Machinery Fault Diagnosis and Signal Processing
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Lecture – 14
Modulation and Beats

In this lecture, we will speak about signal and modulation and beats. In the previous classes, we had discussed about signal analysis in particular time domain signal analysis, frequency domain signal analysis, and the other one being time frequency analysis or analysis which is done for non stationary signals, like wavelets or short time Fourier transform and then empirical mode decomposition.

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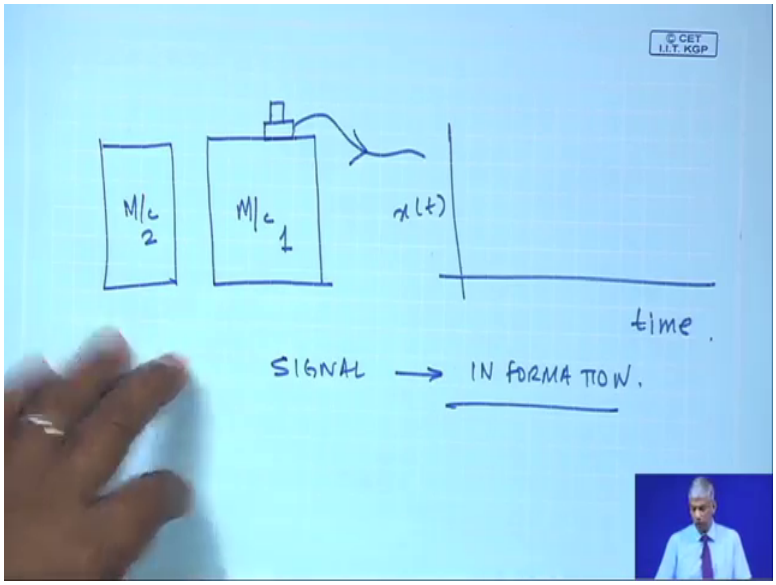

But you know signals come in many types out of machines, so when we have a machine and I put a transducer on it to measure some signal xt.

Now, depending on the characteristics of this machine or if there is another even happening machine 2 machine 1 component 2 component 1. So, these would affect the signal type and so as you know signal basically conveys information. So, depending on the source type the signals exhibit certain features, you know which in other words could be modulated signal or signal beating I will first come to the signal beating which is very easier to understand.

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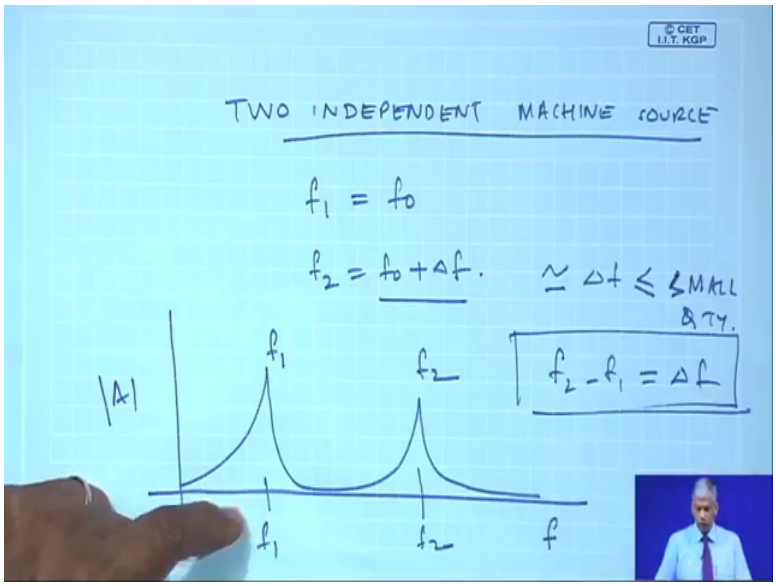

