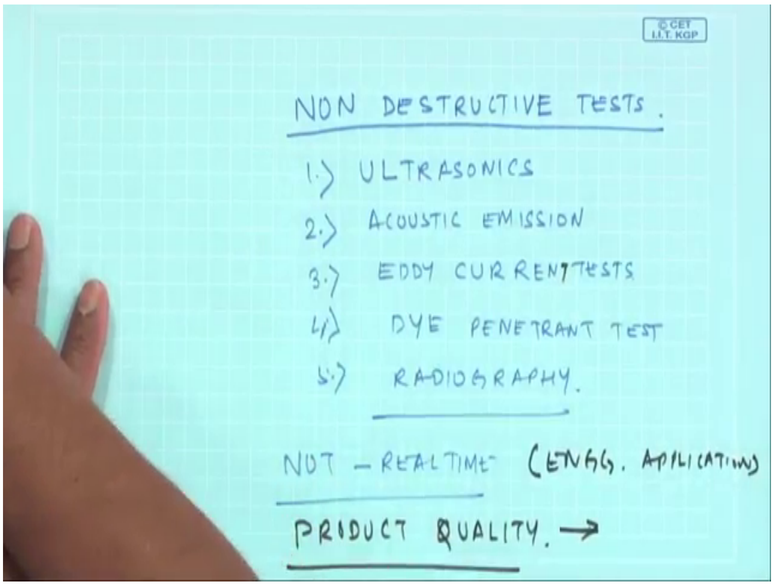
Machinery Fault Diagnosis and Signal Processing

Prof. A. R. Mohanty
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 51
Ultrasonics

Well, in this week, the 11th week, I will be discussing some techniques of NDT; non destructive test techniques which are used in condition monitoring not in real time unlike a vibration monitoring, but some of the tests which are done in stationary machines to detect the faults.

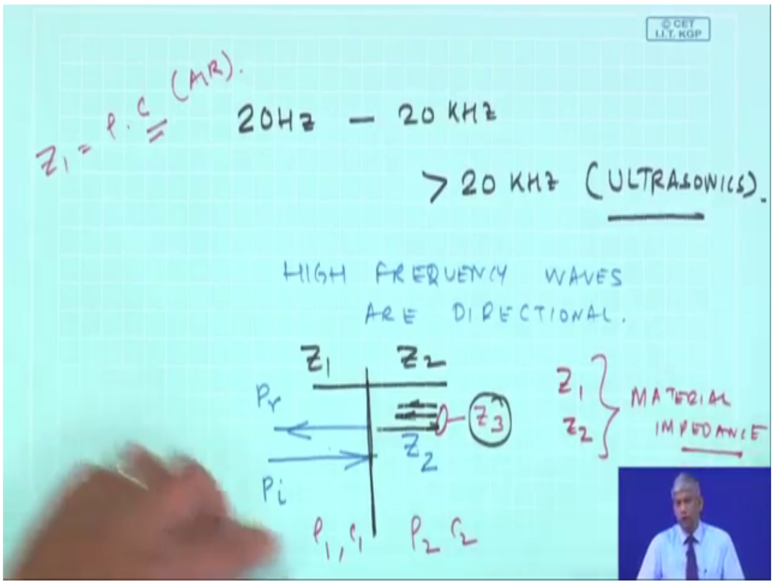
(Refer Slide Time: 00:42)



So, the non destructive tests which are prevalent in the industry for CBM, if I was to list them down Ultrasonics is one of them, then we have the acoustic emission, eddy current test, dye penetrant test, radiography. As you will see, these are not real time, but they have lot of engineering applications to find out the product quality bearing. Perhaps eddy current which could be used too as you have seen in the case of general bearing to find out the clearances ok.

Suppose so, today in this lecture, we will focus mostly on ultrasonics ok, as you know from sound wave.

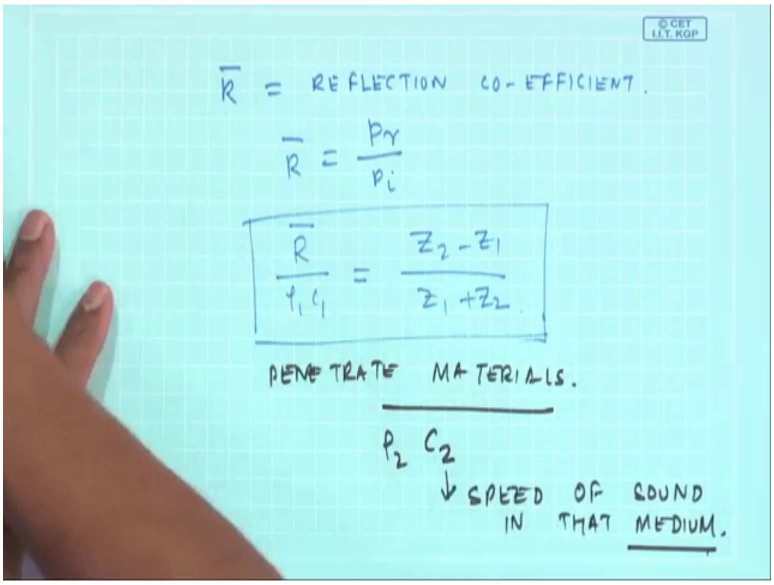
(Refer Slide Time: 02:45)



The human frequency audible ranges from 20 hertz to 20 kilo hertz and something below; beyond 20 kilo hertz are known as ultrasonics and so, they are very very high frequency waves and high frequency waves are directional ok.

So, if I have two materials ok, with having an impedance Z 1 and Z 2, So, Z 1, Z 2 all the material impedance ok, for example, for air Z 1 is rho time C ok. So, speed of sound is dependent on the medium they may be of a different density rho 1 rho 2 and C 1 C 2 speed of sound in the medium. So, what happens if at an interface I have a wave of some incident this will get reflected it is because of this impedance that two.

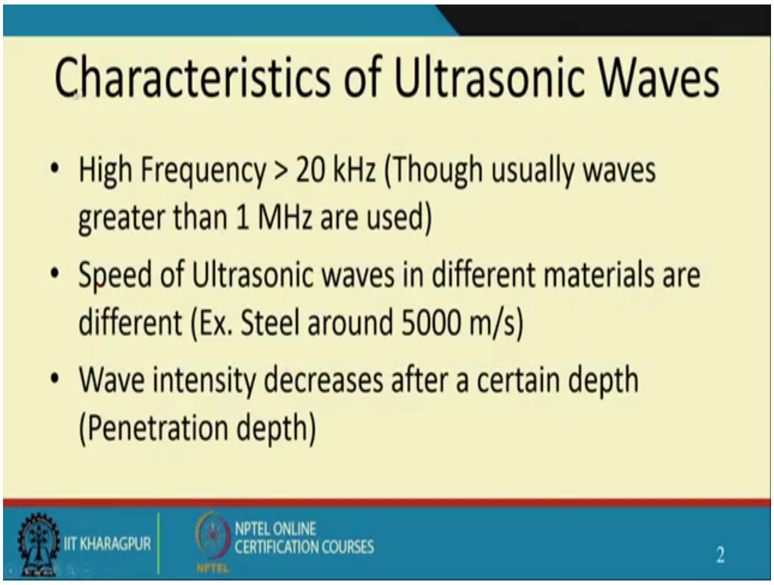
(Refer Slide Time: 04:39)



So, if I consider the reflection coefficient R is nothing, but P r by P i ok. So, R by rho 1 C 1 in this case will be Z 2 minus Z 1 by Z 1 plus Z 2 ok, from wave motion, you can find out. So, what happens if materials have different impedances? They will reflect. Now because these are all ultrasonic waves you know this is true for acoustics audible acoustics as well, if there was a defect in this medium IBM which has a different impedance Z 3 and if I had a system wherein I was because they are linear I was scanning along this surface.

