Machinery Fault Diagnosis and Signal Processing
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Lecture – 19
Cepstrum Analysis

Yeah in this lecture we are going to start talk on Cepstrum analysis, now by now we have seen that there are many instances where signals are modulated. So, and if you have modulations, we get side bands on a signal you know.

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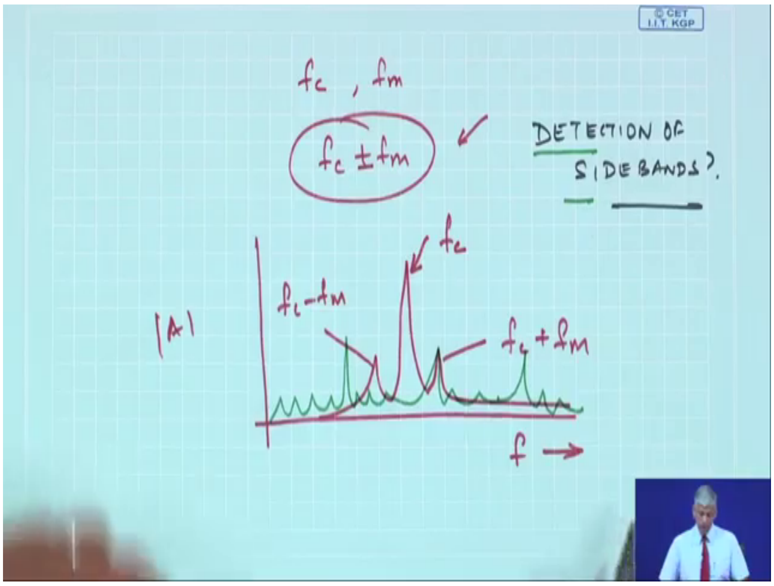

So, if I have a carrier frequency and a modulated frequency, I will have frequency of this kind of side bands around the signal. So, if I look in the frequency domain transformation of a signal and so on some amplitude. So, this is my carrier frequency and this is my; the upper sideband and the lower sideband. So, detection of sideband becomes a problem why? Because in a machinery signal where we are measuring from a say for example, a bearing location there will be instances where there will be lot of other frequencies in such signals. So, it becomes the detection becomes very very difficult. So, this is another technique of detecting sidebands in a signal, and this is actually done through what is known as Cepstrum.

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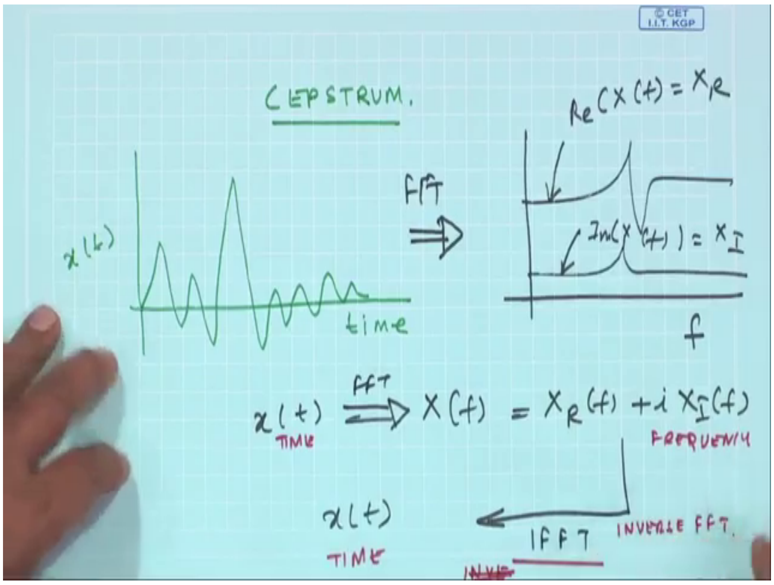

Now, what happens let me tell you this suppose I have a signal in the time domain some signal xt if I convert them through FFT. So, I will get a signal frequency and so, maybe a real part of x f, which I will denote as x real and the imaginary part of x f which I will denote as x imaginary.

So, FFT of a signal xt will give me a complex number x f which can be written as x real frequency plus x imaginary frequency. So, this is a complex signal. Now if I do an inverse FFT I will go back to my original time signal and. So, this is when to begin with I was in time, I come down to frequency and I come back to time by and doing what is another inverse let me write it here for the benefit of the camera inverse FFT. Now what happens is in this inverse FFT, we change some modules in the real and imaginary part. So, I have x r frequency.

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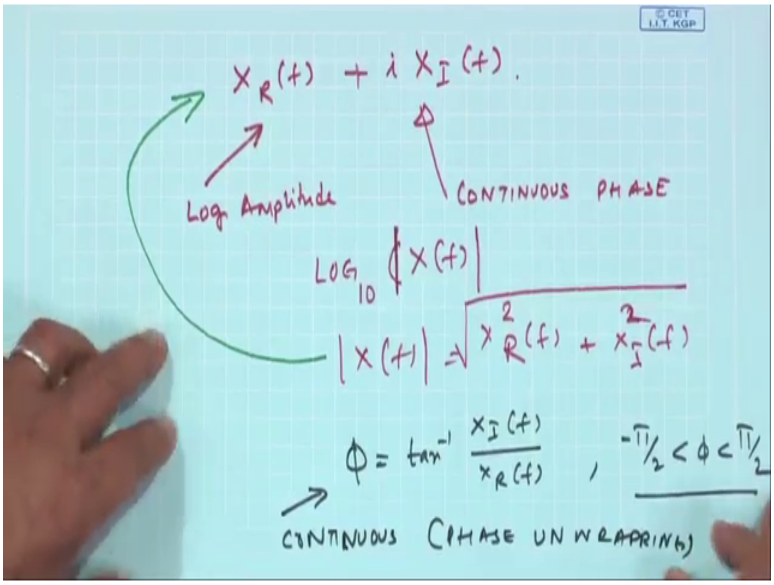

Plus imaginary x imaginary frequency. So, to this I give it will logarithmic amplitude of the signal and to this I make it a continuous phase. So, what is log amplitude of the signal is nothing, but logarithmic to the base 10 of x f amplitude, where xf amplitude is nothing, but x real square plus x imaginary square root.

