

Machinery Fault Diagnosis and Signal Processing
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Module No # 08
Lecture No # 38
Acoustic Emission and Eddy Current Testing

This is another lecture on non-destructive evaluation or testing of structures or machine components for fault detection. And in this module we will be discussing on two techniques today in this class. One is on acoustic emission. Other being the eddy current testing. First I will discuss about acoustic emission.

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Mod-01 Lec-38 Acoustic Emission and Eddy Current Testing

Acoustic Emission

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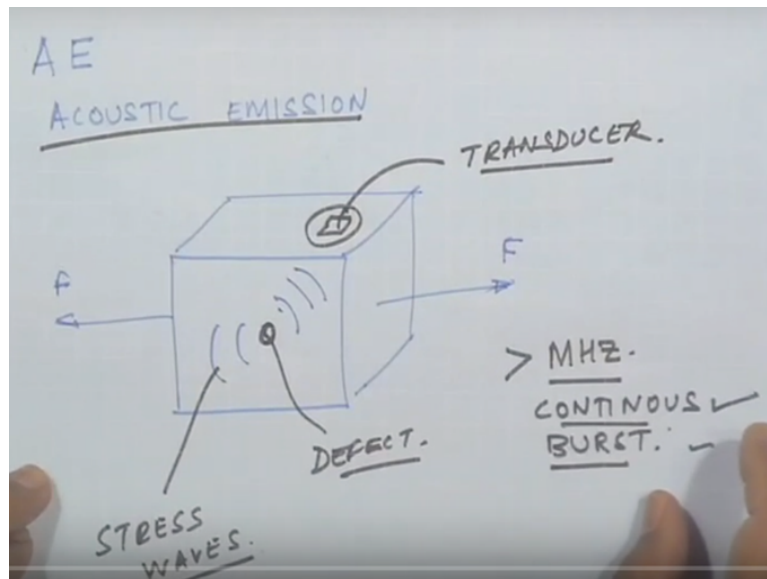
All solid materials have a certain elasticity. They become strained or compressed under external forces and spring back when released. The higher the force and, thus, the elastic deformation, the higher is the elastic energy. If the elastic limit is exceeded a fracture occurs immediately if it is a brittle material, or after a certain plastic deformation. If the elastically strained material contains a defect, e.g. a welded joint defect, a non-metallic inclusion, incompletely welded gas bubble or similar, cracks may occur at heavily stressed spots, rapidly relaxing the material by a fast dislocation. This rapid release of elastic energy is what we call an AE event. It produces an elastic wave that propagates and can be detected by appropriate sensors and analyzed. The impact at its origin is a wideband movement (up to some MHz). The frequency of AE testing of metallic objects is in the range of ultrasound, usually between 100 and 300 kHz

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So as the slide says you know all materials essentially if they are stressed ok they will give back some energy. And this energy if it can be captured and analyzed it gives us clue as to what is the defect in this material ok. So if I look at this definition or what this acoustic emission is. So if anybody or elastic body is subjected to any kind of a stress, it is going to release an acoustical energy.

And this energy is called as an acoustic emission event. As if the material or the machine is crying because of a stress or load on it.

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And the peculiarity or the characteristics of this energy which is known as the acoustic emission is that it is an if a body is stressed whether you can be pulling it with some force. So this gives out some sort of an energy in all directions. And if this energy can be sensed by a transducer, this gives a clue as to what is the defect or the condition. If there is no defect the amount of energy will be different. If there is a defect this amount of energy will be different.

There are certain characteristics of this acoustic emission signal. First of all it is in the megahertz range ok. And then this is either in the form of continuous waveform or as in bursts of certain energy ok. Now the acoustic emission condition or this strategy is to have this transducer which should be able to detect this kind of stress waves ok. And this is what we are going to look into this in this material course and how it can be measured, analyzed and so on.

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Application of Acoustic Emission

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- Non-destructive testing of heavily mechanically stressed components or complete structures of fiber-reinforced plastics or composites, as used e.g. in the aerospace industry.
- Material research (e.g. investigation of material properties, breakdown mechanisms, and damage behavior)
- Inspection and quality assurance, e.g. monitoring of welding and wood drying processes, series inspection of ceramic components, scratch tests and more.
- Real-time leakage test and location within various components ranging from a small valve up to a tank bottom with diameter of 100 m.
- Geological and micro-seismic research.
- Detection and location of high-voltage partial discharges in large transformers.



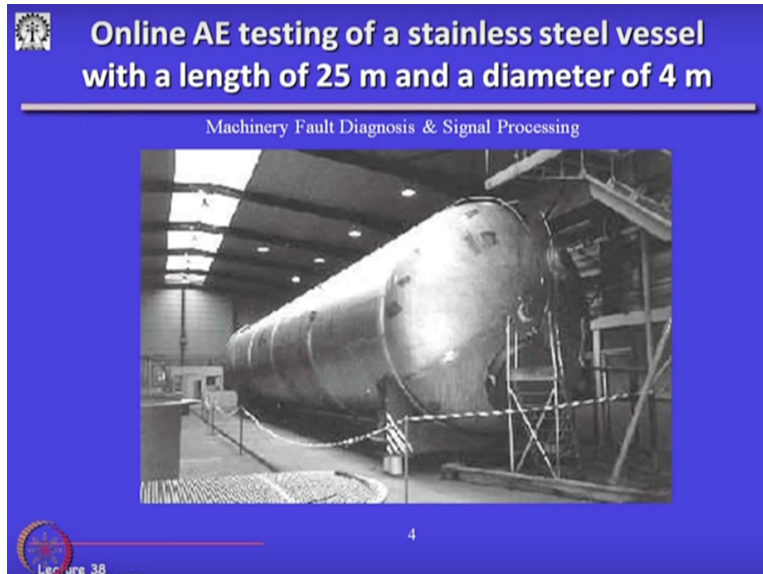
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So if I was to look into the applications of acoustic emission, it is a non-destructive testing of heavily mechanically stressed components or complete structures of fiber-reinforced plastics or composites as used in the aerospace industry. So this can be used both for materials which are metallic and non-metallic. Acoustic emission can be used in materials research to understand the material properties and breakdown or the failing mechanisms or the damage behaviors and materials.

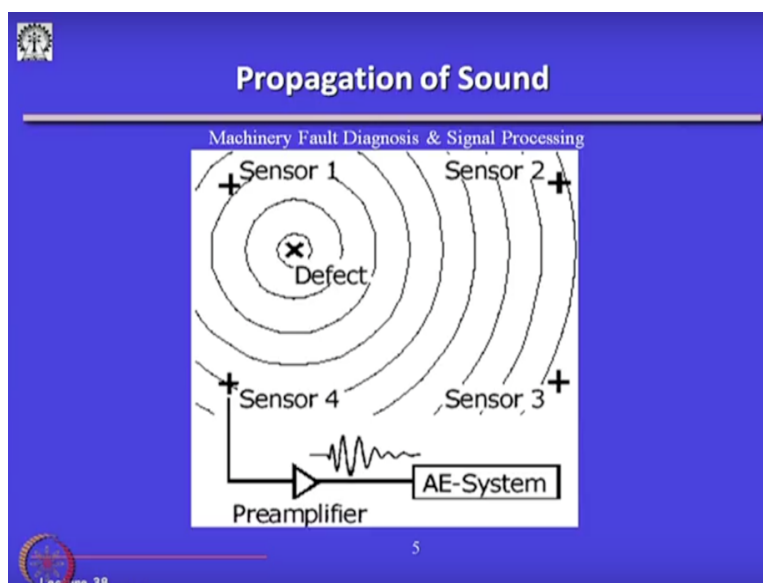
Acoustic emission particularly in non-destructive testing or condition based maintenance is towards inspection and quality assurance example monitoring of welding and wood drying processes, series inspection of ceramic components, scratch test and few more. This is used to detect leaks in large reservoirs or large containers. It is used for seismic research and so on ok.

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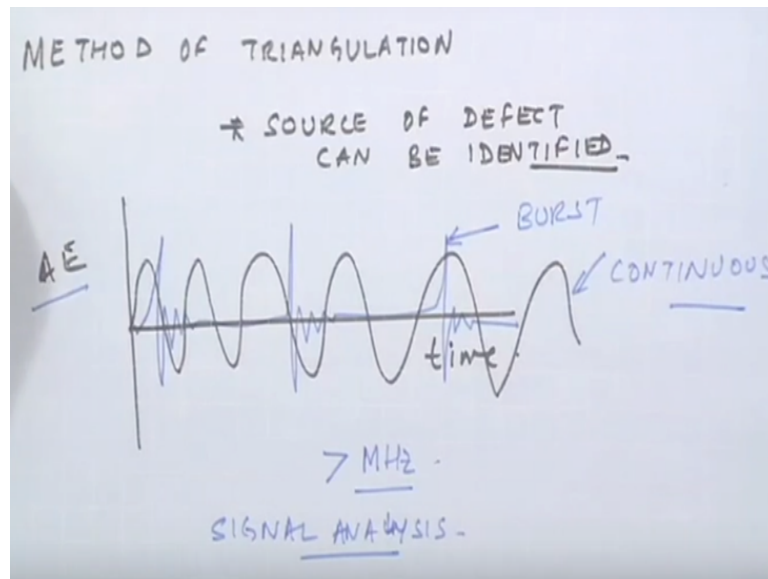
This is one photograph of an acoustic emission testing being done on a 25 meter length pressure vessel of diameter of 4 meter. This can be instrumented with pressure sensors or sorry acoustic emission sensors. And these signals can be analyzed to find out the source of the leaks.

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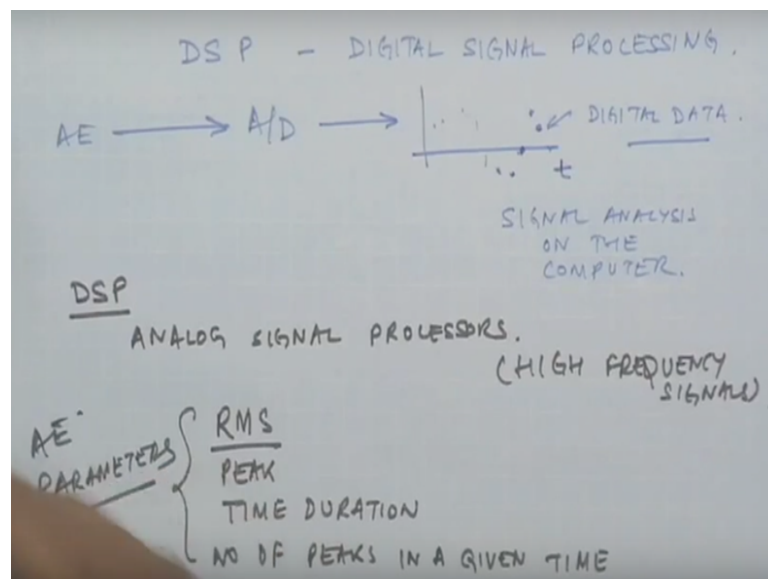
Like this example or this diagram shows, I can be having many sensors ok around a location. And each of the sensors will give us an acoustic emission signal.

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So by the method of triangulation the source of defect can be identified ok. But as I was mentioning you, these signals could be ok in a time domain, they are very high frequency time domain. They could be continuous signals, AE signals or they could be in bursts, burst or continuous signals. Now there is a little historical development in this acoustic emission systems. Because they are of the order of few megahertz ok.

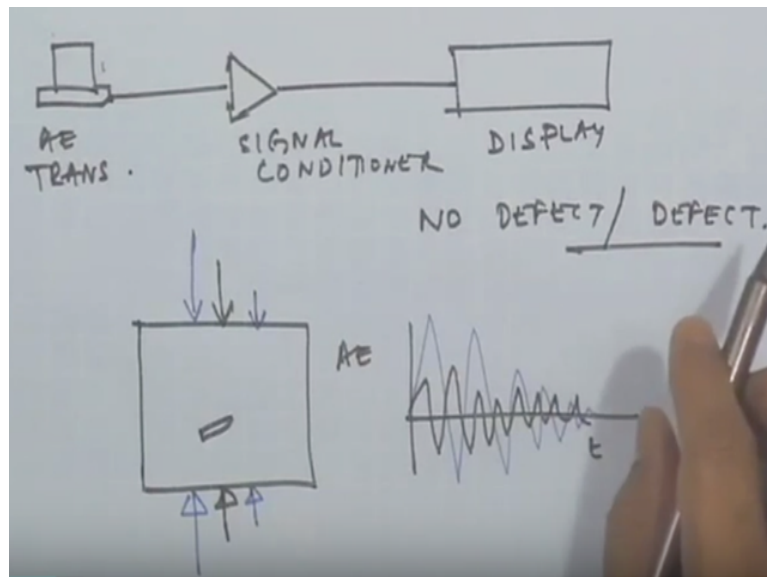
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Now to do any signal analysis if you will recall the class on computer aided data acquisition. To do signal analysis on such high frequency signal you always have to if you have to do DSP on the signal we have to acquire them thru an AD process. And then this is the acoustic emission signal. We have to do an A to D process. Then once we have the digital data, these are the digital data we can do some sort of an analysis on the computer.

