Machinery Fault Diagnosis and Signal Processing
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Lecture – 15
Orbit and Order Analysis

In this a last lecture of the third week we were discussing about orbit and order analysis, how these are techniques of a signal processing which are used to find out the displacements in the rotating shift shafts in the x and y directions.

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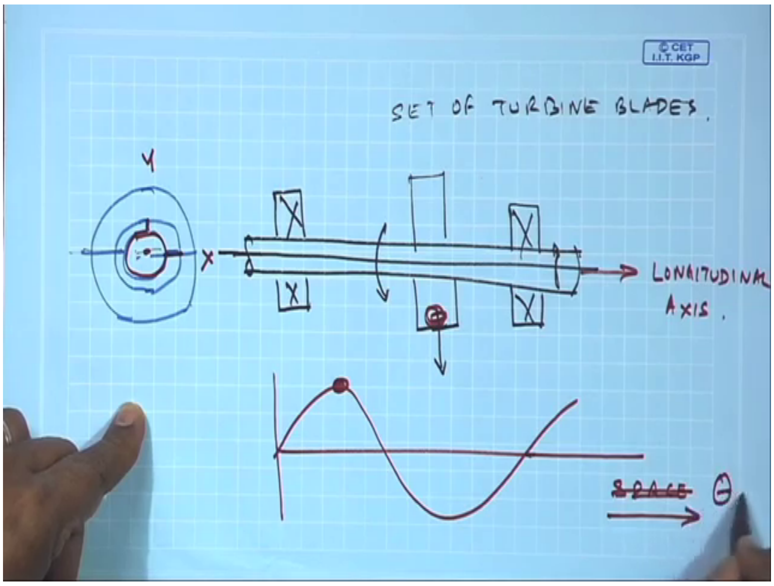

For example, as you know every machine essentially a rotating machine consists of a shaft, which has which is supported on bearings. And particularly when you talk about, we will talk about large motions or large rotors where there is a lot of weights, etcetera like a set of turbine blades.

So, and these kind of large rotor systems or machines are actually supported on general bearings. So, it is this a radial displacement between say or x axis and y axis in the radial plane, and this is my longitudinal axis. So, if a shaft is rotating what could happen that if there was some out of center rotation, or there is a load which is you know an unbalanced load which is rotating, like a hot spot this is in space or some radial theta.

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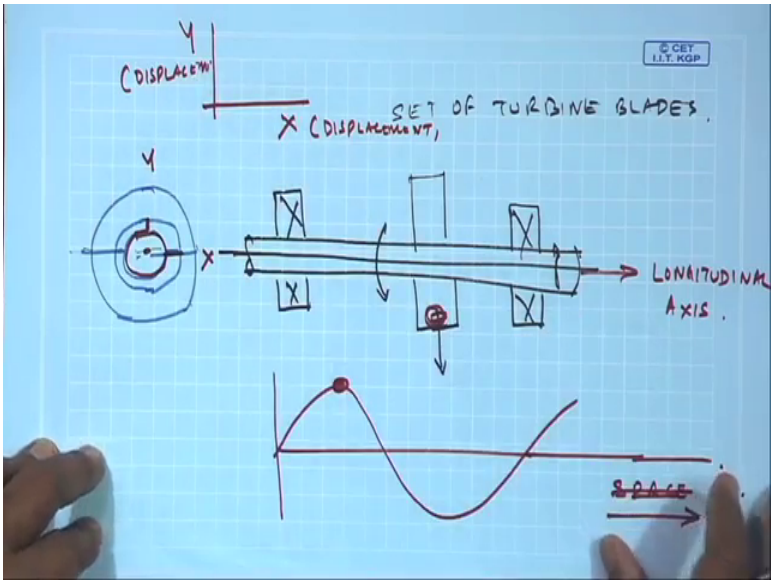

So, what is going to happen is every rotation this point will either decrease or increase. So, there is a variation in x and y in terms of displacement.

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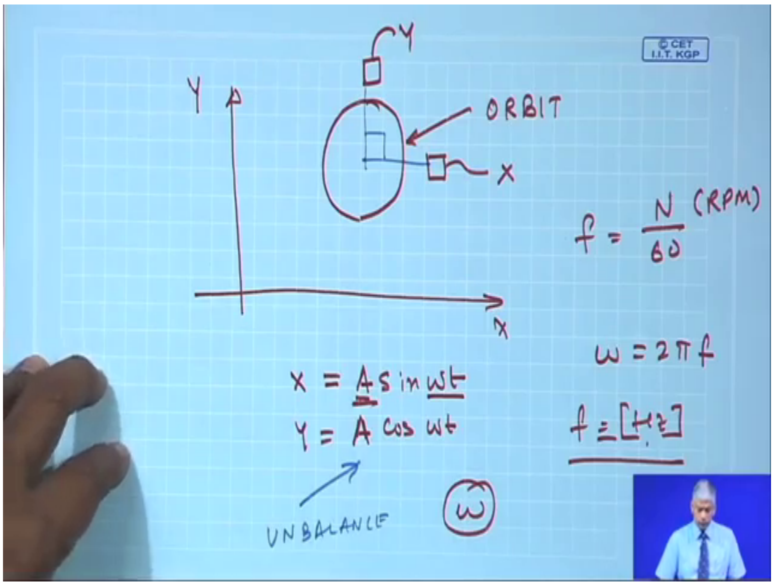

And this kind of plots between the displacements in x and y direction are known as orbits and this is an orbit.