So, this is one argument. So, when I do Cepstrum if I do log scale, I add this here and for the continuous if I have the five phase, phase is nothing, but tan inverse x imaginary and max real phase, but you will see this phase is going to dance between minus pi by 2 phi pi by 2 and so on. So, I can always make it a continuous function, this is a continuous function and which is known as phase unwrapping. So, phase will not jump, but it will have a continuous signal like this, with frequency because I need to give you a continuous signal.

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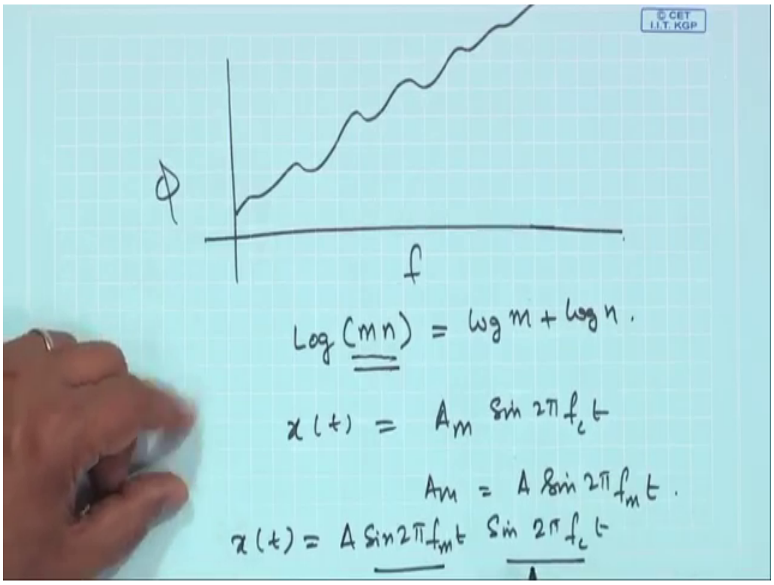

So, with phase may look like this. So, it is the continuously varying phase. So, this becomes the imaginary part and I have the real part as the amplitude of the signal log amplitude. So, if I do an inverse Fourier transform, I will get what is known as the Cepstrum, but I will tell you how this logarithmic scale helps and I am sure all of you know from your high school maths, that log m times n is known as logarithm of m plus log of n. So, if you have modulated signals. So, for example, I am writing an amplitude modulated signal, where xt is equal to A m sin 2 pi fct where A m is nothing, but some A sin 2 pi fmt. So, basically my xt is nothing, but a sin 2 pi f m t times sin 2 pi fct.

So, there are basically 2 functions which I have multiplied. So, if I do a logarithmic they will get added and what happens in Cepstrum is the effect of one signal or event on another is either added or I can also write subtracted depending on the sign.

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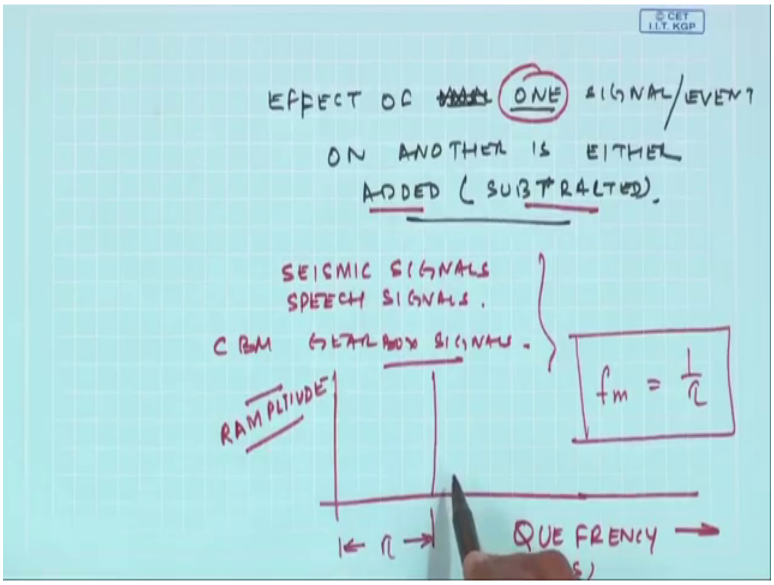

So, Cepstrum helps us remove the effects of any one signal, this signal this effects could be for example, you know Cepstrum is used to understand the seismic signals understand as speech signals and in CBM understand gear box signals. Now because this is added or subtracted I can very easily separate the sidebands by doing a Cepstrum analysis of such modulated signals, and as you will see later on modulated signals do occur in gearboxes and once we have the Cepstrum, they will look like this is known as the Que frenzy is the universal frequency, and instead of amplitude will have ramplitude and so on. So, I will see a single line. So, this now is in time domain actually if you see because I have done the inverse from the frequency to the time.

So, this is in seconds. So, some tau. So, the indication of this the value of this tau we will actually indicate the value of. So, the effects of carrier frequencies has been removed and then I can easily identify the modulator frequency in gearbox or in any Cepstrum signals and we will see this with an example where we are using Cepstrum for CBM in a gearbox, So, there are many ways.