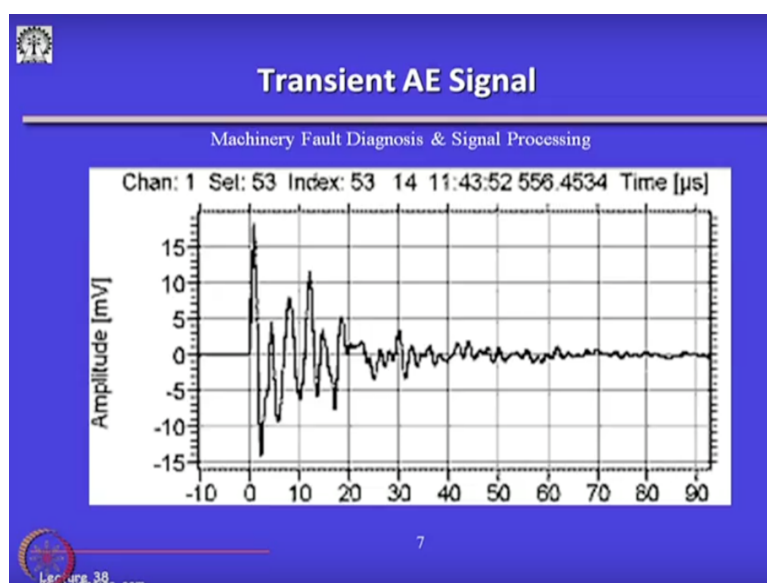
However when DSP was not developed in the early days, people used analog signal processors. And in particular because they are high frequency signals, all we could do was at most find out the RMS level, or the peak level, or maybe the time duration etc. ok, or the number of peaks in a given time. So these were very gross parameters which were used in. And I will show you the details para parameters. This is how they were being done.

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So basically it was a AE transducer. And then some sort of a signal conditioner. And then we have the display, signal conditioner, and AE transducer ok. But this kind of instrumentation was good enough to detect no defect and defect. And it gave us a qualitative feel of the defects in a component or a machine.

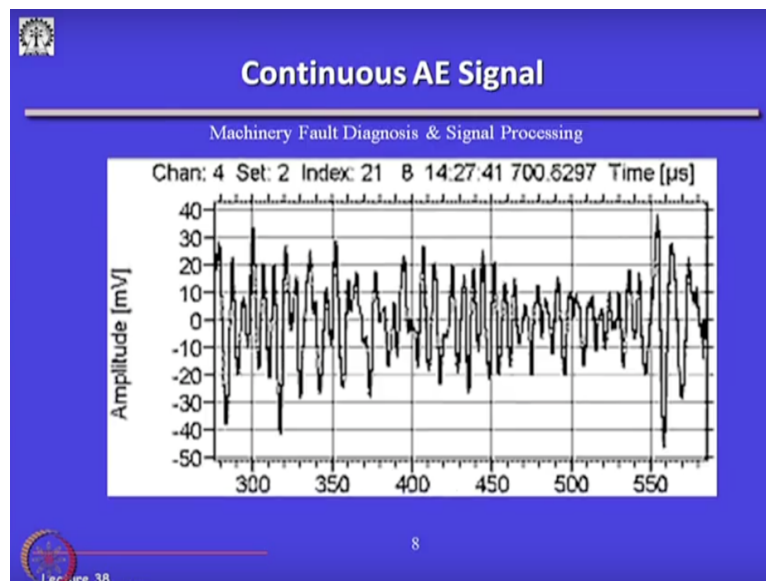
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And this is how a typical transient acoustic emission signal looks like. Mind you this is in microsecond. So you can understand it is a very very high frequency signal. And this has to be captured in a device you know.

This is an analog device ok from which this has been captured. Like a digital storage oscilloscope ok. And from this time domain signal certain features could be found out like number of peaks beyond a certain threshold, number of peaks occurring in a time period. So all this could be done through a simple analog processor.

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And as opposed to the transient signal which was mostly a burst this is what is known as the continuous signal. That is some sort of an energy signal either this is in some millivolt. We get in a particular time waveform of this continuous AE signal.

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Kaiser Effect

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Dr. Joseph Kaiser's dissertation (about 1950) at the Institute for Metallurgy at the Technical University Munich was named: "Examination about the occurrence of sound at tensile tests". At this dissertation Dr. Kaiser indicates irreversible processes during plastic deformation under strain which can be shown by using a piezoelectric crystal. Due to his dissertation and continuing research until his death 1958, the Technical University Munich is known as the origin of the AE-Technology. A friend and colleague of Dr. Kaiser, the Munich Professor Hans Maria Tensi, called the phenomenon Irreversibility of the AE-behavior in materials the "Kaiser Effect".



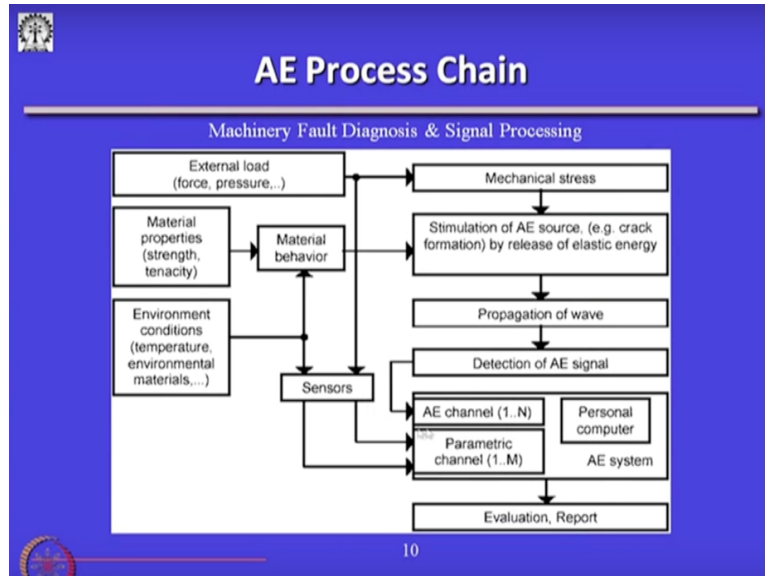
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This is another related effect in acoustic emission which is known as the Kaiser effect. Now this is because of the fact that it was named after Dr. Kaiser. Which says that as an irreversible phenomenon in the behaviors of material called the Kaiser effect. And this says that it indicates irreversible processes during plastic deformation under strain which can be shown by using piezoelectric crystal.

And because of the Kaiser effect whenever the material has stressed beyond the earlier limit then only we will have a meaningful acoustic emission signal coming out of the system. For example just to illustrate the Kaiser effect suppose I have a machine. It has been stressed ok. And there is a defect. So I am getting some signal, some acoustic emission signal.

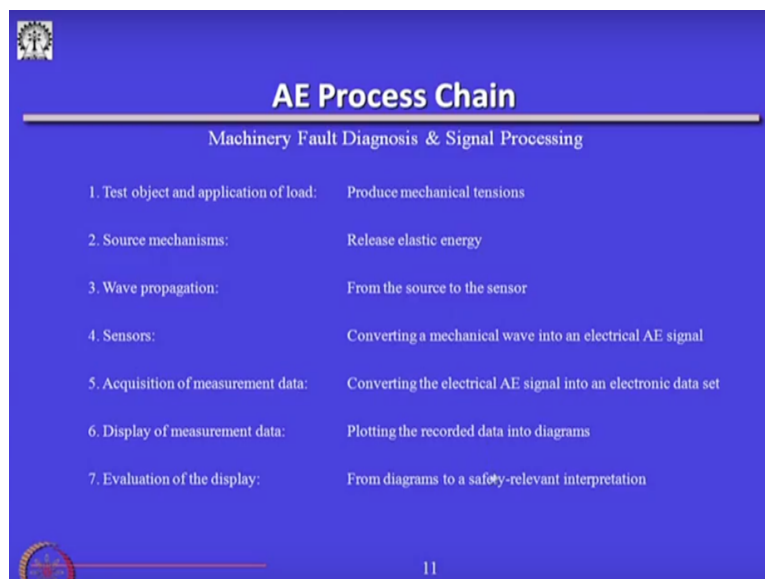
Now in the next instance, if it stressed less than this. Whatever is the acoustic emission sensor signal it will not be realized till I come to a new level of stress which is higher than the previous signal. And then only I am getting a high signal. So this is essentially known as the Kaiser effect ok.

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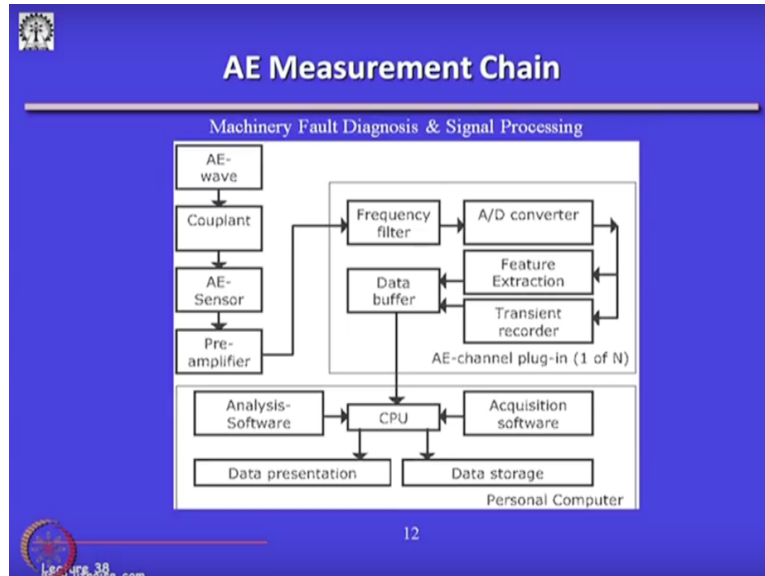
So if I was to look into the analog AE process chain. So the machine or member is stressed and because of this there will be release of this elastic energy. This wave will propagate and then this acoustic emission signal will be detected. And then you can record them with number of sensors. And then put them in a personal computer to analyze the signals.

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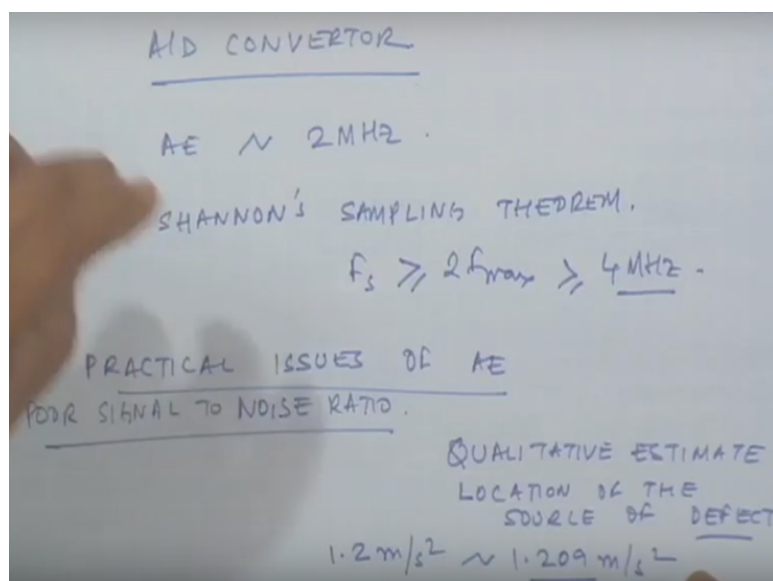
So test object and application of load which produces the mechanical tensions. Source mechanisms are basically the releasing the acoustical energy or the elastic energy. Wave propagation from the source of the defect to the sensors. Sensors basically convert the mechanical wave into an electrical signal. So acquisition converting the AE signal into an electronic data set and you can either display it or store the data ok.