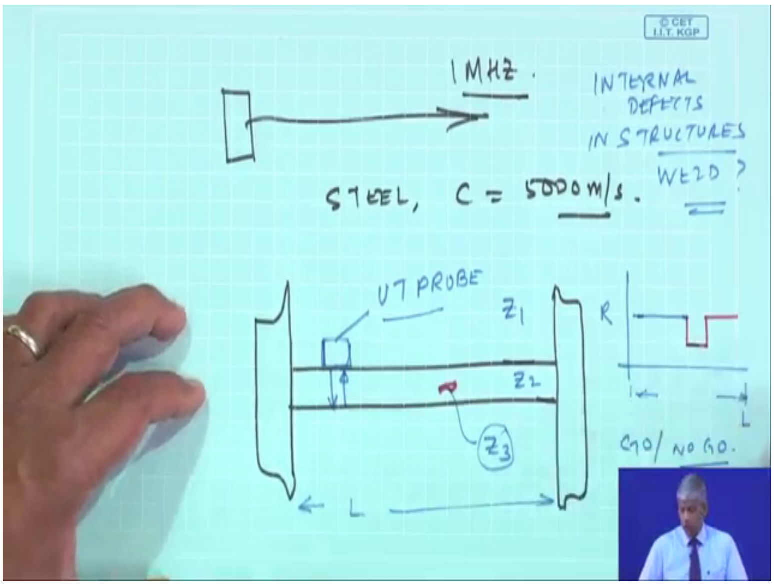
So, every time the P r would change depending on Z 2, but suddenly when it comes here the reflected wave amplitude will change because there is a defect, it could be a void, it could be an air gap, it could be some crack. So, these are very helpful and so, ultrasonic waves can penetrate into the material because there are high frequencies, there are a lot of energies and then we can use them to penetrate materials of course, the power would be very very high, but nevertheless, we can use them to find it of course, the most important thing is that I need to know rho 2 C 2 C speed of sound in that medium ok.

(Refer Slide Time: 07:03)



So, the characteristics of ultrasonic waves is there are high frequency typically usually waves greater than 1 megahertz are used. So, I can have ultrasonic generator which is nothing, but a piezoelectric crystal which is made to oscillate.

(Refer Slide Time: 07:20)



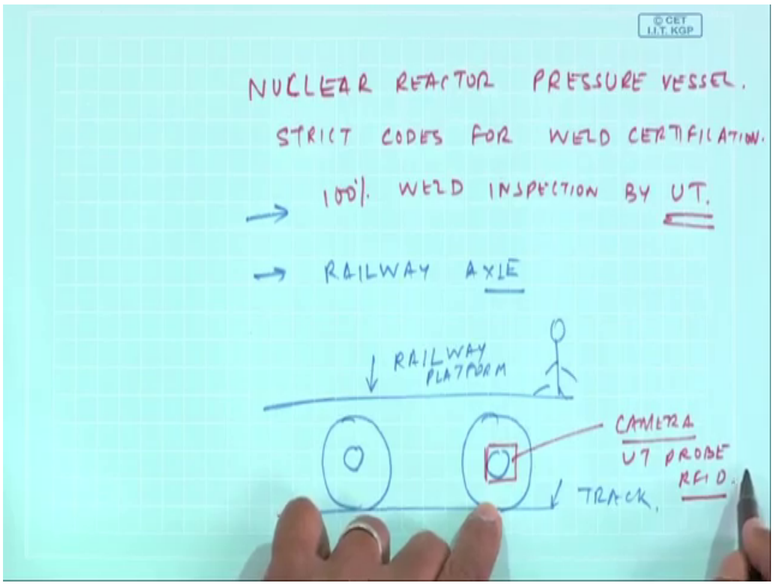
And generate a very very high frequency ultrasonic waves and speed is different in different materials, for example, in steel C is 5000 meters per second and the wave intensity of course, would decrease after a certain depth which is known as the penetration depth.

So, if you have a thicker body we need to have a more powerful ultrasonic wave generator. Now, I will give you an example a practical application say, I have a railway wheel set. Now, imagine in this action a crack has developed ok. so, what I could do on the surface, I could have a probe UT probe which is generating waves and then of course, this is at an impedance Z 1 this is an impedance Z 2, this has an impedance Z 3.

So, if I see the reflected wave back and if I am scanning with maybe this entire length of the axial, I will see a certain intensity of this reflected wave which I can measure in this ultrasonic and suddenly I will see at some location that this has decreased. So, I can know even by a go no go basis. So, something is for in so, because of Z 3, I do not know what it is, but something is not ab normal it is it has to be uniformly Z 2 reflected wave because of Z 2, but here this is because of Z 3 ok.

Such ultrasonic scans are used to find out internal defects in structures suppose you have well data structured, how good is your weld ok.

(Refer Slide Time: 10:28)

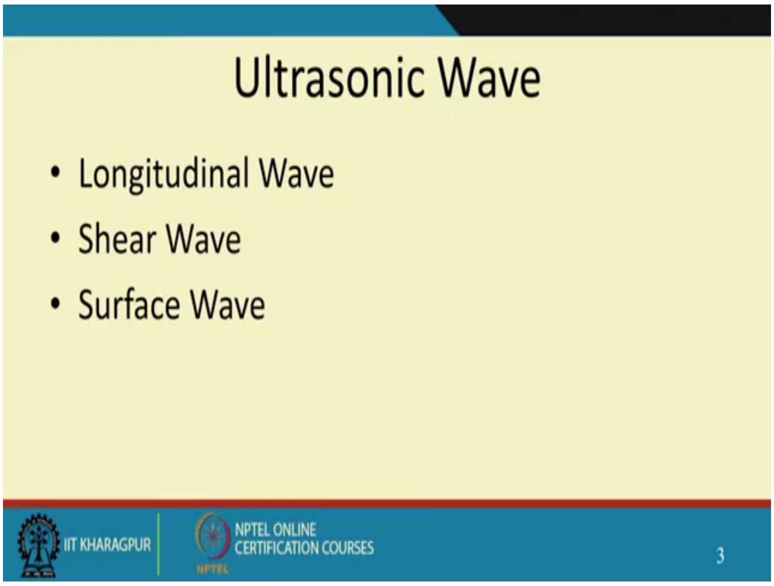


So in fact, some of the standards which are particularly used in nuclear reactors, nuclear reactor pressure vessel are very important components, they have strict codes for weld certification, they require 100 percent weld inspection by ultrasonics ok. I will just give you an example of the railway axial. So, if there was a defect in the axial, this could be scan and so on and today in fact, the idea is we can have such ultrasonic probes.

