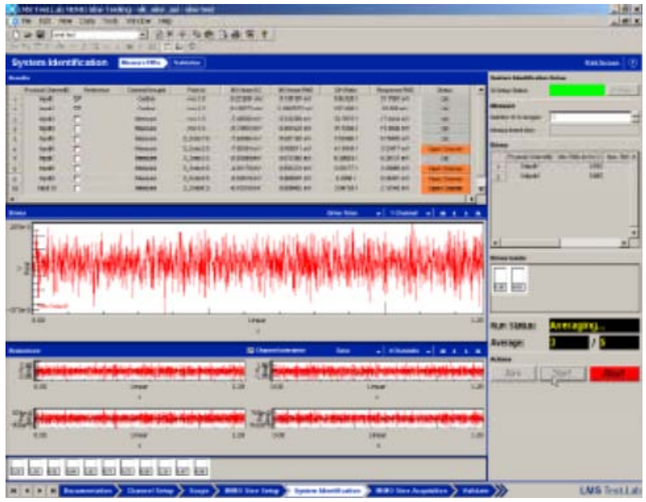
THE CENTER FOR PROFESSIONAL STUDIES



Advanced Modal Analysis

This course focuses on additional test and analysis tools beyond those presented in the Basic Modal Analysis course. Topics include operating data, multiple input multiple output testing, advanced multiple reference modal parameter estimation, structural dynamic modification using both modal data and measured impedances, forced response simulation, and other topics related to advanced manipulation of measured structural dynamic data.

- First, the basics of Basic Modal Analysis and applicable engineering fundamentals are discussed to gain a common understanding of the application and general principles are reviewed.

- Next, participants will focus on further developing their skills beyond Basic Modal Analysis.

- Lastly, participants will be shown how to run the model and interpret output results on LMS software products. A thorough understanding of what these results mean and how to use them to improve the product design will be discussed.

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Course Syllabus

I IDENTIFYING INFORMATION

Course: Advanced Modal Analysis
Prerequisite: Experimental Modal Analysis
Time Frame: 40 total contact hours
Instructor: Dr. Peter Avitabile
Director of the Modal Analysis and Controls Laboratory
BS in Mechanical Engineering
MS in Mechanical Engineering
PhD in Mechanical Engineering
25 years at UMASS Lowell Professor Mechanical Engineering
10 years industrial experience in structural dynamics, modeling and design
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II REFERENCE MATERIALS

1. The Fundamentals of Signal Analysis (Hewlett Packard App Note 243)
2. Fundamentals of Modal Analysis (Hewlett Packard App Note 243-3)
3. Experimental Modal Analysis - A Simple Non-Mathematical Overview
   Modal Space articles originally published in Experimental Techniques

III COURSE GOALS AND OBJECTIVES

1. Understand the steps in the development of an experimental model
2. Understand the considerations for the test beyond a basic simplistic test
3. Understand SDOF and MDOF models and modal space concepts
4. Understand the need for windowing and its effects
5. Know and understand the basic and advanced measurements needed
6. Understand and be able to apply impact and shaker excitation techniques
7. Understand multiple input multiple output employed in modal testing
8. Understand tools used for identification of modes
9. Understand and be able to validate experimental modal models
10. Understand the structural dynamic modification and modeling approaches utilizing reduced order models, modal models and frequency response
11. Understand the collection of operating data and extraction methods for development of a modal model from output only system measurements

12. Understand the forced response simulation procedures using modal data
13. Understand how to apply advanced linear algebra methodologies in the application for solving advanced structural dynamic modeling
14. Understand the basic approaches for the correlation of measured data with analytical models (such as a finite element model)

IV METHODOLOGY

This course is an introduction to advanced modal analysis theory and techniques that are used to characterize the dynamic characteristics of structures. Each module will introduce new material that the student will be allowed to experience for himself with the associated exercises.

Lectures

Each detailed subject will be presented in a lecture format outlining the theory and standardized accepted methodology. A printed copy of the lecture material will be provided for the student's personal in-class use and as a reference material.

Specific Industry Examples

Real life examples will be covered that explain the application of the theory to various industries such as automotive, aerospace, home appliance. This will give the students a clear understanding of how and why these techniques are utilized in different industries and the value they add to noise and vibration refinement.

In-Class Assignments

The student will conduct several hands-on exercises to reinforce the theoretical concepts and to perform advanced analyses. These exercises will increase in complexity as the students further develop their skills in understanding modal theory and practice. Many different data sets are collected as a class and then individual groups are given specific tasks/approaches for the reduction of data; different groups are given different subsets of data to manipulate for operating data collected. The students will present their work to the group for review and discussion. Other more structured lab exercises are also given as individual assignments for the application of SDM, system modeling, forced response simulation, etc.

