Machinery Fault Diagnosis and signal Processing.
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Lecture – 11
Time Domain Analysis

In this third week, you know we will be focusing more on signal analysis like you already know. By now CBM, everything actually depends on our analysis of the signal. So, by signal I mean the information which has been received by the transducer put on the machine it has been acquired and converted into certain values and stored in a computer. I will talk about the conversion part later on, but the signal per say which is nothing, but function of time, certain information be it in the form of voltage or anything.

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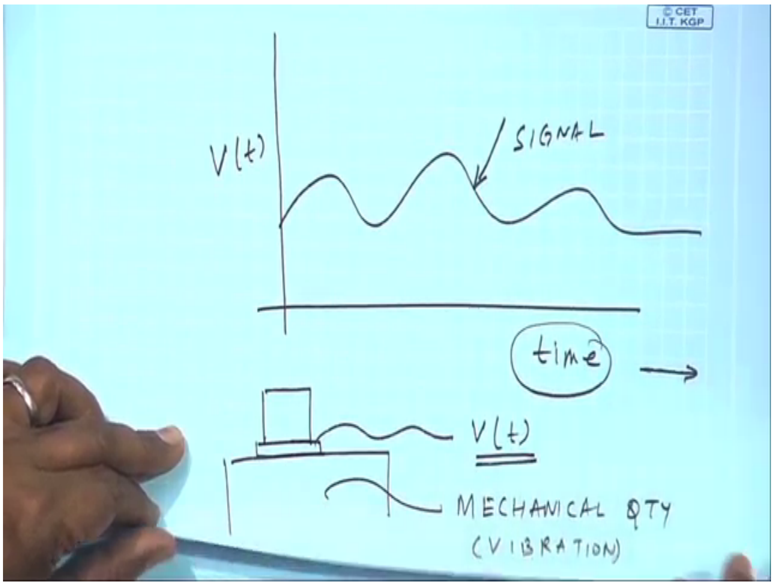

So, this is a signal. So, in this class we will focus on what are the different time domain analysis and how this time domain analysis is done for a signal. So, to begin with you all have a good idea, if what signal is, it is basically something which is conveying information and in CBM. We are actually using a transducer, which is measuring some mechanical quantity in our case, could be vibration and then transducers is give meaning, some voltage signal with as a function of time.

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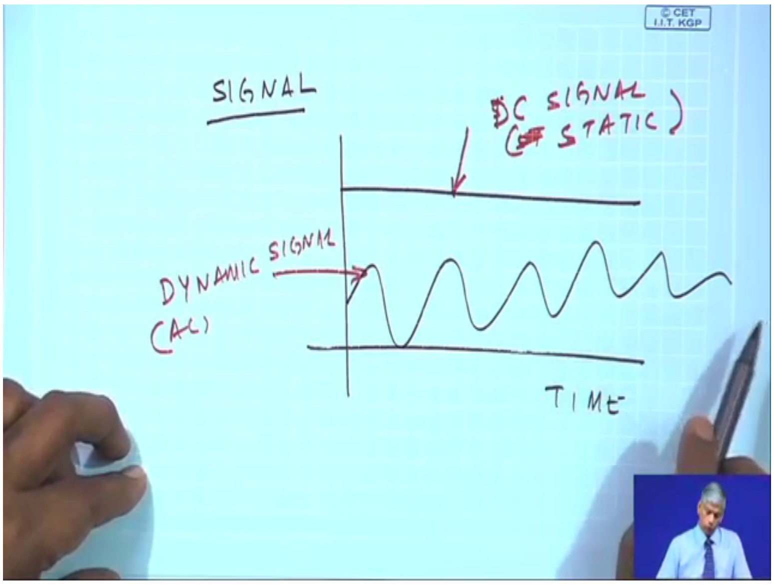

Now, this signal I will come to the different types of signal later, but then I must tell you in CBM we do.

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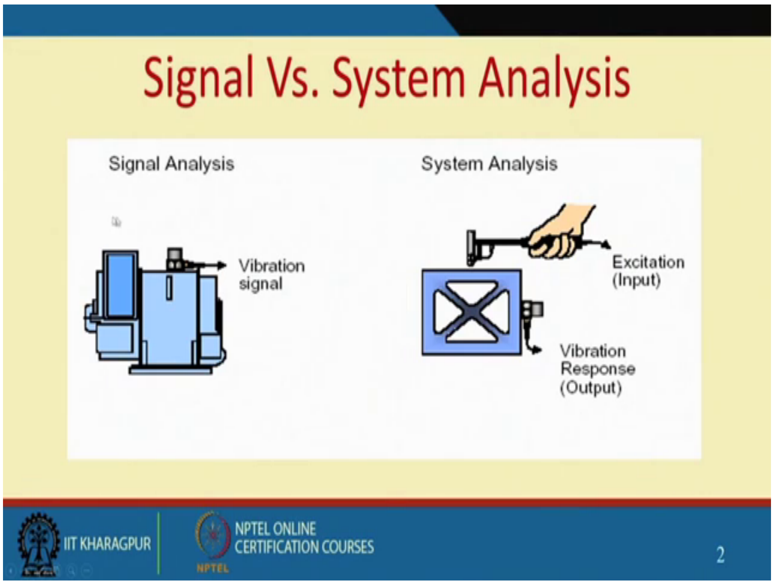

What is known as the signal analysis? So, basically I have a machine put a transducer.

Get a signal by analyzing the signal, I would be able to tell what is the defect in this system as oppose to those, who are in the areas of controls, they would know what is known as system analysis wherein I given a known input to the system in terms of an excitement or excitation and measure the response. So, the response by the input is sometimes what is known as the transfer function or the frequency response function. So, this ratio gives knowledge about the system, by system I mean let us know; what is the natural frequency of the system. What is the damping present in the system and so on. So, this is something which we are not going to focus in CBM, rather we will focus more on this signal analysis.

And when people do experimental modal analysis, they do, what is known as given, known input, and give that a output. So, this output by input is a transfer function and from the analyzing, the transfer function they can find out the; in our case, we measures a vibration had I known the input, my machine would never have been having any problem, because of the make sure that this excitation does not happen. So, we are kind of doing an inverse problem. In the sense, we are measuring the vibration, from there we are trying to find out what could be the possible causes of course.

Nowadays, there are many modal based diagnostic techniques, were in people develop nice mathematical models, validate them with experiments and once the module is well built as I was telling in the previous classes of predicting the remaining useful life, if the good modal is there, we can predict the remaining useful life of that machine, but we are left with something in this signal.

So, signal can be constant with over time. So, this is what is known as a const, like a dc signal or what is known as a static signal as opposed to a signal which is varying with time. This is a dynamic signal or an ac signal, alternative current signal. So, our objective is to find out features of the signal as opposed to another classifications, I must do at this time.

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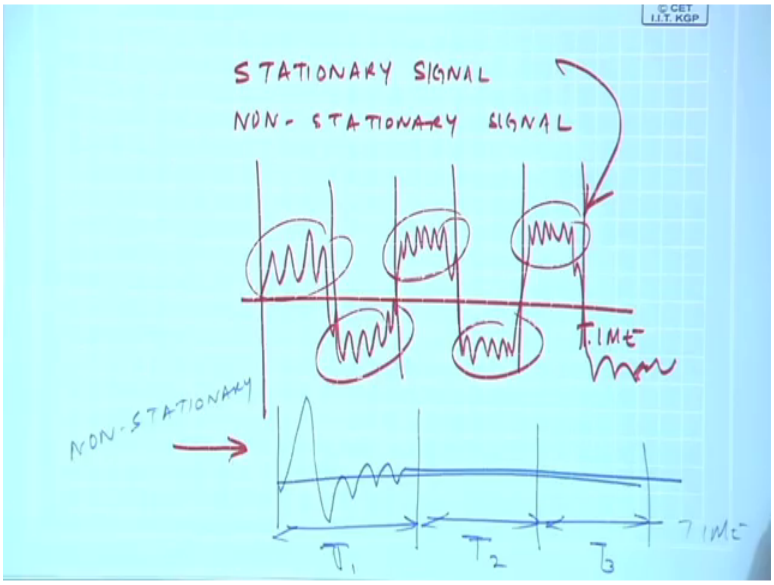

Which is known as a stationary signal or a non stationary, both are alternating signals or dynamic signals, but their characteristics has a difference.

