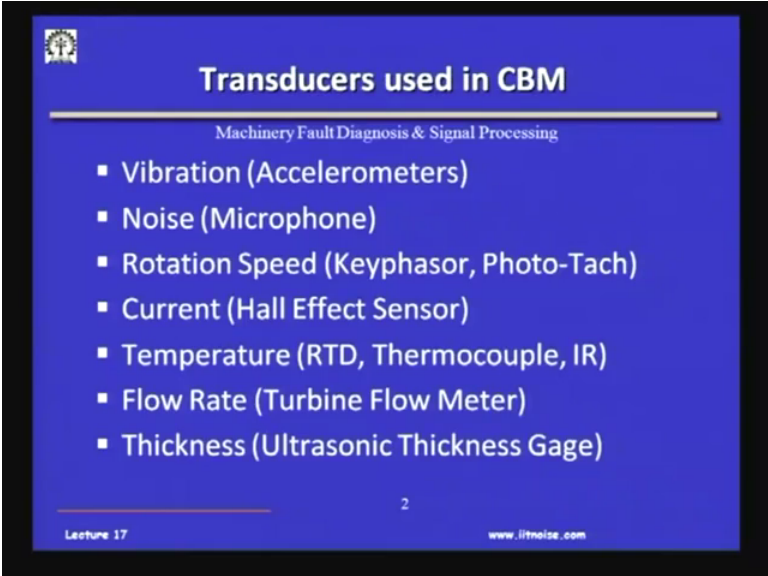


Machinery Fault Diagnosis and Signal Processing
Prof. A R Mohanty
Department of Mechanical Engineering
Indian Institute of Technology-Kharagpur

Lecture -17
Sensors and Transducers

In the last class we discussed about basics of instrumentation. Today we will be focusing mostly on the actual sensors and transducers which are used for condition based maintenance. And of course this list is pretty exhaustive but we will be focusing mostly on the transducers which are commonly used mostly for vibration monitoring, current monitoring, temperature detection etcetera.

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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 Maintenance (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 "2" in the center, and the text "Lecture 17" and "www.iitnoise.com" at the bottom.

Well to briefly discuss in a nutshell the transducers which are used in CBM are for vibration and usually the accelerometers are used so you know whatever you see within the parentheses in this slide are actually the name of the transducers. So, the mechanical parameter vibration is measured by accelerometers.

The noise or sound which we hear are machineries radiate is measured easily by a microphone. This both the accelerometers and microphone could also be used to measure the noise under water when you are talking about a propeller noise inside the sea and in that case those are known as Hydra phones other than microphones.

Similarly if you want to measure the vibration of an offshore structure which is submerged in the water you could use perhaps underwater accelerometers, now we will discuss about them later on. But another very important parameter in mechanical machines as you would have seen in signal crossing is related to the rotational speed.

Because as I was telling you a machine needs to operate and particularly you will see that in many of these machines the most common element is a shaft which is rotating and held on couple of bearings. So, the rotational speed of the shaft may change may fluctuate with time because of load, because of defects.

So, the instantaneous measurement of rotational speed at all times is very, very important. You know you would have studied in our undergraduate you know instrumentation courses that we use ohmmeter to press on a shaft and then we see a use a mechanical tachometer to measure the rotational speed. But in a remotely operating machine so no aware there are no persons.

I possibly cannot have anybody stick in a tachometer mechanical techno meter to a shaft. So, we have to think of optical ways or the key trigger like the key phaser which are used to measure the rotational speed. Another important aspect which we need to measure is the motor current signature analysis. So, current needs to be measured, current we use you know we have used a meters to measure the RMS current.

But current waveform has to be measured you could be using what is known as a Hall Effect sensor. We will discuss that and the next comes temperature temperatures. You know I am I do not mean in a temperature of a human being here. But temperature of machineries, temperature of bearings, temperature of oil baths in the gearboxes and these temperatures could be very, very high. I mean imagine temperature of a blast furnace inside a blast furnace.

I possibly cannot stick in a thermometer to measure the temperature of a blast furnace, so we have to use certain non contacting type sensors like the infrared of the parameters. And a certain

high temperature, high range of temperature which could be measured or perhaps the thermocouples or the RTD is a resistance temperature detector.

And then in many of the process parameters particularly in chemical plants where in you know people need to measure the flow rates of certain fluids or slurries okay and how do you measure such flow rates you know in the lab. We all have used no venture meters, orifice diameters, you know Pitot tubes etcetera or if your system has at the flow rates but then you would have seen you know you need to measure the pressure difference.

From pressure difference you need to calculate the flow rates you have to need to know the area of the pipe and so on. But turbine flow meter is another device which could be very easily put online on a pipeline and then all you will be getting is a certain speed of at which the fluid is flowing through it and once you know the area of the pipeline if you multiply that you will get the flow rate instantaneously.

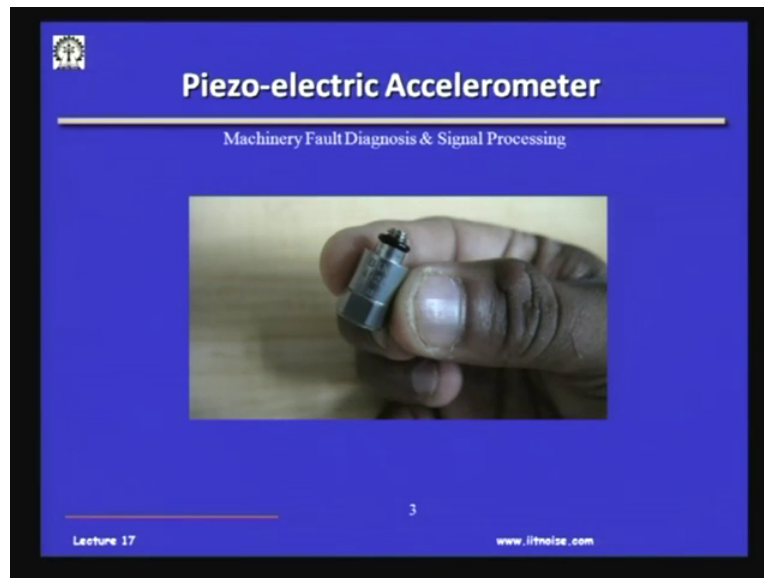
So, when the processes are very dynamic when the flow rates are changing because of the operations on the plant particularly in large oil refineries and chemical plants that is where we use turbine flow meters. And another important very important and NDT, non-destructive test technique is the measurement of the thickness.

Now as I was telling you there is the pipeline because of the fluid flowing through the pipeline what happens deposits get deposited in the inner wall of the pipeline. So, that is going to affect the flow rates. So, such scale formations are deposits will reduce the internal thickness of the pipe. So, from outside how do I know that such a build-up has occurred in the inner walls of the pipeline? This could be very easily measured online by an ultrasonic thickness gauge.

Sometimes people are even do a portable x-ray radiography of the tube from the outside particularly in boiler tubes. When there is a lot of scale formation because the water flowing through the pipe lines there is scale deposits and the thicknesses get reduced because of rather thicknesses increases. So, the effective diameter of the pipeline for flow reduces and this can be measured by techniques like radiography or ultrasonic thickness gauge.

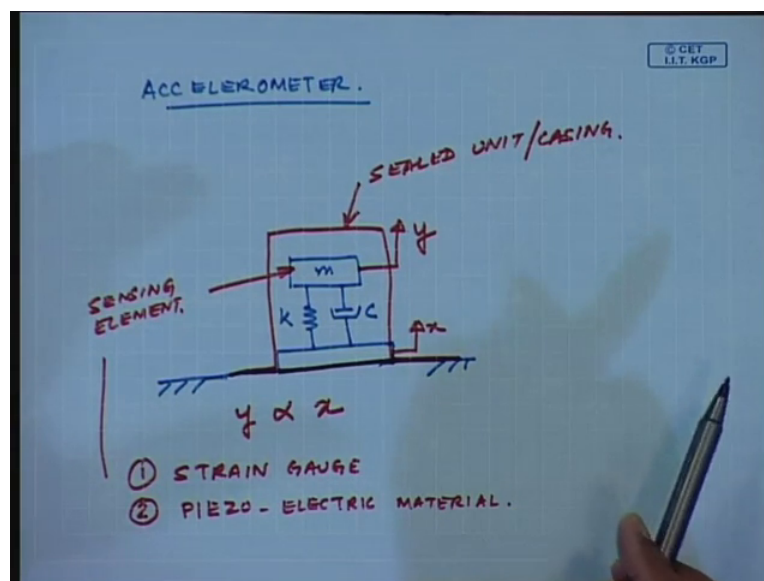
And another important applications of ultrasonic thickness gauge which I had told earlier also suppose there are internal cracks in the structure in the; which cannot be seen visibly from the outside. So, if we have an ultrasonic probe it can be used to measure the presence of the crack. So, I will begin one by one to begin with let me tell you what this accelerometer is about.

