Modal Analysis and Controls Laboratory

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Presentation Topics

- Structural Dynamic Modeling Tools
- MACL Research Overview
- Correlation Applications
- System Modeling Research
- System Modeling Applications
- Force Estimation Applications
- Reverse Modeling Technique - DO IT
- DO IT Equations
- Recent Work
- MACL Lab Resources
- New Research Concepts

Modal Analysis Applications

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Could you explain modal analysis and how is it used for solving dynamic problems?
Modal Analysis and Structural Dynamics

Modal Analysis is the study of the dynamic character of a system which is defined independently from the loads applied to the system and the response of the system.

Structural dynamics is the study of how structures respond when subjected to applied loads. Many times, in one form or another, the modal characteristics of the structure is used to determine the response of the system.
How Do Structures Respond Dynamically?

The raw time response of a structure may seem complicated but it is really nothing more than the linear combination of the effects of all the modes that are excited by the specific input.

response due to a vertical bump superimposed on a random excitation

high speed video showing drop load
Response of a Simple Plate

Simple time-frequency response relationship

increasing rate of oscillation

FORCE

RESPONSE

time

frequency
Response of a Simple Plate

Measure many points on the plate simultaneously to view the actual response.

Different deformation patterns can be seen as the excitation sweeps from low frequency to high frequency.
Response of a Simple Plate

Sine Dwell to Obtain Mode Shape Characteristics
**Analytical Modal Analysis**

**Equation of motion**

\[
[M_n]\{\ddot{x}_n\} + [C_n]\{\dot{x}_n\} + [K_n]\{x_n\} = \{F_n(t)\}
\]

**Eigensolution**

\[
[[K_n] - \lambda[M_n]]\{x_n\} = \{0\}
\]
Finite Element Models

Advantages

• Models used for design development
• No prototypes are necessary

Disadvantages

• Modeling assumptions
• Joint design difficult to model
• Component interactions are difficult to predict
• Damping generally ignored
Finite Element Models

Analytical models are developed to describe the system mass and stiffness characteristics of a component or system.

The model is decomposed to express the part in terms of its modal characteristics - its frequency, damping and shapes.

The dynamic characteristics help to better understand how the structure will behave and how to adjust or improve the component or system design.
Experimental Modal Analysis

Advantages

- **Modal characteristics** are defined from actual measurements
- **Damping** can be evaluated

Disadvantages

- Requires hardware
- Actual boundary conditions may be difficult to simulate
- Different hardware prototypes may vary
Experimental Modal Analysis

Measured frequency response functions from a modal test can also be used to describe the structure's dynamic properties - its frequency, damping and shapes.
Experimental Data Reduction

Measured frequency response functions from a modal test or operating data can be used to develop a model of the dynamic characteristics of the system.
What Are Measurements Called FRFs?

A simple input-output problem

Magnitude

Real

Phase

Imaginary

DOF # 1

DOF # 2

DOF # 3

MODE # 1

MODE # 2

MODE # 3

Real

Phase

Magnitude

Imaginary

DOF # 1

DOF # 2

DOF # 3

MODE # 1

MODE # 2

MODE # 3
Digital Signal Processing Flow Diagram

Actual time signals
Analog anti-alias filter
Digitized time signals
Windowed time signals
Compute FFT of signal
Average auto/cross spectra
Compute FRF and Coherence
Experimental Mode Shapes From FRFs
Experimental Mode Shapes From FRFs

The task for the modal test engineer is to determine the parameters that make up the pieces of the frequency response function.

Mathematical routines help to determine the basic parameters that make up the FRF.
Flow Diagram for Response

Why and How Do Structures Vibrate?

INPUT TIME FORCE

\( f(t) \)

FFT

INPUT SPECTRUM

\( f(j\omega) \)

\( h(j\omega) \)

\( y(j\omega) \)

OUTPUT SPECTRUM

\( y(t) \)

IFT
What is Operating Data?

If an excitation is applied close to a mode, then that mode is excited - if not, then the response is the linear combination of all the modes excited.
What is Operating Data?

The modes of the structure act like filters which amplify and attenuate input excitations on a frequency basis.

INPUT SPECTRUM

OUTPUT SPECTRUM

f(jω)
y(jω)
What is Operating Data?

The raw time response of the structure may seem complicated but it is really nothing more than the linear combination of the effects of all the modes that are excited by the specific input.

response due to a vertical bump superimposed on a random excitation
What Good is Modal Analysis?

The dynamic model can be used for studies to determine the effect of structural changes of the mass, damping and stiffness.
What Good is Modal Analysis?

Simulation, Prediction, Correlation, ... to name a few
Correlation and Updating Models

Analytical and experimental models are correlated and adjusted to provide better component and system models.
Correlation and Updating Models

- Vector tools
- Degree of freedom tools
- Frequency tools
Correlation and Updating Models

- Models can be adjusted to better reflect actual measured system characteristics
- Joint stiffness can be more accurately identified
- Simplistic modeling assumptions can be modified to reflect the actual system
System Models

System models are developed from component models which can be obtained from physical models, reduced models, modal models or measurement models.

All of these methods may be used to develop a system model.
System Models

Modal Models

Reduced Models

Modal/Physical Models

Impedance Models
In addition to more conventional system modeling approaches, measured frequency response functions can also be used to assemble systems and provide more realistic boundary conditions.
Dynamic Force Estimation

Using both measured operating data and frequency response function, estimates of the dynamic forces driving the system can be estimated.
System response can be computed for both linear and non-linear systems by various methods.
System Disassembly and Cascaded Targets

With a specified performance level, modification or adjustment of the system matrices is required.

These modified systems are then used for system disassembly to determine component required characteristics.
System Disassembly and Cascaded Targets

Components may or may not have elemental topology

The problem is difficult
Recent Work - Telescopes

45m in Nobeyama, Japan & both Gemini 8m in Chile/Hawaii
Recent Work - Computers and Peripherals

Operating and modal data collected for massive storage devices - 40 terabyte

Robust design options
Future Work & Job Opportunities

As equipment is designed to be lighter, quieter, more efficient, easier to manufacture, etc., there will always be structural dynamic issues to address.

This is true in all industries and sectors - aerospace, automotive, commercial products, sporting goods equipment are just a short list of applications where structural dynamics plays a critical role in the design and analysis of equipment.
Could you explain modal analysis and how is it used for solving dynamic problems?