Dynamic Characterization of Satellite Components through Non-Invasive Methods

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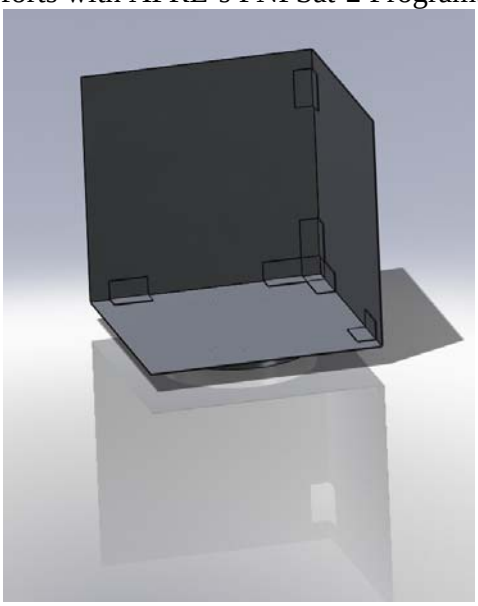
Abstract

The Air Force Research Laboratory has taken on the task of a responsive satellite initiative. The end goal is to refine current testing standards and methods by truncating or eliminating them altogether and achieve a significantly reduced turn-around time on satellites during immediate demand. One of these tests is the vibration test which is used to verify the fundamental frequency requirements and qualify workmanship of critical interfaces, but subjects the structure to launch loads and gives no local analysis to potential sources of error. Structural Health Monitoring (SHM) has been considered and is under investigation as a means of evaluating the dynamic properties of a structure. This requires adequate modeling of complex structures that can be verified and validated with NDE techniques in a responsive timeline. Contact type SHM is considered the most promising as it can be placed almost anywhere on the structure, even when closed up, and is relatively light in mass. Students will develop a simple 3 or 6 sided thin-plate assembly with attached masses (optional), model and verify the fundamental frequency and explore methods of performing the same validation with SHM.

Project Outline

Goal

Students are expected to find a way to qualify the dynamic characteristics of a 3 or 6 sided box structure, which will fundamentally represent a satellite, with the use of an SHM method and compare it with a traditional vibe testing methods. Students will explore the challenges associated with attempting to characterize a global structure using local analysis and model updating. Methods developed here may be integrated with assistance into ongoing efforts with AFRL's PNPSat-2 Program.



Motivation

All components are exposed to a series of intensive environmental tests considering thermal, vibration, and radiation loads to qualify them for space missions. When a final satellite is constructed, the interfaces between all these qualified components must also be qualified. In a responsive scheme, these final interfaces are what hamper the objective of rapid deployment. AFRL/RVSV is attempting to develop SHM as a means of qualifying future spacecraft (thermally, mechanically, and dynamically). Several fundamental efforts are currently underway to explore the feasibility of this vision and has shown promising functionality. One of the important questions being asked is: how can SHM be used to determine the fundamental frequency of a final system if it can't excite the entire structure. It is theorized that modeling combined with local analysis for inputs and model updating can be used to determine the important modes of a final system.

Procedure

To accomplish this task, students will need to understand the Vibe test requirements for typical satellites and the SHM/NDE techniques that are available to perform the same task. Next, model the structure and testable dynamic loads and compare that to the real structure. Students should perform several builds and orientations of the plates and hinges to see what, if any, changes occur in experimental analysis. Students should then refine their modeling to match experimental. Students should now be able to identify what aspects of the structure create uncertainty and error in the model and mount sensors in such a way to inspect these uncertainties. Students will then consider impact modulation, acousto-elasticity or Electro-Mechanical Impedance (E/MI) as a means of characterizing those uncertainties and developing the Damage Indices (DIs) that can be used to determine inputs for model updating. Results will be prepared in the form of a conference paper and presented at the end of the course.

Required reading

http://www.orbital.com/NewsInfo/Publications/Minotaur_IV_Guide.pdf

Damage detection by means of structural damping identification
Engineering Structures, Volume 30, Issue 12, December 2008, Pages 3497-3504
R.O. Curadelli, J.D. Riera, D. Ambrosini, M.G. Amani

Numerical and experimental dynamic characteristics of thin-film membranes
International Journal of Solids and Structures, Volume 42, Issues 9-10, May 2005, Pages 3001-3025
Leyland G. Young, Suresh Ramanathan, Jiazhu Hu, P. Frank Pai

Nonlinear acoustic interaction on contact interfaces and its use for nondestructive testing
NDT & E International, Volume 34, Issue 4, 1 June 2001, Pages 231-238
D. Donskoy, A. Sutin, A. Ekimov

Self-diagnosis of smart structures based on dynamical properties
Mechanical Systems and Signal Processing, Volume 23, Issue 6, August 2009, Pages

1830-1845
C.-P. Fritzen, P. Kraemer

Overview of Piezoelectric Impedance-based Health Monitoring and Path Forward
The Shock and Vibration Digest, Vol. 35, No. 6, pp. 451-463.
Gyuhae Park, Hoon Sohn, Charles R. Farrar, Daniel J. Inman

Week by Week Plan

Week 1- Study requirements
Week 2- Perform Lit Review of potential SHM method
Week 3- Model structure with sine sweep vibe
Week 4- Build Structure, and test dynamics of structure after numerous assemblies. Is it consistent?
Week 5- Update model to match shake results
Week 6- Determine SHM Inspection requirements for extracting necessary inputs for models and mount sensors on structure at points of interest
Week 7- Perform model Update with SHM inspection and compare methods
Week 8- Document results in form of conference paper
Week 9- Present results

Real World Design Issues as a Project Consideration.

The real world application of this is being currently being explored for responsive space programs with complete order-operation deadlines of a week. This extremely reduced timeline allows for hours for qualification testing where typical programs today require months to years. If there is a permanently embedded, non-obtrusive, method of qualifying these systems at their critical interfaces, these structures can be quickly tested in real time without having to dedicate specially allocated time to vibration tests.