Machinery Fault Diagnosis and Signal Processing
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Lecture – 41
Journal and Anti-Friction Bearings

In the beginning of the 9th week, I will continue my discussion on faults in rotating machines starting with faults in a very common machine element that is bearing and then we will talk about gears as well as you will realize, you know every rotating machines have shafts and; obviously, shafts are supported on bearings and since bearings are held in bounds are in pedestals. Actually, all the vibration measurement which we make by contact with measurements are essentially done on the bearing housings ok.

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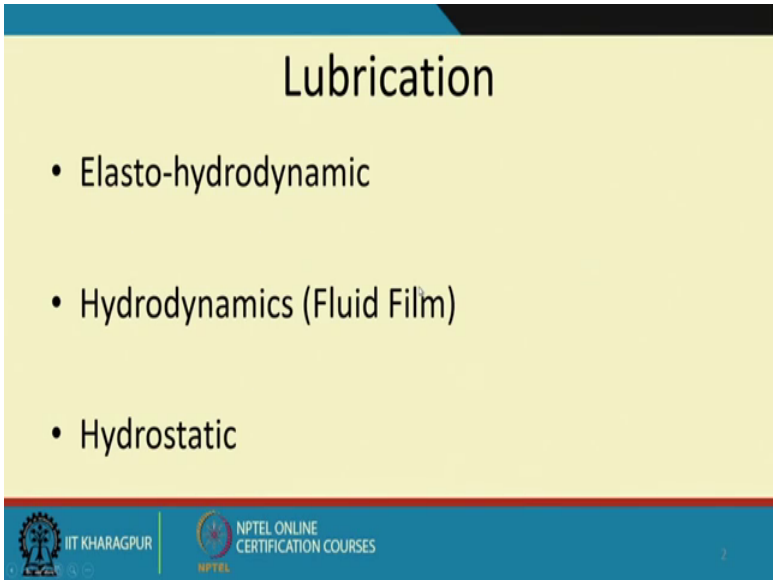

So, today, I will be focusing our discussions on fault detection and bearings and for in particular journal bearing and then the anti friction bearings well as you know the reason, we have lubrication is to reduce the friction between the two rotating elements for example.

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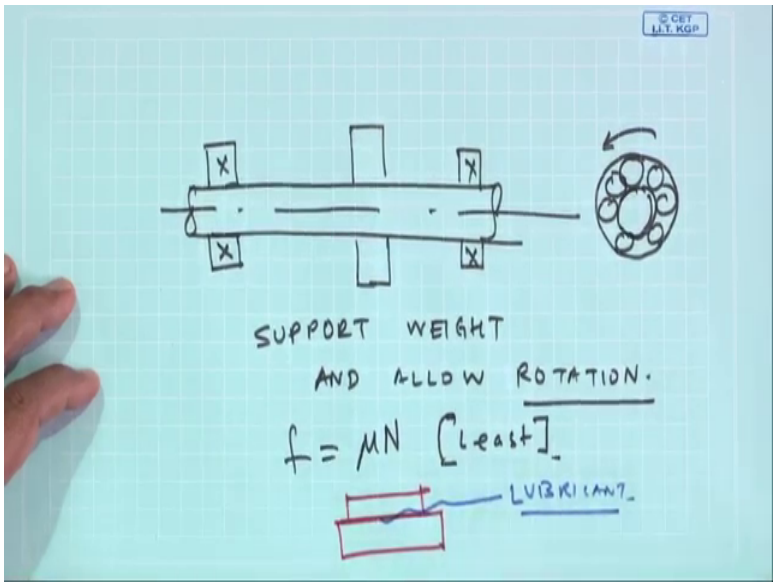

I have a shaft and then shaft could be a member of a machine component which could be carrying a gear or pulley, etcetera, but the shaft to be supported on a bearing which I am indicated by this process.

So, the bearing essentially as journal then I have a shaft. So, the shaft is shrink fit to the inner ways of the bearing and then there are sub rolling elements in the case of a anti friction bearing and they will rotate and then software supported. So, support the weight and allow rotation; obviously, if I allow rotation the friction force mu N has to be least and that is why we have a layer of lubrication between two members which are rolling which are in contact against each other. So, we will have lubricant.

So, depending on the film thickness of lubricant and depending on what kind of actions happened in the lubricant will have a fluid film and if this fluid film Is responsible in the case of journal bearings.

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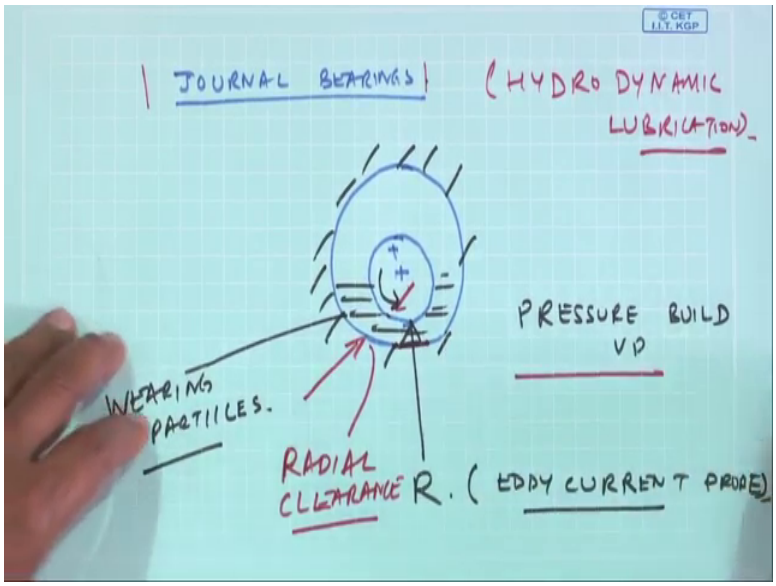

I have little eccentricity and then this is filled with some fluid because of this eccentricity there will be a pressure build up only when there is a rotation and there is this the stationary rays and this is responsible for giving a load reaction or which will carry the load and that is what happens in the journal bearing and everything depends on this radial clearance. So, during wear and tear now the machine is at rest they shaft there will be no pressure build up because there is no rotation.

So, this shaft is going to sit on the seat of the bearing and then again once the shafts tries to rotate there will be a pressure build up and this shaft will get lifted up and this is what happens in hydrodynamic lubrication as opposed to in the case of hydrostatic bearing, there is always an external pressure which lifts the shaft and then it maintains the load which is coming to or which supports the load which is coming on to the journal, but we when we monitor the health of journal bearing, we can see because of this starting and stopping of this machine is heavy shaft will be in touch with this journals on the seat.

So, there will be wearing of particles. So, while analyzing and understanding the composition of the lubricant which has got contaminated by this one particles one can clue get a clue as to the condition of the bearing and that is what you will subsequently discuss when we talk about oil analysis and wear debris analysis, but for the moment, I will say that to monitor the health of a journal bearing one has to monitor the radial clearance this could be done with eddy current probe or approximately probe etcetera

and looking at the oil quality, but we will talk about another class of bearings which is this anti friction bearing of the rolling element bearing.

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So, this antifriction bearings are can be either ball bearings or roller bearings or tapered roller bearings and these bearings always have direct contact for the surfaces which are in contact has to be hard and has to be polished to finish. So, that the friction is the least.