For example, if I plot with over time or stationary signals, this pattern is going to repeat. You know whatever I can draw here, you can see this pattern is repeating at all times. So, this is a good example of a stationary signal as opposed to the different pen, if I am drawing a signal, which happens once and that is it. So, if I take a time t, another time t. The characteristics of this signal at different time. 1 2 3 are not the same, unlike this one. Wherein the characteristics are the same.

So, this is an example of a nonstationary signal, though both the signals are dynamic; that means, they changing with time, but the features are not the same, at different instances of time and that is a nonstationary signal, as opposed to this being a stationary signal, where the features are the same.

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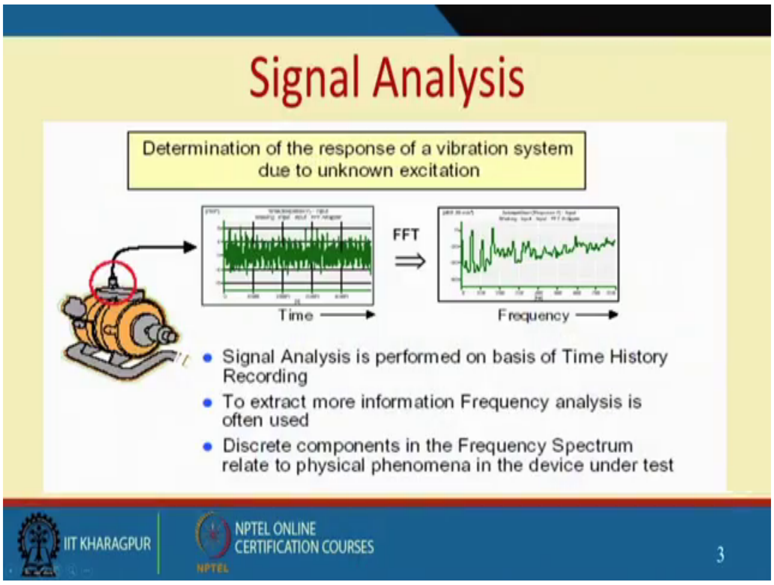

So, we find out in signal analysis, response of a vibrating system due to unknown excitations, if this excitation was known, I would have been having a nice machine, because I would have taken efforts to remove this excitation, but excitation occurs only, because there is a defect which has happened in this machine, because of various reasons could be poor design, could be you know lack of lubrication, could be wrong commissioning, wrong installation, wrong operations.

So, there are many reasons, why this excitations occur, but it is this signal which we have seen in the time domain, which has been measured from this motor with the transducer and later on we will go into frequency response of the signal. So, every peak, here corresponds to a particular component here, but then that is something we will discuss in the next lecture, but even in the time domain, many features can be measured, can be analyzed. So, that. So, that they give us some clue as to what is wrong with this machine.

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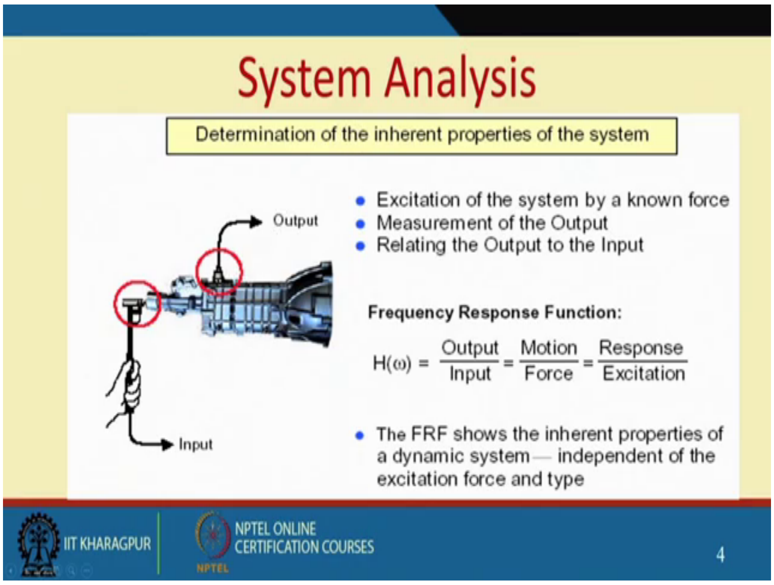

And for the sake of completion, I will just mention to you, mould dusting being done through, what is known as the system analysis? It is this output by input response by excitation. So, the frequency response function shows the inherent properties of a dynamic system, which is independent of the excitation force and type.

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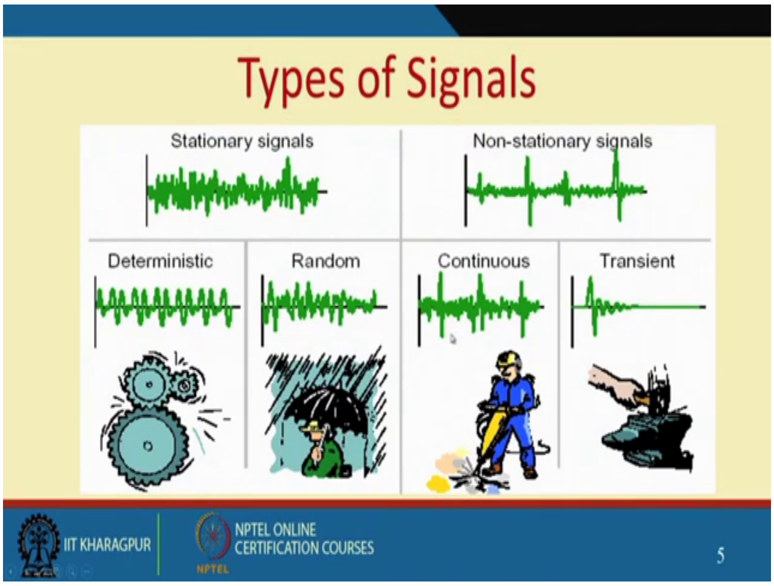

So, signals I had explained you, what a stationarity signal is? What a nonstationary signal is. So, some are deterministics like this periodic signals, because one signal, a one signal here is related to the speed of this. You know; one can relate to this that is a deterministic signal, whereas, this random nature signal will, there is a rain drops falling on this and this is continuously, if you are hammering it, this is a nonstationary signal, because each time you are hammering, occurs there will be a spike in this signal level and they are continuously hammering, unlike if you have hammered it once it is a transient.

So, this signal analysis can, for all these different signals a deterministic stationery signal, a random stationary signal, a continuous nonstationary signal or a transient, non-stationary signal. There are certain features in the signal, which will characterize, the signal better and that will help us, understand the condition of our machine.

