

Machinery Fault Diagnosis and Signal Processing
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Lecture -16
Basics of Instrumentation

This is the very first class in module four on the basics of instrumentation. Essentially in module four we are going to discuss about the issues of instrumentation measurements data recording, data storage, data transfer and so on, because as you know in condition based maintenance the use of transducers is very important to know the conditions of the machines.

Now we had discussed that there are certain parameters which we use in condition based maintenance like as in vibration, temperature, noise, electrical current. So, you know you must have studied in instrumentation because this instrument is in itself is about a 40-hour lecture in any undergraduate program in mechanical or electrical engineering.

But today in this class in about an hour's time we are going to overview the basics of instrumentation and how in particular you will see in the subsequent classes we will discuss about some of the transducers which are used in condition based maintenance to be put on the machines. So, that we can capture the mechanical parameters of the machine that could be vibration, noise, temperature etcetera.

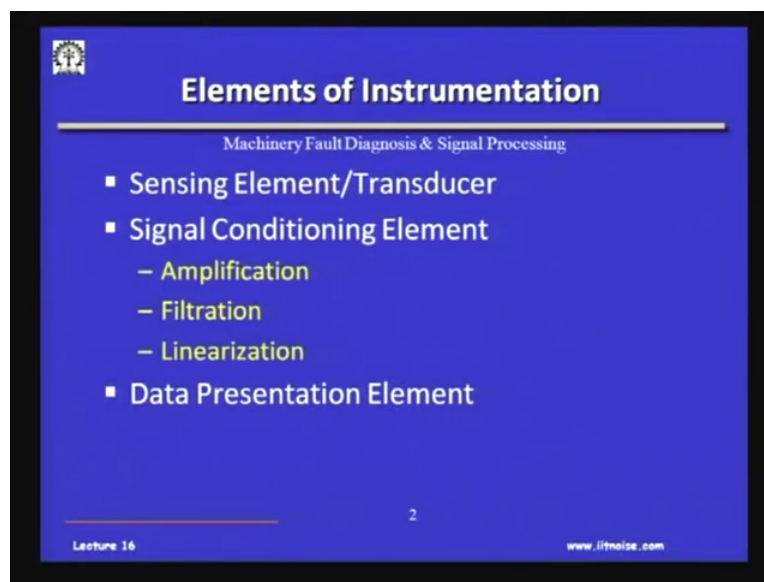
And then of course very important is we have to be very careful that we do not induce or do an extra; bring in an extra noise or error into our measurement because the algorithms of the condition based maintenance depend on the data which has been collected by us or by the transducers and provided to the analyst. So, if we create noise or bring in artificial errors into the measurement system will not be doing a good job.

So, other than knowing the instrumentation the equipment and required to do the signal, acquire the signal from the machines we have to be also careful about how by doing a proper

instrumentation we can minimize error, how we can do the instrument calibration so that we get the exact replication of the phenomena which is happening in the machine.

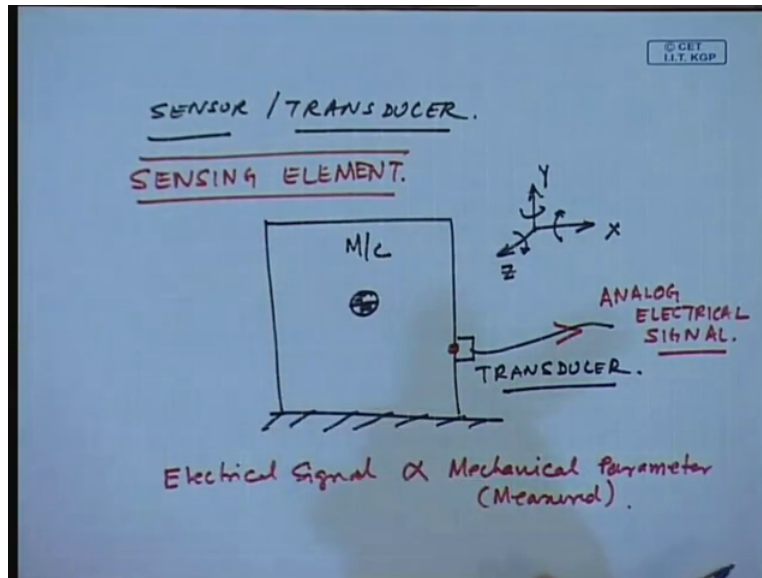
Imagine you go to your doctor and he has a blood pressure meter which is you know which has not been calibrated okay, you can imagine the consequences. Similarly know when we want to capture certain parameters from the Machine would obviously not like to do a wrong measurement. So, with this preamble I would like to start this sixteenth lecture on basics of instrumentation.

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So, let us see what are the important elements of instrumentation? Of course is the sensing element or the transducer essentially, sometimes you know we have been loosely;

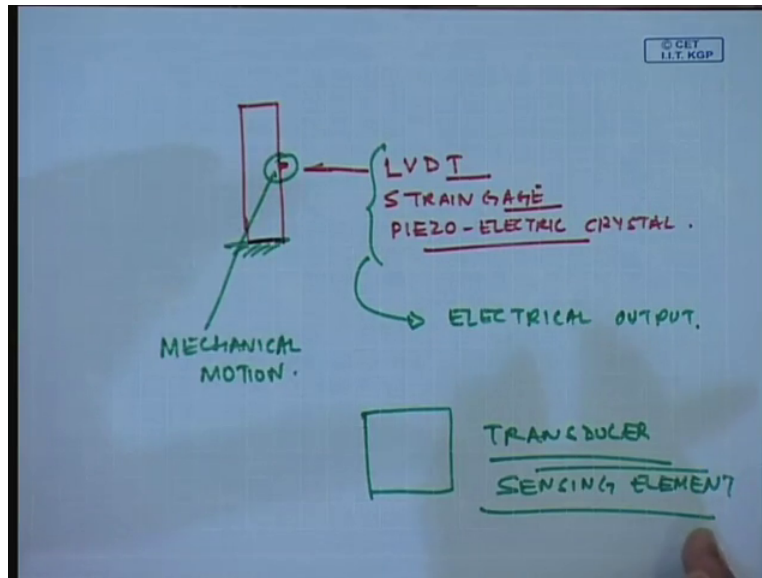
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Sometimes people say that now there it is a sensor or a transducer it is the very most important element which is kept or placed or connected on our machine. So, this is my machine there could be a lot of dynamics happening in this machine you know it could have been having rigid body motions all the rotations. So, how do we and then if you have a transducer the idea is to capture the motion around one of these points okay. And essentially this transducer usually gives an analog electrical signal.

Now this signal which we obtain from the transducer is depending on the mechanical parameter. So, this electrical signal obtained is proportional to the mechanical parameter which has been measured okay. And you all know there is an endless list of mechanical parameters. And endless list of sensing element rather than sensors, sensing element is very, very important. Same mechanical parameter could be sensed by different sensing elements.

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For example either direct or indirect for example I have a body which is having a certain motion at one point. Because of the motion there will be displacement, this displacement could be captured by an LVDT and that is a Linear Variable Differential Transformer and VDT or a strain gauge or a piezoelectric crystal. So, these are the different sensing elements which are used to measure the mechanical parameter could be mechanical motion.

