Structural Health Monitoring (SHM)

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Lecture - 41
Non - Destructive evaluation - I

Welcome, to the 13th lecture in module 2.

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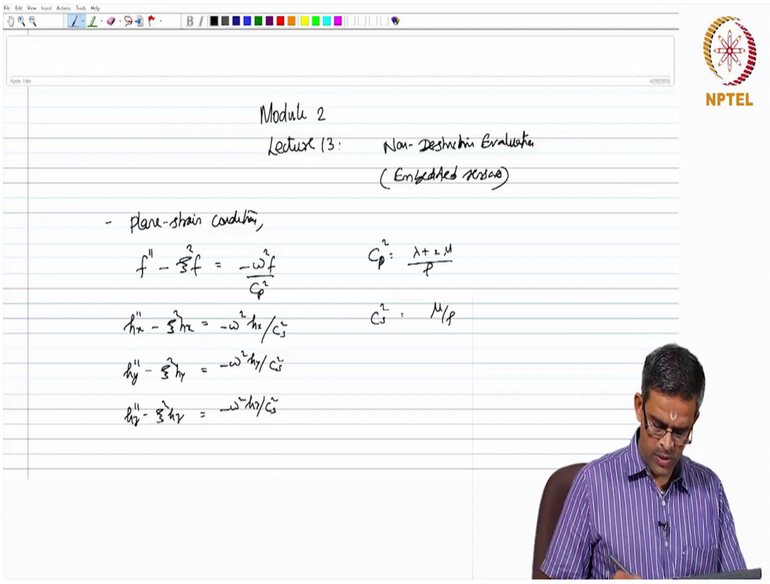

In this lecture, we will continue with Non-Destructive Evaluation techniques, but we will talk about embedded sensors. So, in the last lecture, we are discussing about a plane-strain condition we have equations f double prime minus zeta square f has minus omega square f by C p square, h x double prime minus h x, h y double prime minus h y, h z double prime minus h z or minus omega square h x by C s square minus omega square h y by a C s square minus omega square h z by C s square; where C s is given by lambda plus 2 mu by rho C p and C s square is given by mu by rho.

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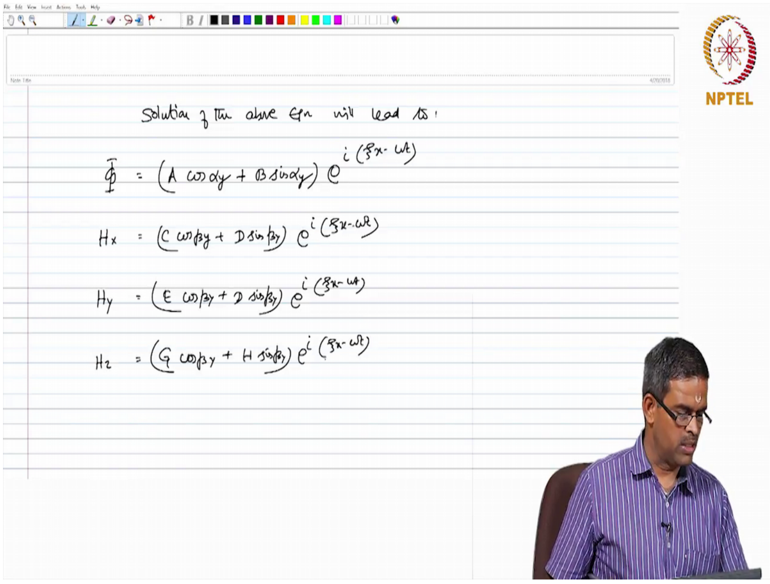

Now, the solution of this equation will lead to solution on phi H x H y and H z, which will be A cos alpha y plus B sine alpha y of e i minus omega t. Similarly, C cos beta y plus D sine beta y e i minus omega t: similarly, E cos beta y plus B sine beta y e i minus omega t and G cos beta y plus H sine beta y e i z x minus omega t.

