

Machinery Fault Diagnosis and Signal Processing
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Lecture -14
Cepstrum Analysis

In this class, we will talk about something what is known as Cepstrum Analysis. Well, by now, you know that in the signals there could be side bands because of modulation, okay. We have just seen that side bands could be because of frequency modulations, sideband because of amplitude modulation. In the case of amplitude modulation, I have this side bands, you know, $f_c \pm f_m$, okay.

And in the case of frequency modulation, I have, you know, $f_c + k \text{ times } f_m$ where there will be multiples of the modulation frequencies. Now, imagine, if there are not one source of modulation, but there are several source of modulations in a signal, particularly, a multi-stage gearbox, so there will be a family of side bands.

So, in a signal if I have a lot of side bands apart from the fundamentals, you can imagine the problem I will have in the frequency spectrum has to relate to which frequency or which side bands came from which machine, okay. That is the problem I have in front of me, okay. So, this Cepstrum is a technique by which we can cluster, a group of side bands coming from one source as a single parameter.

Particularly, cepstrum for its, you know, utility actually what happens in a substance is such a powerful signal, technique, analysis technique, in which it can distinguish between sirens, very easily. Lot of this earthquake signals or seismic signals, they have a lot of side maps, human voice or speech signals, they have lot of side bands, okay.

To understand between different pronunciations, different words which are coming out of an human being, particularly for speech processing, cepstrum is very, very useful. So cepstrum started its origin is from earthquake signals and from human voice signals. And then, when later

on, we, as machinery diagnostic engineers, found out that our gearbox signals also have a lot of side bands.

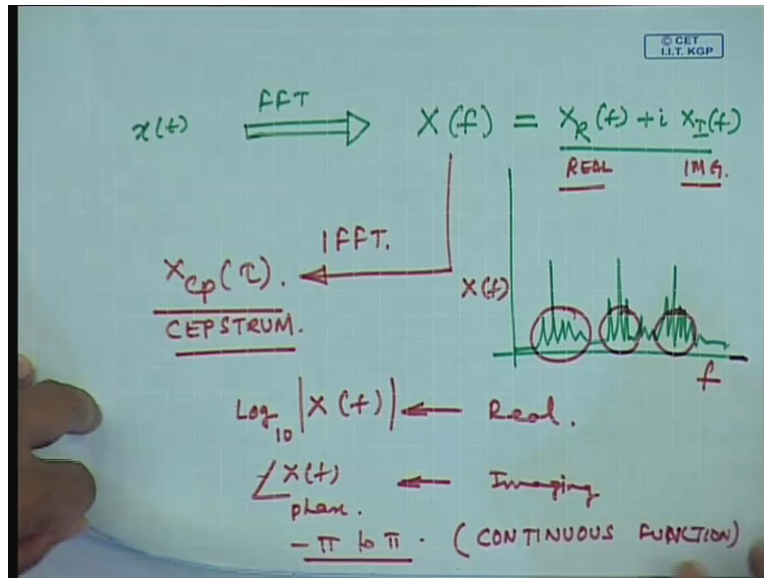
So, why not we use cepstrum to understand more about these gearbox signals, for the fact that, they can distinguish and identify different groups of side bands coming from a gearbox, so, what is this Cepstrum?

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The slide has a blue background with a black border. At the top left is a small logo. The title 'Power Cepstrum' is in white text. Below it, 'Machinery Fault Diagnosis & Signal Processing' is written in smaller white text. The equation $Cp(\tau) = F^{-1} \{ \log F_{xx}(f) \}$ is displayed in a white box. Below the box, 'Detection of Sidebands in Modulated Signals' is written in yellow text. At the bottom, 'Lecture 14' is on the left, '2' is in the center, and 'www.iitnoise.com' is on the right.

If we look into this equation here, it says that Cepstrum of a signal is the inverse Fourier transform, F minus the power minus-1 as the inverse Fourier transform, of the Fourier transform of a signal and its logarithm of that Fourier transform, okay. So, because you are doing an inverse transform here, the cepstrum is again back to the time domain.

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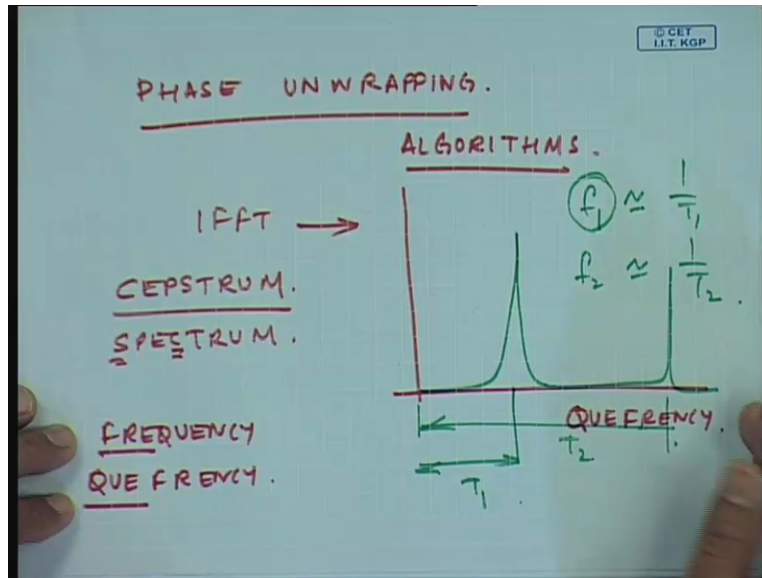


So, let me graphically, represent this to you. Suppose, I have a signal $x(t)$, I do its Fourier transform, I will get a signal X as a function of f , which can be written as x real as a function of f + X imaginary as a function of f , okay. Now, if this frequency signal has, to the sake of argument, has lot of side bands. And these are the sidebands around a particular frequency and on top of it there will be noise.

This becomes very difficult to understand as you will see in an example, I will show you, okay. So, now if I do a, inverse Fourier transform of this, I will get back cepstrum in another time domain. And this is what is known as the cepstrum. Well, how this is done? Because to do the inverse Fourier transform, I am having a real signal quantity here and I am having an imaginary quantity here.

