UNIVERSITI TEKNIKAL MALAYSIA MELAKA

OPENCOURSEWARE

BETM 3583

# Vibration Analysis and Monitoring


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# Contents

1. Experimental modal analysis

# Learning Outcome

1. Understand the procedure for modal analysis experiment

# Experimental Modal Analysis

Review Topic 4 :

Experimental Modal Analysis

# Experimental Modal Analysis

- Modal analysis means a study of the dynamic character of a system which is determined independently from the loads applied and the response of the system
- Modes (also known as resonances) are essential/inherent/permanent properties of a material/structure.
- Modes or resonances are determined by:
  - the mass, stiffness, and damping,
  - system boundary conditions.

# Experimental Modal Analysis

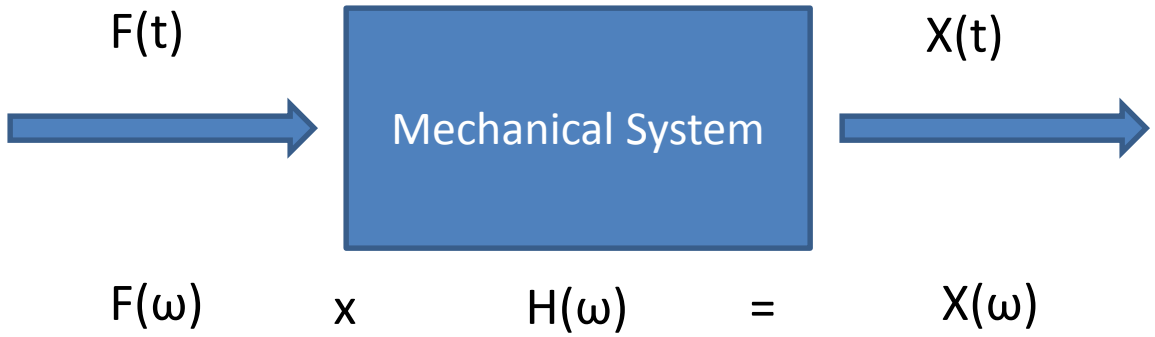
- Recently, impact testing (also known as bump testing) has been widely spread and become the most economical and the fastest ways to find the modes of machine vibration.

- Impact testing involves :
  - Making FRF Measurement
  - Modal Excitation Techniques
  - Modal Parameter Estimation

# Experimental Modal Analysis

FRF Measurement

The FRF describes the input-output relation on a mechanical system (between two points ) as a function of frequency, as shown as