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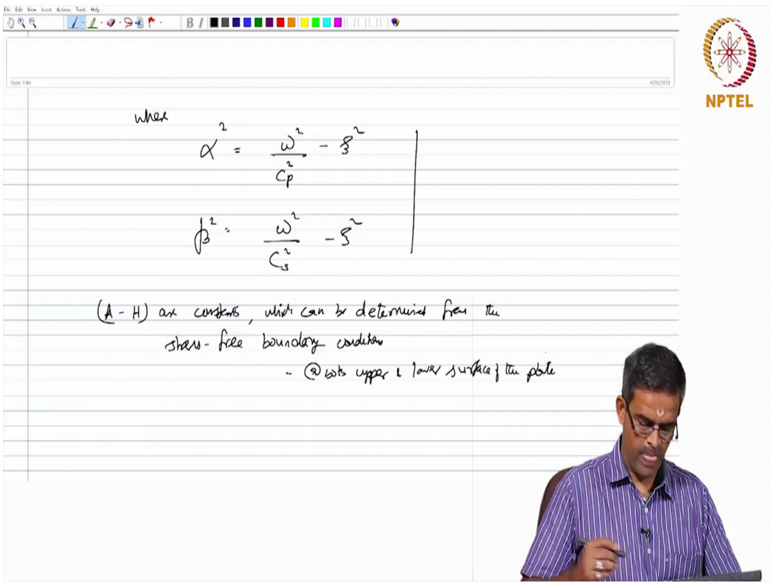

Alpha square is omega square by C p square minus zeta square and beta square is omega square by C s square minus delta square, ok. Look at this equation there are pairs A to H are actually constants which can be determined from the stress free boundary conditions at both upper and lower surface of the plate.

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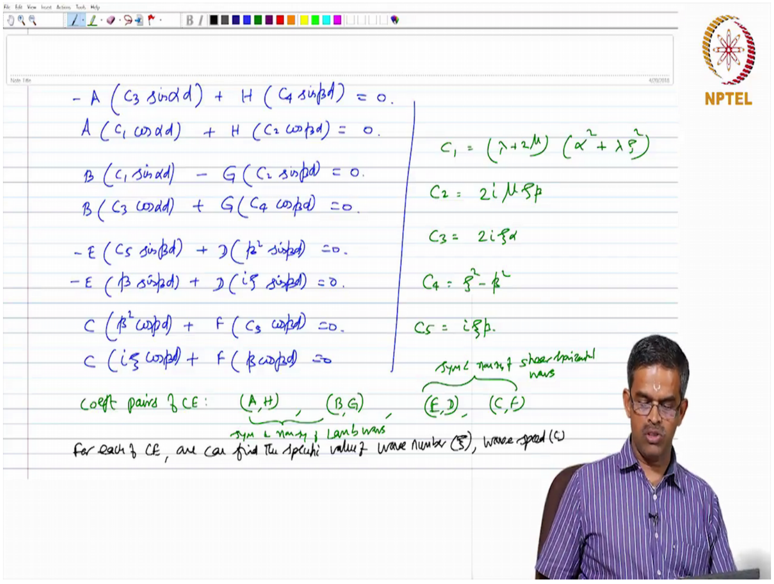

Let us write down those equations A C 3 sine alpha d plus H C 4 sine beta d is 0 A C 1 cos alpha d plus H C 2 cos beta d is 0, these are the characters equations we are writing. B C 1 sin alpha d minus G C 2 sin beta d will be 0, and B C 3 cos alpha d plus G C 4 cos beta d is 0, minus E C phi sine beta d plus D beta square sine beta d is 0, minus E beta sine beta d plus D i psi sine beta d is 0, C beta square cos beta d plus F C phi cos beta d is 0 and C i psi cos beta d plus F beta cos beta d is 0; where C 1 is alpha plus 2 mu into alpha square plus lambda psi square, C 2 is 2 i mu zeta beta, C 3 is 2 i alpha, C 4 and C phi.

