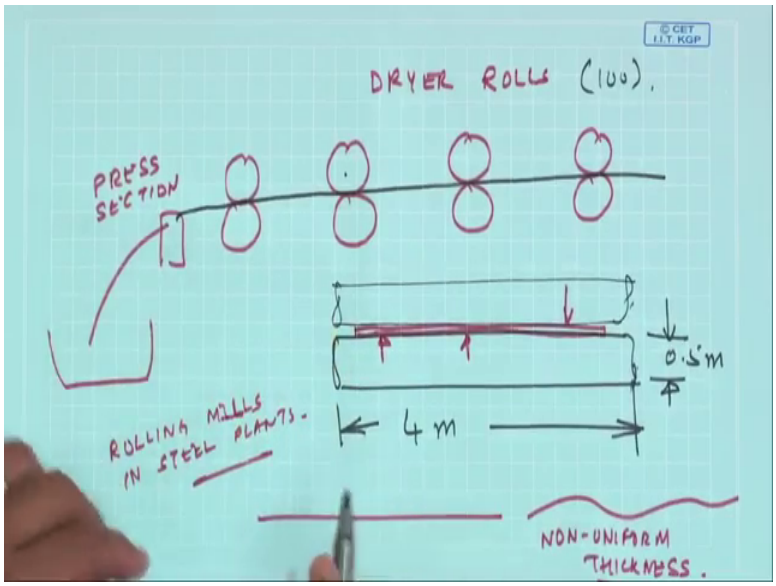

There are many rolls, this could be hundred such rolls and this is a there are process is there press a press section and these are nothing, but the dryer rolls which are steam heated in the inside and the paper which am drawing a black line here go out. Now, if you think of each of this rolls this rolls are the order of this is about four meter long and this diameter could be about you know of a meter imagine this paper which am denoting as here.

Imagine if this rolls long rolls had unbalance what is going to happen you will not get when you have a similar roll on the top as well and the paper which is actually a wet pulp at the beginning and then because of the stream drying roll and there could be such hundreds of such rolls in a paper mill if there was an unbalance what is going to happen the forces would be uneven. So, I will not get a flat paper, but I will get a paper with non uniform thickness. So, the quality would detoriate same is true for even rolling mills in steel plants. So, the product quality gets influenced by the amount of unbalanced in all these rolls. So, the question is how do we detect such unbalance.

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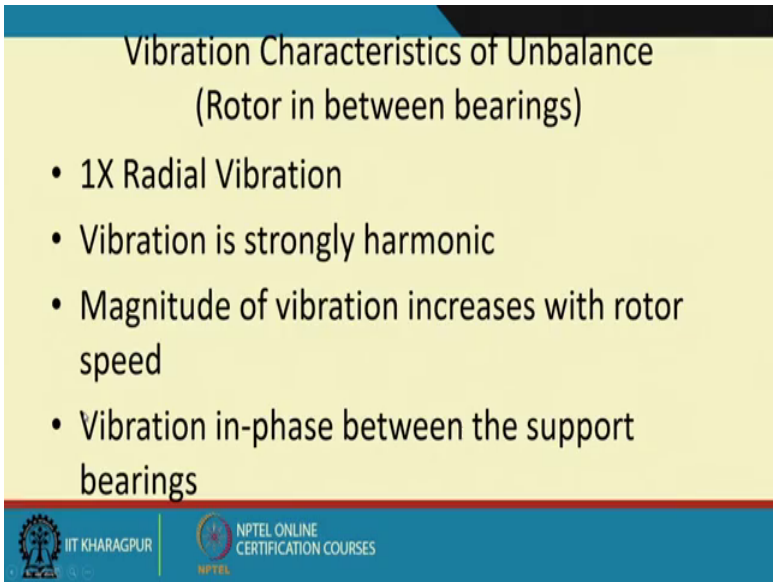

So, what is the characteristics of the unbalance by vibration monitoring.