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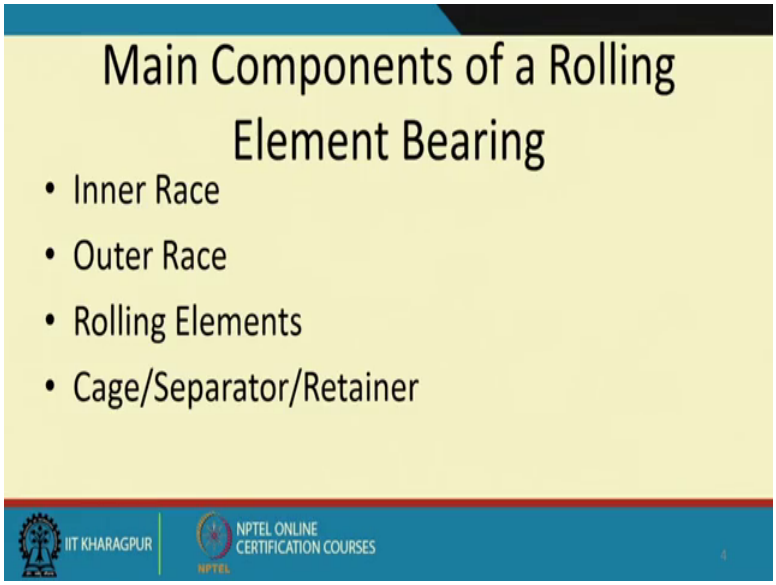

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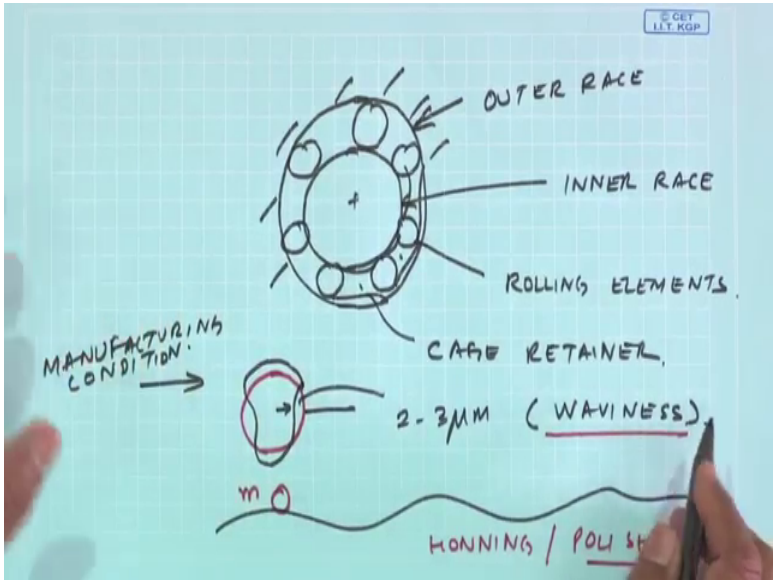

So, the major components of a rolling element bearing are like they are manufactured, this is the outer race, this is the inner race and in between the outer and inner race, there are rolling elements which could be balls rollers for tapered roller rolling elements and then there could be retainer or cage. So, that is ensure that no two rolling elements come in contact with each other and they are actually stand metal cage or retainer.

So, such is the configuration of a rolling metal bearing and this could be fixed the outer is could be fixed and then inner race could have the shaft fitted into the bearing or into the bearing and then the load is being carried by the this is rolling elements. Now why it has a bearing vibrate. Now in my drawing here I have not been able to draw perfect circle and you have thinking that people have to manufacture a perfect ring ok. So, it is very easy to design a perfect circle, but once we manufacture it may happen that this may look like this.

So, and this deviation could you order of two to three micron from the radius. So, this is what is known as waviness. So, this is because of a manufacturing condition and if I unwrap this black line I can have a wavy surface ok. So, all of you would have done the experiments on are the studies on vibrations. So, even on a wavy surface if a body of mass m moving it will experience vibrations in the vertical direction because of the waviness and this amplitude vibration will increase the speed right

So, one has to ensure that one makes this waviness the least and that can be done with special manufacturing operations honning polishing ok, but no matter what manufacturers of bearings try to reduce this waviness to a minimum though you can never neglect it or remove it totally on top of it what happens if you look at this wavy surface if you closely look at the surface they will be having what is known as the surface opness of this nature and with.

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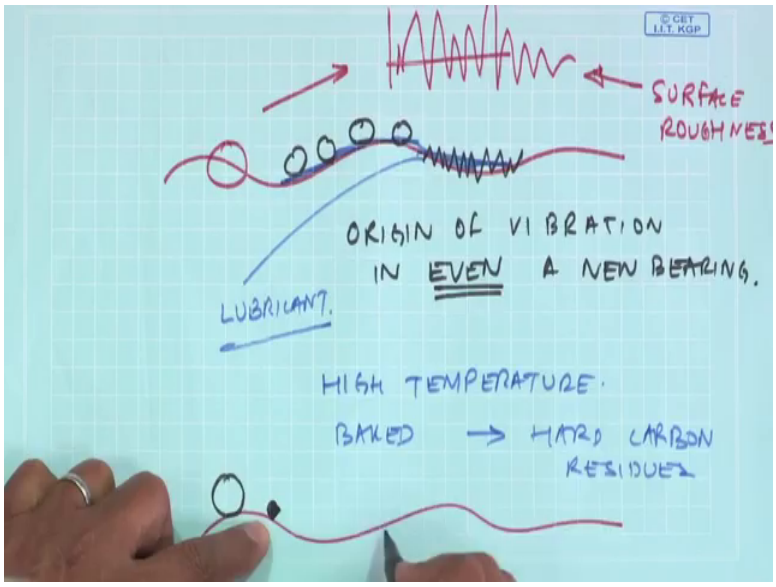

So, imagine I am having a rolling element and then you rather have a series of rolling elements which are moving on waives surface with surface roughness. So, this is the origin of vibration in even new bearing on top of it. So, to reduce this vibration what people do are there in manufacturing they put a layer of lubricant to remove the surface of spirit is. So, lubricant is put and the bearing are sealed for life ok.

But what happens in the process of operation of the bearings the bearings are subjected to high temperature because of the process requirements are because of friction. So, this lubricant will get baked and then they will form hard carbon residues which will be on the surface of this waves ok. So, when the rolling element comes and moves on the surface it is going to get an impulse excitation and sometimes this hard surfaces are the hard residues may have an script the surface and they will generate bits of this nature the average aggregated.

