Machinery Fault Diagnosis and Signal Processing
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Lecture - 40
Crack and Looseness

In this lecture, I am going to discuss about few other types of defects in rotating systems like cracks, looseness, rubs. So, far we have discussed about unbalance and misalignment and then there are few more defects which can occur in rotating systems, one being the shaft having cracks or cracks developing in this shaft and particular right.

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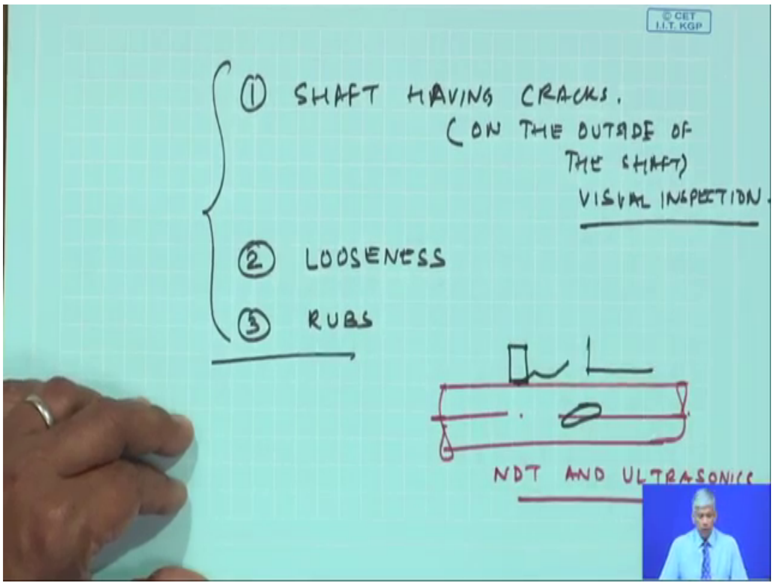

Now I am discussing about cracks on the outside of the shaft, by the way I will pose you another problem here suppose I have a shaft and there was an internal crack. So, this internal crack will also influence something, we sometimes may not be able to visually see it, but then cracks which have shaft which have cracks on the outside with very visual inspection we can see it, but I will tell you in this lecture how through vibration monitoring we can detect such cracks and such cracks which are internal we will again talk about another technique on NDT and ultrasonic's where such internal cracks can be detected and as you all know this shafts carry many components like impellers, pulleys gears, so some of them can become loose.

So, looseness of the system also will influence the vibrations, another kind of related is rubs like some component is rubbing against the rotating shaft. So, they will generate lot of vibrations signature and how we can detect these, what we have to focus in this lecture.

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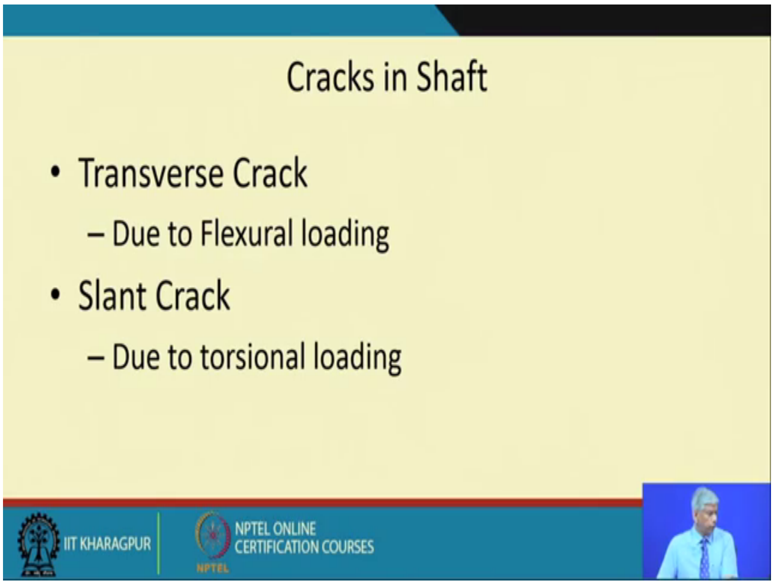

So, the shafts can be transverse or can be slant or and so we will see.

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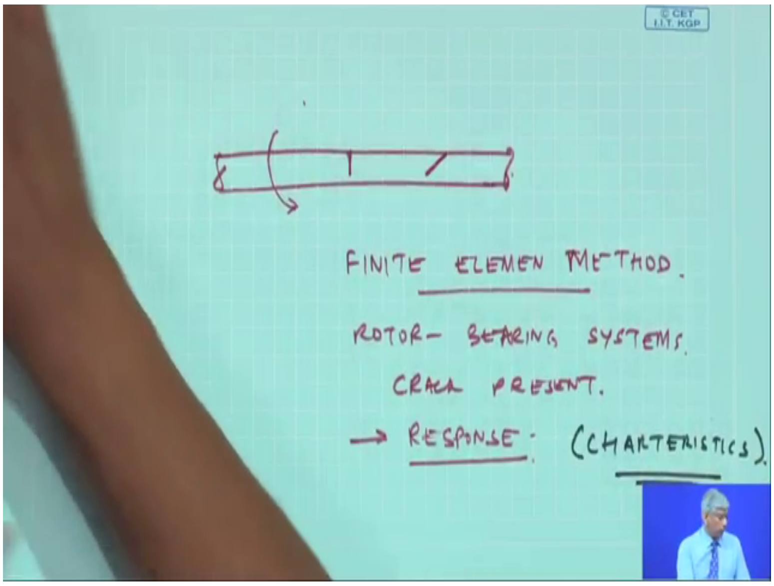

So, many methods how such shafts can be detected due to slant crack due to torsions, due to bending etcetera will see.

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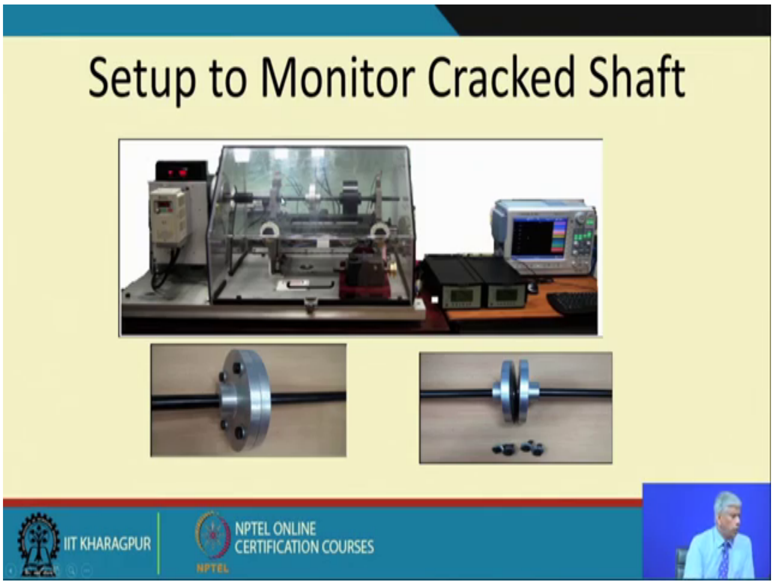

So, in the laboratory again same machinery faults simulator, we are in if you will see here we have a shaft and this black desk is actually a desk which is used to load the shaft and this shaft is actually simulated with cracks there are this 2 plunges you know aluminum plunges and if you see there are this 4 bolts and if I remove all the 4 bolts the 2 shafts will come apart and if I join them the 2 shaft will be a forming to a single shaft.