So, to do the inverse Fourier transform, you take the logarithm of the amplitude of this as the real part. And the imaginary part will be the phase. But this phase will always be from minus π to π ; so, this will be a discontinuous function. So, the smoothen it, this has to be made a continuous function and this continuous function for the phase is done by a technique.

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Which is known as phase unwrapping and there are many algorithms available for doing this phase unwrapping. So, once I have this real and imaginary of the frequency, converted one, the real part being the logarithm of the amplitude and the imaginary part, being the continuous phase once I have such an edited spectrum, then, I do what is known as the inverse Fourier transform, to go back to the frequency to the time domain.

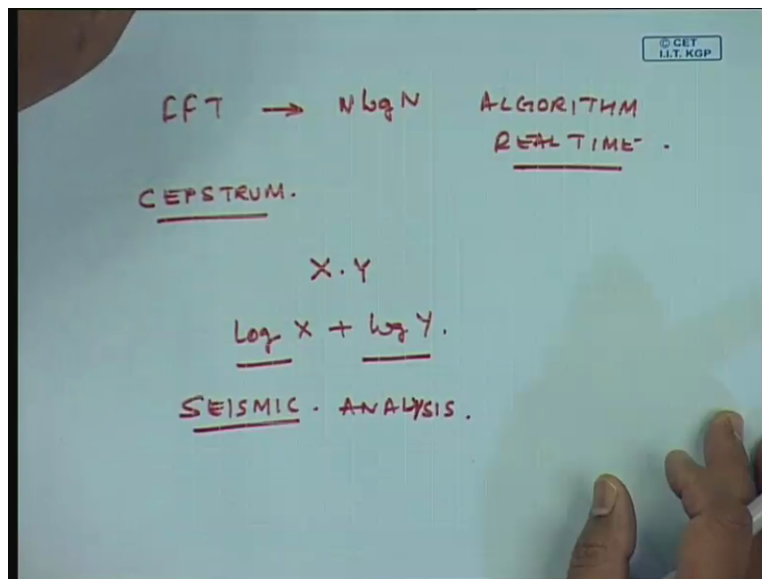
Now, in the time domain what happens? Because in if you look at cepstrum, the way it comes it is just the spectrum C replaced by S, okay. When we had frequency as the x axis, in the spectrum, here it will be, it is known as the quefrency, okay. So, I will get different quefrency here. Now this, quefrency I will get a certain peak season, okay.

Now, this is in time domain, so, say suppose, this is T_1 time, okay. And then, say, this is T_2 time. f_1 will corresponds to 1 by T_1 , f_2 will corresponds to 1 by T_2 . So, if there is a high amplitude at a particular frequency of T_1 , that means, in this spectrum, I have high amount of side bands at frequency f_1 ; because otherwise it will be very difficult, if I go back here.

It would be very difficult; I will show you an example, it will be very, very difficult to find out which frequencies are predominant of which side bands have become predominant from such an FFT analysis. Because FFT analysis, you know, for our class, we have seen in a nice pure tone and nice mathematical functions, we get neat Fourier transforms.

But in reality, once you go to the machines, we will have so many unknown frequencies. It becomes very difficult for us to find out which frequencies are present, which are the defect frequencies and so on. So, if I do this cepstrum, I can do, find out whether f_1 is strong enough or f_2 strong enough or f_3 is strong enough and so on, okay; depending on as many quefrequency as you have.

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Now, question is you would have seen, FFT can be done by the $N \log N$ algorithm. And it can be implemented in a real time, okay. Unlike FFT, cepstrum cannot be done in real time because a block of data has to be taken. They have to be processed to find out their log amplitudes, they have to be processed to find the unwrapped phase as a continuous signal.

So, once we have an FFT, then, once you go for a system analysis, there are software who will do these calculations for you. But then, it is not real time; it will take some time for computation one such computation is done; and then, once you do this cepstrum, you will see the harmony of the amplitudes or the harmonics as they are called at different quefrequency, okay.

And then, you can find out whether a particular group of side bands is present or not. Another effect of cepstrum is deco volute or removes the effect of the path; because if the two signals are convoluted, you know, you will or the effects are there, suppose, a signal X multiplies with

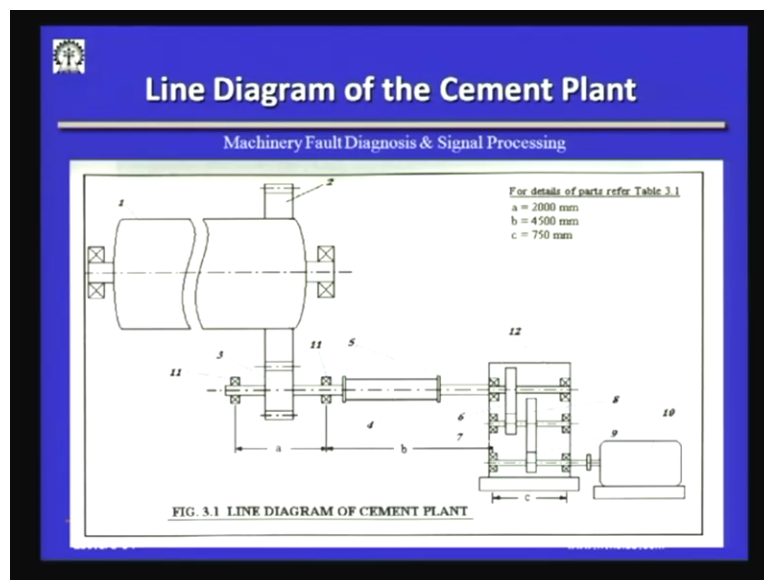
signal Y, okay. But if I take the logarithm, because I am taking the logarithm, it will be $\log X + \log Y$.

So, the effect of the path is actually added to a signal which can be nicely removed once you do Cepstrum. So, that is why, I say, Cepstrum had an important application in seismic analysis of signal; because if an earthquake occurs, the signal which is recorded by us is signal X time signal Y. Y could be because of the path from the epicenter of the earthquake to the location where your transducers were put.

