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Module 2

Lecture 13: Non-Destructive Evaluation (Embedded sensors)

- plane-strain condition,

$$f'' - \xi^2 f = \frac{-\omega^2 f}{c_p^2}$$

$$h_x'' - \xi^2 h_x = -\omega^2 h_x / c_s^2$$

$$h_y'' - \xi^2 h_y = -\omega^2 h_y / c_s^2$$

$$h_z'' - \xi^2 h_z = -\omega^2 h_z / c_s^2$$

$$c_p^2 = \frac{\lambda + 2\mu}{\rho}$$

$$c_s^2 = \mu/\rho$$

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Solution of the above eqn will lead to:

$$\Phi = (A \cos \alpha y + B \sin \alpha y)\, e^{i(\xi x - \omega t)}$$

$$H_x = (C \cos \beta y + D \sin \beta y)\, e^{i(\xi x - \omega t)}$$

$$H_y = (E \cos \beta y + D \sin \beta y)\, e^{i(\xi x - \omega t)}$$

$$H_z = (G \cos \beta y + H \sin \beta y)\, e^{i(\xi x - \omega t)}$$

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where

$$\alpha^2 = \frac{\omega^2}{c_p^2} - \xi^2$$

$$\beta^2 = \frac{\omega^2}{c_s^2} - \xi^2$$

(A - H) are constants, which can be determined from the stress-free boundary conditions

- @ both upper & lower surface of the plate

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$$-A(C_3 \sin\alpha d) + H(C_4 \sin\beta d) = 0.$$

$$A(C_1 \cos\alpha d) + H(C_2 \cos\beta d) = 0.$$

$$B(C_1 \sin\alpha d) - G(C_2 \sin\beta d) = 0.$$

$$B(C_3 \cos\alpha d) + G(C_4 \cos\beta d) = 0.$$

$$-E(C_5 \sin\beta d) + D(k^2 \sin\beta d) = 0.$$

$$-E(\beta \sin\beta d) + D(i\xi \sin\beta d) = 0.$$

$$C(k^2 \cos\beta d) + F(C_5 \cos\beta d) = 0.$$

$$C(i\xi \cos\beta d) + F(\beta \cos\beta d) = 0$$

$$C_1 = (\lambda + 2\mu)(\alpha^2 + \lambda\xi^2)$$

$$C_2 = 2i\mu\xi\beta$$

$$C_3 = 2i\xi\alpha$$

$$C_4 = \xi^2 - k^2$$

$$C_5 = i\xi\beta.$$

coeff pairs of CE: (A, H), (B, G) — sym & nonsym of Lamb waves; (E, D), (C, F) — sym & nonsym of shear horizontal waves

For each of CE, we can find the specific value of wave number (ξ), wave speed (c)

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Embedded sensors

Guided waves can be excited by impinging the surface with ultrasonic beam in oblique angle.

- This can be induced by a large ultrasonic transducer fixed @ the wedge.

- This can generate a combination of pressure & shear waves into the structure

- Alternatively created by Comb-Transducer
  - comb-spacing tunes the guided waves to its half wave-length

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Researches used piezo electric wafer sensors (PWAS) to generate guided waves.

- Advantages of PWAS
  1) Light in weight (60mg)
  2) cheap (≈ $45 each)
  3) simple and thin (0.2mm thk)
  4) unobstructive to the surface

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- These sensors provide bi-directional energy transducers 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

  - Mechanical strain (S_{ij})
  - Mech stress (T_{kl})
  - Electric field (E_k)
  - Electric displacement (D_j)

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$$S_{ij} = S^{E}_{ijkl} T_{kl} + d_{kij} E_k$$

$$D_j = d_{jkl} T_{kl} + \epsilon^{T}_{jk} E_k$$

where S^{E}_{ijkl} - Mechanical compliance of material, measured @ zero the conductor $E=0$

ϵ^{T}_{jk} = dielectric permittivity, measured @ mechanical stress ($T=0$)

d_{jkl} - piezoelectric coupling effect

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Procedure

piezoelectric effect converts stress applied to the sensor into electric charge

Ultrasonic converse piezoelectric effect produces strain, when voltage is applied to the sensor

PWAS - can act both as exciters and detectors of elastic Lamb waves travelling in the material

- They can be used as both active & passive probes

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Application of PWAS

(1) Active sensing of far-field damage with pulse-echo, pitch-catch & phased-Array method

(2) Active sensing of near-field damage with high-frequency impedance method

(3) passive sensing of crack initiation and location by acoustic Emission method

(4) passive sensing of damage through low-velocity impact detection technique

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Exclusive advantages of Embedded sensors (conventional ultrasonic sensors)

Conventional ultrasonic sensors are weakly coupled
- They are connected to the structure through gels

These sensors are resonant, narrow-banded type

These sensors sense Lamb waves indirectly through acoustic waves, emitting them on the surface

Embedded sensors are connected to the structure permanently
- because they are embedded inside the structure

These sensors are non-resonant broad band type.
- They can be tuned for a wide range of frequency of certain Lamb waves

These sensors excite Lamb wave directly through in-plane coupling.

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Summary

- Advantages of Embedded sensors — conventional ultrasonic sensors

- simple, cheap, light in weight " and easy to use

- Wafer - Active sensors
  - Guided waves

- plate like, which can be used for damage detection under free stress boundary conditions

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