Now, a lot of thing can happen depending on the relationship between x and y. For example, if I take x is equal to A sin omega t, and y is equal to A cosine omega t. If I plot them I will get a perfect circle. Now if there is a, this is omega is nothing but 2 pi f when f is nothing but N by 60 where N is in RPM. So, a unit of f is in hertz, for every speed and particularly these machines are not certain constant speed omega.

Now, what happens, when I have a transducer which is measuring maybe a transducer over here y, and the transducer x just looking at this plots, you know if what happens if the amplitude. For example, let this this bn you can unbalance. So, this amplitude of this orbit would grow up. And there is a very sheer way of finding out that radial vector has occurred, because of a defect like an unbalance and this circle is going to blow up and we will see some examples which we have done on a test rate. And then we will see how this orbit looks like, but this is one relationships where a N a x and y are 90 degree out of phase. And though they are you know this this means what, because physically these transducers are 90 degree apart.

So, I should get a circle, and usually in large turbines if you will see large turbines when there are lot of such sets, and they are supported on bearings and every plane they are actually 2 probes are there which are kept at 45 degrees.

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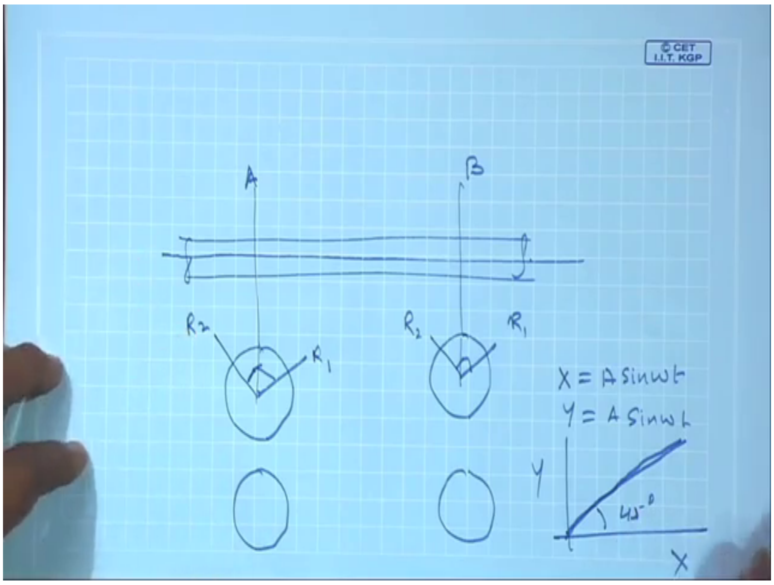

So, this becomes 90 degree so one may be an R 1 R 2, R 1 R 2. So, if you look at the orbits at location A and location B, and they could be a they will be perfect circle, and which time if the circle increases, you know something has happened which has been responsible for increase in the amplitude. Like I told you the case of an unbalanced, but if you know if x is equal to A sin omega t, and y is equal to A sin omega t. Just to recap you should drop line x and y are the same even at a straight line. Because they are the same is of course, at 45 degree.

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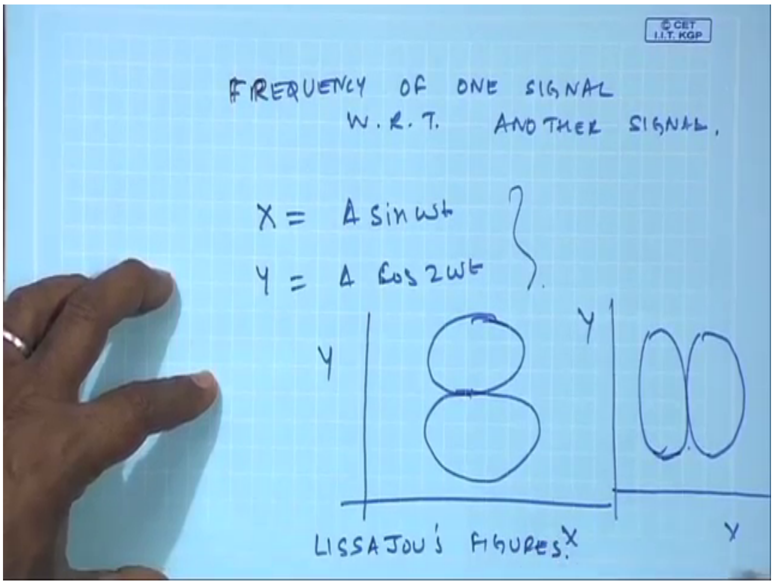

The frequency of one signal with respect to another signal, for example, if x is A sin omega t, and y is A cosine 2 omega t, I will see a plot, where this is x y. This kind of a plot, we will see better plots. So, and then if I change it, one versus the other this could change like this, and so on. So, the relationship between the signals and the frequencies will show up and this and these are known as the lissajous figures. But another thing also happens is the phase difference between the signals.