You can wonderfully see here there are pairs which have been formed which are called coefficient pairs of this characteristic equation. These pairs are namely A, H B, G E, D and C, F. These two correspond to symmetric and non symmetric of lamb waves, these two pairs correspond to symmetric and non symmetric of shear horizontal way. For each of the characteristic equation one can find the specific value of wave number and wave period wave speed and that gives a solution for this equations.

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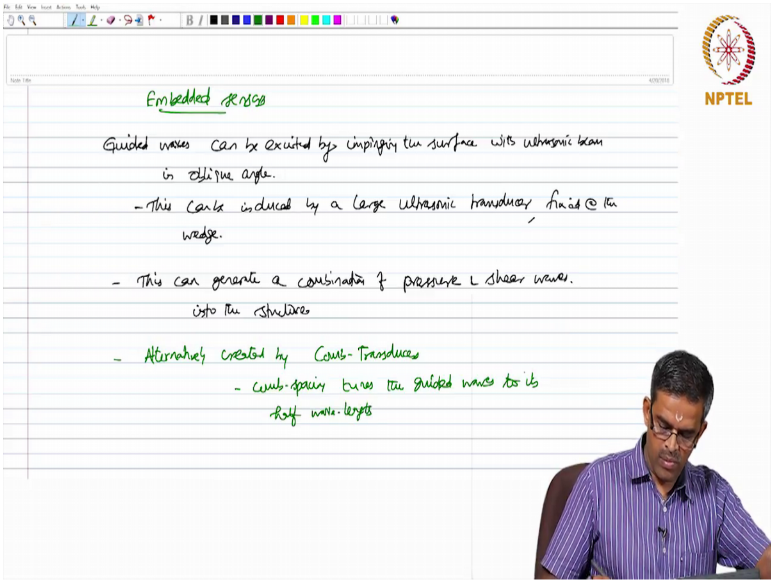

Now, the guided waves can be excited by impinging the surface with ultrasonic beam in oblique angle. This can happen or this can be induced by a large ultrasonic sensor or ultrasonic transducer fixed at the wedge. So, this can generate a combination of pressure waves and shear waves into the structure. They can also be alternatively created by comb-transducers, comb-spacing tunes the guided waves to its half wavelength.

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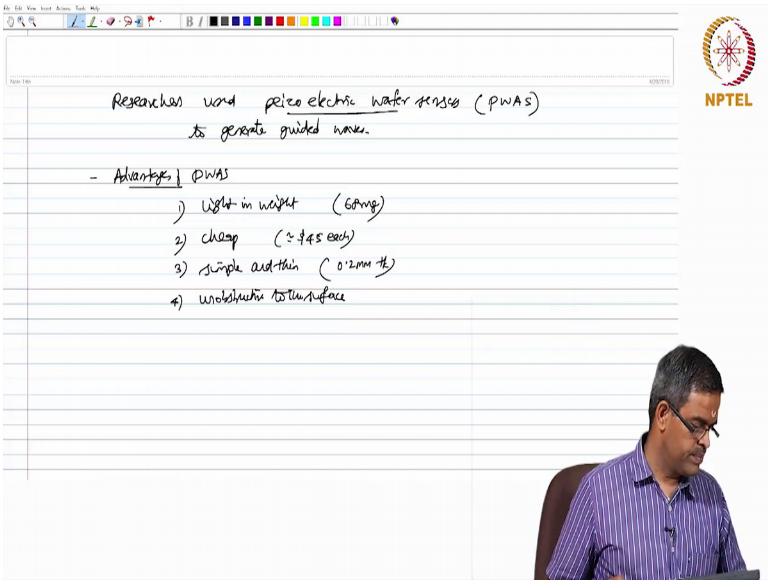

In the recent past researchers have also used piezoelectric wafer sensors, ok, these are called as piezoelectric wafer active sensors to generate guided waves.

