Research Problems Associated with Limiting the Applied Force in Vibration Tests and Conducting Base-drive Modal Vibration Tests

Terry D. Scharton
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, Ca 91109

Introduction

The rationale for including this paper in a session on tailoring vs. standards is to make a case for developing and conducting vibration tests which are both realistic and practical, Tests are essential for finding things overlooked in the analyses. The best test is often the most realistic test which can be conducted within the cost and budget constraints. Some standards are essential, but the author believes more in the individual's ingenuity to solve a specific problem, than in the application of standards which reduce problems (and technology) to their lowest common denominator. Force limited vibration tests and base-drive modal tests are two examples of realistic, but practical testing approaches. Since both of these approaches are relatively new, a number of interesting research problems exist, and these are emphasized herein.

Force Limited Vibration Tests

Most of the major vibration tests at JPL are now conducted by measuring the vibratory force applied to the test item by the shaker and limiting the applied force to that predicted for the flight mounting configuration (Ref. 1). Force limiting results in notches in the input acceleration at the fixed base resonance frequencies of the test item. The responses in force limited tests are similar in magnitude to those expected in flight. In conventional tests without notching, the applied forces and responses are 3 to 10 times the maximum flight values for typical aerospace hardware. This test artifact is the cause of most vibration test failures and is the driver of the design penalties for hardware which is designed to pass the test.

Base-drive Modal Vibration Tests

A second related subject concerns conducting modal verification tests in conjunction with vibration tests (Ref. 2). The benefit of conducting base-drive modal tests in conjunction with qualification vibration tests is one of cost and schedule saving. In the case of a spacecraft system, as much as a month might be eliminated from the integration and test schedule; which in today's faster, better, and cheaper environment may be essential. Modal tests of spacecraft structures are conducted primarily for the purpose of verifying the spacecraft finite element model (FEM) which in turn is used primary for: 1. design, 2. the launch vehicle coupled loads analysis, and 3. deriving response limits for the spacecraft sine and/or random vibration tests. In recent JPL spacecraft programs without development test models, the modal tests occur too late in the program to intersect the design process. Base-drive modal tests appear well suited to the problem of verifying the FEM for the purpose of the coupled loads analysis, particularly in the case of future smaller, stiffer spacecraft. Finally, if force limiting is properly used in the spacecraft qualification vibration test, there is little need for response limiting.

Problems in Measuring Base Reaction Forces

The problems involved in measuring base reaction forces on a shaker are common to both force limited and base-drive modal vibration tests. Most of these problems have been solved with the advent of commercially available three axis piezoelectric force gages and the associated signal conditioning equipment. These gages are very stiff, so they do not significantly reduce the resonance frequencies of the test item. The twelve signals from a load cell consisting of four, three-axis force gages may be combined in real time to provide the six force components, three forces and three moments, at the shaker/test item interface.

The test fixturing to accommodate the force gages between the shaker and the test item remains a problem. Ideally, one would like to have no fixture mass between the gages and the test item, and this is possible when the gages may be simply used as a force washer with a longer than flight attachment bolt. In this case, the large dynamic range (typically - 60 dB) of the piezoelectric gages allows one to sense base reactions associated with the high frequency resonances of very small masses on the test item. (The base reaction force falls off rapidly with increasing frequency as will be discussed subsequently.) The presence of an adapter plate above the force gages creates a wide band noise floor of force equal to the input acceleration times the adapter plate mass, below which test item forces may not be sensed.

A second problem with fixturing concerns the need for a universal fixture incorporating force gages so that special fixturing need not be developed for each test. The use of the shaker armature current or a shaker fixture permanently incorporating force gages have been studied, but there are problems in subtracting out the force consumed by the armature and by the permanent fixturing, particularly when these are massive or flexible, compared to the test item(Refs. 3 and 4). The development of a large, lightweight ring-type fixture for measuring the six components of force applied in spacecraft base-drive vibration tests is described in Ref. 2 and the references therein.