This effects could be added and removed and their efforts can be eliminated once you do Cepstrum analysis; because of this logarithm property of the property of logarithm. That is another advantage of cepstrum analysis. But, you know, here we will see same also happens. Suppose, I have a large gearbox, lot of signal contamination occurs because of the path, whether it is coming from location bearing through bearing A or through bearing A,B,C.

All those effects will be lost or easily removed once we do Cepstrum. So, to summarize, cepstrum is a powerful method, to find out side bands in modulated signals.

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Now, we will go to one example, wherein, we will see how cepstrum analysis helps us diagnose a fault in a cement plant. That is what I will show you here. Actually what happens in a cement

plant? This is a large rotary kiln, okay. This is about if I was to explain you this cement plant here. This is a kiln, wherein, all the mixtures for making the cement or the motor mix, the limestone, mixed with and they are put in this drum.

And in this drum, there are very, very hard stones or rolling kind of rocks, which will be: it is like a tumbler; it is like a tumbler. And this drum this diameter, could be about, you know, 2 to 3 meters, okay. This is diameter and this length could be about, you know, 7 to 8 meters. And this, this, there is a small inclination between this feeding end and the delivery end.

And this could be about 2 to 3 degrees slope. So, you put in the raw materials and this, the beauty of this is, the unique part of this, this drum rotates at about 2 to 3 rpm. It rotates very, very slowly. And this media along with this grinding media, along with this feed is mixed. And finally, end of here, you will have the dry cement powder coming out, okay.

Cement mixing; cement manufacturing is very, very easy, in that sense. If you have the right proportions of the ingredients, you just grind them and you will get cement powder. It could be a mixture of fly ash, limestone, gypsum, etcetera. And then, you just grind them. So, this is nothing but a grinding mechanism. And the same is same also happens to you know, your washing machine, detergent, etcetera.

They are also manufactured in the same process; will have some ingredients, they could be temperature controlled and then, you have a grinding media. But from a mechanical engineers point of view, you see that this is running at 2 to 3 rpm. And I have this big motor here. This could be of more than a 900 horsepower.

This motor is running at about 1200 or 1200 rpm or at 2400 rpm or 2800 rpm. That depends on the number of poles in the motor. So, obviously from 1,400 rpm, if I was to go about 2 to 3 rpm, you can imagine the amount of speed reduction required in this gearbox. So, a very critical thing it is in such a cement plant is this gearbox. So, this gearbox is a heavy gearbox with a lot such a large speed reduction.

Obviously I cannot get such large speed reduction in just one year. So, there are intermediate set of gears, okay. And they are helical gears; they can take lot of load and so on. And then, we have this gearbox which is having the speed reduced. And then, we have sometimes, this speed is also not 2 rpm. We have another which is known as the bull gear here, all around the drum. There is the ring here and then, there is a pinion gear.

And then, finally this brings about the speed reduction. And then, so that the, there is a torsion shaft here and this is the weakest member here. So, if there is any failure the torsion shaft will shear and fail, okay, just a safety measure, in the sense of you know, we do not have, want any, any of the bearings to fail the gears to fail. But just let the torsion shaft is here, okay. And then, they can take in a lot of sometimes this is a held by plumber blocks here.

And the problem here is these bearings in this gearbox, suppose, I put a transducer here, they will be capturing phenomena of all the gears; capturing phenomena of some of the gears here and bearings. So, now, question is which bearing has a fault? And that is what if you do the analysis, you will see that the, the same problem occurs that which sideband corresponds to where and how do, I find that.

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Specifications of the Cement Plant		
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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 just, sorry, this is just to give you a small example of the dimensions on the plan. This drum has an OD of 2500 millimeter, ID of 2350 mm and it is 12 meter long and it weighs about

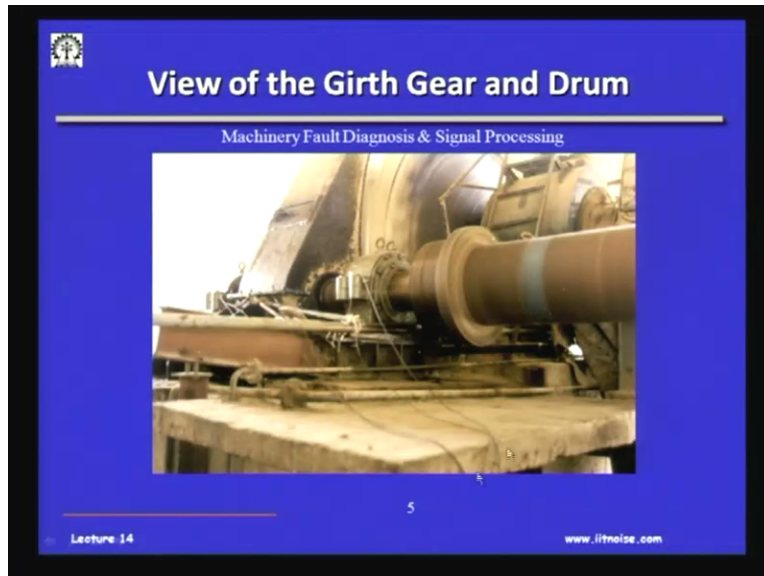
70 tons. You can imagine the magnitude of the cement plant mill or the drum. The girth gear has a 150 teeth, the girth pinion has 21 teeth, the girth gear or the ring gear, okay.

And then, there is the speed direction from 21 to 250 teeth, the torsion shaft has an idea of 395, sorry, OD of 395 OD. There are a couple of gear couplings and, and this gearboxes, there is a pinion here. And all those different modules are there; and then, numbers of teeth are also mentioned here, if you can read that, 17 teeth in the gear stage, one pinion 61 teeth in the stage one gear, 62 sorry 22 in this stage to pinion 34 teeth in this stage 2 gear.

And then, you can work it out. The motor is a three-phase in the induction motor with an 600 kilowatt and it runs at 985 rpm and bearings for location 36 are given; and then, the just for your benefit. The grinding and mixture material in drum is about 39 tons, is the mixture material; so we got about 4,000 kg of cement in it; because this 39 tones is the weight of the grinding media. And then, the cement raw material flow is about 12 tons per hour.