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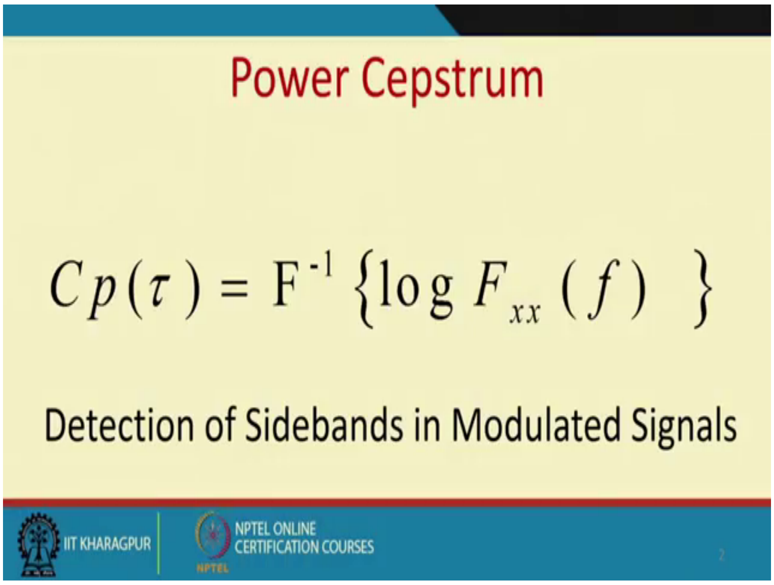

So, Power Cepstrum somebody defines this as a log of this for your inverse. So, I had shown you what this f xx f looks like the internal of it. So, one of them is the log amplitude another is the imaginary part of the continuous phase.

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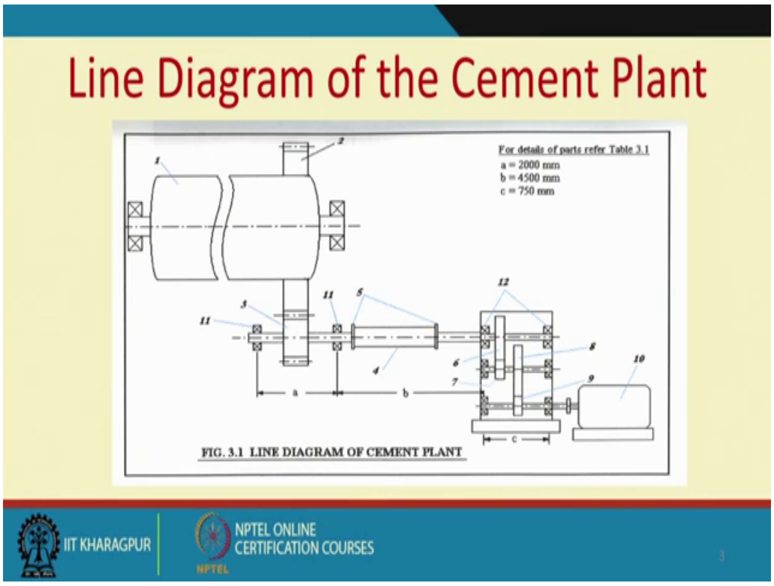

So, detection of sidebands and modulated signals, I will just briefly give you an example of a cement plant where some data has been taken, the reason I am showing you this cement plant is you know because of the fact that we will be coming back to the cement plant again and again, and we will see a lot of things happening here say for example, the way the cement is actually manufactured is there is a big drum. This in this could be about very long schedule about10 meters now this diameter equal to about 2 to 3 meters and this rotates very slowly about 2 to 3 RPM and of course, it is sometimes inclined.

And then of the raw materials for the cement like you know a limestone fly ash etcetera is added and then there is a big grinding media nothing, but strong vanadium balls are there. So, if this is rotating on this drum, but of course, their drum as a liner which will protect it against aggressive wear and tear and because of this grinder at another fine and you will see the fine powdered cement coming out there will be a sieve etcetera, but the fact that this big drum has to be rotated from 2 to 3 RPM, it requires massive speed reduction because the pouring devices at this end, which is nothing, but an electrical motor.

Typically this motor is of the order of you know maybe a 1000 kilowatt 1 megawatt and. So, this easily runs at about you know 400 RPM 1440 RPM and for this massive speed to be reducing we have 1440 RPM here to about you know 3 RPM here. So, there is a substantial speed reduction in a 3 stage gearbox as is shown here. So, all this gears these are actually nothing, but the pinion and the gear pinion and the gear and they are supported on bearings. So, if I want to do CBM on this gear box I have to actually capture the signal from accelerometer put on this bearing in this gearbox, and the output shaft of the gearbox actually connects to a torsion shaft and torsion shaft is a weak structural member in the entire system. So, if the; you know this is a very weak. So, if the brakes you know it will fail here, and this can be replaced and so on, and then this is supported this is driving a pinion or a and then this is driving a crown gear or a ring gear which is mounted all along the circumference of this kill or the drum, and this is supported on bearings. So, we have some vibration signals taken from the entire plan, and I will show you how sidebands occur in such gearbox signals.

