Machinery Fault Diagnosis and Signal Processing
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Lecture – 42

Gears

We will continue our discussion on fault detection in rotating machineries. As you know gears are again a very important component apart from bearings and in the industry in many of the equipment we have a prime mover which is using an electric motor an IC engine and as you know the IC engines, they usually have a speed of range of operation anywhere from a low speed diesel engines from 500 RPM to maybe 3000 or 4000 RPM.

Similarly a petrol engine may be a little higher RPM till about 6000 RPM the normal engines which one uses and then if you talk about electric motors it of course, the speed depends on the pole pairs in the electric motor, but we can have speed variations anywhere from you know the 1400 RPM, 1500 RPM to 3000 RPM depending, again on the pole pair for a 2 pole electric motor running at a supply frequency of 50 hertz, we will have the speed has 3000 RPM and so on.

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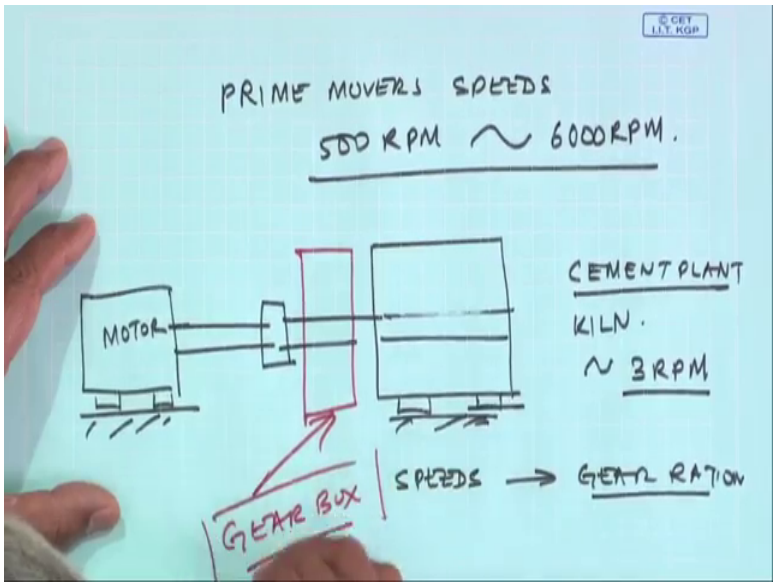

So, the prime mover speeds typically from 500 RPM maybe to 6000 RPM this is what happens, but the mechanical unit which are being moved by this prime mover may have a requirement of another speed like in the case of a cement plant the kiln maybe rotates only a 3 RPM ok, in automobiles, we require different speed ratios speeds.

So, we need to have different gear ratios we need to a different speed ratios because of the dynamics requirement of the automobile I am not going to go into the details of the dynamic requirements. So, in this class, we will focus on gears and how exactly we can find out defects in gears. So, to bring about such a speed reduction or speed amplifications one needs to have a gearbox in between.

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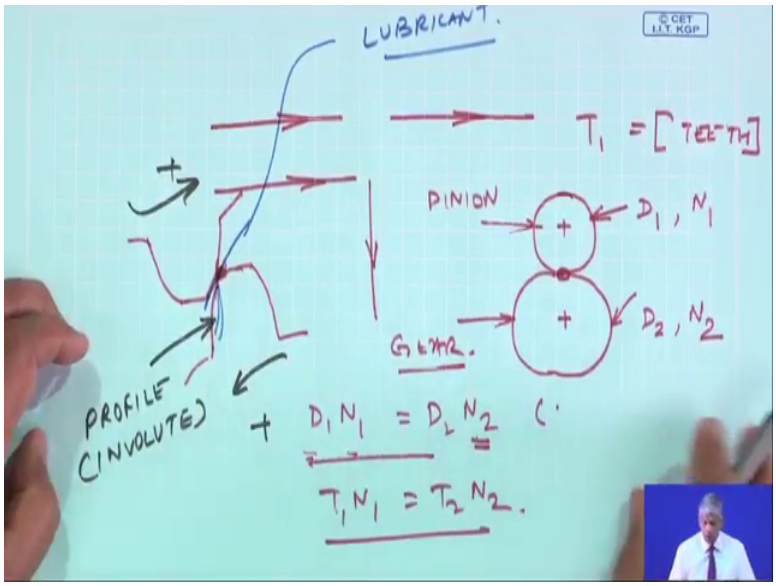

So, gearbox forms a vital component in any mechanical plant or industry and another complicated problem is the power direction. Sometimes, the power is in line, sometimes, I need to have the power direction changed. So, this forms that the speed reduction will be there and as you know from the law of gearing, if I have pinion meshing with the gear, the pinion has a diameter D 1 and its speed is N 1 this has a speed D 2 and speed N 2 speed N 2 means rotational speed.

So, D 1 times N 1 will be equal to D 2 times N 2 because the linear velocity at this point has to be the same that is from the law of gearing ok. So, I can bring about the speed ratio depending on the diameter or that balls down to how many teeth, I can have in a gear. So, the gears are meshing the driven one of the pinion or the driven one is the gear

from the gear dynamics this has to be maintained or T 1 times N 1 is equal to T 2 times N 2 and then there are gearboxes depending on the type of gear ok, depending on certain profile of the gear tooth ok, gears tooth are meshing I am just drawing one tooth.