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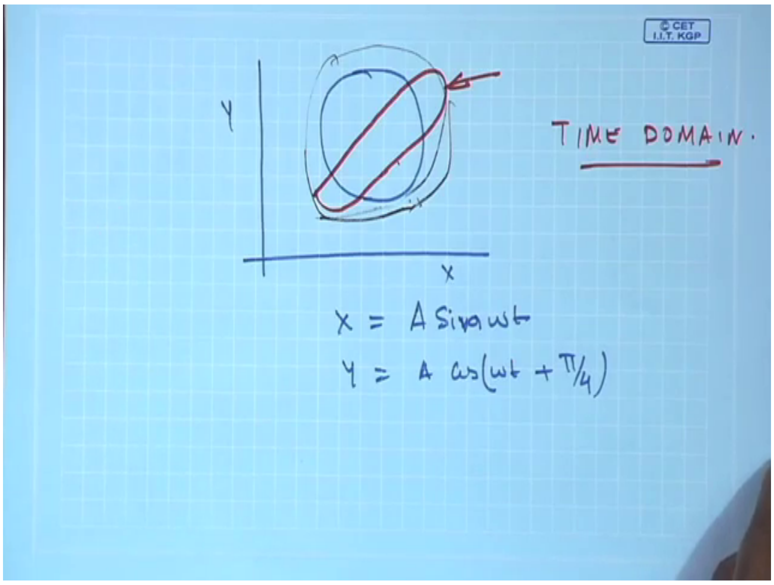

Suppose, x is equal to A sin omega t and y is equal to A cosine omega t plus maybe a phase difference pi by 4.

So, what would happen x y, you will see from an circle, this would become an ellipse and so on. Of course, you know this would be same A. So, this is because of a 45 degree. So, all this studies and these are all being done in time domain. Earlier we had seen that in order to analyze the find out the frequency of a signal, we have to either do an FFT or you know maybe also do a filtering. But in such orbit analysis these are not required just by comparing signals and plotting one against the other, you can get this orbit plots and from the shape of the orbit plot we can find out a lot of information about the phase relationship between these 2 signals, about the amplitude of one signal as opposed to another signal and so on. So, this could be happening.

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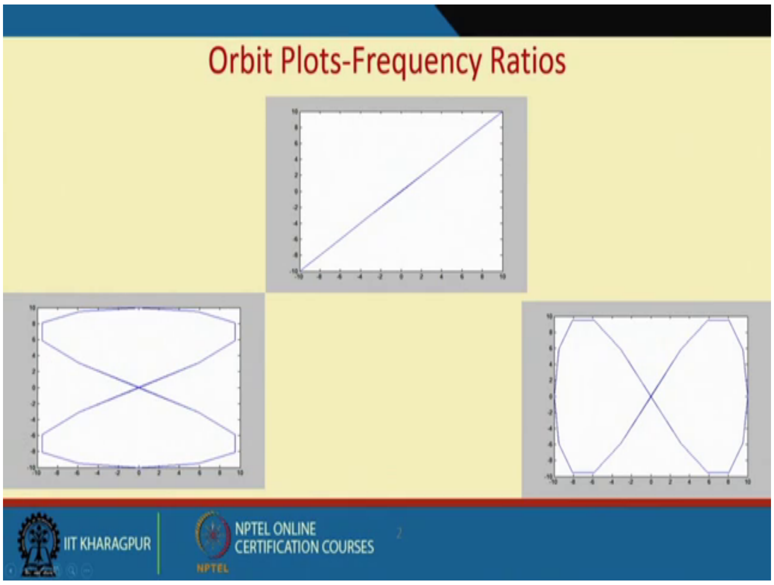

Now, you see here for the same amplitude you know this is what we discussed that the frequencies is the same between the x and the y orbit. And this is one is twice the other and so on and the x axis and the y axis. So, and the of course, if it is 10 times you will see 10 such lobes. So, orbit analysis is a very quick way to find out the limited the wrong pens out of the way, yeah.

So, what happens in the orbit analysis?

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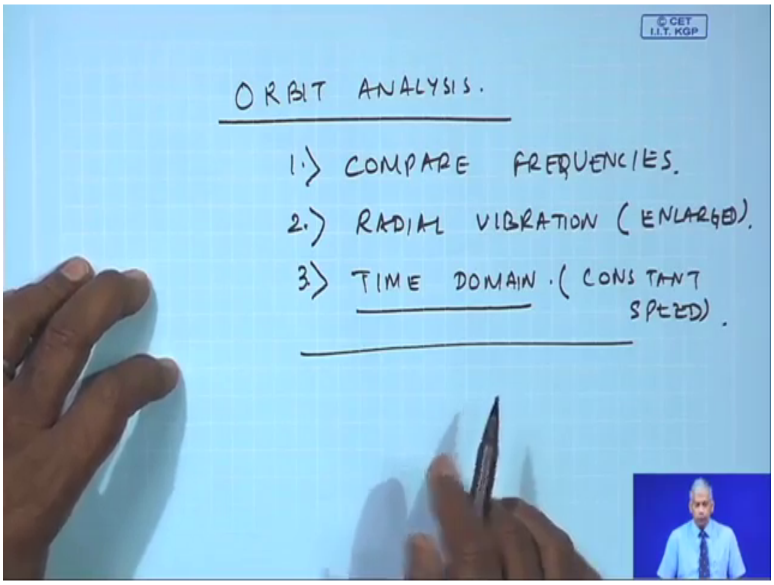

I could do many things. Compare frequencies; that means, if one frequency is known looking at the orbit plot I can say whether the other frequencies twice thrice some multiples of it because the shape of that plot would change. Next is orbit amplitude would grow with a defect in the radial vibrations or displacements increase orbit is going to get enlarged. And this is always in time domain. Of course, the machine is running at a constant speed.

