Fixture Design for Vibration and Shock Testing

Course No. 157-5

FOR WHOM INTENDED This seminar is intended for dynamics test and evaluation personnel desiring an understanding of practical approaches to the design and fabrication of test fixtures used in vibration and shock testing. Tooling Engineers responsible for fixture design need this training.

Quality Assurance and Reliability specialists will find the course useful. So will test and instrumentation specialists. The writers of specifications for environmental tests and for manufacture of fixtures will benefit from knowing of practical limitations that exist. Weapon and product designers who are seeking solutions to vibration and shock problems will also find the course helpful.

A fixture designer must be able to design a test fixture that will transmit the intended input forces directly to the Device Under Test. To accomplish this, a designer must have specific skills as well as an understanding of vibration and shock, structures, dynamic theory, materials, fabrication and welding.

BRIEF COURSE DESCRIPTION This course incorporates a mechanical design fundamentals segment equivalent to Course 310, *Mechanical Design for Product Reliability*, which runs concurrently and may be taken by itself. The course commences with an introduction to vibration and then covers basic dynamics theory including relationships between displacement, velocity and acceleration. Dunkerley's and Rayleigh's methods are introduced, with examples. Damping, transmissibility ratio and resonance stacking are addressed. The course then covers basic structural theory: tension, compression, stress, strain, torsion and moments of inertia. Examples show the torsional shape factors of different structures. The instructor then addresses frequency and stiffness of beams, plates and gussets, providing useful graphs, formulas and examples.

Bolted connections are covered next. Useful data on structures, bolted connections etc., is included in the course workbook which will be an invaluable reference tool back at the workbench. Modal analysis is then discussed, with mention of multi-degree-of-freedom systems, modes and complex systems. Measurement and fixturing for modal analysis and testing are covered before moving on to a brief discussion of random vibration, including power spectral density theory. The concept of RMS acceleration is discussed. Mechanical shock and its design implications are then discussed. Methods of isolating assemblies from shock and vibration are covered.

Fatigue is covered, including discussion of crack growth rates, fracture mechanics, the S-N curve, and the use and abuse of accelerated testing, including Miner's hypothesis.

Material selection is then covered, with information on overall and design-limiting material properties. Tools are provided for comparing different materials. The design fundamentals segment concludes with chassis analysis and general design suggestions, such as methods for increasing natural frequencies.

The course then covers the subject of Fixture Design. While a basic knowledge of shakers and vibration testing is a prerequisite for the class, a chapter is included on these topics. General considerations in fixture design are discussed, along with an introduction to instrumentation and sinusoidal vibration testing, as they apply to the fixture design and evaluation process.

The course outlines a variety of strategies for attaching test items to fixtures, from the simplest adaptor plates to massive custom-designed cast and welded fixtures. Practical simplified designs and fabrication techniques are discussed and class projects are undertaken to design some typical fixtures.

CERTIFICATE PROGRAMS This course may be used to satisfy the requirement for course 310 in TTi's Mechanical Design Specialist (MDS) Certificate Program. It may be used as an elective for any other TTi Specialist Certificate Program.

RELATED COURSES The mechanical design portion of Course 157-5 is available separately in Course 310, which runs concurrently.

PREREQUISITES: Prior participation in TTi's *Fundamentals of Vibration* or the equivalent would be helpful. Participants will need first-year college mathematics (or equivalent experience) and some facility with fundamental engineering computations. Some familiarity with electrical and mechanical measurements and vibration will be helpful, as will an understanding of and familiarity with tooling and manufacturing.

TEXT Each participant will receive a course workbook, including most of the viewgraphs used during the classroom 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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Course Outline No. 157-5

Introduction to Vibration

Dynamic Force and Motion:
- Laws of Motion, Weight vs. Mass • Gravity • Density
- Force, Mass and Acceleration • Degrees of Freedom
- Displacement • Velocity • Acceleration • Natural Frequency
- Sinusoidal Waveform • Modeling Complex (MDoF) Systems
- Dunkerley's and Rayleigh's Methods
- Transmissibility • Isolation • Damping • Examples

Review of Structural Design Fundamentals
- Material Properties • Tension and Compression
- Stress and Strain • Shear • Torque • Moments of inertia
- Torsional Stiffness • Torsional Shape Factors
- Bending Stiffness • Instability of beams and flanges