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So, they have to be have certain profile the gear profile is easily an involute and this gears are carrying certain loads. So, this gear tooth which are in mesh will be subjected to N contact stresses here. So, we put a layer of lubricant there is a lubricant because there is heat generation because of contact and then lubricant is there because of contact the area will be stressed and they will be wearing out of the profile.

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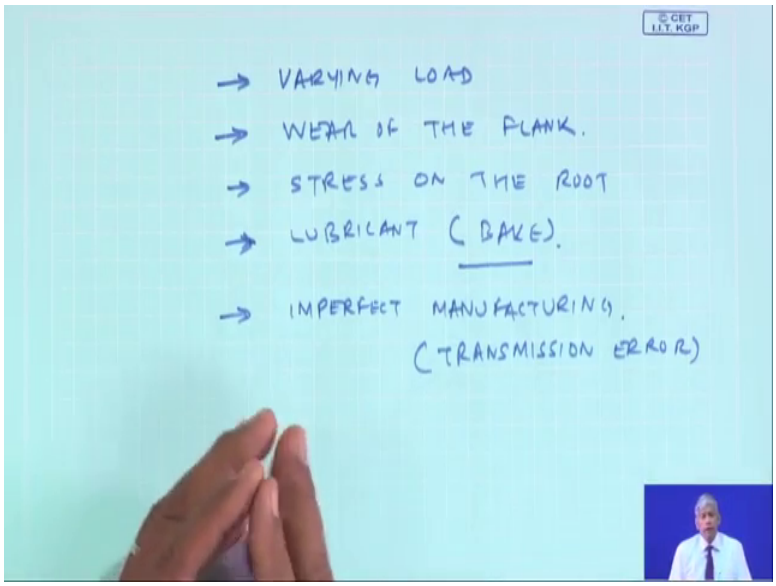

So, a gear under load will be subjected to varying load will be subjected to wear of the tooth flank wear of the flank of the gear stresses on the route will develop and then will of course, in the lubricant can again bake like the example of gear like the example of bearings which you discuss about.

So, all these conditions can happen and on top of it imperfect manufacturing in terms of the transmission error; that means, there are radial clearances in the bearing which are in the in the gears which are meshing against each other. So, all these conditions happen and in the normal operations of a gear this get complicated and so on.

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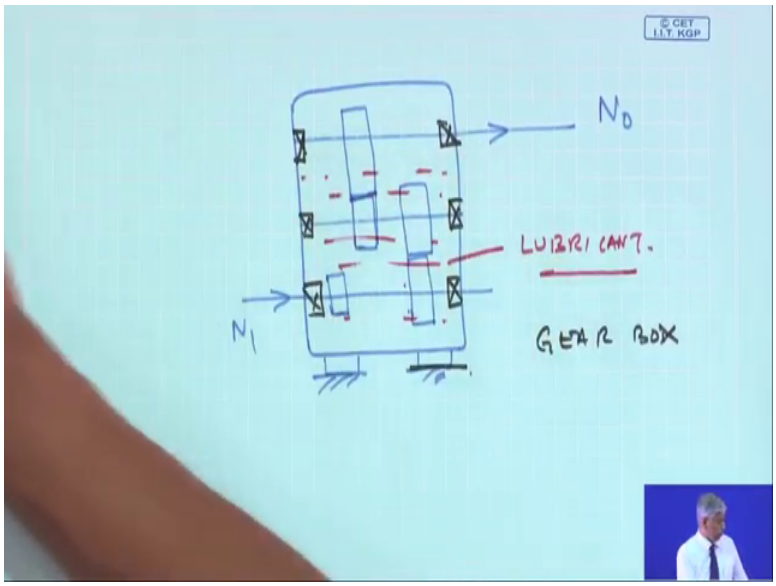

So, if I have a gearbox and as you know, suppose this is a gearbox this is my input shaft there could be an intermediate shaft and there could be an output shaft and so on, this could be happen ok.

So, these gear ratios depending on the teeth ratio the speed output teeth will vary and there are bearings supporting the shafts and there are on a foundation. So, this is the gear box on top of it this gear there is lubricant in the gear. So, wear and tear will happen and then this things will happen and this is in multi stage gearbox there could be change in direction and so on. So, I will give you an example of an automobile gearbox this is how it looks in the inside.

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So, the one is an input shaft with a gear and another is the lay shaft depending the gear you shift and this gear should shift and then the corresponding speed ratios would be selected. So, he could be having a gear shifter which will change the machine gears. So, and then you can have a first gear second gear third gear fourth year and so on or a reversing gear and then of course, you know this is the spur gear and this is a helical gear and so on.

So, helical gears make a nice smooth contact as opposed to spur gears and no matter what these gears are having a gearbox.

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There is lot of lubricant to take the heat away and some of the gearboxes, you know which we are study, what we did is you know, we this is a healthy gear and if you can see this we had one tooth removed and 2 teeth broken in this gears buy enough for our experimental study and how do you detect faults in gears one of course, there are many methods.

