Basics of Modal Analysis for the New/Young Engineer

Sessions 7, 14, Monday, February 1

Developed by: C.D. Van Karsen, *Michigan Technological University*

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Sponsored by: SEM/IMAC Modal Analysis and Dynamic Systems Technical Division

The field of Modal Analysis continues to evolve and mature. In order to allow new or young engineers in the modal field to extract meaningful information from paper presentations at the IMAC Conference, a program has been developed to familiarize the new/young engineer with some of the very basic material related to modal analysis. Held on the first day of the conference, *Basics of Modal Analysis* is geared towards those individuals who have very limited or no experience in the modal field or need a refresher on some of the basic modal nomenclature. The material is centered on the topics of single degree of freedom theory, multiple degree of freedom theory, measurements and linear algebra. The intent is to familiarize the new/young modal engineer with the nomenclature and basic techniques involved in modal analysis; the most basic fundamental equations will be explained in an overview sense rather than developed from a theoretical standpoint. These tutorial sessions should not be considered a training seminar but rather an overview of basic definitions that are inherent in most of the presentations at the conference. By attending this session, the new or young engineer should be able to better appreciate and comprehend more of the material that is presented in the technical paper presentations.

Notes: A copy of notes for *Modal Analysis for the New/Young Engineer* will be available for purchase. To purchase a set of notes, use the registration form or, at the conference, go the Conference Registration Desk. For more information contact SEM, 7 School Street, Bethel, CT 06801, 203.790.6373, Email: shari@sem1.com.

Nonlinear Plenary Lecture

Session 9, Monday Afternoon, February 1

Organized by: D.E. Adams, *Purdue University*; G. Kerschen, *University of Liège*; SEM Nonlinear Focus Group

Exploiting Nonlinearity in Vibration Applications

Steven W. Shaw,
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Nonlinearity is often avoided, but can be used in constructively in certain situations. Two such application areas will be described in this presentation. The first is the design of order-tuned torsional vibration absorbers that are currently being considered for use in fuel-efficient automotive engines. The goal of developing absorbers with minimal inertia requires that the system be designed to account for large absorber travel, resulting in nonlinear effects, most of which are undesirable. Here we will show how one can account for these nonlinearities in a manner that results in effective operation with less mass than would be required for an absorber that remains restricted to its linear response range. The second class of problems is micro/nano-electro-mechanical systems (M/NEMS) which exploit nonlinear response characteristics for sensing applications. One such example is MEMS gyros that are used for yaw rate measurements. These devices rely on Coriolis coupling between two system modes, a drive mode which is driven at resonance, and a resonantly tuned sense mode whose output is proportional to the yaw rate. In order to achieve optimal performance, the natural frequencies of these two modes must be precisely matched so that resonant response is achieved, and even slight detuning of these modes results in a dramatic reduction in the output signal. A number of linear control schemes have been developed to achieve and maintain this tuning in the face of system variability and drift, but an alternative approach is to make use of the broad frequency response characteristics of a nonlinear resonance in the drive mode to insure that it maintains a large response over a range of sense mode frequencies, resulting in robust operation. Another M/NEMS example is the use of shifts in bifurcation points for the detection of specific airborne substances. Typically, in linear-based designs, one measures changes in resonance peaks resulting from target mass that adheres to a specially treated resonator. In contrast, a nonlinear approach is to calibrate and track changes in parameter values at which bifurcations, and attendant abrupt changes in system response, occur. In M/NEMS applications, parameter sweep rates and levels of ambient noise play a crucial role in accurately locating these bifurcation points. It is shown how one can systematically account for these effects, resulting in optimal strategies for measuring shifts in bifurcation points.

The work described in this presentation is the outcome of collaborative efforts with several colleagues, students, and former students, and has been funded by the National Science Foundation, the Air Force Office of Scientific Research, and Chrysler Group, LLC.