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This is just a piezoelectric accelerometer.

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We had we had studied the basic of accelerometers in the lecture on vibrations essentially what happens is let me tell you the internal mechanism here. I have a mass here, so essentially if this is

put on a structure which is having a motion next okay. So, onto this I put a unit like this, so I would like to know measure the motion acts. Now what happens because of this motion x this mass is going to have a motion y , it dependent on the k and c .

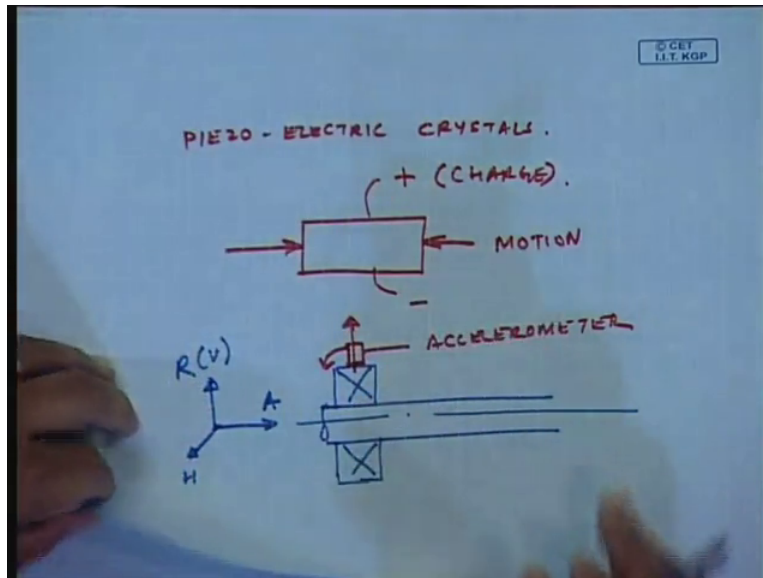
So, somehow if I can have this motion y related to x okay with certain functions of k and c . So, indirectly if I measure y , I can know what the x is? And this x is actually the vibration displacement here. And this I will put it in a nice housing okay. Where in; so this is actually your sealed unit or casing okay. Now because this mass is having a motion y , I could be putting certain sensing element okay.

Now what could be the sensing element the sensing element could be as I have told you it could be strain gauges? Because you know because of this motion there will be some strain and this strain will be indirectly responsible get a measure of what the x is? So this is what initially was the strain gauge type of accelerometers. But no strain gauges within and certain power supplies and they need to know resistance.

They have to be the resistance should not change your temperature, so there are some problems with this kind of accelerometers. But then came, a material which is known as Piezo-Electric material. Now piezo electric are actually naturally occurring materials. If you have not seen a piezoelectric material I do not know if you have seen sheets of mica they look kind of a mica sheets.

And they occur in nature though artificially also we can clear create them in the laboratory I will come to that later on. But these piezoelectric crystals which are found in nature have a certain property.

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That is given a force or a motion they are going to develop a charge, I will I will put a generic motion charge and it is in a particular direction. So, there they give the highest amount of charge when loaded unloaded in a particular direction. So, that is the most sensitive axis of these piezoelectric crystals. So, they are isotropic they have a directional feature. So, if I go back to this mass here if I put a piezoelectric crystal next to this mass or embedded it in this mass.

So, that it is sensitive to the motion in the x direction. Then as soon as I have a motion x, here this piezoelectric crystal here is going to have a motion and it is going to produce a charge okay. So, because of the feature of the piezoelectric crystal if there is a motion in the horizontal direction it is not going to sense, because once I and this is this unit I put on a structure it may so happen that I am only measuring in x direction.

But what if there is a strong motion in the y direction in the z direction is my piezoelectric crystal going to sense it, no and that is the advantage of piezoelectric crystal it is very directional okay. So, the manufacturers find out which is the most sensitive direction of the piezoelectric crystal and they align it in the direction of measurement of the acceleration or the motion because as I was telling you vibration is measured in any direction.

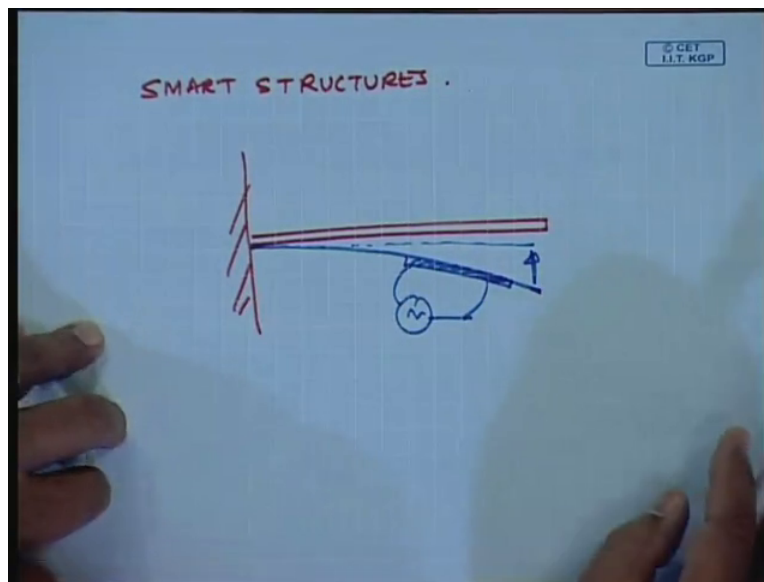
I need to specify the direction for example when I have an vibration transducer put on a bearing of a shaft. So, this is the radial direction this is the along the horizontal direction this is the axial

and this is the horizontal or this is known as the vertical. So, I have put an accelerometer on the bearing housing here. So, it is sensing in only the vertical direction if I want to measure in the axial direction now to rotate it by 90 degree.

So, that this becomes in this direction. So, I have to align the accelerometers along their most sensitive direction. So, coming back to the discussion of resolve is a piezoelectric crystal. So, piezoelectric crystals are found in nature and which have this property that whenever I give a motion they give a charge.

Another very, very important feature of the piezoelectric crystal is given an electrical charge they are also going to have a motion.

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And that is what is used in what is known as we are talking about in particularly in control. When you talk about smart structures just for an example say I have a cantilever beam okay in its first mode of vibration it will have a mode shape like this okay. Now suppose I want to reduce, it is it is having a motion suppose I want to reduce this motion here.

So, what I could do is I could perhaps borne certain piezoelectric material and give an electric charge a proportional electrical charge here. So, that this comes back okay particularly so, whenever you know because of motion there are certain uncontrollable flutters. A flutter concern

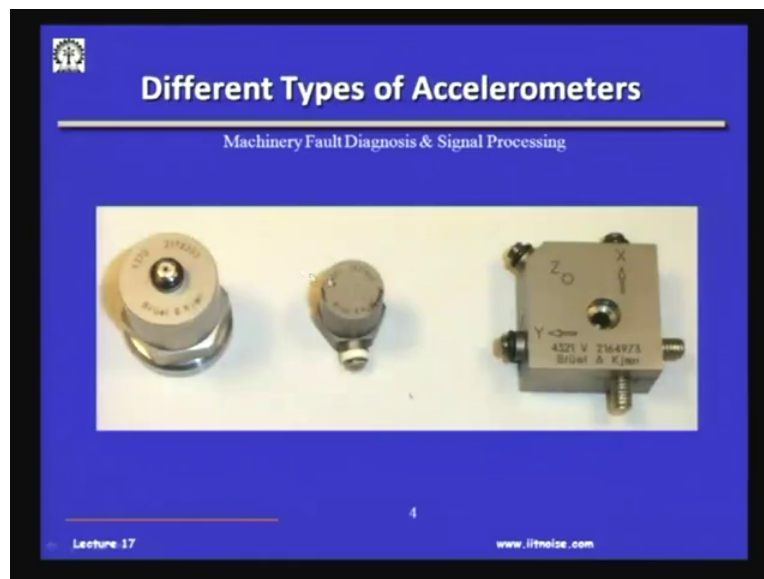
an uncontrolled vibration low frequency and low amplitude vibrations and I could reduce that by putting up with a little crystals.

