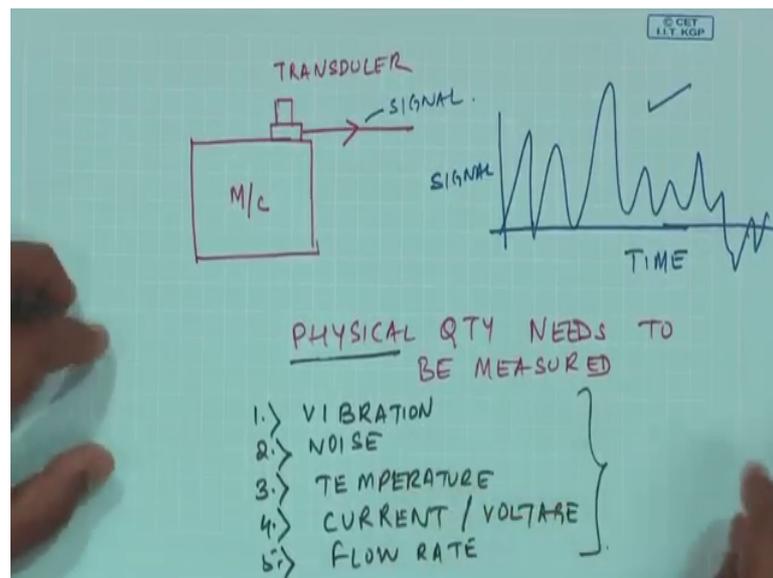


**Machinery Fault Diagnosis and Signal Processing**  
**Prof. A. R. Mohanty**  
**Department of Mechanical Engineering**  
**Indian Institute of Technology, Kharagpur**

**Lecture – 26**  
**Basics of Instrumentation**

Yeah, this week, we will be primarily focusing on measurements and instrumentation and as you would have seen in condition-based maintenance or monitoring. One of the primary elements of monitoring is actually measuring the signals out of this machine. So, measurement plays a very important role in making any meaningful decision about the condition of the machine. So, if I if we all recollect our conventional diagram, which we always make so, this is my machine which I am going to monitor.

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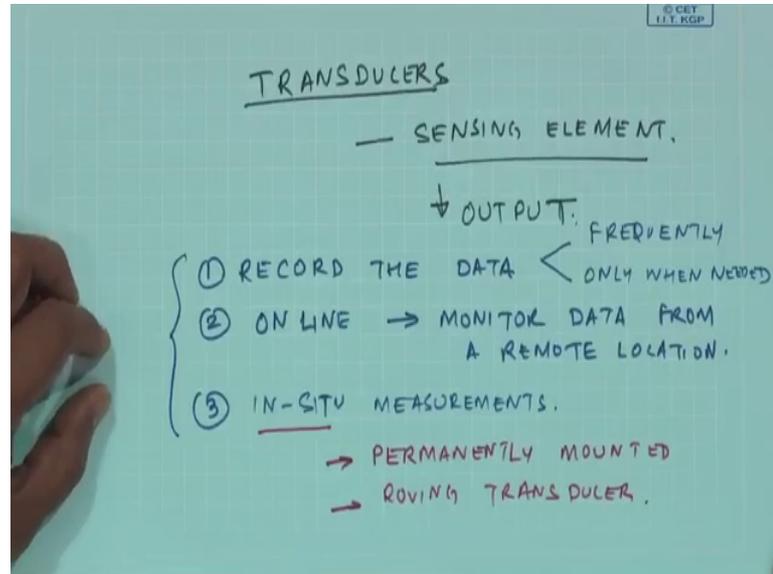


And I have to put an external transducer to get some signal. It is this analysis of the signal which in the time domain on an oscilloscope would something like this. So, is this correct or not? Is our study going to be whether we have measured it correctly?

So, a physical quantity needs to be measured just to recollect, what are the physical quantities? Particularly in c b m 1 is it could be the vibration of the machinery, could be noise, could be temperature, could be the electrical current or voltage, could be the flow rate etcetera. So, there are these are the mechanical physical quantities which needs to be measured. So, as you will recollect, there are transducers which can use which can be

used to measure these physical quantities. So, in this week we are going to see, what are these different types of transducers?