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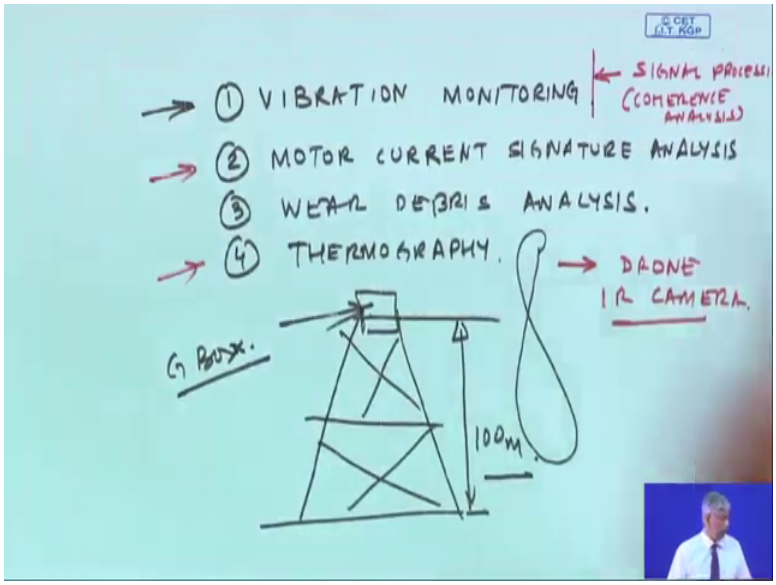

Now one is vibration monitoring which you will focus this class on and another technique which has emerged lot of the research at IIT, Kharagpur is using motor current

signature analysis which you will discuss subsequently later on in a perhaps, next week and then looking at the wear debris analysis this will basically look into the condition of the lubricant in the gearbox and even to some extent we are looking into thermography.

So, traditionally vibration monitoring was being used to measure the vibrations of a gearbox and analyzing them in the time domain in the frequency domain, we can find out the faults in the gearbox and while discussing septum analysis, I did mention that how septum analysis can be used to find out and identify the defects in the gear boxes and then vibration mounting with some signal processing technique like coherence analysis. So, in this class, I will focus mostly on the vibration monitoring aspect and then later on, we will see how motor current signature analysis wear debris analysis thermography can be used because you know as a giving examples earlier also say, I have a large windmill Mountona and then there is a gearbox here.

So, how did I monitor the condition of such a gearbox which is you know maybe hundred meters from the ground. So, this calls for using technique like MCSA or even in a period thermal instruction by using a drone camera drone IR camera. So, these are some of the latest techniques which are happening for monitoring gearboxes and another, particularly today, now people are talking about electric vehicles in electric vehicles we have a motor and you can have a speed controller of the motor or you can have a mechanical gearbox ok, of course, battery is the major component in an electric vehicle.

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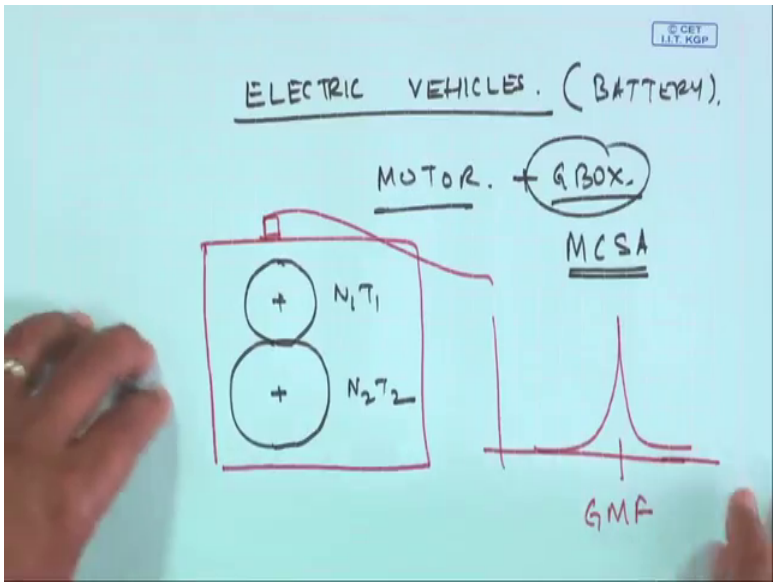

So, how do you monitor the gearbox of such electric vehicle and MCSA is a good area by which MCA motor evolution can be done.