There are some advantages of these sensors. They are very light in weight, it is only about 68 milligram, they are very cheap approximately about let us say 45 dollars each, they are very simple and thin essentially they are about 0.2 millimeter thick and they are on obstructive to the surface where they are embedded.

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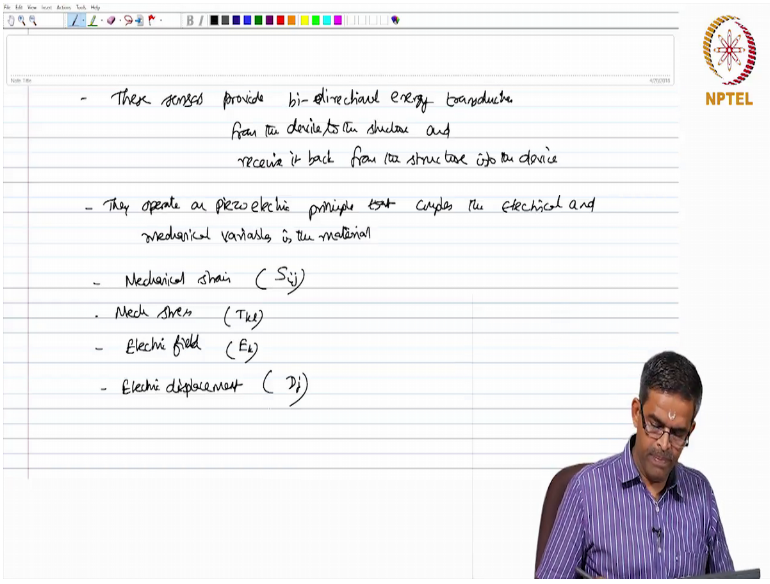

These sensors provide bi-directional energy transduction, that is, from the device to the structure and receive it back from the structure into the device. They operate on piezoelectric principle that couples the electrical and mechanical variables in the material.

Let us say mechanical strain is given by S ij and mechanical stress is given by T kl and electric field is indicated by E k and electric displacement is indicated by D j.

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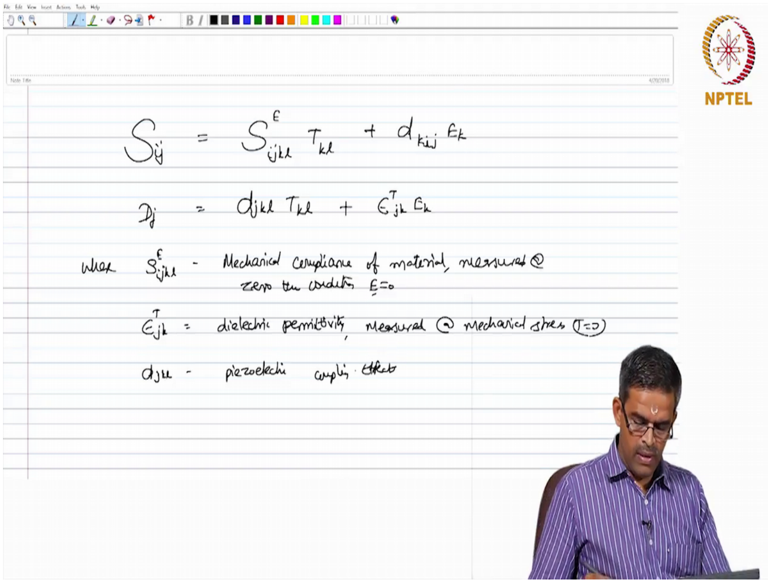

Then following equation holds good, S ij is S ijkl of E, T kl plus d kij E k. Similarly, D j is d jkl T kl plus j k and E k, where S E ijkl is the mechanical compliance of material measured at E equals 0. Whereas, epsilon j k is dielectric permittivity measured at mechanical stress T equals 0, d jkl is piezoelectric coupling effort.