Frequency and stiffness: Beams, Plates, Gussets
- Natural frequency and stiffness graphs for various structures
- Beam Formulas • Plate frequency parameters, examples
- Column Resonance • Axial Resonance
- Example: Stresses in a Loaded Beam

Bolted Connections • Preload • Data on Bolts
- Design of Bolted Joints • Stiffness Data
- Required flange material area • Material thickness, stiffness

Modal Analysis and Modal Testing
- Applications • Modes, Natural Frequencies
- Fixturing for Impedance and Modal Testing
- Finite Element Analysis (FEA) • Example

Random Vibration: Demonstrations—Sinusoidal Vibration,
- Complex Waveform, Random Vibration
- Probability Density • Power Spectral Density (PSD)
- Shaker Power Spectral Density Response • Equalization
- Calculating the RMS Acceleration from Spectral Plot

Mechanical Shock:
- Causes of Shock, Effects and Remedies of Shock
- Transient or Shock Tests
- Shock Pulse shapes, Shock Isolation Example

Fatigue: How Materials Behave: The S-N Curve
- Factors Influencing Fatigue Behavior
- Failure Models & Mechanisms • Crack Growth
- Time-Dependent Failures, Time to Failure
- Goodman and Constant Life Diagrams • Miner's Hypothesis
- Accelerated Testing • Durability, Functional Tests

Material Selection in Engineering Design
- Overall & Design-Limiting Material Properties
- Application-Specific Material Properties
- Example: Optimization of Shaker Table

Chassis Analysis Example
- Chassis Dynamics, Section Properties
- Increasing Resonant Frequency, Torsion • Rotational Inertia

Design Suggestions: Overcoming Problems • Design Guidelines
- Structural rules of thumb • Stresses in Printed Circuit Boards

Introduction to Vibration Exciters: Electrodynamic Shakers
- Force ratings, Displacement and Velocity Limits
- Effective Mass of Exciter Table
- Electrohydraulic Shakers • Reaction Mass Effect • Slip Plates
- Hydrostatic Bearings • Overturning Moment

Introduction to Fixture Design
- Purpose of the Fixture • Fixture Performance
- Considerations in Fixture Design

Vibration Test Fixtures—General Remarks
- The "black art" of designing fixtures • Function of the test fixture
- Difficulty in achieving identical motion at all attach points
- Required information about the test item and the test program
- Required information about shaker • Bolting to the shaker table
- Example of successful redesign • Fixture weight vs. DUT weight
- Fixture design for combined environments

Interface Items: Introduction • Table expanders
- Horizontal accessory tables: oil-film slip tables
- Connecting horizontal accessory tables to shakers
- Horizontal accessory tables: hydrostatic bearings
- Misuse of horizontal accessory tables
- Avoid using bolts in shear • A note of warning on wide plates

Measurement of Sinusoidal Vibration-Accelerometer Systems
- Accelerometers • Amplifiers • Frequency response
- Mounting affects frequency response
- Cable routing affects frequency response • Cross-axis sensitivity
- Hand-held probe accelerometers
- Vibration Intensity and Frequency: Conversion to numbers
- Oscilloscopes and oscillographs • X-Y plotters, pen recorders
- Decibel scaling • Need for tracking filter in evaluating fixtures
- Calibration checks on the entire measuring system
- Day-to-day accelerometer calibration in a "working" laboratory

Sinusoidal Vibration Testing
- Specifications • Mounting the test article • Eliminating variables
- Location of the control accelerometer • Multiple accelerometers
- Fixturing to minimize variations in motion intensity
- Standardization needed

Basic Fixture Types: Introduction • Adapter plates • Cube fixtures
- Hemispheres • Conical fixtures • Enclosed box fixtures
- Drum fixtures • L-type fixtures • T-type fixtures
- Open box fixtures

Fixture Fabrication Methods: Introduction • Materials for fixtures
- Machining fixtures from solid stock • Bolted fixtures
- Cast fixtures • Welded fixtures • Bonded fixtures
- Laminated fixtures • Epoxy formed fixtures • Potted fixtures
- Foamed plastics for damping • Inserts

Analysis of an L-Fixture

Design of a Cubical test fixture

Appendix: Understanding Decibels (dB) & Octaves
- Types of Dynamic Testing • Accelerated Testing

Summary • Final Examination

Award of Certificates for successful completion

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