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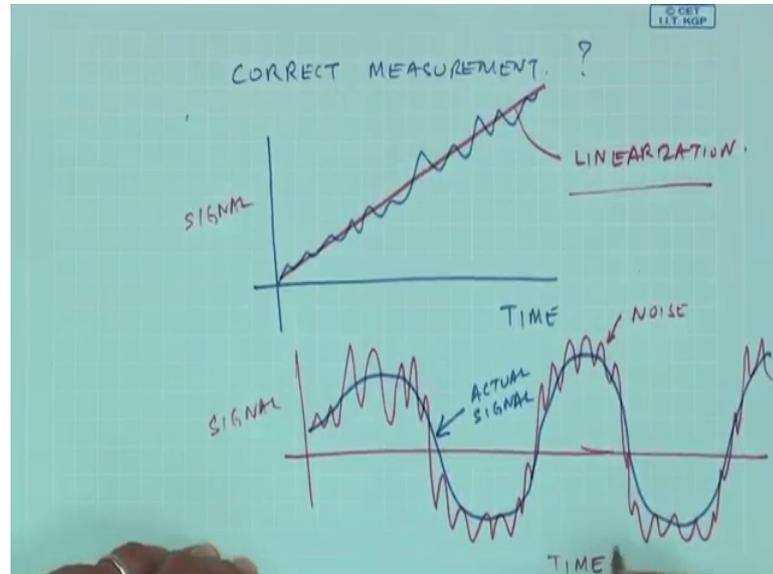
What is the sensing element? And what kind of output does this sensing element give? Now, when we do condition-based monitoring or condition-based maintenance there are certain areas in which these measurements are done.

One is I could just go to the machine and record the data. One is I could online monitor data from a remote location. One is I could even I even this recording the data it comes I can even divide in 2 parts. I can do it frequently or only when needed or I can measure IN-SITU. So, if you look into this 3 aspects of measurement, I could go to the machine and do an IN-SITU measurements I could do it at an frequency every day every 6 months every 2 months and so on. Other is I could be recording the data at a fixed interval or I could record the data only when I need to be. Another location is method is you know I could be remotely monitoring the data which is being continuously generated out of this machine.

So, if you will see the transducers in many of the cases in one case, the transducers are mounted permanently or the other one the roving transducer roving transducer. They are not fixed we will only go to the machine only when at a particular point measure, it and move it go ahead to the next position. Now, question is in system say for example, in a last pen, if we have permanently mounted transducers for doing online monitoring.

Whether, we are doing it correctly is factor to be known? And when we have a transducer correct measurement?

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How do you ensure that? And if I look at this elements of instrumentation in any transducer I have a sensing element.

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## Elements of Instrumentation

- Sensing Element/Transducer
- Signal Conditioning Element
  - Amplification
  - Filtration
  - Linearization
- Data Presentation Element

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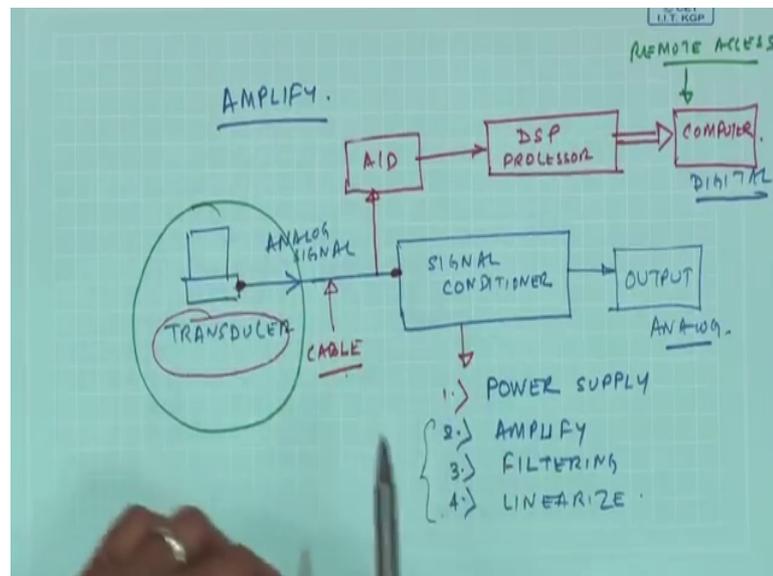
Traditionally, sensing element had been strain gages, but now it is these people have moved in to piezo electric for some of this transducers. Because some of the sensing

elements are passive, some of them are active; some needs to be given an external power supply and so on.

And then when the data which has been measured sometimes by this transducer require some sort of a conditioning. For example, the data with time may be varying like this so, we can linearize this by such a red line or sometimes, there is lot of noise in the signal. You can see this and there is distinctly signal. So, this is my actual signal which is corrupted with noise some signal this is a signal, this is with time.

So, this kind of things may happen while I am doing a measurement sometimes the signal strength is so, low that I need to amplify it.

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So, these are if I have a transducer, it gives an analog signal. So, I need to have a signal conditioner and then we need to get an output. Now, sometimes earlier we had seen that this analog signal I mean I could sometime after the signal conditioning it could be analog signal conditioning, it could be digital signal conditioning.