# Experimental Modal Analysis

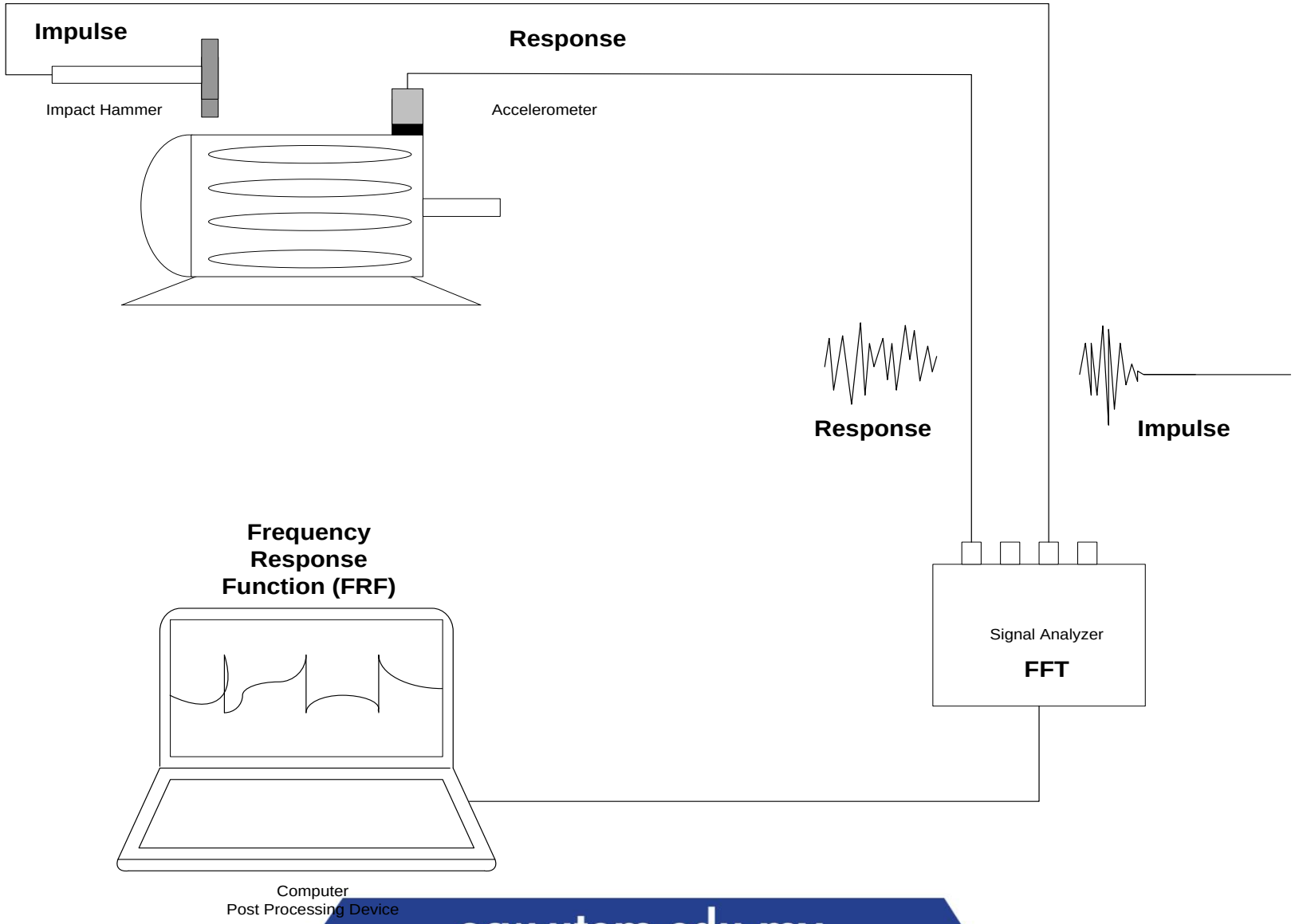
- FRF is defined as the ratio between an output response X(ω) to the input force F(ω)
- Other names of FRF :
  - Compliance = (displacement / force)
  - Mobility = (velocity / force)
  - Inertance / receptance = (acceleration / force)
  - Dynamic stiffness = (1/compliance)
  - Impedance = (1/mobility)
  - Dynamic mass = (1/inertance)

# Experimental Modal Analysis

EXCITING MODE WITH IMPACT TESTING

1. Impact Hammer
   to measure the input force using a load cell on its head.
2. Accelerometer
   to measure the acceleration response at fixed point and direction
3. FFT Analyzer
   to compute/calculate the FRFs
4. Post processing modal software
   to identify modal parameters , also for displaying the mode shape in animation.

# Experimental Modal Analysis



# Experimental Modal Analysis

Model of System Response

The input force (excitation) and output vibration (response) relation is

$$\{Y\} = [H]\{X\}$$

Where *{Y}* is vector of response spectra and *{X}* is excitation spectra. *[H]* is the FRF matrix.

