**Machinery Fault Diagnosis and Signal Processing**
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Lecture - 29
Dynamic Range and Frequency Response

Yeah, in this week we are discussing measurements. And I would continue my discussion on two aspects of measurements, which are very important to dynamic signals which we are using out of rotating machines; that is, what is known as the dynamic range and frequency response.

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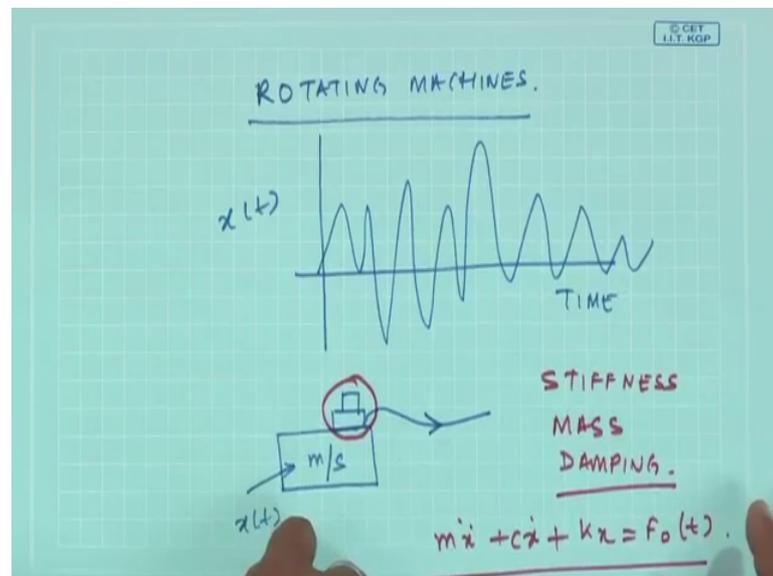
You will see that in rotating machines, or machines which are in operation, the signals in general are time varying. This is a typical signal which comes out of a time varying, or machine which is an operating with 10 times

So, if in such a machine I put a transducer, this transducer will is also going to measure the signal. But the transducer itself is a mechanical system. So, the transducer will have a stiffness will have a mass, may have some sort of a damping inherent in it. So, this transducer itself is a second order system so, as a function of time.

Now, I am interested in finding out the signal because of this machine, which is xt I do not want this signal to be contaminated by the characteristics of this transducer which could be a represented by a second order differential equation.

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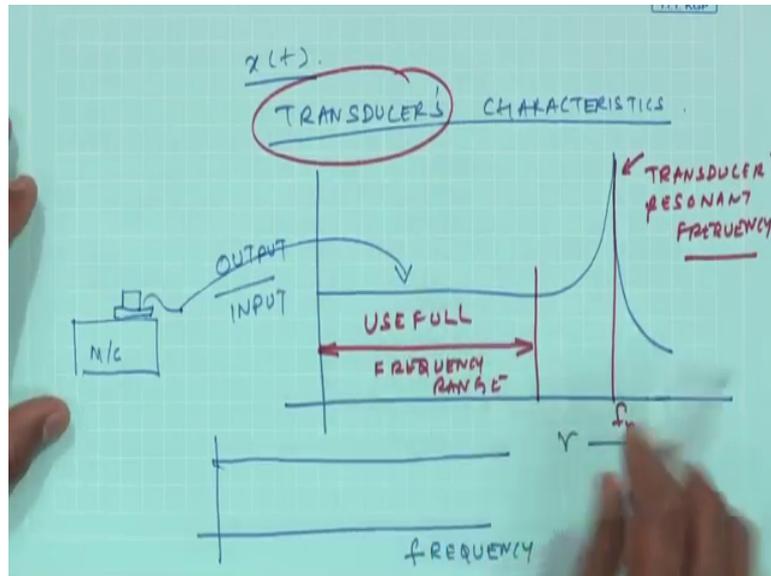
So, to avoid the transducers characteristics corrupt my signal xt; I need to understand the transducers characteristics.

Now, if you will recall for a single degree freedom system, as the frequency response are ok, some output by input. If my input was a signal which had flat amplitude at all frequencies, my output ideally should have been flat, but this will not happen because of the transducer. So, this peak is at the transducers resonant frequencies. So, every transducer would have a resonant frequency. So, in this text this is the useful frequency range of the transducer; that means, whatever is the input, coming from a machine on to the transducer the same thing is going to come as an output.