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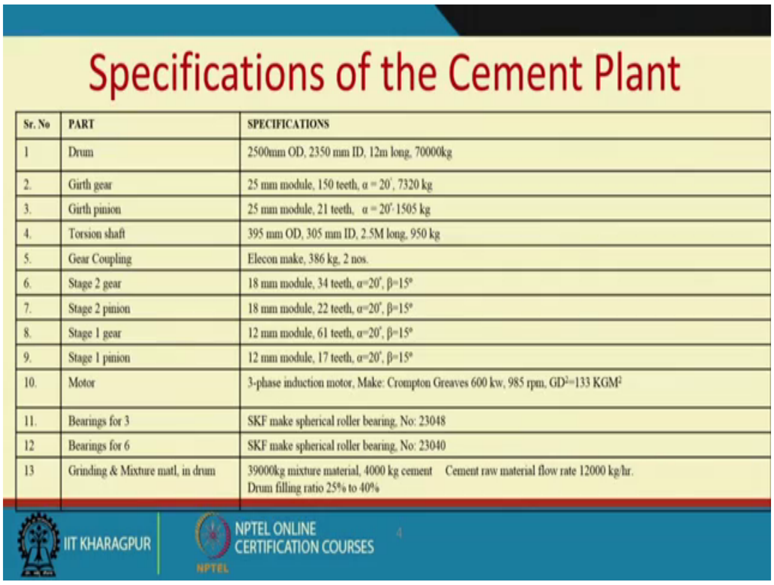

Specifications of the Cement Plant

Sr. No	PART	SPECIFICATIONS
1	Drum	2500mm OD, 2350 mm ID, 12m long, 70000kg
2.	Girth gear	25 mm module, 150 teeth, $\alpha = 20^{\circ}$, 7320 kg
3.	Girth pinion	25 mm module, 21 teeth, $\alpha = 20^{\circ}$ 1505 kg
4.	Torsion shaft	395 mm OD, 305 mm ID, 2.5M long, 950 kg
5.	Gear Coupling	Elecon make, 386 kg, 2 nos.
6.	Stage 2 gear	18 mm module, 34 teeth, $\alpha=20^{\circ}$, $\beta=15^{\circ}$
7.	Stage 2 pinion	18 mm module, 22 teeth, $\alpha=20^{\circ}$, $\beta=15^{\circ}$
8.	Stage 1 gear	12 mm module, 61 teeth, $\alpha=20^{\circ}$, $\beta=15^{\circ}$
9.	Stage 1 pinion	12 mm module, 17 teeth, $\alpha=20^{\circ}$, $\beta=15^{\circ}$
10.	Motor	3-phase induction motor, Make: Crompton Greaves 600 kw, 985 rpm, $GD^2=133\ KGM^2$
11.	Bearings for 3	SKF make spherical roller bearing, No: 23048
12	Bearings for 6	SKF make spherical roller bearing, No: 23040
13	Grinding & Mixture matl, in drum	39000kg mixture material, 4000 kg cement Cement raw material flow rate 12000 kg/hr. Drum filling ratio 25% to 40%

So, this is a little specifications of this cement plant for those of you who are interested, to get in order of magnitude feel is about you know 2.5 meter and outer diameter. So, about 12 meter long and it is about 70 ton, the girth gear on the girth pinion you can see it has 150 teeth 21 teeth is pinion is the torsion shaft as a gear coupling which is driving the torsion shafts and the gearbox.

And then the in the gearbox itself stage 2 gear pinion etcetera all these modules are there as an electrical motor of in this case it is actually 600 kilowatt and 985 RPM, there are few bearings you know and then of course, the grinding and the mixture medium material in the medium is about 39000, 39 tons and then we get about four tons of cement and cement material flow rate is about 12 tons per hour, and the drum filling ratio is about 25 to 40 percent.

So, this works around the clock you know with this kind of operation being occurring and of course, you know we have many cement plants in our country you know which are enough they fly ash from you know power plants and so on and this is used to make such cement.

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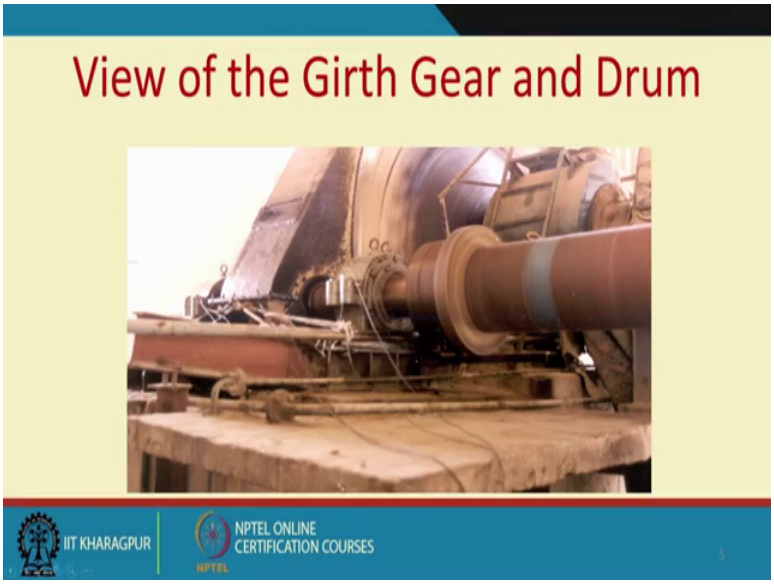

And if I show you because I was talking about data recording in the previous class, if you see this the girth gear and right here and this the drum which is actually rotating, and this is the torsion shaft in the coupling. So, if you see here there is an accelerometer on either sides and these are the long cables, which go to the accelerometer and; obviously, this is the very dusty environment.

So, any sort of signal analysis is actually not very convenient or possible. So, we record the signal.