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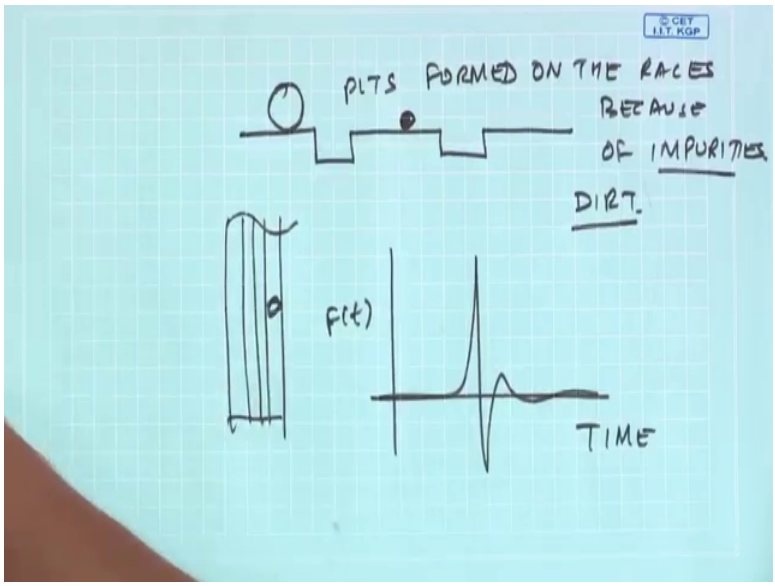

So, I can have pits formed on the races because of impurities one shot of impurities is this carbon residue another form of impurities could be dust or dirt ok.

So, these are all responsible for damaging the surface of the bearings or there could be street marks on the races which I will show you later or there could be pot holes. So, if a rolling element is going across bearing race, it will influence or get an impulse force ok. So, such impact will occur on the races because of the pits formed because of the deposits made ok.

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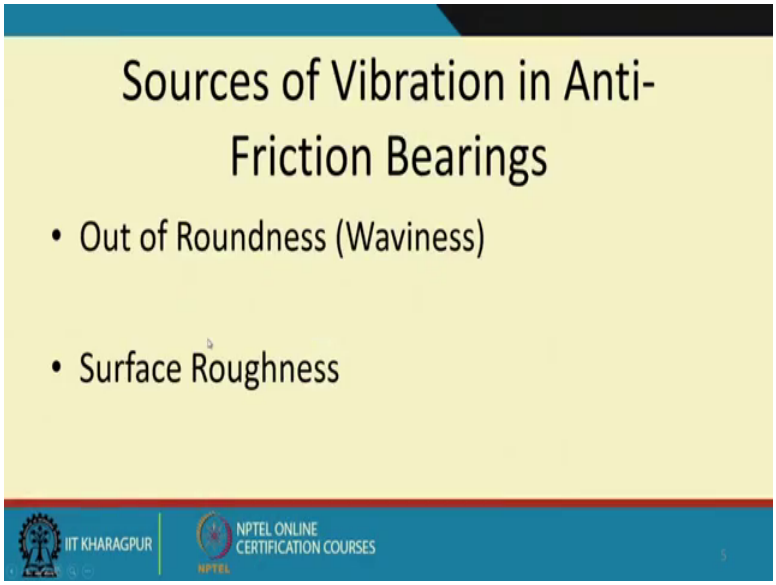

So, when new bearing because of waviness and surface roughness we have the vibration, this vibration will get amplified is there are hard carbon residues pits form because the races are been scrolled ok.

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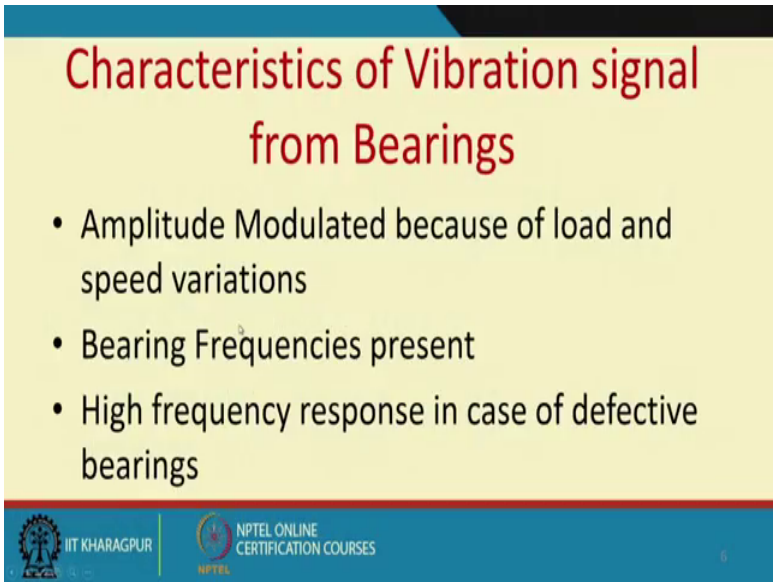

And then the load on the bearing could also be bearing.

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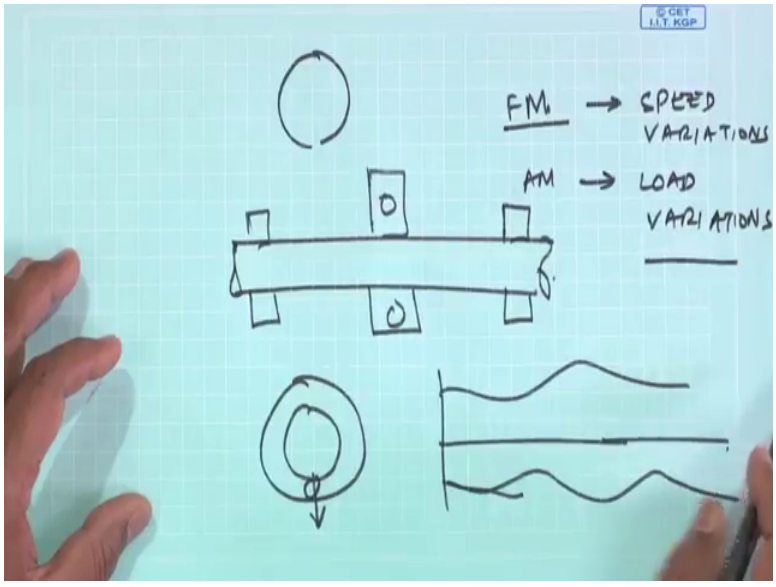

The bearings are supporting there is an unbalanced load.

So, what happens this is radial load is going to change with time. So, it will get loaded unloaded. So, there will be a strong amplitude modulation of the lord which is coming on the bearing and that is the vibrations and there will be for speed variations there will be frequency modulation and for amplitude modulation because of load variations. So, you see the bearings vibrations are pretty complicated because of modulation because of impacts and so on. Now I will come to another example this bearing which has been design.

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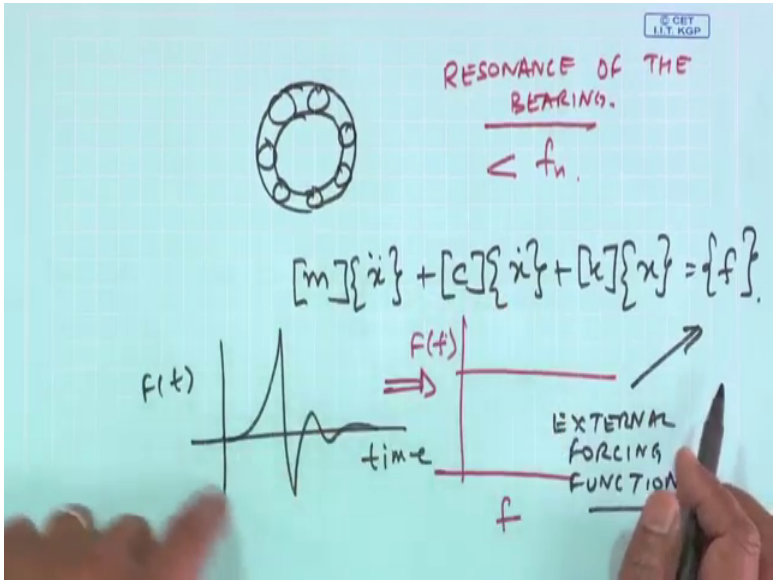

It can be model. In fact, there are many mathematical models as a multi freedom system. So, this bearing can also be model.