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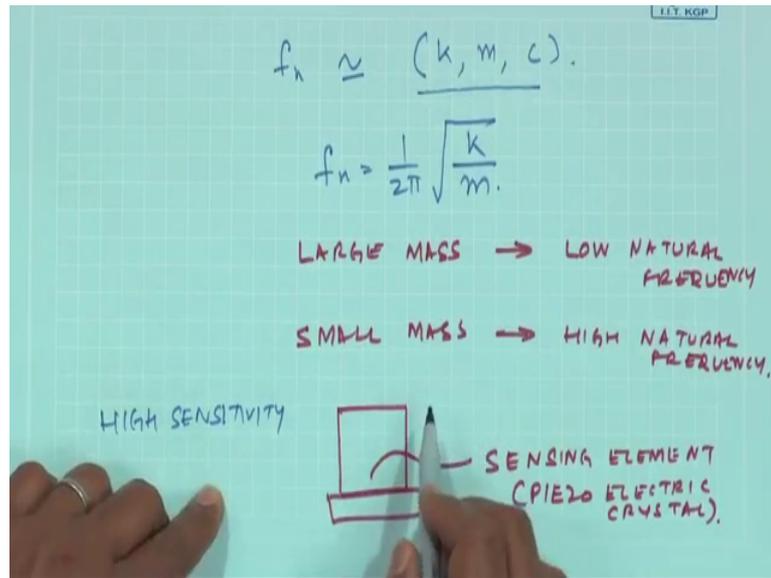
Now; obviously, this resonant frequency fn of the transducer will depend on k mass damping etcetera and, you know, fn is 1 by 2 pi root over k by m. So, that means, you will later on see for a system or a transducer with large mass has a low natural frequency or vice versa small mass as a high natural frequency.

Now, I will give you an example, see every transducer, has some sort of sensing element in it. Like say, for example, a piezoelectric crystal. So, the more the piezoelectric crystal the more would be sensitivity. So, high sensitivity of a transducer means high sensitivity, means, large mass so, that means, low natural frequency; So, and the vice versa again.

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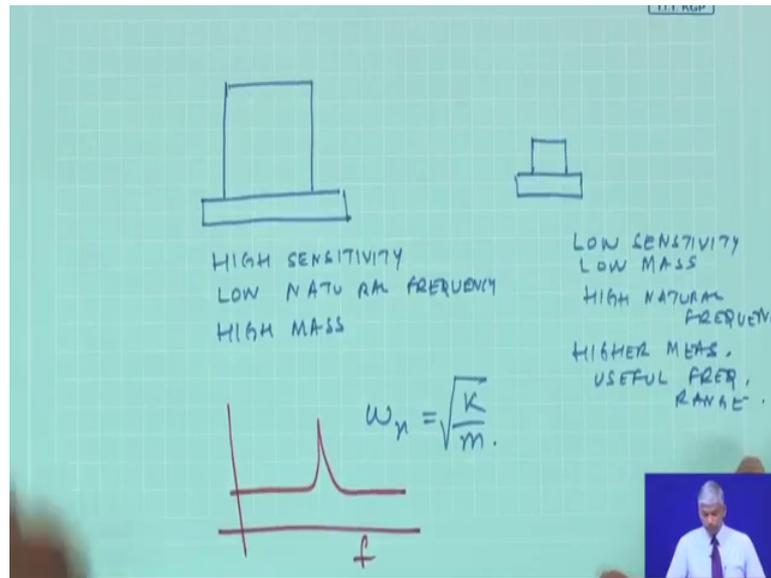
So, the same transducers have a large size, same transducer that have a smaller size.

So, this will have a high sensitivity low natural frequency and will have a high mass or heavy. And similar the vice versa here low sensitivity because of a low mass. And has a high natural frequency. High natural frequency means a higher measurement useful frequency range

So, if you look into the catalog of manufacturers selling your transducer, you will see for the same type of transducer they will be different types of transducers you know different serial numbers etcetera, some have high mass some have you know high sensitivity, some have high frequency. So, you and the reason behind this is because of omega n is equal to root over k by m and you can work around the frequency response of the system, right?