For example you know when you have a space shuttle when you have the you know solar panels deployed out of a Space Shuttle because of motion they will have some amount of motion. So, this motion could be reduced by putting in piezoelectric crystals and giving them proportional charge. So, that they will give a motion back and they will go back and reduce the motion.

So, this is we are not going to discuss this in the transducers for CBN. But it suffices to say that in accelerometers nowadays we use piezoelectric crystals as the most sensing elements because they can withstand high temperature they do not require an external power supply like in the case of a strain gauge. And they can very small in size okay and then they can be also put inside.

If so for example if you look at this accelerometer here this is this is the connector wherein we get these signals to the, we get to charge and which will be amplified and then propagated. So, this transducer this is the base and the piezoelectric crystal is already sealed inside this okay.

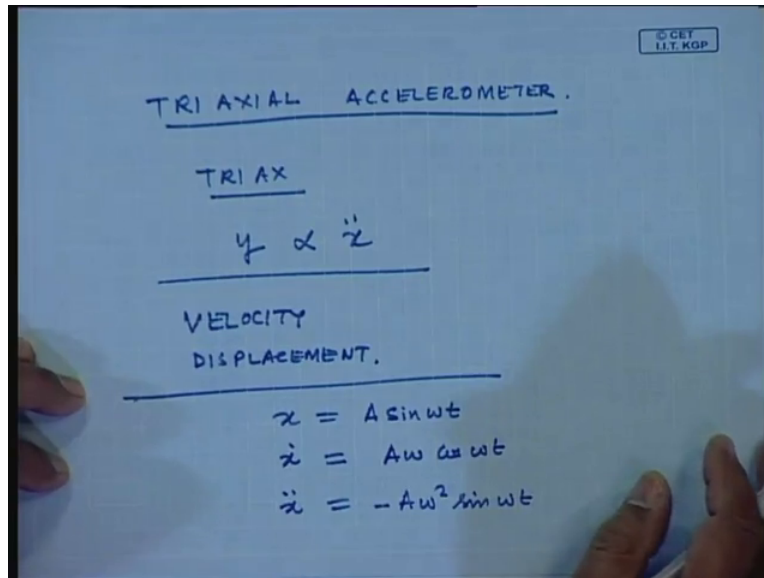
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I will show you another accelerometers this is another accelerometer where this diameter is about the size of a 50 paisa coin and there is a connector wherein we connect the cable and

sometimes the connector is on the top, sometimes it could be on this side. It depends on the convenience of using it. Now this is very, very important accelerometers.

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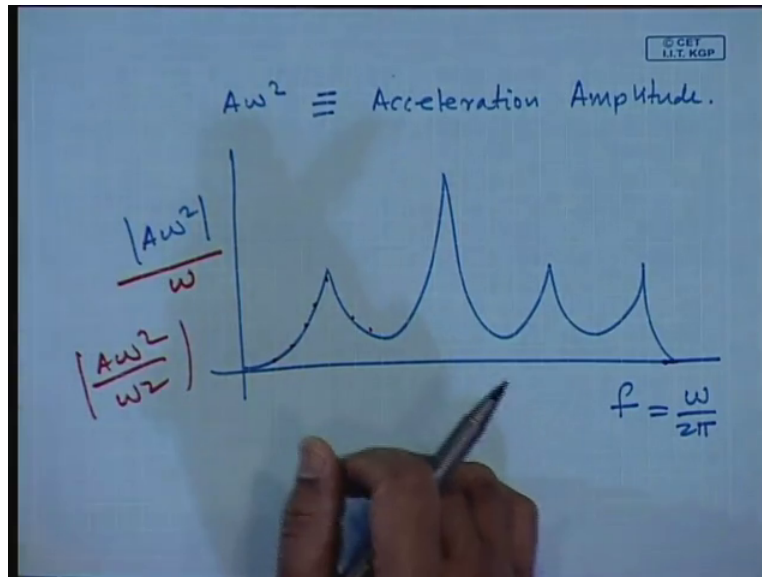
Because and this is known as a tri-axial accelerometer if you see here it is written X, Y, Z and these stads are used to either mount them to this structure where we are measuring the vibration. So, X means the cable connected out of this location is measuring the motion in the x direction. And Z means it is out of the plane of this presentation here and Y is in this direction.

So, you can think of it that three piezoelectric crystals having perpetually mutually perpendicular the orientations have been put together so that at one point I can measure the vibration in three directions okay. So, this is very convenient that I need not put three uniaxial accelerometers rather at one place I put a tri-axial accelerometer.

And sometimes in short it is known as a Triax you know people loosely call it as Triax. So, the output which comes out of the displacement you will see from the equations of vibration that the y can be actually proportional to x double dot and then we will get a measure of the acceleration of the base to which this transducer it is attached. Now sometimes we need to know what the velocity or what the displacement and that measured point is.

If you will recall suppose I will have a motion in general terms $x = A \sin \Omega t$ at any frequency this is the expression for the displacement. So, $\dot{x}$ is the velocity is nothing but $A \Omega \cos \Omega t$ and $\ddot{x}$ the acceleration will be $-A \Omega^2 \sin \Omega t$.

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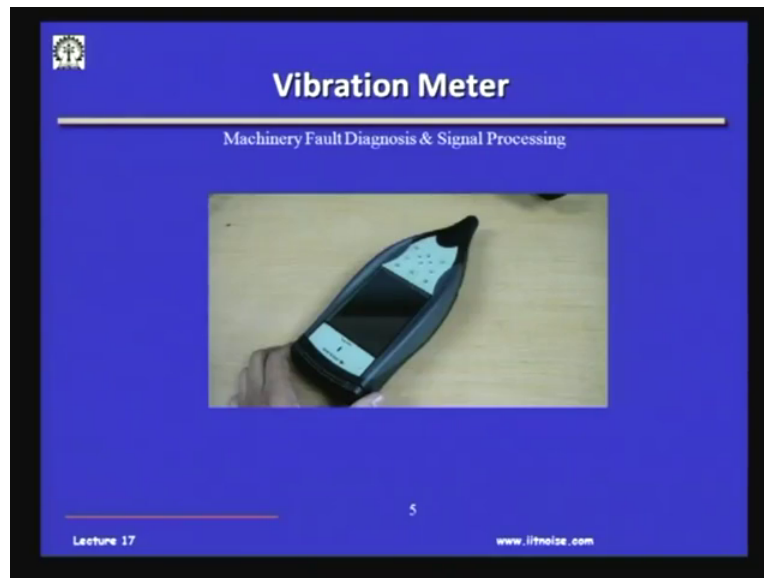
So, I am measuring the acceleration amplitude I know my $A \Omega^2$ is nothing but the acceleration amplitude which has been measured by an accelerometer. And if I plot the spectrum from the signal which is obtained out of the acceleration accelerometer amplitude I may get something like this right. So, this is equal to Ω by 2π .

So such a spectrum we can very easily obtain by doing frequency analysis or Fourier analysis of the vibration signal which measured from the transducer. Now if somebody wants well tell me the velocity spectrum of this signal you could do it very easily or the fact that once you divide this by Ω you will get the velocity spectrum is not it. And then if you divide it by $A \Omega^2$ by Ω^2 you can get the displacement spectrum.

So, this is done electronically once you measure with an accelerometer you measure the acceleration $A \Omega^2$ once you do the Fourier analysis you will get the spectrum all you have to do is at every frequency either a divided by Ω or divided by Ω^2 and then you will get the velocity spectrum or displacement spectrum.

And this so this is done as a post processing many vibration meters essentially a vibration meter is nothing but an accelerometer with its signal conditioning amplifier and a readout is what is involution meter. And the vibration meter you will have an option either to see the velocity spectrum, displacement spectrum or acceleration spectrum.