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So in the modern methods of acoustic emission sensing there has been an A to D converter. Which I had explained or mentioned few slides ago.

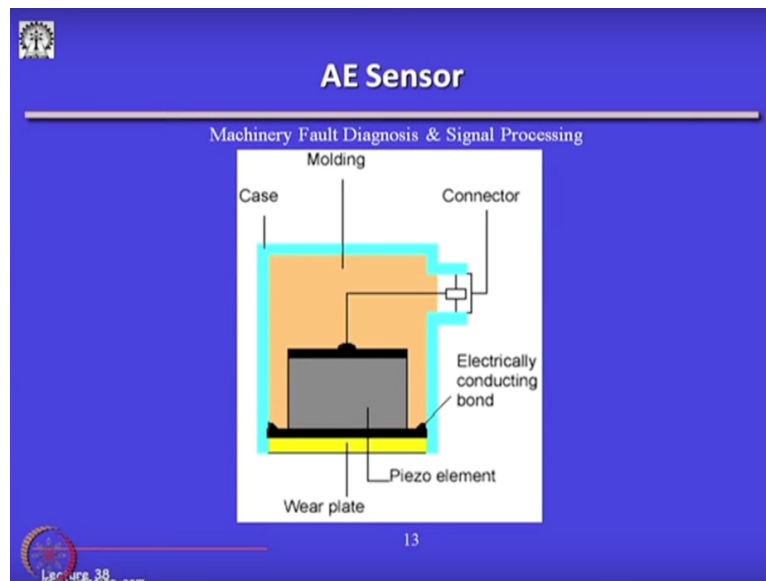
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This A to D converter are now a days available. Say for example if I have to sample an AE signal which is around 2 megahertz. At least because of the Shannon's sampling theorem my sampling frequency F_s should be greater than at least twice F_{max} . So at least greater than 4 megahertz in this case.

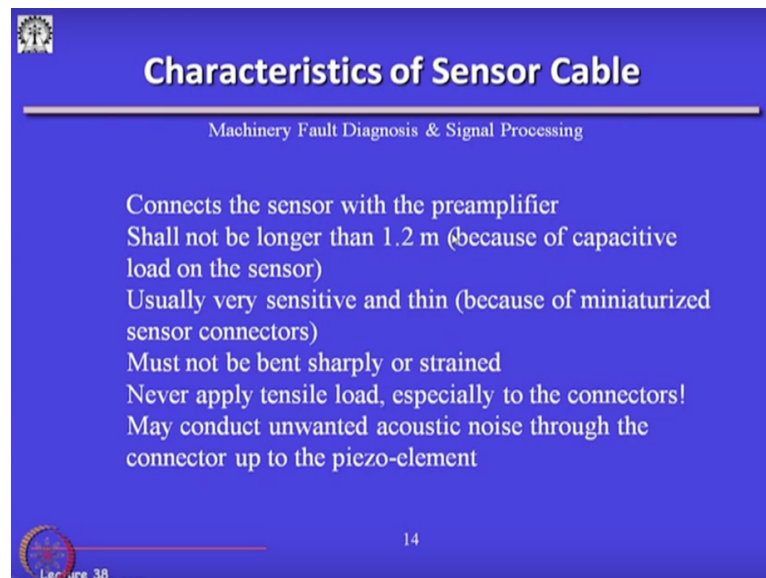
In early days, getting 80 systems with such high sampling rates were a problem. So acoustic emission was one way the distant signal processing for acoustic emissions was not very popular. But off late A to D systems with high sampling rates are available. And they have been used in acoustic emission signal analysis.

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So this is typically like I mentioned to you on the other class regarding ultrasonic transducer where I had a piezoelectric element. Which was made to resonate. Similarly we have an acoustic emission sensor wherein the piezoelectric crystal is there. And then this will be sensitive to this surface waves which are coming through the structure to the surface. And then we will get a signal corresponding to the stress waves.

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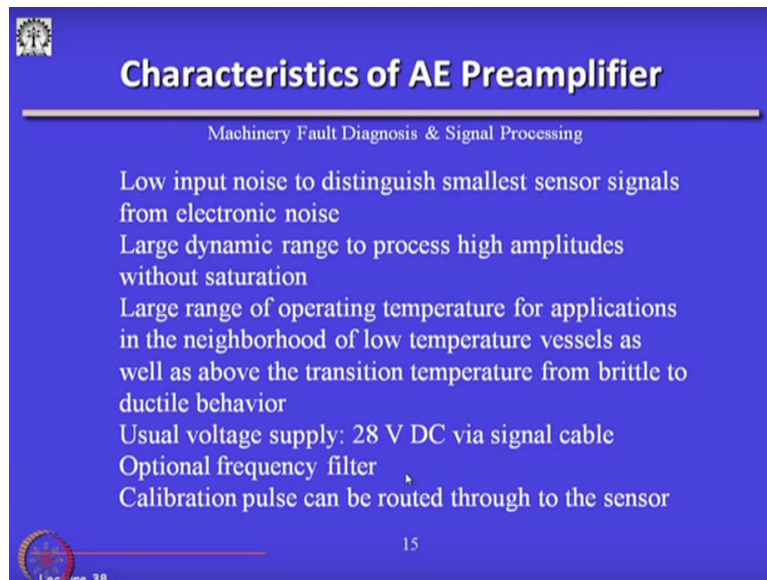


And again because these are all capacitants we have to be very careful regarding the noise. And that is one of the important issues practical issues of AE is the noise or poor signal to noise ratio. Off late acoustic emission has mostly been used for a quick qualitative estimate and location of the source of defect. Rather than unlike vibration wherein we have cases like

the signal I can be very sensitive I mean either I can say 1.2 meters per second square or 1.209 meters per second square.

They are two different quantities. And this can be sensed by systems which is not true in the case of acoustic emission because of this capacitants. And then we have to very careful about this cables not be bent strained ok. And then this special cables which reduces the triboelectric noise are to be used in acoustic emission systems.

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The slide is titled "Characteristics of AE Preamplifier" and is part of a presentation on "Machinery Fault Diagnosis & Signal Processing". It lists several key characteristics of the preamplifier:

- Low input noise to distinguish smallest sensor signals from electronic noise
- Large dynamic range to process high amplitudes without saturation
- Large range of operating temperature for applications in the neighborhood of low temperature vessels as well as above the transition temperature from brittle to ductile behavior
- Usual voltage supply: 28 V DC via signal cable
- Optional frequency filter
- Calibration pulse can be routed through to the sensor

The slide number "15" is visible in the bottom right corner.

And again this AE preamplifier has a low input noise to distinguish smallest sensor signals from electronic noise. It has a large dynamic range to process high amplitudes without saturation. Large range of operating temperature for applications in the neighborhood of low temperature vessels as well as above the transition temperature from brittle to ductile material.

Usually a supply voltage of 28 volt for the preamplifier is given through a signal cable ok. And then of course the calibration pulse and all that will be required.

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Filter Sets

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20 – 100 kHz for tank bottom tests (leakage, corrosion)

100-300 kHz for integrity testing metallic components

Above 300 kHz for reduced range (smaller distance between sensors).


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Filter sets depending on the acoustic emission particularly for leakage and corrosion test. the filters are with anywhere from 20 to 100 kilohertz. For metallic component testing we have filters from 100 to 300 kilohertz. And above 300 kilohertz for small distance between the sensors.

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AE Glossary

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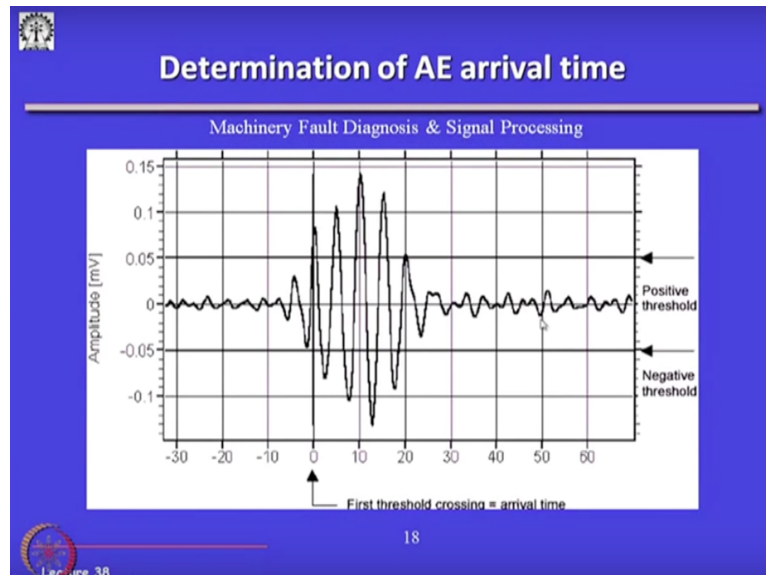
AE (AE):	A transient elastic wave produced by release of (elastic) energy or during certain processes
AE-event:	Physical event producing AE, e.g. crack formation
AE-source:	Physical origin of one or more AE events. This can e.g. be a crack growing step by step. Each growing of the crack is an AE event.
AE signal:	The electrical signal of the sensor resulting from AE
Transient signal, burst:	AE signal with clearly detectable start and end
Hit:	A burst detected by the AE system
AE-activity:	Occurrence of AE signals as a result of AE
AE-Intensity:	The strength of the AE events in units of e.g. energy or amplitude
AE channel:	Single AE sensor including the associated instruments for the acquisition and measurement of the AE signals = measurement chain
Multi-channel system:	System providing multiple AE channels, e.g. for source location, or for examining areas too large for one sensor



Certain terms which are used in acoustic emission I thought I should be mentioning it to you in the class. So acoustic emission is a transient electric sorry elastic wave produced by the release of elastic energy during certain processes which could be mechanical stress. Event is this burst or which we see source or the origin. Signal is the single that you get from the transducer.

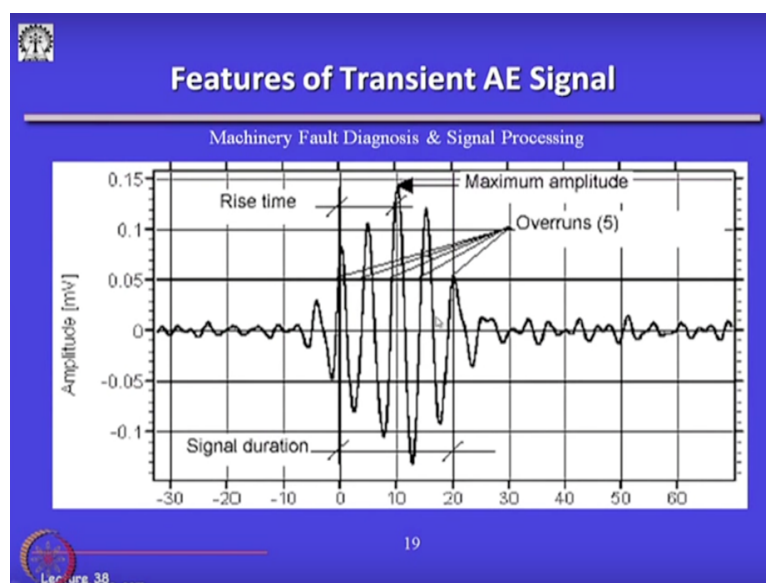
Signals could be a transient or a continuous burst. AE activity is the occurrence of an AE signal. AE intensity is the strength. AE channel is the number of such measurement sensors which we have. And usually we require a multichannel system in machine structure so that by the method of triangulation we can find out the source of the acoustic emission.