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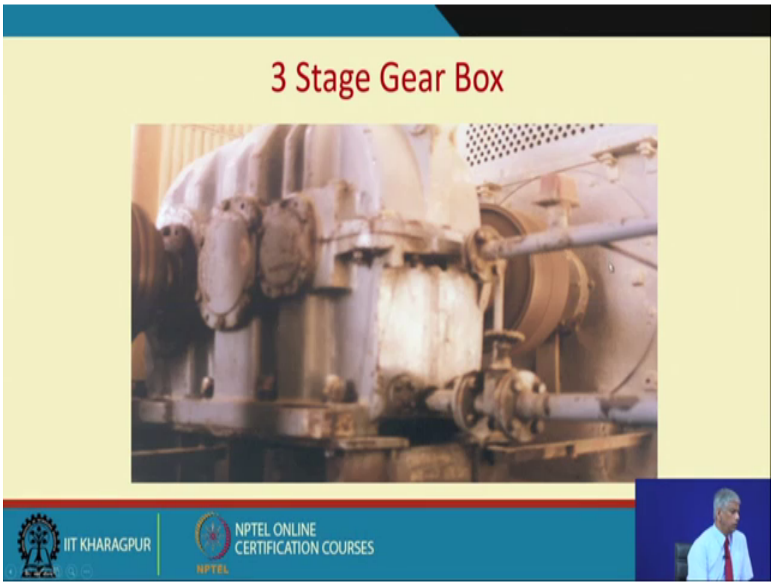

And this is a v of 3 stage gear box, here you will see the electrical motor which is about driving this input shaft intermediate shaft on the output shaft and this shaft is driving the torsion shaft of the cement plant.

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And this is a the same data recorder and you will see this is an typical data tape, where there is a spool and this can you can record about you know 19 minutes to 60 minutes depending on what speed you are recording the signal, and the same tape recorder was used to record eight channels of Iverson data and this is just to give you an relative feel of the dimensions of the cement plant mill we are talking about.

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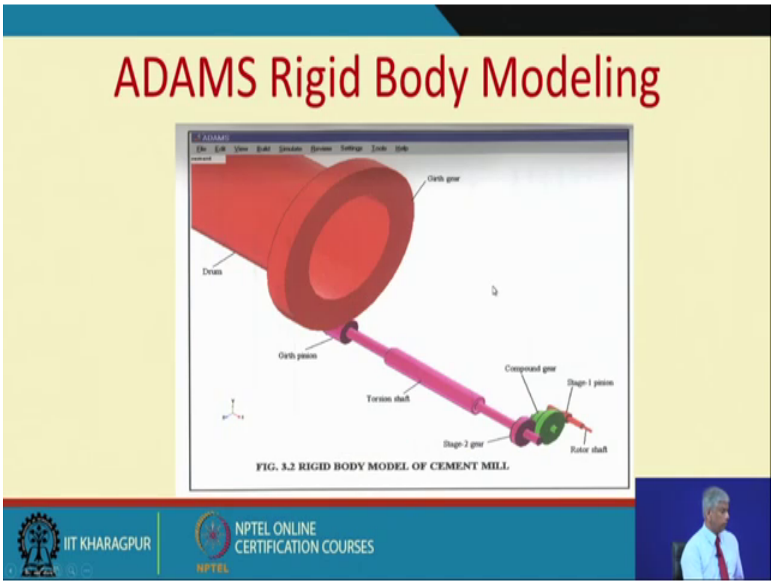

You know because you know one of my students worked on a rigid body model to understand the dynamics of a such a cement plant. So, I have this here, this is the rotor shaft which is driving the gear box and then the torsion shaft girth gear and that is gear pinion pinion and the gear shaft.

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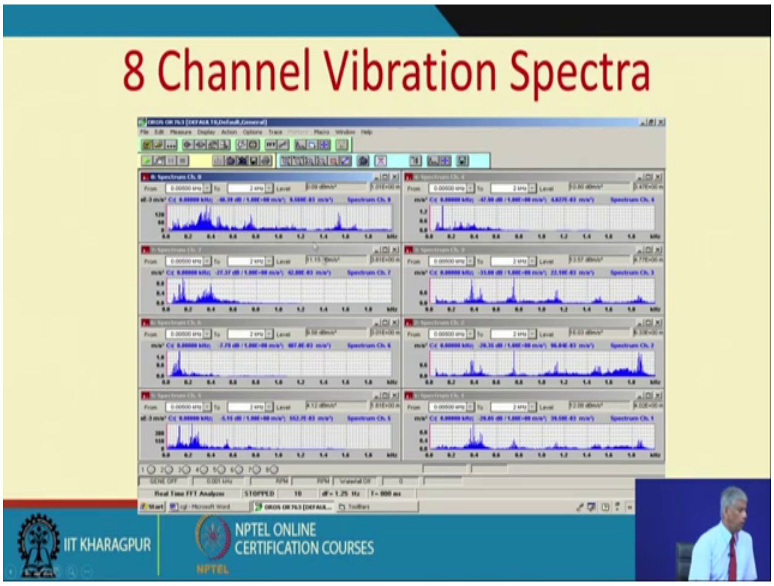

And this is a typical vibration spectra of all the 8 channels which are recorded and this is up to you know 1.2 kilo hertz and so on, and you can see these of 2 kilohertz and you can see these frequency spectrum that you will see there is a lot of stacks of side bands, which is normally not possible in a fast Fourier transform and that is why. In fact, we are doing Cepstrum analysis.

So, if you will see this is the typical you know signal frequency vibration spectrum of the gearbox and so on.