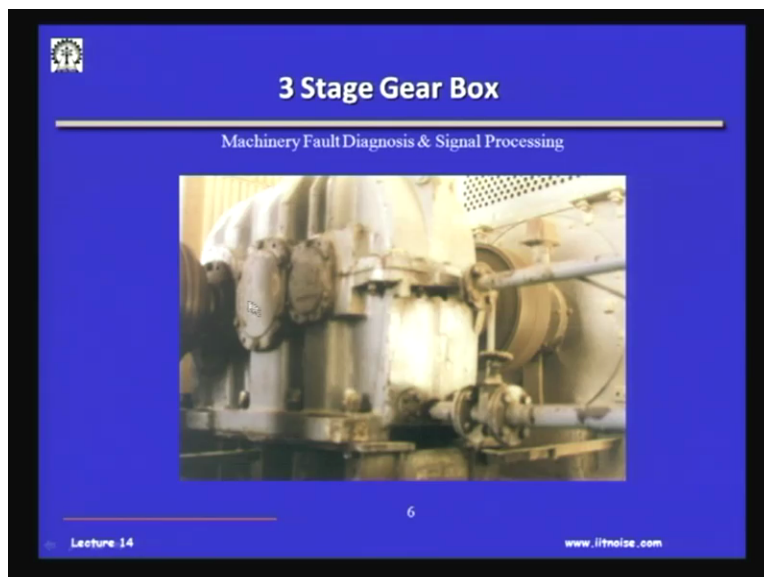
And the drum filling ratio is about 25 to 40 percent drum is of course not entirely fill. It is like a hollow drum which is churning, with this running media and the raw material. So, we are getting about 12 tons an hour of cement from this plant, okay. And this is what it is there in a cement plant. So, as you will realize be it a cement plant, be it detergent plant, this gearbox is very, very critical to the plant. If this gearbox fails or is this motor fails the plant is shut down, okay. And this is some of the views of this:

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This is the torsion shaft and this plant is very close to us, you know, we had done some measurements there after a failure. And then, we had to do a diagnosis also. This is the pinion and this is the drum which is rotating, okay. This is the other side and the ring here or the girth gear is inside this and enclosure, okay. And the pinion is here and there is the torsion shaft and this is the gearbox, okay.

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This is the motor here. So, motor is driving the input stage, intermediate stage. And then, this side goes to the torsion shaft and because of the, I would say, defects because of obvious reason there are certain defects, so, we put accelerometer at the bearing locations, accelerometer near the Foundations. And we had taken the measurements of these vibrations simultaneously.

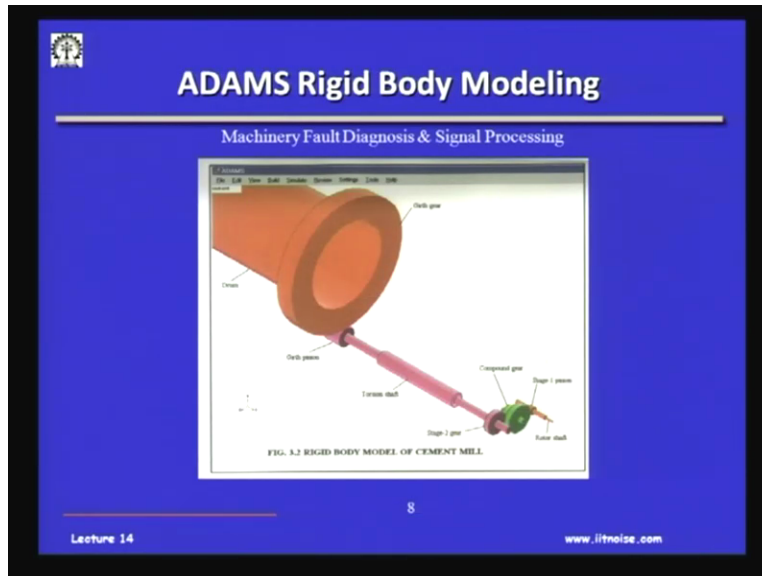
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And obviously these measurements cannot amend this analysis as a selling as cepstrum cannot be done real time, on the fly. So, we have to record the signals in a direct recorder wherein you can record almost eight channels of vibration simultaneously to a bandwidth of 20 Gillard's. You can record them in the step and then, you know, because in such a dusty environment, we cannot be cement dust. If you go to that plant, lot of cement dusts everywhere.

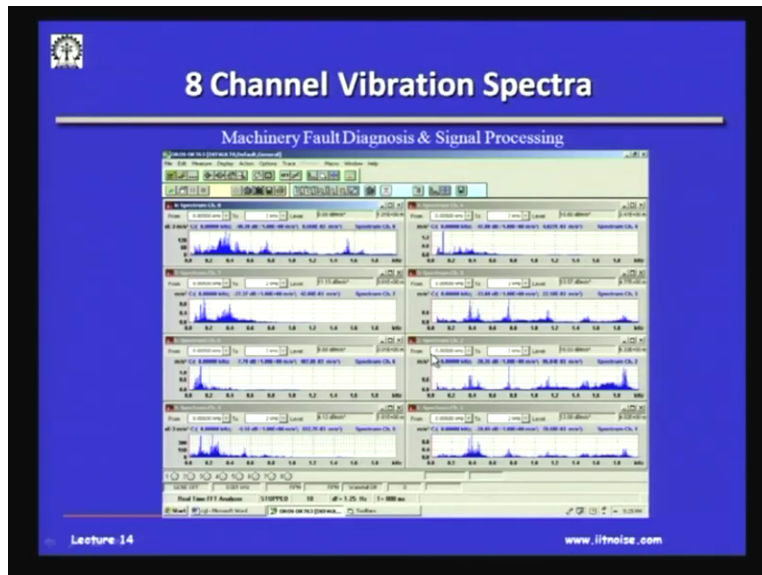
We cannot be putting computers and sophisticated equipments and then doing an analysis setting to a area, you know, cement dust. So, all you do is, you just record them in that media, bring them to the lab and then, use your software of MATLAB, and you can be doing FFT, and then, do this cepstrum analysis as per the algorithm, I just mentioned.