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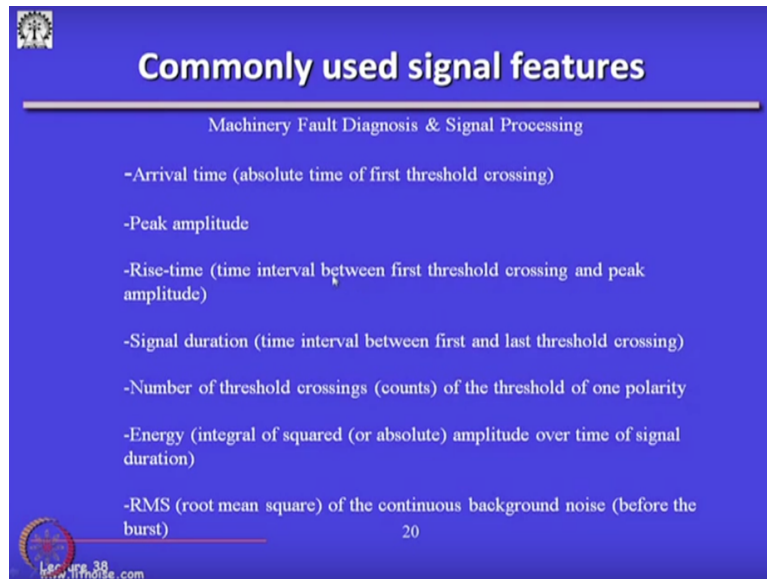
So some in the time given we can set lot of triggering events for example this is the negative threshold. This is the positive threshold. So any number the number of peaks beyond a positive threshold can be used to quantify some of the AE signals like below above a particular threshold. And the first time the crossing happened before the arrival time so all this kind of signals can be processed.

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Then the maximum amplitude, number of overruns, signal saturation so there are a lot of features which are to be measured and monitored in such acoustic emission signals ok.

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Commonly used signal features

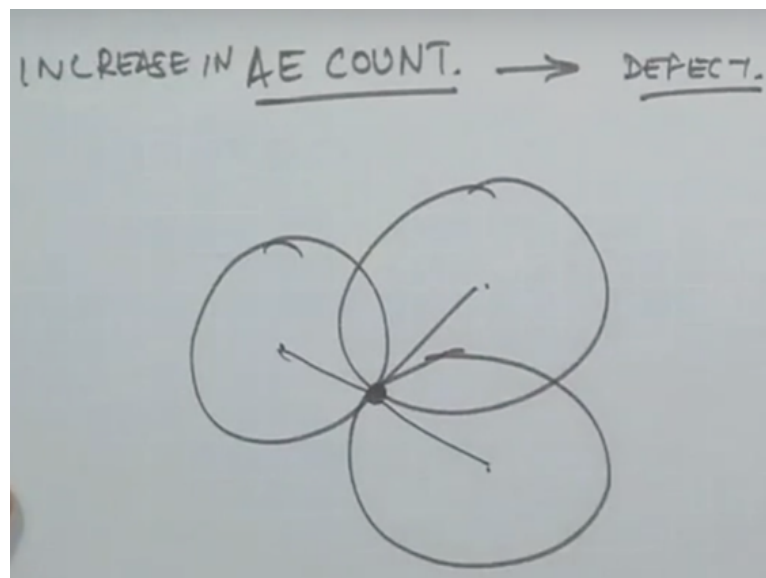
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- Arrival time (absolute time of first threshold crossing)
- Peak amplitude
- Rise-time (time interval between first threshold crossing and peak amplitude)
- Signal duration (time interval between first and last threshold crossing)
- Number of threshold crossings (counts) of the threshold of one polarity
- Energy (integral of squared (or absolute) amplitude over time of signal duration)
- RMS (root mean square) of the continuous background noise (before the burst)

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So arrival time is the absolute time of first thresholding crossing. Peak amplitude, rise time, time between the first threshold and peak amplitude, signal duration, time interval between first and last threshold crossing. Number of threshold cross crossing are the AE counts in one direction.

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So AE counts were earlier used as a method of detecting whether an acoustic event has happened or not. AE count increase in AE count represents a defect in the structure ok.

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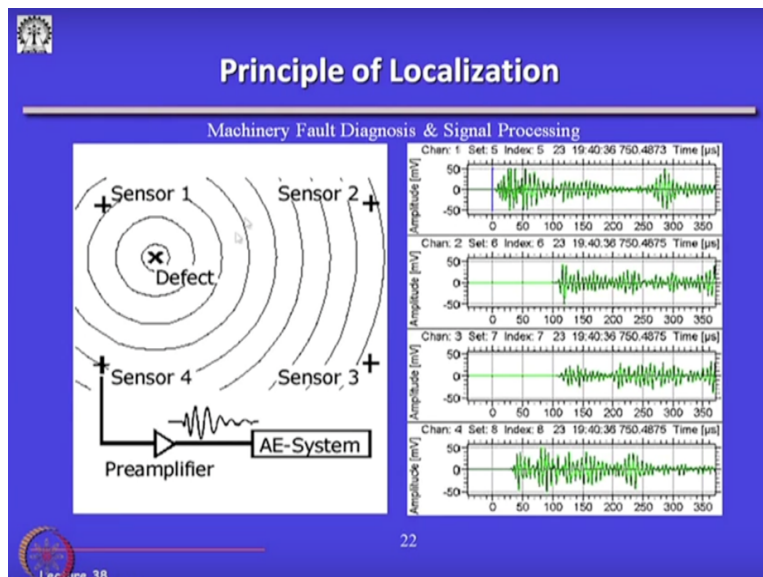
Calibration of AE system

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BY PENCIL LEAD BREAK TEST

So this AE can be calibrated by what is known as a pencil lead break test.

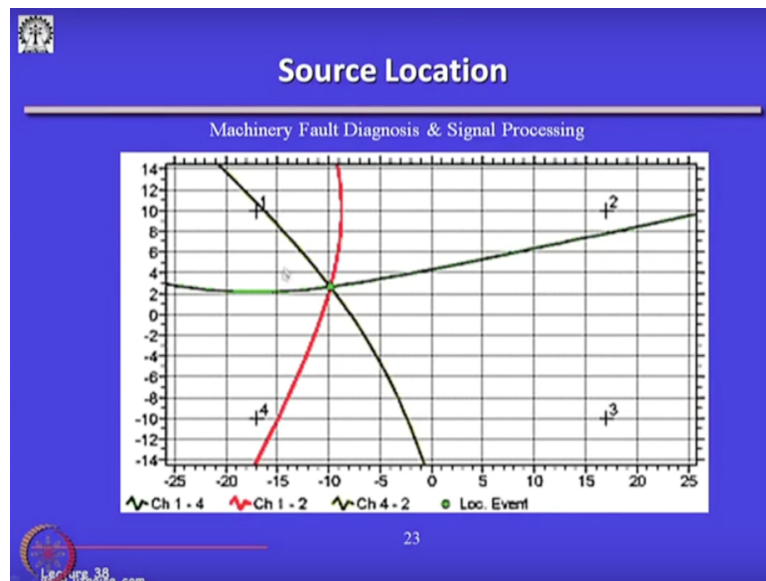
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And this is one example wherein you see how the principle of location is used. Sensors 1, 2, 3, 4 around a defect. And you can see if the signal from the source defect is one. Depending on the time delay for the signal to come to one of these sensor locations people can have a 3 dimensional software. I mean graphic software wherein they can triangulate around 4 spheres or maybe they use 3 spheres to triangulate. Wherever the 3 spheres meet there will be a defect. You can draw them in a 2 dimensional plane.

Suppose one event is here, you can draw a circle around it, a circle around it, and circle around it ok. So wherever these three spheres meet that will be the location of the defect from each of these sensors ok. So these kind of triangulation algorithms are there.

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And this is just one such locations from a software which are used. So by AE transducer by having multiple AE transducers and doing a triangulation the AE source can be determined. Though AE has been very qualitatively popular for knowing whether a defect has occurred and not occurred. Because as I was telling you right in the beginning the material cries under stress.

And these cry signals are high frequency signals which has to be captured by piezoelectric crystals processed. And through a software we can use them to quantify the AE event or even triangulate to find out the source of the AE event ok.

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The slide is titled "Limitations of AE" under the heading "Machinery Fault Diagnosis & Signal Processing". The text on the slide discusses the limitations of Acoustic Emission (AE) testing. It states that defects which are neither growing nor moving do not produce AE and thus cannot be detected. It also mentions the Kaiser-Effect, where only defects detected without exceeding the highest preceding load are active at the actual load level. The slide notes that evaluation criteria do not exist in form of commonly accessible data, and that AE testing is sensitive to process noise exceeding the detection threshold. The slide number "24" is visible at the bottom right.

Defects, which are neither growing nor moving do not produce AE and, thus, cannot be detected.

According to the Kaiser-Effect, only those defects are detected without exceeding the highest preceding load, which are already active at the actual load level and are endangering the component anyway. Only by increasing the load above the previous maximum load level defects can be found, which do not grow at standard load.

Evaluation criteria do not exist in form of commonly accessible data, i.e. the rating of AE-results is set firmly to the knowledge and experience of the service provider.

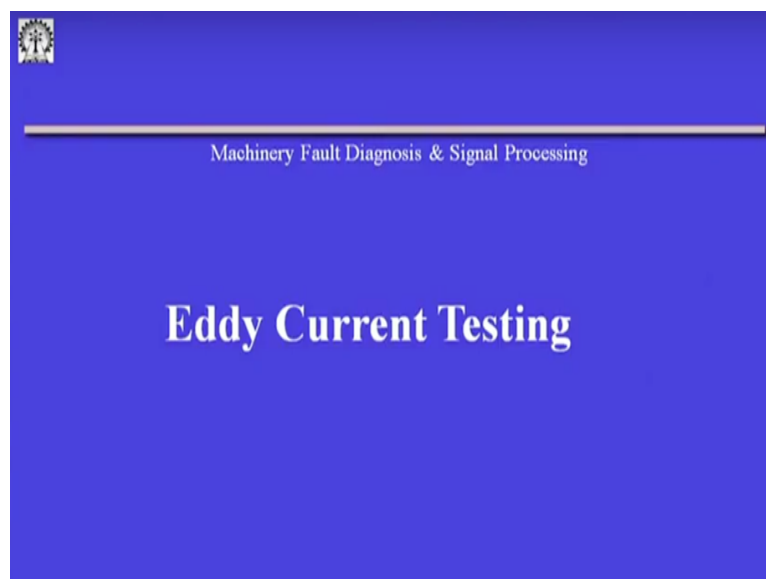
AE testing is sensitive to process noise exceeding the detection threshold. In case the process noise cannot be stopped, the detection threshold has to be increased, which requires smaller distances between the sensors and, accordingly, more sensors and channels. Above a certain noise level, AE testing is no longer efficient.

However there are certain limitations of acoustic emission. One is defects which are neither growing nor moving do not produce AE and thus cannot be detected. According to the Kaiser effect only those defects are detected without exceeding the highest preceding load which are already active at the actual load level and are endangering the component anyway. So only by increasing the load above the previous maximum load level defects can be found which do not grow at standard load ok.

Evaluation criteria do not exist in form of commonly accessible data like the rating of AE. Results is set firmly to the knowledge and experience of the service provider. And AE testing is sensitive to noise threshold. And noise cannot be stopped. And so we have to be very careful about a certain signal to noise ratio. And otherwise AE testing is not very deterministic if I may say so unlike vibration monitoring, motor current monitoring or even ultrasonic or even the next topic which we are going to discuss is Eddy current testing.

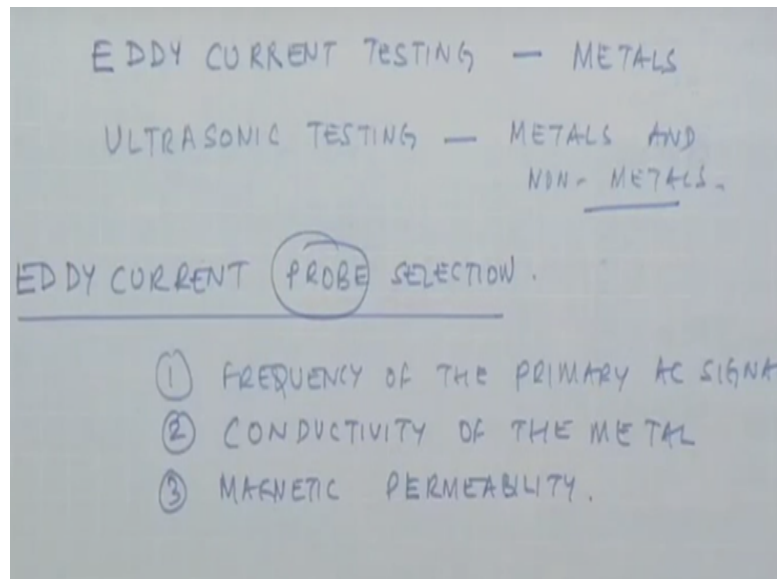
But AE gives us a quick survey whether a defect has occurred because of stress or not and then we can sense it.

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So now I will move on to another related another topic in NDT. And that is what is known as the Eddy current testing.