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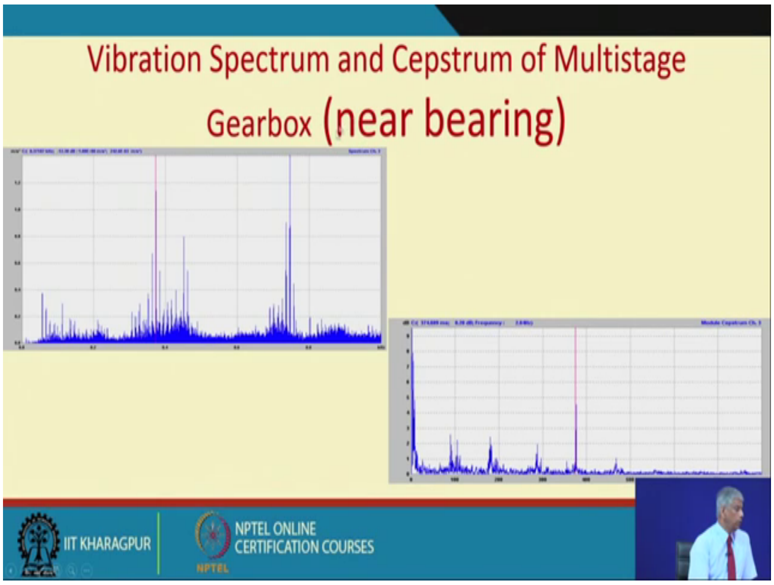

So, now you see this is the vibration spectrum here, and you see there are so many side bands of this multistage gearbox, but if I do this Cepstrum, I will see a peak and if this is in time domain this time actually corresponds you know this value in the time actually corresponds to the frequency of rotation of that particular gear and near that bearing, because see in this signal; let me tell you particularly in CBM as you will see later on whenever we capture data from any machinery.

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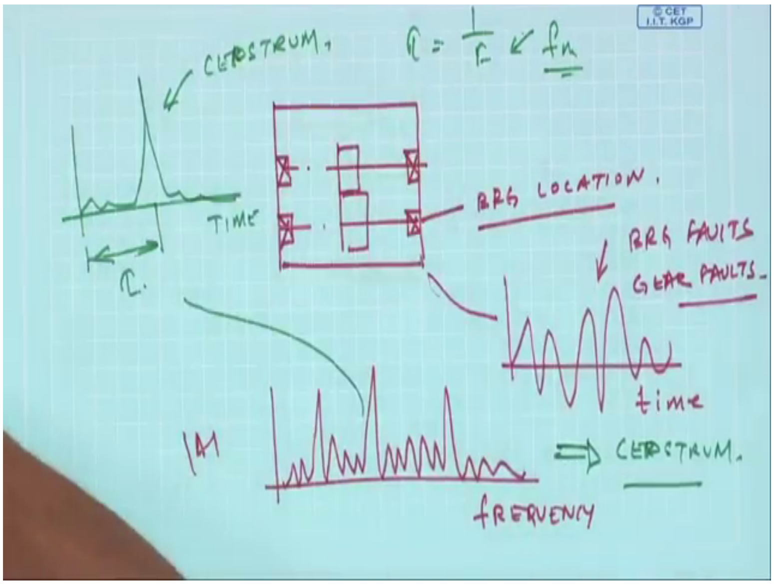

Whatever be the shaft it is actually at these bearing locations. So, this is the bearing location. So, when I record a signal it is a composite signal. So, there could be bearing faults there could be bearing faults or gear faults. So, how can this be reduced so; obviously, you will later on we will see when you do the frequency domain transformation you will see lot of peaks some amplitude. So, Cepstrum is going to help you if I do the Cepstrum it is going to maybe, this you will see one peak and this time period this is in time and this is the Cepstrum. So, this time period tau is nothing, but one by certain F where F is the predominant sideband in the signal like an amplitude modulated signal.

So, this is what we actually found from recording this signal of this gearbox using the side channel data recorder.

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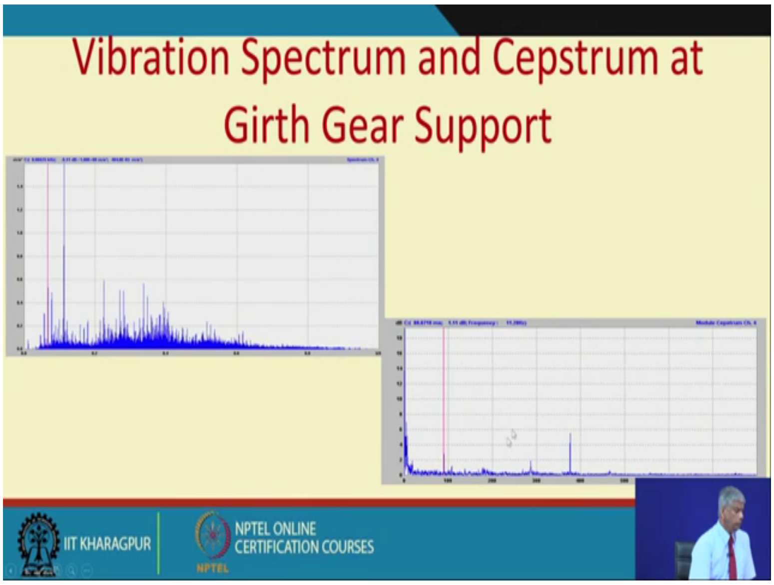

This is another spectrum at the gear girth gear support you will see, a lot of peaks here which is very difficult to identify, which one is from the bearing which one is from the gear which one is for other machine rotor problems like a cracked shaft like a misaligned shaft like an unbalanced shaft. So, everything is a composite spectrum is what we get actually physically. So, to reduce this very easily we can do this Cepstrum and just find out the very important peak, which corresponds to the rotational speed of that system.