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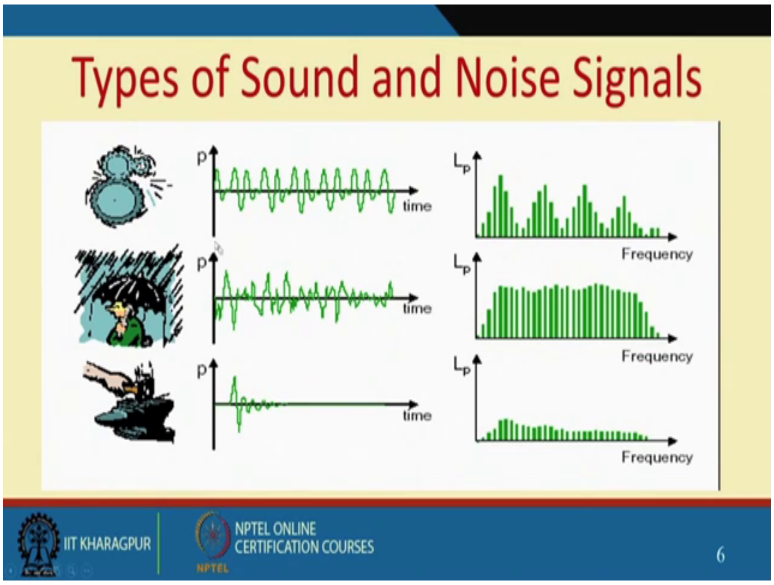

Just to give you another, feel this signals you know which we hear typical sound and noise signals, you know somebody raindrops falling on an umbrella.

Hammering. So, they all have different frequency, characteristics gearboxes, lot of frequencies and sidebands around frequencies. Random noise means many frequencies at a high level are getting excited and so on. So, we will see the different frequency characteristics, later on when we talk about Fourier analysis, but these signals lot of features can be measured and found, which will help us understand the signal better.

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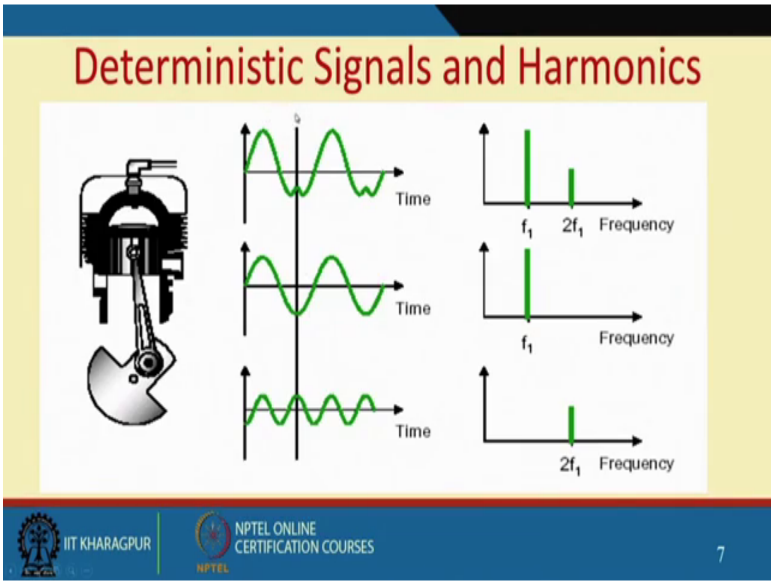

For example, a deterministic signal, it is very easy to understand from this. The frequency of this signal, this is the time and for the same time, I see that to take the time over here actually, you will see for the same time, this frequency when this wave, to complete waveforms, where are, there is one complete waveform. In this case, if the line input is here. So, this one is a single frequency.

Signal frequency is nothing, but inverse of the time period, same is to here. Frequency is inverse of the time period, but the time period here is shorter by half of the earlier time table, time period. So, the frequency of this signal is higher. So, low time period, high frequency is a time in frequency, always have an inverse relationship that is a universal truth, nobody can deny that.

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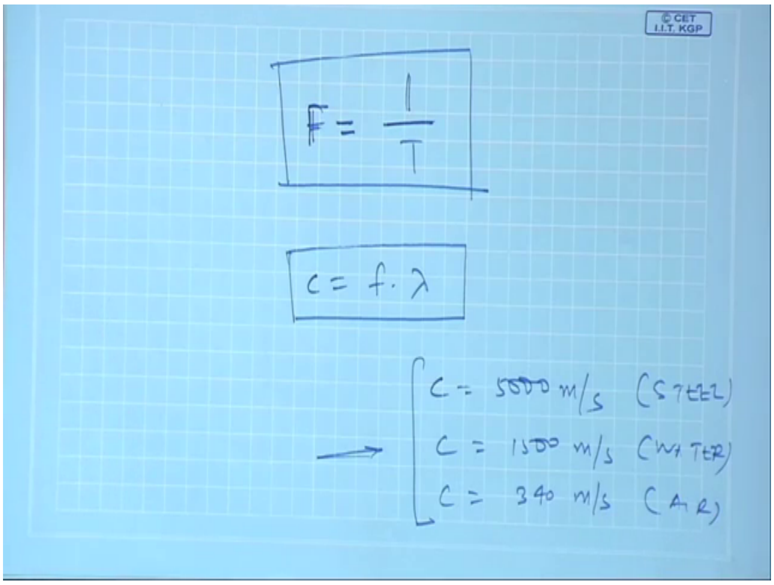

But then when I add up all these two signals, I get both the signals.

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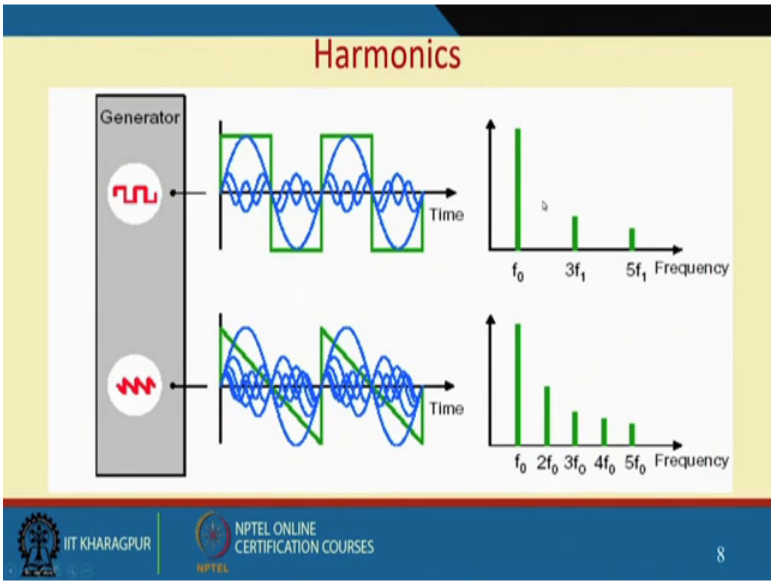

So, if you add many such signals, you see all this blue signals, which are there of all of different frequencies and amplitude, if I add them up with infinite terms. In fact, I will land up this green square waves. So, these are nothing, but the harmonics of the fundamentals, all those green signals, f naught 3 f 1 5 f 1 and. So, on similarly, for a saw tooth signal, they all can be broken up into sums of different sines and cosines and. So, on which we will see in Fourier series.