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Now, related to this there is another term which is known as the range, the range of a transducer is nothing but the maximum value it can measure and from it the difference between the maximum and minimum value. So, in log scale the dynamic range is actually given as, it is nothing but 10 logarithms to the 10 max values by min value.

So, the maximum value could be you know one max if the maximum value is the minimum value is one maximum value is 100. So, a log to be log of 100 a log of 100 is 2 to the base a log of 100 to the base 10 is 2. So, this will be 20 decibels.

So, as such transducers are available and typically now you have transducers from 100 to, 180 dB maybe ok, and so on. When you talk about you know human hearing of course, the reference values are different. So, that means, how much of a value you can measure how large to how small. But another very important thing comes in the measurement chain.
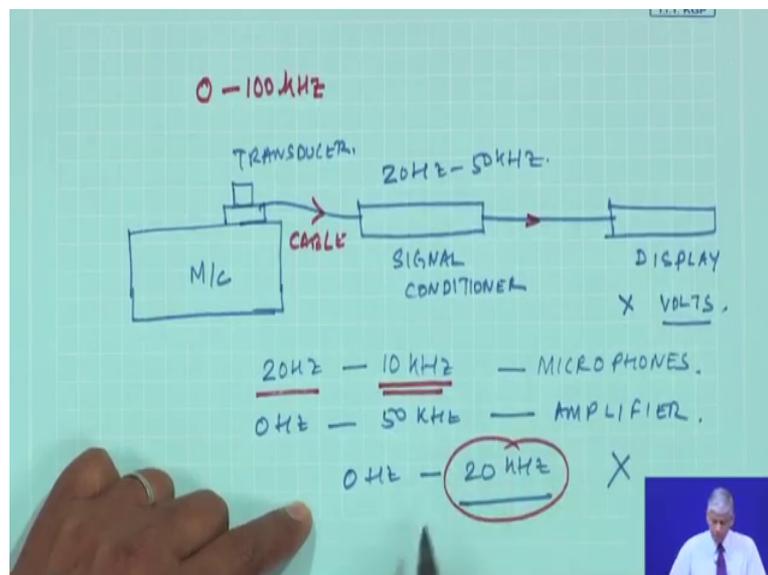
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And that is, when I am measuring anything out of a machine I put my transducer.

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But in between there is a signal conditioner, and then there is a display and this is my transducer.

Now suppose my transducer can measure all the way from 0 to 100 kilo hertz right? Ok, I have a signal conditioner which, and I have this cable is also system because you know cables are coaxial they have a lot of capacitance in them. So, there is they have a

frequency response and of course, a very high, but one has to be very careful about the voltage drop you know because I was telling you in the previous class, if there is a voltage drop I would not know how much the actual value from the transducer has attenuated, because of the voltage drop.

So, that is why we had that provision of field calibration wherein we gave a known mechanical input and saw the output. But leaving aside that suppose I have a signal conditioner now, whose frequency response is only from 20 hertz to maybe 50 kilohertz. So,; obviously, you would be asking. So, when I say a display a certain value. So, I can not say that whatever value I get x volts, it is from 0 to 100 kilohertz, because if it was from 0 to 100 kilohertz, because this signal conditioner is not going to respond to anything below 20 hertz or anything above 50 kilohertz.

You may be having values from 50 kilohertz to 100 kilohertz, but that would not get propagated, because the signal conditioner it has a limitation.

So, one has to be very careful that if I have got a very wide range transducer I need to have corresponding signal conditioners which are also wide range like in amplifier, but usually the vice versa worse the trans the signal conditioners, or the amplifiers have a very wide frequency response the transducers are different.

For example, I cannot be using a microphone, which measures from 20 hertz to only 10 kilohertz microphones. And use an amplifier from 0 hertz to 50 kilo hertz amplifier, and say that my measurements are good from 0 hertz to 20 kilo hertz. no, because the transducer has a sensitivity only from 20 hertz to 20 kilo hertz. And so, so, the amplifier measure from 0 hertz to 50 kilo hertz. So, it has covered the entire microphone, but then I cannot say for sure that I am measuring till 20 kilo hertz because my microphone has limited till the values to till 10 kilohertz.