So, if it is digital I will have an A to D then I will have a DSP processor and which will give data to a computer. So, in this signal conditioner many of them can be done, this is signal conditioner sometimes provides power to the sensing element, sometimes it amplifies the signal, sometimes it can done some sort of a filtering to remove noise or I could linearize the response and so on. So, some of this quantities can also be done by an

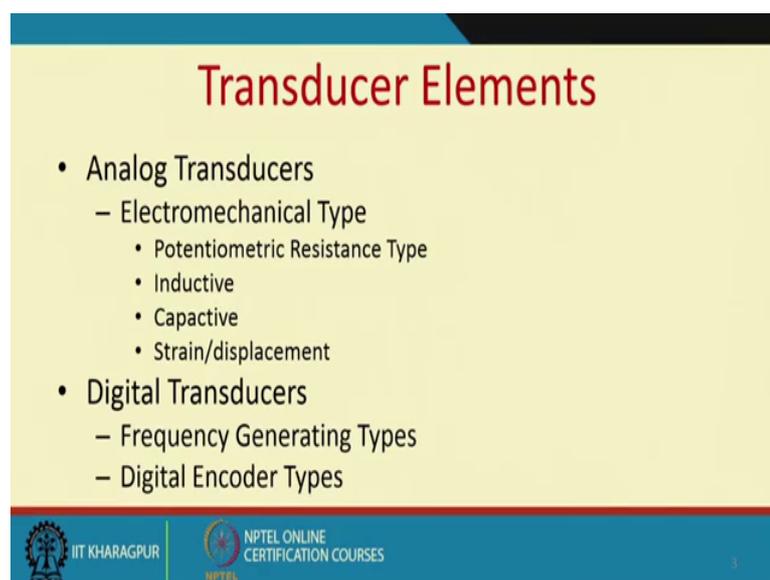
A to D and suitable DSP processor, before we displayed and this could be an data display unit either analog or digital. Now if you look into this there is there is a there is also a cable which is also a device which is transmitting signal from one end to another end have a transducer.

So, there are certain lot of properties associated with the transducer itself which we will discuss. So, in an instrumentation setup this is the very generate nature of how the setup is. So, you know traditionally we have been people have been doing the analog processing. So, we have you know dials etcetera which will display an RMS volt meter etcetera, which will display the output out of an analog transducer, but now a days with advanced instrumentation we can have an A to D convertor and right after the A to D convertor.

We can have a DSP processor where all this signal conditioning can be done and the output is displayed on a computer. It could be stored on a computer, it could be accessed remotely. So, the present-day scenario in instrumentation is this is the route people take. The transducer a to DSP processor computer which may be remote access, but then we are going to focus mostly on this transducer part.

But to give you an overall picture, we need to know that this is what actually happens in an instrumentation system.

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The slide is titled "Transducer Elements" in a large, bold, red font. Below the title, there are two main bullet points: "Analog Transducers" and "Digital Transducers". Under "Analog Transducers", there is a sub-bullet "Electromechanical Type" which includes four further sub-bullets: "Potentiometric Resistance Type", "Inductive", "Capactive", and "Strain/displacement". Under "Digital Transducers", there are two sub-bullets: "Frequency Generating Types" and "Digital Encoder Types". The slide has a yellow background with a blue header and footer. The footer contains the logos of IIT KHARAGPUR and NPTEL ONLINE CERTIFICATION COURSES.