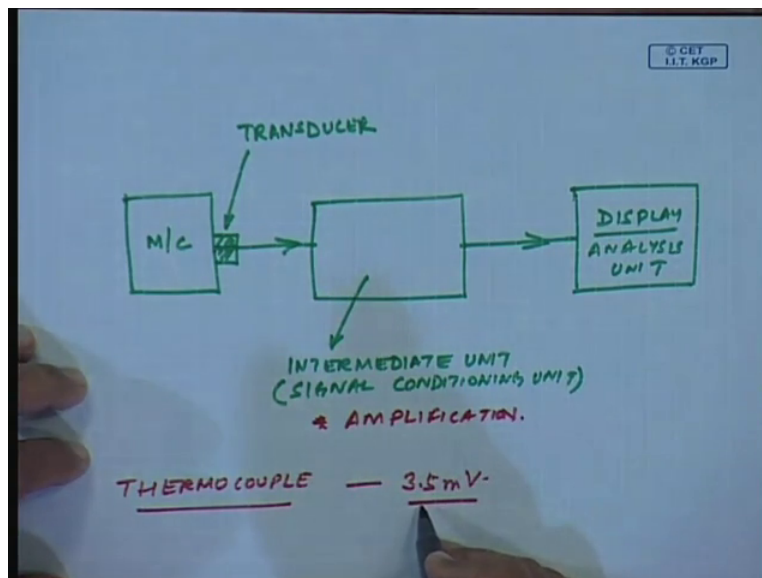
This is just to give you an example of the body. Now from these sensors I will get an electrical output, now you may be wondering yourself well why do, we have so many different sensing elements. Well it is because of the fact that these sensing elements have different characteristics. Some may have a poor response, some have an excellent response, some may not respond at certain ranges.

Some may not work at high temperatures; some may not have a linear output. So, these are careless characteristics of sensing elements. So, a transducer or a sensor a transducer has an essential element which is the sensing element. Sensing element is the most important part of a transducer and this list of sensing element is endless. In fact it is a very large list but we will try to focus our attention mostly to mechanical motions, vibrations, noise temperature process parameters and so on.

So, we will home in towards these few mechanical parameters and see. Because if you recall I had told you in the very few first few classes that that the condition based maintenance around the world 70% of the cases are by vibration monitoring whereas 20 by were debris analysis and the remaining 10 by either by ultrasonic's, NTD techniques, motor current signature analysis.

So, we will focus our attention to mostly how do you correctly measure vibrations and how do you correctly measure temperature pressure current and the wear debris parameters. So, with that we will be kind of looking into these elements. So, coming back to our discussions on the sensing element there could be LVDT, strain gauges, piezoelectric crystal etc.

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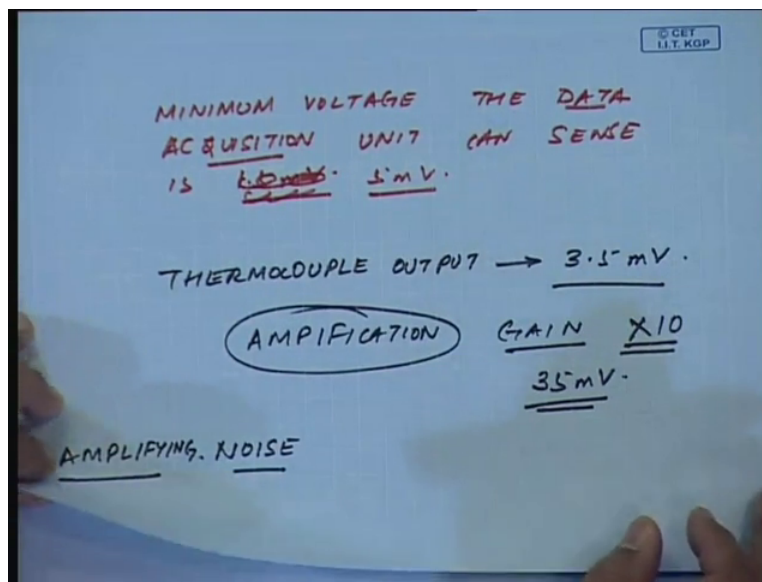
But the between the machine I have certain intermediate step nowhere and I put a transducer, I will have some intermediate unit which is essentially a signal conditioning unit. And then we will have these either the display or the analysis unit and of course associated this there are a lot of secondary devices like the archival device to store the data, to plot the data etcetera. We are not going to discuss this.

So, I am depending on this transducer output my signal conditioning element could be many I have listed few of them in here in the slide. One is definitely sometimes an amplification is required. I will give you an example of an amplification which is used mostly in condition based

maintenance. For example we are using a thermocouple okay, suppose a thermocouple at a certain voltage or certain temperature it gives only about 3.5 millivolt okay.

And with the; if you recall the measurements done by thermocouple when the temperature increases this voltage output will increase because 3.5 million volts never becomes 10 volts okay. But this goes you know 3.5 to maybe you know maybe 2 volts and so on. So, the range given by this sense the output produced by the sensing element may be from 0 to 2 volts okay. That may be very, very small compared to the range of display which I could have.

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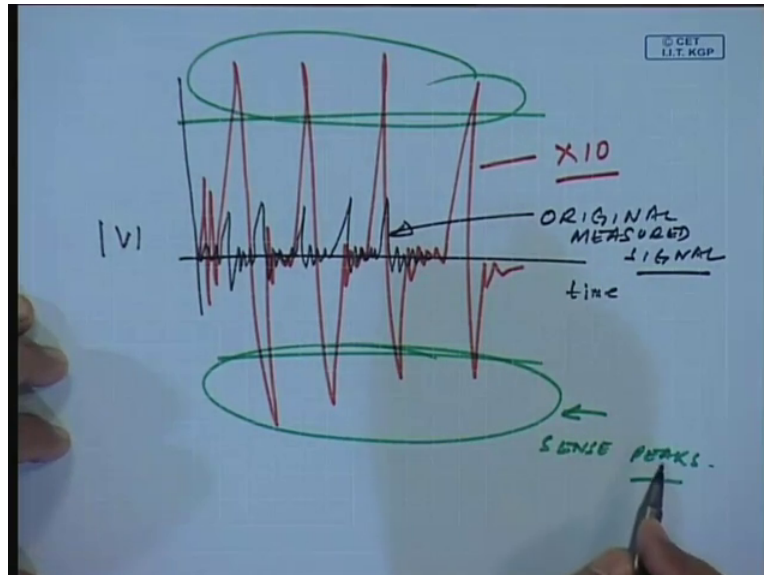


Or for example recall back to the lectures on data acquisition ok. Is the minimum voltage the data acquisition unit can sense is say 1.5 millivolt ok or I will take it so 5 millivolt and this is an hardware requirement; a characteristic of the data equation unit. Now if my thermocouple output in this example is 3.5 millivolts obviously my display or analysis unit because data equation unit is actually sitting in here and unless it is in it.

I am not able to capture or sense the thermocouple output well that is a problem I have. So, obviously I need to amplify, so amplify amplification is a solution to the problem ok. Maybe I will increase it by a gain of 10 again usually written by X10, or multiplied by 10 that means this becomes 35 millivolt okay.

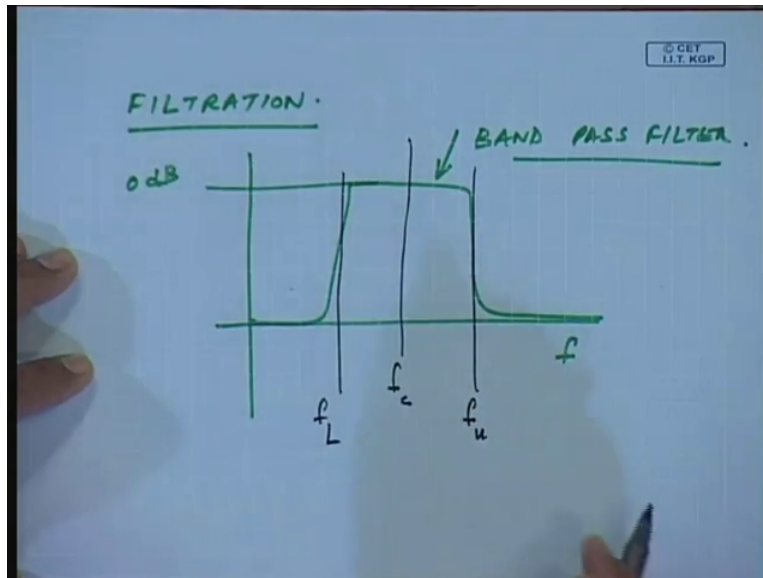
So, one such intermediate unit or signal conditioning unit is a amplifier or an amplification unit but this may sound very easy I have increased the voltage again by 10 volts but I also have amplifying the noise okay. This is an associated problem so how do you remove it so there are issues okay.