So, by loosening this bolts I can simulate cracks into shafts and this kind of experiments or simulations were done in our laboratory and these 2 you will see this signal conditioners being used for the accelerometer and the signals were eventually picked up in a data logger were in you can store, the data there is a news today lot of numerical techniques also exist, what is known as by the method of finite element method; people have enlarged rotor bearing systems with crack present and done I mean they are done for rotor bearing system which is of important to us they are done for beams columns having cracks. It is this response which we measure from such systems and the characteristics of this response gives us clue as to how bad or how good the shaft is in terms of crack.

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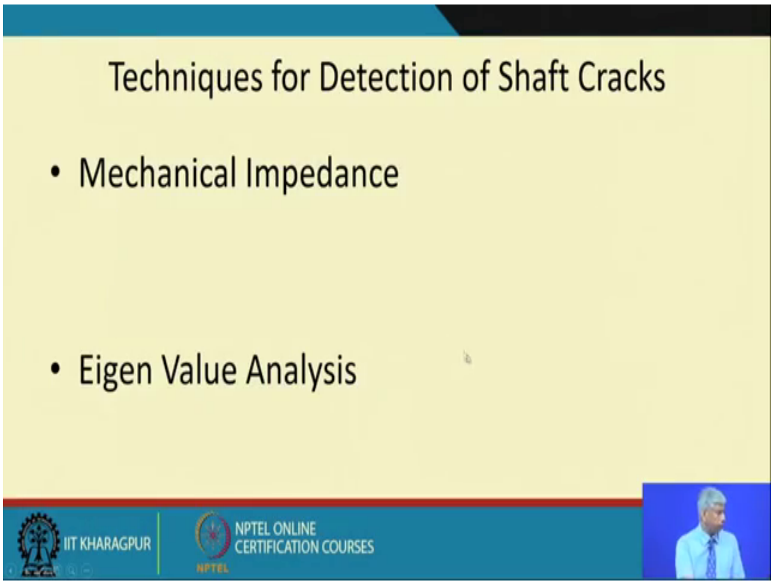

Now physically what happens if there is a crack in a system all of you can realize that the stiffness of the system would change.

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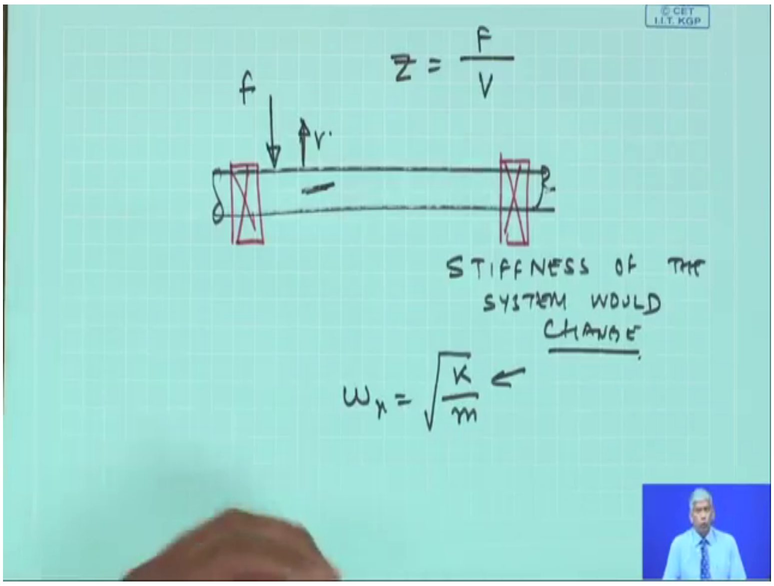

If system changes what happens in as you know omega n is root of k by m. So, if the system stiffness changes the natural frequency would change and that would mean the Eigen from an Eigen value analysis. We can do that another is if a systems property has changed I can measure it is impedance, what is this impedance is nothing but force by velocity. So, for a system I can give or known force f I can measure the response v;

obviously, if for a rotating shaft this has to be done on the bearing housing. So, about 2 decades ago now we did this the research at IIT kharagpur in our laboratory, wherein we measured the mobility of this shaft crack.

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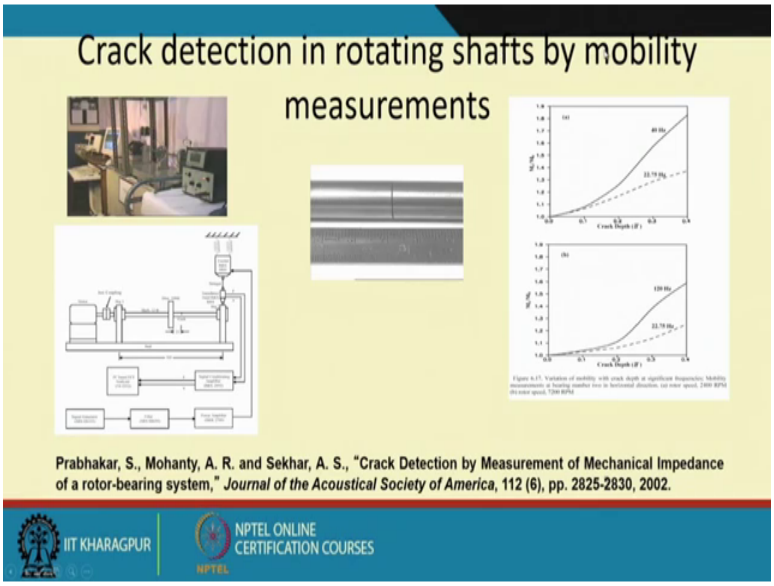

So, let me explain you what this is here this is a shaft where we artificially made a crack and then we have measured the mobility. So, if you look at the experimental set up here of the motor coupling shaft with a desk and we introduced a crack here at some distance and we are giving a force through a electromagnetic exciter and then we are measuring the response with the impedance head, by the way I talked about the accelerometers. But then there are also physiolated devices which can be used to measure the force. So, these are known as force transducers and there are devices known as impedance heads, where I can measure simultaneously force and vibration or acceleration.