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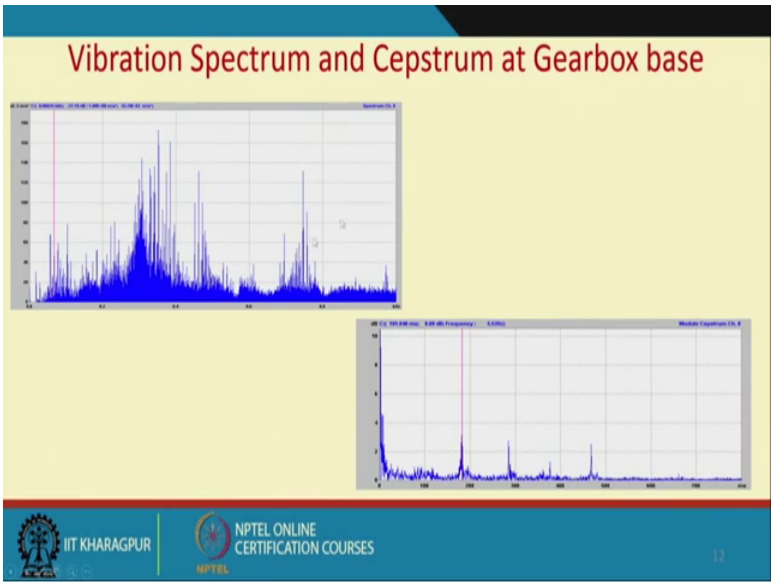

Another at gearbox this you see lot of side bands are there. So, if somebody asks them what are the frequencies it is very difficult, but if you look at these peaks here and sometimes some of them have harmonics, you will see that this length this distance is actually in tandem this is in frequency here, this is in time domain here. So, this time is inverse of that would be the speed corresponding the; that device, and this is how Cepstrum actually helps us remove the effect of one signal over the other.

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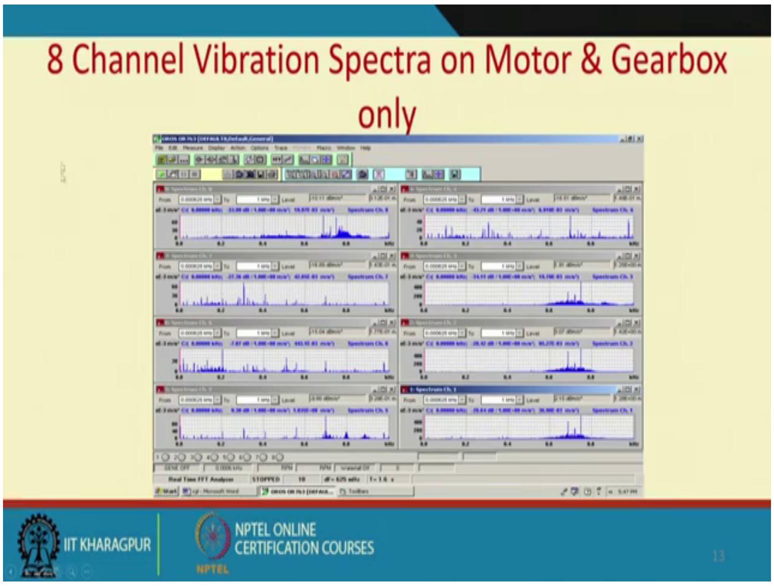

And if you will see on motor and gearbox analysis only the signals are kind of very different. So, this kind of analysis helps us find out the faults in the system.

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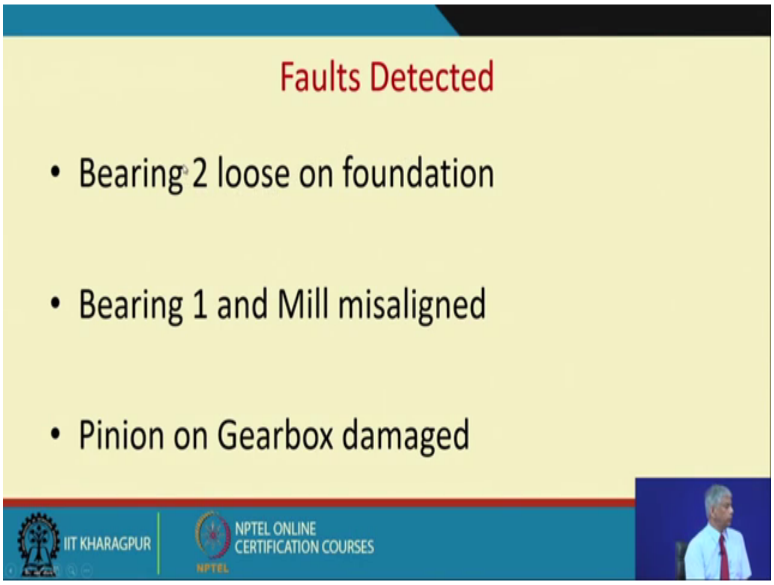

So, we will later on of course, you will see how a varying fault can be distinguished between a gear faults.

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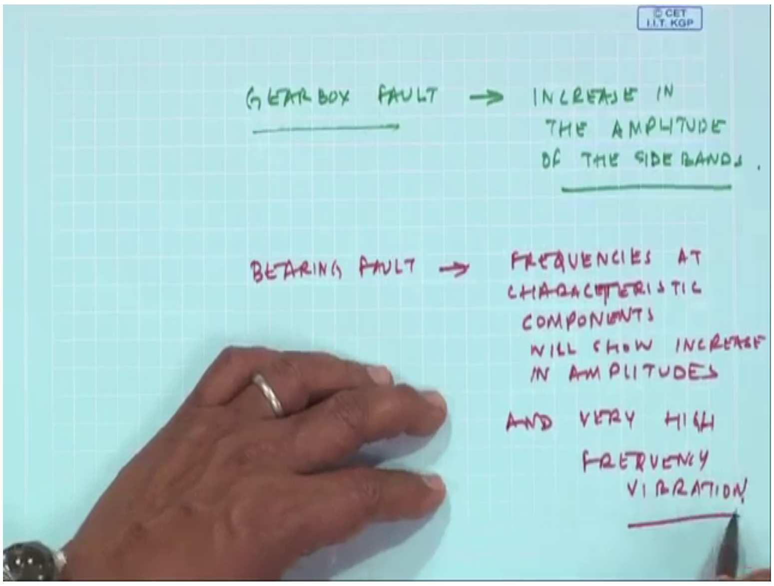

But I will right now tell you a gearbox fault is actually manifested in increase in the amplitude of the side bands.