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Once this noise has increased I could already know for example to begin with know my signal in the time domain look something like this. Certain voltage from increase it by a factor of 10 maybe this will all okay. This becomes by 10 and there is my original signal the black one of the original signal okay. I have amplified the noise but then you will see sometimes you know there are detectors if I put detectors that do you sense only the peaks. I should be able to sense the peaks this is in time domain.

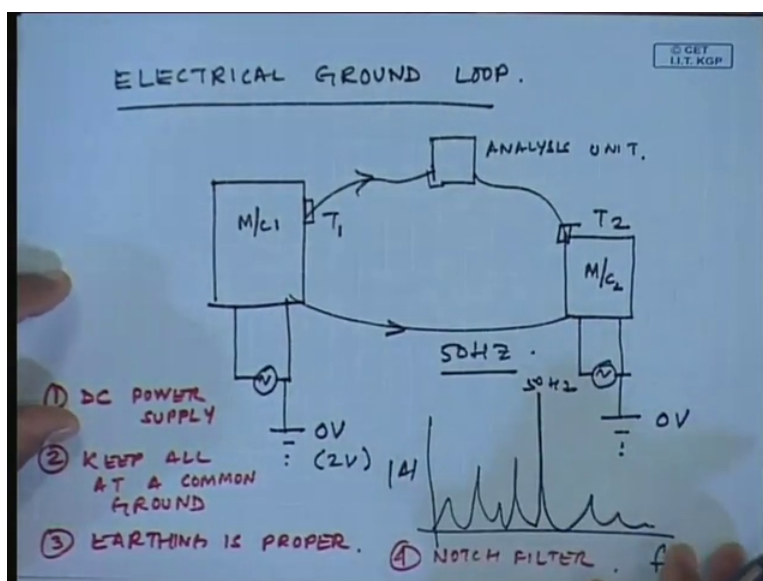
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But sometimes here it is in sometimes we can do certain filtering because the frequency domain, if I know my signal is in this band, I can put a band pass filter. So, it is going to eliminate the noise in the bands which are not of interest. So, this is my f lower and f upper and this will have a center frequency f_c , depending on you know you recall your mass understanding of filters where there's an octave filter one third octave filter.

Is a linear band pass filter we can decide on this or whether it is a notch filter. Particularly when we do measurements in mechanical systems wherein there is an electrical power supply.

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There is a problem of what is known as an electrical ground loop okay this is very, very important particularly in many measurements when we do at site on condition based maintenance. What happens suppose I have one machine and another machine okay and they require and say an AC power supply.

There you have AC power supply on machine 1, machine 2 all right and suppose physically this is the ground potential of this ideally it should be zero voltage. But you would have seen in many cases suppose, this is the two volt instead of a perfect round is that a 2 volt and that 0 volt. So, if I do lot of instrumentation sigh and I conduct each one by wires okay there will be flow of current because the potential difference is only 2 volts.

It is good enough for a current to flow and this current will flow at the supply frequency of 50 Hertz. So, any measurements, if I put a transducer here, if I put a transducer here T2, T1 and then I go to my analysis common analysis unit okay, you will see; because of the potential difference because this has a separate power supply, this has a separate supply power supply.

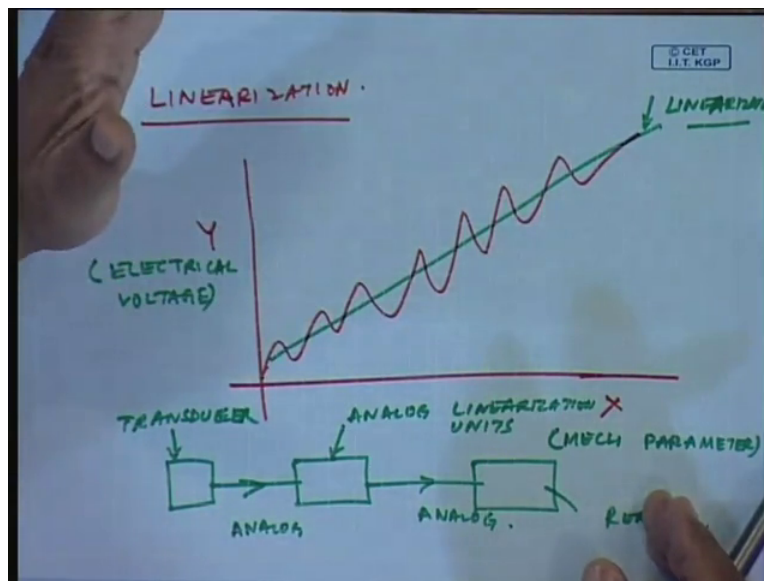
And one is at a different ground know, we may very emotionally say well they are all at the same ground but in real life between rooms you would have seen one is not a perfect ground that is perfect or they even if a 2 volt is there this is large enough for a current to flow. And whenever we do the analysis you will see in the frequency domain.

You may be doing a vibration measurement you know all the vibration measurements will come but there will be a strong 50 Hertz signal okay. This is a real controller with instrumentation and once we go to the field, we have to avoid the round loop okay. So, well I will just tell you some of the tricks to avoid ground loop.

One is wherever possible use DC power supply, battery resource. Next is keep all at a common ground that means if all the potentials all are common then this will be no potential difference and then there will be no flow or make sure earthing is proper. Sometimes I have seen earthing of 10 volts you know very poor earth and this is responsible for; because this signal adding cables are actually metal conductors.

So, there is path for the electrons to flow and they get buried in the signal which is being captured by the transducer okay. So, this could be done by having a proper intermediate element which is a signal filter I could the next one I could have number 4 is a notch filter and that means from the signal. It is going to remove the 50 Hertz component okay so; 50 Hertz's effect will be removed.

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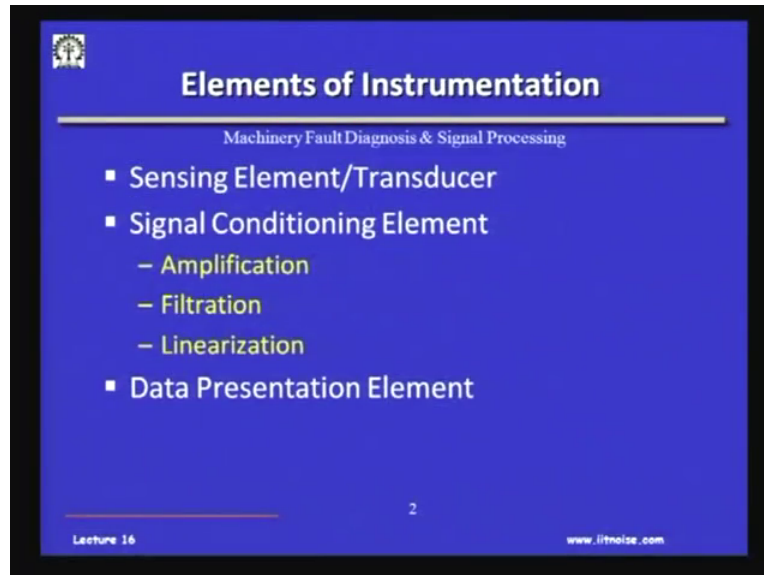
Few more amplification units are linearization particularly sometimes in some strangely this that sort of the outputs are not linear okay. Suppose my output with time or with certain range is against some X and Y parameter this is my output. So, I could because if you imagine because if this was my mechanical parameter and this was the corresponding electrical voltage.