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So Eddy current. Of course the first and foremost thing which separates Eddy current from ultrasonic testing which we have discussed earlier is Eddy current testing is only possible with metals. Unlike ultrasonic testing which is both for metals and non-metals ok.

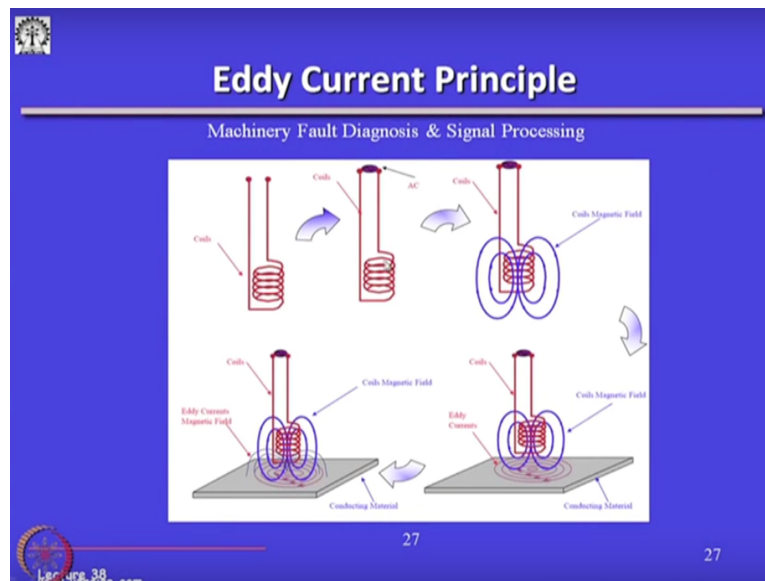
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Applications			
Machinery Fault Diagnosis & Signal Processing			
Metal thickness	- Alloy sorting - Heat treat condition - Heat damage - Plating thickness - Cladding Thickness	Insulation Thickness Nonmetallic coating thickness vibration Diameter of tubing or bar stock	Cracks Seams Porosity Corrosion Erosion Segregation Inclusion

So these are some of the applications of Eddy current. I can measure the metal thickness. I can use to sort alloys, find out the heat treatment condition, damage because of heat treatment, the plate thickness or the cladding thickness, insulation thickness, non-metallic coating thickness, certain vibrations.

Particularly in Eddy current proximity probes are used to find out the displacements in turbines or shafts, diameter of tubing or bar stock, cracks, seams, porosity, corrosion, erosion, segregation, inclusion. All these can be found out in metals by Eddy current testing.

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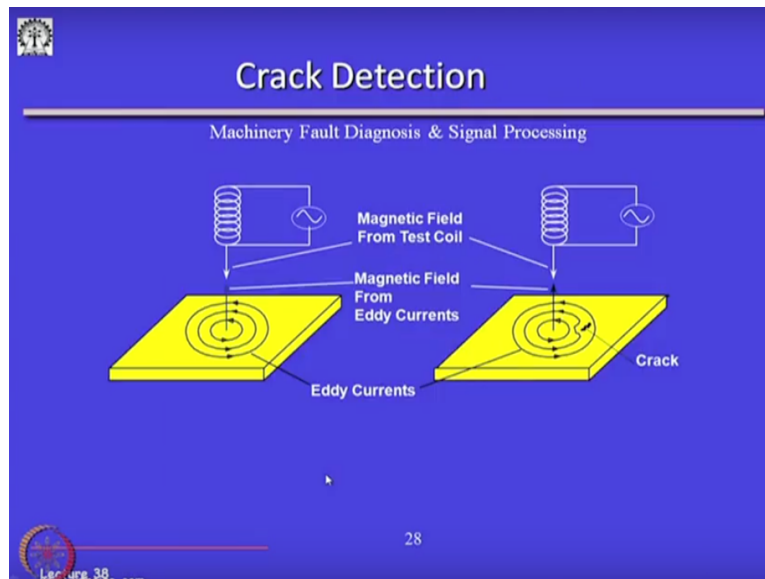


So let us try to understand how and what is this Eddy current testing. So the principle behind this Eddy current testing is given in this slide. For example, if I have a coil through which I pass usually a high frequency AC signal. So because of this signal being alternating, there will be a magnetic field associated in this coil. Now what happens? If I bring this coil, because of its magnetic field around a conducting material series of circular Eddy currents will be formed ok.

Now this Eddy current will also have a magnetic field. Now what happens if there is a defect or change in thickness in this conducting material? The magnetic field produced by this Eddy currents will be different. And obviously because of Lenz's law this will oppose. So if some way we can detect this difference in the magnetic field because of the Eddy current which could be different if there was an foreign intrusion.

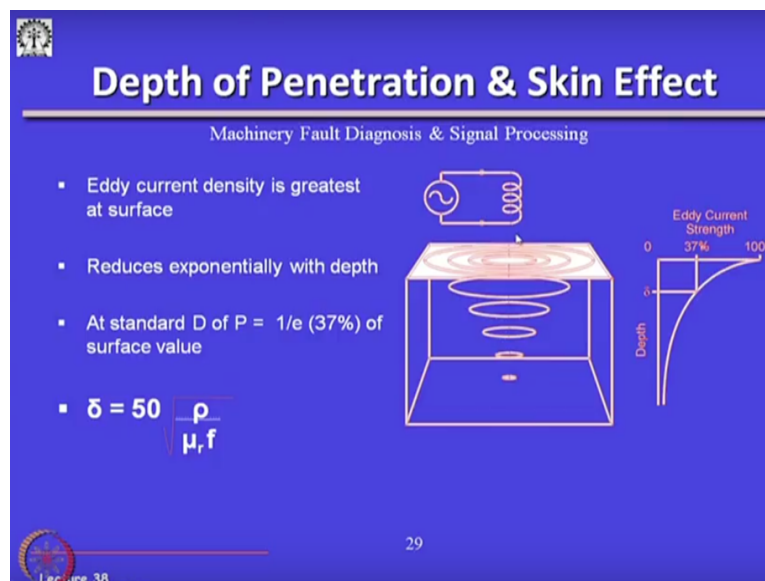
If there was a defect, if there was an change in thickness. This gives us an indirect method to measure the thickness, the displacement of the coil etc. from the conducting material and so on.

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So how is this Eddy current used for finding out the cracks in a material. For example this is a test coil. Usually the primary is you know 400 hertz or sorry 40 kilohertz very very high frequency signal. And then we will have a magnetic field. Because of this Eddy current if there is a crack this magnetic field is going to change. And then the voltage corresponding voltage would change.

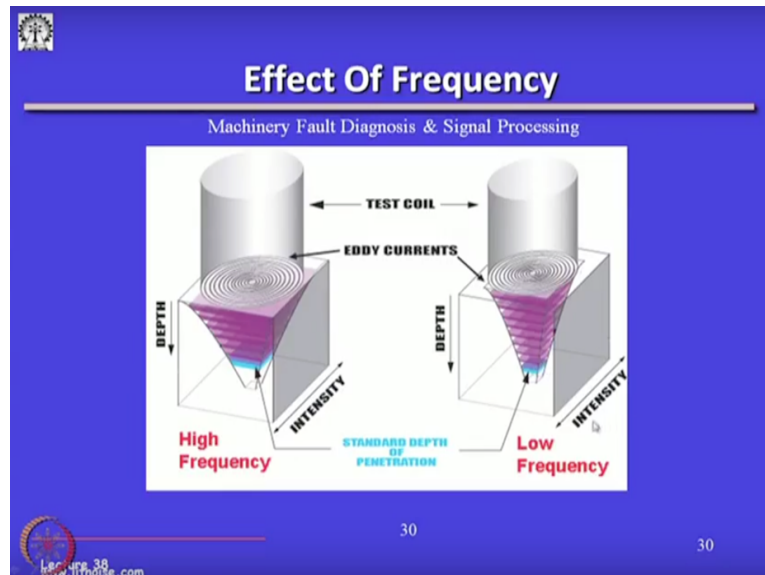
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Now there are certain relationships as to how close I need to bring this coil to the surface. So there is an relationship between the depth of penetration and given by the magnetic permeability and the frequency of excitation. So all this expressions are there. The Eddy current strength is optimum to certain depth ok.

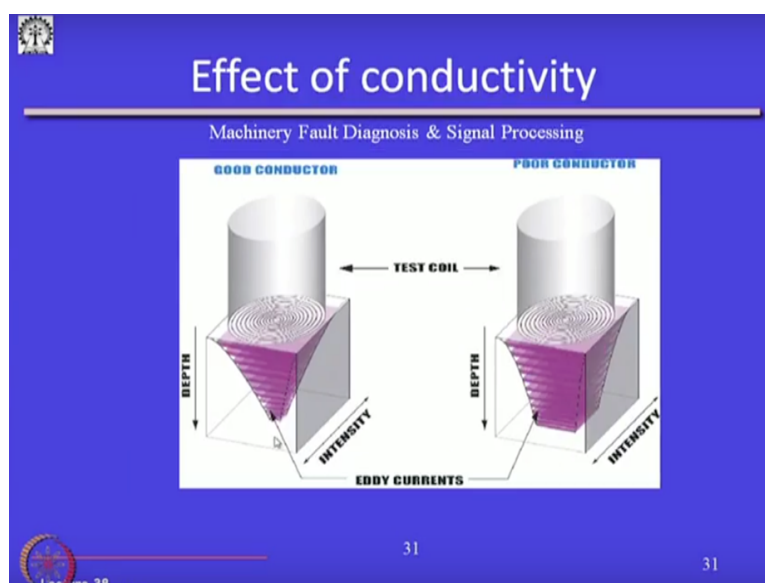
So Eddy current density is greatest at surface. And reduces exponentially with depth. So it is good to measure the surface thicknesses or change at the surface. So that is why a lot of this coating thicknesses, insulation thicknesses we can find out or surface defects or such cracks on nice surfaces can be very easily measured through Eddy current probes.

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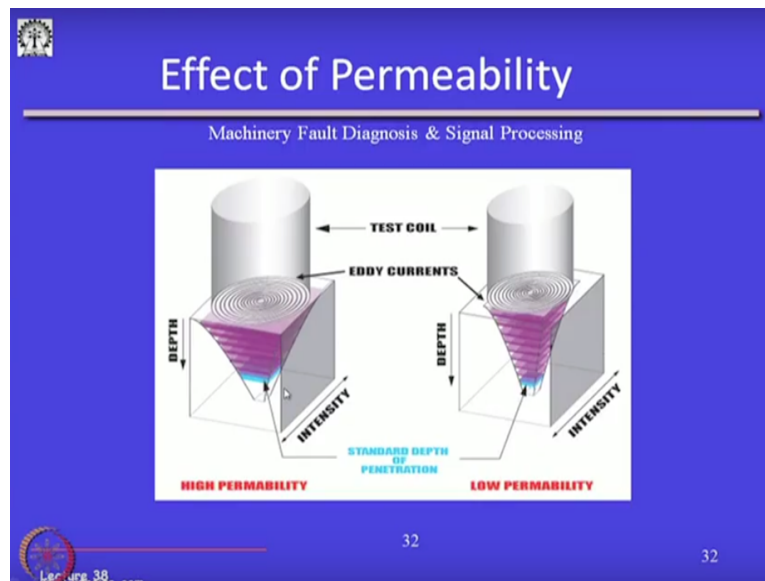
So there is an effect of frequency. If the frequency is high the primary coil in the test coil frequency of excitation is high the penetration depth is pretty low. And if the frequency is low the penetration depth is high ok. And then you can see the proportionate intensity and depth ok. These are some things which we have to keep in mind from this expression here where δ is the depth of penetration.

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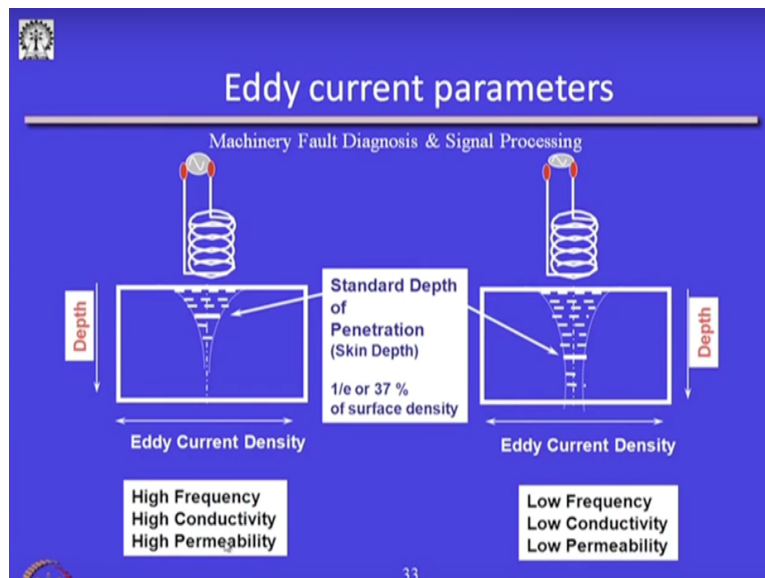
Similarly the conductivity of the material does play a role ok. If the poor conductor the Eddy current intensity is a different. And then with the a good conductor and so on.