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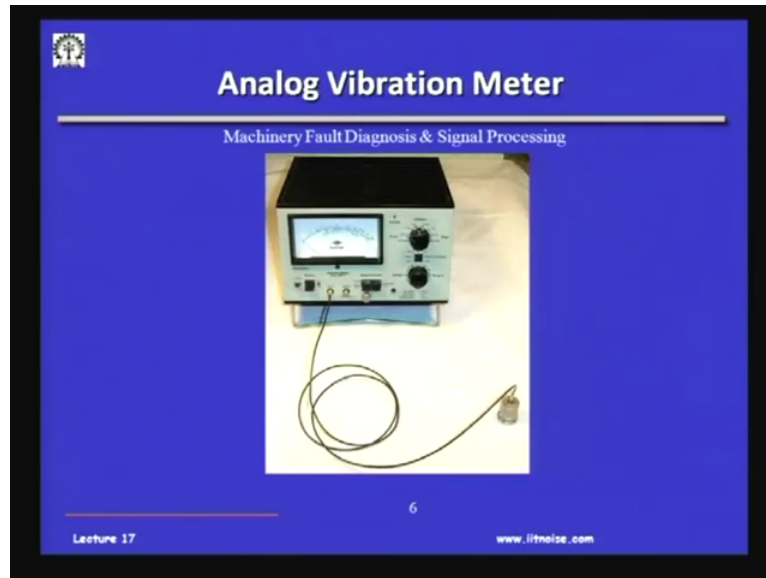


I will show you a typical vibration meter you know which is available nowadays. And this vibration meter of course the reason this is pointed like this is. This also has an option that this electronics could be also used as a sound level meter and if you replace this end by a microphone this becomes a sound level meter. Otherwise you know since we are using it as a vibration meter there is nothing here just a dummy cap here.

All you have to do is with the cable attached your accelerometer into this okay. so, all the electronics in terms of the signal conditioning is here and on this screen you could see the spectrum of the vibration or the velocity or the displacement you could put a filter so that if you say I am only interested to know the vibration at 100 from 100 to 1000 Hertz, you can very well do that and this will display you the overall valuation level in the meter okay.

But before we had this vibration and this is a digital version meter which pretty recent and this we have just acquired in our lab

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But then if you go to the earlier days you know we had this analog vibration meter and this is what it looked like so this is the accelerometer which I was just talking about. This uniaxial accelerometer. So, the piezoelectric crystal is inside this okay. And this can withstand very, very high temperatures may as well go up to about 200 degree Celsius or 300 degree Celsius. This is shielded from moisture, humidity, rain etcetera.

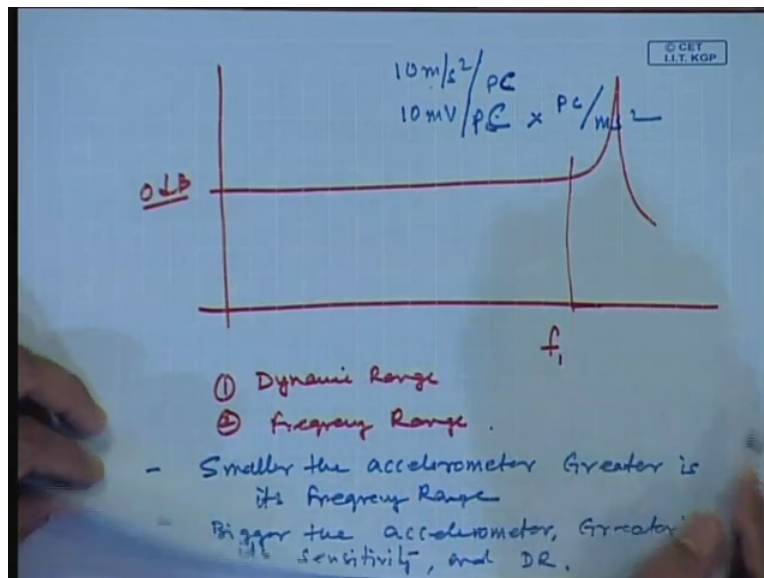
And then this cable because as soon as the charge is produced will cut the details of the vibration transducers regarding the mounting etcetera in the subsequent classes. But all it suffices to say a charge is produced and this charge goes into an amplifier wherein the charge is converted to voltage. So, once I have a voltage signal corresponding to the acceleration.

All I can do in this meter here in this vibration meter there are options whether you own to see the analog displacement, analog velocity because there are analog filtering units this is not a digital device but the example or the device I showed you before this is a digital device. So, there is an AC to DC converter.

Once we have digital we will get the velocity and axial displacement very easily just by dividing my Omega Square and Omega. But in those days when the computer rated detection was not available people were using electronic integrators or in this case yeah electronic integrators to obtain the displacement and velocity from the measured acceleration okay.

And then you had an analog readout so this is kind of very obsolete but this was a very popular equipment of a particular manufacturer okay. Now before I conclude my discussions on the vibration measuring transducer which is an accelerometer we will discuss about the details of how the vibration accelerometers have to be mounted on structures and so on later on.

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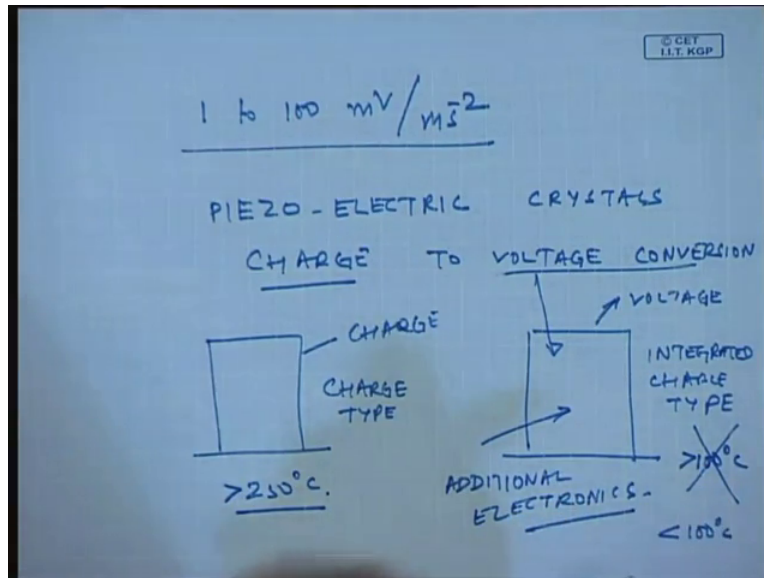
But it suffices to say right now is this vibration accelerometers I have very good frequency response there is a typical frequency response curve of a vibration accelerometer. And this and sensitivity I mean take it back, so there are two important parameters one is the dynamic range and another is the frequency range.

Because we are talking about two we are talking about dynamic signals, so the accelerometers have a very, very large frequency range and this smaller the accelerometer smaller the accelerometer greater is its frequency range and bigger the accelerometer greater is its sensitivity and maybe dynamic range.

Typically the sensitivity of these accelerometers are maybe know 10 meters per second square per Pico Coulomb ok. So, this is the acceleration to the rather I put it this way 10 millivolts to Pico Coulomb and this will be converted to Pico columns to sorry millivolts to meter per second

square and then we will do another converse on Pico coulombs to meter per second square and then finally we will get millivolt to meter per second square.

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Typically the frequency or the sensitivity ranges of these accelerometers are about 1 to 100 millivolts per meter per second square okay. Now question is the piezoelectric crystals produce a charge, so I cannot store charge for a long time they discharge and then decay with time. So, a charge to voltage conversion needs to be done.

And once I have the voltage I can send it through the signal so some accelerometers which we just discussed they are the charge type another is the integrated charge type. Here the output from this is a charge; here from the output from this is a voltage because the voltage conversion is done inside this. So, there is an additional electronics built into this kind of accelerometers because straight away I am getting a voltage.

Now this additional electronics are basically IC chips. So, because they are inside this element you know which is put in a stainless steel casing I cannot subject this integrated child type of accelerometers to more than 100 degree Celsius is not enough okay. They have to be at a lesser than 100 degree Celsius.

But this charge type because the electronics is outside in the vibration meter. I can go maybe up to 250 degrees Celsius okay. So, this is two things you have to keep in mind particularly when you are doing vibration monitoring of places where the temperatures are high, high gear box temperatures are bearing temperatures we have to use charge type of accelerometer.