# Experimental Modal Analysis

It can also be written as

$$Y_i = \sum_j H_{ij} X_j$$

$Y_i$ : output spectrum

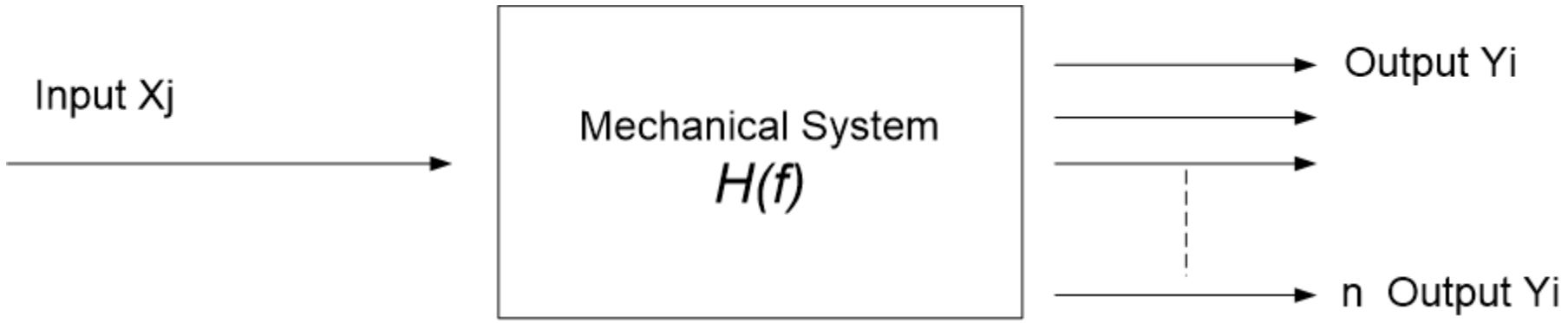
$X_j$ : input spectrum

$H_{ij}$ : FRF

The output is the sum of each input effects.

# Experimental Modal Analysis

## Single Inputs




$$Y_i = \sum_j H_{ij} X_j$$

# Experimental Modal Analysis

The FRF can be estimated such as

$$H_1 = G_{XY} / G_{XX}$$

Or

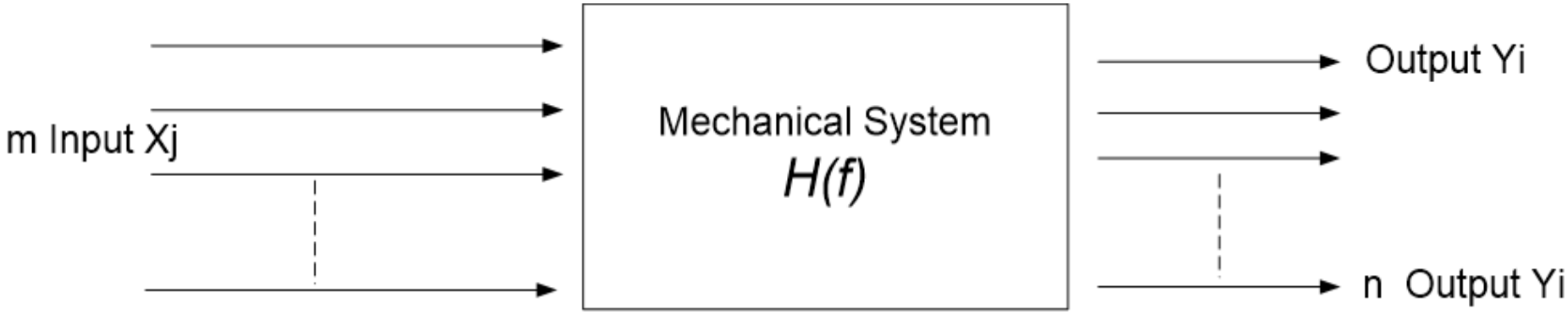
$$H_2 = G_{YY} / G_{YX}$$

$G_{XX}$ and $G_{YY}$ : the autospectra of input and output.

$G_{XY}$ : the cross-spectrum between input and output. $G_{YX}$ : the cross-spectrum between output and input.