So, signal which is time varying, can be represented as finite sums of sines and cosines, another thing I must tell you with example of

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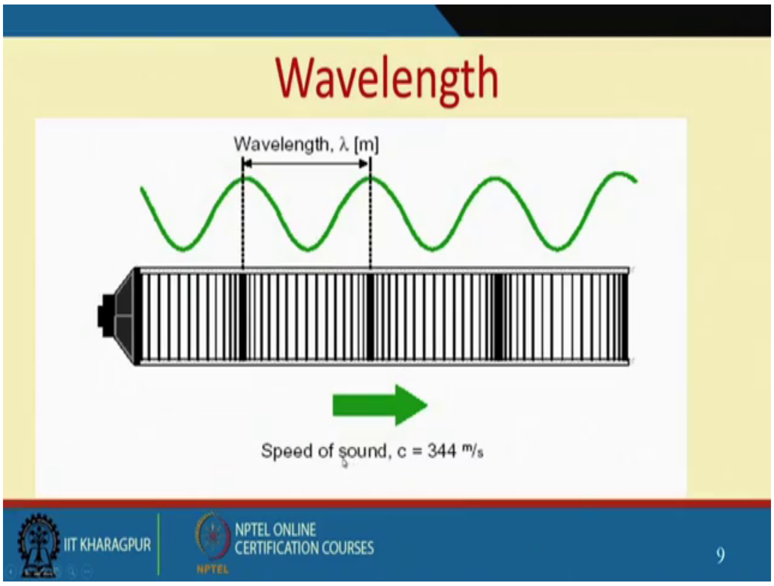

Sound, you know I am just telling about a sound wave, sound wave in air is a longitudinal wave. So, there is compression. So, there is an increase in the density rare refraction, decrease in the density and this is responsible for the pressure waves, getting propagating from one end to another. So, this speed, at which this wave, front moves is nothing, but the speed of the sound that is 344 meters per second of course, the particles themselves do not move, they always oscillate about their mean positions and that is what is known in the particle velocity or the vibration velocity and this waves, cut behalf many form and this is just a longitudinal wave, just for the demonstration I have written here. So, wavelength and speed of sound, there is again a relationship that c is equal to f times lambda.

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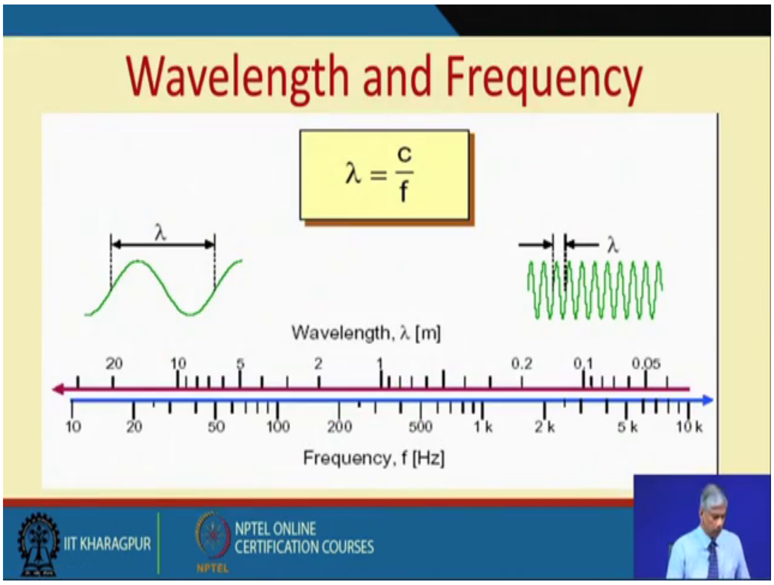

So, higher the wavelength lesser is the frequency and smaller the wavelength higher is a frequency. So, this is universally true and for the case of air at room temperature and normal pressure conditions, it is 343 forty three meters per second in air speed of sound, in water it is 1500, in steel it is, you know 5000 meters per second. There are some idea, you know, you must keep this handy, you know whenever we are doing diagnostics, you will see that this relationships helps you understand some of a physics, which will discuss later on.

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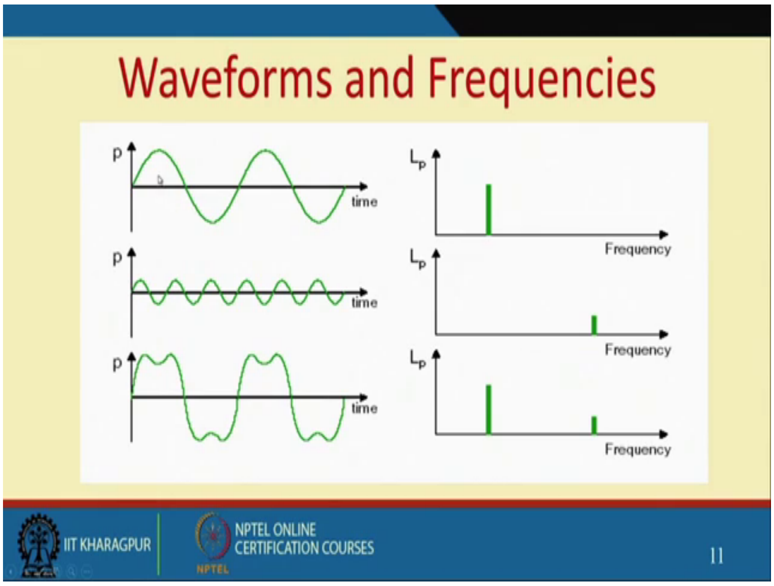

So, we are already discussed. This is, by this is; obviously, high frequency signal. So, all of you must develop an, I looking at an oscilloscope, when it comes with lot of practical experience looking at a signal, you should be able to tell whether it is high frequency and low frequency, because many phenomena are related to the frequency of the signal.

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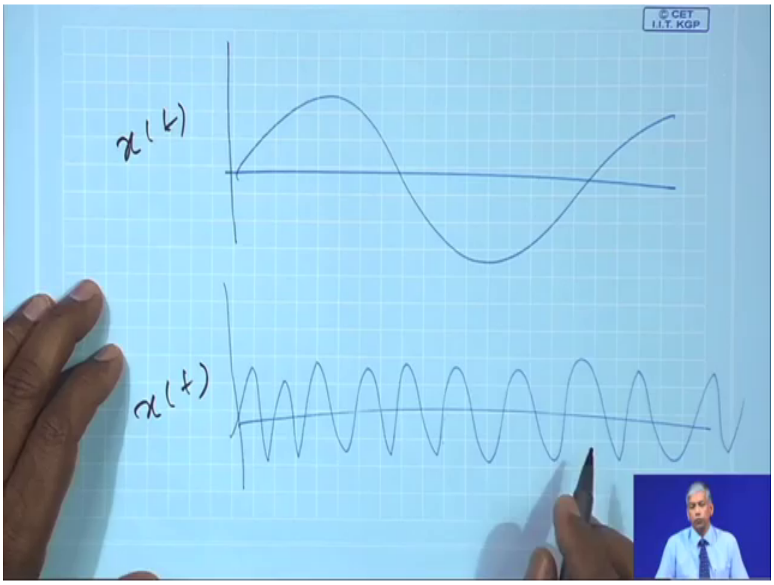

So, this is a low frequency signal, this is high frequency signal, at same time steps. So, this kind of visualization of a signal helps you later on realize, because when you, many times when you do time domain analysis, all you do is I have a machine, put a transducer and get a signal.

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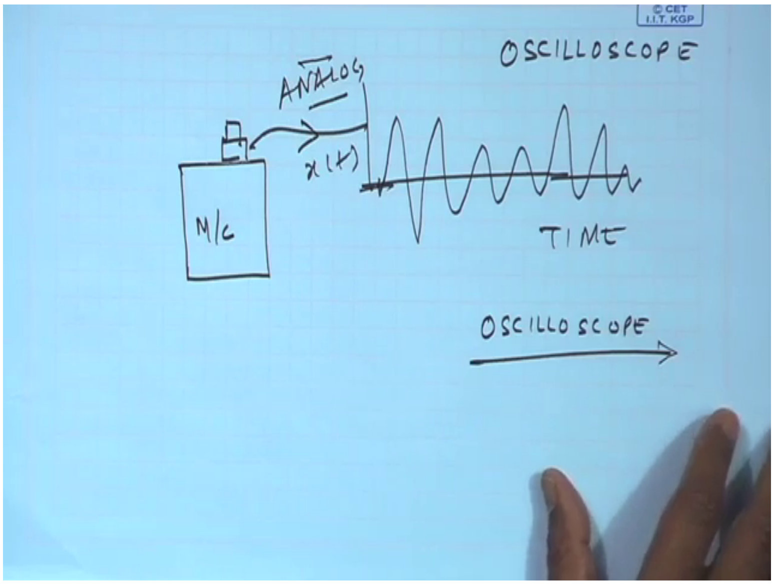

So, this signal you can see in an oscilloscope even in the time domain . So, you all must as a prerequisite, you know I am sure, all of you who are taking this course must have, had an experience with an oscilloscope, is device to represent an analogue time domain signal. By the way these are all analog signals. I will talk about digital signals, later on when you do talk about digital signal processing, after we talk about computer data acquisition, but this signals can we seen and visualized in an oscilloscope.