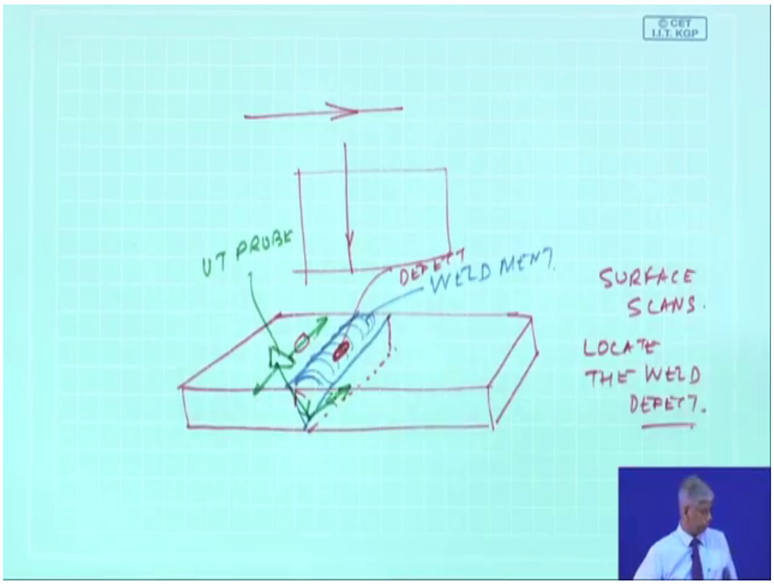
Suppose, you have a platform and then your railway wagon, just comes in to the platform. So, you can have, there is the where we have a person standing and there is a there is the track. So, we can have cameras with UT probe, we can RFID tag every axial has an RFID tag.

So, we can when the locomotive or trainers come into the platform and it will pass through this camera, it a probe instantaneously you can have this UT scanning and then say whether it is or not of it is not ok, you know the from the RFID you know the you can identify the location and then have the axial replaced or change whatever you need to do. So, these are some the things which you can think, they are no longer science fiction. But they are happening as we speak.

(Refer Slide Time: 13:08)

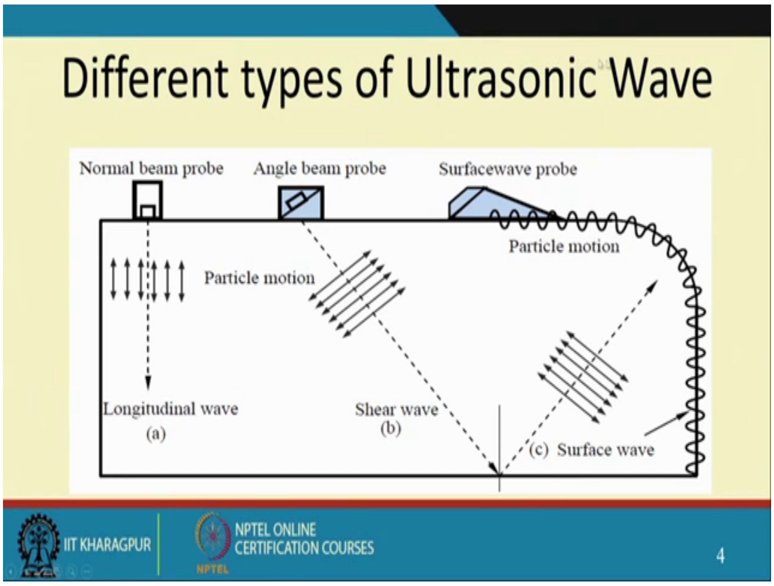


(Refer Slide Time: 13:12)



So, this way you know which I drew as a straight longitudinal wave depending on the incident wave you know, I can have a different modes of this wave. So, I will explain you here.

(Refer Slide Time: 13:27)

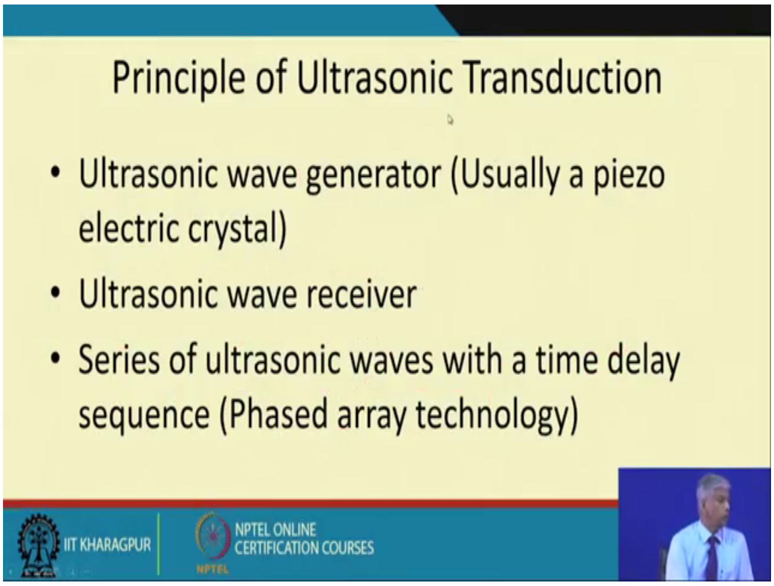


So, different types of ultrasonic waves and these are piezoelectric crystals wherein I can have a longitudinal wave here, did not I produce a shear wave. So, you will come across here and then get reflected because there is an impedance mismatch.

Surface wave if I if I change the angle of inclination here this wave would go on the surface. So, depending on where I want to identify a fault, I can use some of these probes I will give you an example again, suppose I have an two materials which I have welded and usually to weld we will; so, this is my weldment. So, we have made a v group here and these are all relevant. So, this is ok.

So, along the thickness, so, what I could do is I could put an UT probe here. So, what happens this will get and then and then this will get reflected now imagine if this and then I scan it all along. So, wherever there is a defect the probe would get a different intensity of the reflected wave. So, such surface scans can be done to locate the weld defect ok.

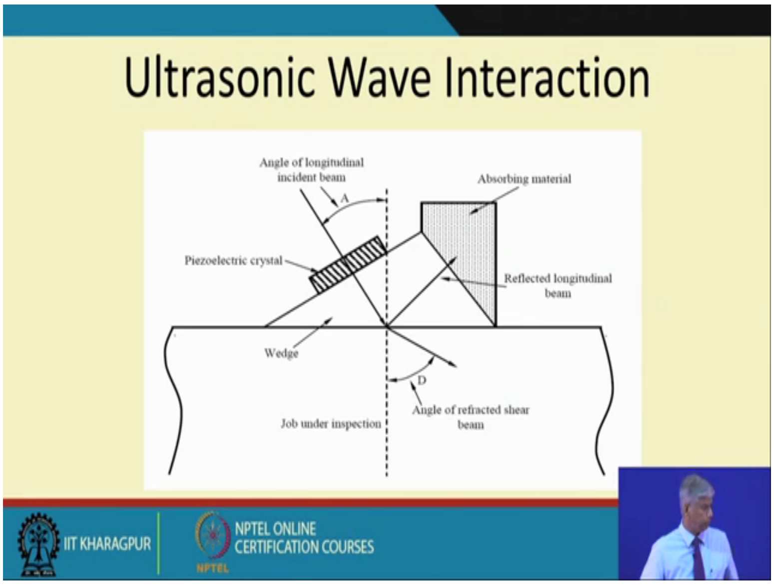
(Refer Slide Time: 16:09)



So, what how this ultrasonic transept transduction happening. so, this is nothing, but the wave generally usually a piezoelectric crystal and then we have a wave receiver.

So, series of ultrasonic wave; so, the time delay sequence can also be used to produce the phased array. So, that in one go I can scan the entire surface and there is something which we will see.