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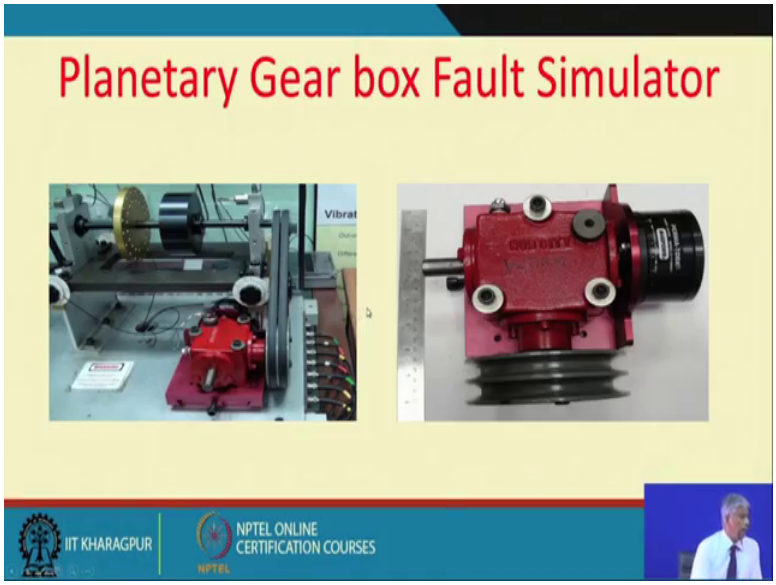

And this is another that seems fault simulator which you have in the laboratory, we have a planetary gearbox and you can find out the faults in such planetary gearbox by measuring the vibrations and this is pulley driven and there is a load clutch which give some load on the gearbox and you can measure the vibrations on the gearbox are varying load, etcetera. So, gearboxes could be they you know you can also have a planetary gearbox. So, we will see if you go to my book you will see the equations which give you the characteristic frequencies of bearings of a gears in a planetary gearboxes and I will not discuss planetary gearboxes per say, but going back to my example of a gearbox just having a pinion and a gear.

So, this is N 1 T 1 and N 2 T 2. So, there is something, if I measure the vibration of this gearbox at one of the bearing locations where I put a transducer here and predominantly you will see a very important component which is known as GMF.

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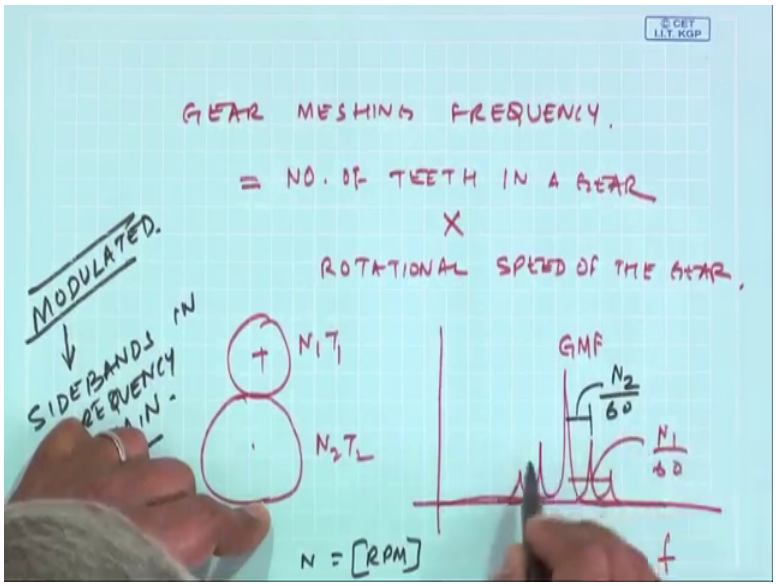

GMF stands for gear meshing frequency and which is nothing, but number of teeth in a gear times rotational speed of the gear. Now, what happens if the gears are meshing, this is N 1, T 1, N 2, T 2, if I and because of load these signals are modulated and as you recall modulated signals in the time domain will give side bands in frequency domain.

So, characteristics of gear vibrations in the frequency domain is actually presents of sidebands this is the GMF and in this case N 2 T 2 being large N 2 will be smaller. So, this distance is nothing N 2 by 60 where N is in RPM and this will be N 1 by 60 and so on. So, I will have in a gearbox spectrum vibration spectrum I will have GMF plus minus N 1 by 60 GMF plus minus N 2 by 60 and GMF ok.

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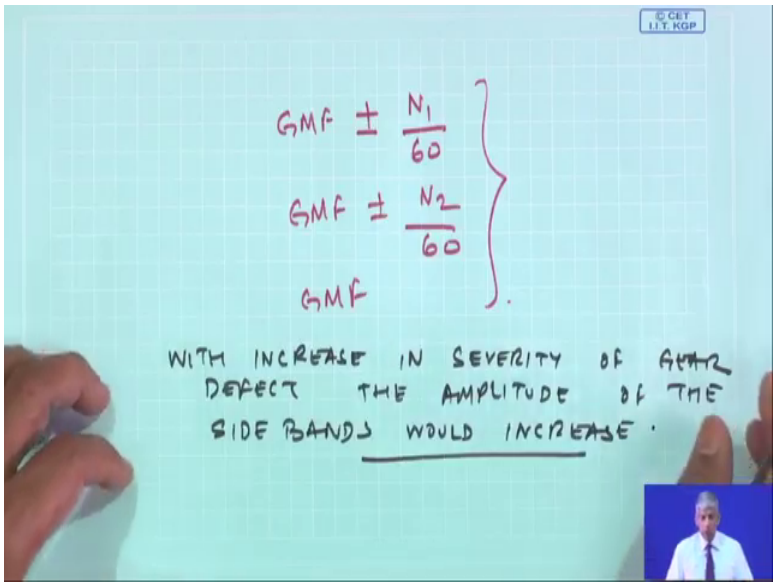

So, what happens the amplitudes with the increase in the severity of the defect, let me write this down with increase in severity of gear defect the amplitude of the side bands would increase.