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And then, of course, you know, another study which we did, just to see the dynamics of the bearings here. This is another view of the cement mill is, you know this is, the stage on pinion the rotor shaft, the compound gear end, torsion shaft, girth gear and this is the drum. So, you can imagine the dimensions of the problem, okay.

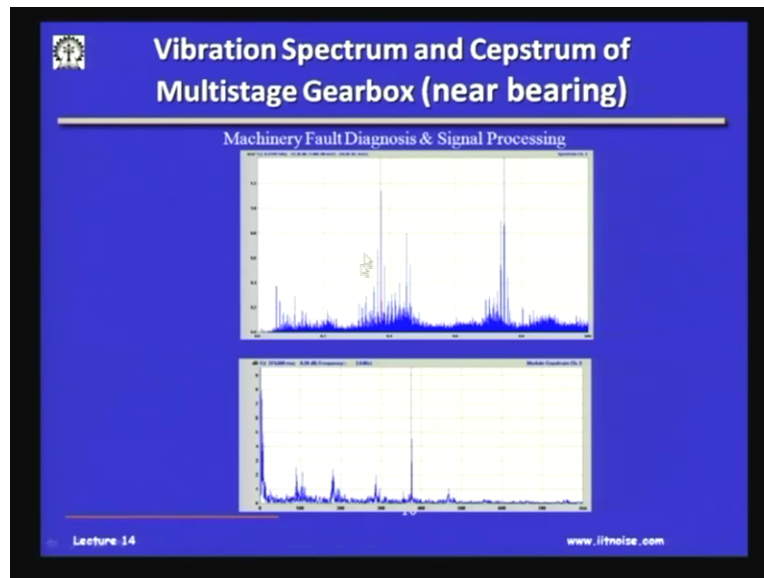
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Now, these are the vibrations of the cement plant at different, different locations. And all I have shown you here is this spectrum. These are just the FFT spectrum and these are real effective spectrum obtained from the 8 different locations on the cement plant, while the operations were going on.

And if you look at any one spectrum, it becomes very, very difficult for anybody to find out which kind of side bands are there. And if I show, this is very, very difficult for us from a signal analysis part of you, to find out the group of side bands. So, this is just to tell you the severity of the problem, you have in hand.

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So, now this is the virus in spectrum, on the top one is the vibration in spectrum, this is in 10 kilohertz near the bearing of the multistage gearbox. And then, you will see a group of sidebands occurring, okay. And then, I would not know. So, if I, if I come to the second plot here, they are all in time domain. And if you look here the corresponding frequency will be shown.

And you will know, well, this corresponds to a particular rotational shaft of the gear and then, we know its frequency content. And from this frequency, we will know, well, this means, this has an high amplitude means, this is the strongest sideband. And that is what cepstrum helps us in. I will give you another example here just from this gearbox.

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If I look into the time history of the signal which I have measured, I will get something here, at, utmost the analysis. I do in time domain, I can find out their RMS, Mean, Kurtosis, and etcetera. But this will only give me a relative measure of the strength of the signal and that is all. I cannot pinpoint whether my fault has occurred in a pinion or a gear.

But if I do a FFT analysis, what is going to happen is, I may see on a 8 Hertz signal, 20 Hertz signal, a few other signals. But what is going to happen is: And this is very, very important. This could be 8 Hertz, this could be corresponding to the rotational speed of the gear; this could be 20 Hertz, corresponding the rotational speed of the pinion.

This is the gear meshing frequency of 400 Hertz. But what I will also see is the side bands, around the gear racing frequencies, and I will draw another family here, okay. This spacing in one case will be 8 Hertz, in another case it will be 20 Hertz, why has this occurred? Because modulation is there, because of modulation sidebands have occurred.

So, I have got a group of side bands okay. Now this is very nicely drawn here. But if you go back to my actual measurement and this is what it does, looks like. It will be very difficult for me to find out. I may find out the gear missing frequencies. But here, other than the gear machine frequencies, there will be frequencies coming from the bearings, frequency coming from many other machineries.

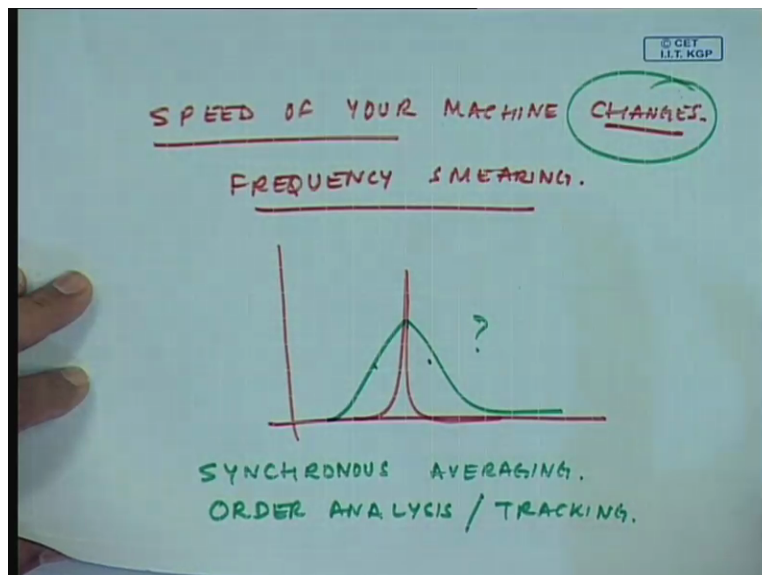
So it is very difficult to for me to know whether the sideband is because of opinion or because of a gear. So, the power of the cepstrum is to identify which sideband is more strongly predominant. For example, in this gear box, I will know, if a sideband occurs at 8 Hertz, that means, I have signal coming from my gear.

If my sideband occurs at the 20 Hertz I know this will be from my pinion okay. So, what is the, what is going to happen now? If there is a defect, it may so happen that the amplitude of the side bands around the gear box is going to increase. The frequencies are not going to change frequencies effects because of the phenomena so that amplitude of the side bands will increase.

