Mechanical Shock and Modal Test Techniques

Course No. 142-4

APPLICATIONS The effects of shock are important in many engineering applications ranging from appliances to computers to ships to automobiles, trucks and military vehicles to high-performance aircraft and missiles. Shock is often part of the service and/or transportation environment. Military Standards such as MIL-STD-810 call for shock testing.

The possible effect of shock must be considered for almost every product that has to be shipped and handled. Care can be taken in a controlled environment but during the transportation phase the product within its package must be designed and tested to withstand the anticipated environment.

FOR WHOM INTENDED Engineers involved with dynamics and structural test applications.

Most engineers need specialized education in order to properly measure, quantize and analyze the shock environment, and to reproduce it in environmental test laboratories. This course is for test laboratory managers, engineers and technicians. It will also help quality and reliability specialists and acquisition personnel in government and military activities and contractors.

Instrumentation specialists who will measure transportation, service and laboratory shock need this course. Metrologists learn about shock calibration of accelerometers and systems. Project personnel, structure and packaging engineers learn about developmental shock testing. Product assurance and acquisition specialists learn to evaluate shock test facilities and methods, and to interpret shock test specifications.

This course is designed to serve the varied needs of scientists, engineers, aides and senior technicians. The instructor maintains good balance between practical training and theory.

BRIEF COURSE DESCRIPTION The course begins with a review of structural and dynamic theory before examining methods of measuring frequency response from the structure under test. The causes and effects of shock are reviewed in detail, including the different shock pulse shapes.

Experimental modal testing is introduced by a brief discussion of theoretical modal analysis. The single degree of freedom (SDoF) model enables us to understand the fundamental concepts of free and forced vibration, natural frequency, resonance and damping. However in MDoF systems, resonance may occur at a number of different frequencies, each of which corresponds to a different pattern or shape of the system's motion. These are known as the natural or normal modes of vibration or mode shapes. There is a differential equation of motion for each degree of freedom; a set of ***n*** simultaneous equations is needed to mathematically describe a MDoF system. These equations are usually solved using matrix algebra.

In the experimental method of Modal Testing, the structure is excited by applying forced vibration and measuring the responses, from which the vibration modes are determined and a structural model developed. This is the reverse process to the theoretical method. Various methods of input excitation are discussed, such as shaker and impact hammer. Structural preparation and suspension methods are also examined.

A review of transducers and signal processing equipment is made before discussing analysis methods, time-domain curve fitting. Modal test philosophy including the sequence of steps and practical considerations in undertaking the test are discussed.

The tabulation of results and derivation of mode shapes and construction of spatial models (mass, stiffness and damping) are covered before discussing the application of the modal test results.

The Shock Response Spectrum (SRS) is discussed as it relates to shock measurement and testing. The course then covers shock measurements, also calibration. The relative merits of various types of shakers and shock test machines are briefly considered before covering various shock test methods, including pyrotechnic shock testing. Some typical shock test procedures and specifications are described, both military and commercial.

CERTIFICATE PROGRAMS This course is required for TTi's Dynamic Test Specialist Certificate. It may be used as an elective for any of TTi's Specialist Certificate programs.

RELATED COURSES See TTi courses 142, Mechanical Shock Techniques, and 195, Modal Analysis for Structural Validation, which were combined to create this course.

PREREQUISITES Prior participation in TTi's "Fundamentals of Vibration" would be helpful. Some familiarity with electrical and mechanical measurements and vibration will be helpful.

TEXT Each student will receive a course workbook containing most of the viewgraphs used in the presentation.

COURSE HOURS, CERTIFICATE AND CEUs Open courses meet seven hours per day. Upcoming presentation dates can be found on our current open course schedule. Class hours/days for on-site courses can vary from 14–35 hours over 2–5 days as requested by our clients. Upon successful course completion, each participant receives a certificate of completion and one Continuing Education Unit (CEU) for every ten class hours.

For schedules, general information and registration forms, see TTi's web site.

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Single-Degree-of-Freedom (SDoF) and 2DoF Systems
- The Single Degree of Freedom System:
  - Spring, k; Mass, m Damper, c
- Motion of an SDoF System
- The Impulse Response Function, h(t)
- The Frequency Response Function (FRF) • Displaying the FRF
- Nyquist Plot • Structural Dynamic Relationships
- Two Degrees of Freedom (2DoF) • 2DoF Frequency Response

Multiple-Degrees of Freedom (MDoF) Systems
- Natural Frequencies and Mode Shapes
- Modal and Frequency Matrices
- Orthogonality and Normalization
- Decoupling the Equations
- Single Point Excitation and Response
- Mode Shapes for: Cantilever; Plate • Mode Shape Animation