So, one could be monitoring the amplitudes of the side bands of the gearbox and see so.

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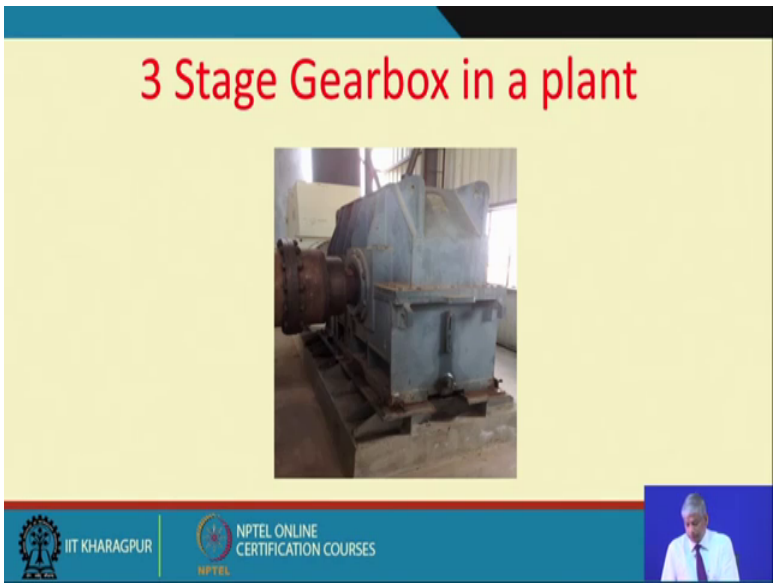

This is another 3 stage gearbox in a plant there is some view which I am going to give you, you can see there is a motor here and motor is along into the plane of this projection here, but do you see there is a 90 degree turn in the power direction. So, we have a strong

bevel gear in this gearbox and this is the same example, he recall in one of the classes I was mentioning that how misalignment can occur, you see this gear these shrimps and the foundations have corroded because this was very close to you see, this is the port and the gearbox foundations corroded and this gave rise to misalignment and there are a lot of vibrations and the gearbox, but coming back to my discussion on gearboxes.

So, we can measure the vibrations near the bearings and on the foundation of the gearbox and so on, but actually in a actual gearbox the problem is in the while you are monitoring there are and on top of it, I cannot separate the bearing vibrations from the gear vibrations.

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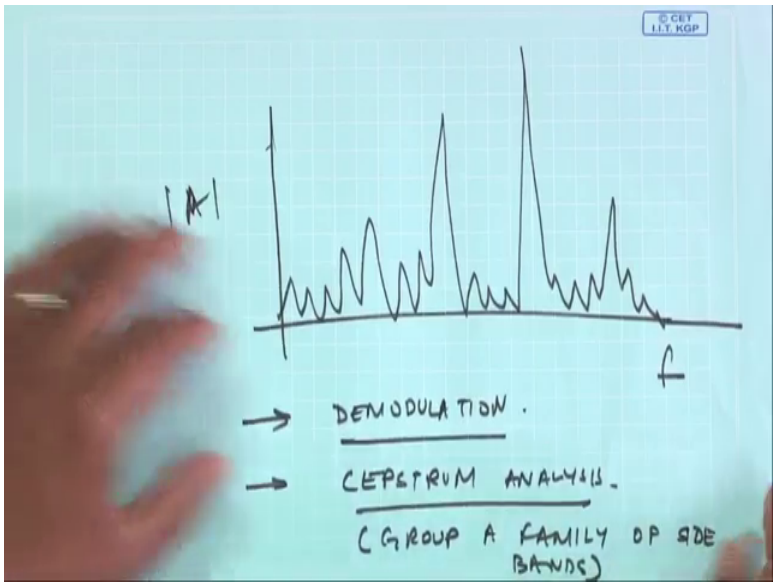

So, there will be a lot of frequencies and in this you have to detect these side bands and that is why to detection of side bands either we have to do what is known as the demodulation or to do the classify family of side bands or group of family of side bands we have to do what is known as a system analysis we discussed about Cepstrum analysis earlier and so, Cepstrum analysis is used to monitor gearbox signals and group or family of side bands and I have been always asked this question.

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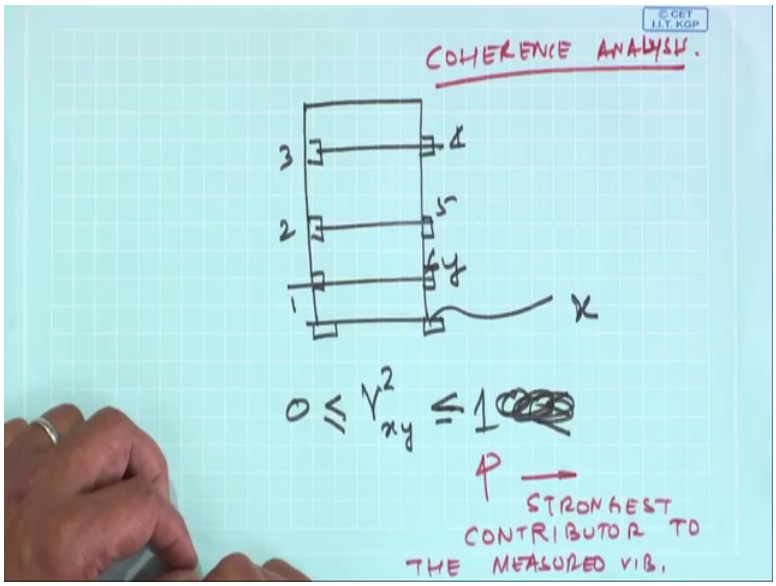