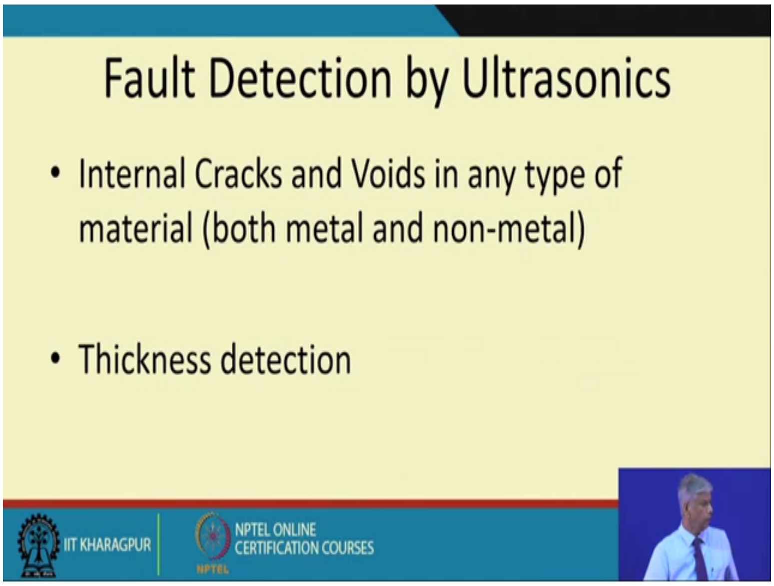
(Refer Slide Time: 16:33)



So, when I have a piezoelectric crystal. So, I will have an incident beam. So, job under inspection it will get refracted because of the density difference and then some will get reflected ok, I am not interested in this reflected beam rather I want to see how much of refraction is happening. So, I can put have an ultrasonic absorbing material here.

So, by this we can understand and I say if I move this into the plane of this projection here throughout the edge of the surface I can know whether any defect has occurred and so on.

(Refer Slide Time: 17:18)

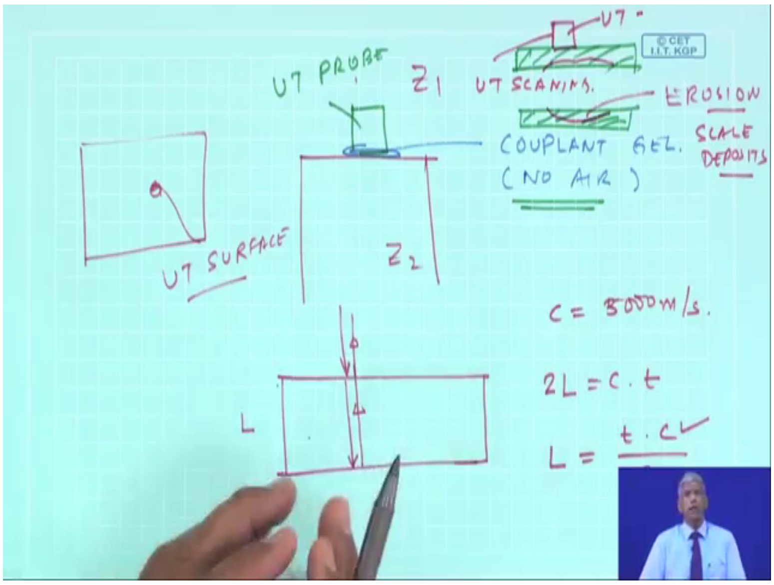


So, ultrasonic is used to find out internal cracks and voids in any type of material both metal and nonmetal though for nonmetal I will require a high power ultrasonic and usually for thickness reduction imagine on the outside.

(Refer Slide Time: 17:41)

So, for example, here this is a steel block and we have artificially cut a slot here and I am putting this longitudinal probe by the way this ultrasound is very similar to the ultrasound you know people do or to find out baby in the mother's womb.

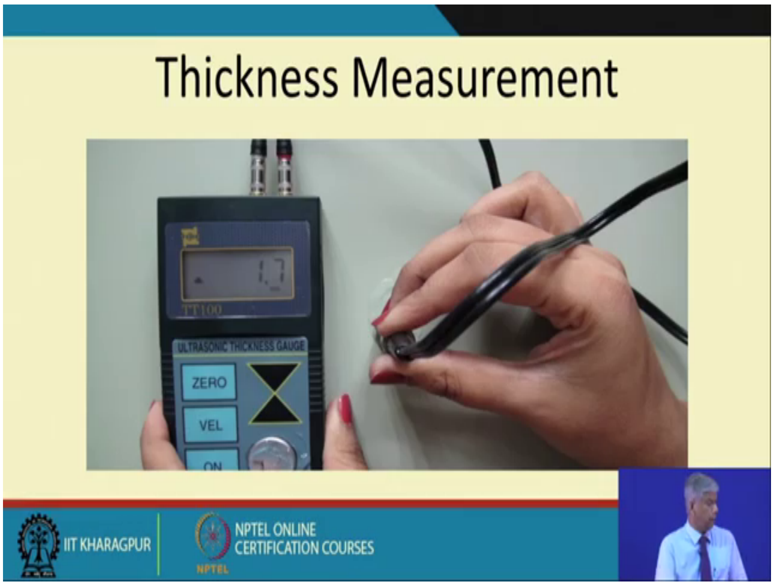
(Refer Slide Time: 18:09)



So, we put some sort of an gel because it this impedance Z 1 and this impedance Z 2 on this layer we put a couplant gel there is nothing, but a water based compounds. So, that there is no air between the interface of the probe and the material. So, to remove air a couplant and gel is applied and here also on this surface we are given a couplant gel. So, what happens how is it measuring the desert has taken as accurately is like this.

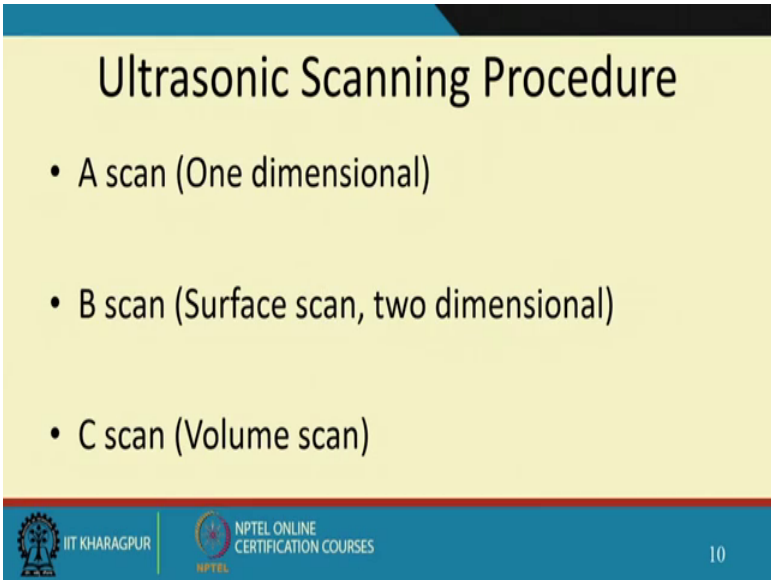
So, if this is my material, if I am sending an incident beam. So, in this distance is L this beam is going to get reflected back. So, by knowing the time period between the incident and reflected wave and knowing C is for steel 5000 meters per second. So, twice L is C times t ok, t is the time. So, I can find out L as t time C by 2. So, this is known to me this is what this circuitry would measure and then I can find out the thickness.