And this is very nicely explained here. But in real world signal, it will be very difficult, first to identify the side bands. Forget about whether to know, whether they have increased or decreased; but if I do a cepstrum see the queffreny and know well, you know, it is this frequency which corresponds to the pinion which is increasing.

I can say for sure that the sideband of the pinion has increased. So, pinion is at fault. And that is the power of cepstrum analysis. So, sometimes if you have that a good measurement, a good kind of frequency analysis, if you have a good ΔF , you can do a good resolution. And then, you may be able to distinguish them but cepstrum otherwise is a very, very powerful technique to determine modulations in signals, okay.

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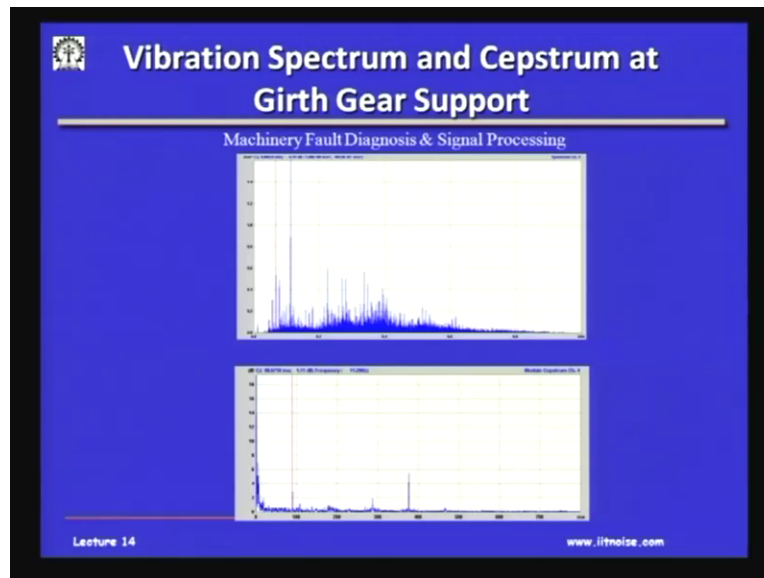
But this will be again complicated by the fact that, while doing all these operations, suppose a speed of your machine changes, then, what is going to happen? We will have frequency smearing, okay; because once it does, 1 Hertz say, 10 Hertz next time, it was 10.1 Hertz, next time it is 9.1 Hertz. So, instead of getting and then if you do multiple averages, instead of getting a sharp peak, you will land up with a signal like this.

So, now you will be confused know what has gone wrong with my machine. Is it this frequency, this frequency, is this frequency? So, this is very important, by doing all this analysis, we have to ensure that the speed is not changing. Or otherwise we do what is known as the synchronous

averaging; or which we do, what is known as the order analysis, or order tracking. By order, I mean one rotation or one rotational speed, no matter of what.

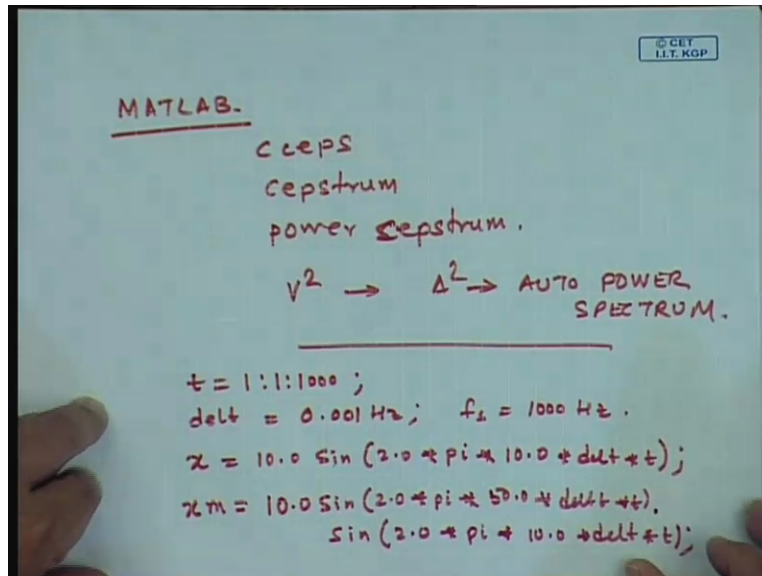
So, it is the time taken to rotate by one revolution and its inverse, okay. So, order analysis if the speed is fluctuating, this signal will be taken for the complete revolution. So, we will not miss that and that something we will discuss in the later class. But in Cepstrum analysis, the advantage is it; it will detect the sidebands and also remove the effect of the path.

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So, if I was to go back again to the vibration spectrum and Cepstrum of the girth gear support, this is how it is. The real world signal is full of so many frequencies because in the frequency domain it becomes very difficult to identify well, whether it is this frequency, this frequency and so on, okay. But once you do this cepstrum, you will see the importance, group of frequencies getting clustered into these frequencies, okay.

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So, again in MATLAB you know, the software which we are using in our class, you could look into the commands like: Cepstrum, CCEPS, okay; if you do not take the logarithm of the amplitude, you know, you may also land up with, you know, different forms of this cepstrum, whether it is a complex cepstrum or a magnitude cepstrum. So, there are many ways by which people represent the debt out of a cepstrum, okay.

And sometimes they call it as a power spectrum if you are dealing with a power signal and auto power spectrum. Then, you will have a power cepstrum; if there is a voltage square term I , or an amplitude squared term I can call it, as an auto power spectrum. So, I do a cepstrum of an auto power spectrum, it will become what is known as a power cepstrum. There are different ways of representing this data but we can generate signals in MATLAB.