Steven W. Shaw is a Professor in the Department of Mechanical Engineering at Michigan State University. He earned an A.B. in Physics (1978) and an M.S.E. in Applied Mechanics (1979) from the University of Michigan, and a Ph.D. in Theoretical and Applied Mechanics from Cornell University (1983). He has held visiting appointments at Cornell, the University of Michigan, Caltech, the University of Minnesota, the University of California-Santa Barbara, and McGill University. His interests are in dynamical systems and mechanical vibrations, including applications to nonlinear vibration absorbers, micro/nano-electro-mechanical-systems, vehicle dynamics, and structural vibrations. Steve currently serves in editorial positions for the *Journal of Vibration and Acoustics*, *Communications in Nonlinear Science and Numerical Simulation,* and *Nonlinear Dynamics*. He is the recipient of best paper awards from the SAE (Arch T. Colwell Merit Award, 1997) and the ASME (Henry Hess Award, 1986). Steve presented the inaugural Sethna Lecture for the Department of Aerospace Engineering and Mechanics at the University of Minnesota (1994), was a Westinghouse Distinguished Lecturer for the Department of Mechanical Engineering at the University of Michigan (1990), and has presented keynote lectures a number of conferences, including the First ASME Dynamic Systems and Controls Conference (2008). He was elected to the rank of Fellow of ASME in 1995 and earned the MSU Distinguished Faculty Award in 2008.

Sensors and Instrumentation Tutorials

Sessions 21, 28, 35, 42, 49, Tuesday, February 2- Thursday, February 4

Organized by: G.C. Foss, *The Boeing Co.;* SEM Sensors and Instrumentation Technical Division

Credit for much of the progress in the field of modal analysis over the last twenty five years is owed to substantial advancements in sensors, electronics and computing platforms. Many of those involved in modal analysis and testing have personal and professional interests in the associated equipment and sensors. The SEM Sensors and Instrumentation Technical Division was reorganized at IMAC 25 to address this interest.

Achieving accurate test results depends on an adequate knowledge of the test equipment; its selection, use, and limitations. This series of tutorials, presented by a distinguished group of experts, is meant to offer IMAC attendees an opportunity to learn more about their test instrumentation, and explore the application of emerging technologies such as wireless communication and fiber optics.

The tutorials are oral presentation only, but some of the material will be posted to the SEM Web site at a later date.

Substructuring: Best Practices and Current Challenges

Tutorial and Panel Discussion

Session 19, Tuesday Morning, February 2

Organized by: D. de Klerk, *MüllerBBM VAS/Delft University of Technology*; M.S. Allen, *University of Wisconsin-Madison*; SEM Experimental Dynamics Substructuring Focus Group

Tutorial Chair: D.J. Rixen, *Delft University of Technology*

Panel Discussion Moderated by: M.S. Allen, *University of Wisconsin-Madison*

Substructuring concepts have received increasing attention in recent years because they have the potential to dramatically reduce the computational cost of analytical models. Experimental-analytical substructuring may allow one to avoid modeling difficult subsystems altogether by representing them with experimentally derived models instead. This session includes a tutorial that will review the fundamentals of both frequency based (impedance or admittance) and modal substructuring. This will be followed by a panel discussion in which experts in the field will discuss current barriers to experimental-analytical substructuring and will highlight some possible paths forward.

Numerical Dynamic Substructuring

Session 26, Tuesday Afternoon, February 2

Organized by: D.J. Rixen, *Delft University of Technology*; D. de Klerk, *MüllerBBM VAS/Delft University of Technology*; SEM Experimental Dynamics Substructuring Focus Group

Substructuring methods in structural dynamics are efficient and versatile strategies to reduce the complexity of large models. Choosing the right ingredients in the reduction basis per substructure has been a challenging research question for long and additional issues have arisen in the last years such as accounting for damping, multiphysical coupling or parametrization. This session will be devoted to substructuring techniques used as numerical techniques for reduction and dynamic simulations. Including experimentally measured substructures in models will be treated in session 40. Session 19 will consist of a tutorial and panel discussion.

Experimental Dynamic Substructuring

Session 40, Wednesday Afternoon, February 3

Organized by: M.S. Allen, *University of Wisconsin-Madison*; D. de Klerk, *MüllerBBM VAS/Delft University of Technology*; SEM Experimental Dynamics Substructuring Focus Group

This session highlights recent advances in experimental and analytical substructuring techniques, which allow one to predict the performance of built-up structures where the model for at least one subcomponent is derived from test. Uncertainty often plays an important role in those predictions, so a number of papers will address that issue in particular.