(Refer Slide Time: 19:51)



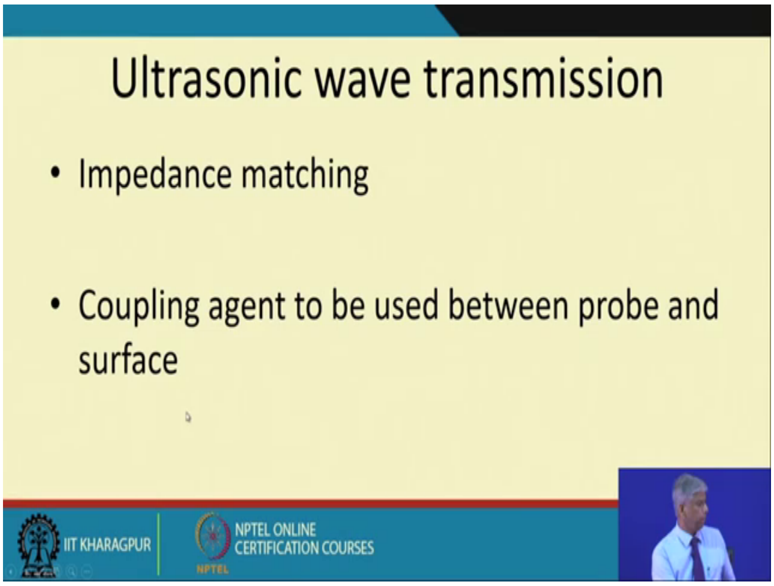
Now, this is a demonstration, but in the laboratory, we have a machine ; obviously, from the outside, we cannot measured thickness all you do is put on you tube probe on its surface and then we can find out and in this case, it is one point seven mm many times in many of the process plants have seen pipe lines thick pipe lines because of corrosion the material gets eroded erosion has occurred or the other way scale deposits have occurred. So, externally to monitor the quality of the internal thickness of the pipe, I can put on you to do a new to scanning you can do it UT scanning ok. So, there are many applications of ultrasonics in condition monitoring be it finding out thickness finding out cracks weld effect and so on.

(Refer Slide Time: 21:09)



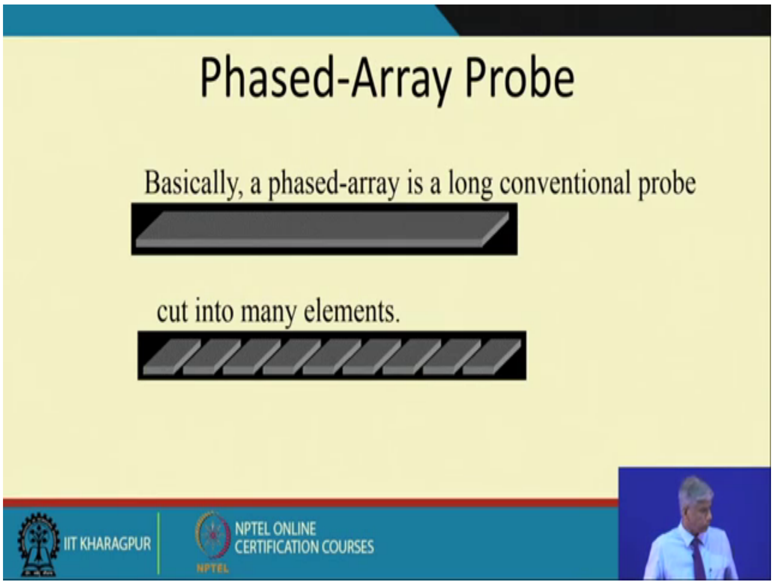
So, the scanning procedure there are names given for it A scan is a one dimensional scan, B scan is a two dimensional scan or a surface scan and C scan is a volume scan.

(Refer Slide Time: 21:23)

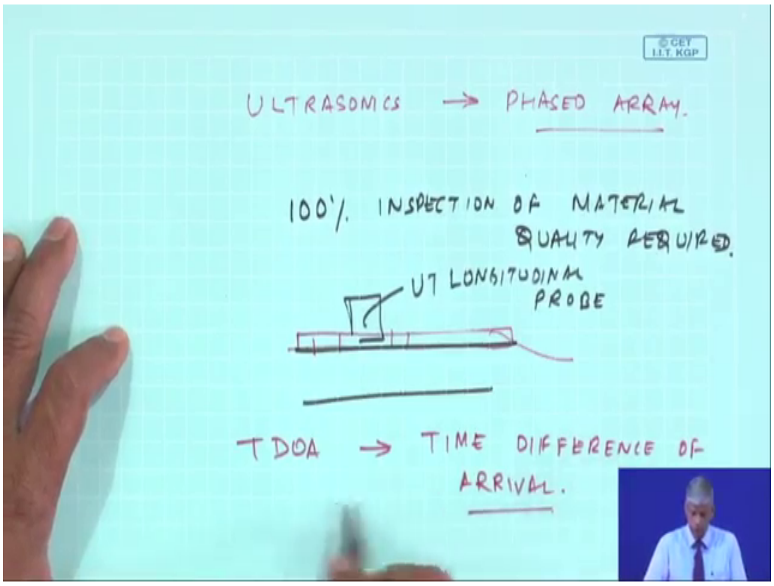


But most important is as a machine this impedance matching. So, coupling coupling agent is to be used between probe and surface and that is something one has to keep in mind.

(Refer Slide Time: 21:37)



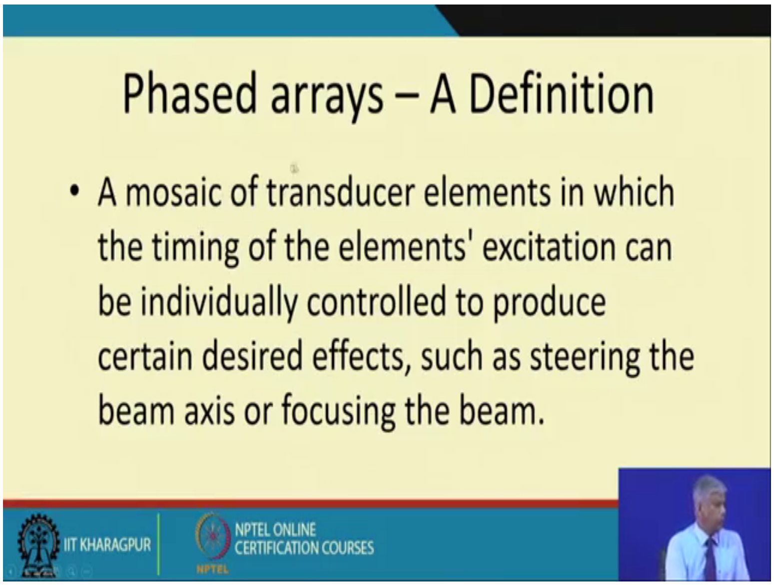
(Refer Slide Time: 21:44)



Now, recently a new technique has come in ultrasonics that is the phased array technology wherein rather than having a long conventional probe we have this something element cut into many many elements and each one of them could be energized to give an ultrasonic wave.