So, this force is the external forcing function ok, now imagine when I had an impulse I have an impulse force. So, the impulse force in frequency domain would look like this entry considered. So, an impulse would excite or would represent excitation at all frequencies. So, it may so happen that it is exciting the resonance of the bearing because the bearing designer would recommend operating speed which are less than the resonant frequency of n, but when I have an impulse generated because of a hard residue on the race because of a pit it will excite the system. So, system is going to resonate and thus have high vibrations at very high frequencies.

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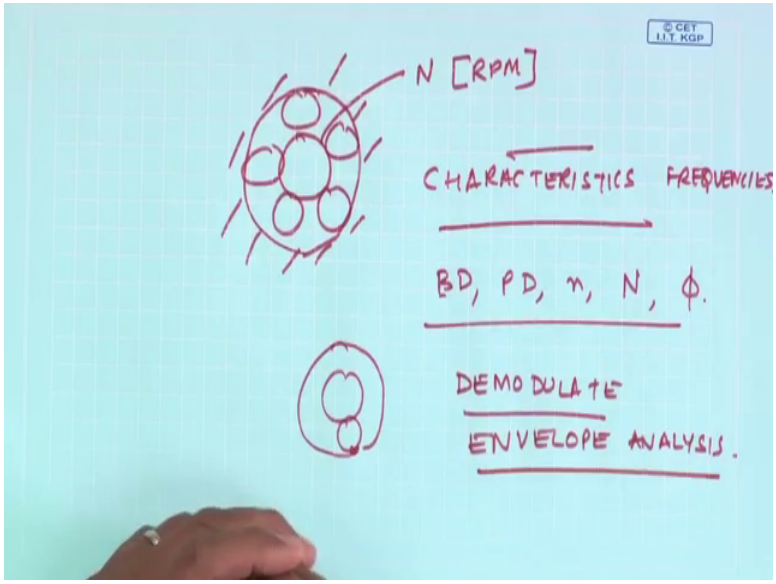

So, on top of it, if you look at the bearing dynamics, if this shaft is rotating at speed N RPM and if they are all held all these individual components will rotate at their respective characteristic frequencies. So, if you look at the bearing vibrations both new bearing and good bearing, you will see the statistics frequencies and then the bearing vibration itself is a complicated and so on and then I will show you some of these examples.

So, characteristics of vibration signal from bearings amplitude and frequency modulated because of loading speed variations bearing frequency represent which this depends on the geometry like the ball diameter the pitch diameter number of balls or number of the elements RPM contact angle, etcetera, I will give you the equations and these equations can be very easily found out from the equation of dynamics a very useful machine used for detecting bearing fault is this shock pulse meter is nothing.

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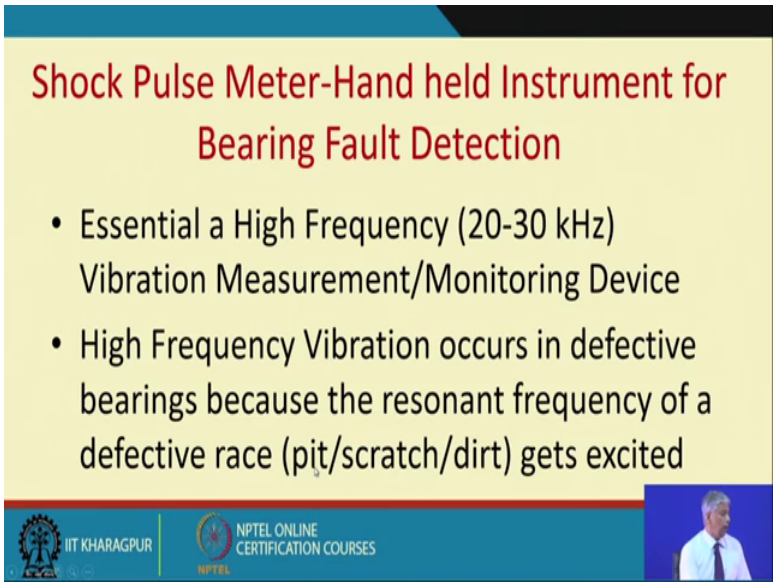

But, essentially the high frequency vibration measurement. Because high frequency occurs because of the resonant frequency which gets excited because of the defective race like a pit scratch or a dirt.

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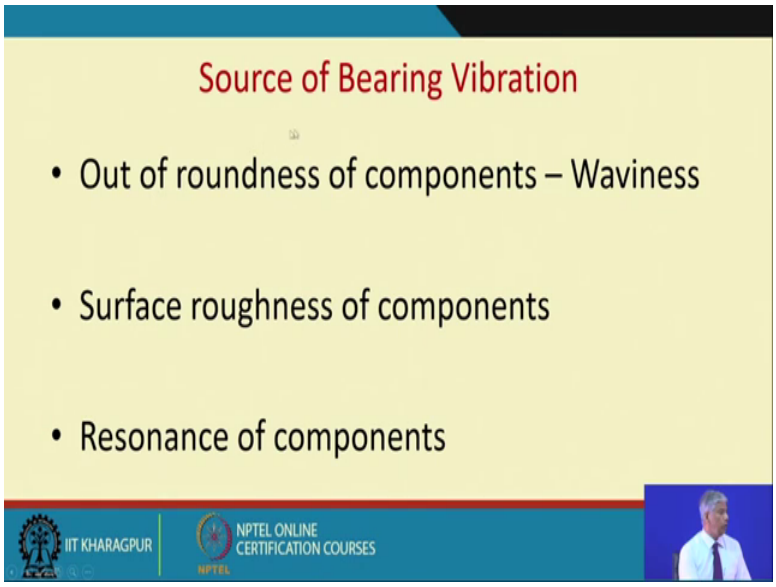

Now, so, we know the sources of bearing vibrations is out of roundness of the manufacture components or surface roughness of the manufacture components and then the resonance of the components.

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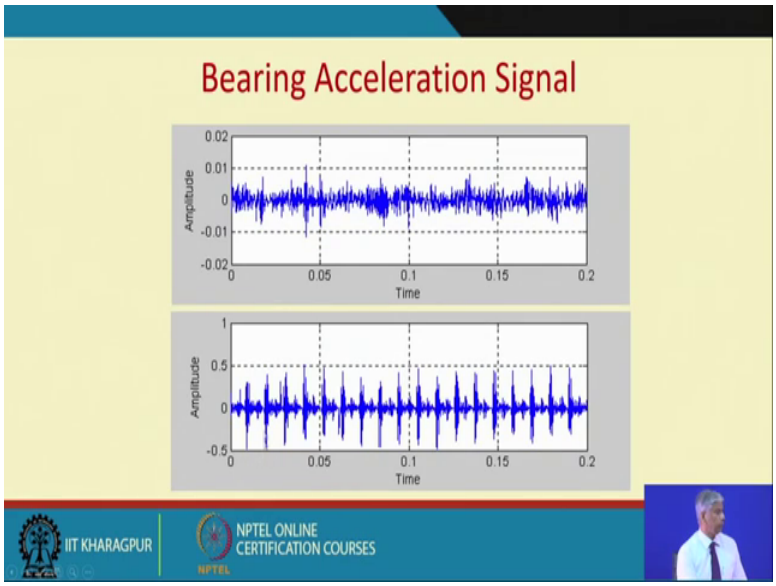

So, this is the typical example of the vibrations coming out of a good bearing acceleration signal, you can see the amplitudes are low the pretty much periodic, but this is for a bad bearing vibrations you see the amplitudes are high and they are periodic in nature is impacts hitting every rotation the impulse are been generate because some rolling element or ball is going and coming and hitting against a defect in the races or in the ball.