That how do you identify which gear is defective in a multi stage gearbox well the access to you is the bearing locations.

So, all you do with a common point of vibrations x you can measure the roving y at location 1, 2, 3, 4, 5, 6 and find out the coherence gamma square x y between these signals and this value will be somewhere between 1. So, if it is close to 1 you can know that a vibration at a particular location only because of that. So, you can find out the strongest contributor to the measured vibration by what is known as coherence analysis and such analysis people do follow in condition monitoring.

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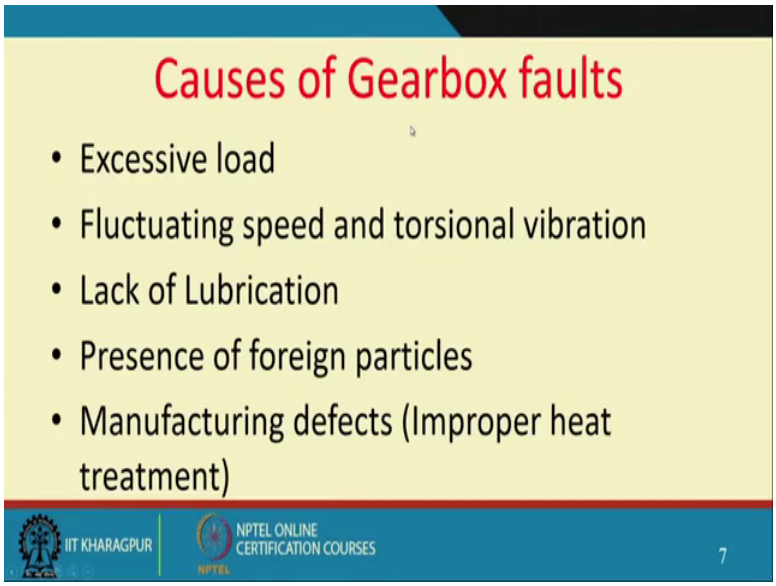

So, what are the causes of gearbox faults excessive load fluctuating speed and torsional vibration, why does fluctuating speed occur by now, you must have got an idea why fluctuating speed occurs one is the prime mover.

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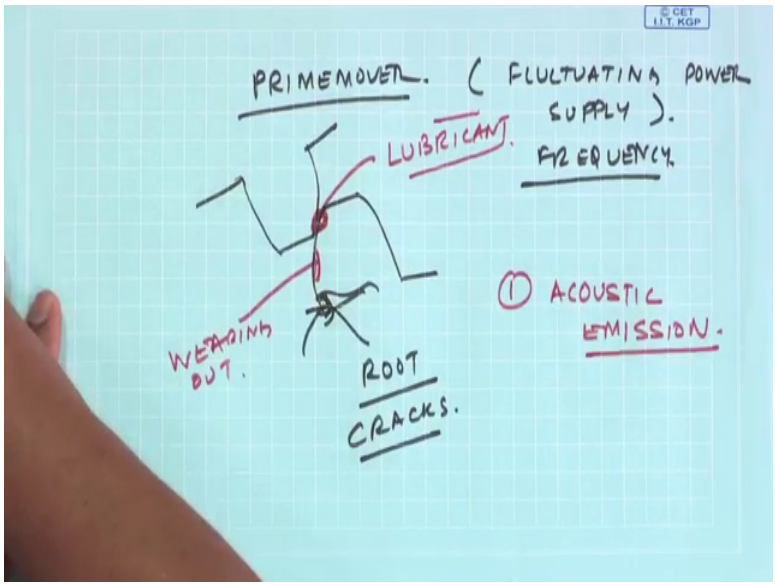

It could be fluctuating power supply in terms of the frequency if there the case of an electric motor. So, this will all give rise to torsional vibrations and then there will be excessive vibrations lack of lubricant because if you see the gears which are meeting there is always contact.

So, is this lubricant is not there, there will be high heat generations and then there will be lot of wear then the if there is presence of foreign particles in a gearbox I have been to plants when we open up the gearbox, I see on the slide on the sides lot of sludge over the period of time the gearbox was not overhauled and a lot of this sludge which has been formed because of the debris and the oil get deposited and they become like a grinding media and wear out the particles and as you know this surfaces had to be very hard and they undergo heat treatment and if you look at the stresses here the stresses are the maximum the root.

So, there could be cracks which can develop and if this go unnoticed eventually they may fail. So, even another new technique people have used is something called acoustic emission which I am going to discuss in a later class that how acoustic emission can be used to find out even defects in gearboxes.