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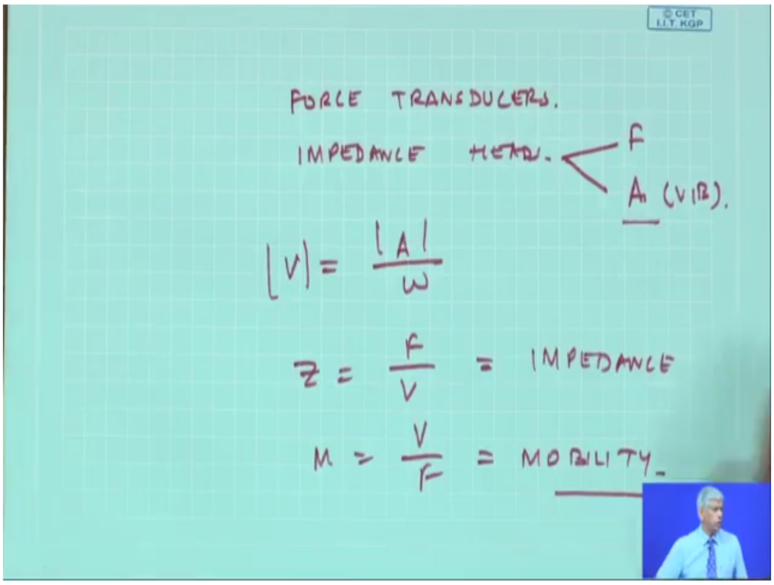

I can measure the impedance once as acceleration in terms of acceleration velocity as you know is a by omega. So, I can find out the velocity and impedance is f by v or mobility is v by f inverse. So, in such a system we run the system at different speeds and we measure the crack depth ratio.

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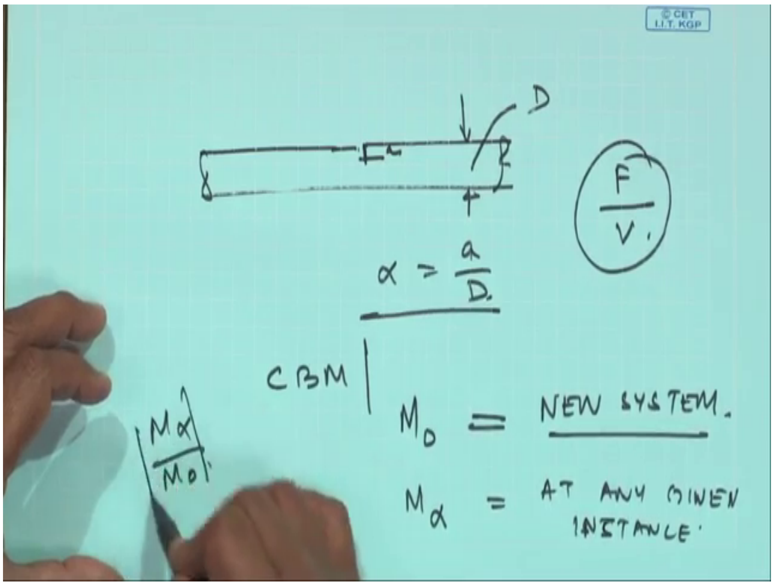

This is the shaft diameter d sum a, s alpha is nothing, but a by d for such crack depth ratio this has been normalized, we measured the change in the mobility and this was published in 2002 here almost more than 1 and half decades. Now also very popular work which we are done then still being followed by many researches throughout the world. So, you see the variations in the mobility ratio, the change in the mobility through the original mobility with different crack radiuses at 2 different speeds, you can see that right 120 degree at 40 degree and so on ok and this gives an idea us to if crack has occurred.

So, in system which is running and initially in cbm, if you had taken the care to measure m 0 new systems. So, at periodically if you measure m alpha at any given instance, of course it requires certain extra instrumentation for measuring force and the velocity. So, you can do m alpha and then plot. So, at whenever the crack depth has increased considerably they effect is large, but you know we cannot afford to have a very high crack depth, because the system strength would have reduced significantly. Otherwise there are cases wherein cracks have occurred in soft and systems and then they fail another failure occurs.

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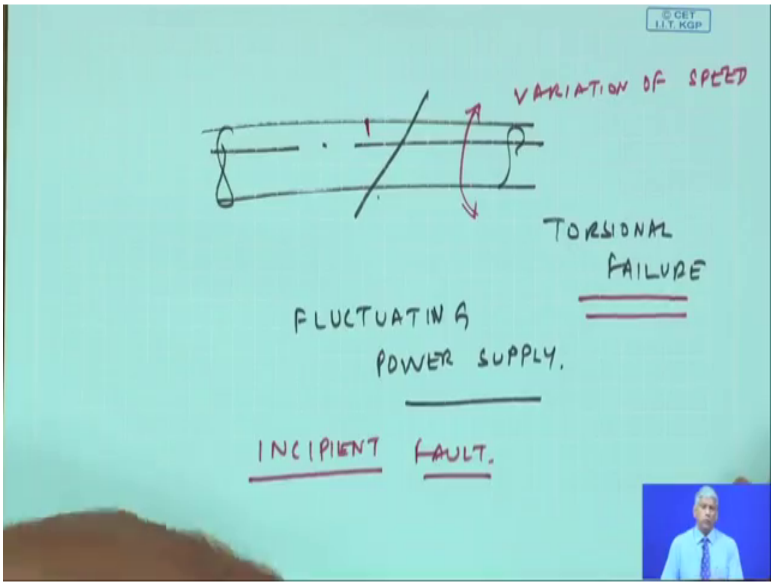

Because of the torsional variations particularly in many of the torsional failure, many of the rotating systems because fluctuating power supply leads to the variation of the speed, on top of it if there is a crack this will lead to an immediate failure of the system.

So, 1 has to say if guard and then you must keep in mind in cbm or machinery health monitoring condition monitoring, that to 1 incipient fault if goes undetected it will lead to few other faults and then you will try to be lost in finding out the reason behind such incipient fault or what actually cause really failure. So, 1 has to be careful and now a days in condition monitoring research throughout the world, people are finding out methods by with we can find out incipient faults beat in bearings gate in gears being shafts and that is the thrust area today.

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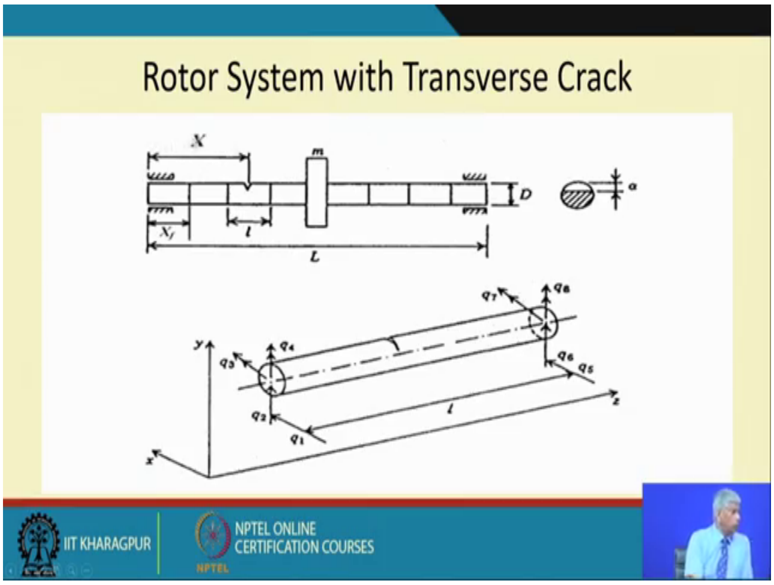

So, this rotor system with transverse crack was modeled by fire and elemental methods and this is that normalized I mean distance a. So, alpha is a by d or a by prime a bar is a by d and so on. So, this could be modeled in the techniques of fire and element method.