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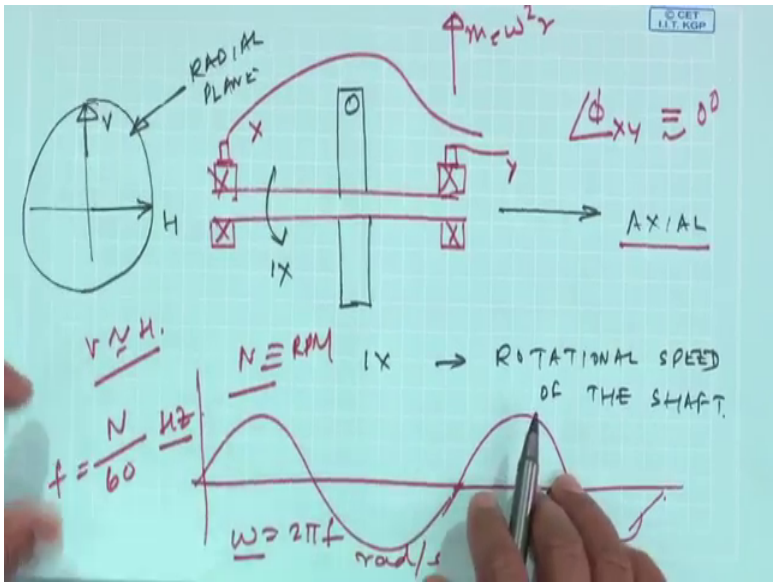

So, if I was to take a shaft supported on bearings, I will because of; so, you see this is my axial direction and this is the radial plane where I have the horizontal and then this is the vertical.

So, this is the radial plane and things are rotating at 1 X by 1 X I means the rotational speed of the shaft. So, when it is 2 X it means 2 times 3 X 3 times and so on. So, this is an unbalance this is a rotating. So, I will have force me omega square r. So, this is

nothing, but harmonic force because it is rotating along with the speed. So, it is as opposed to vibration in the axial direction it is more in the radial direction.

So, I will have this is for rotors between bearings short rotors a strong radial vibration if you look at the magnitude in either V and H are the much much higher compared to axial and usually because of this balance system V and H will be the same order of magnitude and will equal to the same and; obviously, this will increase with rotor speed as square in phase between the support bearings.

For example, if I measure the vibration here with the transducer and vibration here with the transducer because of one unbalance if I measure signal X signal Y, if I measure the phase between X and Y, I should get them to be 0 degree or close to 0 degree because they are in phase means when its maximum here it is also a maximum here when it is a minimum, here it is a minimum.

So, vibrations are in phase by the way just to recollect, how do I calculate the vibrations phase between 2 sensors X and Y.

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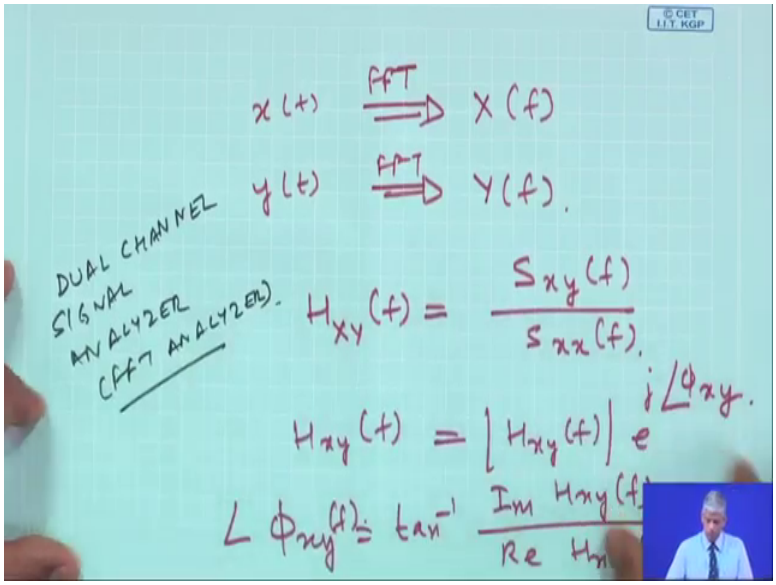

So, I know x t is a measure vibrations if I do an FFT, just to recollect, I will get the phrase spectrum of x t as X f. Similarly for yt, I will get Y f. So, I have to do them simultaneously. So, the transverse X hxy is nothing, but s xy f by sx X frequency and the this transfer function will have magnitude and phase part phi X y.

