Shock and Vibration Measurement Technology Course Outline

I. INTRODUCTION TO VIBRATION

Sources of Vibratory Energy In Machines, Vehicles and Structures
Machine Elements
Buildings and Large Structures
Aeroacoustics
Transportation

Effects of Vibration and Noise

Introduction To Dynamic Motion
Rigid Body Motion vs. Structural Response
Single Degree of Freedom System
Free and Forced Vibration
- Free Vibration and Natural Frequency
- Response to Forced Vibration – Resonance
- Transmissibility Ratio
- Single Degree of Freedom System – Resonance
- Single Degree of Freedom System – Isolation

Damping
Multiple (Mechanical) Degrees of Freedom
Continuous Systems
- Single Frequency Excitation
- Multi-Frequency Excitation
- Critical Frequencies
- Examples of Complex Vibrations
- Continuous Systems

Modal Analysis

The Specialized Language of Vibration
Terms, Definitions and Equations of Motion
- Displacement
- Velocity
- Acceleration
- Force
- Errors Caused By Distortion

Dynamic Range (dB Scaling)
Peak vs. RMS Values
- A Helpful Vibration Calculator

Random Vibration
- Introduction To Non-Periodic Motion
- Random Vibration – What is it?
- Random Vibration is Common
- Random Vibration Testing
  - Narrow Band Response
- Measurement and Analysis ff Random Vibration
  - Suitable Instruments

Effect of Filter on Sinusoidal Signals
Effect of Filter Bandwidth on Random Signals
Various Analyzers Differ in Bandwidth
Power Spectral Density
Investigating the Entire Spectrum
RMS g From Root Area
Probability Density
Probability Density Analysis
Variance and Standard Deviation

II. SHOCK MOTION

Transient Motion

Terms and Definitions (Shock)
Velocity Shock
Classical Pulse
Complex Shock
Pyroshock
Description
Peak Amplitude
Pulse Duration
Rise Time
Decay Time
Frequency Spectrum
Shock Response Spectrum (Srs)

Sources of Shock
Transportation
Impact
Drop Shock
Ballistic Shock
Shipboard Shock, Automotive Crash Test, etc.
Explosives
Pyroshock
Near Field
Far Field
Blast Effects
Other Shocks

Structural Response Shock

Shock Response Spectrum

III. HOW SHOCK AND VIBRATION ARE MEASURED

Optical and Fixed Reference Measurements

Seismic Transducers

Measuring Vibratory Displacement
Optical Methods
- Eyeball Estimating
- Optical Wedge
- Parallel Limits
- Measuring Microscopes
- Stroboscopes
- High Speed Motion Pictures & Videos
- Interferometry And Holography

Displacement Sensors
- Non-Contacting Sensors
- Attached Sensors
- Strain Gages
- Displacement Meters

Measuring Vibratory Velocity
Velocity Pickups
Integration of Acceleration Signals
Differentiation of Displacement Signals
Laser Doppler Vibrometers

Measuring Vibratory Acceleration
Servo Accelerometers
Wire Strain Gage Accelerometers
Piezoresistive (PR) Accelerometers
Piezoelectric (PE) Accelerometers
Isotron (IEPE) Accelerometers
Variable Capacitance (VC) Accelerometers

Measuring Vibratory Force

Measuring Shock

Force, Displacement, Velocity or Acceleration?

IV. ACCELEROMETER PERFORMANCE CHARACTERISTICS AND ERROR SOURCES

Accelerometer Mass Loading Errors

Accelerometer Mounting Effects on System Response

Frequency Response and Resonance
Low Frequency Response
High Frequency Response
Resonance Frequency

Phase Shift and Damping

Transverse Sensitivity (or Cross-Axis-Sensitivity)

Amplitude Range and Linearity

Sensitivity Change with Temperature

Transient Temperature Effects
Effect of Humidity
Strain Effects (Base Bending)
Acoustic Noise
RF and Magnetic Fields

Nuclear Radiation
General Effects
Magnitude of Radiation Levels
Radiation Resistant Accelerometers

Zero Shift

Stability and Aging

V. ACCELEROMETER DESIGNS AND PERFORMANCE

Piezoelectricity
The Piezoelectric Effect
- The Discover of Piezoelectricity
- What is The Piezoelectric Effect?

Crystals and Ceramics
- Single Crystals
- Ferroelectric Ceramics
- Pyroelectricity
- Depolarization
- Temperature Effects

Manufacturing of Ferroelectric Ceramics
- The Manufacturing Process
- Endevco Piezoelectric Materials

Comparison of Material Properties

Piezoelectric Accelerometer Designs
Design Requirements
Effects of Crystal Configuration
Compression Designs
- Simple Compression
- Single-Ended Compression
- ISOBASE Compression

Shear Designs
- Annular Shear
- ISOSHEAR

Flexure (Bender) Designs
Multiaxial Designs
- Biaxial Designs
- Triaxial Designs

Transducer Electronic Data Sheet (TEDS)
Network Sensor Specifications (Example)

Comparison of PE, IEPE, PR and VC

PE – Piezoelectric
- Signal Conditioning
- Temperature Environment
- Frequency Range
- Amplitude Range
- Electromagnetic Environment
- Size and Weight
- Other Advantages and Disadvantages

IEPE – ISOTRON® Integral Electronic Piezoelectric
- Signal Conditioning
- Temperature Environment
- Frequency Range
- Amplitude Range
- Electromagnetic Environment
- Size and Weight
- Reliability
- Other Advantages and Disadvantages

PR – Piezoresistive
- Signal Conditioning
- Temperature Environment
- Frequency Range
- Amplitude Range
- Electromagnetic Environment
- Size and Weight
- Other Advantages and Disadvantages

VC – Microtron Variable Capacitance
- Signal Conditioning
- Temperature Environment
- Frequency Range
- Amplitude Range
- Electromagnetic Environment
- Size and Weight
- Other Advantages and Disadvantages

Which Type For My Applications?