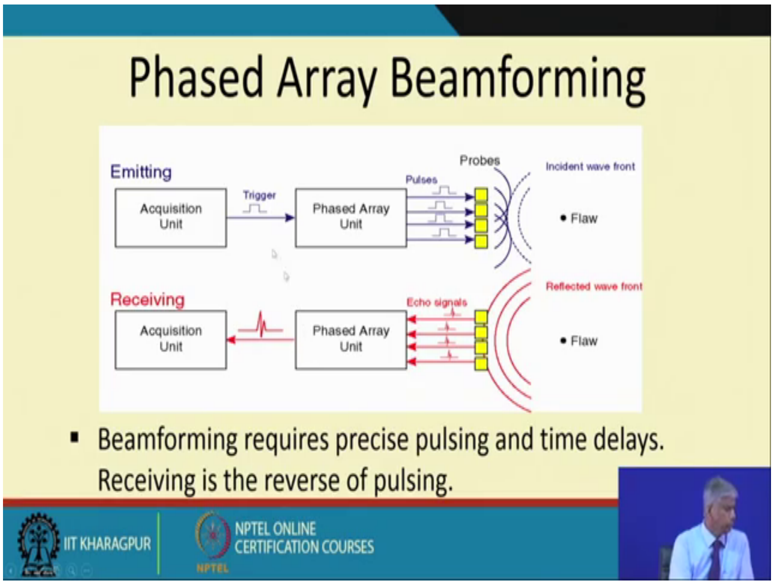
So, in a quickly because in as you know when there is hundreds percent inspection of material quality required, it becomes time consuming to just do a scanning with one UT longitudinal probe. So, instead of that imagine if I have a full surface full of probes ok. So, this can be made and then mosaic can be done.

(Refer Slide Time: 23:10)



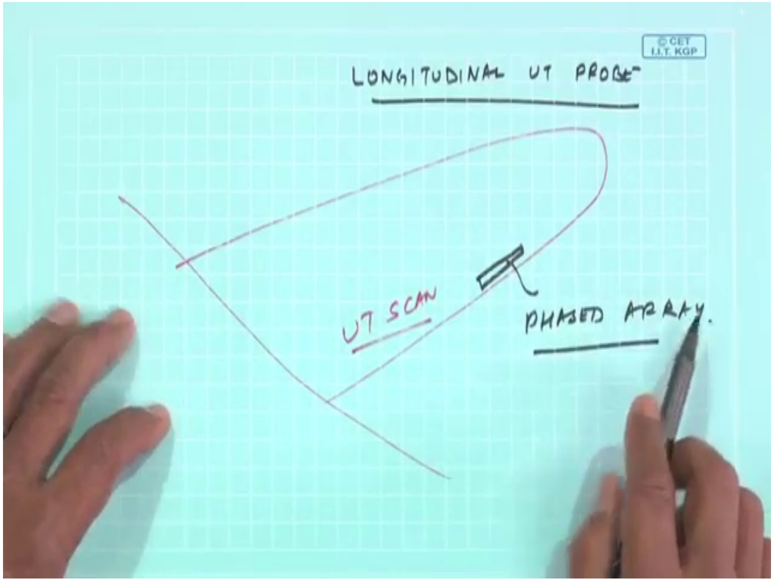
Phase; there is a mosaic of transducers elements in which the timing of the elements excitation can be individual controlled to produce certain desired effects such as steering the beam or focusing the beam, for example, I could be giving excitation I could timing it maybe I will illustrate it in the next diagram.

(Refer Slide Time: 23:31)



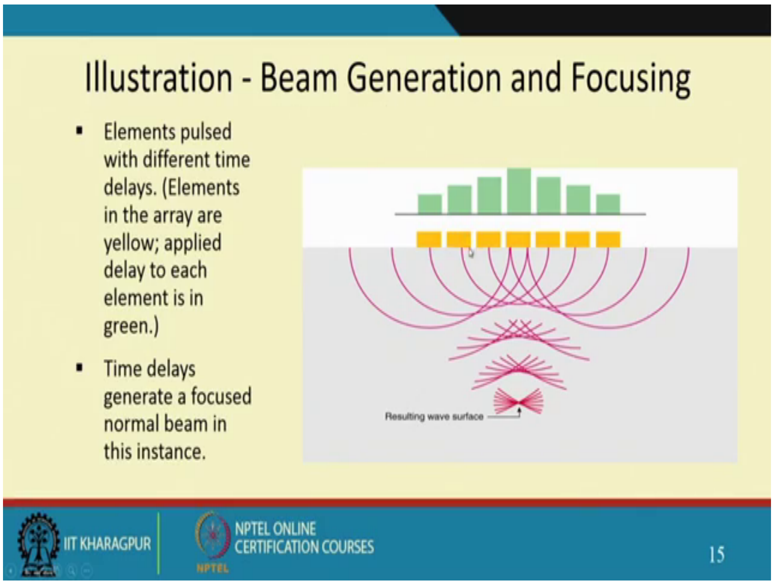
So, some of this phase there are beam forming is done ok, so, if I give a pulse into this unit and if I delay and play around the pulse durations I can get a circular wave length wave front I can get a planar wave front I can get it a pointed wave front ok. So, this kind of arrangements can be done and then of course, the reflected signals or the echo signals is dependent on the flow flaw and there will be a time delay. So, and by processing this time delay we can pinpoint the fault. So, this is known as t d o a technique time difference of arrival and then by this we can find out the fault for example, in large aircraft wings.

(Refer Slide Time: 24:46)



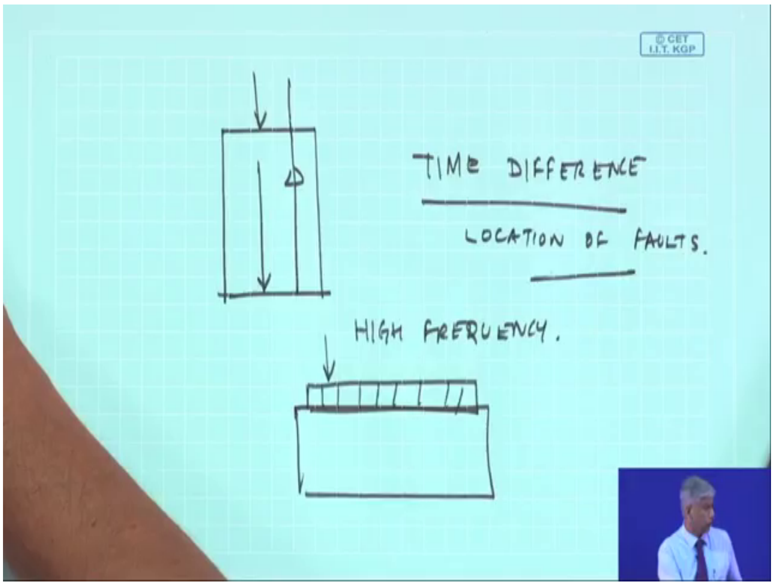
This fuselage ok; we can do UT scanning to find out or defect on the surface of the skin of the air long ok, of the flaps and then we can find out the faults by having such phased error technique.

(Refer Slide Time: 25:25)



So, you see how this different beam generation and focusing can be done elements are pulsed with different time delays elements, in the array are a yellow applied to each element is in green the delay has been given. So, let us delay here and that is why we can focus our beam to this. So, what happens in the sense because my region of interest is right here I can focus it by having such phase area? So, they are more powerful than a conventional single longitudinal. So, because there is a lot of signal processing involved because the most essential element is this.