So, phi xy is nothing, but tan inverse imaginary part of H XY f by real part of H XY f these are all functions of frequency and particularly at the rotate because this is rotating at a particular frequency the forcing frequency nothing, but n by 60 hertz and what is house relation to omega. LOmega is nothing, but 2 pi f where n is in rpm. So, n omega in radius per second or f in hertz, they are all related and the forcing function is the external force which occurring at a frequency omega is responsible for this vibrations X and y on the bearing.

So, the characteristics of unbalance in a rotor in between bearings is strong 1 X radial vibration. Vibration is strongly harmonic magnitude of vibration increases with rotor speed and vibrations in phase between the support bearings and this can be estimated or calculated by a measurement dual channel signal analyzer or an FFT analyzer.

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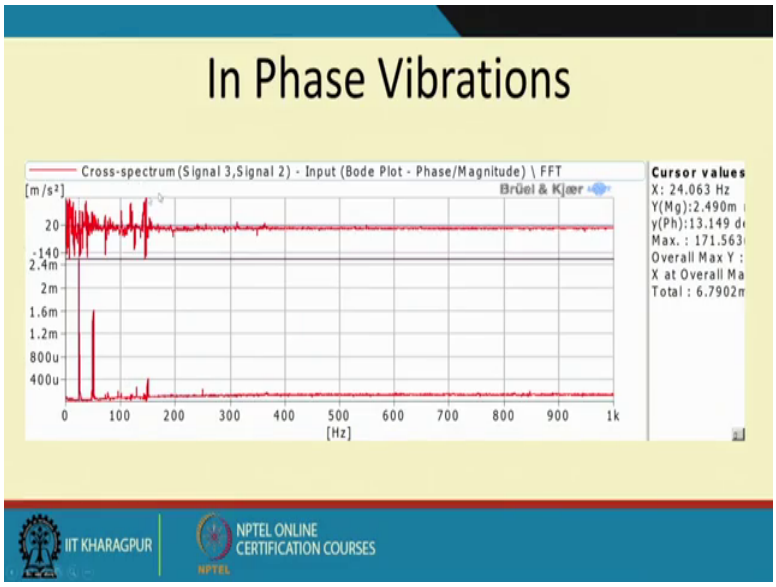

Now, this is just to give you an example where we have measured the cross spectrum between 2 signals and you will see the phase angle is only 13.149 degree this is subject to other unbalances in the system.

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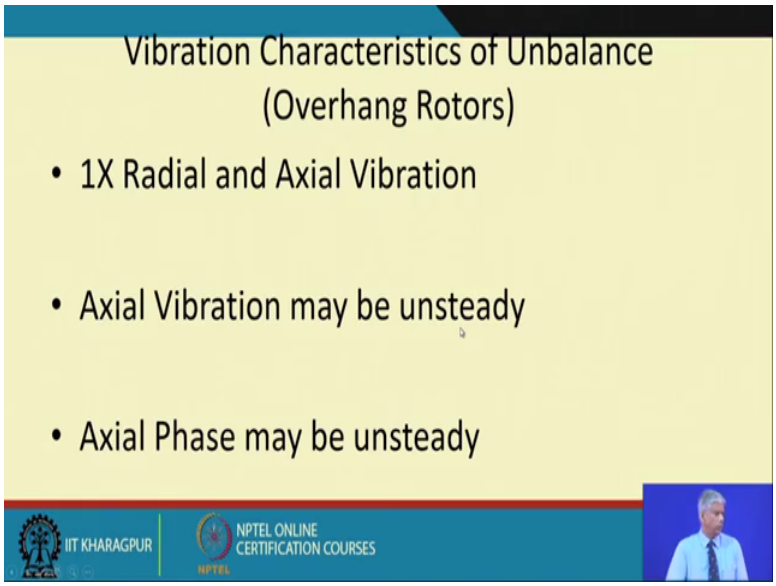

So, with the frequency of 24 hertz at the rotational speed in hertz, I can measure the magnitude and so on, these are case of in phase vibration.