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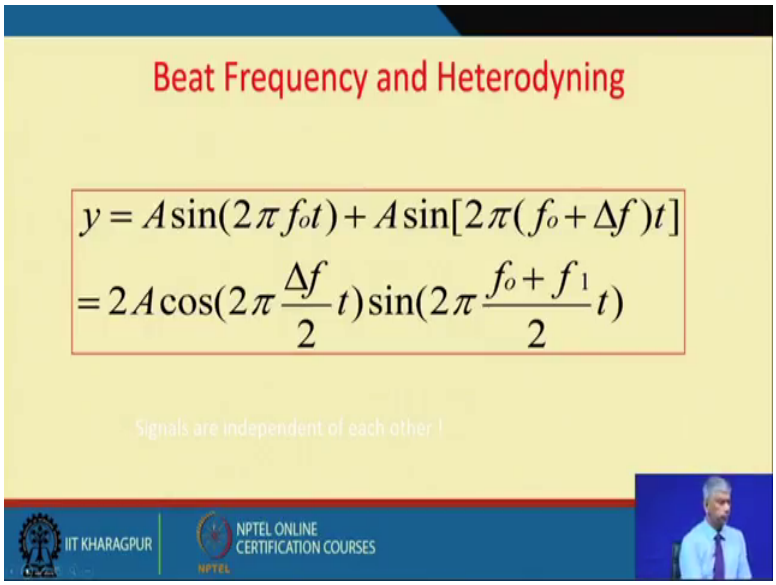

If I have 2 independent machine source, like we see here, if I have 2 independent signal f naught is 1 signal and f naught plus delta f is another signal. So, if my f 1 because the f naught and f 2 is equal to f naught plus delta f, where as you would have seen in the frequency domain if I have 2 independent signals f 1 and f 2 some amplitude, they are the 2 independent signals they are not interacting, but if you bring this 2 singers close by where delta f is very small.

So, there is a marginal difference between f 1 f 2 very small quantity, in the time domain the signals could look something different And f 1 minus f naught and this is f naught plus f 1.

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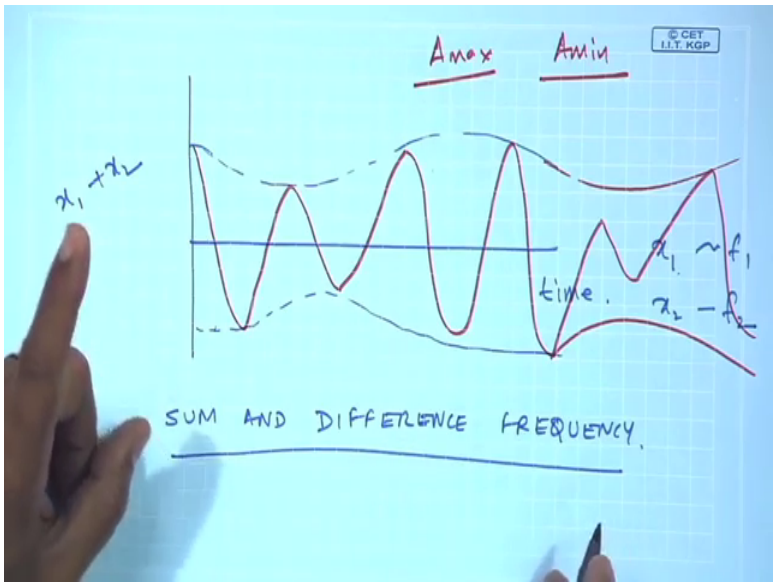

So, we will have what is known as sum and difference frequency. So, if I plot them in the time domain because 2 signal x 1 one of frequency f 1 and 2 signals the x 2 another sigma f2. So, this is x 1 plus x 2 may look something like this, I will draw the envelope first. So, they will decrease increase and so there is an amplitude max and an amplitude min.

So, if somebody was to listen to the signals you will hear what is the this waning and walking waxing of noise increasing and decreasing of the amplitude level of the signal, you can hear it in terms of noise you can hear feel it in terms of vibrations. So, this happens when 2 sources which are independent are very near to each other, so if they are near to each other.

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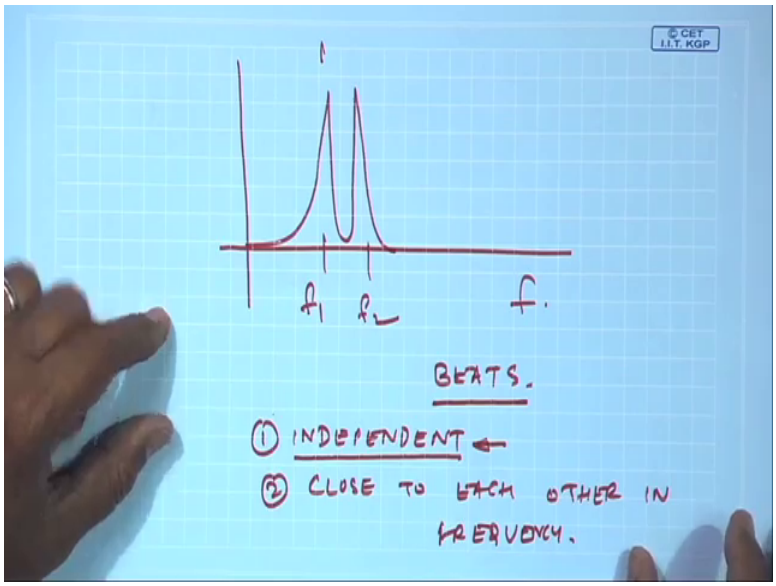

If I have analyzed them in this frequency domain very close f 1 f 2 and they are then told to have given what is known as phenomena of beating.