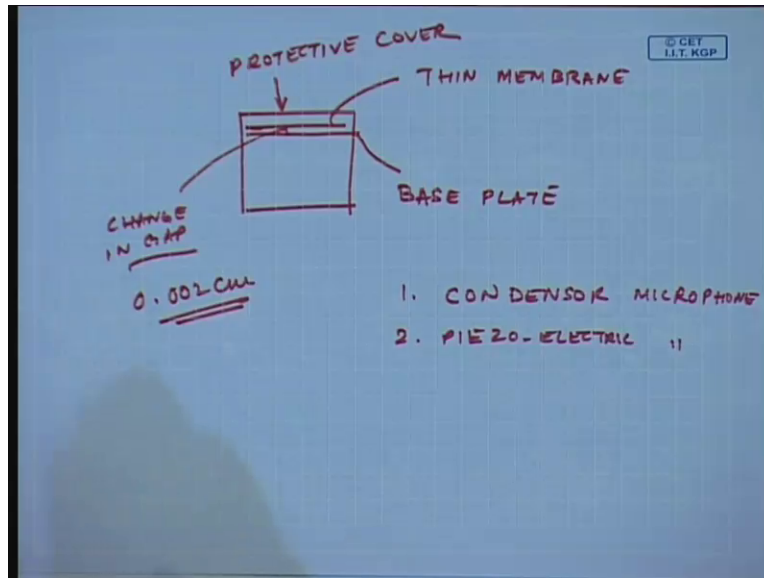
And this integrated charge type of accelerometers or ICP type of accelerometers could be used in room environment. When you are doing modal testing when you are doing you know in low temperatures you can use this kind of accelerometers. But for high temperatures for rugged industrial accelerometers which if you need to always use charged up. So, yeah this selection you have to keep in mind when you are using accelerometers.

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Now let us talk about another important mechanical parameters this mechanical noise and this is essentially measured with a microphone.

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So, microphone as I was telling you has two plates so one is the base plate and another very thin membrane or a diaphragm. So, this membrane is going to deflect and this gap is going to change and this gap to begin with could be about 0.002 centimetres. So, you can imagine the care they take in manufacturing this piezoelectric there is microphones okay.

And this microphones could be of many type one is this is what I have drawn here is a condenser microphone what I am showing here is a piezoelectric microphone. The question is they look very similar from the outside okay and this is a protective cover. So, this is the slots here below this slots is the diaphragm. Actually this is a protective cover and it is always advisable not to remove this protective cover.

This is possibly the thinnest foil you can ever imagine okay. Even if you blow hard you may sometimes damage the eye membrane okay. So, this is why the very, very sensitive equipment. So, he had a very careful and thus this is this protective cover which is that was not to be open. So, what happens either bit condenser microphone or piezoelectric microphone the only difference is that.

In the case of a condenser microphone because of the deflection of the membrane here this gap is going to change. So, the capacitance between these two plates is going to change thus I look at a

charge which is which is or voltage which is proportional to the motion of the diaphragm that is what is the condenser microphone okay.

But as piezoelectric microphone what we have connected to the base plate we have certain piezoelectric crystals. So, because of this motion the piezoelectric crystals will have deformation and then and that is why they will have the output. Now the difference between condenser microphone piezoelectric microphones is condenser microphones can last forever practically because there are just two metal plates okay.

But piezoelectric microphones will lose their sensitivity because the present crystals could possibly age because they are exposed to the elements. In the case of the sealed accelerometers the piezoelectric crystals were sealed forever. They were not open to the moisture or air and so on. But here in the case of piezoelectric microphones they are exposed because we have to have an opening for the air to be impinged on the membrane.

Further it has two different I cannot seal it totally since they are open they will lose with their sensitivity with time, so they may age, so, if a condenser microphone just if it cost 50,000 rupees a piezoelectric microphone will cost perhaps about 10,000 rupees just given order of magnitude. And in your high school physics you must have talked about the carbon granule microphones know voice call.

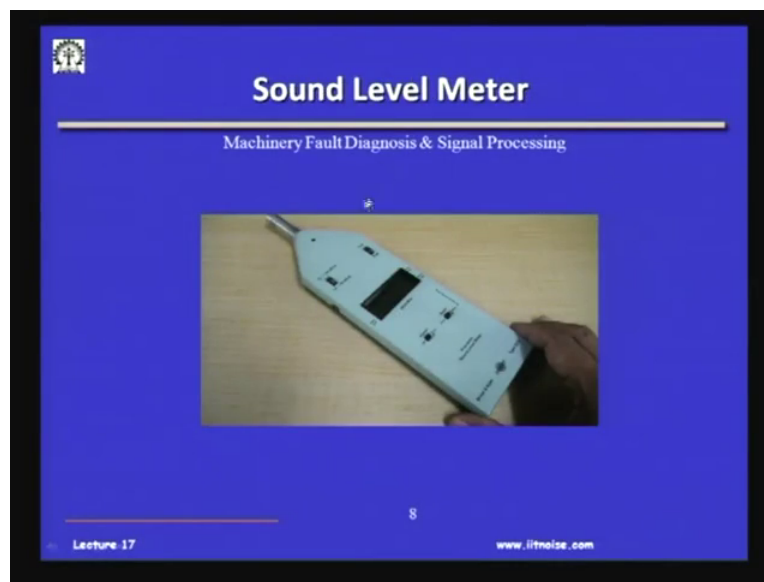
So, there is it because the diaphragm moves because there is a movement of the diaphragm so the coil will move and then a proportional voltage will come because of the movement of the diaphragm where to which this coil is attached. So, that microphone cost 100 rupees, piezoelectric cost 10,000 rupees and this will cost 50,000 rupees.

So, you can imagine what kind of ranges we are talking about. So, this kind of microphones have very, very high dynamic range at the same time very, very wide frequency response they can measure as low as 0.1 Hertz to as high as 100 kilohertz. I know we only hear about 20 kilohertz but there are many phenomena's the ultrasonic phenomenon's beyond 20 kilohertz which can be monitored through such condenser microphones.

And again similar to the observations and accelerometers when the diaphragm diameter reduces their natural frequencies high, so, the smaller the diameter and this is about as you can see this about half an inch here this one so this has a typical frequency range up to about 20 kilo Hertz. If I make it smaller I will have accelerometers up to 70 kilo Hertz up to 200 kilo Hertz.

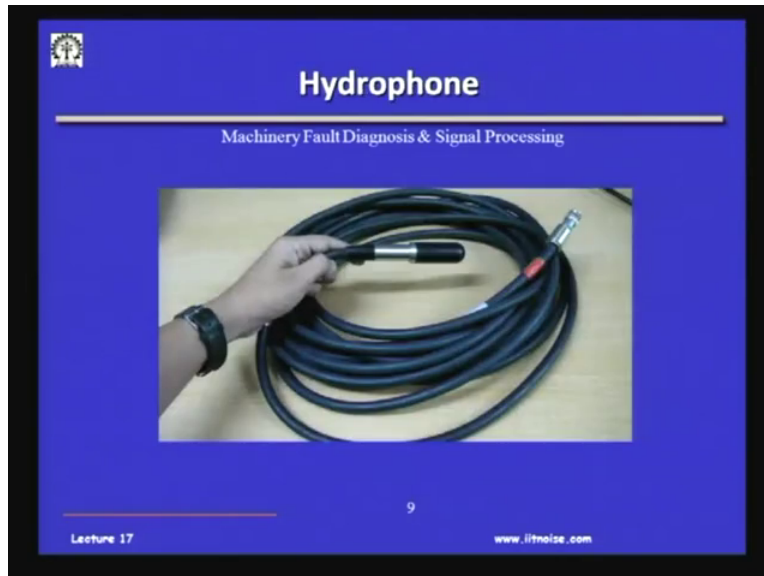
Because you will be wondering what did I do with 200 kilo Hertz because I cannot hear in the sound at 200 kilo Hertz that is fine but there are a lot of mechanical phenomenon of phenomena occurring at such high frequencies particularly whilst you are doing ever jet machining, water jet machining etcetera they produce lot of ultrasonic waves and which could be captured by such microphones similar to the vibration meter.

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These microphones are also put in a sound level meter. So, this is a sound level meter wherein the microphone is only this part okay and then we again have a preamplifier and display unit which will give you the over sound pressure level in a particular frequency range. And then you have an option of selecting the frequency band and so on and also you have an option of either recording the output okay. So, this is a typical sound level meter.

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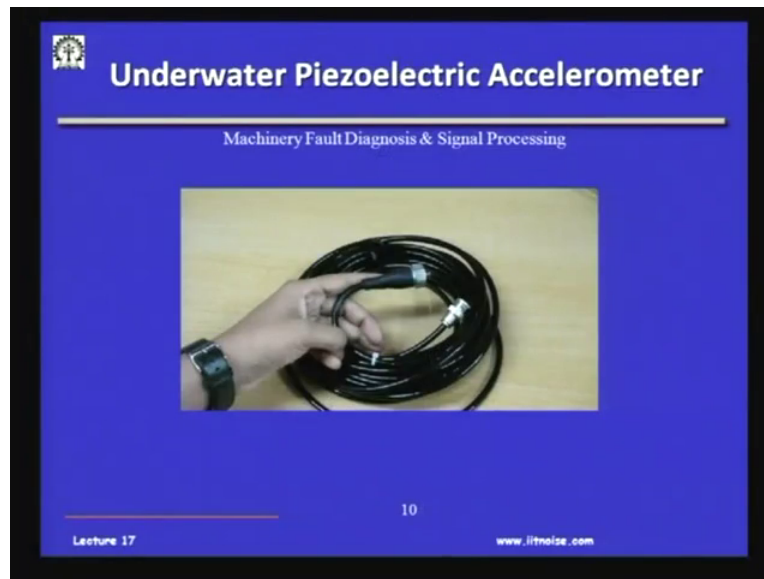
Now this microphone could be used to measure noise underwater and these are actually known as hydrophone. So, the piezoelectric sensing element is here and this black one is just a protective cover. So, when the water waves or the waves come and impinge on this surface the piezoelectric crystal inside this also gets a motion and this signal is converted and sent to a charge amplifier.