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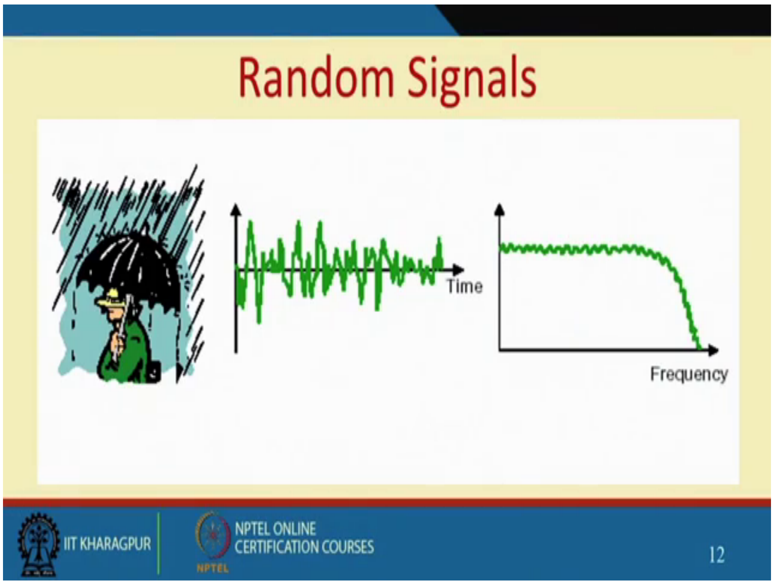

So, this is typically the frequency, characteristics of a random signal, by random signal I mean all frequencies are present at a certain amplitude of course, beyond a certain cut off frequencies.

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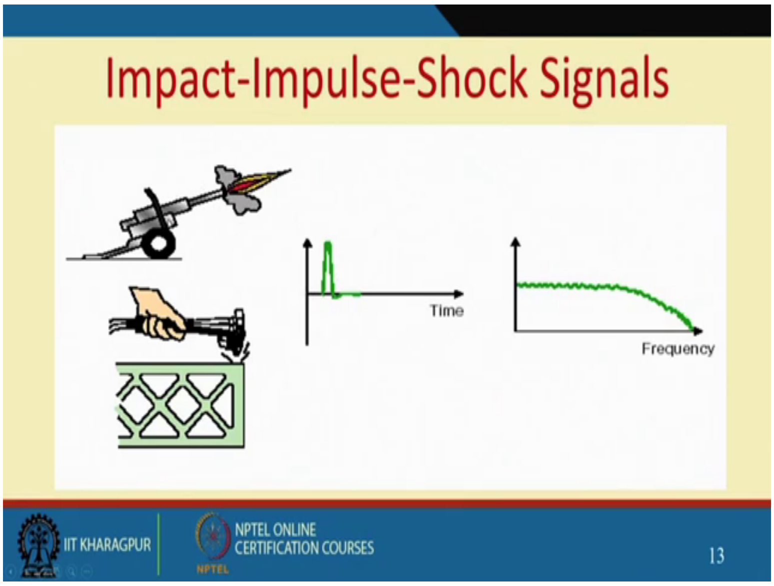

When we have an impulse like missile getting fired or something hammering it is an impulse function. So, an impulse function in the frequency domain will look like this, wherein this is the flat part of the spectrum of course, this is frequency range depends on the duration of this impulse. I will just relate this with an example, which I do in my class, I am not sure whether I can repeat that here, but all of you will experience that of a peak is very sharp in the time domain, this will boil down to very high frequency signal.

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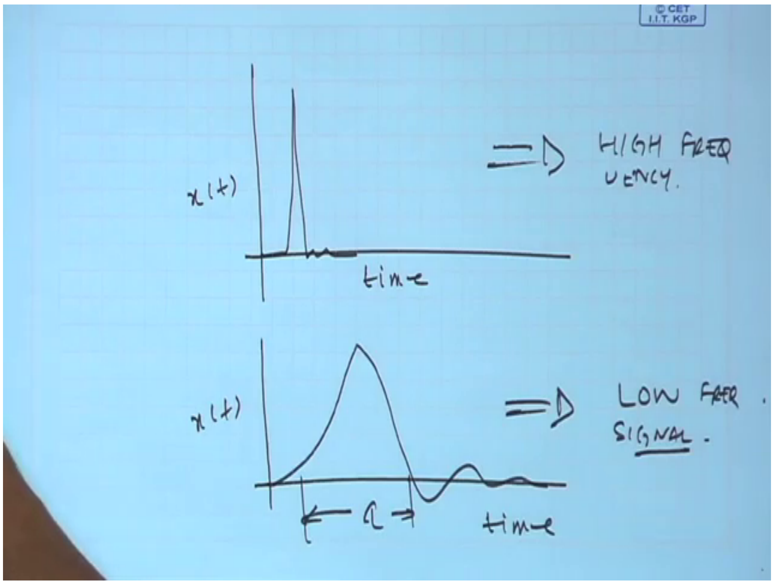

For example, two metals you know, I do not have to metals here, but two metals striking each other that metallic ting ting noise is a very high frequency noise, because the time duration of impact is very less, but if I have two very soft, this is very soft, this is relatively soft, compare to a metal and the noise is little low frequency. So; that means, the impulse is very the time duration is very large. This gives rise to a low frequency signal.

So, wherever you have impacts, occurring things falling in machines dropping. So, they will, there are metallic compounds, you will hear lot of impacting metallic noise, which are high frequency as opposed to something falling like a (Refer Time:19:23) in a very damp environment, you will have a large time period. So, low frequency signal, just keep that in mind.

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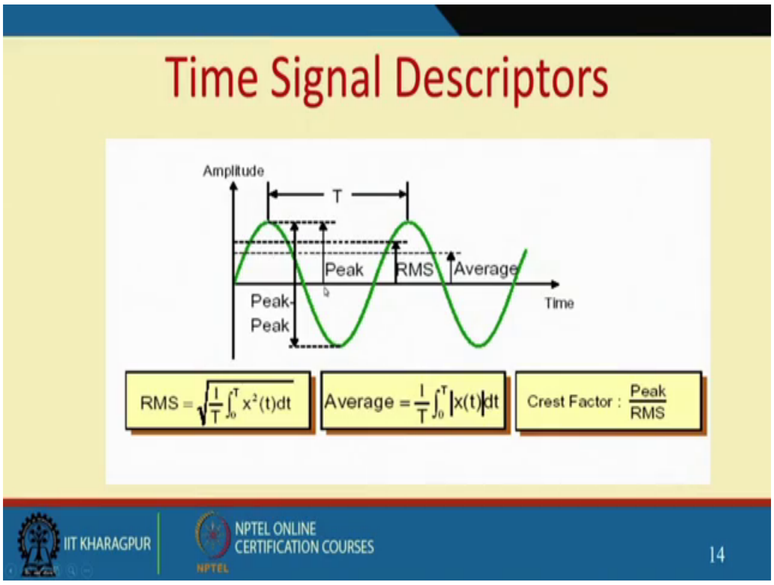

Now, qualitatively we have got a feel of the signal; high frequency, low frequency. How they look? How they sound? But then there are many features of the signal, which can be measured from this signal here, certain definitions one is, this is the green one, is the signal which could be a sine wave. In fact, it is a sine wave. So, the peak amplitude is from the 0 line to the maximum, is peak amplitude of the signal.