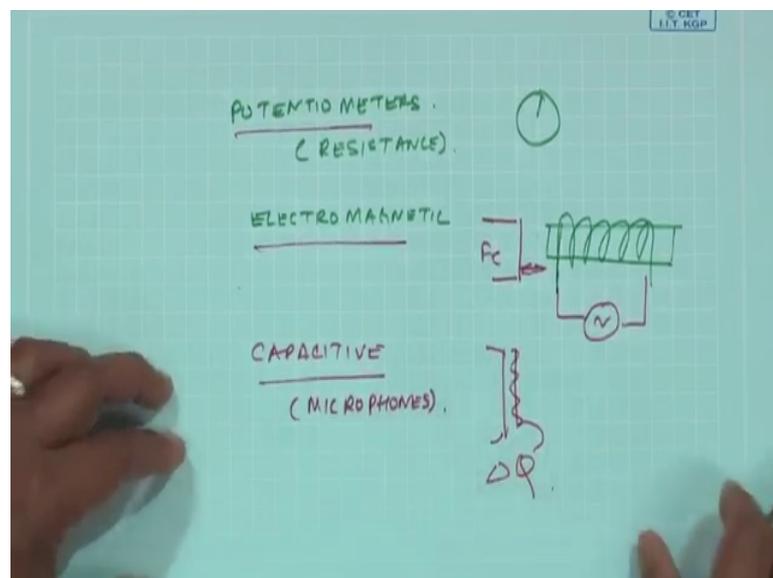
## Transducer Elements

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

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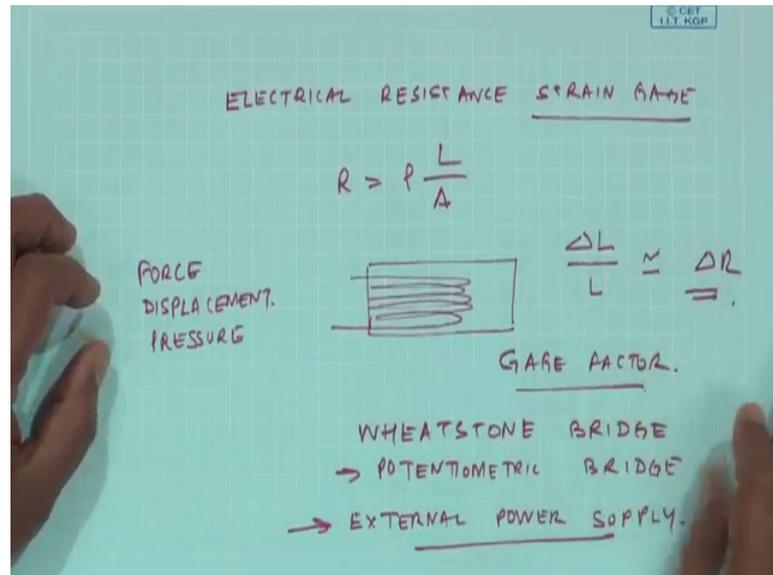
So, if you look at the transducer elements, the analog transducers are the electro mechanical type. Wherein we have a resistance change to give an certain output like the potentiometers. We have an change in the inductance or change in the magnetic field to get an output. We have an capacitor where you know there is change in the capacitance to get an output. We have a strain gage type of sensing element where in for a change in the strain because of a mechanical load or displacement we can get an electrical output. So, these are the traditional electro mechanical type analog transducers. So, one is the potentiometer.

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So, all the knobs we know which you see in some of the analogs it is basically changing the resistance. So, it will give a corresponding output inductance like an electro magnet if you move the electro magnet close to a surface an RN surface remove this they will be an electric voltage generated. And then capacitance, if there is a change in the one is fixed with the polarized voltage and if there is a motion they change in the capacitance. So, there is a charge which is produced which could be sensed like in the microphones etcetera.

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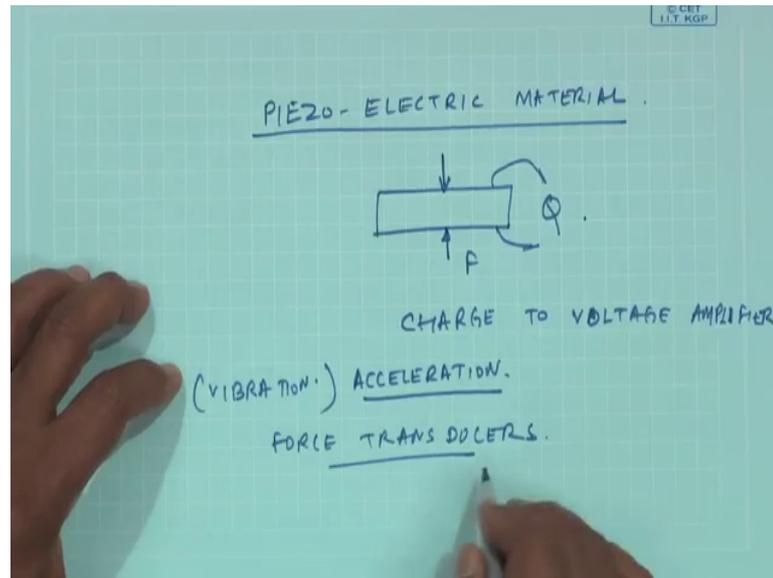
Of course, the electrical resistance strain gage you know the resistance  $r$  is equal to  $\rho L$  by  $A$ .

So, resistivity of the material of the wire  $\rho$  is cross sectional area  $A$   $L$  is the length of the wire, the change in the length there will be change in the resistance which can be measured by a wheat stone bridge circuit. So, this is how the strain gages are made so,  $\frac{\Delta L}{L}$  will produce change in the resistance and so on.

Depending on this parameters if you do a take a log and a derivative of that you can find out the strain gages are sensed by their gage factor. And you will require to measure the change in the small resistance you require, what is known as a Wheatstone bridge circuit or a potentiometric circuit.

The problem of this is they require an external power supply, but. So, any place when there is a mechanical force, displacement, pressure, they the strain gages could be used as the sensing element.

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But in the recent times the piezo electric material are being used as a sensing element in piezo electrometry. What happen it is a material which has a very sensitive axis? If it is pressed by a force across the it will develop a charge. So, this charge could be converted to voltage, by what is known as a charge to voltage amplifier and you will get a voltage corresponding to this mechanical force.