He will be wondering why such a long cable because this is about not 10 meters long cable this could be this could be ordered to even thousand meters 1000 meters, 1 kilometers you want a measure your noise deep in the ocean you can have an hydrophone just dropped into the ocean and then you will have a long cable coming from that and in the air they are on these on the ship you could be possibly instrumenting it to an amplifier.

And then see the output okay and such are known as hydrophones you could have an array of hydrophones to sense from which the direction the sound is coming. And particularly in ship hulls and submarines in the front there is a lot of such hydrophones which are which actually work as sonars okay. And this is a very, very costly I know when I was talking about the microphones is the microphone 50,000 rupees this is about 3 lakhs of rupees.

So, I am just giving a feel of the price of this equipment and how sensitive and important these things are.

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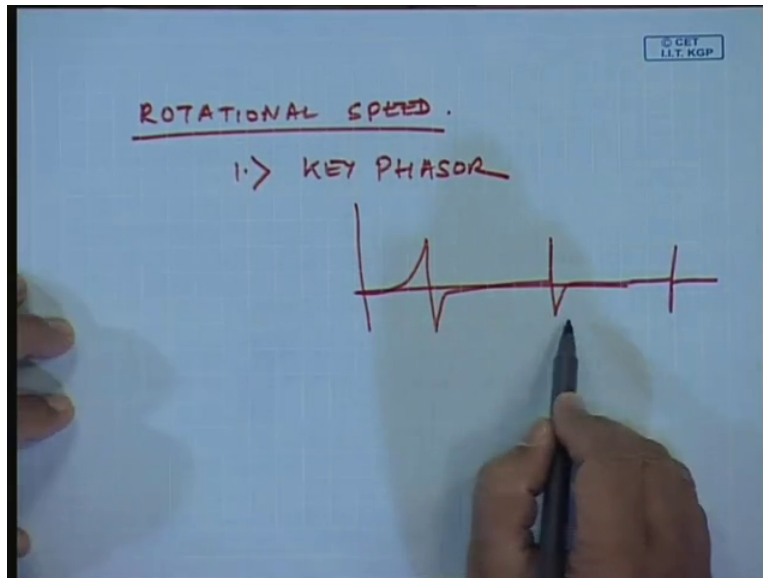
Similar to the hydrophones we also have underwater piezoelectric accelerometer again you see a long black cable and this is the accelerometer and which is again this is this and has to be just attached to the structure and then you take the long cable and then go outside on the air or in the ship or in your lab measure this using an amplifier okay. So, we just concluded measuring the - talking about the vibration and noise measurements.

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Let me talk about the rotational speed measurements, two important equipment are used to measure the rotational speed.

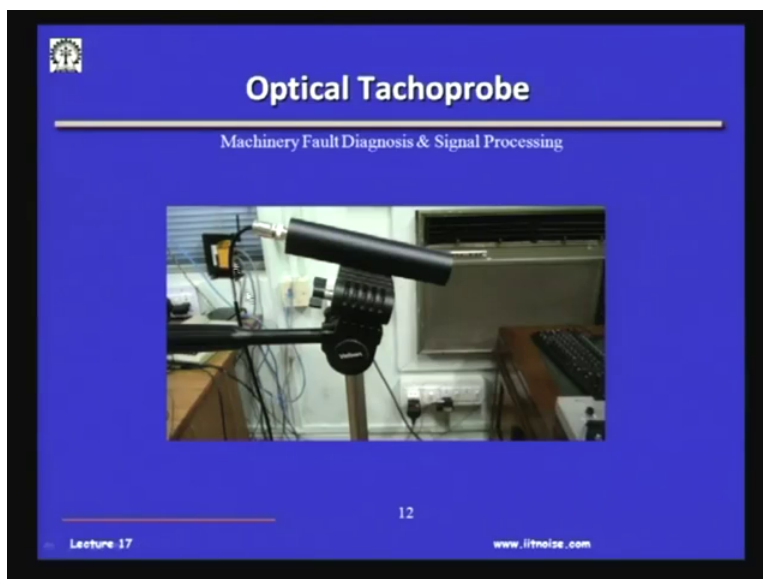
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So, one is the key phaser what essentially you have is you know you see this and there is the coil inside it okay. And then one this shaft is rotating of course I do not have a shaft here the shaft is rotating because of the keyway this the gap between the keyway and this is going to reduce every revolution right. So, then because this gap is reducing you will get a flux.

So, you look at a spike this will not give you absolute rpm but measuring this on a time this you can know what is the inverse of it is what is the rotational speed or this could be used to trigger the occurrence of an event and that is what is the key phaser okay.

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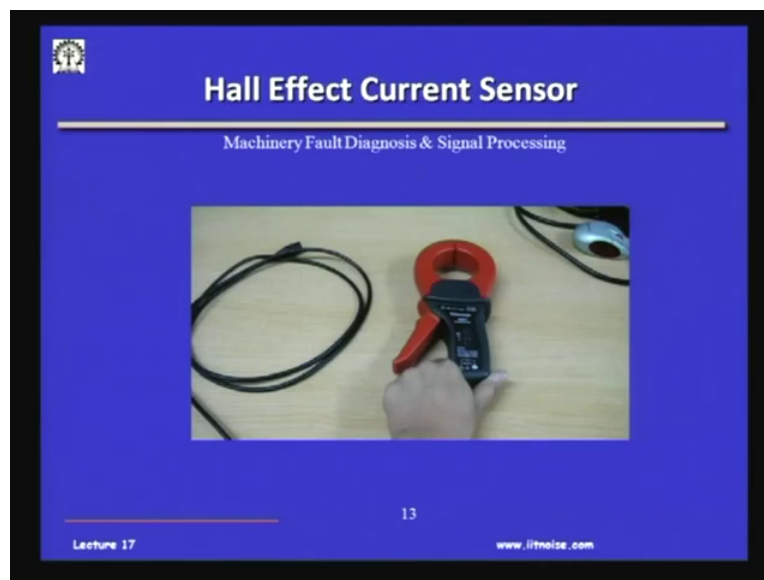


The next one is the photo tag and of course you do not see the set up here but this is a device variant I give an optical out optical light okay. And on the shaft I can put a reflective tape and every rotation this reflective tape is going to come just below the transmitted light so it is going to reflect it back again, so I will get a light pulse back.

So, again from the electronics I can measure the distance between the time distance between the transmitted and reflected and now the time taken for one rotation. So, such photo tag the beauty of such photo tag is unlike mechanical tech emitters wherein you have to press onto a shaft and because of such a load the shaft speed could reduce.

These are not loading the structure and they have a very fast response time you could measure speeds as high as 50,000 rpm with such photo tag or tachoprobes.

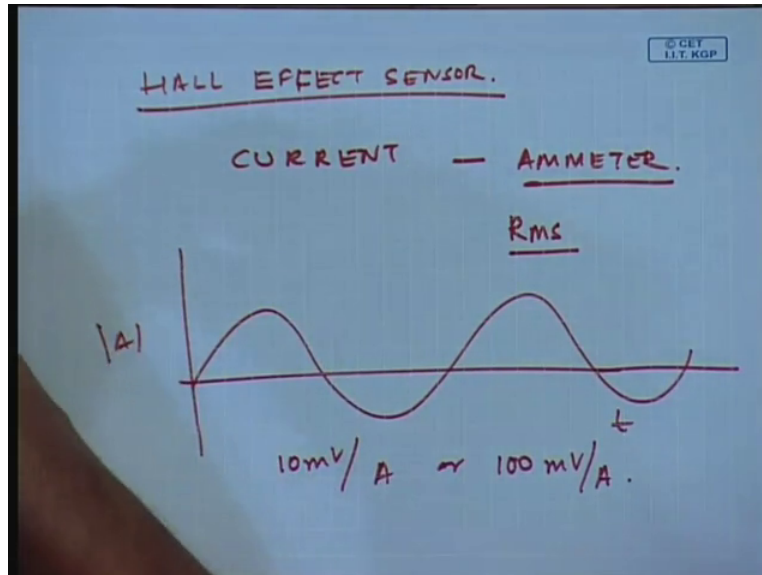
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Now another transducer which you use is the Hall Effect sensor. Now to measure current we all know that ammeters are used. But ammeters give us an RMS output but I am interested to know the current waveform as a function of time okay. And this is given by a Hall Effect Sensors are very easily it happens here is this conductor a conductor and I all I produce here is a magnetic field okay.