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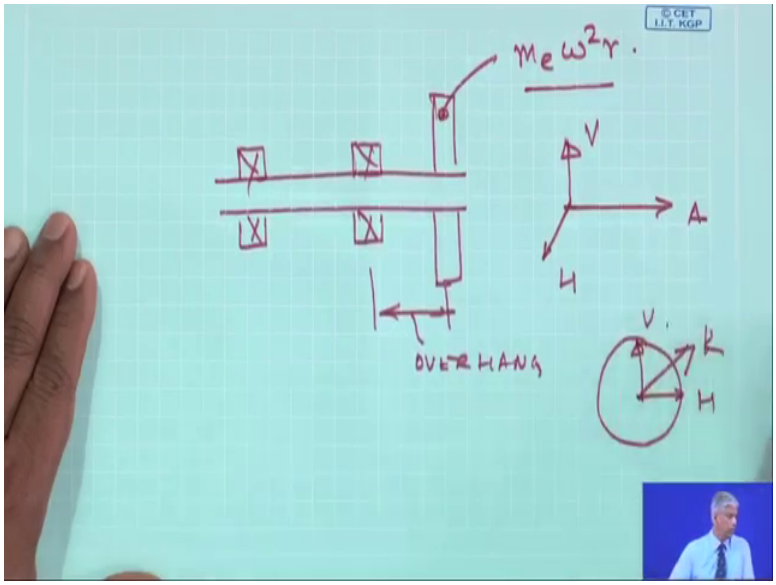

But when there is an overhang rotor supported on bearings and have a disk put here which is at an overhang and there is an unbalance mass there could be a strong axial along with the radial. So, in the real radial plane I will write H and a V and then axial vibrations may be on steady because it may not be uniform and axial phase may be

unsteady if we measure the phase angle between them this can happen. So, these are some of the scenarios which can happen in machinery condition monitoring.

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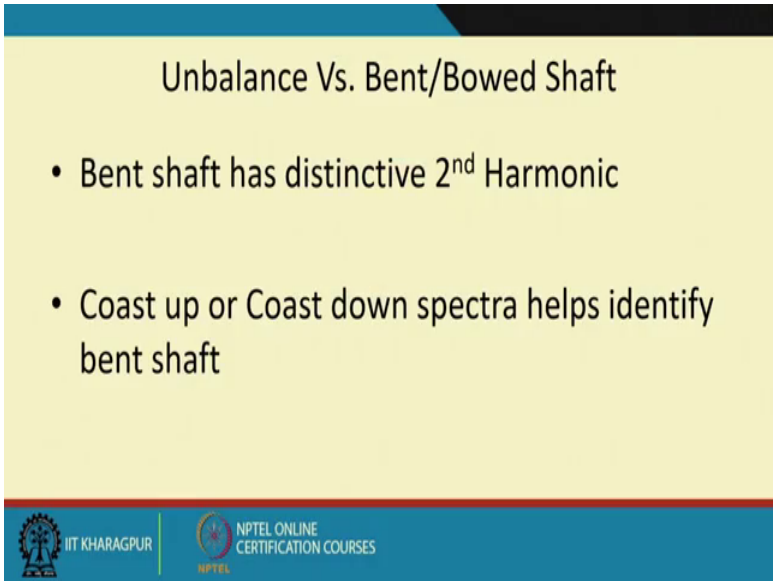

As opposed to shaft being unbalanced there could be a scenario where the shaft is bent.