So, beating frequency is nothing but the difference between these 2 frequencies. So, signals beat if they are independent and they are close to each other in frequency, but most important thing is independent, suppose you have to monitor the health of 1 machine which generates a frequency f 1 and if there is a machine which is very close by and generating a frequency f 2 where f 2 is close to f 1.

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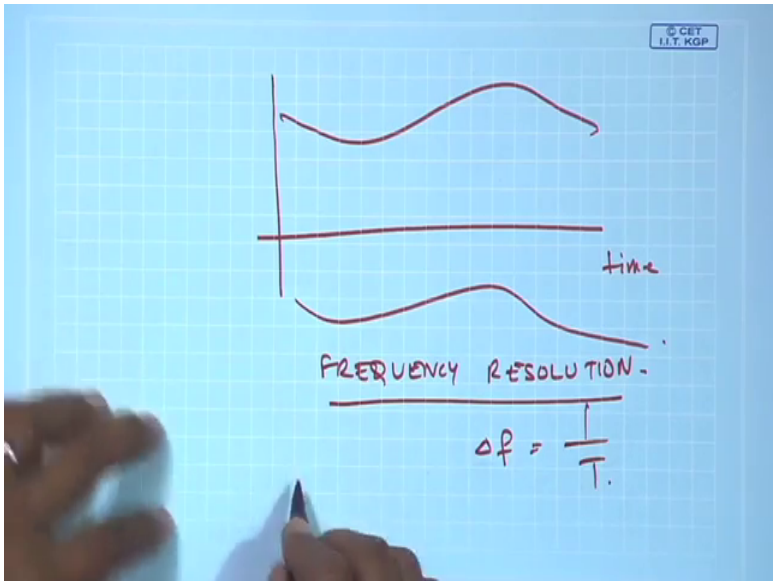

When I measured the signal out of these 2 I will get what is this beating occurring, but to identify these beats you know what we have to do is we have your frequency resolution, which we studied in the class on delta f is nothing but 1 by capital T.

So, this has to be very close by for example 1 machine and how this happens practically let me tell you.

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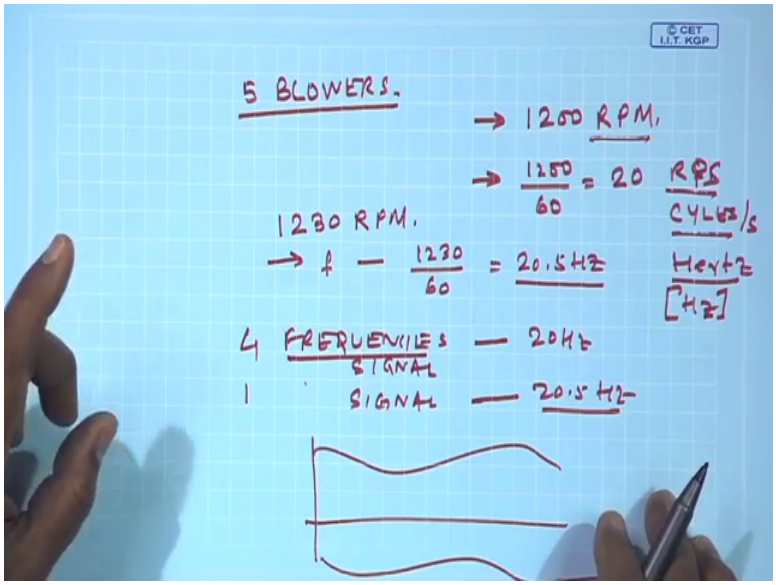

Suppose you know plant I have 5 blowers and each of 1 of them is supposed to run at 1200 rpm. So, in rps or cycles per second this will be to 1200 by 60 that is 20 rps or cycles per second or hertz represented as Hz. So, in many of the case places you will see units of frequency given in either in rpm rps cycles per second cycles per minute hertz.