You see lot many oscillations okay, so either through a device either analog or digital I could linearised the response, while we are doing the measurements. You have my transducer the intermediate unit and the display unit these are all analog signals. So, there are analog linearisers or linearization units these are my transducers and the readout unit okay.

So, because the signals are analog we have to have certain sets of electronics to do the linearization. But again I will just tell you because we had courses on digital signal processing had I given you this red signal on a computer you could have very easily linear as it no which

you all loved doing while you plot an excel graph or do a regression analysis okay. So, you can imagine the power of digital signal processing.

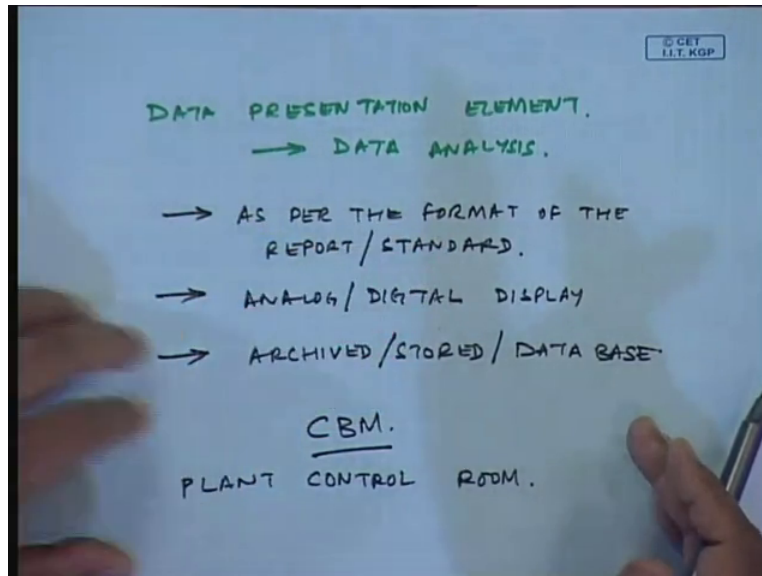
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Think of the days when digital signal processing were not available where computers were not available however people getting linear output of a lot of sensing elements. They had to have some electronic hardware to do that okay. But gone all of those days, now it is I will just get the signal from a transducer, by having a proper data acquisition take it in the computer put a software do the linear output okay.

And the next element of this instrumentation of could the last element very important is the data presentation element okay. Because finally either you can call it as data presentation or data further analysis or because you know once the signal has come from the transducers through the signal conditioning element to digital representation element. We have to now see the format in which the data has to be presented

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Sometimes once the data presentation is done we have to do the data analysis. Now this presentation is in a proper format this format could be if you are just doing a measurement and reporting it, it has to be as per the format of the report or a standard. Now this presentation whether it is analog display or a digital display whether this data which has been presented whether it does needs to be archived or stored it will go to a database.

Because finally our CBM software or technique will be working from this data only, I can store them if the data is large, should I store them in ASCII characters or binary. Because the storage space is very important, if I am doing all this measurements I imagine you know you can complicate you have a small laptop, handheld laptop and you have to do the measurements all around the plant and capture all the data into your laptop.

Imagine in one day you are on full up your hard disk ok, so the format of storing the data, if there are certain image files we cannot be storing large image files. So, that is why all these formats of JPEG, TIFF all those compression formats have come up. You might heard of zip files because only the process is to compress the data.

So, a binary method of storing data is much, much useful in the sense that the memory requirement will be less when you are storing digital data. Earlier there is no issue if you go to any plant control room. Particularly if you go to the plant control room of an electrical power

station you will be noticing that there are there are a few engineers or operators looking at the wall full of dials.

Because they have critical components which they will be recording in fact many of the you know steel plants, cement plants etcetera around the clock when their production. The shift in charge do nothing but they will be maintaining a log okay and then next day morning the in charge going to come take a look at it. But these are done about a decade ago nowadays everything is automatically data log.

And if there is an deviation you will either get an alarm maybe on your mobile phone. If you are sleeping at your house you look at mobile phone such and such bearing in a plant has become abnormally hot and this is the state of the art nowadays. I mean earlier days, thirty years ago, twenty years ago still plant, what they were doing the control room in the night they were just logging down in every half an hour this is the temperature of the blast furnace.

These are that coolant pump, this gearbox, that gearbox temperature, pressure, flow rate all this and this was being done manually when all the computer edit data acquisition systems were not available. Now a days you need not worry it is totally manpower less there is no Manning okay. Everything all from all the data transducers are put permanently around the instruments signal analysis units are there data is being logged into your computer.

And data if the certain data suddenly some data's are there which are abnormal. Which are not as for the prediction models you will get enough alarms? Alarms could be right there at the plant alarms could be right there on your mobile phones also okay and that is what is the present state of the art? Okay. So, well essentially all this you know which you have discussed so far are the elements of instrumentation.

And to summarize the three elements of instrumentation are the most important is the sensing element and then is the signal conditioning, the intermediate equipment or analysis unit and then the data presentation element okay.

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Transducer Elements

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- Analog Transducers
 - Electromechanical Type
 - Potentiometric Resistance Type
 - Inductive
 - Capacitive
 - Strain/displacement
- Digital Transducers
 - Frequency Generating Types
 - Digital Encoder Types

Lecture 16

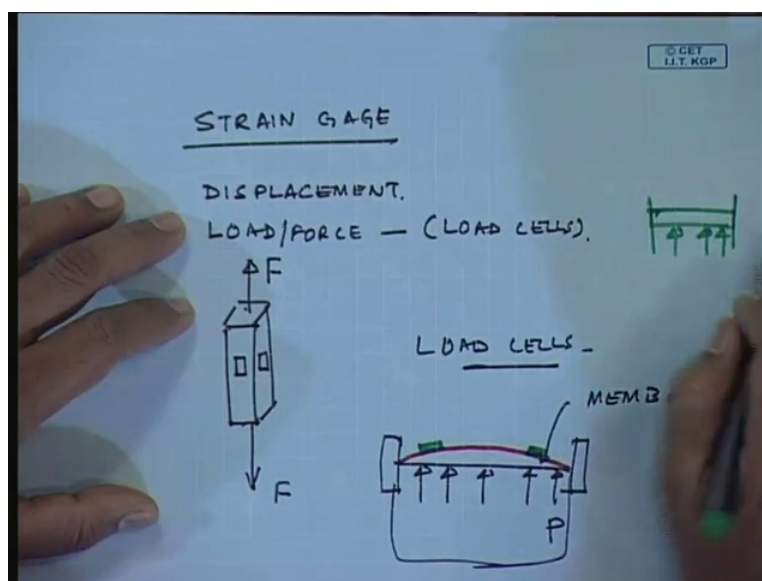
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Now let us see what are the different transducer elements available to us to do measurements, if you look at the two broad classifications one is the analog transducers and other is the digital transducers. And in the analog transducers we have the electromechanical type basically a resistance type and inductive type, a capacitive type or a strain displacement type okay.

