Vibration Testing of CubeSats: Ensuring Mission Success

Dr. Ing. Carmine Salzano (PCB Piezotronics, International Manager- Aerospace & Defense and Test Sector)

Abstract

Vibration testing is crucial for satellite development and validation. It simulates launch stresses, ensuring the satellite can withstand them without damage or functional issues. Join us to explore advancements in vibration test systems, including shakers, vibration controllers, and accelerometers.

Longer abstract

The Importance of Vibration Testing in Satellite Development is crucial and there are several reasons listed below:

- Qualification Testing: All spacecraft must pass minimum qualification and acceptance testing to be launched. Test profiles are determined by the launch provider.
- Ensures structural integrity and reliability: Vibration testing simulates the launch environment to ensure the satellite can withstand the stresses encountered.
- Identifies potential issues before launch: Early detection of design flaws or manufacturing defects reduces the risk of mission failure.
- Critical for mission success and longevity: Ensures the satellite operates as intended throughout its mission life.

Small satellites, such as CubeSats, are mostly subjected to the same types of tests as larger satellites. There are many tests, but we will focus as above mentioned, on the various types of vibration tests. These tests, normally performed on the same large shakers traditionally used for testing large satellites, can now be performed on shakers of significantly smaller, cheaper and easier to handle, using a new technique. Not only will we describe this new technique in these pages, but also new vibration sensors technologies for various types of tests, as well as those performed in the usual excitations (sine, random, etc.) but also in particular environments such as high shock levels, micro vibration measurements, and thermo vacuum. Other type of test will be only mentioned: structural or modal test, acoustic stress test (executed with precision condenser microphones and accelerometer) and force limiting vibration test executed with force sensors that, through a NASA standard, regulate the procedure aimed at avoiding overstressing the satellite and its components. In particular in present paper, we will describe following new sensors technologies advancement representing today state of the art of measurement sensors technologies for satellite vibration test: Accelerometers for shock and pyroshock, Accelerometers for micro vibration test, Accelerometers low outgassing for thermo vacuum test, Accelerometers for vibration stress screening and new vibration excitation system for small satellite and CubeSat.
Therefore main part of the article will consist of description of all new sensors technologies above listed and finally the new solution for vibration excitation shaker accompanied by a case study.
The most popular accelerometer technology is piezoelectric, in particular ICP (IEPE) technology for satellite testing. In these accelerometers, which measure motion, the invariant seismic mass, 'M', is forced by the crystals to follow the motion of the base and structure to which it is attached. The resulting force on the crystals is easily calculated using Newton's Second Law of Motion: F=MA. Thus, after a brief working principle, we will focus on the recent results achieved in the field of design and manufacturing of accelerometers suitable for the different types of tests mentioned with their related benefits.
After new sensors technologies part, we will describe the basics of satellite vibration testing and types of vibration tests, there will be a quick description of equipment and facilities used and testing procedure.

The vibration testing, as already above anticipated, is very important because it's a simulation of launch and operational conditions to ensure satellite durability with objective to validate design, ensure durability, and predict performance under stress, reducing in this way risk of in-orbit failures and improves design robustness.
There is different type of vibration testing: sinusoidal, random, SRS (shock testing), acoustic stress. Testing procedure will be also briefly reported as well as equipment and facilities used: shakers and controllers, test fixtures and sensors. Each of these 3 main components designs of test and measurement test will be summarized.
The new vibration excitation solution consists to streamline CubeSat vibration testing with a new CubeSat test fixture which provides a broader standard mounting fixture to meet the standardized sizing of 1U, 2U, and 3U CubeSats. With the common fixture base that is built to interface directly with the vibration shaker, the user can quickly mount up to 3U size satellites in horizontal or vertical configurations for critical vibration qualification and acceptance testing based on NASA or other standards to ensure survivability during launch. Installing and configuring this new unique and dedicated shaker fixture is easy using included screws and tools. The simple removal also allows the shaker to easily be used for testing of sub-assemblies mounted either directly to the shaker, via head expander, or with optional slip table for additional component level vibration testing.
The benefits of this new solution are:

- Supports the mounting of various size CubeSats (up to 3U) to the shaker in different orientations
- Includes lightweight magnesium mounting fixture, dummy payloads, mounting accessories, and a heavy-duty case.
- Simplifies qualification testing of CubeSats to NASA testing or other standards

Index.

1. Basic definition of Vibration testing and types of vibration testing

The design and construction of satellites of all types as well as many other modern structures subject to dynamic loads has made static stress and wear measurements alone insufficient and has made dynamic measurements based on vibration tests necessary. Vibration tests are performed in dedicated laboratories and are an integral part of the development and testing as well as necessary for the qualification and certification of satellites before their launch into orbit. Satellites of all types and sizes are subjected to a level of vibration in accordance with the specific procedures of international standards and specific design requirements. Therefore, to find the dynamic properties of a structure and therefore also of a satellite, the same is subjected to certain vibration forces and then the relative vibration response of the object under test, i.e. the satellite, is obtained with suitable transducers.

