Fixture Design for Vibration and Shock Testing

Course No. 157

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. 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 and fabrication methods.

BRIEF COURSE DESCRIPTION This course incorporates a mechanical design fundamentals segment equivalent to Course 310, *Mechanical Design for Product Reliability*, which 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 mechanical shock and its design implications. 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 covers general design suggestions, such as methods for increasing natural frequencies.

The course then moves on to a brief discussion of random vibration, including power spectral density theory. The concept of RMS acceleration is discussed, followed by a basic introduction to shakers and vibration testing.

General considerations in fixture design are discussed next, 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, including bonding, bolting and welding, are discussed and class projects are undertaken to design some typical fixtures.

DIPLOMA PROGRAMS This course is required for TTi's Dynamic Test Specialist (DTS) Diploma Program. It may be used to satisfy the requirement for course 310 in TTi's Mechanical Design Specialist (MDS) Diploma Program. It may be used as an optional course for any TTi Specialist Diploma Program.

RELATED COURSES The mechanical design portion of Course 157 is available separately in Course 310, which runs concurrently. Course 157-3, an abbreviated version of 157, is available for on-site presentation to experienced designers.

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 student will receive 180 days access to the on-line electronic course workbook. Renewals and printed textbooks are available for an additional fee.

COURSE HOURS, CERTIFICATE AND CEUs 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.

ON-DEMAND OnDemand Internet Complete Course 157 features over 24 hours of video as well as more in-depth reading material. All chapters of course 157 are also available as OnDemand Internet Short Topics. See our on-line course outline for details.

Technology Training, Inc.
(a tti group company)
Toll-free telephone:
866-884-4338 (866-TTi-4edu)
International Tel. 805-845-5050
E-mail: Training@ttiedu.com
www.ttiedu.com

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Course Outline No. 157

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 • Fracture toughness
  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
  (Course 310 ends here)
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 Review
Award of Certificates for successful completion

Technology Training, Inc.
(a tti group company)
Toll-free telephone:
866-884-4338 (866-TTi-4edu)
International Tel. 805-845-5050
E-mail: Training@ttiedu.com
www.ttiedu.com