So, I will show you a practical demonstration of a video, wherein we are doing an orbit analysis on a test rig.

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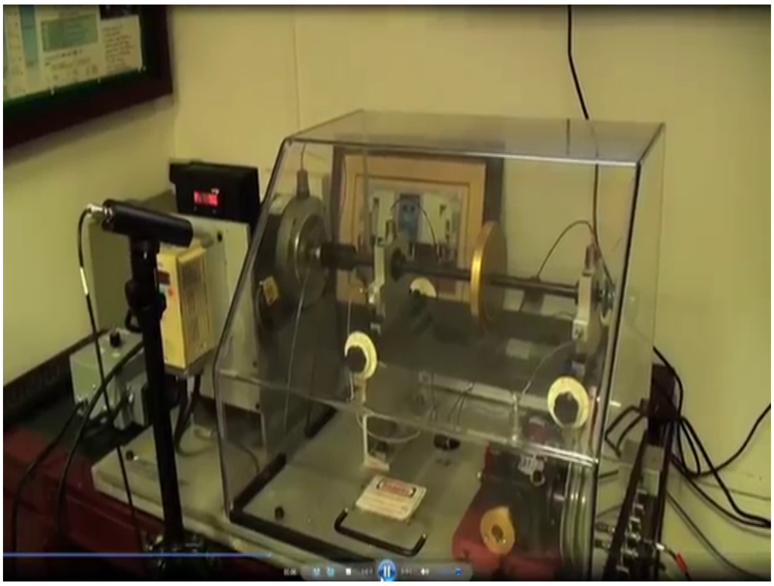

And let me show you this. If you see here this is an rotor rig, wherein we have put transducers in, explain you know if you see here. There is one in the x plane and one in the y plane. And these transducers are for some other measurements which we are doing in the laboratory, and this is a rotor which is supported on 2 bearings driven by a motor at a constant speed. And these are the 2 transducers, measuring one is measuring x and other is measuring y.

So, these are actually accelerometers, but then once we have the acceleration we can integrate them to get the velocity. And then another integration we can get the displace. So, this is going to rotate and this is a photo tack which is used to measure the rotational speed.

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And now this is going to run.

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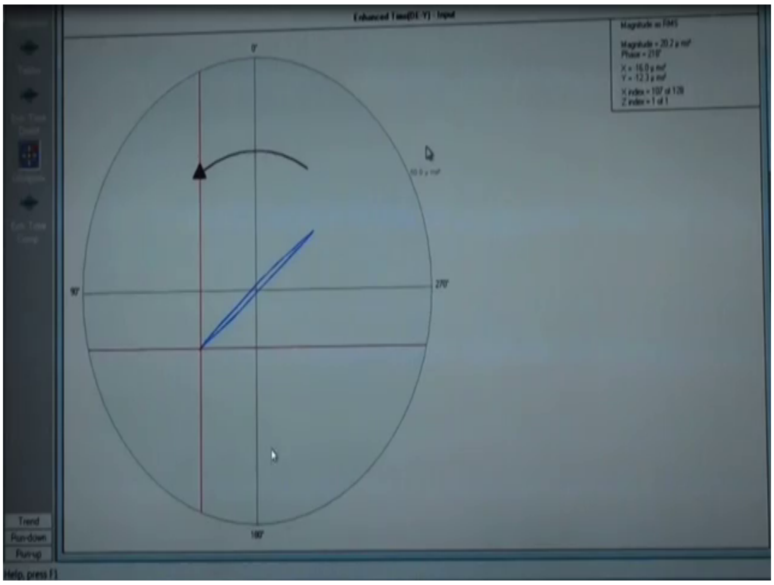

If you see here this is the orbit between the x and y transducers and you can see a value here.

Next is what we did is we increase the; next is we put a mass to it so that we created an artificial unbalanced.

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And you see here the amplitude increased because of the unbalance.