2. Equipment and Facilities Used: Measurement chain for vibration testing

In order to produce a certain vibration, an electromagnetic/electrodynamic exciter (shaker) is used, which converts an electrical signal into a mechanical movement that is in turn controlled to maintain a certain level of vibration or forcing on the test object, in this case the complete satellite system or one of its components.

The basic instrumentation, or measurement and testing chain, consists of an exciter, a power amplifier and measurement transducers as well as a system for generating, acquiring and analyzing the signals produced and detected.

The most commonly used measurement transducer is the accelerometer. In a shaker vibration test system, an accelerometer at least acts as a control of the vibration produced by the shaker in a closed loop, that is, the same excitation produced by the shaker is controlled in real time according to an appropriate level set in the generation and amplification system through the use of an accelerometer. Other accelerometers are then used during the test mounted directly on the DUT (device under test) or the satellite, to measure its response consequent to this exciting vibration profile set.

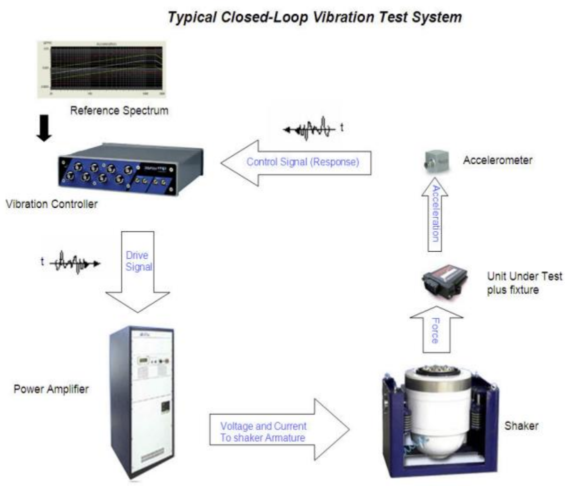
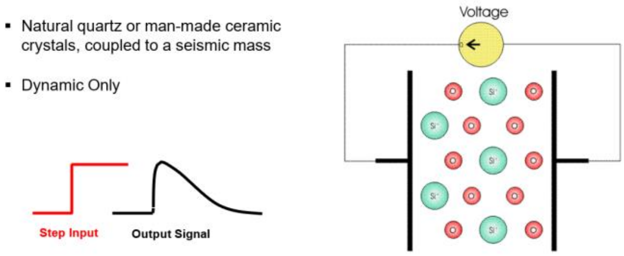


Figure: Vibration Test and measurement system configuration

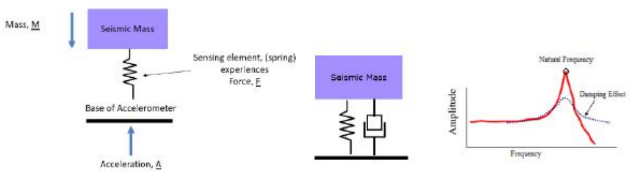
3. Response Measurement Sensor: Accelerometers

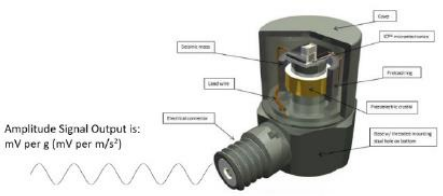
There are some different technologies for accelerometers: Mems (capacitive, piezoresistive) and piezoelectric (charge or ICP). the piezoelectric one.

For vibration tests, being purely dynamic tests, the most used technology is the piezoelectric one.



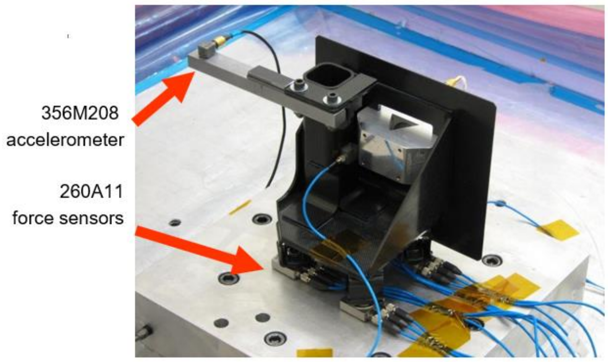
Piezoelectric Accelerometers**.** The accelerometer technologies used in dynamic tests can be divided into piezoelectric or MEMS types. Piezoelectric accelerometers were originally created with charging output, but then the technology of amplified piezoelectric accelerometers, better known as IEPE or ICP, was developed. In contrast, MEMS are mainly of two types: piezoresistive, used for tests at high acceleration values such as impacts and shocks; and capacitive, which can sometimes also be used in these types of dynamic measurements characterized by limited acceleration values. The main benefit of MEMS capacitive compared to ICP lies in the possibility of measuring from 0Hz. This is note essential for a dynamic test, which is why the ICP accelerometer has established itself as the main sensor for general dynamic and vibration test.
An ICP accelerometer is a sensor that generates an electrical output proportional to applied acceleration. ICP accelerometers are designed to measure vibration and shock for a wide variety of applications. They are simple to use and accurate over a wide frequency range, making them the recommended choice for many testing situations.
An accelerometer structure can be characterized as a single degree of freedom system that is governed by Newton's Law of Motion, **F=MA.**
A variety of mechanical designs are used to perform the transduction required for ICP accelerometers. The designs consist of sensing crystals that are attached to a seismic mass. A preload ring or stud applies a force to the sensing element assembly to make a rigid structure and insure linear behavior. Under acceleration, the seismic mass causes stress on the sensing crystals, which results in a proportional electrical output. The output is collected on electrodes and transmitted by wires connected to the microelectronic circuitry in ICP accelerometers. The schematic of the ICP accelerometer is shown in Figure below.