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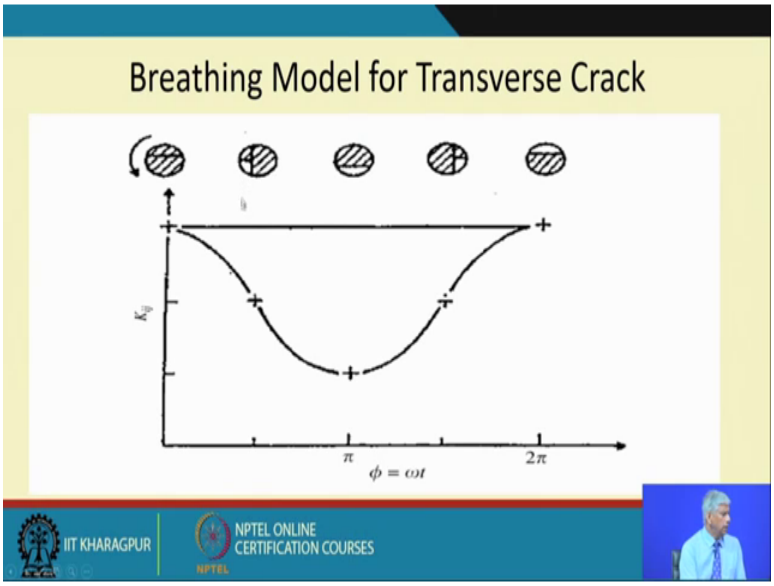

And then for a transverse crack some of the breathing modes are there it is change with the rotation of the shaft and this cracks will open and close depending on what position they are.

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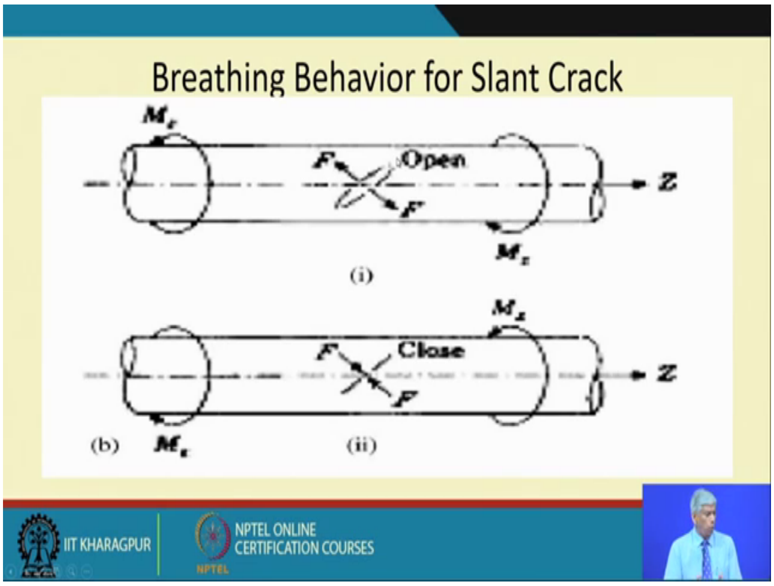

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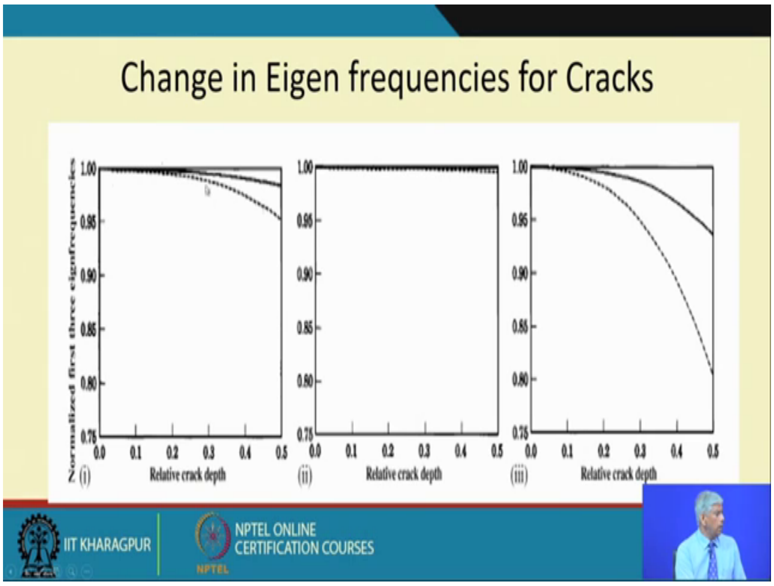

So, these kind of signature will lead to the changing in the Eigen frequencies of the crack because, I was telling you the natural frequency would change because of this factor k by m, so for the present Ks alpha.

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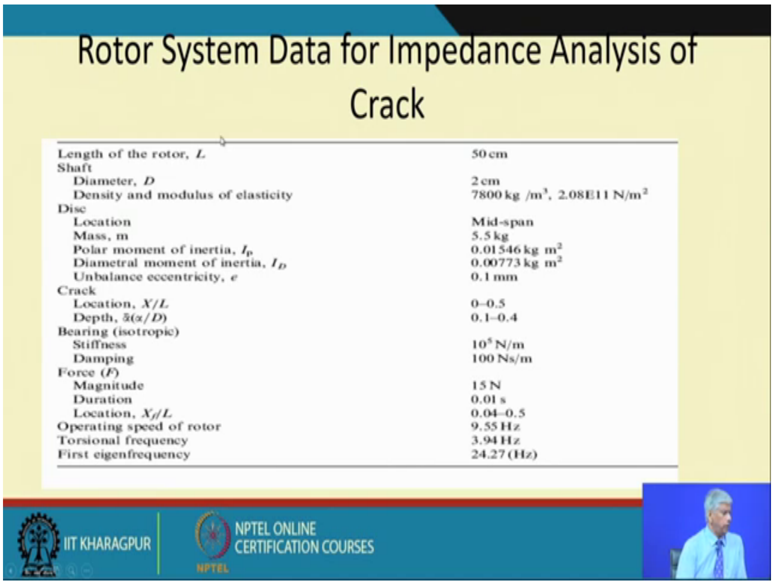

The example which I showed you this is for somebody those who are doing research in this area, those of I can remember those students who are attending this course and would like to know more about this they can refer to our paper which happened in 2002 in journal of acoustical society of a America and these are some of the examples in the laboratory we took a shaft of 2 centimeter diameter length 50 centimeter of a steel shaft we had a desk mid span and the crack location was varied and the crack depth alpha bar was varied and bearing stiffness was assumed to be constant force was 15 Newton for duration of 0.1 seconds and then we bared the operating speed and found out the Eigen values Eigen tritons and so on.