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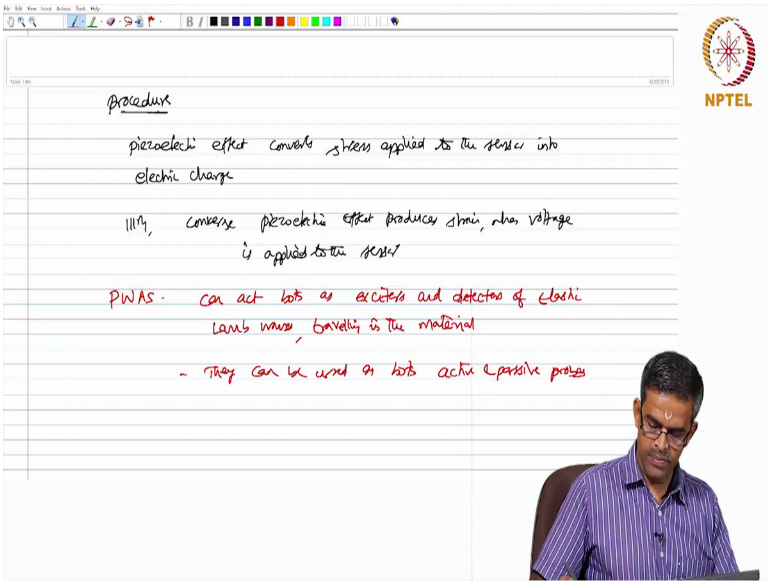

Let us see what is a procedure on which the piezoelectric wave active sensors works. The piezoelectric effect converts stress applied to the sensor into an electric charge. Similarly, the converse piezoelectric effect produces strain, when voltage is applied to the sensor.

So, interestingly these piezoelectric wave active sensors can act both as executers, sorry exciters, and detectors of elastic lamb waves traveling in the material. They can be used as both active and passive probes.

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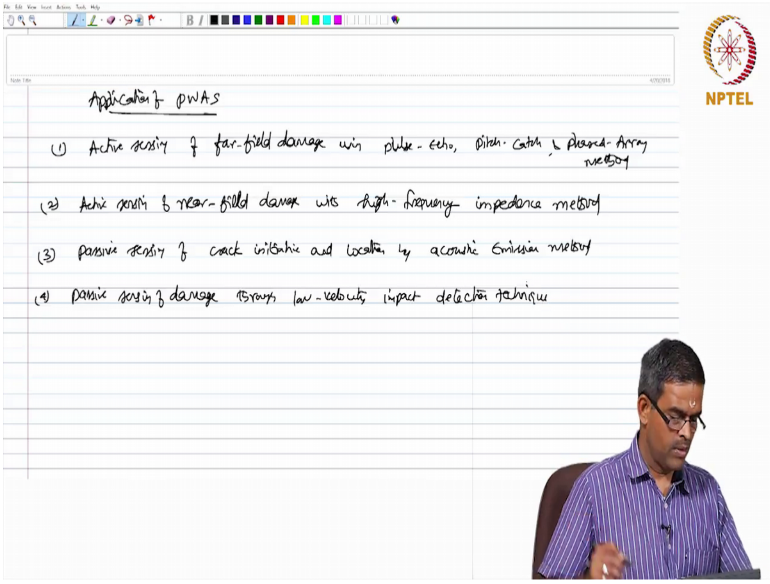

Let us see the applications of piezoelectric wave active sensors. One, they can be useful in active sensing of far field damage using pulse-echo precision, pitch catch method and phased array method. They can also be useful in active sensing of near field damage with high frequency impedance method. Further, they can be useful in passive sensing of crack initiating and location by acoustic emission method. They can also be useful for passive sensing of damage through low velocity impact detection technique.