I can briefly tell you, how to generate a signal in MATLAB. For example, we can first, as you know, in MATLAB, we can write your own m file. Say, for t is equal to, if I take Δt as a 0.001 Hertz, that means, $f_s = 1000$ Hertz. I can generate a signal x is equal $10.0 \sin 2.0 \star \pi \star f \star \Delta t \star t$, maybe $10.0 \star \Delta t \star t$. So, this will generate a signal x . I could modulate this signal by x_m as $10.0 \sin$ of $2.0 \star \pi \star$ times $\sin$ of $2.0 \star$ times. So, if you generate such a signal;

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$$f_c = 50 \text{ Hz} \text{ — CARRIER FREQUENCY}$$

$$f_m = 10 \text{ Hz} \text{ — MODULATED FREQUENCY}$$

$$f_s = 1000 \text{ Hz} \text{ — SAMPLING FREQUENCY.}$$

$$x_f = \frac{2.0}{1000} * \text{abs}(\text{fft}(x_m));$$

$$f_c + f_m, f_c - f_m, f_c, f_m.$$

$$x_c = \text{cceps}(x_f) \quad \text{CEPSTRUM OF } x_f.$$

$\downarrow$
TIME DOMAIN
 $\downarrow$ QUEFREQUENCY.

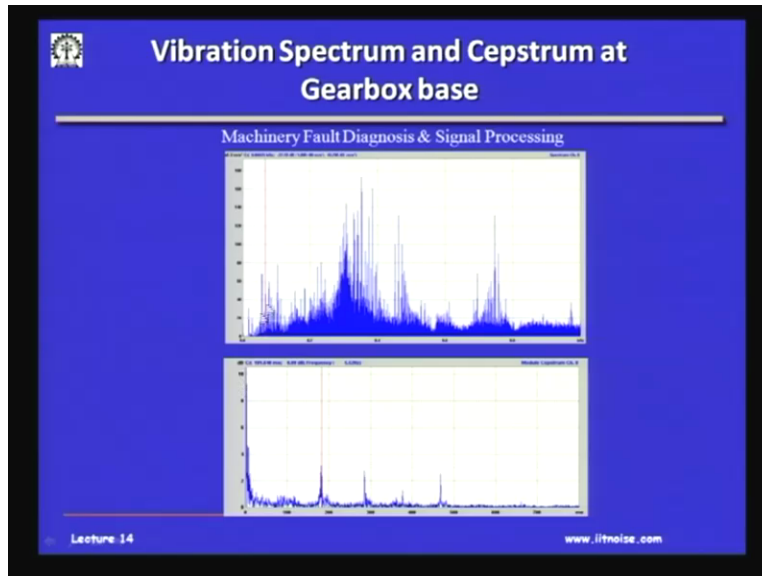
FREQUENCY

I have a carrier frequency of 50 Hertz, a modulated frequency of 10 Hertz, a sampling frequency of 1000 Hertz, modulated frequency and the so on. So, once you do the FFT of such a signal exam, how do you do that FFT of such a signal f_m ? Suppose, you write x_f is equal to 2.0, I suppose, you have taken 2.0 by 1000 data points star absolute value of FFT of x_m . You will get the amplitude in the frequency domain.

And then, in such a spectrum, you will see the frequency of $f_c + f_m$; you will see $f_c - f_m$, you will see f_c okay. And if you do this cepstrum of this signal, you need not take the FFT. So, you have to look into the algorithm. cceps of x_f , let us see cepstrum of x_f . So, effects this is in the frequency domain and this is in the time domain. So, you will get all the signals which has which corresponds to this will give you in the quefrequency.

So, you will get the quefrequency corresponding to the frequencies of f_c minus f_m and f_c plus f_m in the Cepstrum. And these you all can do in a program like MATLAB, okay.

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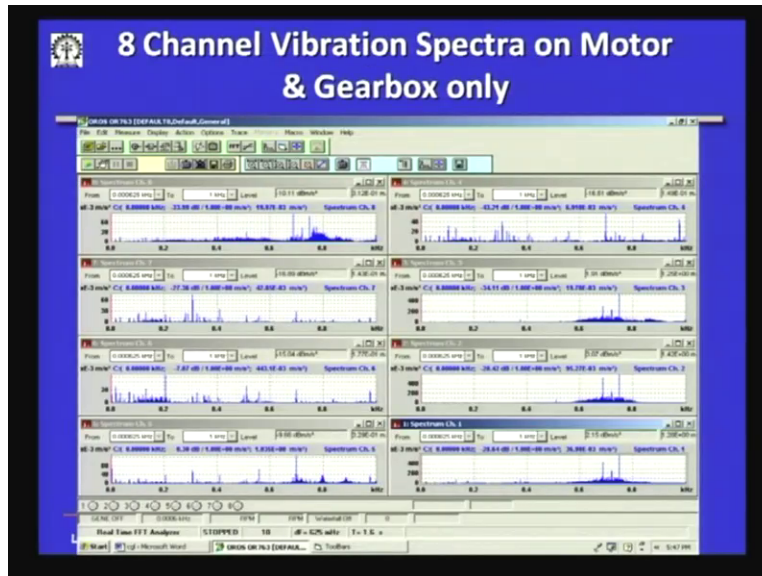


My first, to come back to my example here again, look at the Vibration spectrum and cepstrum at gear box, gearbox base. So, just to compare the gearbox base because of a very, very poor foundation, you see, so many frequencies are coming up in this spectrum and even if I asked anyone to find out the frequencies contained in the signal, you will be all scratching your heads, getting lost what are the frequencies here.

But the same spectrum converted to Cepstrum, you will see the group of side bands coming up quefrequency clustered side bands, clustered into their families. And you will see whichever quefrequency has the highest amplitude, you know, that has a strong presence in that signal. And that is how Cepstrum helps us identify signals, helps us finding out the important frequencies in a spectrum, okay.

The effect of the path etcetera is lost because you know, if you look here, at the gear box bears lot of effects of the path etcetera was that the gearbox base was loose in fact we had discovered many looseness in the gearbox foundation itself. And all those effects are nullified once you do the cepstrum. Those efforts can be easily removed.

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And similarly when we did on the motor and gearbox, only we could see the spectrum of different nature's altogether, okay.