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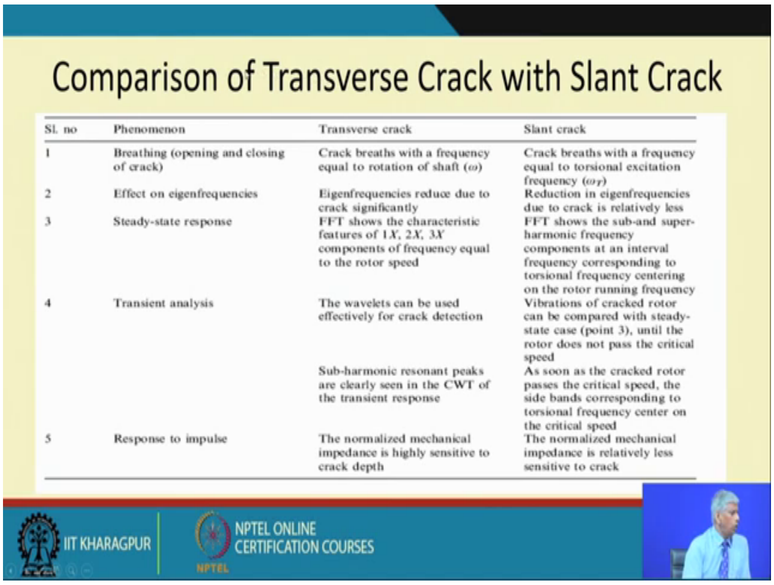

But won't comparison I must give you between the transverse crack and slant crack and what is the phenomena because of the opening and closing effect on the Eigen frequency steady state response, transient response and response to impels. So, crack breath with the frequency equal to the rotation of shaft and slant crack breath with the frequency equal to the torsional excitation omega t Eigen values reduce due to crack; significantly but reduction in Eigen values due to crack is relatively less in the case of slant crack and most important this steady state response show the characteristics features of 1 x 2 x 3 x components of the frequency equal to the rotor laws rotor speed; whereas in the case of slant cracks we will see sub and super harmonic frequencies. So, you will see Fractional frequencies of some fraction of 1 x and so on in this spectrum.

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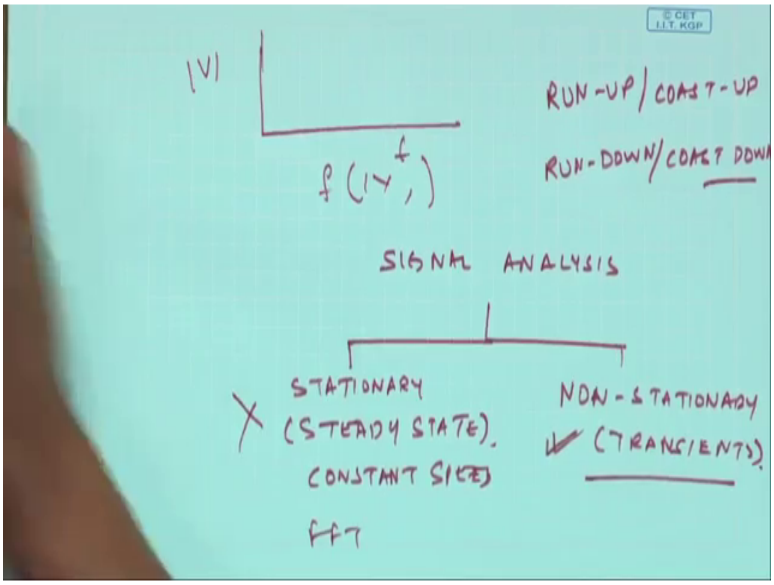

Now in transient you know as opposed to if you recall again this causes some times I recall what are I would have studied or thought you earlier in terms of signal analysis, broadly we can classify signal as stationary and non stationary. So, stationary signals occur during steady state, because they are constant frequency there is no speed change constant speed is a better word to use and this happens in the case of transients; like here we have just started off the machine, if you start off the machine it will known as run up or coast up.

If you are shutting down it is run down or coast down. So, from 1 speed you decelerate to come to rest or from are rest you go up to a particular speed. So, this transient will occur and you can very well detect if there is transient. So, non stationary methods of FFT etc will not work we have to use transient and there is a signal processing technique called wavelets.

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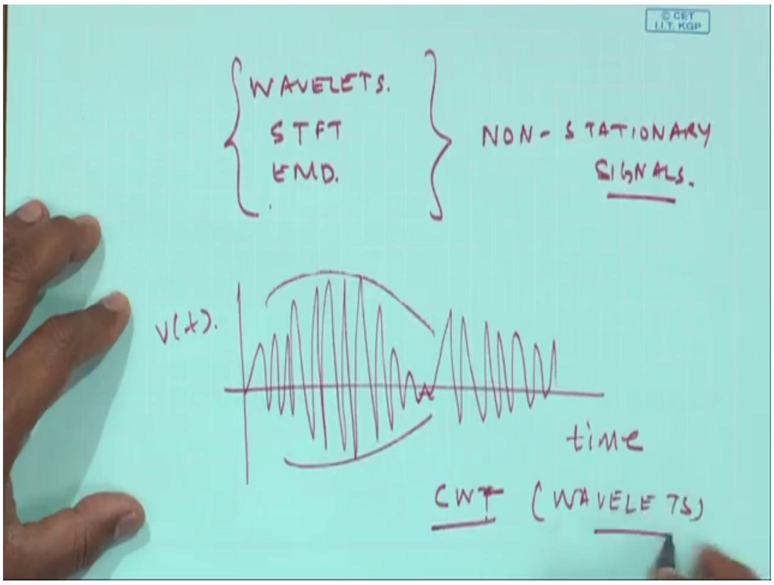

Which can be used or STFT of course, or EMD etc these are some of the non stationary signal analysis, which can be used very easily and effectively to find out such occurs on cracks. Vibrations of cracks rotor compared until this speed does not posucate, because speed sub harmonics are there in the transient response and so on. So, if you the soft as a crack there will be lot of sub harmonics in the time domain anal mine envelope and so on.

Some Vt and this can be only found in continuous wavelet transform etc. So, those who are interested to study more about cracks in rotating systems can refer to many of my papers again which will be available in Google scholar or at my website.

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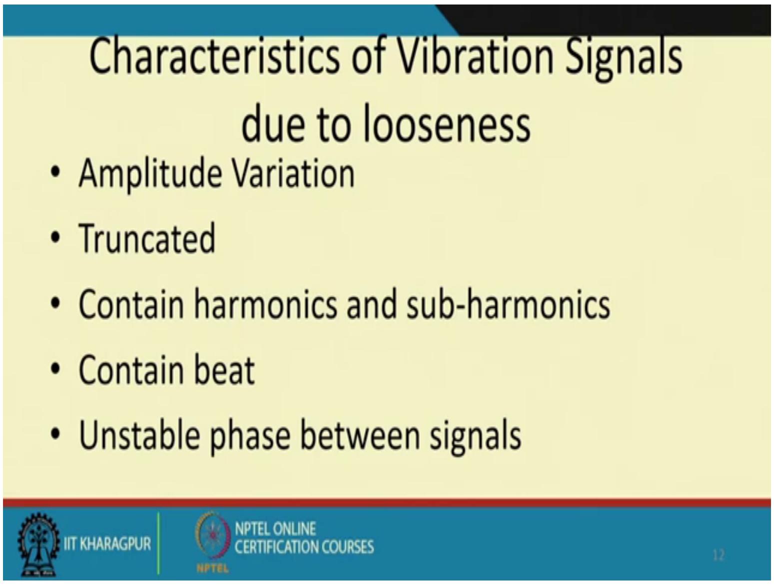

Now with that kind of a background on cracks shafts, I will give you some title science of what happens if the components are loose in a system; now what happens if components are loose in a system they will hit and so the amplitude of the signal and will be very high.