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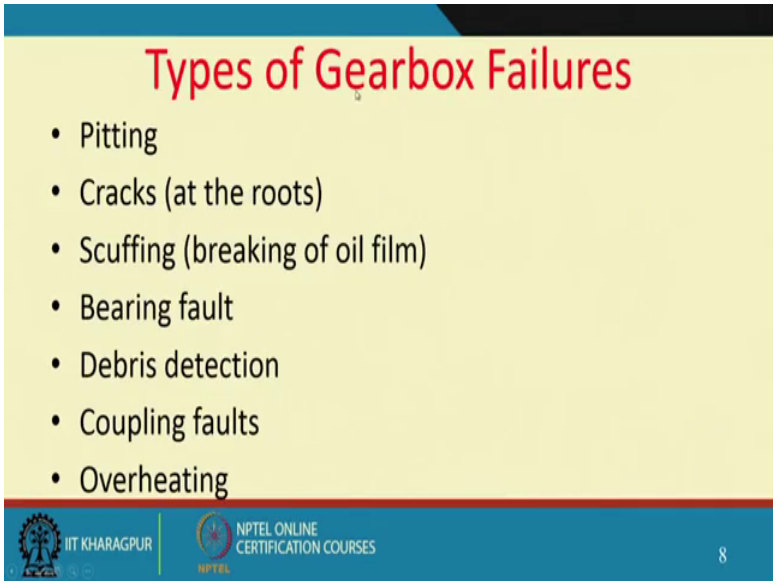

So, these are how gearbox faults occur. So, types of gearbox failures pitting cracks at the root scuffing is what is known as braking of the oil filling a bearing fault the bridge detections coupling faults and overrating. So, these are all are responsible for the bearing faults.

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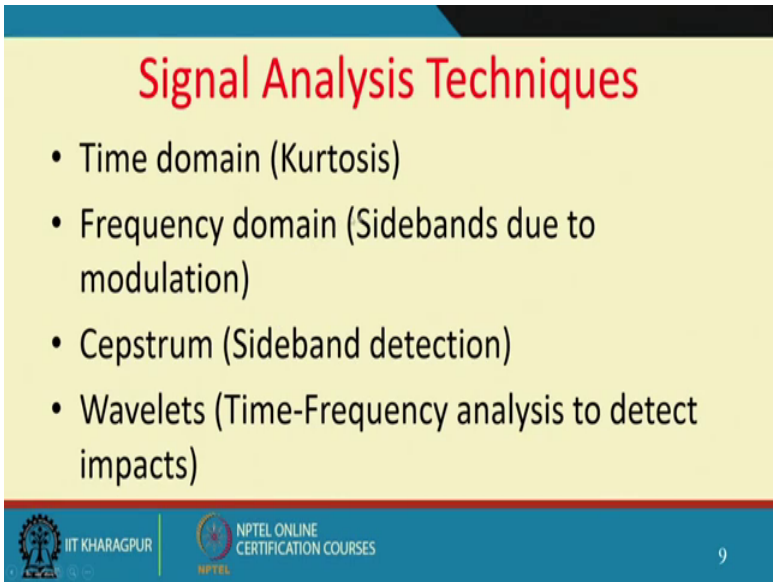

So, some of the signal analysis techniques which are used, I can still do kurtosis because there is a lot of pickiness in the signals frequency domain analysis side bands due to modulations and modulation occur because of amplitude effects.

So, to detect side bands we can use cepstrum we have discussed this before and because there is a lot of transients occurring and the signals are not stationary one can do what is known as the prime frequency analysis to detect impact like wavelets.

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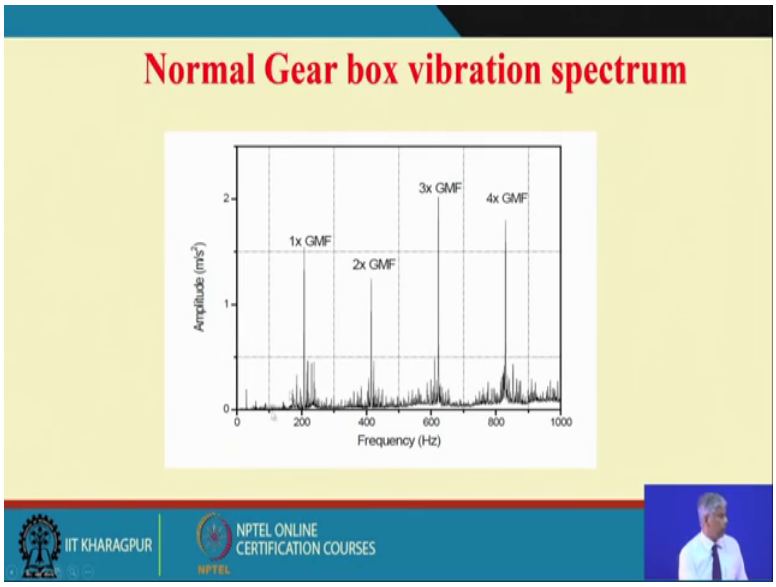

So, this is even in a normal gearbox out of the rig in the laboratory which we saw, we can see such gear meshing frequencies coming up.