So, this kind of a repeated impacts do occur in bearings and they are as you can see statistically speaking they are a p k signal. So, parameters like kurtosis etcetera or this time domain signals can also be used to detect the bearing faults of the other than going into the frequency domain.

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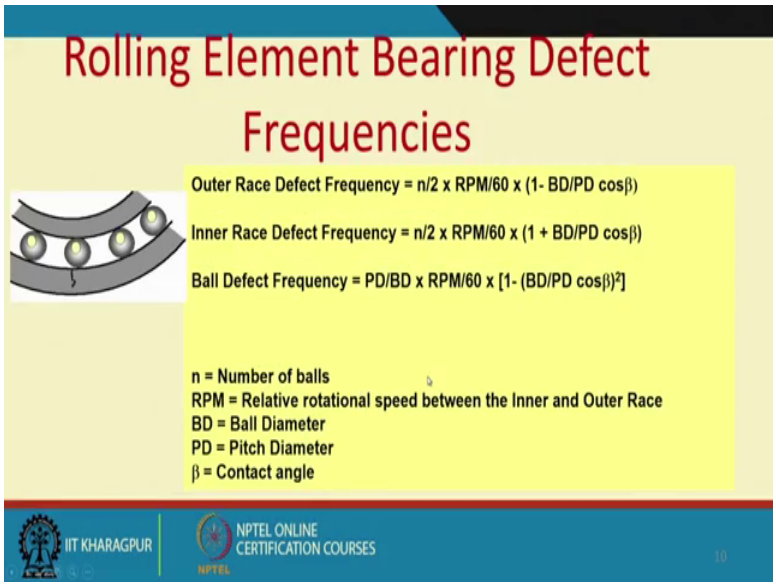

So, these are the rolling element defect frequencies the outer race defect frequency is by this expression where the inner race by this expression ball frequency defect ball defect frequency by this expression and this equations the outer race is assume to be fixed and inner race is rotating for example, I give you an example like a ceiling fan, it is just the opposite the inner race rotates the inner race is fixed to the axel or the shaft which is hung from the ceiling or the rod and the outer race rotates disconnected the hub and the blades are attached ok.

So, RPM of the rotational speed between inner and outer race PD is the pitch diameter BD is the ball diameters so on.

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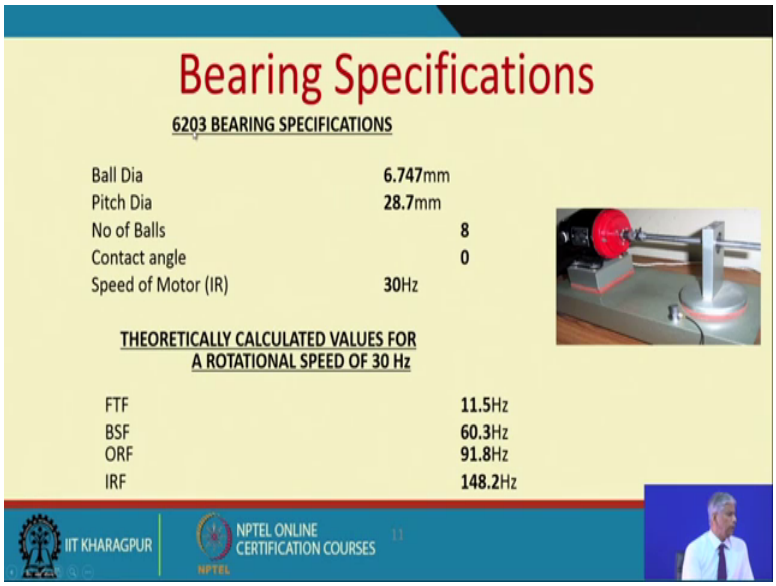

So, for a typical 6203 bearings which was mounted here some of the dimensions are here using this equation, the fundamental train frequency, the ball spin frequency outer race frequency inner race frequency for a speed of 30 hertz, these characteristic frequencies are calculated and if you see this spectrum of the vibration.

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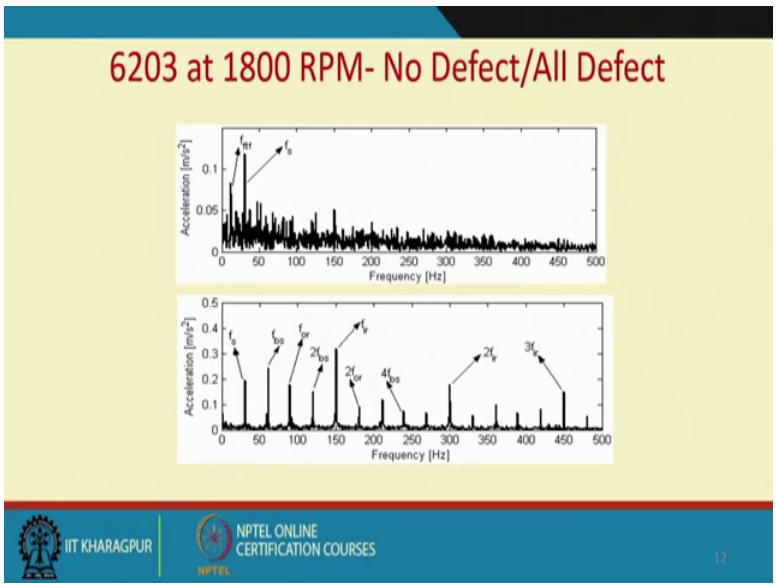

These frequencies will show up in the vibrations spectrum measured at eighteen hundred RPM correspond to 30 hertz. This was measured in a laboratory, this is the case when there is no defect and then you can see only the rotational speed of the inertia speed

coming up of 30 hertz and then for the all case are different because we have manufacturer nearby who helped us manufacturer bearings will artificial seaded defects and then we tested this bearings on a testering and then for this class we have generated such vibrations spectra

So, you can see the ball spin frequency the outer race frequency harmonics of the balls in inner race outer race all these show up in the case of defective bearings, but sometimes you know I am speaking from experience what happens in many of the cases because bearings are an easy are bearing housings are in easy location to bound accelerate meter to measure the bearing vibrations measures, there could be vibrations because of misalignment because of unbalance because of cracks because of gear defects because of bearing defects everything gets completed and they look very it becomes very difficult to analyze.

So, to understanding bearing signals we must demodulated demodulate the signals or what is known as the envelope analysis.