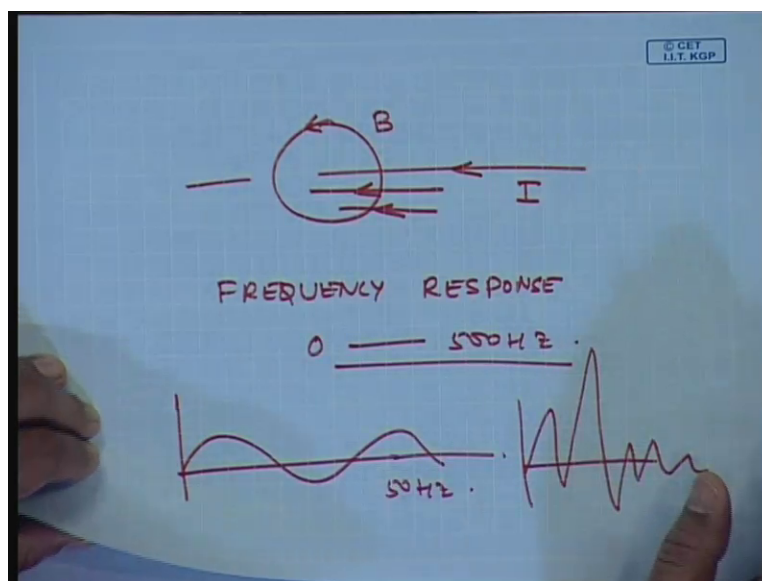
I have a battery source I produce a magnetic field and then there is a current carrying conductor. So, depending on the intensity of the current depending on this magnetic field this guy is going to generate a voltage. Now, the simple laws of 9.9 busy okay and this current is proportional is shown as an output voltage.

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So, usually the typical sensitivity of such Hall effects sensors is about you know 10 millivolts per ampere or about 100 millivolts per ampere okay.

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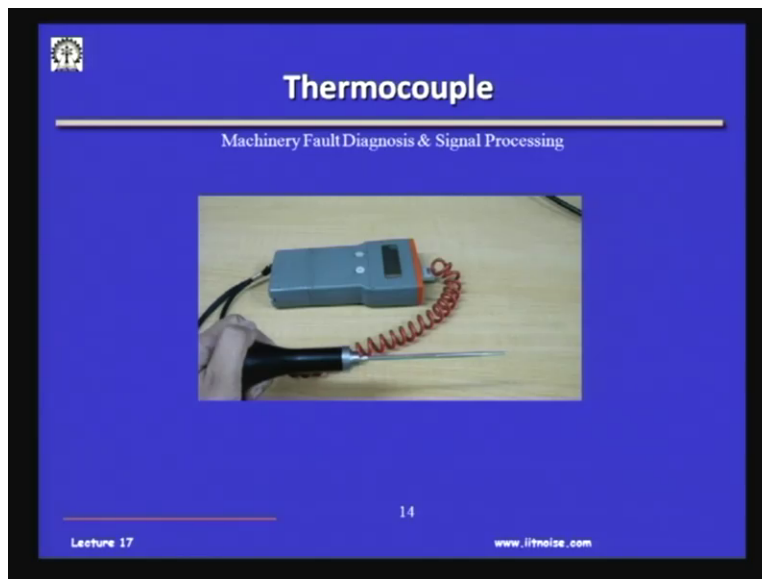
I can increase the sensitivity of this by instead of one cable suppose this is a ring and I produce a current carrying and there is a certain magnetic field is going around to increase the sensitivity or

output of this system I could be putting in few more current carrying conductors so the output will increase and I can always zero set it.

The advantage of this is this as a good frequency response almost from 0 or 0 to 500 Hertz you can measure with such a current carrying Hall Effect sensor which is not possible with ammeter. Now typical current supply current is about 50 Hertz okay and this emitters can measure only up to 50 or 100 Hertz.

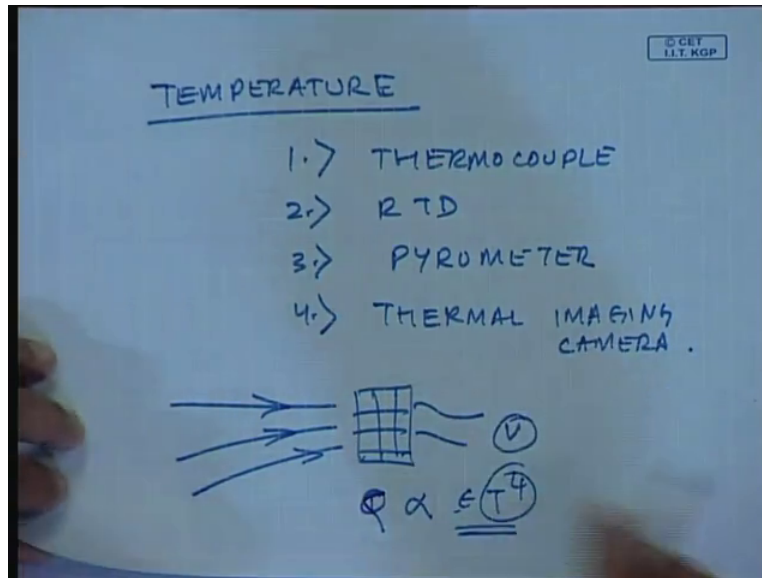
What you will see later on when you talk about the motor current signature analysis when you are discussing about how this waveform can be analysed to find out the mechanical defects I need to know the waveform whether there is any fluctuations in the waveform etcetera. At what frequencies so this is where these Hall Effect sensors are very advantageous and I will get a voltage output corresponding to the current carrying by the carried by the conductor.

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And another mechanical parameter is the temperature

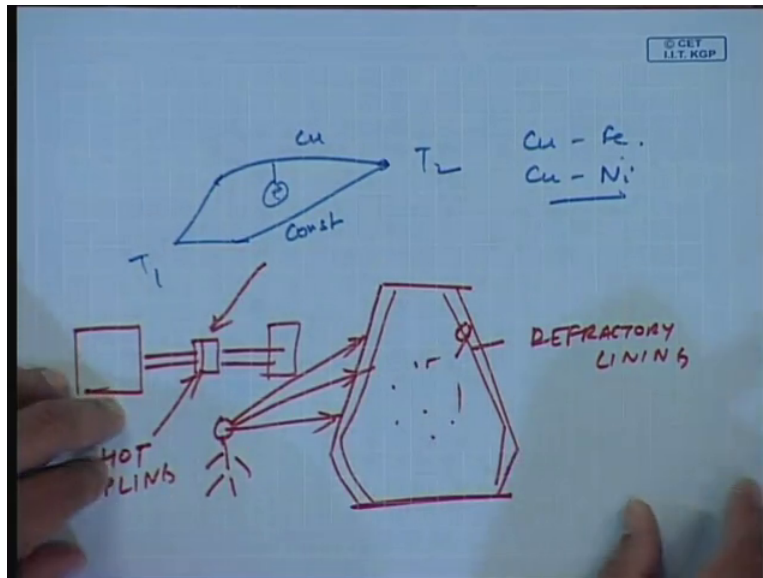
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And temperatures could be measured by thermocouples, RTDS, pyrometers okay. Because nowadays the thermal imaging cameras are available because there are many devices which will change colour excuse me which will change colour based on the temperature? Look at the charge coupled devices and then they will give a voltage output corresponding to the colour and which are used nowadays in the cameras etc. So, these have been if you can focus beam into such cells okay and then they will give you a voltage corresponding to the intensity and the colour.