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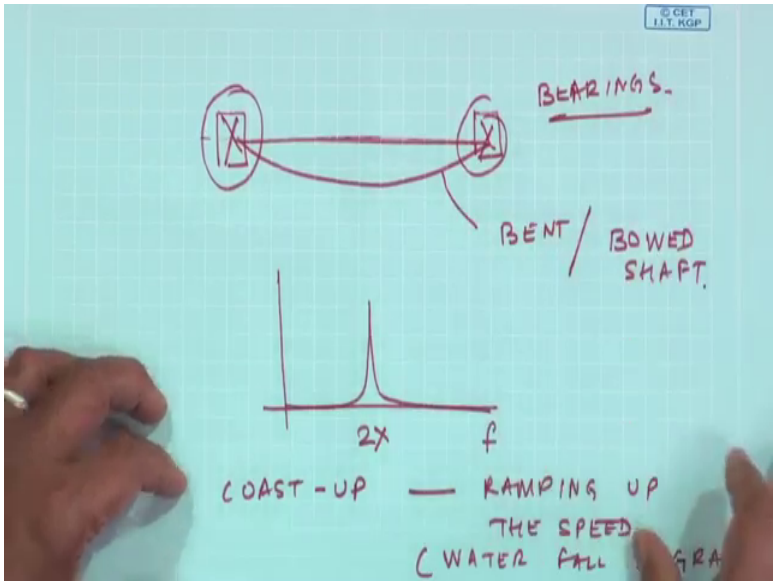

This my original shaft, but it has bent or bowed these are the bearings bent or bowed shaft.

So, a bent shaft has the sting second harmonic; that means, I will have a strong 2 X component and this can be easily measured by a coast up by coast up I mean am ramping up the speed and which you can see in what is known as an water fall diagram. Now the problem with condition based monitoring condition monitoring is the original source could be a bent shaft or unbalance, but the affect is actually felt in the bearings and why it is felt in the bearing is something I will explain to you.

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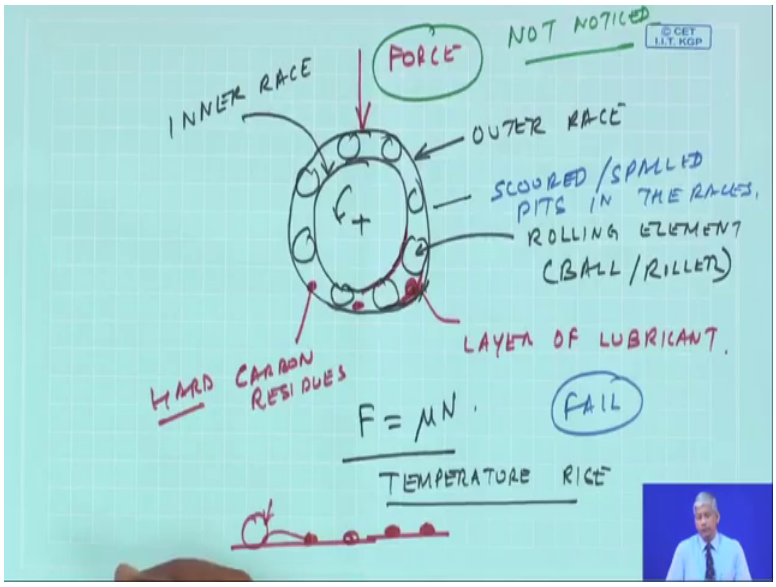

Now, imagine a bearing, those a few had a course in machine design will know a bearing have see this is my outer race this is my inner race and this is my rolling element which could be a ball or a roller what happens because this are all very hard nice surfaces we have lot of lubricant a layer of course, there is a returner which I have not drawn layer of lubricant.

Now what happens if this force increases some force. Now, what is the origin of this force, it is reactions which have increased at the support because of unbalance. So, this force occur increases the normal forces increases the frictional force is nothing, but mu times N. So, the frictional force will increase.

So, what does the frictional force increase? So, what is going to happen because it is going to rub against the surfaces the temperature would rise if temperature rises lot of heat generation because of frictional forces the lubricant could get baked if the lubricant

gets baked you know lubricant is a chemical fluid I mean. So, the lubricant will burn and the burned particles will become hard hydrocarbon residues and they are very hard.