And then the peak to peak is twice of the amplitude, the RMS value is given by this expression, if you do it over a time period t, you do this integration and then you square it, then integrate it, divided by the time period and take the square root. So, in RMS value, is the similarly, actually conveys what is the energy in the signal. For example, if you look at a signal, which is and the average value is something like this arithmetic mean. So, this signal if you look at a sine wave, its mean value is 0, then, does not mean that it is not conveying any energy. The RMS value is a true representation of the mean of the signal, because all the negative quantity, here will actually get nullified if you square it.

So, RMS that way, has an advantage that you can find out the true energy, in a signal and the crest factor of a signal is given by the peak value of the signal divided by the RMS value. In fact, there are many features of the signal, even in time domain, which could be calculated, but one thing if you should notice here, to do this integration I need to have the value xt dt.

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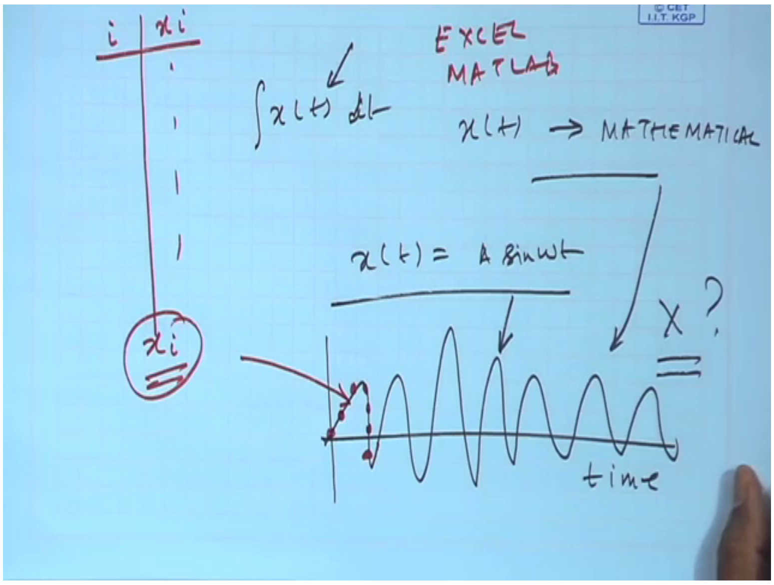

So, this xt as to be given to me in a mathematical form, to do this integration, this is good for 1 xt is equal to a sin omega t. I am sure all of us must have done this, in our first year electrical circuit course.

But in a real world machinery the problem lies, that signal looks like this and I possibly cannot define it with a mathematical signal. I do not have it, this is not known to me. So, how do I go ahead and do this computations or do this integrations. So, in that sense later on, we will see that each of the signals, could be made out of a series of xi and I am sure if i give you this signal, not the mathematical waveform, but this series of numbers as xi, all of you could use popular software like Excel, MATLAB, etcetera. To find out the mean value of the signal or the RMS value of the signal.

So, later one we will see how from an analog signal, we can get the digital values xi of the signal.

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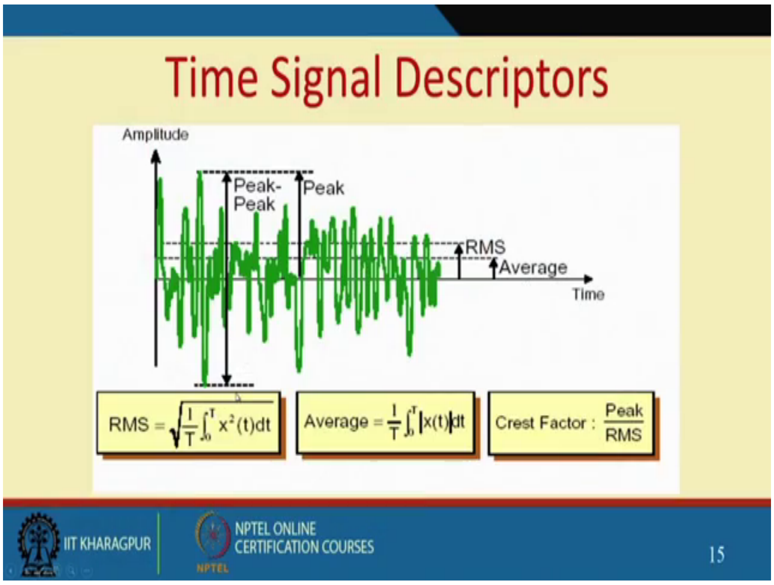

So, signals always will not be sine waves. In fact, real world signals are this and the challenge is I do not have a mathematical expression for x which I had already told you.

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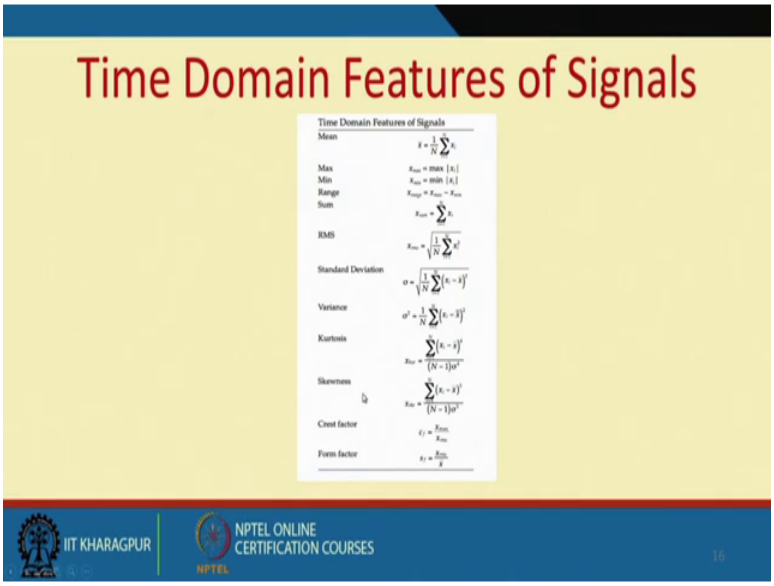

So, if you look at the time domain descriptors of the signal, all these quantities are given in xi. So, if you see the mean maximum value, min value range of the signal, some of the signals RMS values standard deviation variance, kurtosis skewness crest factor form factor. So, for any given signal, given to me as an array xi. I can compute all these features digitally and later on you will see in a digital signal processing even in the time domain

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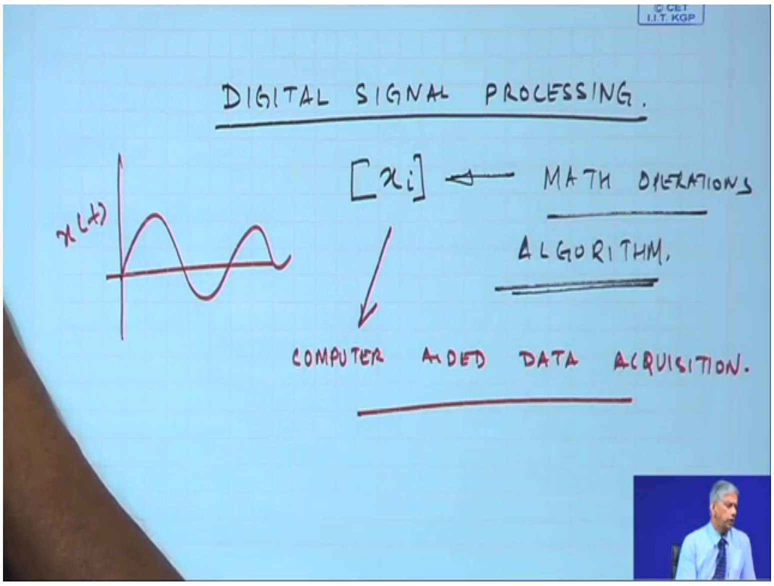

All I do is this array xi. So, I can do all math operations on this. It all depends on my algorithms, which I am going to use. So, how? So, we can all program this all somebody has to give me xi and that later on we will see the technical computer aided data acquisition. How this xi can be obtained from the signal xt. So, once xi is known to me, all these features which I have described here in this table xi maximum, minimum range sum RMS value. See this integration has been replaced by a summation over n values similarly, the standard deviation variance kurtosis skewness crest factor form factor and so on.