# Experimental Modal Analysis

## Multiple Inputs




$$Y_i = \sum_j H_{ij} X_j$$

# Experimental Modal Analysis

The FRF can be estimated such as

$$[H_1]^T = [G_{XX}]^{-1}[G_{XY}]$$

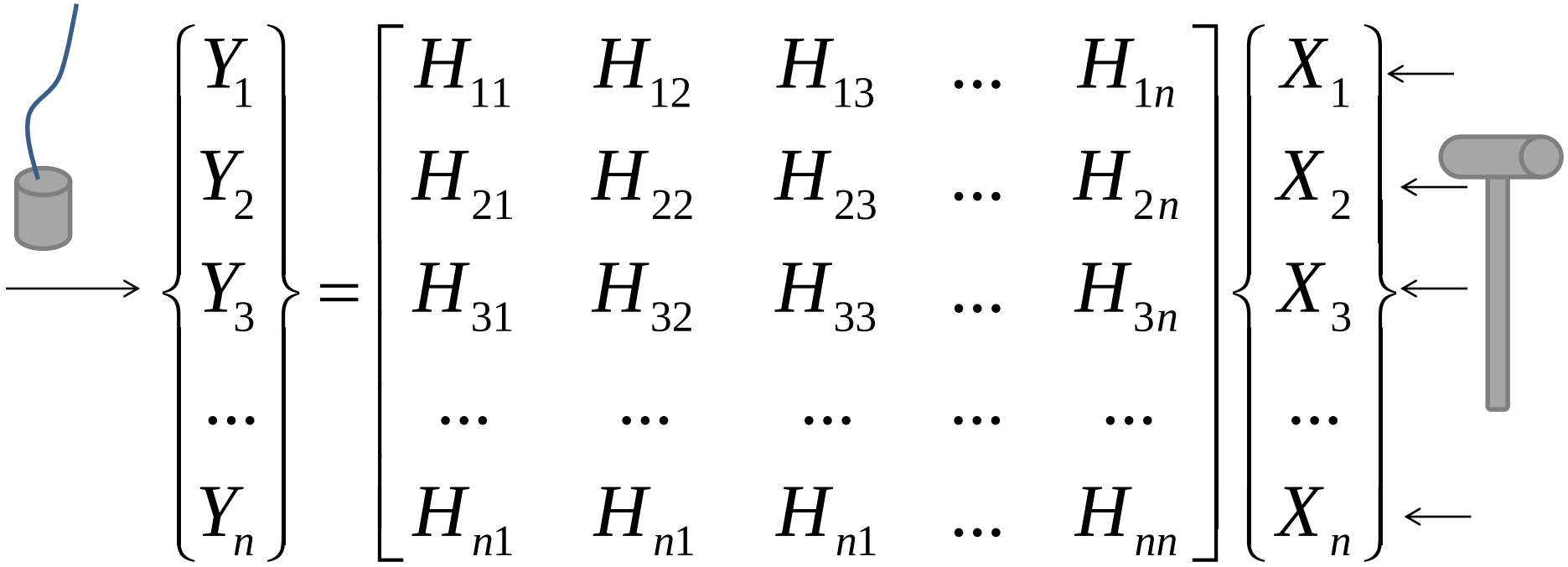
$[G_{XX}]$ is the matrix of the auto and cross-spectra.

$[]^T$ is the transposed matrix.

$[]^{-1}$ is the inverse matrix.