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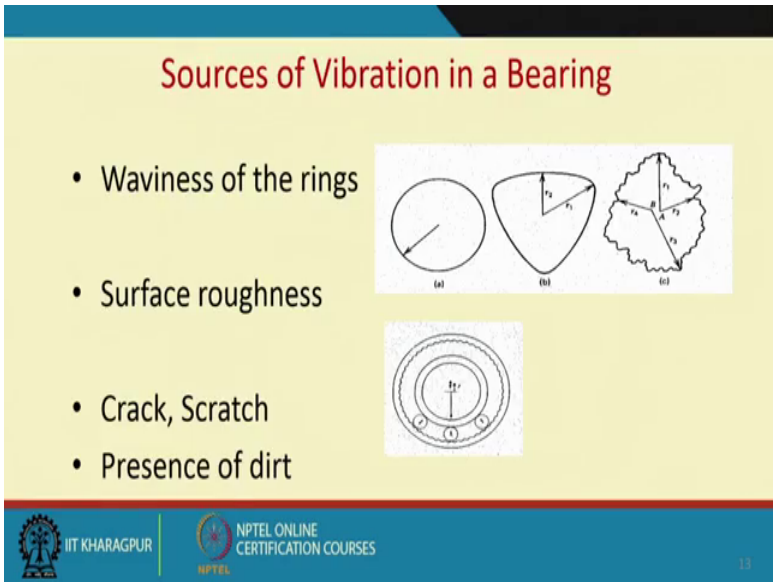

So, such analysis needs to be done this is to be give you a view of what has going to explain to you on the resources of vibration in a bearing. So, this is the perfect circle of course, this has got we; I like an ellipse because of the projection here, but then you should go to manufacture a the it may look like this.

So, manufacturer try to make a perfect circle, but it is very difficult to make a perfect circle while manufacturing on top of it there is surface roughness and there could be dirt, etcetera. So, just to summarize you must differentiate why even a new bearing vibrates, it vibrates because of the waviness and surface roughness on top of it which use because of the presence of crack scratch or dirt the signals get amplified because they would excite the high frequencies. So, shear way of knowing whether vibration defecting in a bearing has occurred is just by monitoring the high frequency vibrations given out of the bearing beyond its operating zone and typically it is in the resonant frequency zone somewhere from 30 to 30 kilo hertz

So, commercially there are many equipment which are known as shock pulse meter which only monitor the high frequency vibration coming out of the bearing and then if the amplitude of vibration energy is high, they will see that the bearing is defective ok.

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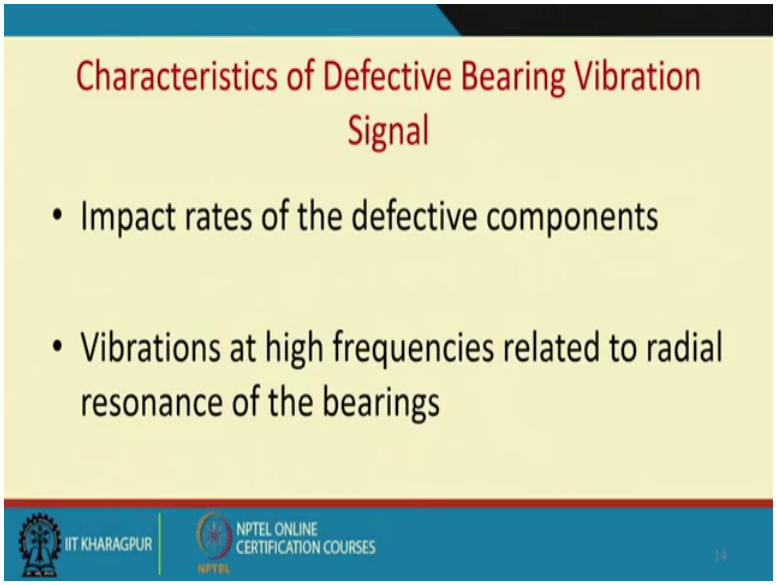

So, characteristic of defective bearing vibration signals impacts rates of the defective components and then vibrations at high frequency frequencies related to radial resonance of the bearings.

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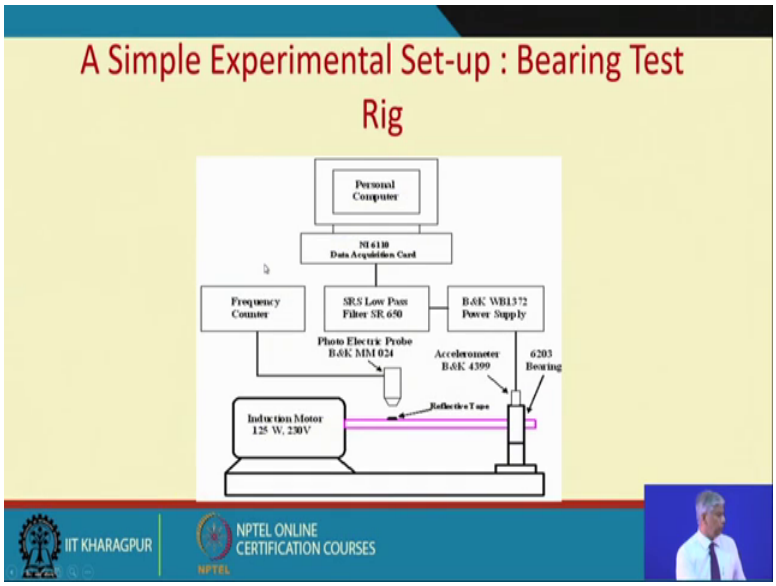

So, we just discuss about these and those of who want to do certain experiments in the laboratory, this is actually bearing test rig, we have a motor driving the housing where there is a bearing we put in accelerate meter to the power supply we have a filter and then we have data acquisition system and then personal computer we have an photo electric probe to measure the steep.

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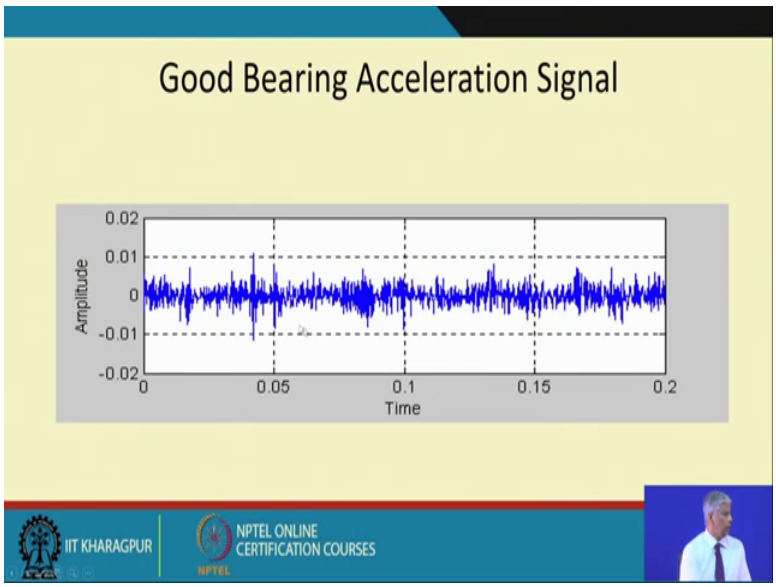

So this is the good bearing vibration signal amplitudes are low by the way they are deterministic periodic signal because of the variations and then with the outer race defect

you can see the impacts increasing and this is what we discussed with the case of no defect with the case of outer race defect when we demodulate the measured vibrations signal this characteristic frequency and their amplitudes do show up in the spectrum.