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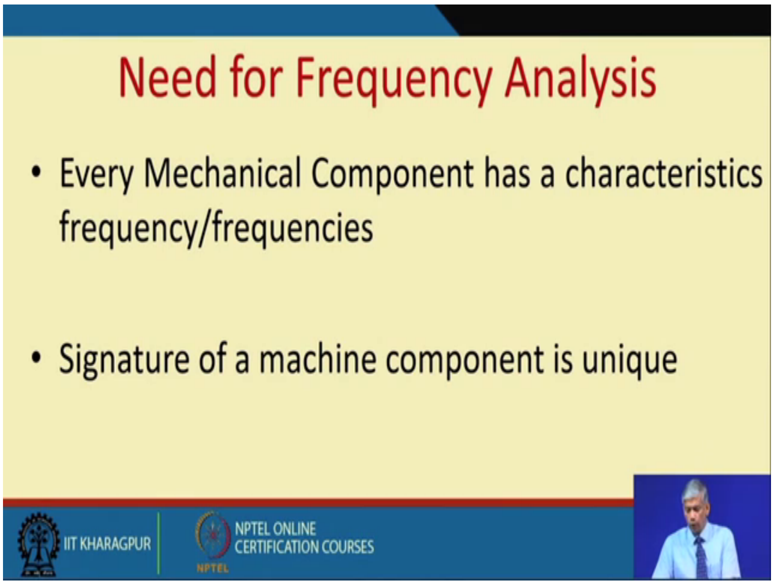

But always the time domain analysis is not sufficient, because every mechanical component has a characteristic frequency or frequencies and signature of a machine component is unique and that is why from the time domain analysis.

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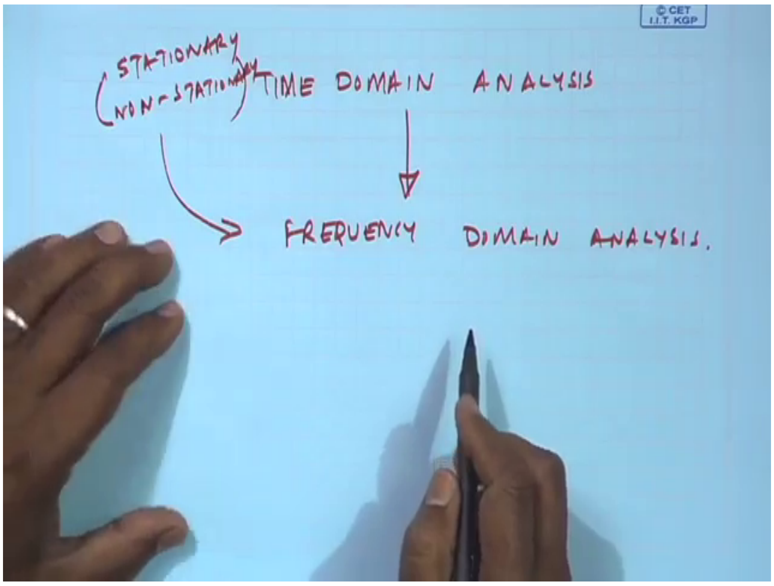

We will move to the frequency domain analysis and this is true though for stationery and for nonstationary. So, we will talk about frequency domain analysis, both for stationary signals and both for nonstationary signals and how this can be done; just give you an idea here.

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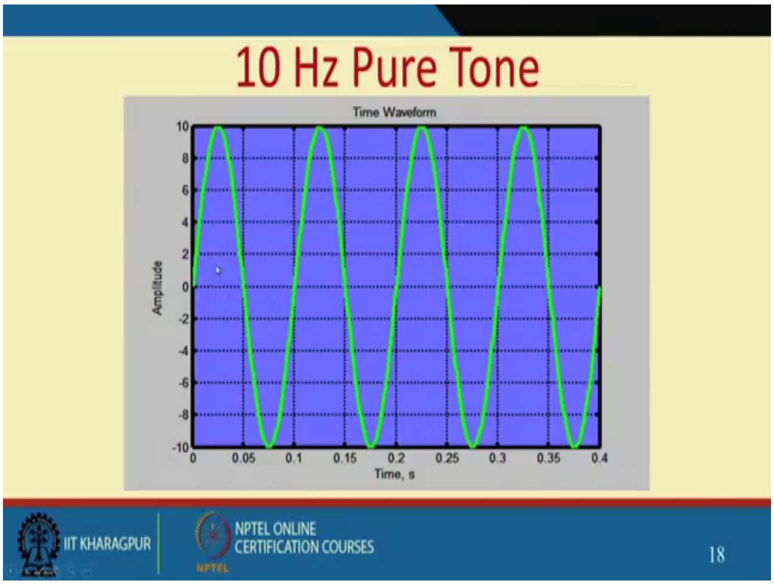

So, this is a 10 hertz pure tone, how can I say that well. This is a, if you look at the time period here, it is 0.1 seconds. So, inverse of 0.1 is 10. So, that is 10 hertz.

So, for a pure tone, just measuring the time period and I am sure many of you would have already done this in your electrical lab experiments, on oscilloscope. I can take the inverse of the time period and find out the frequency and rightly told.

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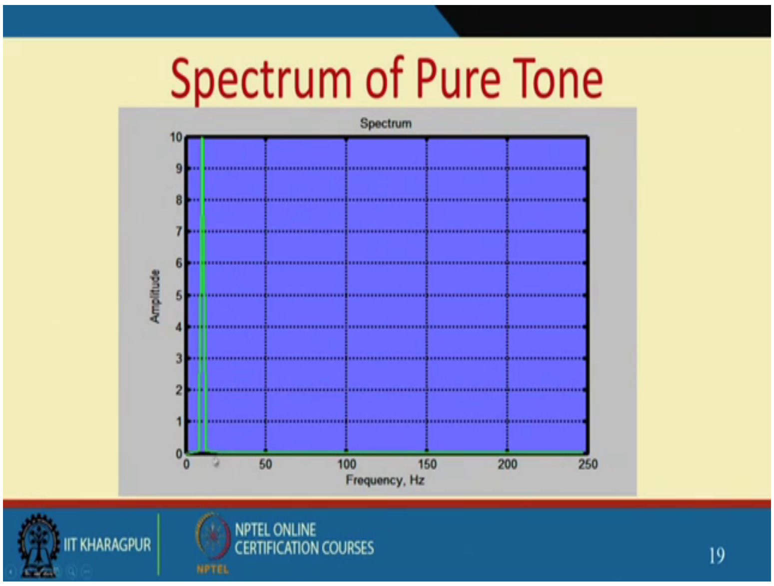