Modal Parameter Estimation Round Robin

Session 31, Wednesday Morning, February 3

Organized by: C.D. Van Karsen, J.P. De Clerck, *Michigan Technological University;* SEM Modal Analysis Technical Division

Modal parameter estimation (MPE) is a common activity for experimental structural dynamicists. Many MPE algorithms are documented and compared in the history of the IMAC proceedings. MPE is the final step to determine the modal parameters for a particular structure under test. MPE is calculation intensive and several commercial and custom software tools exist to automate the calculations and guide users through the MPE process.

The purpose of the Modal Parameter Estimation Round Robin is to compare MPE results from a wide range of participants using various commercial and custom implementations of MPE algorithms. To ensure consistency, the same data sets will be available to each participant. The organizers will then collect and compare results. At a special session of IMAC 28, participants will have the opportunity to present their work, and the organizers will present a comparison of results.

Each standard data set will contain:

- Numeric Data (Universal File Format)
  - Single or multiple reference frequency response functions (FRFs)
  - Corresponding ordinary coherence functions
  - Geometry information (point identification and 3-D coordinates, connectivity)
- Descriptive Information
  - Boundary condition(s)
  - Excitation technique
  - Data acquisition conditions and parameters

The organizers request that the participants provide:

- Numeric Results
  - Scaled mode shapes, natural frequencies, and damping information (UFF type 55)
  - Synthesized FRFs for the measurement DOFs included in the original data set (SDF or UFF type 58)
- Descriptive Results
  - Software used
  - MPE algorithm(s) used
  - General comments about the user confidence in the results

The organizers will compare the submitted results using several methods:

- Modal Assurance Criteria (MAC) to establish mode correspondence
- Statistics of natural frequencies for corresponding mode shapes
- Statistics of damping values for corresponding mode shapes
- Comparison of synthesized FRFs
  - Individual
  - Multivariate Mode Indicator Function (MIF)
  - Sum of the square amplitude

Several data sets are available on the Michigan Technological University web site (**www.me.mtu.edu/imac_mpe**). Participants are required to submit MPE results for the calibration data sets, to identify any overall scaling bias. Users can then choose from any combination of the other data sets.

Description of available data sets:

1. Calibration 1 – Proportionally damped lumped parameter model
2. Calibration 2 – Non-proportionally damped lumped parameter model
3. Calibration 3 – Constant Modal Damping
4. Plexiglass plate - 25 responses / 3 inputs
5. Dryer cabinet – 300 responses / 4 inputs
6. Automobile – 398 responses / 3 inputs
7. Aerospace data - 240 responses / 5 inputs

Volunteers should contact the organizers, Chuck VanKarsen (cdvankar@mtu.edu) or Jim De Clerck (jdeclerck@mtu.edu), to submit their results.

Ares IX Launch Vehicle Modal Testing

Session 39, Wednesday Afternoon, February 3

Organized by: R. Buehrle, *NASA Langley Research Center;* P. Bartolotta, *NASA Glenn Research Center*

The first test flight of NASA's Ares I crew launch vehicle, called Ares I-X, is scheduled for launch in 2009. Ares I-X will use a 4-segment reusable solid rocket booster with mass simulators for the 5th segment, upper stage, crew module and launch abort system. Flight test data will provide important information on ascent loads, vehicle control, separation, and first stage reentry dynamics. As part of hardware verification, a series of three modal tests were conducted at the Vehicle Assembly Building at NASA's Kennedy Space Center. The first test was performed on the 71-foot 53,000-pound top segment of the Ares I-X launch vehicle known as Super Stack 5 and the second test was performed on the 66-foot 146,000-pound middle segment known as Super Stack 1. The third modal test was performed on the 327-foot 1,800,000-pound Ares I-X launch vehicle mounted to the Mobile Launcher Platform. Presentations will describe the tests, identification of subsystem test goals based on traceability to vehicle target modes, adjustment of modal test data for boundary interface compliance, and the model calibration process.

The modal test was a multi-center effort including NASA's Glenn Research Center, Langley Research Center, Marshall Space Flight Center, Kennedy Space Center, and the Aerospace Corporation.