So, they are all related only thing is that if you have to convert; obviously from minutes to seconds you are divided by 60, now if these five blowers are running at 20 hertz and it so happens that 1 because, there is a voltage fluctuation and 1 runs at 1230 rpm. So, the frequency corresponding to that will be 1230 by 60 there will be 20.5 hertz, so that means I have 4 frequencies from 4 blowers running at 1200 rpm at 20 hertz and 1 frequency are 1 signal 1 signal at 20.5 hertz.

So, particularly if you go to a plant room you know this why this is running at 20.5 hertz is a different issue which you will not discuss, but if you this could be an electrical voltage fluctuation or some sort, but then the fact that 1 blower out of these 5 blowers is

running at a slightly different speed will gives rise to what is known as signal beating and I know many of you would have experience going to plant rooms, where you know lot of industrial blowers are running at high speeds and that is there is a slight change in the speed of 1, this would give rise to what is known as the phenomenal beating.

So the way to identify beating is to do a frequency domain analysis with a very fine frequency resolutions and they will you will see these 2 distance so next to each other.

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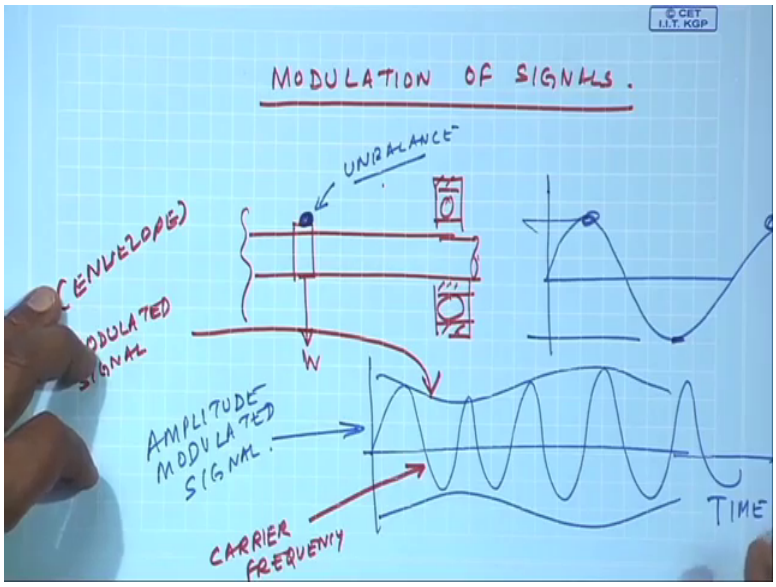

But another signal type occurs which is very similar to what is known as signal beating, but this is known as modulation; in modulation what am by the way before I going to modulus and I will just given 1 example of beating.

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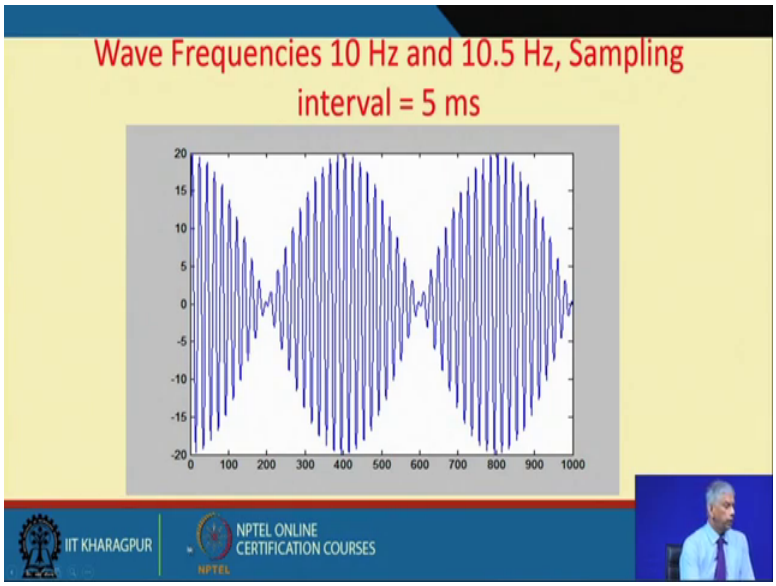

See here r2 signals 1 at 10 hertz another at 10.5 hertz they have been sampled and they are plotted at every 5 milliseconds and you see if this was a sin wave of 10 hertz and another very close by sin hertz of 10.5 hert, if you sum them up this wave form the composite waveform looks like this; that means, the amplitude is increasing decreasing increasing decreasing and this would be the mid frequency and 1 has to be careful about such an analysis ok.