Some Essentials of Signal Processing
- Analog to Digital (A-D) Conversion • Aliasing • FFT • DFT
- Windowing for Continuous, Random and Transient Signals
- System Identification Using the FFT • Signal Averaging
- Coherence • Rules of Signal Processing
- Time and Frequency Domain Terminology

Introduction to Shock: What is Shock? • Causes of Shock
- Effects and Remedies of Shock • Natural Frequency
- Single-Degree-of-Freedom Transient Response
- Transient Response Problem • Free Response
- Forced Response

A Closer Look at Shock: Terms used in Mechanical Shock
- Input Pulse and Response of a Sprung Mass
- Typical Complex Shock Pulses
- Shock Pulse Shape Parameters
- Haversine Shape • Classical Shock Pulse Shapes
- Critical Frequency Response • Response to Shock Pulse

Background and Theory of Modal Testing
- Experimental Modal Analysis (EMA) • Theoretical Modes
- Experimental Examples — Ship Hull Section, Bridge Deck
- The Time Domain Structural Response
- The Frequency Domain
- Experimental Modal Analysis (EMA) Procedure

Modal Test Planning and Set-up: Selecting a Test Procedure
- Steady-State • Random • Impact • Burst Random / Chirp
- Shaker Testing • Impact Testing • Response Transducers
- Strain gages • Laser • Accelerometers • Charge accelerometers
- Voltage Accelerometers • Voltage vs. Charge Accelerometers
- Mounting Accelerometers • Transducer Selection

Meshing: Definition, Considerations
- The “Pretty Picture” Approach
- Fine Mesh vs. Coarser Mesh • An Interpolation Example
- Practical Aspects of Marking a Mesh

Setting up the Modal Test: Support the Structure
- Free Boundary • Mounting Transducers • Contact Resonance
- Mounting Methods: Stud, Superglue, Beeswax, Magnet,
  - Mounting Base, Double-Mount
- Suggestions for Making Life Easier • Setting up the Analyzer
- Random Excitation • Impact Excitation
- Windowing the Response
- Coherence Function • Coherence Examples

Modal Parameter Extraction
- Natural Frequencies, Modal Damping, and Modal Constant
- Modal Inferposition Using Single Mode Methods
- “Quadrature” method • “Circle Fit” Method • Modal Residues
- Multiple Mode Methods

Documenting Modal Test Results
- Average Coherence Example • Viscous Damping Coefficients
- Presenting Mode Shapes:
  - Deflected Shape, Undeflected & Deflected Shapes
  - Deflected Extremes, Arrows, Persistence
- Color Rendition • Presenting Mode Shapes – Animations

The Shock Response Spectrum:
- Measuring and Analyzing Shock • Mechanical Analog
- Definitions • Developing SRS • SRS Maximax Values
- Max. Response Spectra for Various Shock Pulse Shapes
- Some Properties of the SRS • Velocity Sensitive Region
- Damping and SRS • SRS Damped Spectra
- Maximum Response Spectra for Linear SDoF System
- Designing with SRS • Absolute and Relative Deflection SRS
- The Use of the SRS in Shock Testing
- Shock Test Specification—Required Spectrum and Allowable Tolerances
- Types of Shock Spectrum Analyzers (SSA)

Measurement of Shock:
- Force Sensors • Load Cell Characteristics
- Motion: Displacement Trackers
- Characteristics of Motion Trackers • High speed Photography
- Electro-Magnetic Induction
- Motion—Velocity Sensors and Accelerometers
- Seismic Transducers • Seismic Transducer Characteristics
- Pendulum Calibration
- Dynamic Calibration of Motion Sensors
- Cabling • Accelerometer Attachment
- Accelerometer Quick-Check Calibration
- Accelerometer Loading Effect

Shock Testing: Types of Mechanical Shock Testing
- Impulse Shock Test
- Shock Pulse — Acceleration, Velocity and Displacement
- Drop Test Machines • Navy Impact Machines
- The “Light-Weight” Shock Tester
- High-Amplitude, High-Frequency Impact Transient Simulators
- Impact Shock Simulators • MIPS Table
- Programmable Systems • Mid-Frequency Transients
- Shakers : Electrodynamic, Hydraulic, Piezoelectric
- Shaker Technologies—Stroke vs. Frequency Range
- Generating Prescribed Pulses • Optimized Tailoring
- Generation of Oscillatory Transients
- Decaying Harmonic Acceleration
- Shaker Optimized Cosine (SHOC) pulses
- Least Favorable Response
- Simulating the Damage from a PyroShock
- Pyrotechnic Shock • Rupture Energy Fixture
- More Realistic Pyroshock Arrangements
- Shock Testing Problem Areas • Data as We See It
- What Our System Has to Handle
- Drop Machines • Pendulum Type Shock Machine
- Free-Fall Shock Machine • Drop Testing Machine

Typical Shock Test Specifications

Summary • Final Review

Award of certificates for successful completion

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