We can get a indication of the temperature of the target and you all recall the Stefan Boltzmann law okay to treat the power house it depends on the emissivity and ϵ to the power 4 okay, it flux okay, so this is the absolute temperature of the body to the power 4. And the surface emissivity and this has been used in thermal imaging cameras and parameters. But here I want to show you what we have is a thermocouple essentially a thermocouple in if you will see here thermocouple.

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Is nothing but when we have two wires kept at different Junction which could be copper, constantan, copper, iron etcetera, copper, nickel? So, many such combinations are there and based on these combinations they have different temperature ranges. So, such a junction if it is kept at a temperature I will get an EMF okay.

And this could be another T_1 , T_2 I am not going to details of this but suppose and if this is at a known temperature I know the voltage I can look into the calibration tables I know the temperature other way there are many ways of looking at it I can have an electronic compensation because of this reference temperature and then I will get a voltage corresponding to the properties.

And this could be calibrated to display with the temperatures, so, this is just one end because you know you would have studied there are thermocouples means I need to end where is the other end. The other end which could be a ice bath or a boiling point bath actually all I need to do is just the reference voltage.

So, this could be given electronically and this is what is given in such hand held temperature detectors which is essentially an electronic unit and this is the unit of target or the probe which has actually two ends which could be put to the temporal place. Where you are going to measure the temperatures and this is a handheld device.

Nowadays many data loggers are there which will just record this voltage and then you will get a record of the temperature signal. Particularly when you are talking about temperatures around an engine wherein we need to know the inlet temperature the exhaust temperature. So, we can put all around the engines not of this thermocouple sensors.

In fact nowadays if you look into any modern engine you will see on the display in your car that the temperature of the engine is displayed either it is hot and cold but the detectors are RTDS or thermocouples okay. But the oil temperature is increasing, what about coolant temperature is increasing etcetera.

So, thermocouples are built around it and then nowadays even in engines there are automatic diagnostic modules. So, I will talk about this when you talk about the case studies you know but such modules always keep a log of the temperature of the important functions systems in your vehicle engine particularly the exhaust temperatures the inlet temperatures, the oil temperature, the coolant temperature and so on.

And this is automatically logged into the data logger so if you and it always overrides and once you go to the service station if there is an abnormality it will record in the data logger. So, nowadays if you take to your car to your service station they will hook up a data logger and retrieve the data from your car's engine and then they will do a diagnostics okay.

Because they know the process tree of your vacant which is apparently ignorant to we when we want drive a car but nowadays it has become mandatory in the abroad and it has become mandatory in our country also to have an diagnostic modules to be placed on an engine okay. Where in particularly now we are not in an engine we are not particularly talking about vibration or noise but mostly the temperature and pressure and so on.

So, temperatures are measured while you are driving it is apparent not obvious to the driver but these things do happen and it gets stored in a simple memory model in the engine diagnostics

module okay. And once you go to the service station you will say sir your thermostat is having a problem.

You would have no clue for how we came to that conclusion but looking at the diagnostics look at the past data he can see the abnormality and so on okay. So, technology has gone so far we do not know about it yet.

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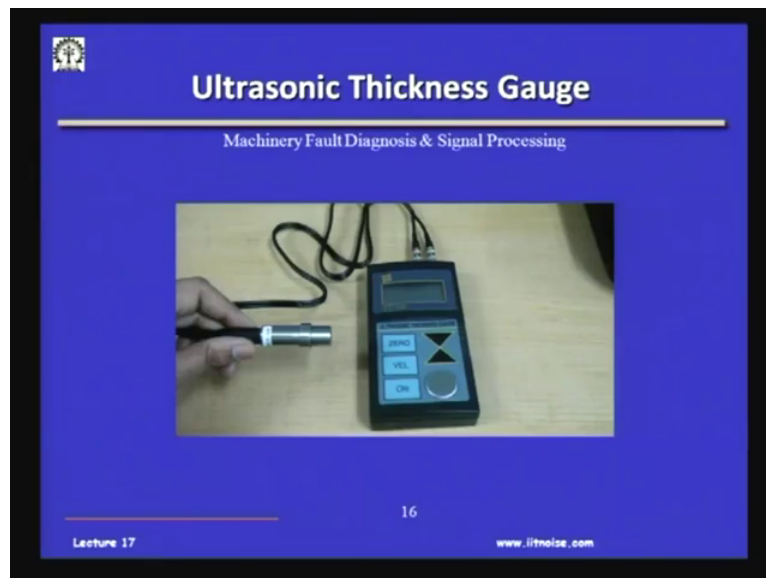
And this is the infrared temperature detector okay again which works on the principle of parameters. So, this we give an optical light beam and depending on the reflected intensity back, we can know the temperature. All you have to do is it is set for a particular emissivity but there are much, much sophisticated versions of this infrared temperature detector wherein you can choose and select the emissivity.

You can have an plot or a storage of the temperature automatically over a period of time and then many places wherein we physically cannot go to measure the temperature okay. We can aim this at that surface. For example in a blast furnace, this blast furnace in the inside they have a refractory lining okay and a lot of very high operations are going what happens when the blast furnace actually ages, some of these reflected linings may weaken may break off.

So, if you from the outside if you do a if somebody is standing next to the blast furnace and does a thermal scanning either through a thermal imaging camera or just an infrared temperature digitally. If he will see some spots where in the temperature has suddenly increased because the insulation the refractory insulation thermal insulation has deteriorated we can easily record it okay. See because CBM always does not mean of dynamic signals.

But these give us some clue as to what could be possibly wrong with the system okay. For example in other places I have a pump or a motor driving a pump and because of misalignment this coupling is becoming hot. So, from a far off place I could put an image a temperature detector and see the temperature of the coupling temperature of the bearing etcetera, so, I can do that okay.

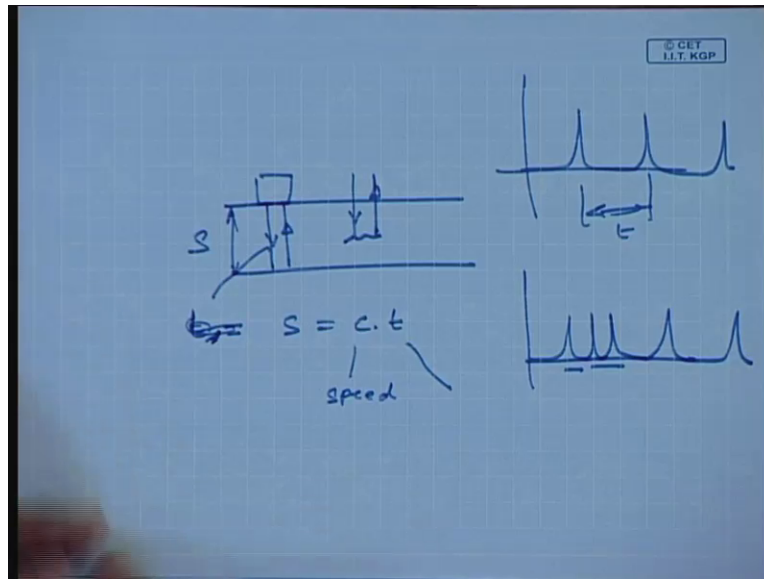
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Another very important equipment is ultrasonic thickness gauge which I had discuss about it you will see this is the ultrasonic probe which has to be put onto a surface whose thickness or I need to measure. So, you will see here two signals one is the transmitter it will transmit the ultrasonic wave so once this wave reflects back is a receiver again by knowing the time difference.

You will know whether the; and because the speed of the ultrasonic wave in the medium is being set here you know how much time it should take for a certain distance to cover.

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So, because if you are scanning this probe on the surface and if there is a defect here. Every time this is going to get incident reflected but once it comes here it is going to get incident and reflected okay. So, in one in the ultrasonic thickness gauge I need to measure this distance t , t is nothing but or I will put it this distance s is nothing but c times the time taken see the speed in this material t is the time taken.

So, in this probe there will be a constant time, so by knowing this t , c is set by you can know what s is so this is the principle we had this ultrasonic thickness gauge and because being high frequency high frequency waves are always very directional. So, they are directional but this ultrasonic thickness gauge could be also used to detect crack, ultrasonic crack detectors in the vice versa you will see how much time it took.

For example if you are scanning and suddenly you see the time between this crack decreased that means there is a short distance this wave has gone so there is a defects impedance mismatch and that is the principle behind ultrasonic crack detectors okay. So, these are some of the equipment which we are going to use or transducers which are going to use in CBM.

And I just gave you a brief about the this transducers and we will discuss about them in detail when we go about the specific cases of vibration monitoring, noise monitoring, motors and monitoring entity and so on okay, thank you.