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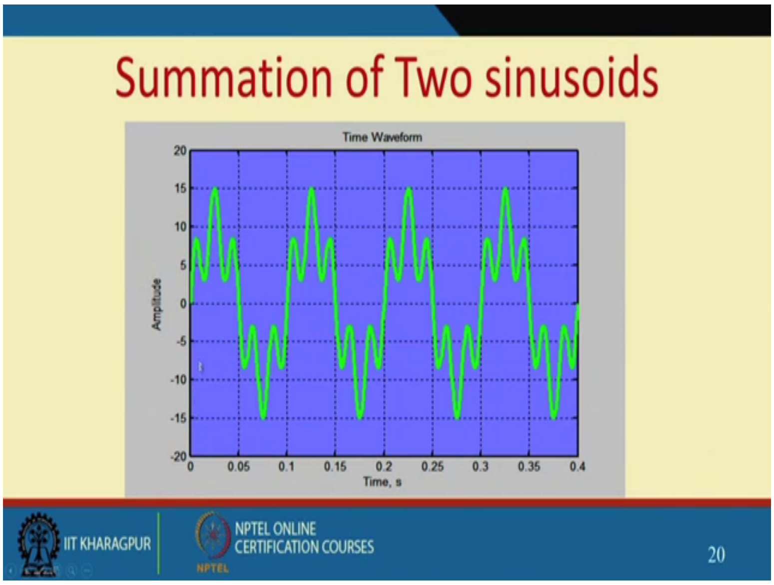

10 hertz corresponds to the amplitude 10 here in the spectrum but when I sum up two sines. It is very difficult for me to look at this time domain and tell what are the frequencies and what the amplitudes, but then if I go to frequency domain I can say well, that sin signal which I showed you here, basically consists of a 10 hertz 10 amplitudes sines or 10 hertz 10 amplitude sin wave and 5 amplitude 50 hertz sin wave sum together.

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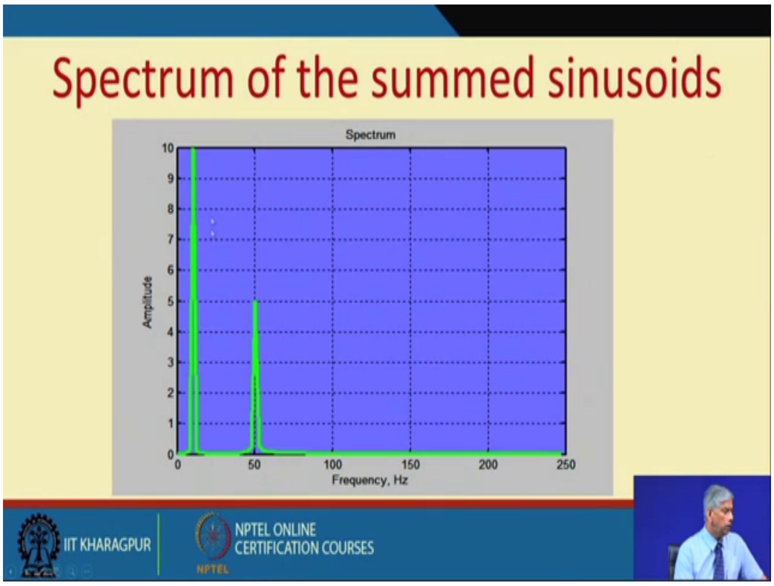

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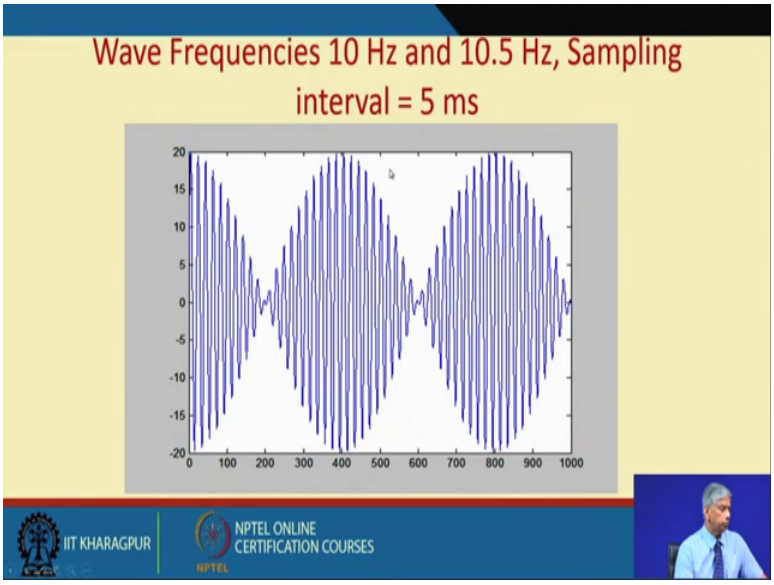

And some other times, if it is you will see when the frequencies are close by, I will see the amplitudes increase and decreasing and this is the phenomenon of beating, which you will hear and analyses later on when you talk about signal beating and heterodyning.

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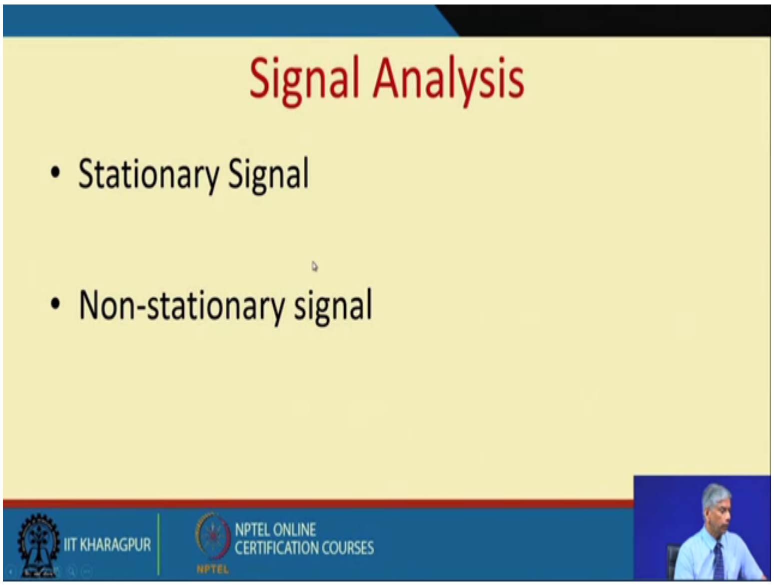

So, we will focus subsequently on stationary signal and nonstationary signal.

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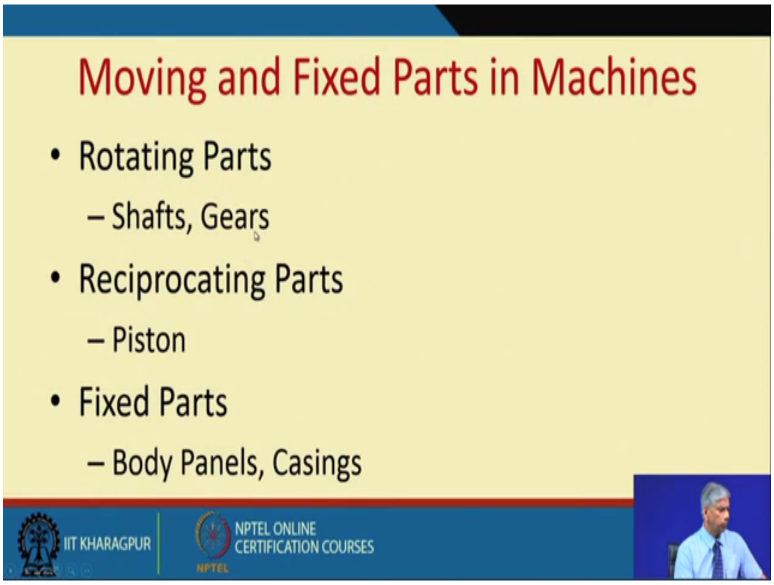

And as you know in any machine there are moving and fixed parts in machine rotating parts, reciprocating parts. So, all of these parts, when they rotate, they are responsible for generating signals, which are varying with time and it is this time varying signals, which we have to analyze in time domain in frequency domain in time frequency domain to find out what are the possible faults in the systems.

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