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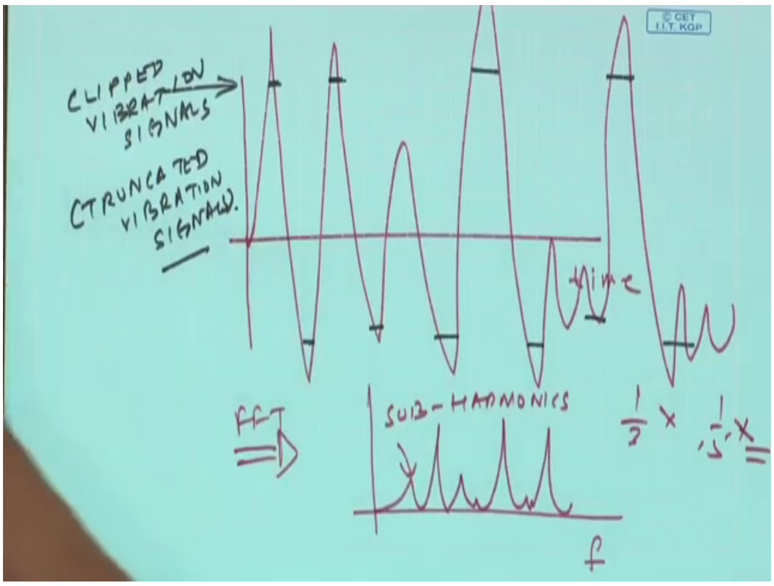

It will be so high 1 reason is the data efficient system has a limit to how much it can take. So, these are responsible for clipped vibration signals or what are known as truncated vibration signals. So, these kind of truncations will give rise to what is known as clipped wave form and if you do an FFT of this clipped way form which has been created because of looseness, you will see lot of sub harmonics and these are sub harmonics.

Sub harmonics I mean 1 by 3 x 1 by 5 x etc where x is the rotational speed. So, amplitude variation truncations contains harmonic and sub harmonics contain beat and unstable phase between signals they are very erratic. So, if I have bearing component or rays loose on housing it will be hitting against each other.

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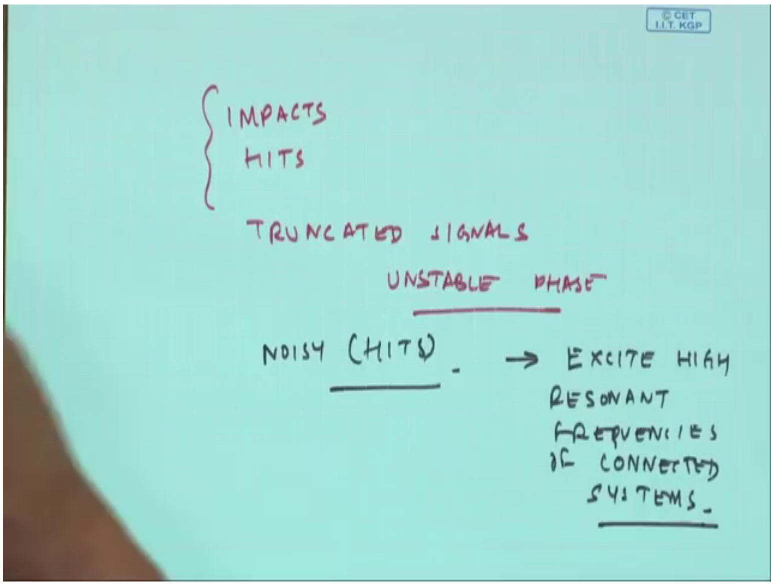

So, lot of impacts hits will occur give rise to truncated signals and unstable phase and from a noise analysis you will see lot of noisy hits and sometimes what happens because of this they will excite high resonant frequencies of connected systems, sothat can occur also occur.

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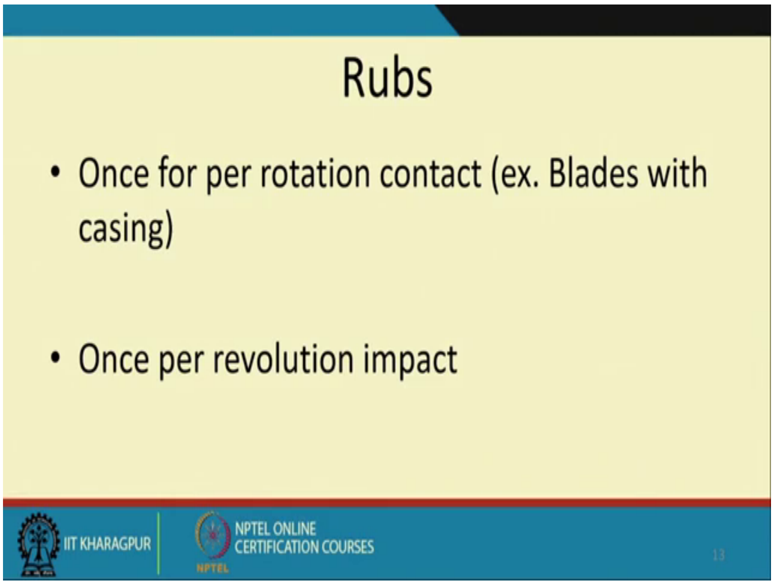

But another problem which we will come across is known as rubs.

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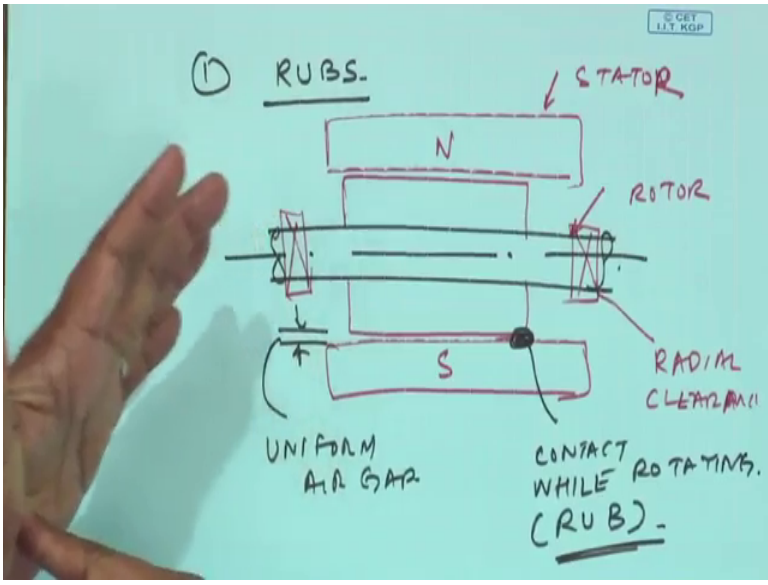

See rubs so happens for example if I have a shaft, particularly this has lot of effects. So, for example, if I have rotor of a motor inside stator, this is the rotor this is the stator of a motor. So, basically 1 is creates a magnetic field and this air gaps are very there to be uniform air gap that does, the magnetic reluctant and then the rotor moves to the magnetic field and that is a different story, but imagine if this bearings which are holding them have large radial clearance. So, what is going to happen? it may happen this may drop down so there will be a strong contact while rotating, so this is a rub.