So, this can be unlike a bearing fault, which may have frequencies we will discuss this later on, but I just wanted to drive frequencies at characteristic components will show increase in amplitudes and very high frequency vibration we will discuss about this, later on now I will give you an example of this gearbox, if you do an Cepstrum analysis just for the sake of discussion.

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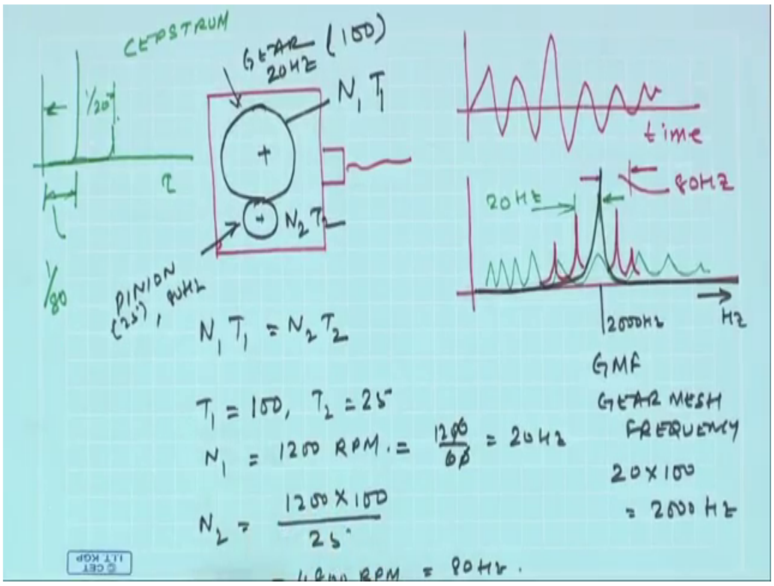

For example if I have a gear driven by a pinion. So, this is N1 T 1 and this is N 2 T 2 from the law of gearing I have N 1 T 1 is equal to N 2 T 2, for the sake of discussion if T 1 is say 100, T 2 is say 25 N 1 is say 1200 RPM your N 2 is nothing, but 1200 times 100 by 25 this is nothing, but 4800 RPM. So, in this RPM corresponds to 1260 that is 20 hertz and there is about 80 hertz.

So that means, this gear which has a 100 teeth is rotating at an speed of 20 hertz, and this pinion which has a 25 teeth is rotating at 80 hertz. So, if I put this in a casing and put a transducer and take a signal from such a gearbox, I will get a signal like this. So, if I do the FFT, I will see a frequency of this is nothing, but the GMF which is nothing, but the gear mesh frequency, which is nothing, but 20 times 100 is a 100 teeth. So, this is about 2000 hertz.

So, around 2000 hertz this is in frequency I will see sidebands corresponding to one corresponding the gear another correspond to the pinion. So, this spacing here in one case will be 80 hertz, in another case this will be the closer one will be 20 hertz. So, if the sidebands increase at 20 hertz and in 80 hertz I may be able to detect it in us FFT, but if I do a Cepstrum, if I see a peak because this is in time domain. So, this corresponds to 1 by 80 and this corresponds to maybe 1 by 20, I will say you know there is a fault at one by 80, 80 means our pinion has a fault. So, this is the advantage of Cepstrum and in real world this is the very noisy signal like this. So, Cepstrum helps us identify the sidebands in a signal ok.

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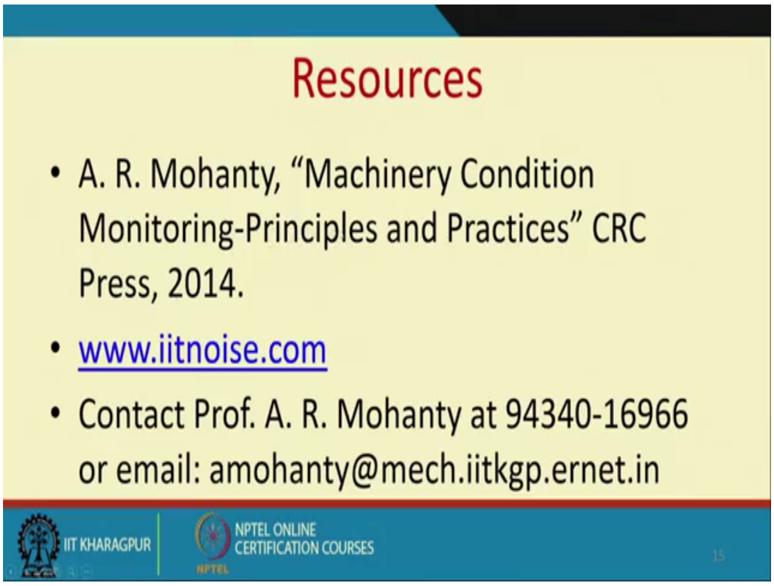

So, well there are resources available on this in my book.

Thank you.