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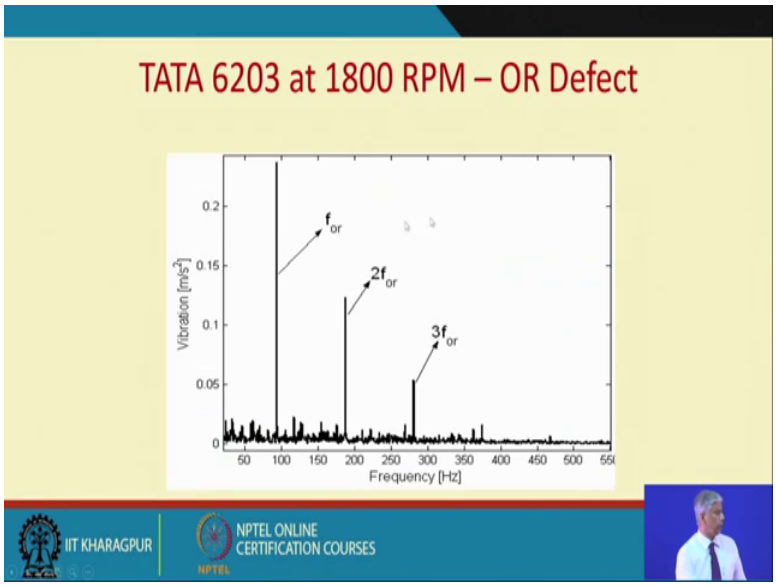

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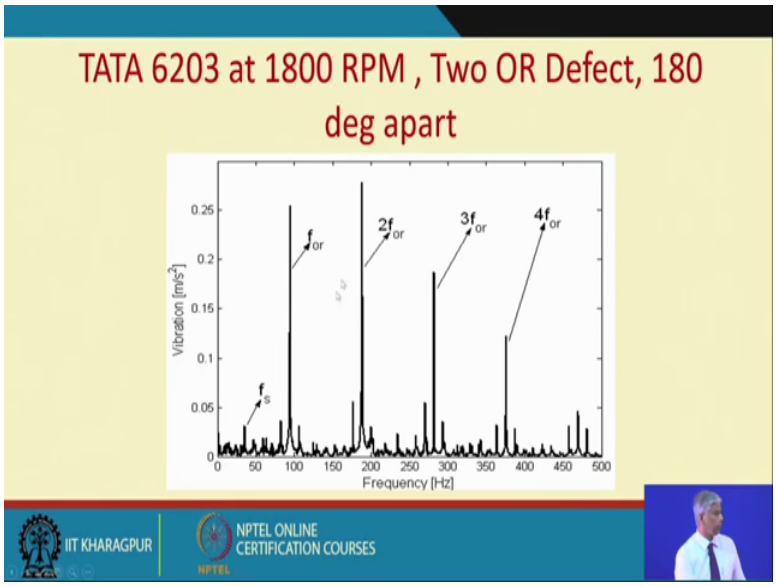

And then we had the outer race defect 180 deg apart and so on.

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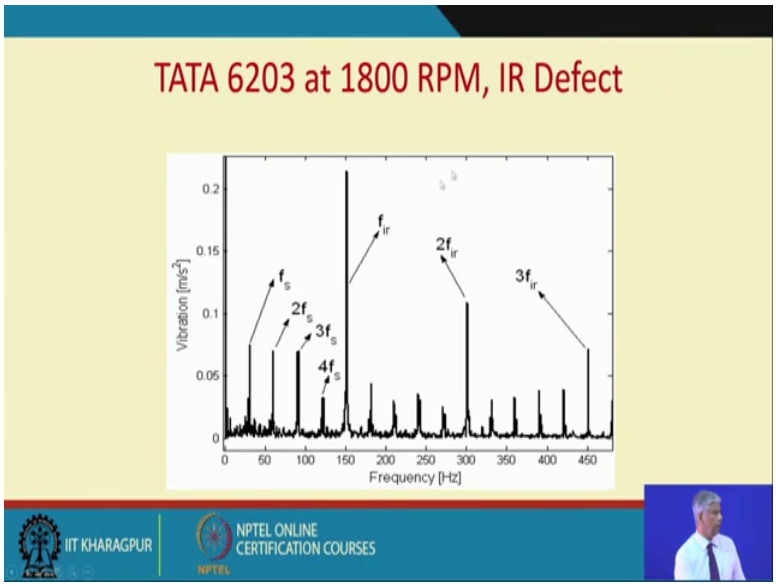

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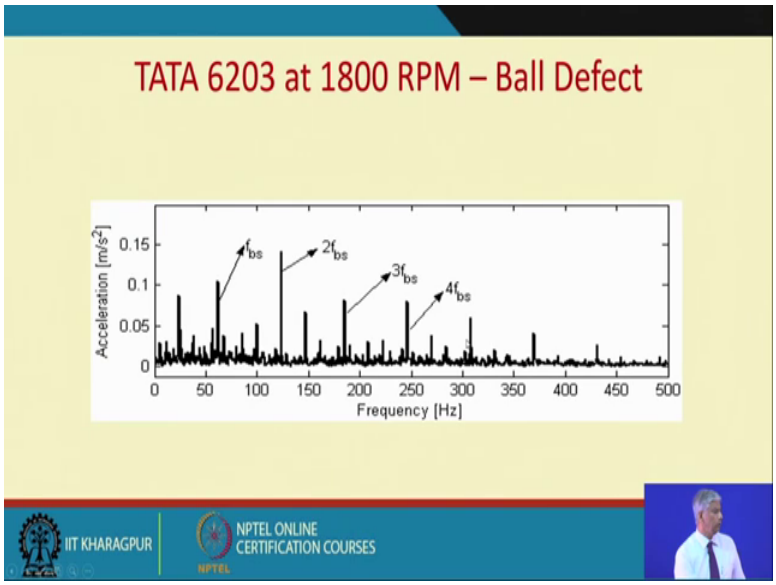

Within race defect and with the ball defects with all kinds of defects.

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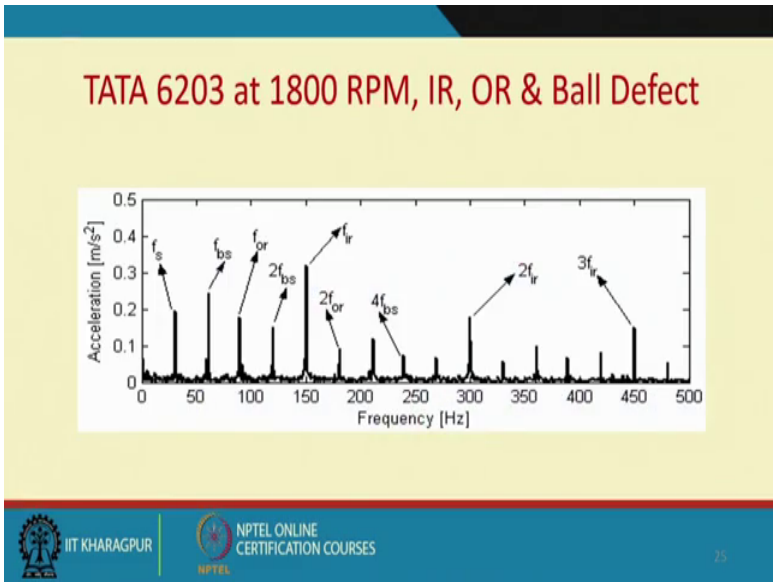

So, in see if you can clearly identify, these defects frequencies from the measured vibrations signal and if you see high harmonics it is the one way of knowing that the defects has occurred another is definitely mountain the high frequency vibrations.