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Effect of magnetic permeability. You can see low permeability and high permeability. You can see how the depth and the intensity vary in Eddy currents. These are all very qualitative expressions. But the equations are also there for different kinds of Eddy currents.

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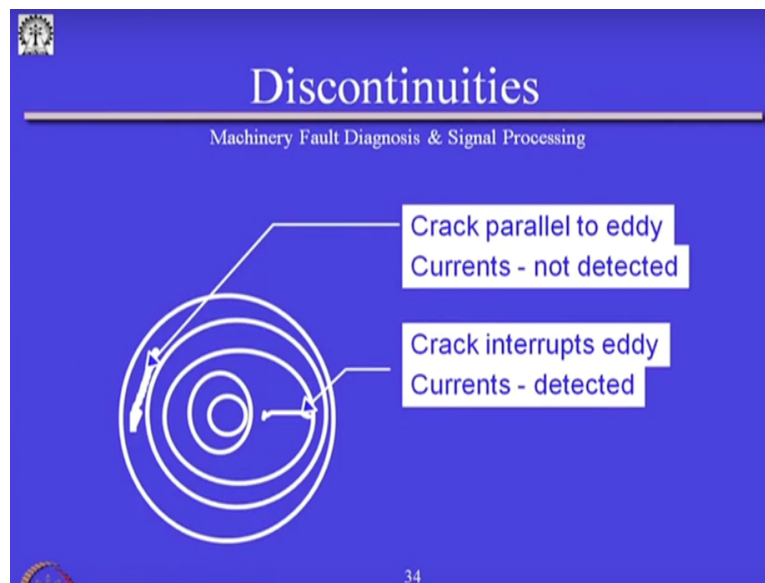


So what are the parameters by which this Eddy current can be has to be can be influenced. One is high frequency, high conductivity, high permeability; one case. Another case we have low frequency, low conductivity, low permeability. So to decide on the right probe for the Eddy current the choice of these few parameters have to be made. The frequency of the

primary AC signal, frequency of the primary AC signal which is used to create the magnetic field. Then the conductivity of the metal. And of course the magnetic permeability.

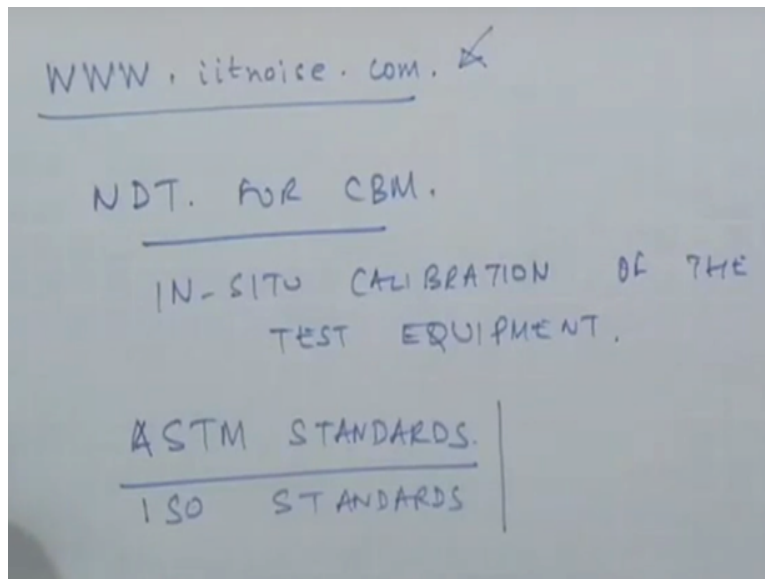
So based on this there are different types of probes available. If you if you go to any manufacturer there will be different types of probe depending on how thick material thickness you are going to measure, depending on the type of material on which you are going to measure. So all this criteria will let you decide on the selection. Or let you decide on the type of probe to be Eddy current probe to be used for such measurements ok.

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Now certain things are also to be noted. So when supposed the Eddy current from the top view if the cracks are parallel to the Eddy currents you will not detect any Eddy currents ok. Because they are not interrupting the Eddy currents. If they are interrupt like in this cross dimension. You can see the Eddy current is disturbed and then you will get a signal for that ok.

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By the way some of these details about this instrumentation can also be found in my website [www dot IIT noise dot com](http://www.iitnoise.com) ok. In our lab we have these measurement facilities. Both for Eddy current ultrasonic and so on. So you can visit this website to get an updates on the instruments which we have.

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Edge effect

Machinery Fault Diagnosis & Signal Processing

- Edges produce signals just like cracks and mislead inspector
- Different techniques can be used to avoid edge effect

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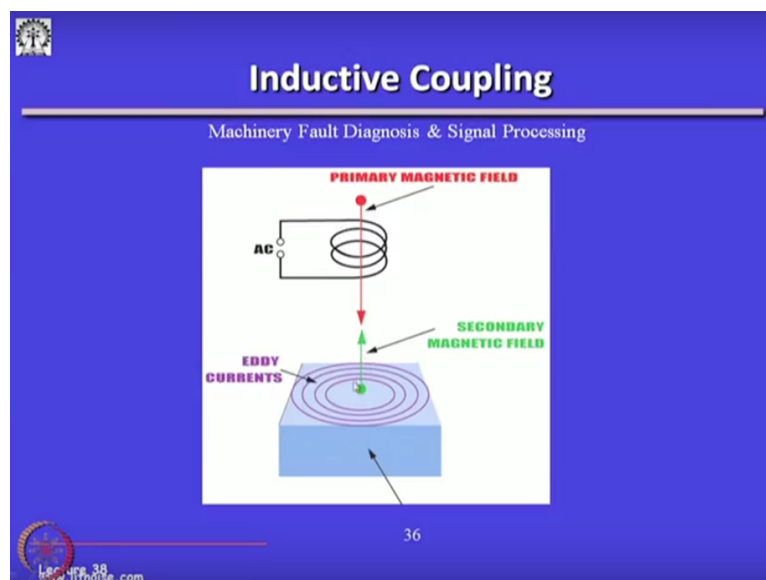
Certain edge effects are also occur ok. Sometimes edge produce signal just like cracks and mislead the inspector. So different techniques can be used to avoid edge effect. So a lot of these NDT techniques you know if you think of thermography ultrasonic, dye penetrant test, Eddy current, acoustic emission lot of this actually go depends on the experience of the operator. Operator who is using them in the field to do the measurements.

So in a classroom you know we can very nicely tell you the theories of these measurements. But you know once you go out to the field to do these NDT test techniques many times you will be either misled by poor signal to noise ratios or because you do not have the right kind of transducer to capture the phenomenon. Because if you have a digital signal processing followed by a display unit you know garbage in is garbage out.

So we have to be very very careful while doing measurements in the field using such techniques which are tested well tested and proved. But always I would recommend you know any of you who are practicing NDT techniques for CBM to always do what is known as an INSITU calibration of the test equipment. And for such NDT techniques there are lot of ASTM standards both for Eddy current testing, acoustic emission, ultrasonic, thermography etc. Even certain ISO standards are there ok which need to be referred.

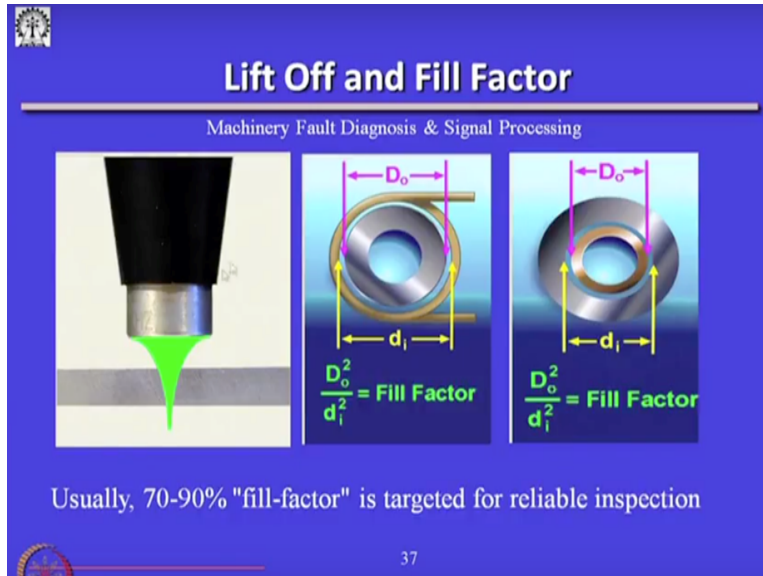
And sometimes we have these kind of standards in this website so you can have the list of the standards. And then of course you can get these standards in your local library or from their websites. So these has to be followed whenever you are doing such NDT types techniques testing techniques for CBM.

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So there is some sort of an inductive coupling between the primary coil and the secondary magnetic field because of the Eddy current. So this coupling is what we sense. And then we use it.

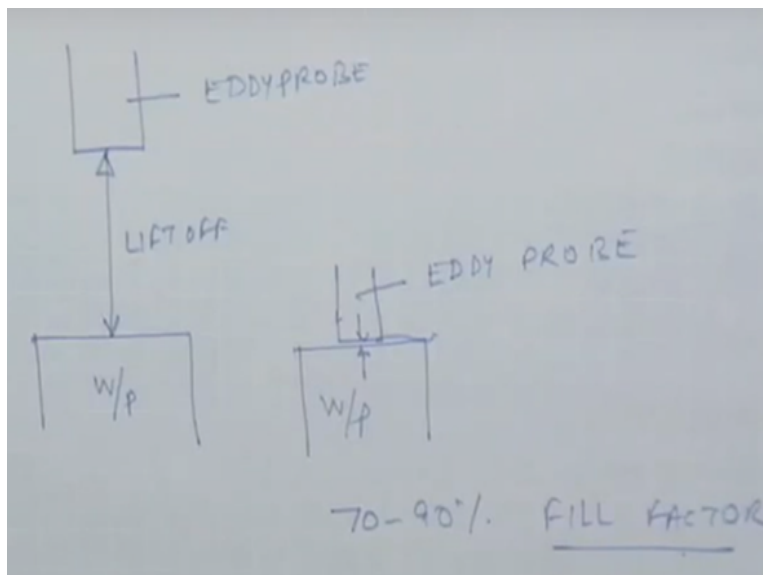
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There is another parameter. Which we have to be very careful as to how close shall I bring this probe to the surface. And that is something defined as the lift off and fill factor ok. This fill factor if you know the diameter D naught and d_i .

So this D naught square by d_i square ok is what is known as the fill factor. Usually 70 to 90 percent of the fill factor is targeted for reliable inspection. So if you lift off ok this diameter and this diameter is going to change because of the lift off. So we have to be careful about that we are within 70 to 90% the fill factor for reliable inspection.

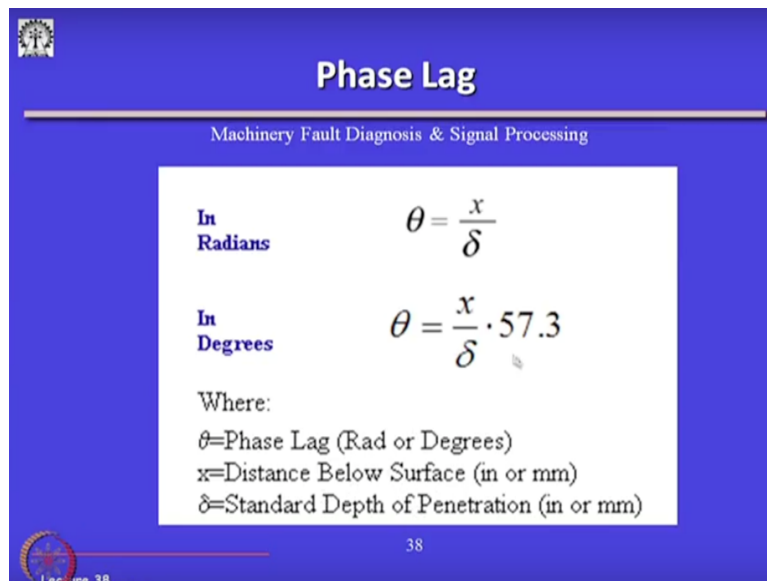
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So what I mean to say you should not be too far away or too close ok. This is the work piece. This is the Eddy probe. This is the Eddy probe. So this distance I meant as the lift off. Similarly lift off is here. So this depends on the seventy to 90% of the fill factor ok. We have

to keep that in mind. So these kind of experiences have come from the analysis in the field. And these are some thumb rules we have to keep in mind while you are measuring the field.