So, that we will not mistake it as a modulated signal or something, now let me tell you what happens in a modulated signal; let us take the case of an bearing is a shaft put anti friction bearing these are the races and there is a load from the shaft I am not doing the other part here. So, the reaction load and there is a stronger amount of unbalance in this shaft.

So, every rotation what happens this bearing gets of load, which is the loading on the bearing is not steady, but because of this unbalance it is getting loaded. So, what happens if you look at the vibrations of this bearing they will look, so this is what is known as an amplitude modulated signal this is in time domain?

So, to our naked eyes modulated amplitude modulated signal looks very similar to a beating signal, but you see 2 frequencies are predominant here 1 this frequency is what is known as the carrier frequency and this is this envelope is known as the modulated signal. So, by modulation a transducer is going to capture this signal. So, you know but

this envelope contains the information of the signal which is of interest to us, such signals occur because of load variations this occurs in gearboxes this occurs in bearings and so on and if you look at the signals do the fft of such signals modulated signals you will come across signals which is known as fc plus minus fm.

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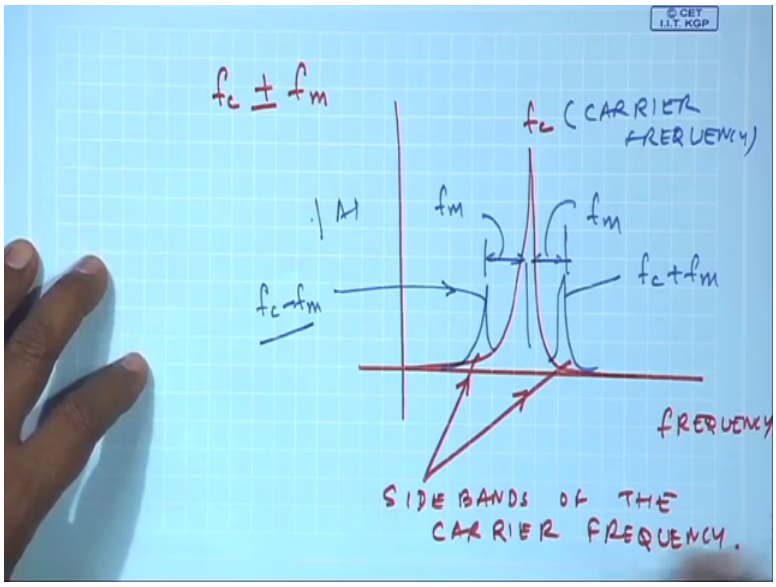

So, if I have a carrier frequency fc in the frequency domain, I will also have amplitudes at frequencies of fc plus fm and fc minus fn, some amplitude of this amplitude modulated signal. So, this has the name so this is the carrier frequency and these are the modulated signal which are known as you know spaced at distance of fm. So, on other side of the carrier frequency, so these are known as side bands of the carrier frequency ok.

So, 1 has to do such analysis so if you have an amplitude modulated signal, you will see carrier frequencies which are in this case the amplitude modulation occurred because there is a load variation, I given example of a bearing signal which has been loaded on a shaft which there is a strong amount of unbalance these things also. So, there was a defect in the gearbox. So, for example in the bearing you know we will discuss this later on when you discuss about bearings.

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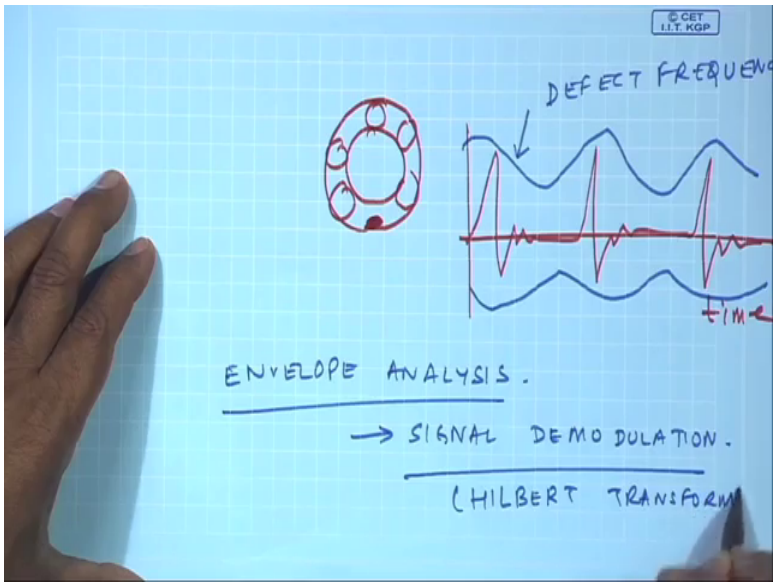

If there was a defect here in the race and every time, every revolution this defect would give rise to a pulse and this could be amplitude amplified during load.