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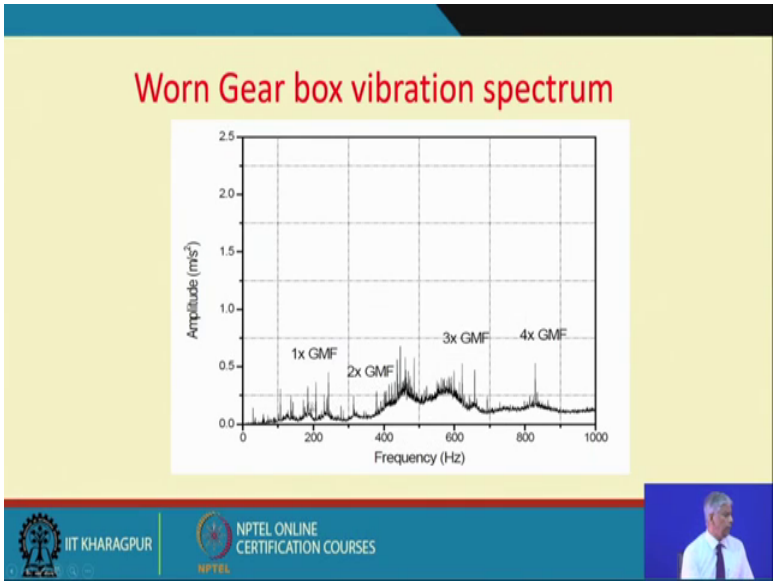

But the intensity of the sidebands would increase when the gearbox owns out.

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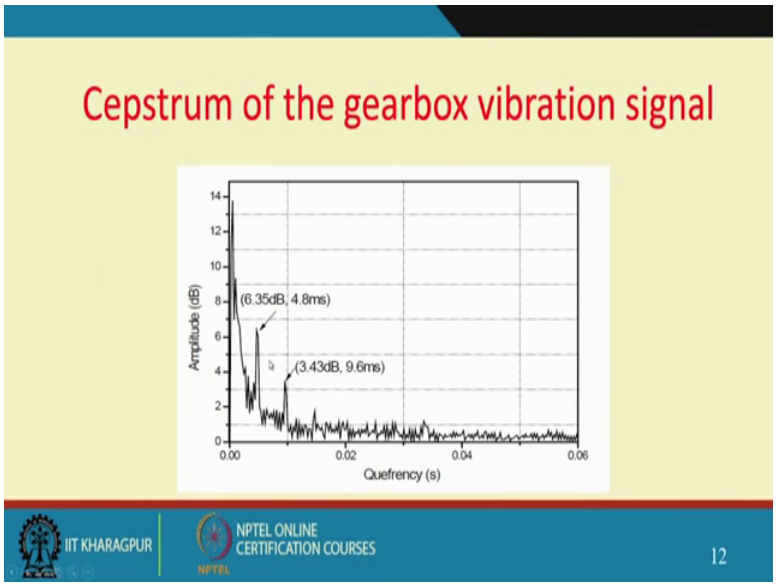

So and to detect the particular gear all you require is the septum analysis given in quefrency and if you see 4.8 milliseconds or 9.6 milliseconds and there is an amplitude. So, this means the gear which is having a time period of 4.8 milliseconds is severely getting affected. So, if I monitor this amplitude over a period of time in a gearbox where

the lot of vibrating signals I can monitor at the quefrencies and find out defaults in the gearbox.

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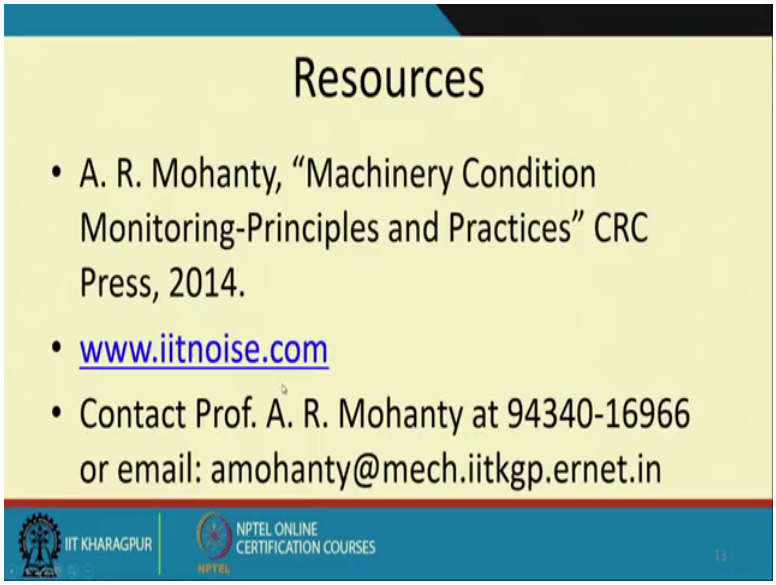

So, this is all gearbox defects can be found out of course, there are other methods like thermography motor current signature analysis etcetera which we will discuss subsequently and some of them are discussed in my book.

Thank you.