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Phase Lag

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In Radians $\theta = \frac{x}{\delta}$

In Degrees $\theta = \frac{x}{\delta} \cdot 57.3$

Where:

θ = Phase Lag (Rad or Degrees)

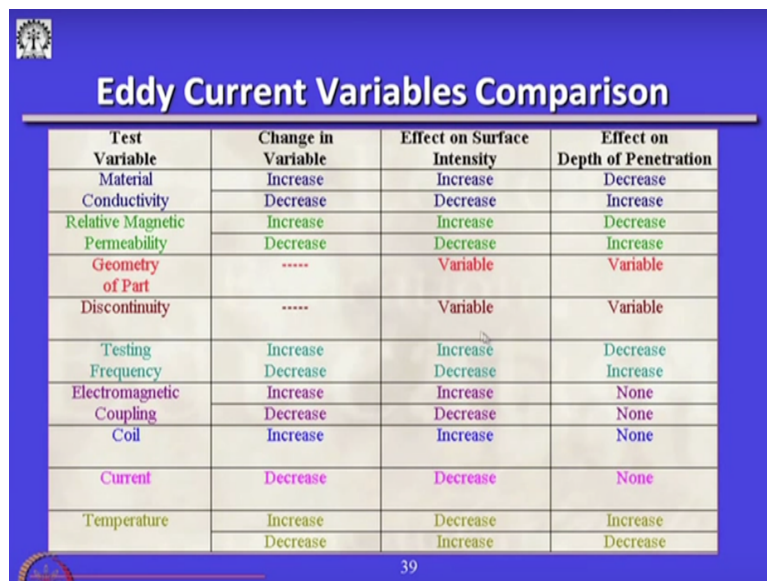
x = Distance Below Surface (in or mm)

δ = Standard Depth of Penetration (in or mm)

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And there will certain phase lag between the surface and the depth of penetration. And this can be given by this method.

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Eddy Current Variables Comparison

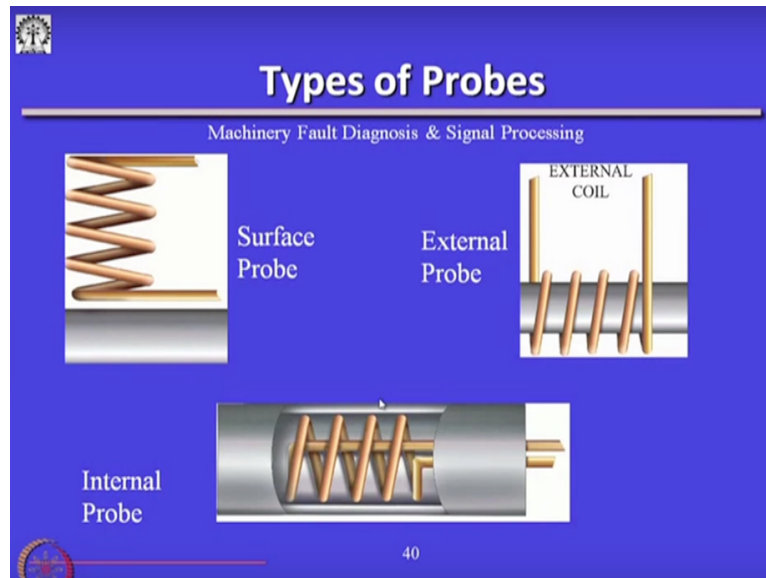
Test Variable	Change in Variable	Effect on Surface Intensity	Effect on Depth of Penetration
Material Conductivity	Increase	Increase	Decrease
	Decrease	Decrease	Increase
Relative Magnetic Permeability	Increase	Increase	Decrease
	Decrease	Decrease	Increase
Geometry of Part	-----	Variable	Variable
Discontinuity	-----	Variable	Variable
Testing Frequency	Increase	Increase	Decrease
	Decrease	Decrease	Increase
Electromagnetic Coupling	Increase	Increase	None
	Decrease	Decrease	None
Coil	Increase	Increase	None
Current	Decrease	Decrease	None
Temperature	Increase	Decrease	Increase
	Decrease	Increase	Decrease

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So certain variables comparison we can do. So this is the test variable. So change in the variable and that effect on the surface intensity and effect on the depth of penetration. So depends on the material conductivity, relative magnetic permeability, geometry, discontinuity, testing frequency, electromagnetic coupling, coil, current, temperature. So these are the variations. I will not go into the details.

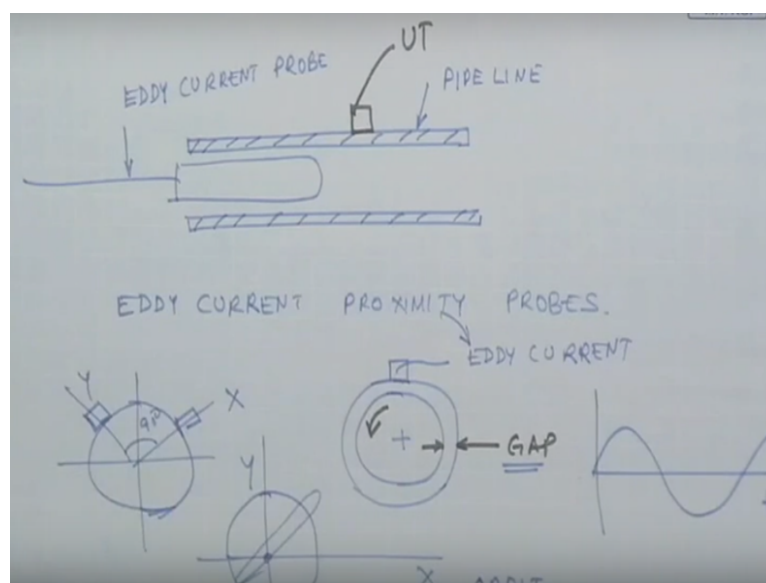
So like if I want to say material conductivity increase it will have an increase in surface intensity or the decrease in the depth penetration. So this kind of a table helps one understand which is what to be done so that we have good signal to noise ratio and good measurements. So this is a handy table which somebody can use and keep it in mind to for a ready reference. And let me tell you this is something you all can keep in mind and then you can visit them again and again to ensure that you have a good acoustic sorry Eddy current measurements.

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This how the type probes which can be used. This is like a surface probe ok. And this is like an external probe like an external coil. And is like an internal probe. You can you can use Eddy current also to measure the internal thickness of tubes and pipes.

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Like in you can have an Eddy current probe going inside a pipeline. So they can be traversing and then you can see. So these are used to measure you know the wall thickness from the inside ok, these are a method. Like in one of the classes I was mentioning how we can use an acoustic emission sorry ultrasonic transducer. But you can also use an Eddy current probe if it is a metal tube to find out its thickness. This kind of being done.

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Mode of Operation

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Absolute	Differential
Sensitive to both sudden and gradual changes in properties.	Not Sensitive gradual changes in properties
Easy to interpret	Difficult to interpret
Show total length of long flaws	Detect only ends of long flaws
Sensitive to drift due to temperature changes	Less Sensitive to drift due to temperature changes
Sensitive to probe wobble	Less Sensitive to probe wobble
Single Coil	Pair of coils
Absolute value of impedance and induced voltage is measured	Changes in impedance or induced voltage is measured

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So this mode of operation can be either absolute or differential depending on the whether it is one coil or two coils. You can find out whether it is sensitive, whether it is not sensitive ok. So this is how we can use these kind of Eddy current probe configurations.

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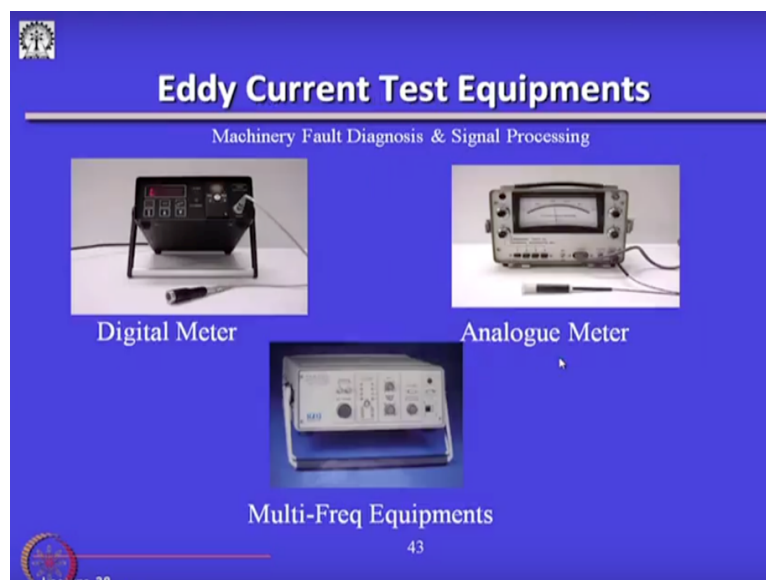
So these are the views of some of the Eddy current probes you have in the laboratory. These are some of the internal probes, some of the external probes. In fact in vibration monitoring I

was also mentioning about the Eddy current proximity probe. For example when we have a shaft ok which is there on a particularly a turbine shaft which is on a channel. While this is rotating if there is a change in this gap because of an out of roundness this gap.

And here I can be putting in any of these locations you know. Maybe I can put an probe Eddy current probe such proximity probe, and I can measure the gap. If it was a sinusoidal, so it will be essentially a sinusoidal with rotation. So this kind of displacements can be measured by Eddy current proximity probes. And in fact some of these Eddy current proximity probes are permanently mounted on turbines at an angle of 45 degree to such probes. And you can use them to plot what is known as the orbits. These about 90 degree.

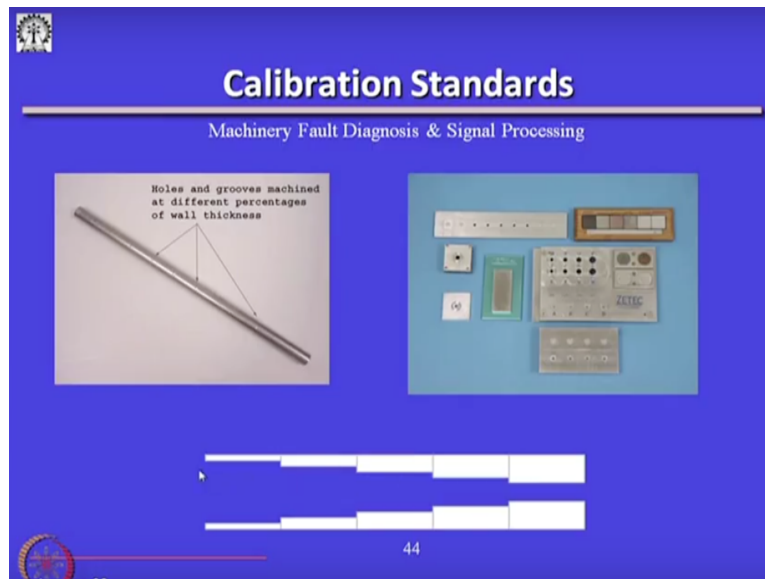
So you can have an X and a Y and you can plot them, these signals ok. And then you can get a circle ok or if you can get a point, you can get an ellipse. So depending on the phase relationship between X and Y you can find out from the orbit plots what is the problem with the shaft which is rotating the machine. Such Eddy current proximity probes are also used in turbines or vibration monitoring or displacement monitoring. And though here we just explained to you few probes which are used for measuring the coating thickness and so on.