So, if you can do an envelope analysis you can find out the defect frequency on the carrier frequency. So, this sort of because the reason free and then you have to analyze this to the idea of finding out envelop analysis, there are many commercial software's available to find out the envelope of a signal and which is nothing but signal demodulation and later on we will see by a process called Hilbert transform, we can find out the envelope up such signals.

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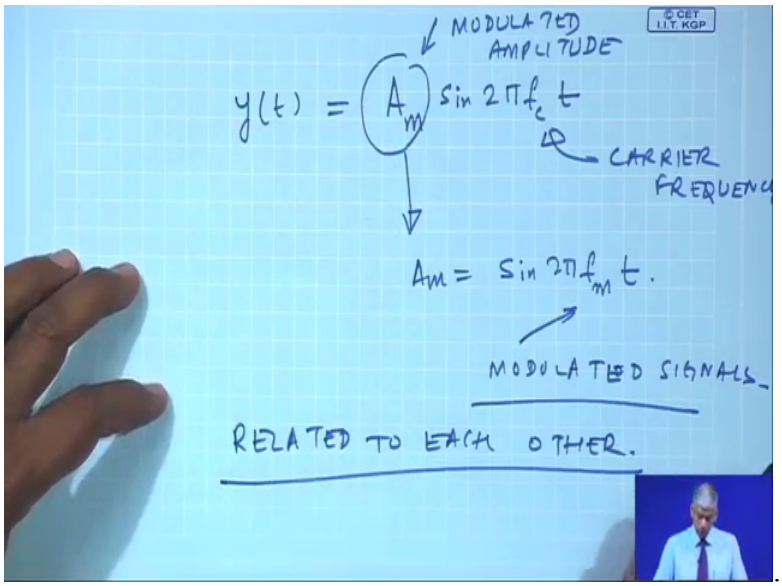

If I also write the equation of this signals say an amplitude modulated signal yt, in general is a m sin 2 pi fc t where m equal to another maybe sin 2 pi fmt .

So, basically you are multiplying 2 sins you know sin a time sin b. So, you will have components sin a plus b or frequency in a plus b terms and a minus b terms. So, this is the modulated amplitude and fc is the carrier frequency and this is the modulated, but you see here in the case of modulations the signals are related to each other, 1 is creating other unlike beats where they are independent here they are related, so obviously depending on the carrier frequency the modulation would change, the modulation frequency would change and so on. So, this is an amplitude modulated signal which particularly in condition monitoring occurs when we have bearing defects when we have gear defects. So, people do certain analysis you know we discussed about by system analysis we can find out the families of side bands and gearboxes and so on.

So, the occurrence of side bands in frequency spectrum indicates that there is some sort of a modulation. So, it is again our signal processing technique whether be it signal demodulation envelope analysis by which we can find out the those carrier frequencies and the moderator frequencies.

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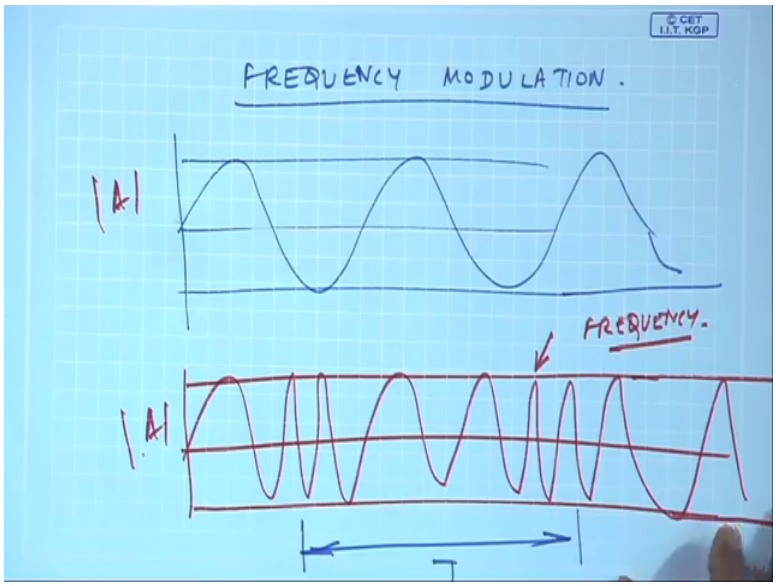

But another type of modulation which is known as the frequency modulation, see if I have a sin wave; what I could do physically see I could increase the frequency decrease the frequency and then I could have I will have another information being conveyed by the same signals.