So, as a something is rotating and then you are pressing onto it, so this will generate what is known as high frequency excitations or also some squeaking noise squeaking or streaking noise.

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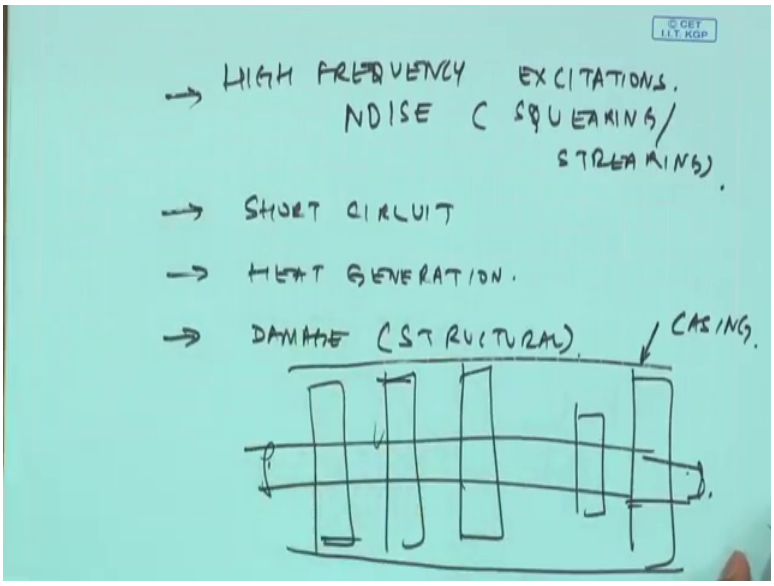

So, happen because of such rubs eventually this coil can get shorten, coil there will be heat generation short circuit, heat generation because of rub and eventually damage structural damage imagine. You know you are talking about large turbine with many sets of blades and range, so lack of space I have not drawn all of them in the direction, imagine if this touches the casing because there is a radial plane.

So, usually in such systems these shafts are actually held in very proper rigid frame Or stays.

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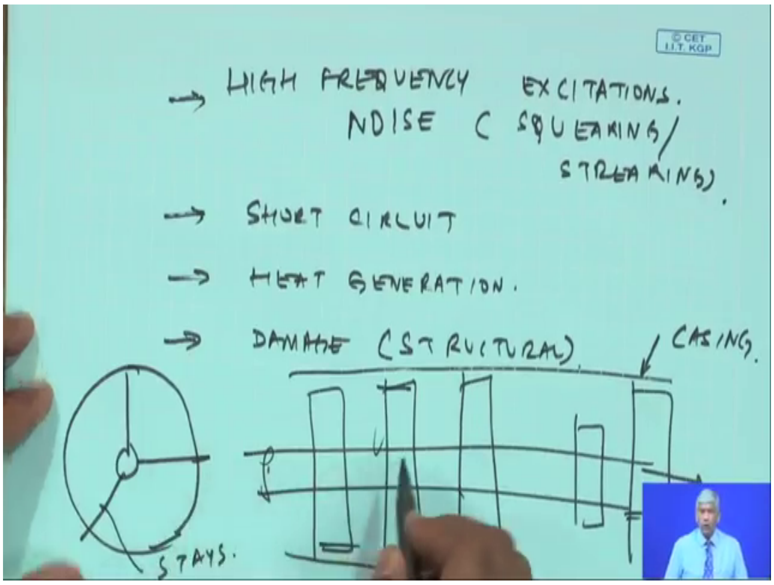

So, stays are there but if there is a radial plane, it will touch against each other rubs etc. So, this is very similar to your looseness and so on and this can be very easily directed by signal processing technique called wavelets.

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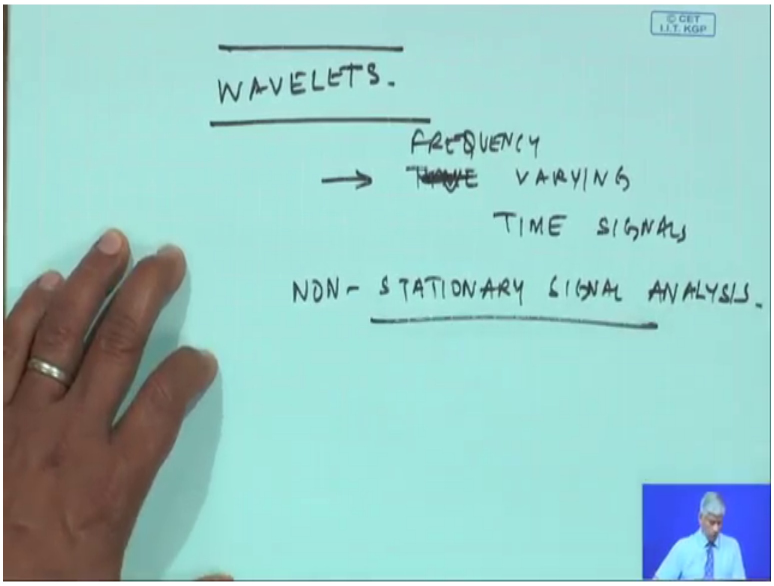

So, wavelets happen give rise to time varying sorry frequency varying time signals, so this call for non stationary signal analysis to find out the faults in such systems.

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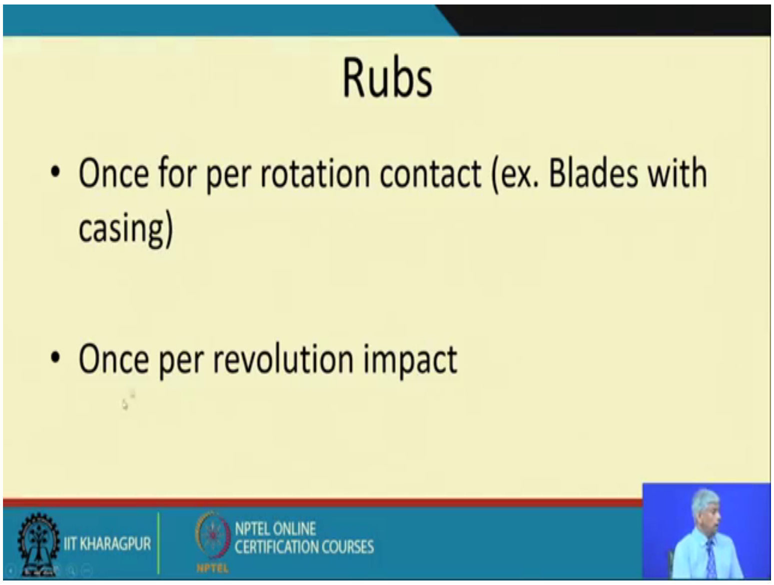

And if it was once per rotation content you can see the impact once per revolution and so on.