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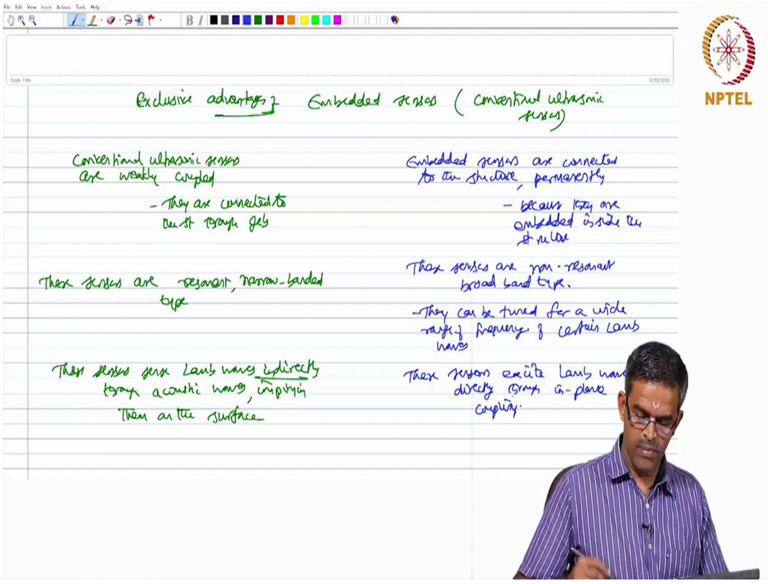

Of embedded sensors, in comparison to conventional ultrasonic sensors, let us see what are they. The conventional ultrasonic sensors are weakly coupled because they are connected to the structure through gels. Whereas, embedded sensors are connected to the structure permanently because they are embedded inside the structure.

Conventional sensors are these sensors are resonant, narrow-banded type, whereas these sensors are non-resonant broadband type. They can be tuned for a wide range of frequency of certain lamb waves. Conventional sensors sense lamb waves indirectly through acoustic waves by impinging them on the surface whereas, these sensors measure sorry, excite lamb waves directly through in-plane coupling.

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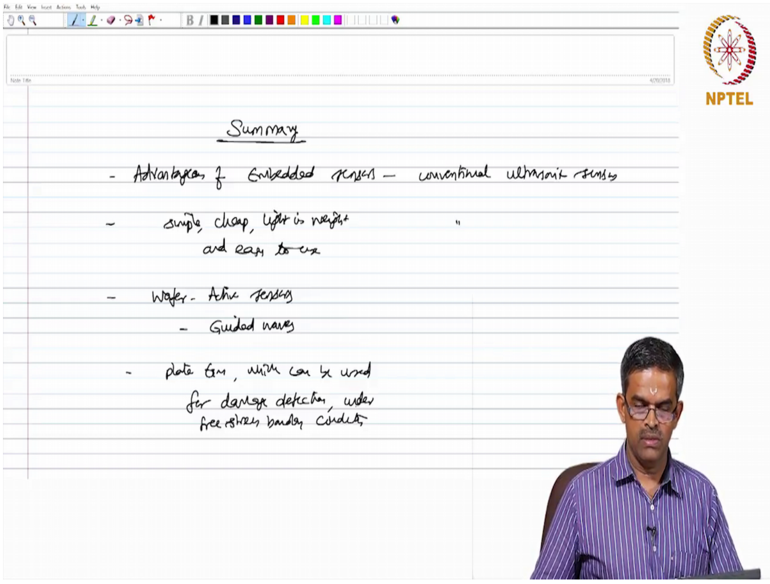

So friends, we have seen the advantages of in comparison to the conventional ultrasonic sensors. We have also said they are very simple, cheap, light in weight and easy to use comparison to these sensors. Wafer active sensors which are useful for guided waves application; the plate equation, which can be used for damage detection under free stress boundary condition.

In the next lecture, we will discuss further about the NDE methods, different kinds of sensors applicable to NDE and their usefulness in structural health monitoring processes.

Thank you very much.