Frequency increasing again decreasing again increasing and so this is a high frequency range and again a high frequency. So, this is an; and then if you see here the amplitude is not changing only thing is that change in the frequency. So, by changing the frequency I can convey a low frequency signal, you know what is a low frequency signal this has a very high frequency carried, but a low frequency is this is the time demand this could be the time domain which is repeating.

So, through an fm signal without changing the amplitude I am changing carrying information which is related to a slow speed event, In fact frequency modulation signal transmissions have a higher signal to noise ratios.

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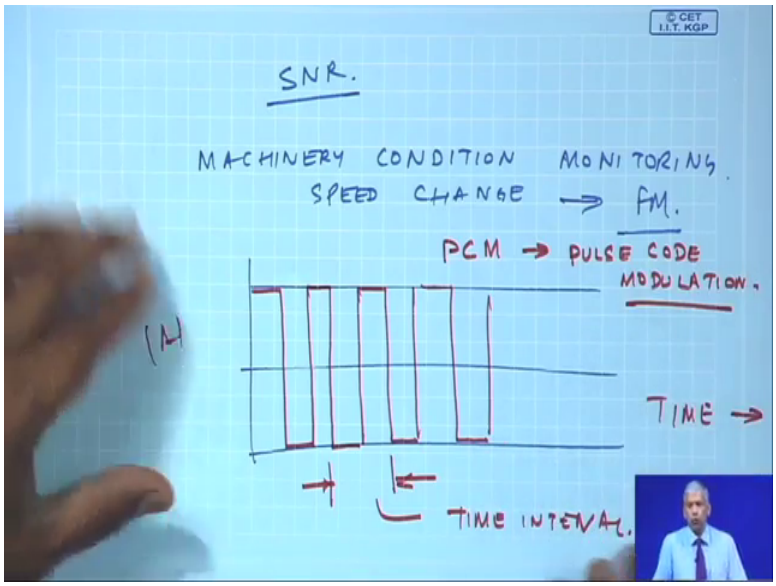

But in machinery condition monitoring whenever there is the speed change. So, there will be a frequency modulation, of course a nowadays you know once you are talking about modulation these are all an analog signals. So, I could have a pulse strain an uniform pulse strain wherein this is in time domain, some amplitude I could again increase and decrease the time interval and convenient for me.

So, this is known as PCM or what is known as pulse code modulation. So, pulse code modulation is nothing but frequency modulation of digital signals unlike the analog signals. So, now a day you know PCM technology used for signal recording signal digital signal transmission et and even in CBM right.

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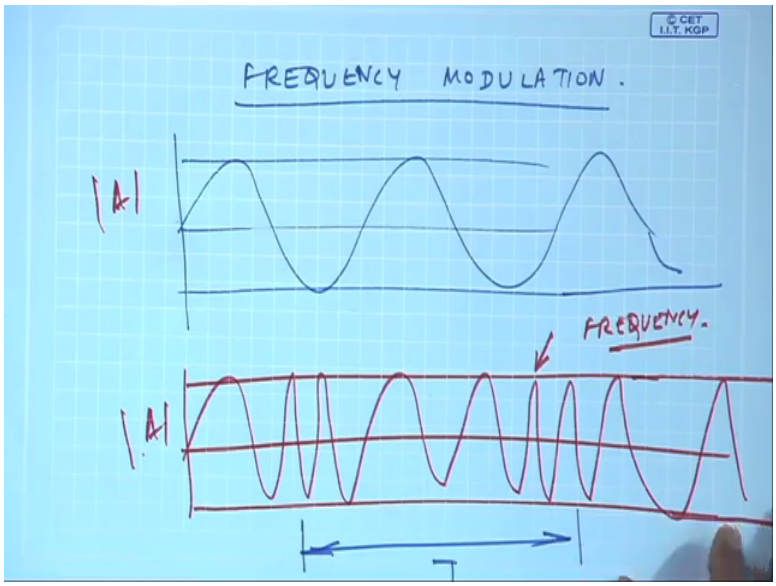

When we have a machine we put a transducer, I can have a to d which we are going to converter talk in the next class or in the few next classes down the road, once we have this digital signal I can do a modulation and convey or transmit a low frequency signal with high frequency carrier, as you see here in frequency modulation there is no change in the amplitude unlike the amplitude modulated signal.