So, this is the idea I wanted to drive home regarding the significance of frequency response in dynamic measurements.
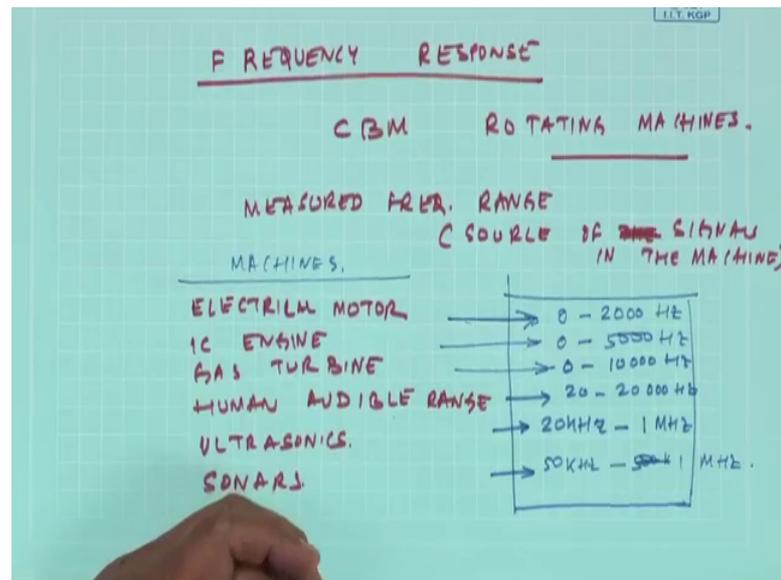
But usually I am asked this question. So, for CBM out of rotating machines, what should be the measured frequency range. Well, measure frequency range depends on the source, source of the machine, source of signals in the machine.

So, if I talk about mechanical signals. Say for example, an electrical motor giving in vibration signals. And IC engine or gas turbine human audible range, ultrasonic's, sonar's. So, I will give you a reason what is the typical frequency range of these signals. So, for an electrical motor all the phenomena occur around the electrical supply frequency and few harmonics.

So, for if you are monitoring the signal sort of an electric motor virulence a 0 to 2000 hertz is good enough. If you are talking about IC engines engine firing frequencies we know how we can calculate the engine firing frequency. And a typical maximum speed of an IC engine even at the highest rpm of it is power delivery could be around 5000, 6000 rpm unless you are talking about the formula one a sports car engines you know that could go up to maybe 13000, 15000 rpm.

So, these frequencies are very good from about 0 to 5000 hertz. If you talk about gas turbines you know some working around 30000 rpm and so on maybe 0 to 10000 hertz human hearing so, 20 to 20000 hertz. Ultrasonic's are the names are anything beyond 20 kilohertz. So, maybe 20 kilo hertz to ultrasonic are also used in sonar maybe one

megahertz or 2 megahertz. Sonar usually they are ultrasonic beams 50 kilo hertz to maybe 500 kilohertz or few mega or I can say it one megahertz.

And then of course, you know another thing like acoustic emission etcetera we will talk about it at them later on. So, you get a feel of the typical frequency range of the signals which come out of such rotating machines, and then one has to decide on the appropriate transducer having these kind of frequency response so that the phenomena physical phenomena is actually captured. No matter what we do with measurements we may be having very sophisticated accurate and precise transducers to measure the phenomena, but then if we are not measuring in the right frequency or measurements has no meaning because I need to capture the signal.

So, once of course, we have captured the signal, and of course, if you want to do processing it I will just recollect in our data.