V COURSE OUTLINE & ASSIGNMENTS

Module 1 – Overview of Structural Dynamic Modeling Techniques

Modal Analysis and Structural Dynamics
Analytical Modal Analysis and Finite Element Models
Experimental Modal Analysis and Experimental Modal Reduction
Frequency Response Functions (FRFs) and Mode Shapes from FRFs
Correlation and Updating Models
Overview of Advanced Applications of Structural Dynamic data

Module 2 – Review of Basic Modal Analysis Theory and Related Topics

Different Mathematical Model Formulations
SDOF and MDOF Theory Overview
Frequency Response Functions
Linear Algebra Concepts for Structural Dynamic Applications

Module 3 – Review of Basic Measurement Definitions

Linear Spectra and Power Spectra
Derived Relationships and Effects of Noise – Estimators H1, H2, Hv
Auto Power and Cross Power Spectrum; Frequency Response Function; Coherence

Module 4 – Review of Basic Impact and Single Shaker Excitation

Overview Basic Impact Testing Procedures
Review Multiple Reference Impact Test
Overview Basic Shaker Testing Approaches & common excitation signals utilized

Module 5 – Multiple Input Multiple Output Shaker Testing

Multiple Input Shaker Testing
Principal Component Analysis
Multiple and Partial Coherence
SISO vs. MIMO

Module 6 – Mode Indicator Techniques

Review of Identification Functions Typically Employed
(such as Mode Indicator Function, Multivariate Mode Indicator Function, Complex Mode Indicator Function, Stability Diagram and Poly MAX)

Module 7 – Basic Modal Parameter Estimation

Parameter Estimation Concepts and Parameter Extraction Considerations
Classification of Modes; Time and Frequency Domain Representations
Different Forms of the Same Equation; Why Have Different Methods
Modal Parameter Estimation Concepts and Extraction Considerations
Mode Determination Tools; Model Order; Stability Diagram
Modal Extraction Methods
SDOF Modal Parameter Estimation
MDOF Modal Parameter Estimation
Modal Parameter Estimation Considerations

Module 8 – Modal Parameter Estimation Guidelines and Practical Considerations

Basic Curve Fitting; Considering Complicated Structures; Curve Fitting Guidelines
Historical Perspective of Modal Parameter Estimation
Case study of a very complicated aerospace structure with methodology used to decipher MIMO test results to obtain useful modal parameters

Module 9 – Model Validation – Basic and Advanced Tools

Animation
Modal Assurance Criteria
FRF Synthesis
Modal Participation; Mode Complexity
Mode Phase Colinearity / Mean Phase Deviation
Amplitude Weighted Assessment Function with application to Rib Stiffened Plate
Extended Amplitude Weighted Assessment Function

Module 10 –Test Reference Identification Procedure with Applications

Identification of Reference Locations using Singular Valued Decomposition
Practical Development of the Test Reference Identification Procedure using SVD
Rib Stiffened Plate Example; Repeated Root Plate Example; Composite Plate Pseudo-Repeated Root Example; Composite Fin Plate Pseudo-Repeated Root Example
Application of TRIP on Large Chiller Unit

Module 11 – Additional Topics in Modal Analysis – Advanced Formulations

Re-visit the Input-Output Frequency Domain Formulation of Dynamic Response
- Develop the Forced Response Simulation Approach
- Develop Operating Data Approach – Output Only Systems
- Develop the Force Estimation from Operating Data

Module 12 – Operating Deflection Shapes

Characterization: Time or Frequency Domain
ODS: Time Domain
ODS: Frequency Domain, Linear Spectrums
ODS: Frequency Domain, Transmissibility
ODS: Frequency Domain, Cross Spectrum
ODS: Frequency Domain, Reference Criteria
ODS: Multiple Uncorrelated Sources
ODS: Principal Component Analysis

Module 13 – ODS Scaling Techniques-

Overview the Approaches Available for Scaling Operating Data
- Scaling Operating Data using the Drive Point Residue Method
- Scaling Operating Data using the Mass SDM Approach

Module 14 – Operational Modal Analysis – Practical Examples

Develop Operating Modal Data from various approaches for Output Only Measurements

Module 15 – Structural Dynamic Modification

Types of Models Used in Modification Studies
Real Normal Modes or Complex Modes
Modal Space Models or Impedance Models
Simplistic Modifications or Realistic Modifications
Structural Dynamic Modification and System Modeling
Truncation Effects and Rotational Degrees of Freedom Considerations

Module 16 – Frequency Based Sub Structuring

Formulate the Impedance Modeling Approach for a Single Modification (SMURF)
Formulate the Impedance Modeling Approach for Multiple Modifications (FBS)

Module 17 – Effects of Rotational DOF for Impedance Modeling Applications

Identify the Important of Rotational Measurements in Practical SDM and System Modeling Applications

Module 18 – Test-Analysis Correlation-Updating Considerations -

Identify the basic tools used for test-analysis correlation
Discuss vector based and DOF based approaches
Identify the various correlation tools such as MAC, CoMAC, POC, FRAC, RVAC
Exercises-

- Modal Parameter Estimation
- Operational Modal Analysis
- Modification of a Free-Free Beam
- Structural Modification of a Support Beam with a Tuned Absorber
- Combining Modal Beam and Support Beam
- Coupling of Modal Beam and Support Beam Using FRF’s