So, this is this is the technique I mean I am not; these are not the mechanical parameters the mechanical parameters could be anything. But by having this sensing elements I can measure the mechanical component. I will just give an example here.

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So, for example all of you know what a strain electrical resistance strain gauge is to measures strain but you see this strain gauge could be used to measure a mechanical parameter displacement another mechanical parameter as a load or a force which are actually load cells okay. Suppose I have member okay because of certain force this member is either going to get an axial pull or compression?

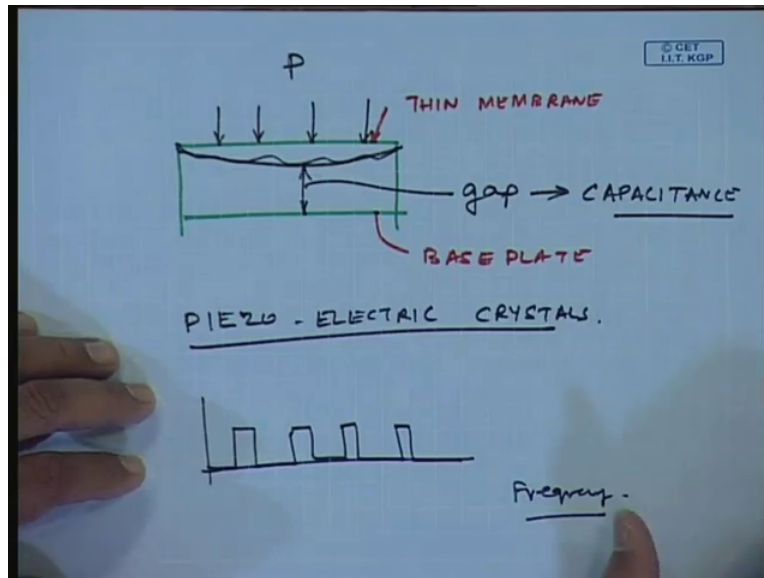
And then if I put electrical resistance strain gauges here because of this load compressive load I will get a strain. So, by measuring the strain knowing the parameters of this member in terms of the cross sectional area, the young's modulus the length, I can indirectly measure what the force load is and that is what is the load cell. So, an electrical resistance strain gauge is this sensing element but the mechanical parameter could be load, could be displacement, could be pressure.

For example there are diaphragm types of pressure gauges okay and these are held in this is a thin membrane and there is certain pressure here P and suppose this is there in the housing etcetera. Because of this what is not going to happen is this membrane is going to have a deflection right. Now in this membrane suppose there are certain strain gauges attached.

So, because of the pressure this membrane is going to deflect because of the deflection the membrane will have a strain and that is against sense by the strain gauges. So, strain gauge has become a sensing element mechanical parameter could be pressure instead of strain. I could have put piezoelectric crystals they would have produced an charge okay so, some of the; for example microphones.

In a microphone we have two membranes or two discs rather and they are maintained at a certain potential.

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And let me do it another page here, is a very thin membrane like a metallic foil okay. And then this is another base plate metallic, so if there is a crosser fluctuation this pressure has become, because of the acoustical waves which are being incident. So what is going to happen, this membrane is going to deflect as per the pressure waves which are incident okay. So, what is going to happen?

So this is going to happen this gap is going to change because this gap has changed its, capacitance has changed. So, by sensing the capacitance change in the capacitance because the capacitance has seen the charge produced will be change okay and because they are maintained at a particular voltage. These plates are maintained at a particular voltage now the capacitance is challenging because the gap has changed.

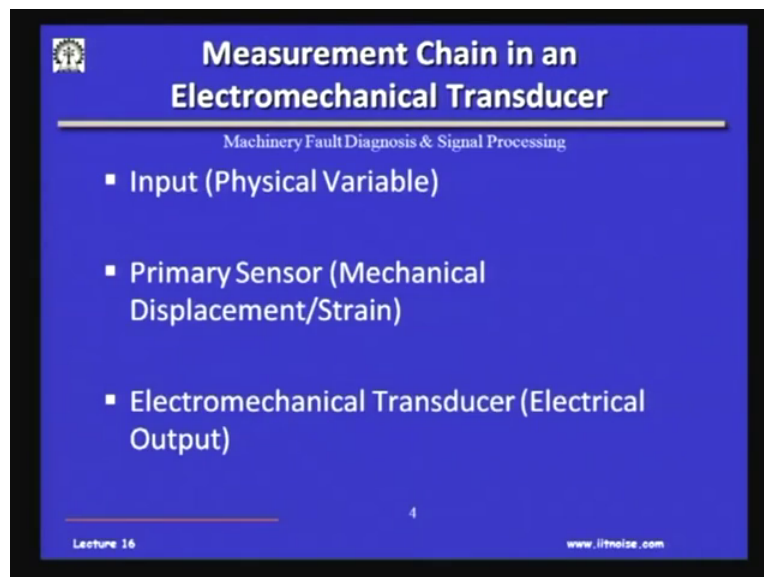
And then we will get a charge which is corresponding the mechanical pressure P . So, these are what are, what I mean are this sensitive elements resistance, inductance, capacitance, strain etcetera. And these are used as sensing elements in mechanical systems to measure the mechanical parameter instead of strange guages and we are also nowadays using piezoelectric crystals.

In fact in CBM some of the instruments which you are going to discuss are basically nowadays having piezoelectric crystals as this sensing element. And some of the other type of transducers

are the digital transducers they will generate the frequency generating type or the digital detail encoder types wherein we will get a pulse, pulse strain. And by measuring the pulse strain width we will get the frequency estimation okay.

And these are used in particularly in CNC machines, lathes etc to find out the speed fluctuation etcetera okay. sNow based on these sensing elements certain transducers are built manufactured and then we use them in CBM.

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But then this sensing element, so if I was to go back to the discussion of the pressure gauge. So, input so the measurement change in an electromechanical transducer are this three, one is the physical variable, physical variable could be the load force in the case of a load cell, pressure in the case of a pressure gauge. But the primary sensor is that mechanical displacement or strained it was that membrane which deflected.

And on that membrane I had kept a strain gauge I could have kept us piezoelectric crystals that was my primary sensor and then I will get an output which corresponds to the characteristic or deflection of these sensing element strain gauges or piezoelectric crystal and finally I will get an output. So, everything to put together as an electromechanical transducer okay so, now a transducer is a little bigger superset of the sensing element.

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Performance of Instruments

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- Static Characteristics
 - Accuracy, Precision, Resolution, Sensitivity, Range, Hysteresis, Impedance
- Dynamic Characteristics
 - Frequency Response, Time Constant

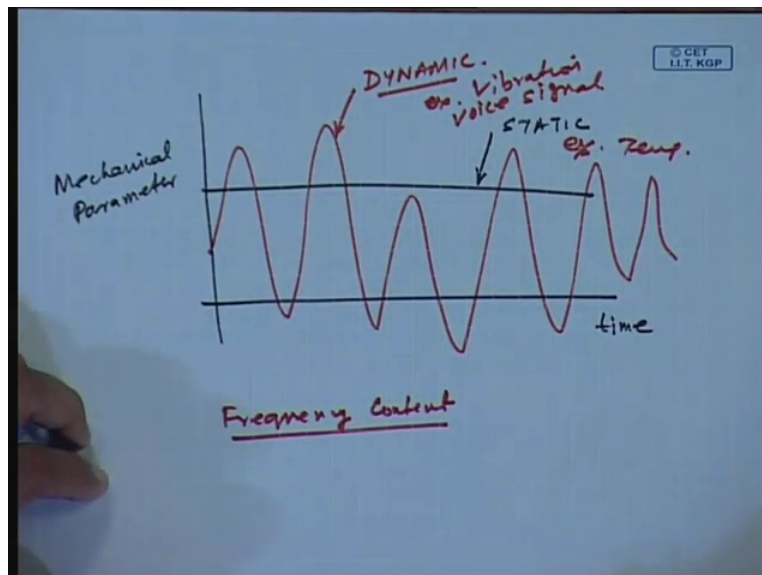
Lecture 16

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Now, once we have understood what these transducers are? Let us see how do you know whether we are measuring them correctly. So, some of the static characteristics because the primary mechanical parameter.