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Faults Detected

Machinery Fault Diagnosis & Signal Processing

- Bearing 2 loose on foundation
- Bearing 1 and Mill misaligned
- Pinion on Gearbox damaged

Lecture 14
14
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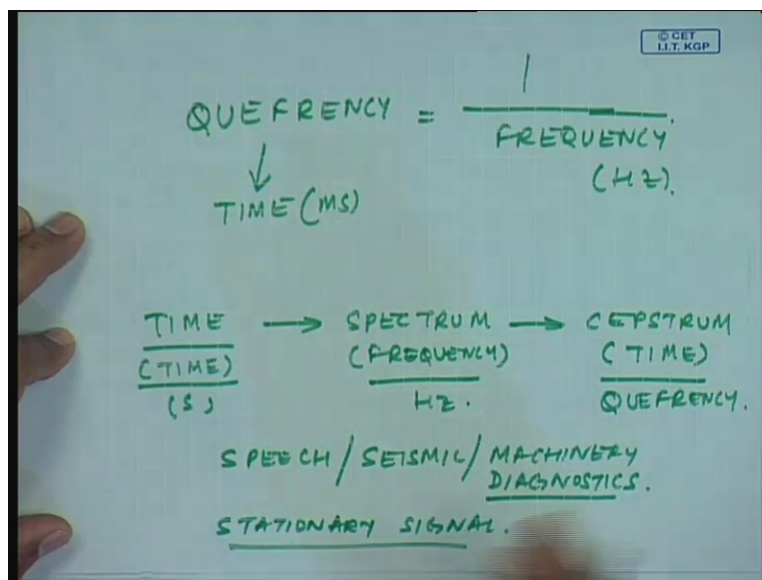
And from this example, actually what happened we could find out the characteristic frequencies of this signal which were not apparent in the spectrum. But once we do this Cepstrum, we could find out the characteristics frequency in this cepstrum. And we could pretty well conclude that the bearing 2 was loose on the foundation, bearing 1 and mill were misaligned and pinion on the gearbox was damaged.

In fact, later on, we remove the gearbox and subsequently it was reported that one of the pinions in the gearbox had a damaged tooth, okay. So, this tells you how powerful cepstrum is to actually, you know, not let you scratch your head, when you see a spectrum from a real world machinery signal, ok.

Spectrum from a real world machinery signal has lot of frequencies which we may not be able to account for, ok; because of all I know is the defect frequencies. But there are so many extraneous signals which could be from nearby machines; which could be from machinery parameters; which I am not even aware of.

But if I know, I am looking for a particular family of sidebands; I can very easily do Cepstrum Analysis and then see the multi quefrequency.

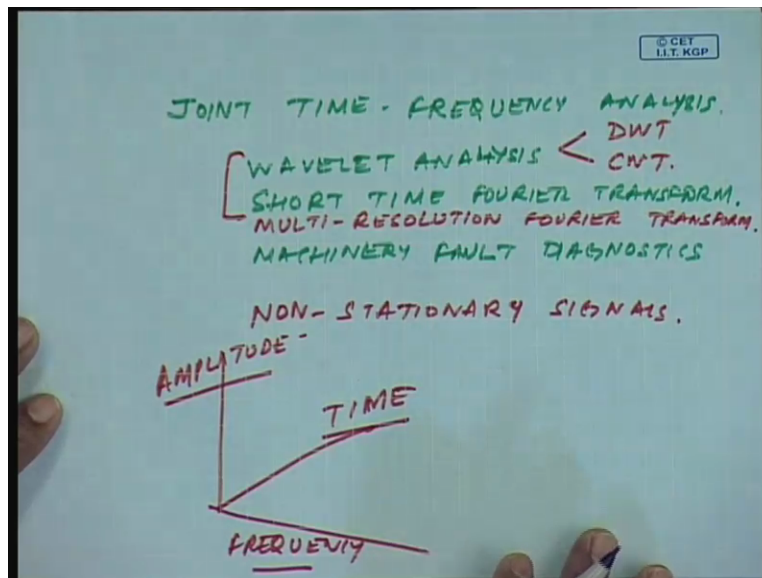
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Because one thing you should recall or, recollect quefrequency is won by inversely. I will not say 1 by what is related to this, by the frequency. So, quefrequency is in time domain; is in milliseconds and this is in Hertz. So, there has to be an inverse relationship. So, we have a time to spectrum to cepstrum. So, this is in the frequency domain and this is in the time domain. Of course, this is true, okay. This is the relationship and this is time quefrequency; and this is Hertz.

So, the effects of all the path properties are lost once we do cepstrum. Cepstrum Applications are also speech, seismic and then, of course, in machinery Diagnostics. This is not a real time operation. This is on a stationary signal. I may not be able to do cepstrum on a non stationary signal. For example, one transient very, very difficult, okay. But if this transient is captured, we can do some sort of an analysis of it, okay. But this was given way to, nowadays, you know.

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What is known as simultaneous or joint time frequency analysis and there are a few modern methods of signal processing, like the wavelet analysis, short time Fourier transform, which has been nowadays used in machinery fault diagnostics, particularly for non stationary signals. But in this very preliminary, the first course on machinery for diagnostics and signal processing, I will not be focusing on these aspects of signal processing.

But just to it will suffice that there are methods available today wherein, we can do analysis of non stationary signals, by the wavelet analysis, short term for transfer wherein the signals frequency is changing from sample to sample. And then, we I need to know in three dimensions as a function of time; as a function of frequency, amplitude. And these techniques are available when we can see.

For example, I will give you examples of non stationary signals: something breaking, cracking, impulse, door slamming, etcetera. These are phenomenon or something hitting, rubbing. This can

be very easily understood by, wavelet analysis. Wavelet analysis also, there are two types: Discrete wavelet transform and the continuous wavelet transform. And then short time Fourier transform because you know, we can.

And then, there are the multi-resolution Fourier transform also. But we will not stress on this, in this course, being the very first course in machinery for diagnostics and signal processing. But these techniques are available nowadays in the literature. And people have been practicing them for using them in condition monitoring.

And we will later on see some applications, when we talk about applications, how some of these techniques are used particularly fault diagnostics; and bearings and gears and rotating machines where the shafts have cracks, etcetera. How these techniques can be used to find out their faults, ok. Thank you.