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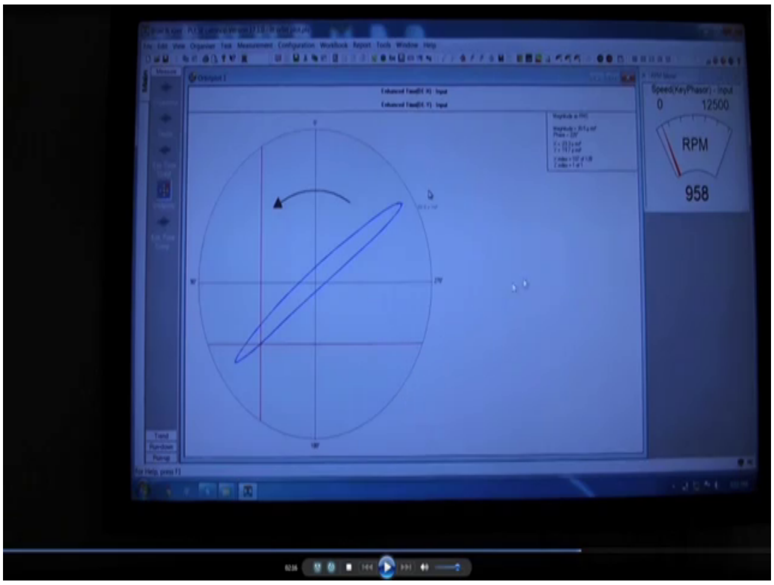

And a lot of takeaways from this we of course, are running this rotor at a constant RPM of 958 RPM. And this magnitude has increased compared to the previous case when there was no unbalance, but you see this if this radial displacements of x and y values were same, I would have got it as a perfect circle. But there is a phase difference because there is some other defects in this.

So, this has given a phase difference of 45 degree apart from the x and y axis. So, this kind of orbit helps you qualitatively very easily look into the machines. And then find out the one of the faults in them.

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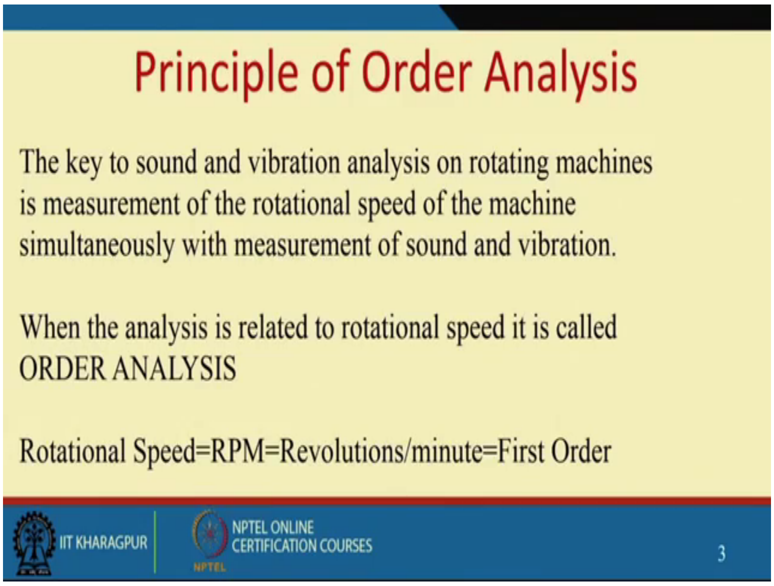

Another topic of interest which is known as order analysis; so, in order analysis it is the as it says, when the analysis is related to rotational speed it is called ordered analysis. Now let me give you an example of y order analysis is helpful.

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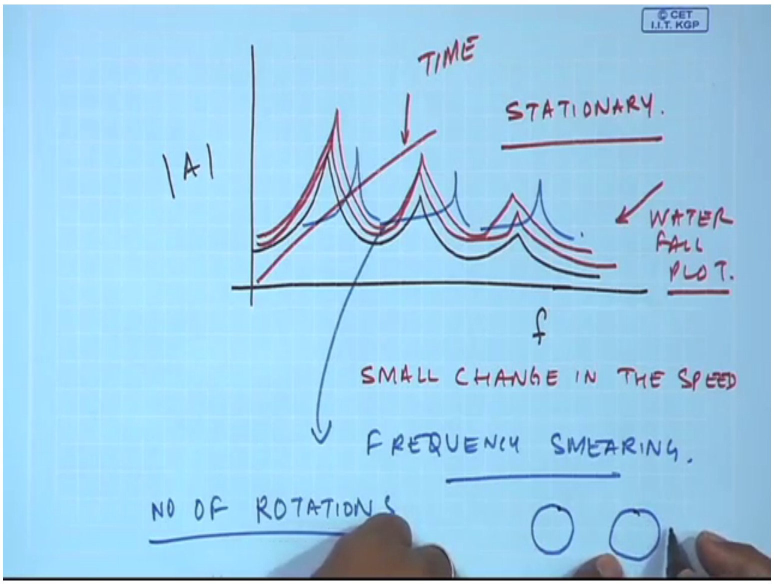

Now when we do a frequency domain transformation of any signal, we have assumed that the signal to be stationary.

But what happens if there is a small change in the frequency speed, in the speed. And if I am doing multiple frequency domain transformations that is you know I do because you know as you are you will I will we will discuss this later on to reduce the random error in any measurements we must average. Similarly, when we do the frequency domain computations using fast Fourier transforms to reduce the random error of the numerical computations. We always you know do good number of averaging, because this random error could be because of a variation in the signal which is reflected in the fast Fourier transform, but when we do the averaging it takes certain time.