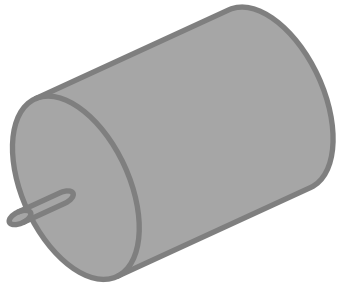
# Experimental Modal Analysis

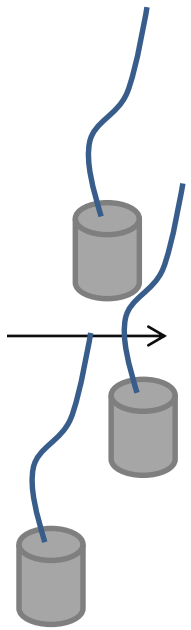
Single reference modal test



# Experimental Modal Analysis

Multi-reference modal test

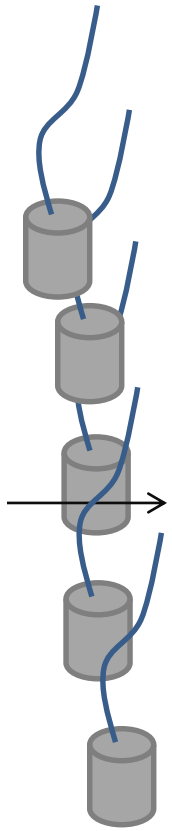




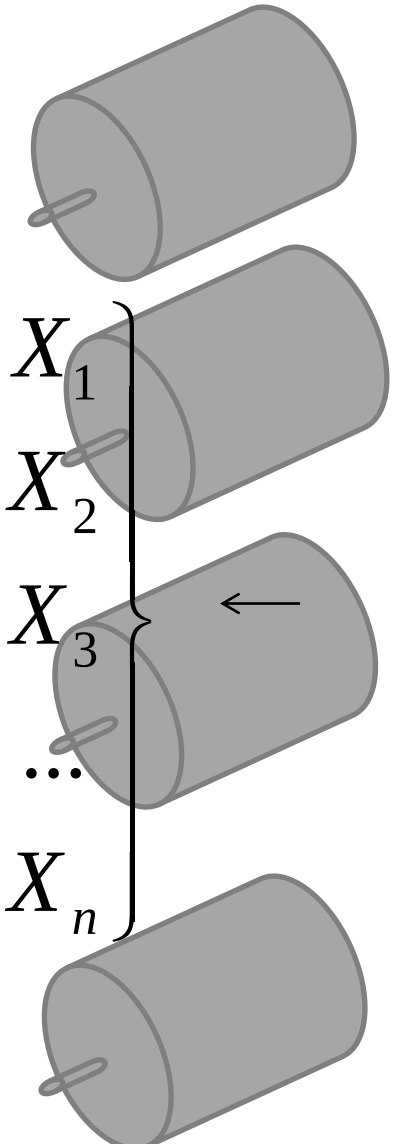
$$\begin{Bmatrix} Y_1 \\ Y_2 \\ Y_3 \\ \dots \\ Y_n \end{Bmatrix} = \begin{bmatrix} H_{11} & H_{12} & H_{13} & \dots & H_{1n} \\ H_{21} & H_{22} & H_{23} & \dots & H_{2n} \\ H_{31} & H_{32} & H_{33} & \dots & H_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ H_{n1} & H_{n1} & H_{n1} & \dots & H_{nn} \end{bmatrix} \begin{Bmatrix} X_1 \\ X_2 \\ X_3 \\ \dots \\ X_n \end{Bmatrix} \leftarrow$$

# Experimental Modal Analysis

Multiple-input Multiple Output (MIMO) Modal test

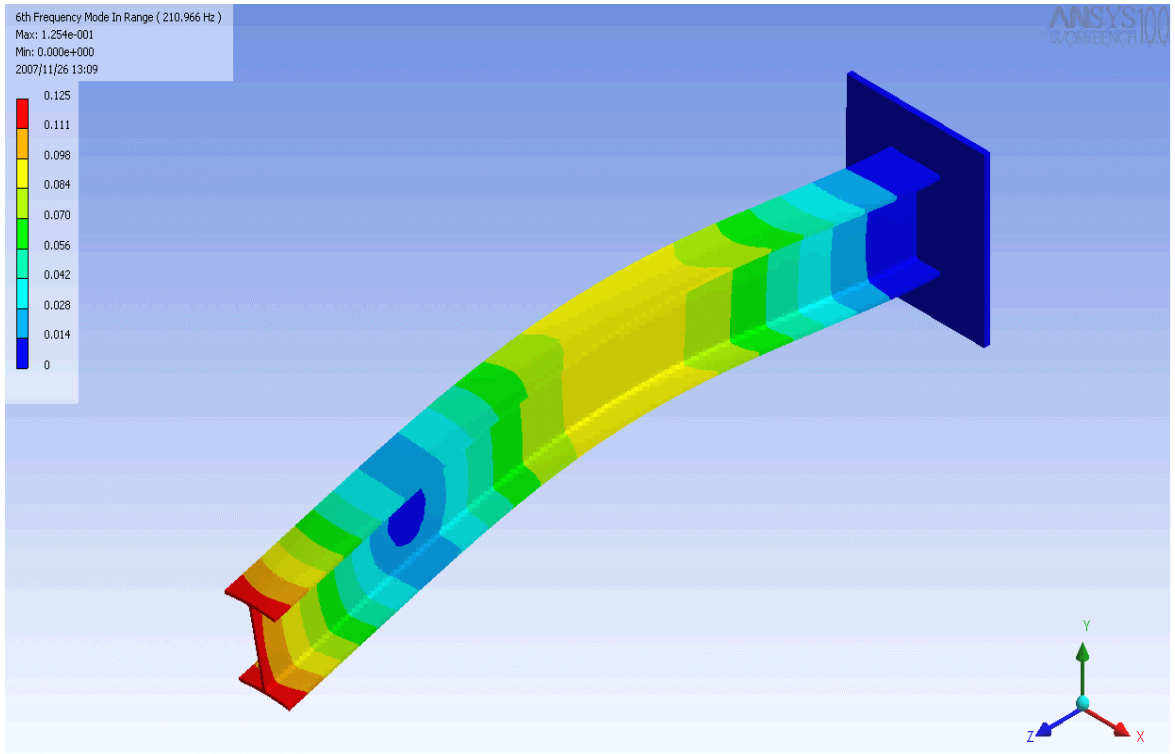


$$\begin{Bmatrix} Y_1 \\ Y_2 \\ Y_3 \\ \dots \\ Y_n \end{Bmatrix} = \begin{bmatrix} H_{11} & H_{12} & H_{13} & \dots & H_{1n} \\ H_{21} & H_{22} & H_{23} & \dots & H_{2n} \\ H_{31} & H_{32} & H_{33} & \dots & H_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ H_{n1} & H_{n1} & H_{n1} & \dots & H_{nn} \end{bmatrix} \begin{Bmatrix} X_1 \\ X_2 \\ X_3 \\ \dots \\ X_n \end{Bmatrix}$$