VI. SIGNAL CONDITIONING, SYSTEMS AND READOUTS

Cabling and Connections

For PE Accelerometers
For Isotron Accelerometers
For PR and VC Accelerometers

Piezoelectric Transducer Conditioners

PE System Overview
Voltage Amplifiers

System Noise and Noise Rejection
Noise Sources
- Transducer Noise
- Cable Noise
- Amplifier Noise
- Effects of Source Capacitance
- Effects of Input Shunt Resistance

Differential Amplifiers

Isolation and Shielding

Signal Distortion Problems
Saturation and Clipping
Zero Shift
- Piezoelectric Accelerometers
- Piezoresistive Accelerometers
- In-Line Filtering
- Amplifier Ranging and Overload Protection
- Filtering Out Thermal Zero Drift

Slew Rate Limiting
Phase Shift

Programmable Signal Conditioners

Readout and Recording Devices
Input Characteristics
Meter Characteristics
Errors in Digitizing

Airborne Measurements
Accelerometer Selection Criteria
Limiting Amplifier Input with Bandwidth
Amplifier Ranging and Over Load Protection
Optimizing Data Bandwidth

VII. ACCELEROMETER CALIBRATION

Calibration Methods
Static Accelerometer Calibration
What is a g?
Accuracy, Error and Uncertainty
Dynamic Checks
Optical Calibration
- Large Displacements

Laser Interferometry
Interferometric Fringe Continuing Method
Interferometric Fringe Disappearance Method
Quadrature Laser Interferometer
General Considerations

Reciprocity Calibration
Test Procedure
Calibration Accuracy

Comparison Calibration, Vibration Input
The Standard Accelerometer
    Transfer Standard
    Comparison Standard
    Other Calibration Accelerometers
Test Procedures
Error Analysis

Frequency Response Calibrations
Calibrations Over A Wide Frequency Range
The Importance of Frequency Response Tests

Automated Calibration Systems

Comparison Calibration, Shock Motion Input
Evaluation of Accelerometer Standard
Test Procedure
Error Analysis

High Amplitude Chock Calibration
Theory
Apparatus
Calibration Results
Uncertainties

Extreme Temperature Calibration

Transverse Sensitivity Calibration

Informal Procedures
Filed Practice
Frequency Response
Linearity Checks
Calibrate The Entire System

Do's and Don'ts of Calibration (and Use) of Accelerometers
General Accelerometer Mounting Guidelines
Temporary Mounting with Adhesives
Fixtures
Cables
Cable Strain Relief
Grounding
Signal Conditioning
Mechanical Excitation Sources
General Calibration Goals

VIII. APPLICATIONS CONSIDERATIONS

Extreme Temperature
High Temperatures
Low Temperatures

Modal Testing
Sinusoidal Excitation
Random Excitation
Impulse Excitation

Shock Testing
Velocity Shock
Oscillatory Shock

Flight Vibration Testing

Vehicular Crash Testing

Nuclear Radiation Environments

IX. SPECIAL CASES

Torsional Motion and Angular Acceleration
The Specialized Language of Torsional Vibration
Measuring Torsional Motion
- Angular Displacement Sensors
- Angular Velocity Sensors
- Angular Acceleration Sensors
- Angular Force (Torque) Sensors
- Getting The Signals Out

Rotating Machinery Vibration
Instrumentation
Accelerometers
Spectral Analysis
Rotational Unbalance and Balancing
Aircraft Engine Monitoring
U.S. Navy Shipboard Vibration Monitoring

X. SELECTING THE BEST SYSTEM FOR YOUR APPLICATION

Transducer Characteristics

Signal Conditioner Characteristics
The Most Obvious

Less Obvious
- Overload Characteristics
- Vibration Amplifier Design vs. Shock Amplifier Design
- Output Current and Slew Rate
- High Frequency Rolloff Characteristics

System Characteristics

Instrument Selection

Transducer
- Will the accelerometer operate satisfactorily in the measurement environment?
- Will the accelerometer characteristics provide the desired data accurately?
- Is the proper stud being used for this application?

Cable
- Will the cable operate satisfactorily in the measurement environment?
- Will the cable characteristics provide the desired data accurately?

Power Supply
- Will the power supply operate satisfactorily in the measurement environment?
- Is this the proper power supply for this application?
- Will The Power Supply Characteristics Provide The Desired Data Accurately?

Amplifier
- Will the amplifier operate satisfactorily in the measurement environment?
- Is this the proper amplifier for this application?
- Will the amplifier characteristics provide the desired data accurately?

Data Acquisition and Readout

Installation

Transducer
- Is the unit in good condition and ready to use?
- Is the stud in good condition and Ready to use?
- Cement mounting

Cable

Power Supply, Amplifier and Readout

XI. GLOSSARY