So, what happens if I stack all of them together one by one. So, I will get what is known as this in the; this is the time domain axis, this is the frequency, this is this time. So, this is known as what is known as an a waterfall plot. But you see because this takes certain time to do in the time when this number of averages are being done. What if the machine speed change, how is that going to affect. That would affect because the things are related to the machine speed these frequencies you change.

So, what I would have is known as frequency smearing. Now to avoid this frequency smearing, what we do instead is look at the rotation number of rotations. So, was; obviously, when it is moving at a constant speed, the time taken for one rotation will be different for time taken for another rotation if the speed changes.

But if I look at the angular displacement it is one rotation whether it be at a different speed. So, best is to look into an angular domain or the rotational domain. And that is why many systems where speed changes are related to the rotations of one speed. This order analysis helps us identify frequencies which are changing with the rotational speed and not changing with the rotational speed I will give an example to explain this.

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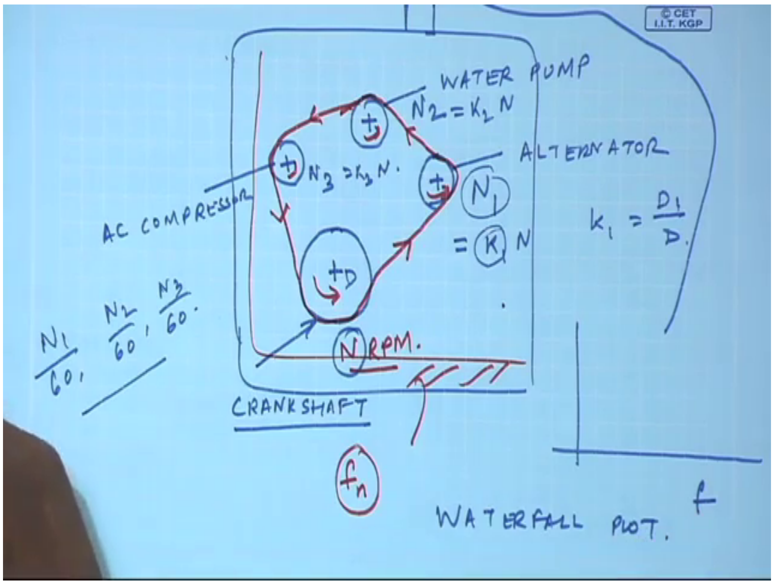

So, this is an automobile crankshaft. From the crankshaft we have a maybe a pulley for the alternator, maybe a pulley for the ac compressor, maybe a pulley for the water pump.

So, what happens a belt would be going around this way or say. So, this is a rotating in a particular direction. So, all of them are rotating. So, this is at N RPM depending on the pulley diameter. So, this is my crankshaft. So, this is my alternator. This is the water pump. This is the ac compressor, particularly in an engine. Crankshaft is which the powering shaft. So, all the speeds of this you know N 1, N 2, N 3 there are all functions of N.

Now, if N changes and one would change N 2 would change N 3 would change. So, if I if I you know somehow from the engine I would measure the vibration. And did an FFT as a waterfall plot. What would happen? If this was running at constant speed, all this N 1 N 2 N 3 they are related to the N 1 so on maybe some is some fractions or some multiples of N maybe for the sake of argument. This is some you know K 1 times N this is some K 2 times N. This is K 3 times N. So, you see K 1 K 2 K 3 are constants which depends on the diameter ratio.

So, maybe d and this is the diameter d dy that is a d 1 by d N so on. So, certain constants will happen. And because and they are all running at the same linear speed, the belt is moving at the same linear speed. This kind of ratios will occur, but question is if in the process of averaging, this speed has changed, if I do in a waterfall plot all the frequency would smear and it will be very difficult for me to find out frequencies at N 1 by 60 N 2 by 60 N 3 by 60.

So, rather if I see an order that at what multiples of N is my alternator frequency. So, this K 1 is going to be constant. So, somebody say the alternator is the tenth order of the rotational speed of the crankshaft; that means, whatever be the speed of the crankshaft 10 times that is going to be your alternators frequency and so on. So, this helps us identify components which are changing with speed and components which are not changing with speed.

For example, suppose I had one component, which had a struct maybe the engine casing, it has a natural frequency which is equal to fn. And no matter how different the speed is going to be your fn is never going to change, isn't it? So, this can be seen in such an waterfall order analysis.

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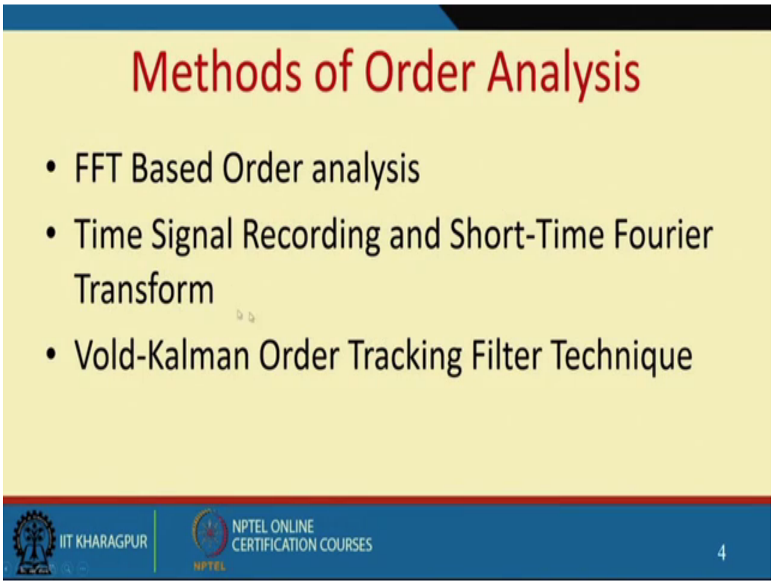

So, the methods of order analysis is FFT based order analysis, time signal recording and short time. Fourier transform and Vold Kalman order tracking to demonstrate this I will show you another video.