So, imagine in your rolling element bearing because of an unbalance force the temperature rose nobody noticed it the lubricant baked nobody noticed it lubricant became hard impurities and then what has happened imagine you are going in a surface where there are lot of rocks on the road; obviously, you are going to variant here. So, the bearing is going to have a bearing surfaces get scoored, spalled and then there will be lot of pits in the races and imagine what would happen the bearing would suddenly fail.

So, what has happened is defect in a rolling element bearing is being noticed because of this force which was not noticed by the operator. So, this is the common scenario I have seen I get calls you know people say we have a bearing failure when I look at the past data I see the beling bearing fail because of an unbalance force because nobody took this into account. So, these are some of the scenario one has to be very very careful when we attack problems in the real world.

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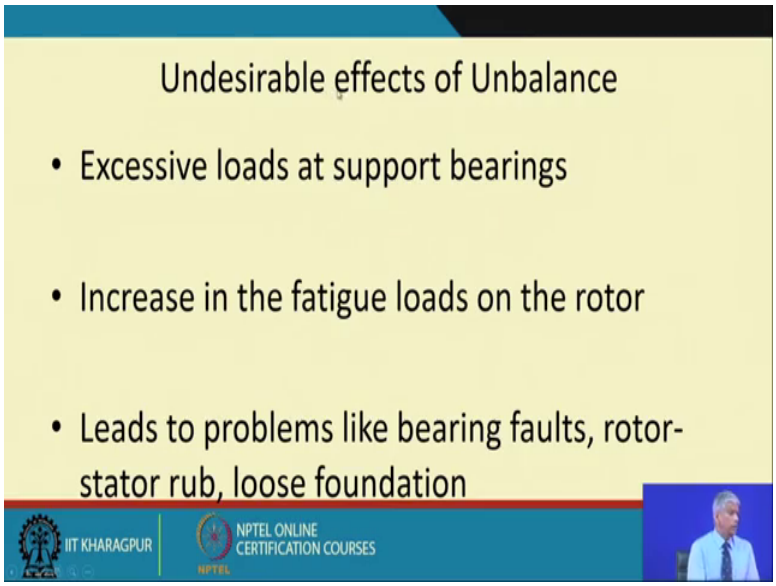

So, undesirable effects of unbalance excessive loads at support bearings increase in the fatigue loads on the rotor as I just told you leads to problem like bearing faults rotor stator rub loose foundations. So, these are issues scenario because know foundations will become loose because periodically there is a force which is hitting on the bearings ok.

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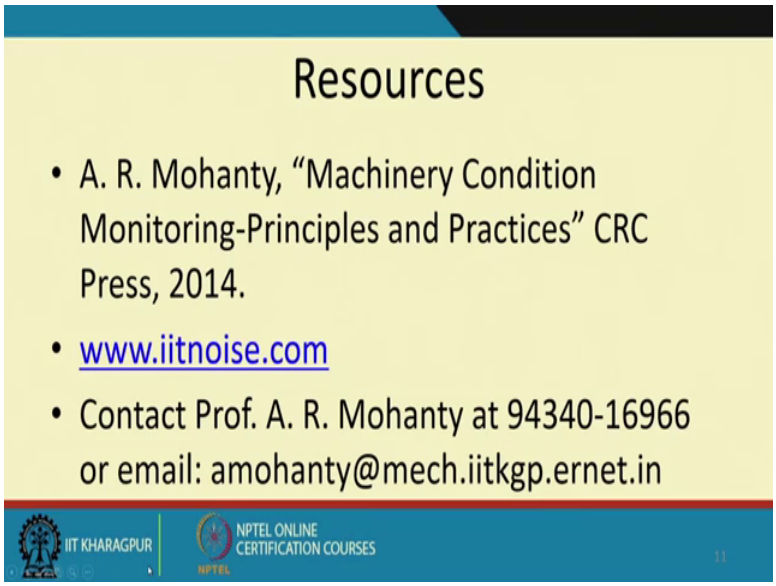

So, more of these we will discuss in the subsequent class how to actually if a balance unbalance has occurred, how to fix it and that is the methods of balancing which I will discuss in the next lecture.

Thank you.