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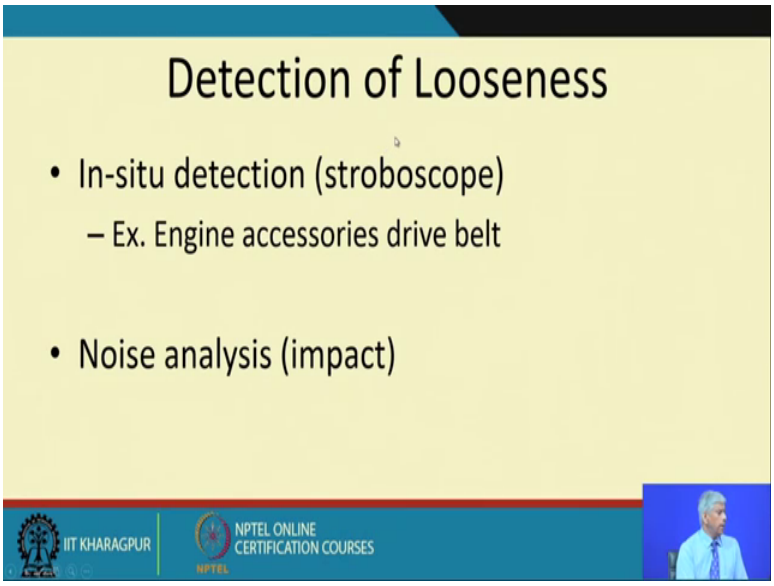

And while we talked about stroboscopes I had given in examples how detection of looseness can be done, using stroboscope if when engine accessories belt is slipping etc and noise analysis can be used to find out defects.

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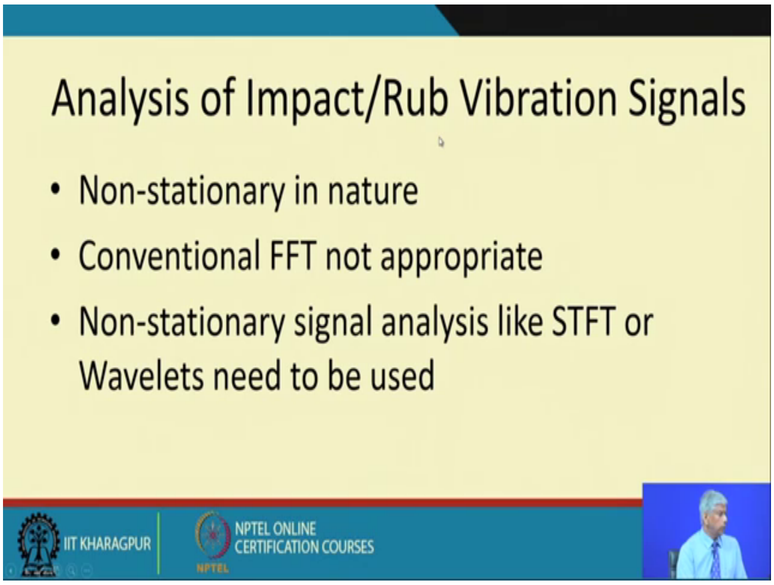

So, analysis of impact rub vibrations signals are non stationary in nature convectional FFT is not appropriate non stationary signal analysis like STFT or wavelets need to be used.

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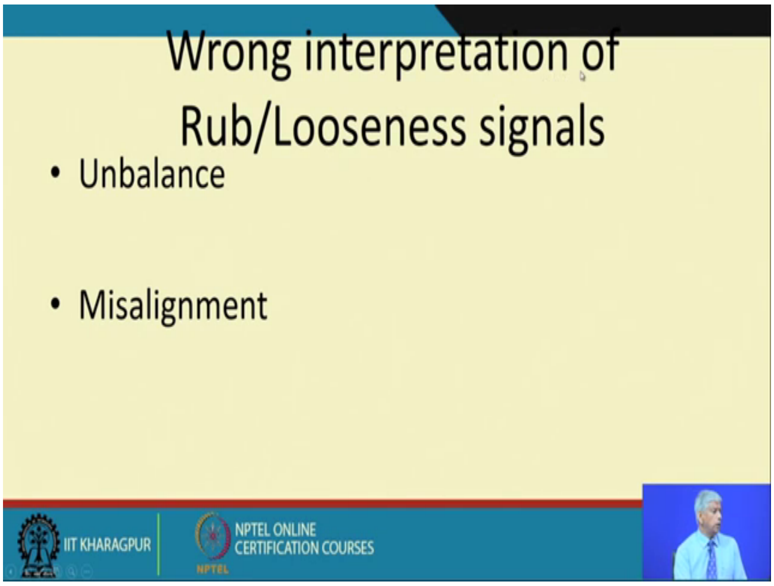

So, sometimes wrong interpretation of rub and looseness signals keep will you know call them as unbalance misalignment, because we know everybody does not have access to non stationary signal analysis tools. So, grid signal processing or beat analyzer, so this can happen in industry. Never the less they are non stationary and we have to use certain advanced signal processing techniques like wavelets and of course recently our group has find out the technique of empirical mode decomposition to analyze non stationary signals and this can be used for finding out faults like rubs or looseness in systems or in fact crack as well.

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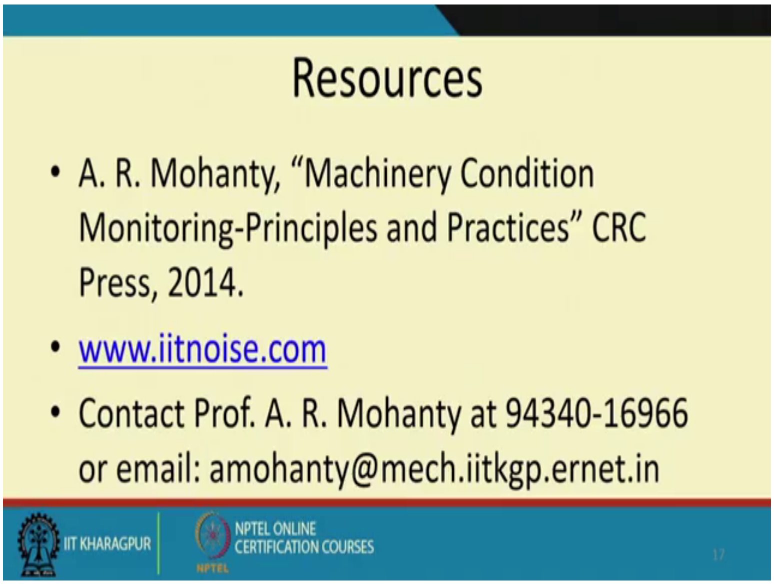

Ok.

Thank you.