(Refer Slide Time: 26:29)



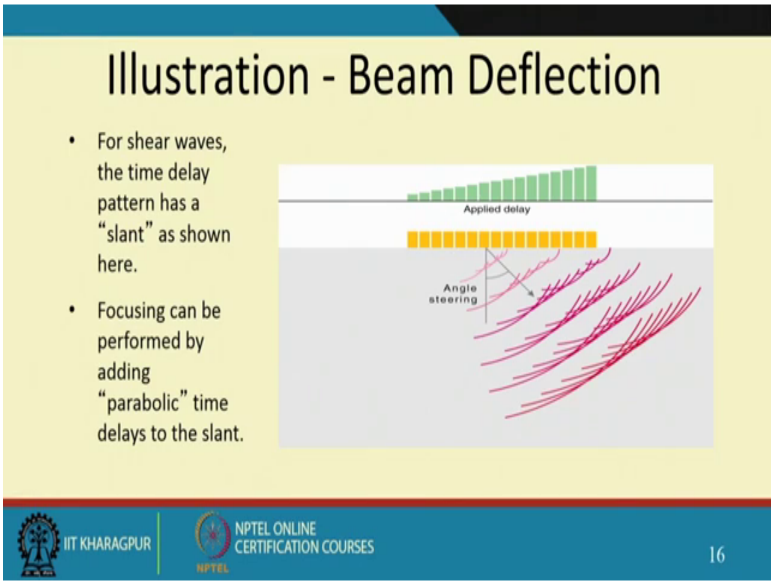
Student: (Refer Time: 26:30).

Time delay;

Student: (Refer Time: 26:31).

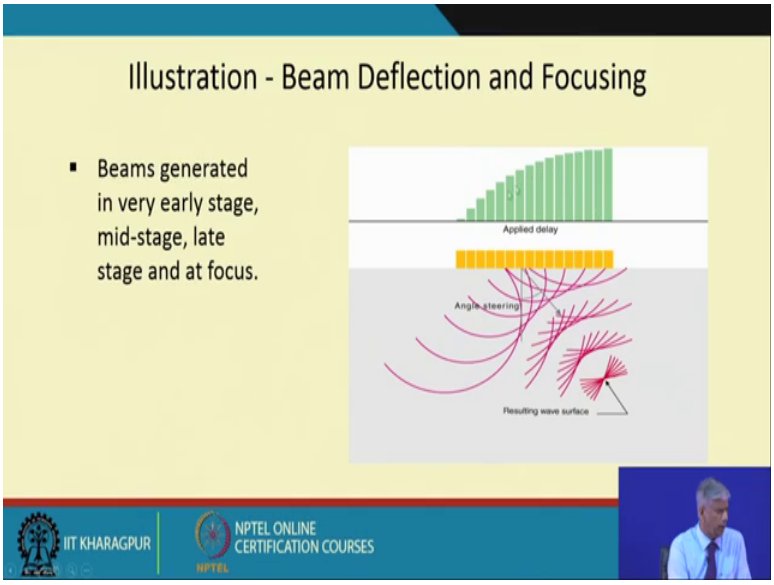
Between the incident and the reflected waves ok. So, time delay or time difference is the key to finding out the location of the fault, this has been exploited to find out develop ultrasonic thickness gauges and this has been exploited to use them to find out weld effects.

(Refer Slide Time: 27:06)



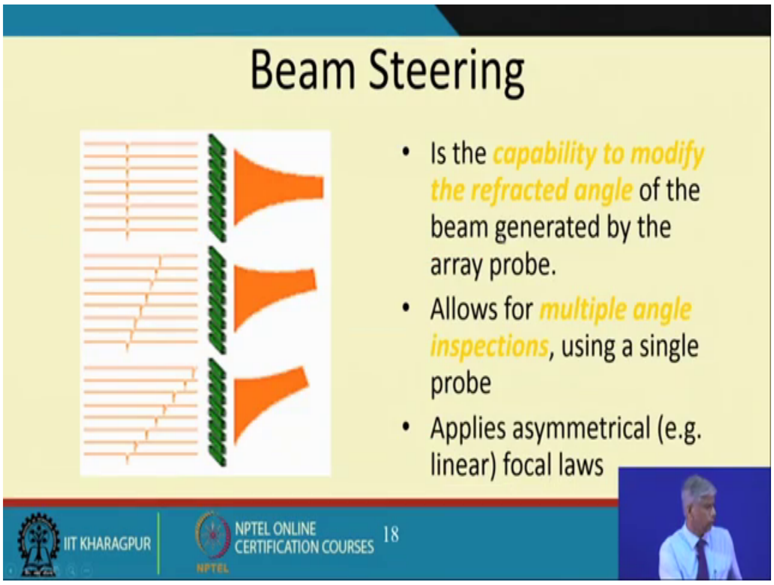
So, here in a shear wave the time delay has a slant pattern. So, focusing can be added you know I can steer the angle ok. So, all these are done through signal processing units and many commercial such handled and lasers are available ok.

(Refer Slide Time: 27:35)



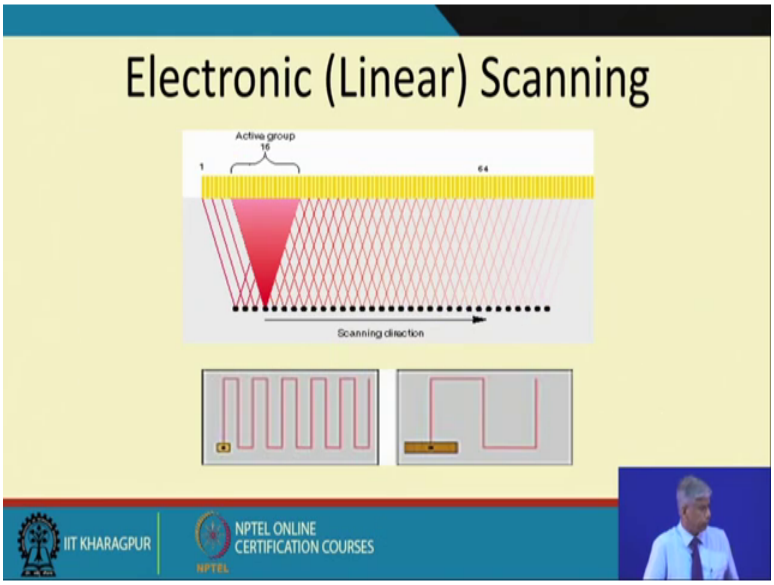
So, this can be applied and so on.

(Refer Slide Time: 27:37)



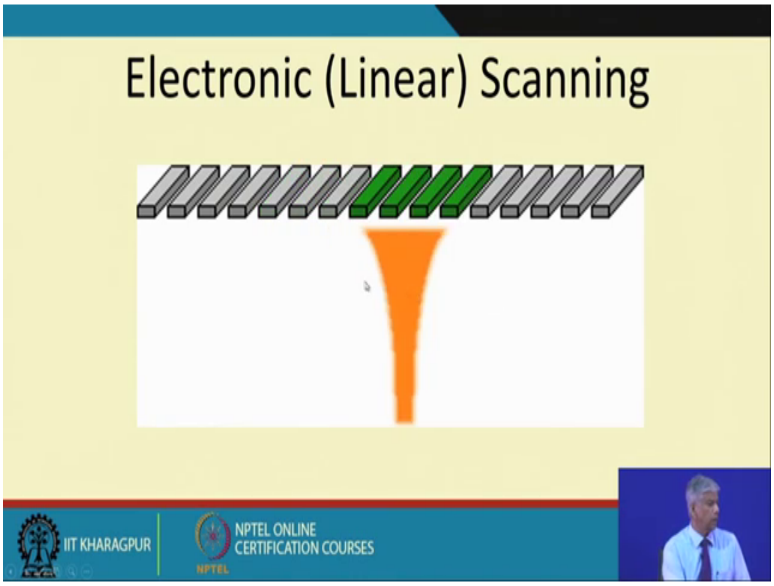
So, the beam steering can be applied as the capability to modify the refracted angle of the beam generated by the area probe allows for multiple angles inspection using a single probe ok. So, this becomes very easy for the user to do a scanning by ultrasonic.