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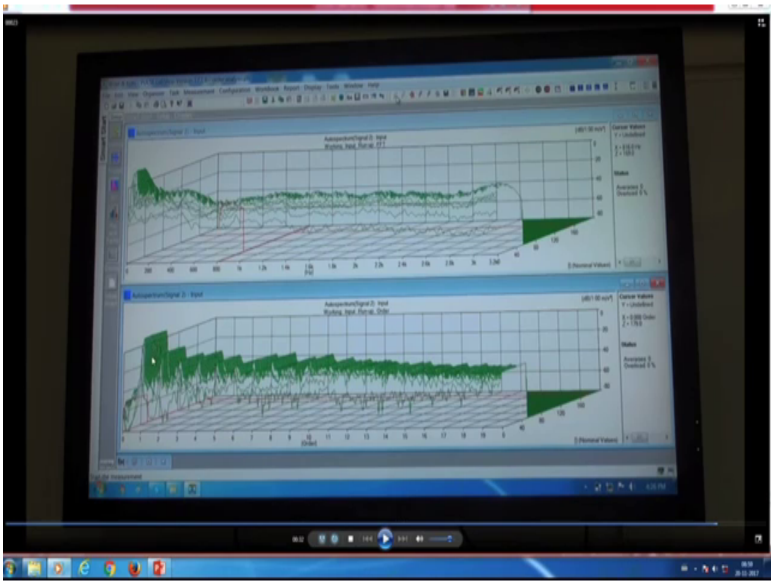

See this is the same brig. Now, there are 2 plots here. One this is the frequency domain plot and this is a number of FFT's or in this could have been time domain as well and the amplitude. So, in the process what we did now we increase the speed and decrease the speed.

So, in the frequency domain here do you see sorry, in the frequency domain you see I am not able to see clearly and indistinct frequencies. Because the speed was changing the frequency got smeared, whereas, in order analysis, they are all related to the rotation. So, 1 x means, the first rotational speed and multiples multiple orders. So, multiple orders will not change you know this is related to the speed. So, if I stack them up somehow at the of course, this is running at a different speeds. Even though it is running at different speeds I will see events which are related to these ratios K 1 K 2 K 3 and K 3 and so on. So, this is a linear FFT and this is how order analysis helps us identify things which are rated related to the rotational speed.

Now, I imagine in this order analysis if there is one frequency which was not related to the order which is a constant it would stay and it would not move. And that is the advantage of such order analysis. And the same plot we have plotted also in spectrogram.

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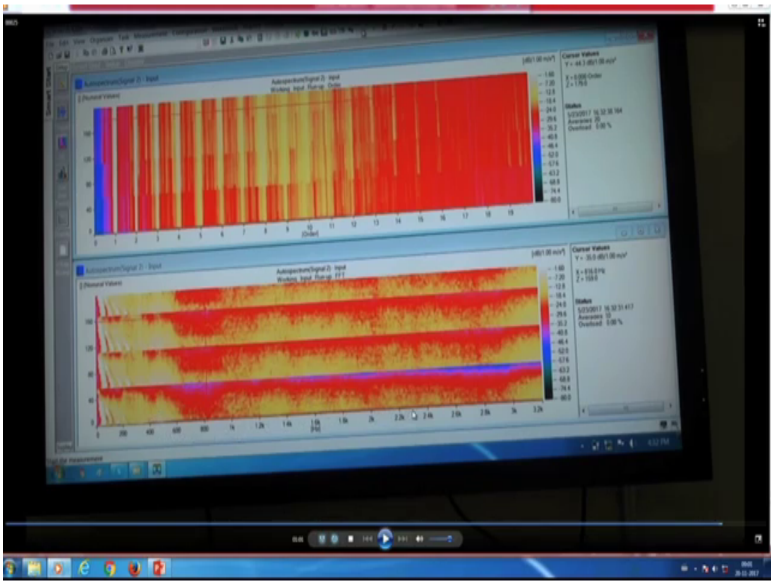

So, I am increasing decreasing the speed about 4 times in this run. So, you see here the top one is the order analysis plot, and the bottom one is the normal FFT plot, and this is the spectrogram; that means, the colored FFT is or serve with the into the plane of the projection is the color contour. You see there is a lot of frequency smearing and this is still 3.2 kilo hertz, and these are 4 times you have increased and decrease the speed of that rake.

So, you see there is good amount of frequency is smearing, but if you look at the order plots you will see that the distinct orders which are related to the rotational speed strictly come out as straight lines. So, there is a strong presence of rotational orders in such a system.