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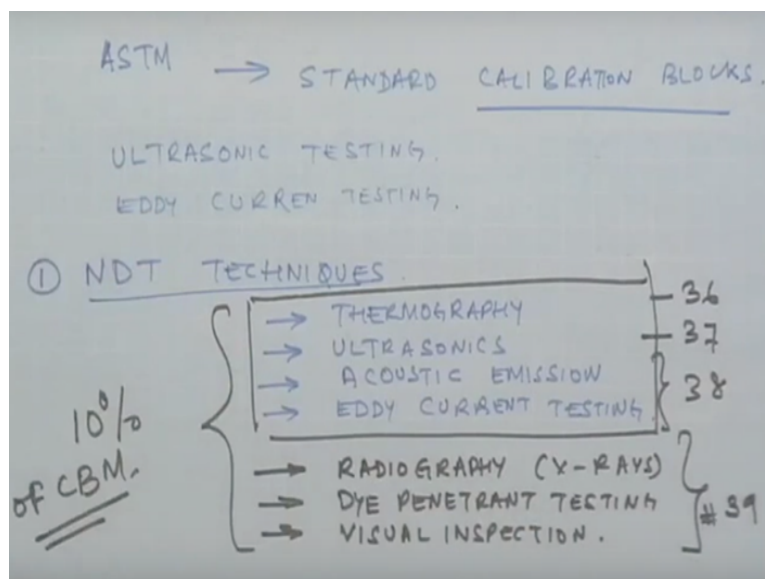
And this is a typical Eddy current probe with it you can have a digital meter or an analogue meter. We can see the voltage you know. This can be all calibrated to a equivalent displacement. You can have multi frequency equipment you know where multiple probes can be done.

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So certain probes are used or certain calibration standards are available. Wherein holes and grooves are machined at different percentage of wall thicknesses ok like this on the inside. So I can move the Eddy current probe inside it. And then I can see what kind of signals are there.

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So like I was telling you in all this ASTM standards there are what are known as standard calibration blocks available. Both for ultrasonic testing. I had mentioned about ultrasonic testing in one of the previous classes, ultrasonic testing and also for Eddy current testing. So whenever you purchase such equipment or sensors for Eddy current testing or ultrasonic testing I would recommend that you also purchase a standard calibration block for example. Then you can calibrate it in the field ok.

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Testing Procedure

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- Balance on sound portion
- Set Sensitivity (Drive Level & Gain)
- Set Frequencies
- Draw Calibration Curve
- Take signal with constant speed
- Note Phase lag and amplitude for each indication

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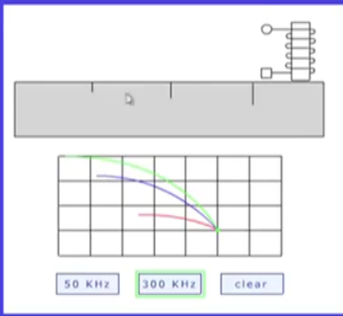
So some of the testing procedures is balance on the sound portion. And then you know because these Eddy current probes are actually the signal which we get can be balanced through a Whitestone Bridge circuit. And then you can set the change the resistances to see what was what, you can balance it by changing the resistances. And if there is a difference because of the Eddy currents you can sense it through an galvanometer or some sort of a display meter.

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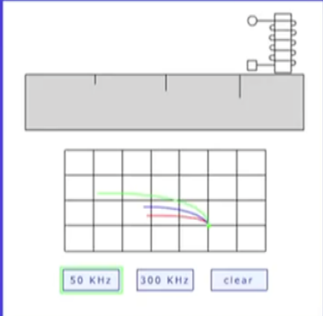


Effect of frequency on signal

Machinery Fault Diagnosis & Signal Processing



50 KHz 300 KHz clear

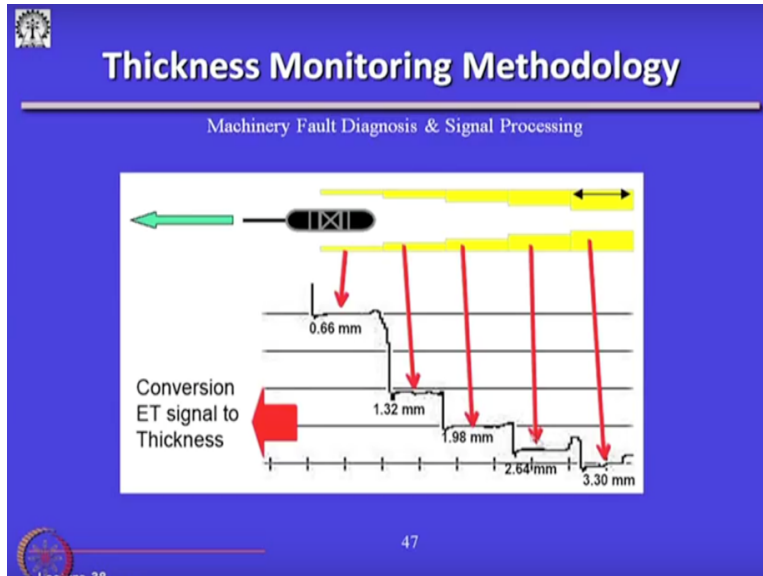


50 KHz 300 KHz clear

46

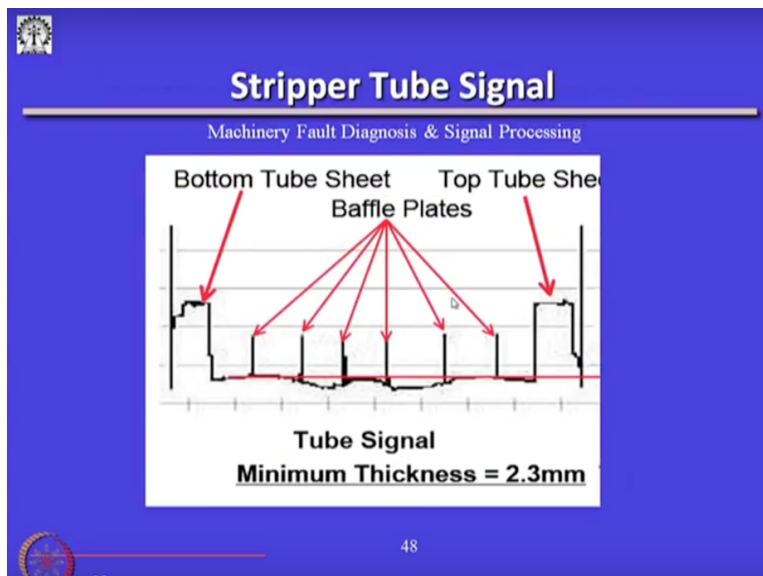
So effect of frequency on the signal you know you can see. So these are all different calibration standards. So you can see the frequency for high frequency and low frequency. These kind of effects can be done.

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Now you see if you move this acoustic sorry the Eddy current probe inside a tube which is made artificially with certain thicknesses you will see converting the Eddy current signal to thicknesses. So 0.6 MM, 1.32, 1.98 2.64, 3.30. So if this kind of (()) (45:15) calibration is done it gives us confidence as to whether what we are measuring is correct ok. And this is a standard calibration tube which is made available to buy. And this can be used to test the deflect ok.

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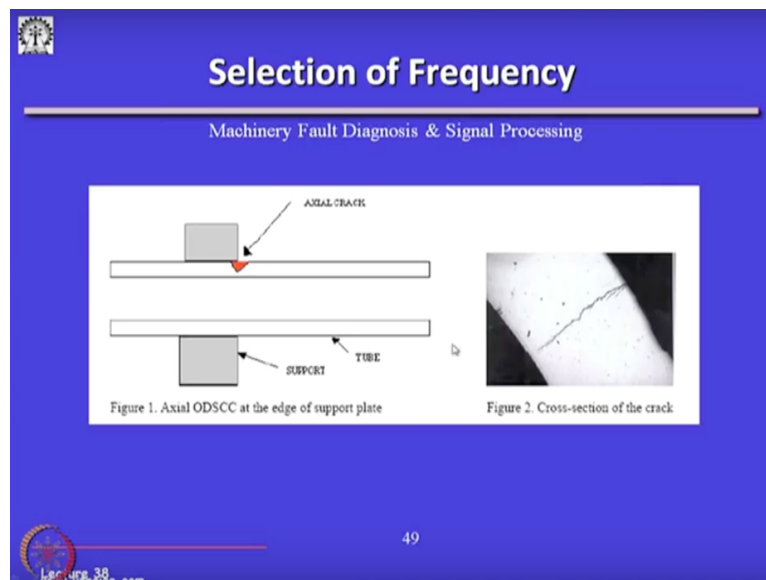


And this is another example where we had a tube ok. Bottom tube, top tube, different baffles are there in the tube. And then the thickness measurements were done and this can be done. This can be achieved ok. So Eddy current to summarize is actually used for systems where there is a metal present.

Because when only we have metal there will be an electromagnetic induction between the primary flux or primary magnetic field which will produce a secondary magnetic field. And then these two magnetic field will interacts and we will get an EMF ok and then according to Lenz's law. And these if the material was not metallic I would not would never get and Eddy current ok.

And few things we which we have to keep in mind regarding the penetration depth, lift off, good signal to noise ratio is the magnetic permeability, the depth of penetration, the frequency of the signal. Which has been used to drive the Eddy current, the diameter of the coil and so on ok. This is something which one has to keep in mind ok.

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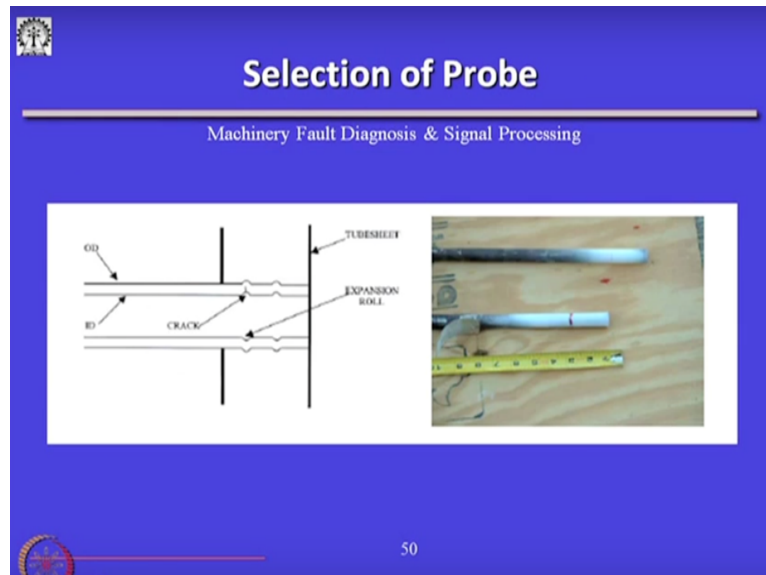


This is another example depending on the crack ok. So this cross section of the crack which can be very easily detected by moving the Eddy current probe ok. This can be also done. But like I was telling you all this NDT techniques. So far we have discussed about thermography, then we have ultrasonics. And we have what we did was acoustic emission. Then we have Eddy current. We have discussed these NDT techniques so far.

And few more which we are going to discuss are the radiography, or what is known as the x-rays. Then we have the dye penetrant testing. And of course the last one the easy one is the visual inspection on places hard to reach. So we are going to discuss about this in the next class on NDT techniques. That will be our lecture number 39 ok.

And just to recap. Almost ten percent of CBM or condition based maintenance use such NDT techniques ok. And we just discussed about these four so far in 3 classes. I think this is lecture number 36, 37 and this was 38. So these 4 lectures would actually corresponds to you know 10% or the CBM techniques which are used worldwide ok.

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And one has to be coming back to this Eddy current testing. One has to be very careful about the frequency, the diameter of the probe ok. And the traversing speed, magnetic permeability. So few examples wherein such cracks can also be detected by acoustic sorry by Eddy current probe.

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This another view which I am going to show you is these kind of surface defects on pipes. You know this kind of surface defects on the pipes can be detected by Eddy current testing

techniques ok. So just to recap I mean Eddy current is convenient like ultrasonic. But only thing that we have to keep in mind the material has to be a metallic. And again lot of this NDT testing techniques lot depends on the skill of an experience of the operator and user of this equipment. And mistakes do happen.

So it is always recommended that (()) (50:43) field calibration is done while using certain NDT test equipment ok. And then unlike vibration which is very well established where the signals are has have very good signal to noise ratios. They are well deterministic and can be analyzed through you know software. And that is the reason why vibration monitoring is used for 70% of the machinery fault diagnosis throughout the world ok. So this would bring to close this lecture. Thank you all.