(Refer Slide Time: 27:59)



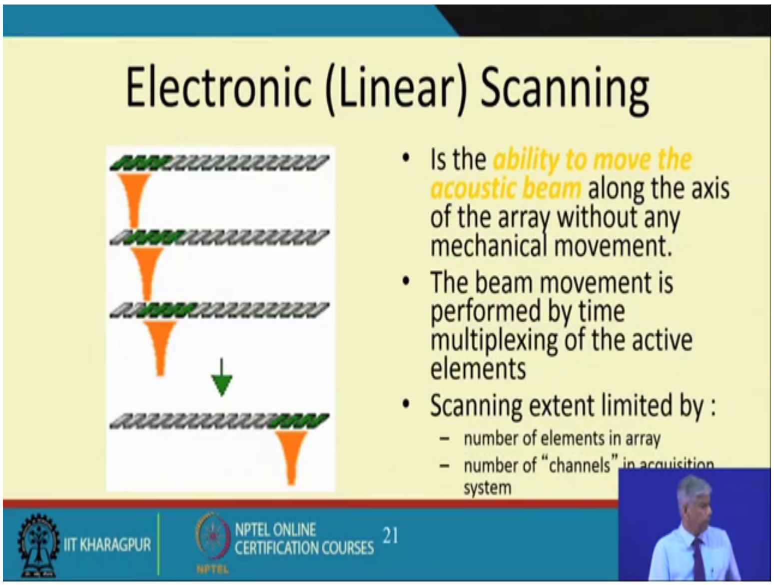
I can do linear scanning I can have the elements, but then electronically I can give a signal. So, that the elements do not move, but I will move this signal of excitation. So, I just place an electronic mosaic of elements on it do not move anything here, but move the excitation signal higher frequency and then do a scanning and so on ok.

(Refer Slide Time: 28:36)



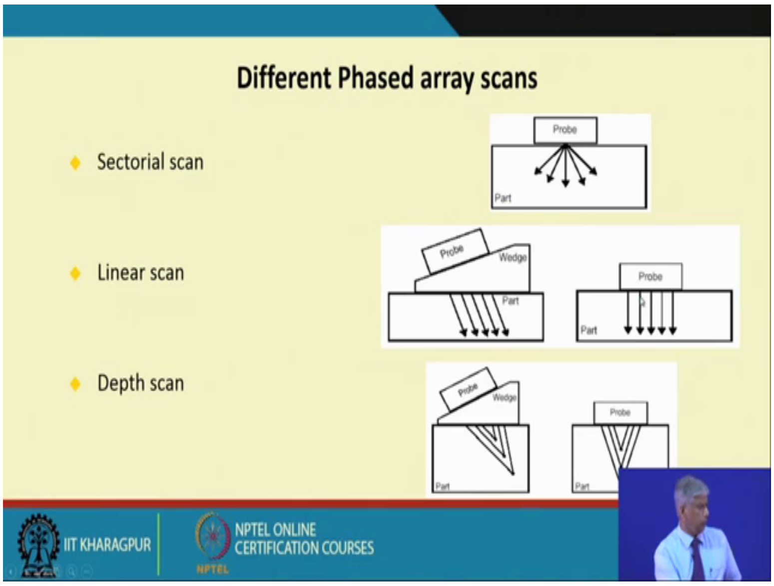
There is an example of the linear scanning, we are on charging them separately, I am not physically moving the transducer, but just exciting them the one by one the elements of the phased array. So, this is also very very important also a lot of new technologies are being developed.

(Refer Slide Time: 28:54)

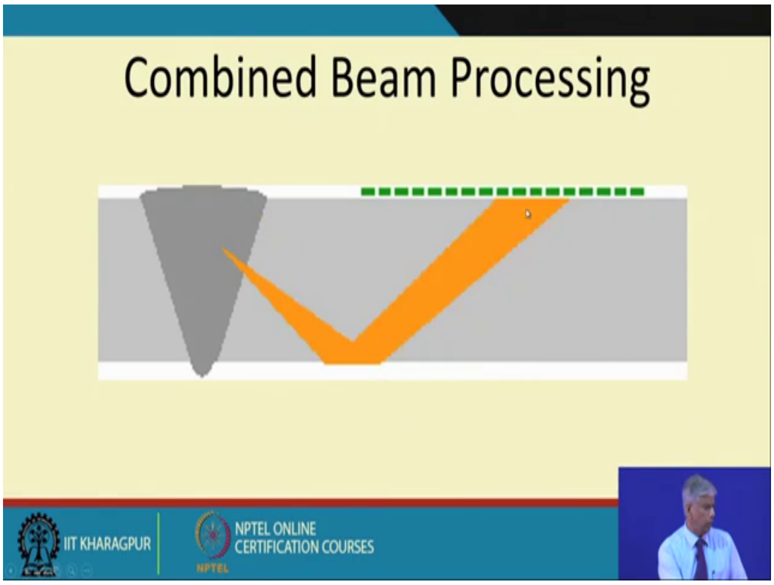


And commercially some of these are available.

(Refer Slide Time: 28:58)

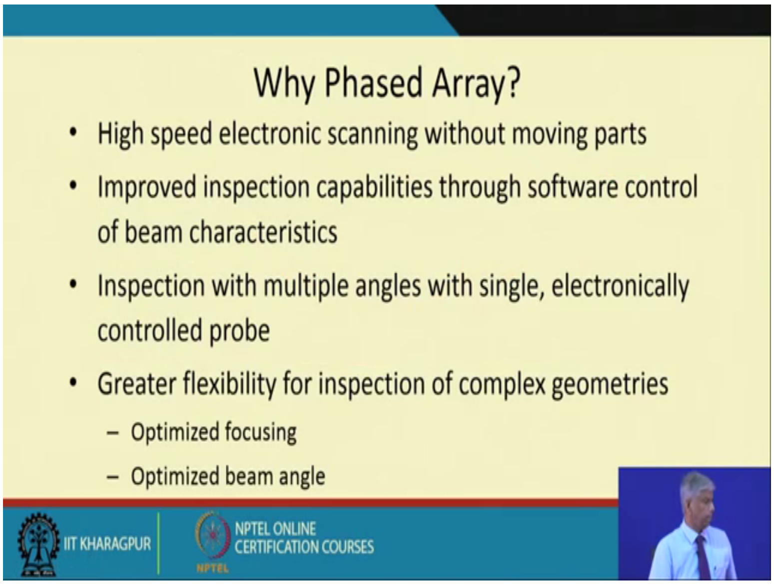


(Refer Slide Time: 29:02)



So, different phase there is scans are available ok. So, this is an weld effect. So, we can do that and so on ok. So, the entire depth of this weldment is scanned um, since I am moving it, this angle is not changing, but as opposed to this. So, we can scan the entire surface and this is what is essential when we do the weld defect scanning and. So, I can identify if there is a reflection here I can identify where this plot is. So, such arrangements are there ok.

(Refer Slide Time: 29:37)



So, why phased array high speed electronic scanning without moving parts improved inspection capabilities through software control inspection with multiple angles with single and electronically control and greater flexibility ok.

(Refer Slide Time: 29:54)

So, this is a view of a typical phased array equipment which we have in our laboratory and some of these, I will show you maybe in the last slide of our lectures here ok.

Thank you.