So, in this piezo electric material can be used to measure force, can be used to measure you know based motion or acceleration. So, in other words vibration is measured through such piezo electric accelerometers and even force transducers have such piezo electric materail sensing element. By the way this piezo electric material also have a property that if give an electric voltage they will also have a mechanical motions and this materials are also used in control as an activator in small devices etcetera.

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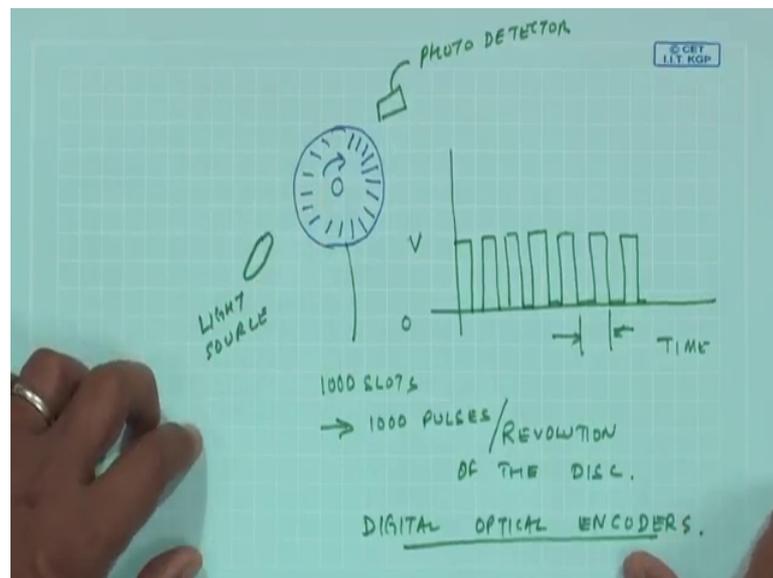
## Transducer Elements

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



But then there are also certain digital transducers like they will generate a frequency or they will generate the digital encoder or digital pulses.

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For example, if I have an disc with lot of radial slots and so on which is made to rotate and if I put a light source and a receiver at photo detector other end. So, if the rotation of this disc if I look at the time, I will get certain pulses and so on. And this pulses could you know, if there are 1000 slots they will correspond to 1000 pulses per revolution of the disc.

And because these are optical they are very light weight. So, such disc are known as the digital optical encoders. Now, many a times you know if the speed changes, this pulse width is going to change and this is 0 to some voltage may be voltage because it is a light source and a photo detector has a very quick response. So, the detection will be either no or yes no or yes. So, it is a logic circuit such digital signals can be generated out of this transducers. And they can be used for you know sensing the speed of rotating shaft which is attached to and where the. So, optical disc is attached to and so on.

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**Measurement Chain in an Electromechanical Transducer**

- Input (Physical Variable)
- Primary Sensor (Mechanical Displacement/Strain)
- Electromechanical Transducer (Electrical Output)

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so, if you look at the measurement chain in any electromechanical transducer, I have an input which is my physical variable. This physical variable could be voltage, could be current, could be vibration, could be strain etcetera.

And then I have a primary sensor and this primary sensor could be the sensing element be the strain, be the piezo electric crystal and predominantly in our CBM we are talking about talk about transducers where piezo electric material is the most important sensing element. And then we will get a corresponding output from this transducer.

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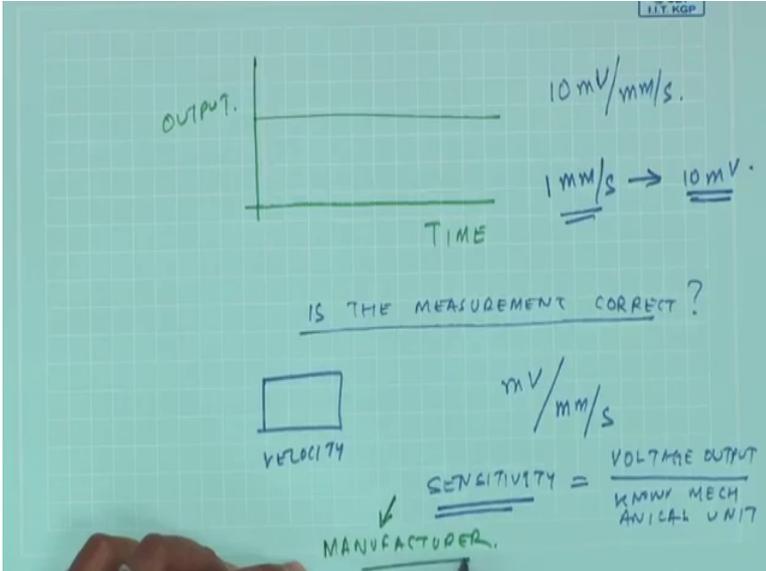
## Performance of Instruments

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



Now, if I was to come to the performance of any measuring instrument or transducer I get some output.