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So, this was the set up for order tracking which I just showed you in in the video.

So, here we change the unbalanced mass. And through this very occur we could increase and decrease the speed in that range. And this is the photo tack used to measure the RPM.

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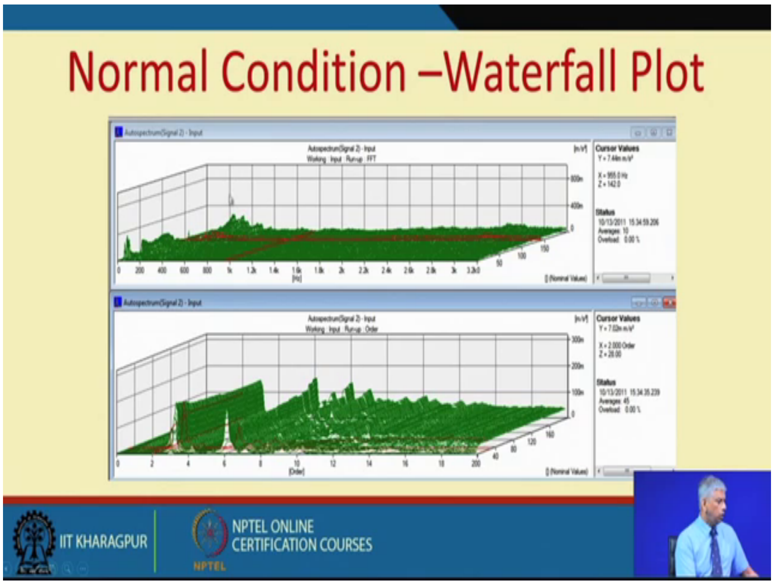

So, this is the normal condition waterfall plot, and there is frequency is smearing. And there is some amount of initial unbalanced. This is the run up order. And the same thing in the contour plot, you see these spectrums. But is the unbalanced plot what has happened, the intensity of this vibrations radial vibrations are increase. So, you see strictly strong orders which is missing in the FFT when we show it in the waterfall.

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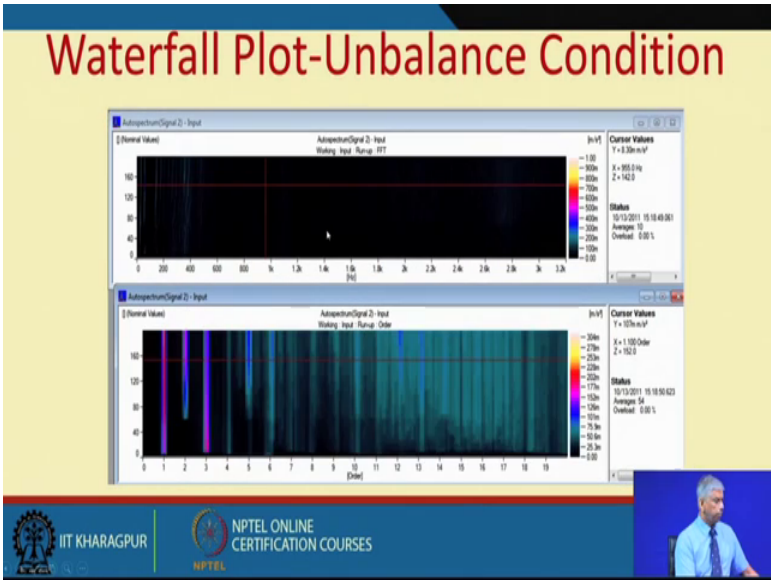

And you see this strong lines here. So, order analysis helps you identify frequencies which are related to the rotational speed of the powered shafts.

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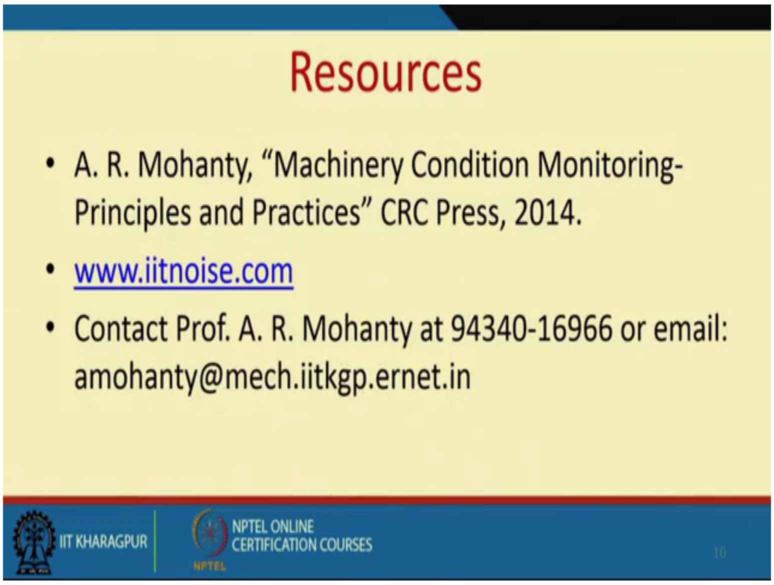

Thank you.