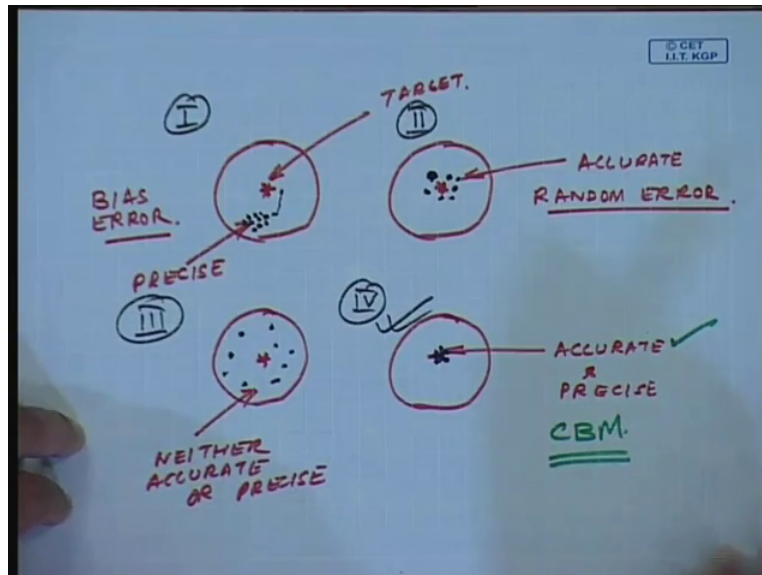
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As a function of time, mechanical parameter could be anything; it could be either static, not varying with time, example temperature in this room almost static okay. Or the parameter is changing with time maybe the so this is the dynamic, examples vibration of a structure, voice signal in this classroom example here in static case is the temperature. So, the mechanical parameter is either a static or dynamic characters causing a dynamic characteristic.

So, that means static means it is not changing with time it has a DC value it is not having any frequency. But dynamic means it is varying with time, so it has a frequency content okay.

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Now what are the frequency static characteristics of an equipment or a transducer. For example I know I will give you an example, I know that this is my actual quantity which is to a measure okay but each time I measure I am reporting these values this is one case. Another case could happen this is my target of the bull's eye. Another is okay these are the cases another could be all over the place okay. And another could be okay like this; this is my target in this case.

I am precise and in the sense that I am always measuring around a particular value here. Here I am accurate but not quite, in this case I am both accurate and the precise and this I am neither accurate nor precise okay. The best would be this kind of instrument wherein I always measure accurately and precisely.

In the first scenario there is an error; there is an actual offset okay. So, this offset if I know this value I can always remove this offset and get the correct measurement. So, this is the measurement has been by asked the constant shift. So, this is the case of a bias error okay and here in the case of accurate if I do more averages and more measurements and did many averages I could be perhaps close to the target.

So, this is the case of an random error, here I have both random and biases and here have removed both the random error and bias error. So, you get a feel that in any measurement this happens but my CBM wants only this we have to be both accurate and precise okay. So, today if you go to the market to buy a thermometer.

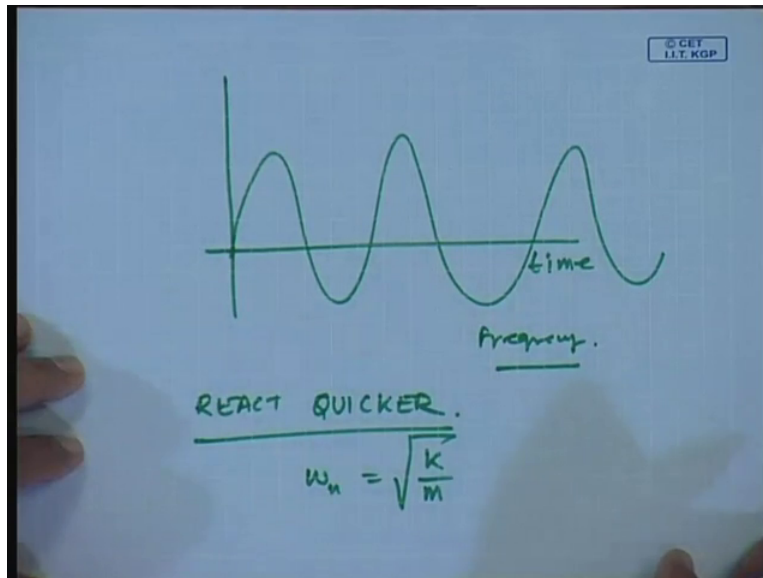
You will get a thermometer of 5 rupees, you will get a thermometer for 20 rupees, you will get a thermometer for 2,000 rupees okay not that the cost is towards the profit margin of the supplier. But it is for these values whereas the same amplifier, same vibration meter which we use for accurate scientific measurements and R&D are very, very costly.

Same microphones now which I am using here could be you know 100 rupees, but then there are microphones which are 100, 1000 rupees doing the same thing but they are more accurate and precise, because of this scenario. So, accuracy and precision go hand in hand and then as CBN we have to remove this bias error and random error and this is done by random error reduced by doing more averages bias error by doing a calibration.

And some of the important other characteristics are the resolution, sensitivity, range, hysteresis impedance etcetera. Resolution is the least value with my measurement system can measure and so on. And so in a static instrument which we use for measurements we are doing very careful about whether it is accurate whether it is an accurate instrument, whether it is a precise instrument or transducer.

And you will see because how accuracy and precision can hamper your results. And now let us come back to the dynamic characteristic of an equipment okay. By the dynamic characteristic of an equipment I mean or a transducer that means;

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If my mechanical parameter which is to be measured is varying at a certain rate, it is varying at a certain frequency is not it. Now imagine that means high frequency means it is varying at a high rate. So, my measurement system cannot be slower than the mechanical system, does it? Suppose every instance the vibration is changing I cannot come with the transducer which will measure vibrations only at intervals of 10 minutes.

So, I am going to lose these phenomena is not; it so my instrument has to be has to react faster than the quantity or the mechanical parameter which I am measuring that is very, very important. I use the word react, quicker because of the fact every mechanical transducer has inertia, has deafness, has a natural frequency and if you recall this natural frequency is nothing but stiffness by mass.

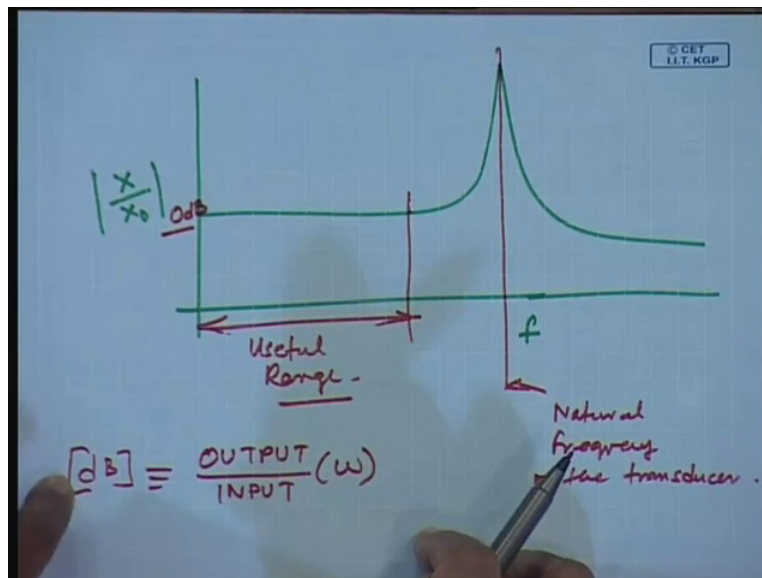
If mass is low then natural frequency is low okay, so if I want a very sensitive equipment in terms of very fast response its mass has to be less. I will give you another related example. You know many must have seen the jockeys riding the horses on the horse track ok. Have you seen why the jockeys are very less weight the person was riding the horses, because my object is there the horse has to go from the starting point to the finishing point quickly.