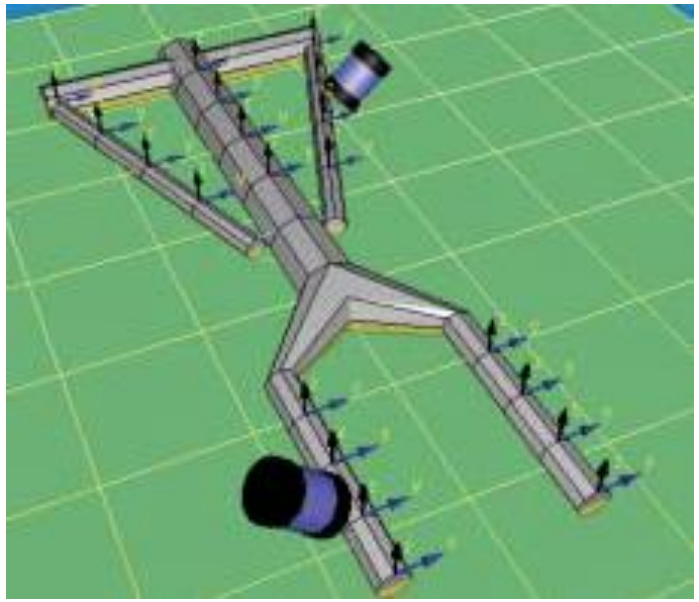
# Experimental Modal Analysis

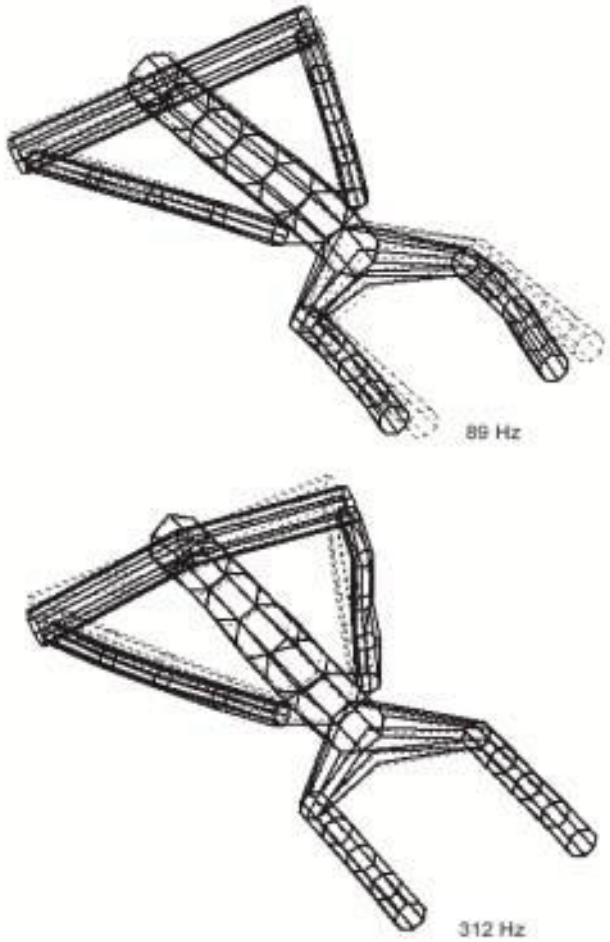
## Example



# Experimental Modal Analysis

## Example






Herlufsen, H., *Modal Analysis using Multi-reference and Multiple-Input Multiple-Output Techniques*, Bruel & Kjaer Application Note, BO0505 -12

# References


- Herlufsen, H., *Modal Analysis using Multi-reference and Multiple-Input Multiple-Output Techniques*, Bruel & Kjaer Application Note, BO0505 -12

# Thank you

# Q n A