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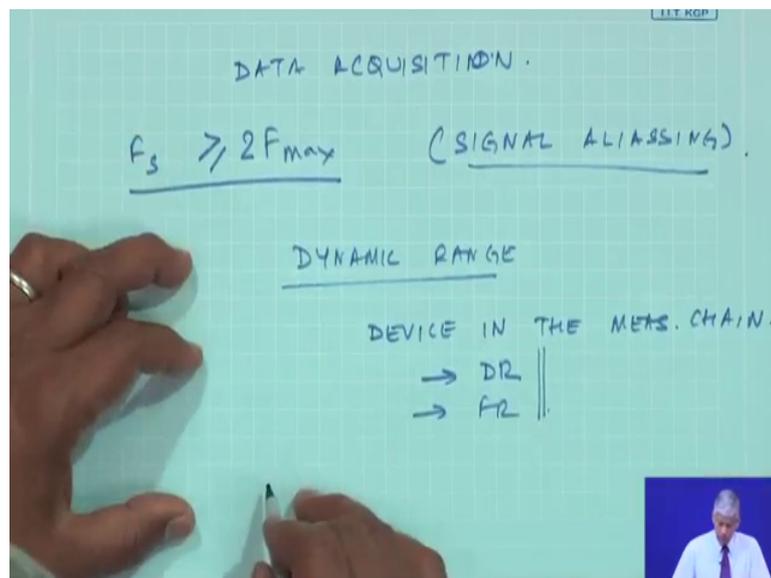
Acquisition system, if my maximum frequency is of max, I need to always sample at a frequency Fs which is greater than twice f max. So, my sampling frequency has to be such that I obey I avoid signal aliasing, right?

Now, once we know we are talking about dynamic range of equipment for a transducer. So, the we have looked just looked in the x axis, but the dynamic range also should also we should look in the y axis that the dynamic range of the lowest dynamic range or the

lowest frequency response is the frequency response of your measurement chain and lowest dynamic range is the lowest dynamic range is the dynamic range of your measurement chain.

So, every transducer or every device in the measurement chain must have DR known to us and a frequency response known to us ok, and then the lowest of it is the frequency response. Because I cannot be measuring authorized you know the computer systems are; they will give you some garbage output to a garbage input. For example, when you talk about retardation we see that the how the amplitude resolution could be improved some input voltage, where 2 to the power n; where n is the bit size.

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So, if I am able to sense, higher values I need to increase the bit size. So, this is what I meant by range. So, unless I am able to sense the amplitude resolution may my amplitude resolution is fine enough to sense the signal I would not be registering such a signal, and that is why if you recollect in the measurements of temperature using thermocouple. We always had an amplifier with a gain in it ok.
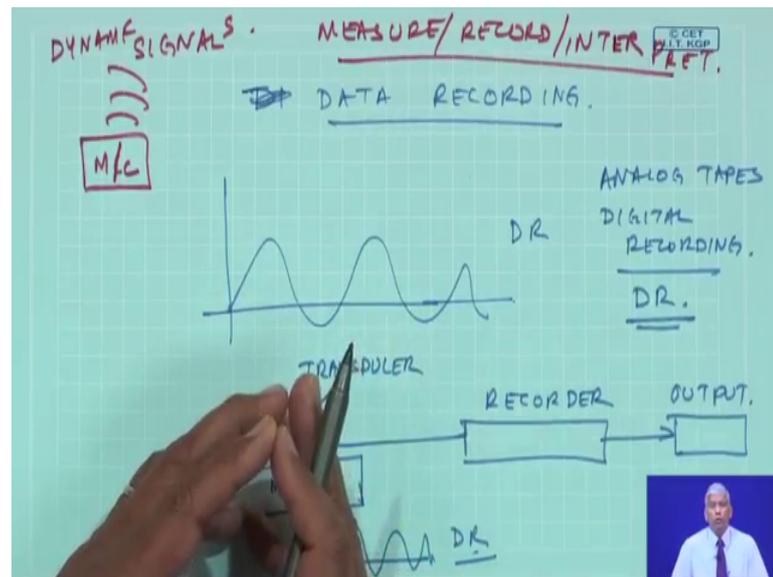
So, that this would be registered in the; and many a times we discussed this in the case of digital data recording or data recording. I have some signal a very high dynamic range signal. Because you tape recorder also comes between your transducer, machine, and transducer some recording the tape recorder. And then of course, you will get an output we done in. So, I have a very high signal with a very high dynamic range. But if my tape recorder is not able to record at such high dynamic range, I will not reproduce such a high dynamic range signal. That is why people nowadays you know they are more from this analog tapes to digital recording because of the high dynamic range ok.