A third problem concerns the inherent errors in force gage measurements. Many sources of these are discussed in Ref. 5 and in the references of Ref. 2. Experience with the three axis piezoelectric force gages indicates that most of these errors are small (< 1 %), if: 1, the gage preloading is not exceeded and 2. the surfaces mating to the gage are flat.

Problems in Determining Drive Point Apparent and Effective Modal Masses

The apparent mass, the frequency response function obtained by ratioing the drive point force to acceleration, is a key parameter in both force limited and base-drive modal vibration tests. Since little or no flight vibratory force data is available, the limits for force limited vibration tests are derived using measured or FEM values of the test item and flight mounting structure apparent masses, One problem involves deriving the apparent masses from the accelerances (the reciprocal of apparent mass) commonly measured with force hammers in modal tests. It is often not possible to invert an experimentally determined accelerance matrix for different locations to obtain the corresponding apparent mass matrix. A related problem concerns combining apparent masses measured at multiple mounting points to obtain the appropriate apparent mass when all drive points move in phase as in a vibration test. Both of these problems are discussed in Ref. 3.

A related parameter used to develop force limits is the effective modal mass, which is the modal contribution to the reaction force divided by acceleration at the excitation interface (Ref. 6). A problem concerns the method of terminating a structure, say a spacecraft, to calculate the spacecraft effective mass at an interface where the a test item, say an experiment, is attached to the spacecraft. How much of the spacecraft structure is needed to accurately calculate the effective mass at the experiment interface at a given frequency?

Another important problem concerns estimating the effective mass from apparent mass FRF's measured with tap hammers or shakers with force gages. The frequency averaged apparent mass, sometimes called the asymptotic mass or skeleton mass (Ref. 7), is approximately equal to the residual mass, which for base drive of a free object is the sum of the effective masses of modes with resonance frequencies above the excitation frequency. The importance of modal effective masses (and stiffnesses) for base-drive modal tests is discussed in Ref. 2 and the references therein.

Other Problems

Another problem concerns the measurement of apparent and effective inertias. Moment gages and rotational accelerometers are becoming available, but FRF measurements of inertia are unknown, It is also a problem that most current vibration test controllers are not set-up to control phase, particularly as regards random excitation. A final problem is the lack of flight vibratory force data at the interface of payloads and support structures, for example at the spacecraft and launch vehicle interface.

Conclusions

It should not be concluded that because of all the aforementioned problems, one cannot proceed with force limited or base-drive modal tests. On the contrary, over a dozen force limited vibration test projects involving flight hardware have been successfully conducted at JPL over the past four years (Ref. 1), and many base-drive modal tests have also conducted. It is the newness of the vibratory force measurement technology that makes it a fertile subject of application and research.

Acknowledgement

The work described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration.

References

1 Scharton, T. D., "Force Limits for Vibration Tests", Spacecraft Structures and Mechanical Testing Conference Sponsored by CNES and ESA, Paris , FR, June 1994.

2 Meurat, A., Girard, A., and Marce, J. L., "Dynamic Force Measurement for Seismic Test or How to Perform Modal Identification During Vibration Tests", Eurolab Conference, Florence, Italy, April 1994.

3 Piersol, A. G., White, P. H., Wilby, E. G., Hipol, P. J., and Wilby, J. F'., "Vibration Procedures for Orbiter Sidewall-Mounted Payloads" Astron Research and Engineering, Santa Monica, CA, Phase 1, 7114-01, Nov. 1988, Phase II, 7114-02, Feb. 1989.

4 Smallwood, D. O. and Coleman R. G., "Force Measurements During Vibration Tests", *Proceedings of 64 th Shock and Vibration Symposium, 1993.*

5. McConnell, K. G., **"The Interaction of Force Transducers with their Test Environment",** Inter. Jour. of Analytical and Experimental Modal Analysis, v8 n2, April 1993.

6 Wada, B. K., Bamford, R., and Garba, J. A., "Equivalent Spring-Mass System: A Physical Interpretation", *Shock and Vibration Bulletin, No. 42, 1972,* pp. 215-225.1. CNES paper

7 Skudrzyk, E., Simple and. Complex Vibration Systems, Pennsylvania State University, University Park, PA, 1968.