So, signal to noise ratio is very good and the signal strength is maintained in frequency modulated signals and that is the reason when you listen to you know or 98.3 or any fm stations now the 98.3 megahertz, it is the signal stations a carrier frequency on which a certain voice signal you know musical signal or whatever somebody is singing it is transmitted by fm waves and I am sure all of you would have realized the signal strength clarity is much better in a frequency modulated radio signals, which you hear rather than a amplitude modulated signal.

So, this is something which you have to keep in mind, but of course nowadays if you are talking about digital transmission we can have an a to d, we can have a digital signal we can modulate it and then transmit it.

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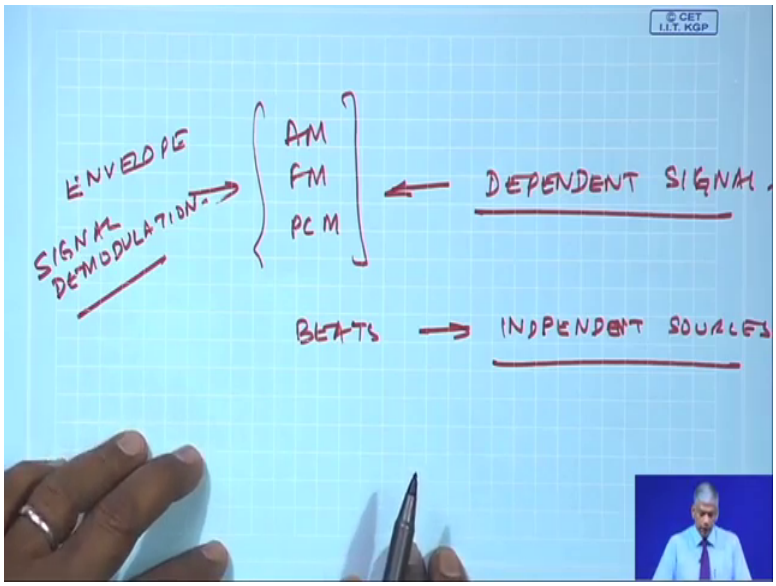

So, to summarize we again both amplitude modulated, frequency modulated pulse code modulation these are all dependent signal 1 is influencing the other, whereas the beats are because of independent sources. So, we have to keep this in mind when we are analyzing signal, but nevertheless to decode these signals we have to do what is known as an envelope analysis, because the in meaningful information there is the modulated signal the other with the amplitude modulator or the frequency modulator and not the carrier.

So, this is known as signal demodulation which we will see how signal demodulation is used to remove the carrier frequency from the signal, so that we have the amplitude modulated signal ok.

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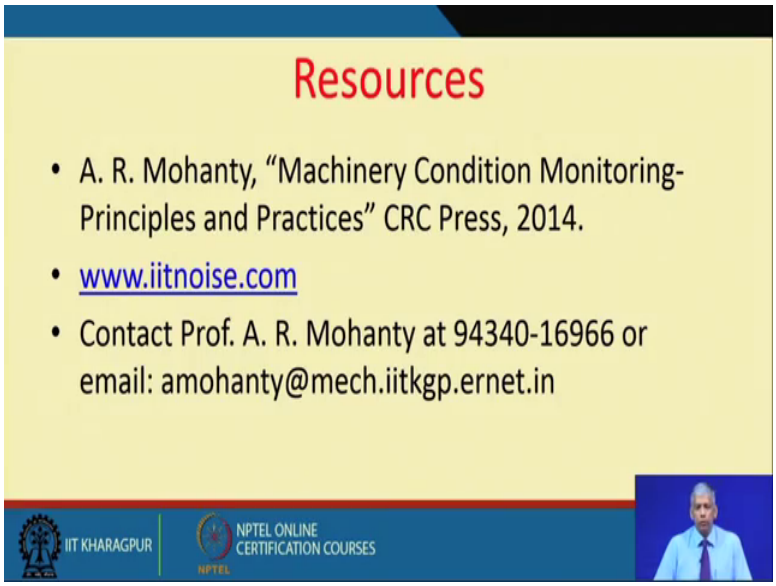

So, we will continue this in the subsequent classes we will have few more examples, then you will see how the modulations occur in bearings in particular and so on.

Thank you.