And jockey is loading the horse ok, the horse should not become sluggish or should not react late because it has got loaded ok, so that is how jockeys have a lesser weight. Same token here if a

mass is very heavy the transducers will be having a very, very poor frequency response. They cannot react faster ok, you would have; we all cut jokes with you know persons were overweight they do not have they have a poor reaction time because of this.

Similarly transducers which are heavy and bulky they cannot respond fast the mechanical parameters which are sensing okay. So, we have to have sensing elements which will react faster or which will have a response quicker to them.

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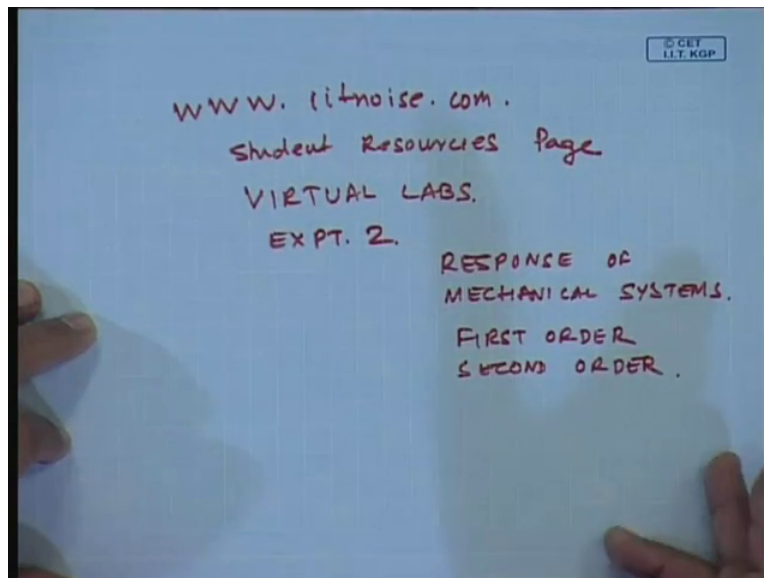


So, now going back to the transducers because the transducers because they have natural frequencies if I was to plot the natural frequency response of a transducer maybe certain parameters. So, this is the natural frequency of the transducers. So, I should be doing a measurement in the band much, much away from the frequency response of the frequency in natural frequency of transducers.

So, this is my useful range okay, so, if I was to define the frequency response of an instrument that is the response of the output to the input in the frequency domain is really given in decibel. Because if my input is having a certain characteristic the output should be identical, so, this in the decibel scale will become zero decibel.

Because if I come to these ranges my output is getting affected by the natural frequency of the transducer because we have to live with it the transducer has a natural frequency. So, my output cannot be getting amplified because I am measuring in this frequency range. So, every transducer has a useful frequency range wherein the output to input ratio is 1 or in log scale this becomes zero decibels okay. Similarly we have the time constants.

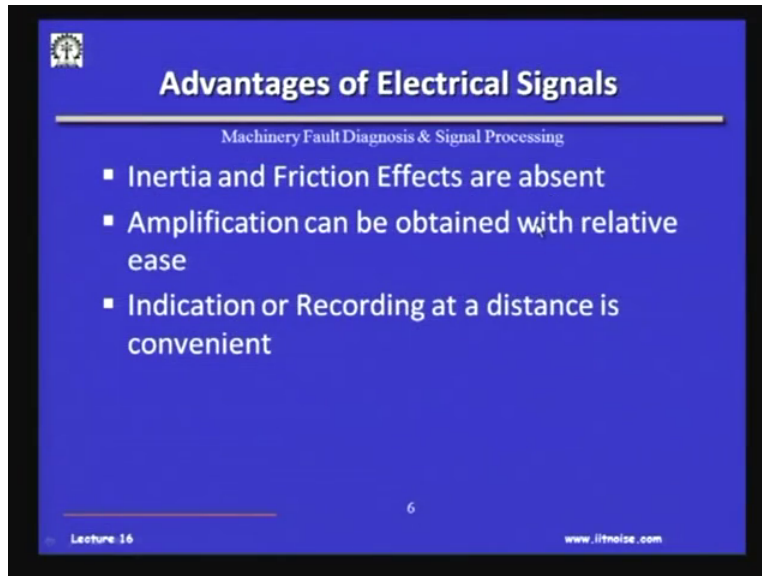
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So, here I will directly to my website www.iitnoise.com, in this website if you go to the student resources page, there is a tab on virtual labs, so if you go to the experiment number two, in this virtual labs, that is the response of mechanical systems, you can have an understanding of the response of first order, second order systems.

So, you know you all can go to this place and just for yourself study look into this website okay. So, well you must be wondering why do you always use electrical signals because of these inertia and friction effects are absent.

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The slide has a blue background with a black border. In the top left corner is a small logo of a tree inside a circle. The title "Advantages of Electrical Signals" is in white bold text. Below it, the subtitle "Machinery Fault Diagnosis & Signal Processing" is in a smaller white font. A list of three advantages is shown in white text: "Inertia and Friction Effects are absent", "Amplification can be obtained with relative ease", and "Indication or Recording at a distance is convenient". At the bottom, the slide number "6" is centered, and "Lecture 16" and "www.iltnoise.com" are on the left and right respectively.

Advantages of Electrical Signals

Machinery Fault Diagnosis & Signal Processing

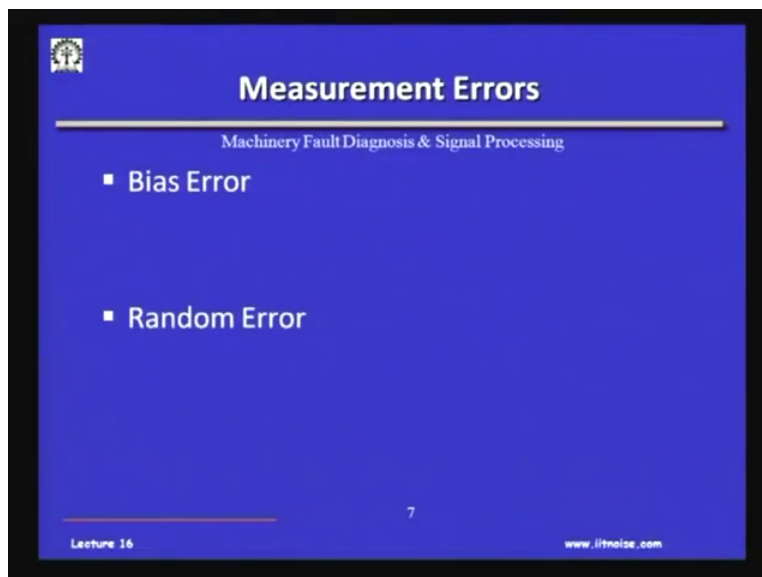
- Inertia and Friction Effects are absent
- Amplification can be obtained with relative ease
- Indication or Recording at a distance is convenient

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Lecture 16 www.iltnoise.com

Amplification can be obtained with relative ease and recording from any more distance is also possible because electrical signals I can transfer it to a large distances which is not possible by mechanical systems. I cannot have linkages and relays and bars for large distances and that is why, in a transducer traditionally we have been using all the sensing elements and we get an electrical output.