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OUTPUT.

TIME

$10 \text{ mV/mm/s.}$

$1 \text{ mm/s} \rightarrow 10 \text{ mV.}$

IS THE MEASUREMENT CORRECT?

VELOCITY

$\text{mV/mm/s}$

SENSITIVITY =  $\frac{\text{VOLTAGE OUTPUT}}{\text{MECH ANICAL UNIT}}$

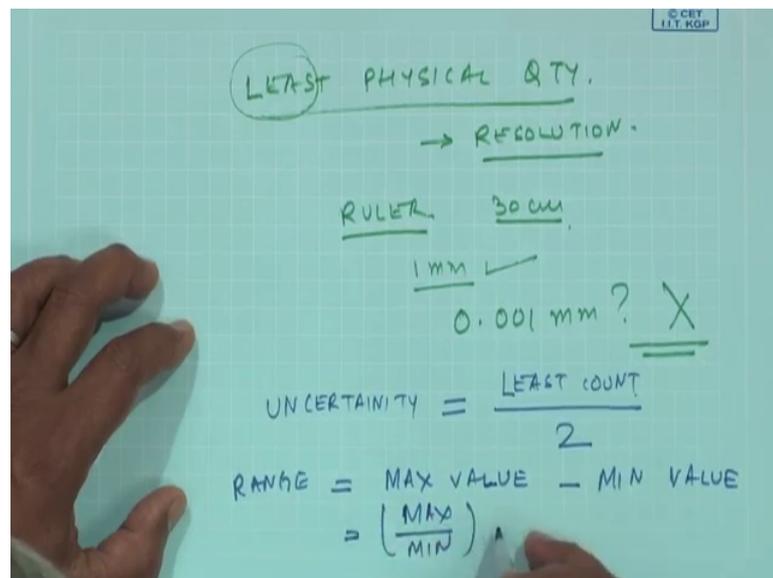
MANUFACTURER.

So, we will see for this transducers, there are certain terms static characteristics like accuracy and precision, resolution, sensitivity, range, hysteresis and impedance. Because, a first question anybody ask is the measurement, correct how does one ensure that? One is this accuracy and when we discuss about errors I will discuss more about accuracy and precision, but right now I will talk about sensitivity.

For example, I am measuring a mechanical quantity say velocity I am getting some voltage output in millivolt sensitivity could be some voltage output for a known mechanical unit for example, the sensitivity of the transducer was 10 millivolt per millimeter per second; that means, one millimeter per second of mechanical velocity will produce an output of 10 millivolt.

So, this sensitivity is a quantity which is given by the manufacturer. Because as you know, when you talk about data activation devices all we do is getting some voltage signal and then we try to acquire the voltage signal, but so, in terms of the physical unit this sensitivity is very, very important. At the same time, you will see that what is the least physical quantity a transducer can measure? That is known as the resolution.

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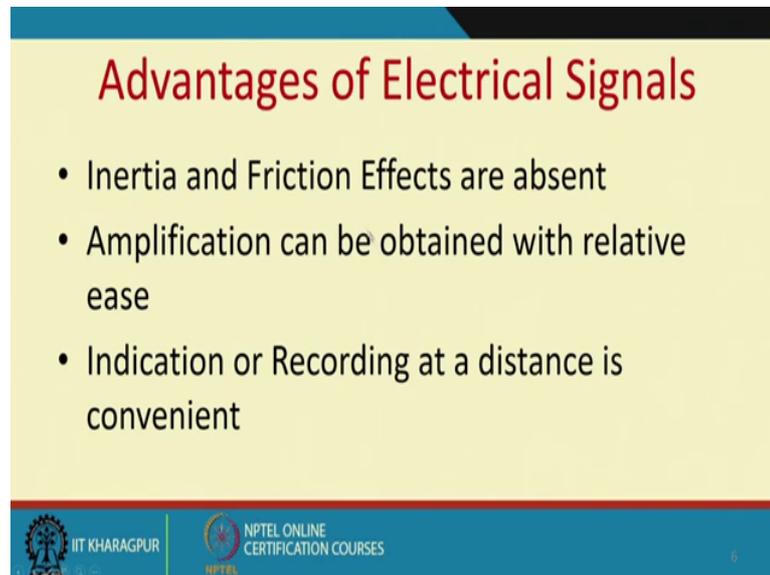


Obviously, if I have you know ruler which we use in our class room a 30-centimeter ruler, if you will recall their the least resolution is about 1 millimeter. Question is with such a resolution can I measure 0.001 millimeter no it cannot because a least it can sense is 1 m m. So, there is a term called uncertainty, uncertainty of a measurement is nothing but the least count divided by 2.

