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Module 2

Lecture 12: Non destructive Evaluation

(1) Non-destructive test (NDT)

(2) Non-destructive evaluation (NDE)

(3) Non-destructive inspection (NDI)

$\Bigg\}$ for SHM scheme

- Inspection methods
- continuous / intermittent health monitoring.

To detect the structural failure (damage - local)

- Ultrasonic inspection - most commonly practised technique in SHM

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<u>Basic principle</u>

In a infinite solid medium, Elastic waves can propagate in 2 modes

(1) Pressure wave (P waves)

(2) Shear wave (S waves)

If the medium is bounded, then these wave reflect @ the boundaries to form a complicated wave pattern.

- Guided waves, which remain contained within the wave guide

  <u>Lamb</u> waves are guided waves, travelling along the plate

  Rayleigh waves are guided waves, constrained to the surface

Love waves are also guided waves, which travel in layered materials

Stoneley waves are guided waves, constrained to material interface.

Ultrasonic Non-destructive Evaluation (NDE) rely on Elastic wave propagation and its reflection within the material.

These wave-field disturbances are caused due to local damage and any other defects that are present

damage detection is analyzed

Any disturbance caused to this wave field is an indication of presence of damage

Ultrasonic waves involve the following measurements:

1) TOF : time of flight, wave transit (or) delay
2) path length
3) frequency
4) phase angle
5) amplitude
6) acoustic impedence
7) Angle of wave deflection (refraction, refraction)

Techniques of ultrasonic method

1) pulse - Echo method

2) pulse - transmission (or) pitch - catch method

3) pulse - resonance method

<u>Procedure</u>

- An ultrasonic probe (commonly used is a piezo-electric) placed on the surface of the member induces waves in the material
- These probes establish contact with the structure using special couple gels
- Based on incidence of the Transducer, wrt the surface of the member

It generates P, S wave (or) its combination

- These waves detect anomalies around the sound parts.

- In pitch-echo method, defects are detected in the form of echos

- In pitch-catch method, flaws are detected by wave dispersion and its attenuation due to damage

Major draw-backs of using ultrasonic method

- Sound parts traverses only on a small portion of the material volume. Hence, Transducer should be moved, to cover a large volume
  - This is time-consuming

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Alternatively, one can use C-scans, but they are expensive

- ultrasonic waves cannot be induced normal to the surface of the structure

Hence, cracks, which are normal (⊥r) to the surface cannot be detected readily by this process.

But guided waves can be used to detect such flaws.

Lamb waves are commonly used guided waves

- They are used to detect damage/faults in sheet metal, airframes, large containers and pipes.

Lamb waves can detect

- cracks
- inclusions
- disbonding in metallic and composite structures

- They are very useful for detecting damage in thin plates & shells.

Rayleigh waves are more useful in detecting surface defects

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Embedded NDE

Sensor network, used for monitoring can be completely embedded (permanently fixed) into the structure. These sensors can be used for monitoring.

passive SHM

uses passive sensors that are monitored over a period of time

- monitored data will be useful in updating the system characteristics

Example of passive SHM

1) load
2) stress
3) Environmental conditions
4) acoustic emission from cracks etc

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passive SHM only listen to the structure

It doesn't interact with the structure

Active SHM detects presence of damage and also estimates its extent and severity

One of the Active SHM is piezoelectric Wafer Active Sensor (PWAS)

- These sensors send signal (Lamb waves) and also receive Lamb waves to identify presence of damage in the structure (cracks, delamination, debonding, corrosion etc)

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In flat plates, ultrasonic guided waves travel as Lamb waves and shear horizontal waves.

Lamb waves are vertically polarized while shear horizontal waves are horizontally polarized.

Let us consider a plate with stress-free upper & lower surface as shown in the figure

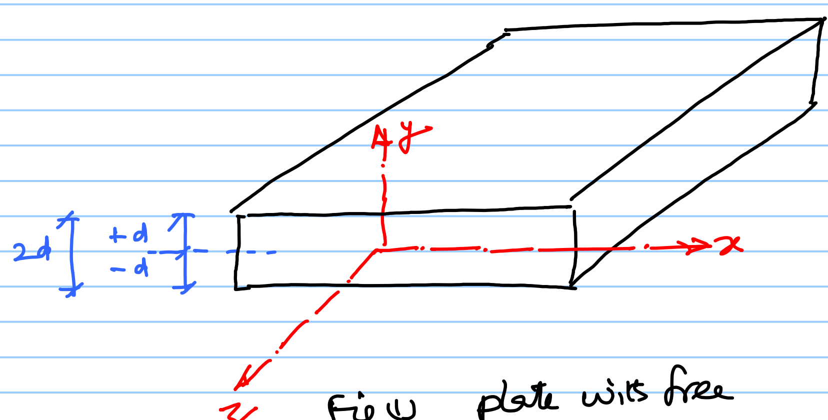

Fig (1) plate with free boundary

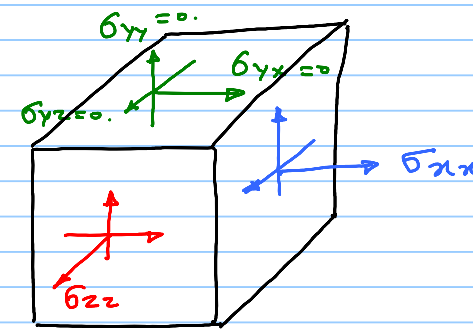

fig (2) free body diagram of a small area, extracted from the plate

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plate thickness = $2d$

Eqn. of motion for an isotropic elastic motion is given by:

$$\mu \nabla^2 U + (\lambda + \mu) \nabla \nabla \cdot U = \rho \frac{\partial^2 U}{\partial t^2} \quad -(1)$$

where λ, μ - Lame's constant

ρ - mass density

U - displacement vector

Assuming the displ. vector as below: $U = \nabla \Phi + \nabla \times H \quad -(2)$

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where Φ & H are potential functions and given by :

$$\left.\begin{aligned} \Phi &= f(y)\, e^{i(\xi x - \omega t)} \\ H &= \left(h_x(y)\, i + h_y(y)\, j + h_z(y)\, k \right) e^{i(\xi x - \omega t)} \end{aligned}\right| \quad (3)$$

where ω - circular frequency

ξ - wave number

wave speed, $c = \omega / \xi$

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Assuming (ω, ξ, c), governing Equation is now written by:

$$\nabla^2 \Phi = \frac{1}{C_p^2} \frac{\partial^2 \Phi}{\partial t^2}$$

$$\nabla^2 H = \frac{1}{C_s^2} \frac{\partial^2 H}{\partial t^2} \qquad (4)$$

$$\nabla \cdot H = 0$$

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For the plane strain, (which is z invariant)

Eq(4) now reduces to the following form:

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

$$h_x'' - \xi^2 h_x = \frac{-\omega^2 h_x}{C_s^2} \qquad (5)$$

$$h_y'' - \xi^2 h_y = -\frac{\omega^2 h_y}{C_s^2}$$

$$h_z'' - \xi^2 h_z = \frac{-\omega^2 h_z}{C_s^2}$$

where

C_p : pressure wave speed

- longitudinal component

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

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

C_s = shear wave speed

= transverse component

Summary

- Non-destructive Evaluation methods
- ultrasonic waves — monitoring purposes
- different form of waves
  - guided waves
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