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The slide has a blue background with a black border. In the top left corner is a small logo of a tree inside a circle. The title "Measurement Errors" is in white bold text. Below it, the subtitle "Machinery Fault Diagnosis & Signal Processing" is in a smaller white font. A list of two types of errors is shown in white text: "Bias Error" and "Random Error". At the bottom, the slide number "7" is centered, and "Lecture 16" and "www.iltnoise.com" are on the left and right respectively.

Measurement Errors

Machinery Fault Diagnosis & Signal Processing

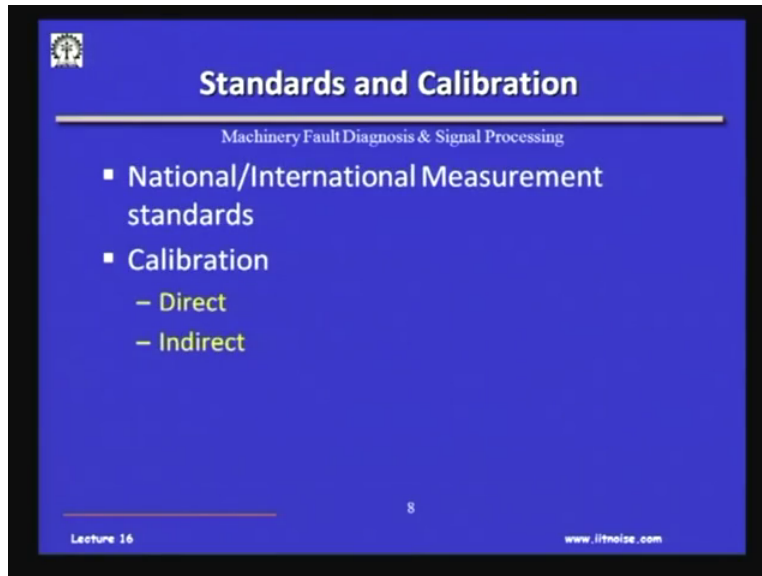
- Bias Error
- Random Error

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And then we just had discussed about these measurement errors, one of the bias errors and the random error and of course they can be removed by having proper calibrations.

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Slide 8: Standards and Calibration

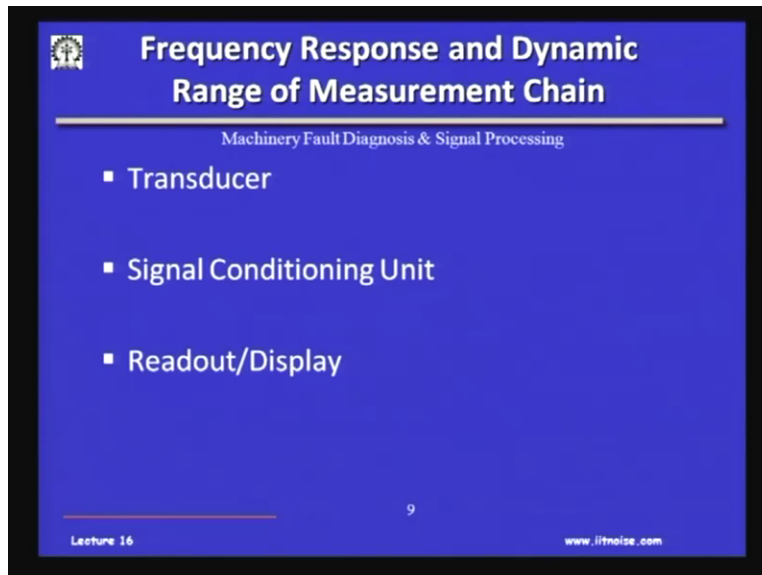
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- National/International Measurement standards
- Calibration
 - Direct
 - Indirect

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So, calibrations and measurements of course measurements have to be done as per the international standards because once we report our vibration measurements done in lab A to lab B we should ensure that the same standards and equipments are calibrated. So, that the data is reproducible and data can be exchanged between different communities and groups.

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Slide 9: Frequency Response and Dynamic Range of Measurement Chain

Machinery Fault Diagnosis & Signal Processing

- Transducer
- Signal Conditioning Unit
- Readout/Display

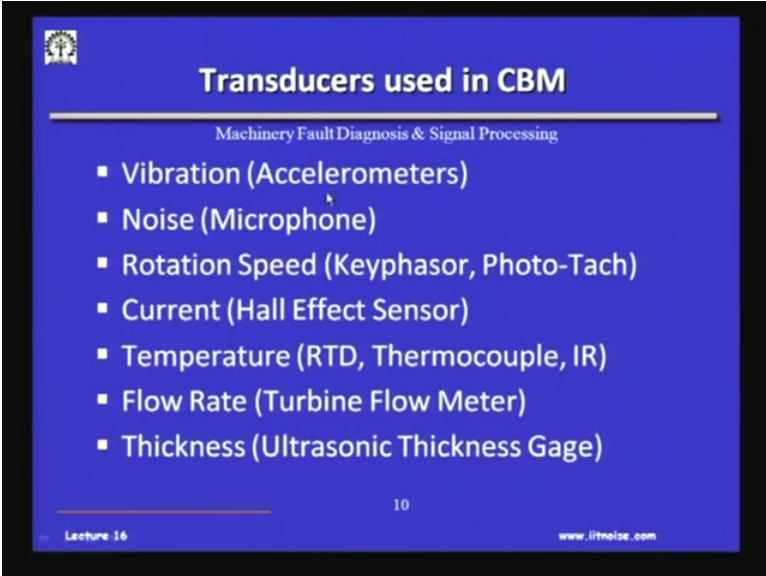
Lecture 16 9 www.iitnoise.com

So, when we have the frequency response of the transducer and in an entire measurement chain when you are talking about a transducer having a good frequency response of 10 kilohertz and I put a signal conditioning unit of a response up to till 5 kilohertz and digital display of only 2 kilohertz I cannot say that I have a 10 kilohertz bandwidth of measurement and that is the

important mistake people do. And we will discuss that in the subsequent classes when you talk about the transducers.

So, you have to keep in mind that the frequency ranges and the dynamic range of the measurement chain. And dynamic range is nothing but the ratio of the highest to the lowest values which the same sensing element can sense ok. We will as now with this kind of background with this instrumentation we will now be specific or discuss about the specific transducers in the subsequent classes.

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The slide is titled "Transducers used in CBM" and is part of a presentation on "Machinery Fault Diagnosis & Signal Processing". It lists seven types of transducers used in Condition-Based Monitoring (CBM):

- Vibration (Accelerometers)
- Noise (Microphone)
- Rotation Speed (Keyphasor, Photo-Tach)
- Current (Hall Effect Sensor)
- Temperature (RTD, Thermocouple, IR)
- Flow Rate (Turbine Flow Meter)
- Thickness (Ultrasonic Thickness Gage)

The slide also includes a small logo in the top left corner, the page number "10" in the bottom center, and the text "Lecture 16" and "www.iitnoise.com" in the bottom left and right corners respectively.

And in particular some of these are the transducers which will be discussing because these are the mechanical parameters vibration, noise, rotational speed, current, temperature, flow rate and thickness and these are the transducers which are conventionally used like accelerometer microphone, speakers for attack, RTD is flow meters are resonance, thickness gauge and these the principles behind this equipment we will be discussing in the subsequent classes, thank you.