So, I need to find out what is my least count to measure the minimum value of a physical quantity which I am measuring. So, and this range is nothing but the either the maximum value, minus the minimum value or sometimes, in the logarithmic scale it is the MAX by minimum value in an log scale.

So, we will talk about this in the subsequent classes regarding the hysteresis impedance, accuracy precision and the dynamic characteristics which is very important to transducers which are using which we are going to use in condition-based monitoring.

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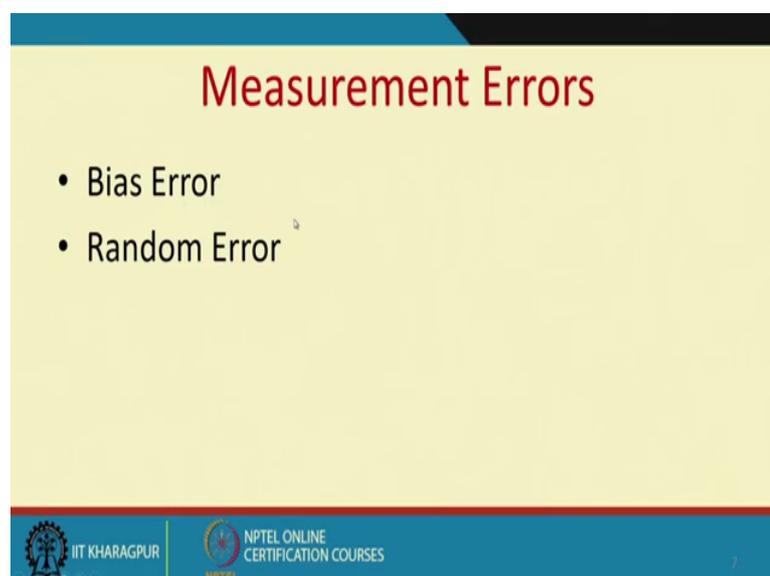
## Advantages of Electrical Signals

- 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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Of course, at the same time we must know that why what are the advantages of electrical signals? Because inertia and friction effects are absent and amplification can be obtained with relative ease. That is why electrical signals are very convenient and recording or remotely monitoring is very, very conveniently done with electrical signals.

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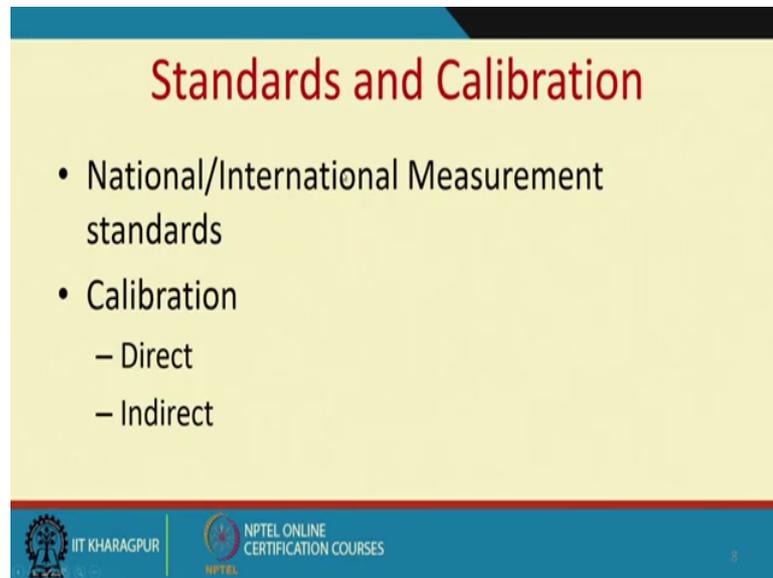
## Measurement Errors

- Bias Error
- Random Error

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So, every transducer which we have talked about needs to convert the quantity which is measured to an equivalent electrical quantity of course, we will discuss about errors in the subsequent classes.