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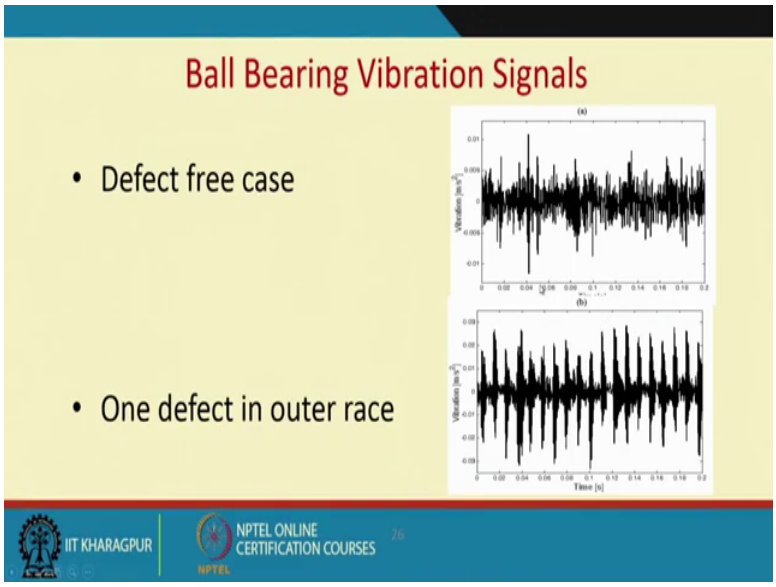

So, this is the defect free vibrations. So, people can develop I for your not even looking the frequency spectrum just looking at the time domain of the signals just looking at the ball bearing vibration signals and then the outer race defect frequencies.

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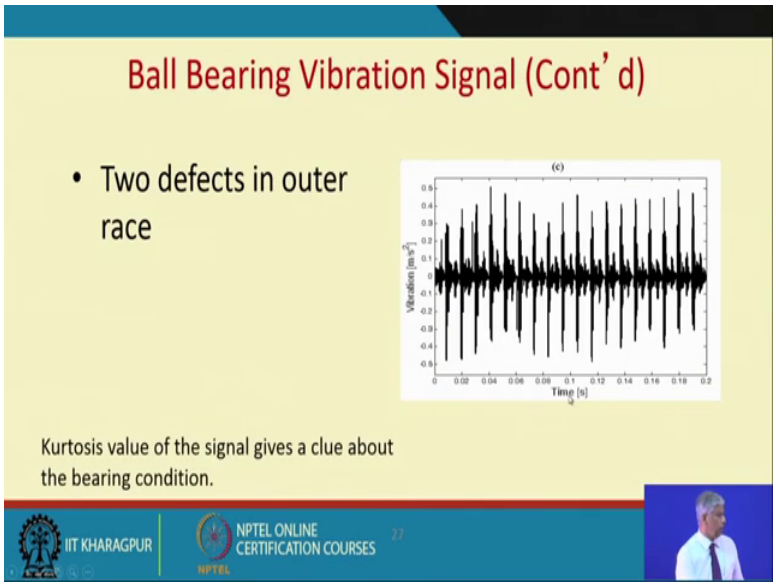

And this kurtosis value of the signal gives a clue about the bearing conditions. So, bearing vibration mountain is very important in a many industries.

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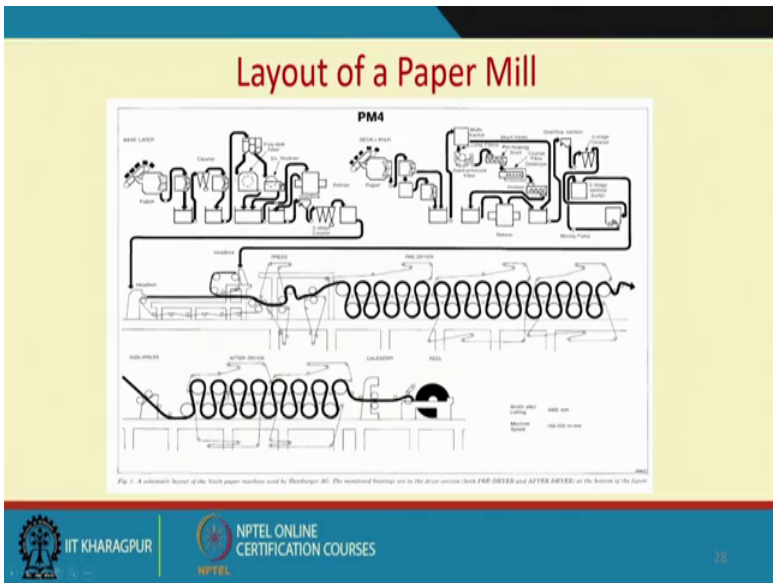

And then I will discuss about this paper mill, etcetera, in the subsequent class when we do vibration monitoring of are the case study in paper mills and how important it is. So, you can as you can see there are so many rolls supported on bearings and imagine if one bearing of a roll filled the plant had to be shut down. So, we will discuss this in the case

of case study I just want to give an example that these things do happen and how important they are.

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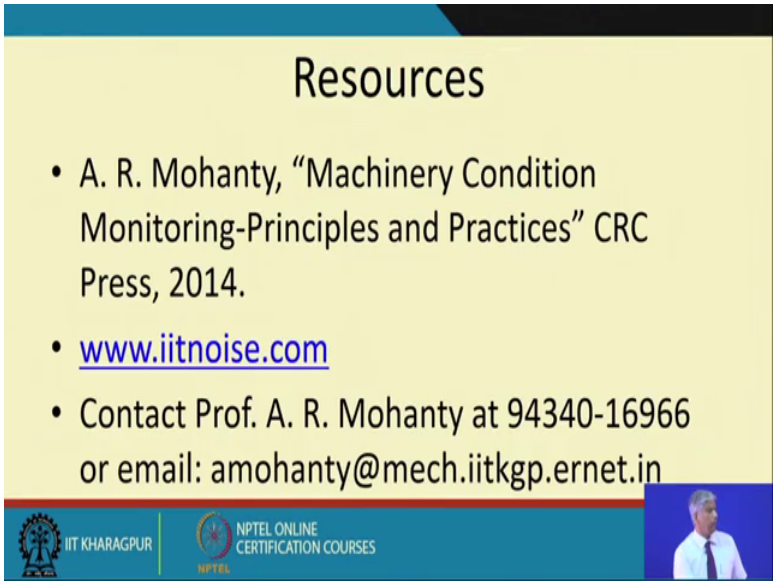

Thank you.