Mechanical Shock Environment Synthesis and Experimental Testing

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Abstract

Shock Response Spectra (SRS) are commonly used in dynamic testing to describe the mechanical environment in high-energy, non-stationary events, such as impacts or pyrotechnic shocks. Oftentimes, the service environment to which a structure will be exposed is difficult to reproduce in the laboratory, but design engineers desire a laboratory screening test to determine whether the structure will survive the anticipated environment. In this project, students will explore methods of defining laboratory screening tests based on matching several different aspects of the anticipated environment related to their potential to damage the structure, including the SRS, peak strain, energy deposition, event duration, and others identified in the course of the project. Students will synthesize laboratory environments to reproduce the measured environment with respect to the identified criteria. Students will conduct experiments to assess their ability to reproduce the synthesized environments in a laboratory setting, and rate the performance of each method with respect to their ability to elicit anticipated failure modes in a series of destructive tests.

Project Outline

Goals

Identify metrics for the damage potential of a given mechanical shock service environment and implement environment synthesis methods to reproduce the damage potential of the service environment in a laboratory setting. Conduct a destructive experimental study to compare the efficacy of the various metrics and synthesis methods in eliciting failure in multiple copies of a test article on a bench-top shaker table or other apparatus.

Saturn V first stage separation

Motivation

Mechanical environment screening tests are an important part of design and system qualification for high consequence structures, such as space vehicles, satellites, and nuclear weapons. Such screening tests should be designed to elicit failure modes anticipated in the structure’s service environment in order to provide feedback for design iteration or evidence that the structure is qualified for its intended environment. Failure to screen components correctly can lead to catastrophic failure of the overall system. Space vehicles delivered on multiple-stage rockets are often subjected to significant pyrotechnic separation shocks that are difficult to reproduce in a laboratory setting. The SRS approach aims to reproduce the damage-causing potential of a particular shock environment in a manner reproducible in a laboratory setting. However, there is no general proof that the SRS approach will succeed, and there is a need to explore other metrics of damage potential as the basis for defining screening environments for high-consequence structures.

Procedure

1. Conduct a literature survey of mechanical shock environment synthesis methods
2. Determine metrics for the damage causing potential of a given service environment
3. Implement methods of synthesizing service environments in a laboratory setting, including SRS-based and time domain approaches.
4. Design, analyze, and fabricate multiple copies of a test article using solid modeling and 3D printing for use in destructive environmental testing.
5. Complete a numerical study comparing the performance of the identified methods and synthesis methods in terms of their ability to elicit structural failure in a finite
6. Complete an experimental study using the identified metrics and synthesis methods to assess the ability of the methods to elicit anticipated failure modes in the test article

Background Literature

Introductory Articles

http://en.wikipedia.org/wiki/Shock_response_spectrum

http://en.wikipedia.org/wiki/Multi_stage_rocket

Books

Harris, C., Piersol, A., Harris Shock and Vibration Handbook, Fifth Edition, McGraw-Hill, (2002), ISBN 0-07-137081-1

Lalanne, Christian. "Shock Response Spectrum." Mechanical Shock: Mechanical Vibration and Shock Analysis, Volume 2, Second Edition (2009): 51-94.

Journal and Conference Articles

Paez, Thomas L., and Norman F. Hunter. Representation of random shock via the Karhunen Loeve expansion. No. SAND2000-3053C. Sandia National Labs., Albuquerque, NM (US); Sandia National Labs., Livermore, CA (US), 2000.

Smallwood, David O., and Thomas L. Paez. "A frequency domain method for the generation of partially coherent normal stationary time domain signals."Shock and Vibration 1.1 (1993): 45-53.

Smallwood, David O. "Characterization and Simulation of Transient Vibrations Using Band Limited Temporal Moments." Shock and Vibration 1.6 (1994): 507-527.

Utilities

Chacon, Scott, and Junio C. Hamano. Pro git. Vol. 288. Berkeley, CA: Apress, 2009.

Weekly Plan

Week 1	Orientation and literature review
Week 2	Identify criteria to match service environments; Implement shock synthesis methods
Week 3	Design and analyze test article; Refine synthesis methods using damage metrics
Week 4	Fabricate test article; Finalize analysis to predict failure modes
Week 5	Design experiments; Conduct numerical study comparing synthesis methods
Week 6	Conduct experiments; finalize numerical synthesis method study
Week 7	Conduct experiments; analyze results to compare actual synthesis method performance
Week 8	Finalize experimental results analysis with comparison to numerical predictions
Week 9	Final Report and Presentations

Design Issues

Students should consider the ability to implement the synthesized environments in a laboratory setting. Experiments should be designed to explore the limits of feasibility to that end.

Equipment Requirements

Electrodynamic shaker
Impact testing apparatus
Test article(s)
Shock accelerometers

Software Requirements

3D modeling package
Finite element package
Matlab
Data acquisition
Shaker control