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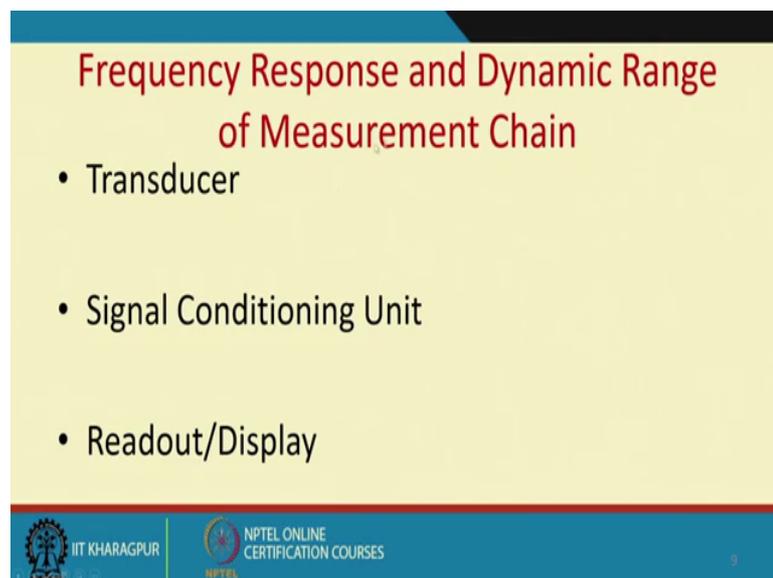
**Standards and Calibration**

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

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And then how errors can be mitigated.

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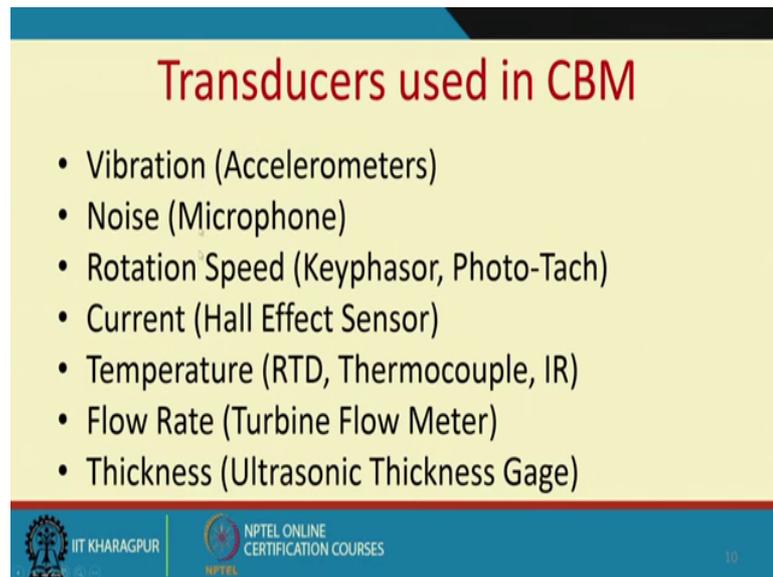
**Frequency Response and Dynamic Range of Measurement Chain**

- Transducer
- Signal Conditioning Unit
- Readout/Display

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And then of course, we will see the effect of frequency response and dynamic range on the entire measurement chain.

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## Transducers used in CBM

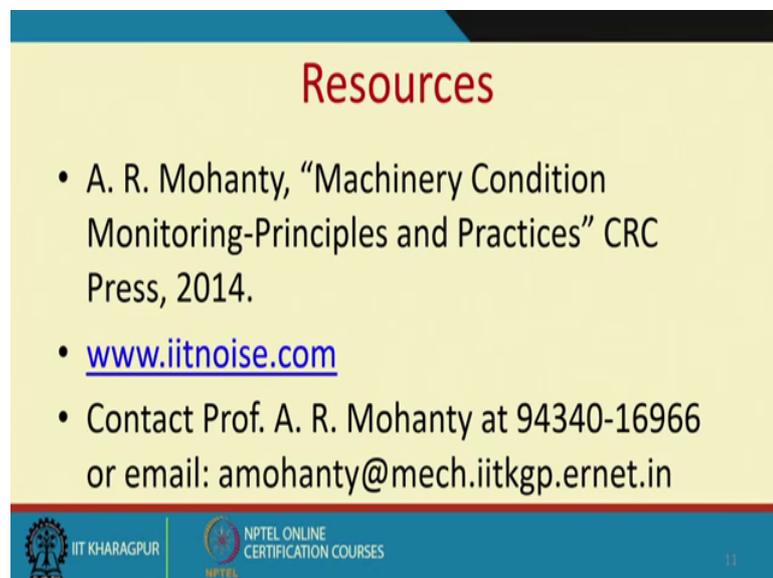
- Vibration (Accelerometers)
- Noise (Microphone)
- Rotation Speed (Keyphasor, Photo-Tach)
- Current (Hall Effect Sensor)
- Temperature (RTD, Thermocouple, IR)
- Flow Rate (Turbine Flow Meter)
- Thickness (Ultrasonic Thickness Gage)

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These are the some of the transducers which we will be using in CBM then there are few other sources in my book.

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## Resources

- A. R. Mohanty, “Machinery Condition Monitoring-Principles and Practices” CRC Press, 2014.
- [www.iitnoise.com](http://www.iitnoise.com)
- Contact Prof. A. R. Mohanty at 94340-16966 or email: amohanty@mech.iitkgp.ernet.in

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Thank you.