And once because I would not see my final aim is my machine; whatever it is generating signal, I need to either measure record and interpret the signal correctly. So, for doing this and particularly dynamic signals, one needs to be aware of the limitations of the transducers in terms of their dynamic range, and frequency response know what their sensitivity is, when they were calibrated and what are the environmental factors or extraneous factors which could be contaminating our measurements. For example, particularly when we are measuring dynamic signals.
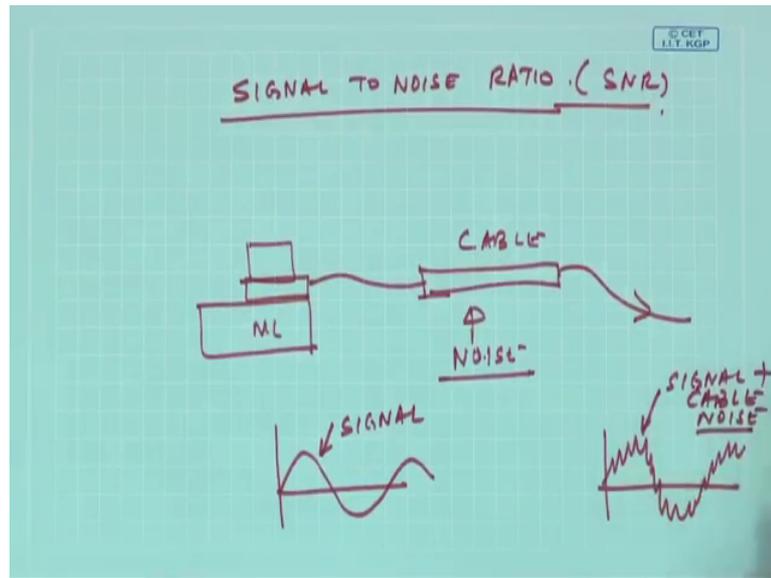
The signal to noise ratio is a very important parameter SNR.

So, for example, I have a transducer which is measuring something on a machine, but then I have a cable, which is because of it is movement generating certain charge and creating noise ok. So, a neat signal at the transducer end could be getting contaminated because signal this is signal plus cable noise. The reason I am mentioning this you know this is because of the fact that I have experienced this myself do not know doing measurements in the field, that one of the very careful about the quality of the signal quality of the dynamic signal, as to the signal to noise ratio.

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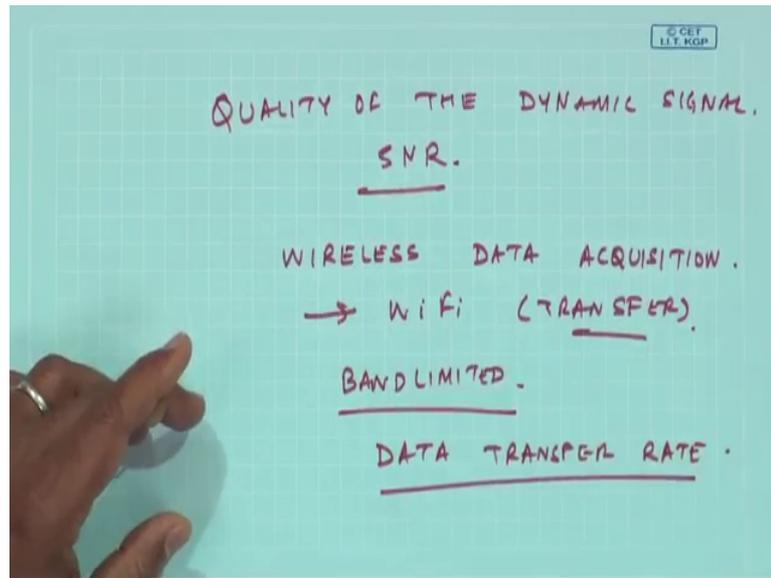
So, these are issues which we will understand of course, today many of these signals you know right at the transducer level if I have the wireless data acquisition. And then of course, you know transfer data; many of these problems are getting solved, but for the fact that they are also we have problems which is known as band limited I had told you the data transfer rate data transfer rate is a big hindrance to the present day state of the art which is improving.

So, these are issues one has to keep in mind so that bottom line is wrong measurement is no measurement do not spend money on buying and transducer which has been not understood, which has been wrongly mounted and which is being operated in a specs; it is not designed for and we are trying to interpret data as if everything is correct. And mind you this is if we have measured data correctly, analysis will follow depending on the algorithms which you use. But very most important aspects in CBM; is to measure all the signals from the machine correctly, unless, we measure data signals correctly. Everything is of no use to us thank you. So, more on this you can find in my book.

Thank you.