Accelerometer Selection

There are many types of ICP accelerometers depending on specific testing requirements, but for now we will only briefly describe the main characteristics required for an accelerometer used for structural testing. Desirable specifications to consider for CubeSat and in general vibration test accelerometers are: Amplitude (dynamic range), Frequencies of interest, Sensitivity, Resolution, Mass of test article vs. sensors, Single axis or triaxial, TEDS, Environment (i.e. Low outgassing Y/N), Mounting/cable management, Calibration.



James Webb Space Telescope
NIRSpec Bracket Assembly

Low Outgassing sensors (accelerometers and force sensors) are needed in the event the UUT needs to go through thermal vacuum chamber testing. Using LO sensors, cables, accessories can simplify testing plan. Materials selected per NASA report RP-1124, “Outgassing Data for Selecting Spacecraft Materials”.

Common Uniaxial Accelerometers

<table>
<tr><th>Model</th><th>352C22</th><th>352A21</th><th>352A59</th><th>352M212</th><th>333A22</th><th>333B32</th><th>333B30</th><th>352A24/NC</th><th>TLD352A56</th></tr>
<tr><td>Sensitivity</td><td colspan="5">10 mV/g
1.02 mV/(m/s²)</td><td colspan="4">100 mV/g
10.2 mV/(m/s²)</td></tr>
<tr><td>Range</td><td colspan="5">±500 g
±4,900 m/s²</td><td colspan="4">±50 g
±490 m/s²</td></tr>
<tr><td>Mounting</td><td colspan="5">Adhesive</td><td>Adhesive</td><td>Stud</td><td colspan="2">Adhesive</td></tr>
<tr><td>TEDS</td><td colspan="2">N</td><td>Y</td><td></td><td>Y</td><td>TLD333B32</td><td>TLD333B30</td><td>N</td><td>Y</td></tr>
<tr><td>Ground Isolation</td><td>Y</td><td colspan="4">N</td><td colspan="2">N</td><td>Y</td><td>N</td></tr>
<tr><td>Hermetic</td><td colspan="2">N</td><td colspan="3">Y</td><td colspan="2">Y</td><td>N</td><td>Y</td></tr>
<tr><td>Low Outgassing?</td><td colspan="2">N</td><td>Y*</td><td>Y</td><td>Y*</td><td colspan="2">Y*</td><td>N</td><td>Y*</td></tr>
<tr><td>Notes</td><td>Ground iso</td><td></td><td>Included Cable is LO</td><td>Integral cable</td><td colspan="3">Cubic, single axis for easy alignment</td><td colspan="2">Cable not included</td></tr>
</table>

Common Triaxial Accelerometers

Model	356A19	356A03	356A09/NC	356A33	356A43	356A45	356A15	356A16
Sensitivity	10 mV/g 1.02 mV/(m/s²)					100 mV/g 10.2 mV/(m/s²)		
Range	±500 g ±4,900 m/s²					±50 g ±490 m/s²		
Mounting	Stud	Adhesive	Adhesive	Stud	Adhesive	Adhesive	Stud	Stud
TEDS	Y	TLD356A03	N	N	Y	Y	TLD356A15	TLD356A16
Ground Isolation	Y, w/pad	J3456A03	N	Y/ w/pad	J356A43	J356A45	Y, w/pad	Y
Hermetic	Y							N
Low Outgassing?	Y	356M239	Y	Y	Y	Y	Y	N
Notes	Up to 13k Hz	Mini, integral cable	Connectorized 0.25" (6.35mm)	Pair with standard or LO cable				

Control Accelerometers, Shaker Testing

Specifications required: 10 mV/g (500g) is a common selection and then adjust range as needed for your test's specific amplitude/frequency/resolution requirements, Triaxial is common but can use uniaxial, ICP is preferred, Stud or bolt attachment to table desired (best frequency transmission), Electrical Isolation. Shakers are notoriously noisy. Ground or case isolation can help mitigate electrical noise contamination of your accelerometer measurement.

354C03

Ground Isolated
Freq: 0.5-2k Hz +/- 5%
BB Resolution: 0.0002g rms

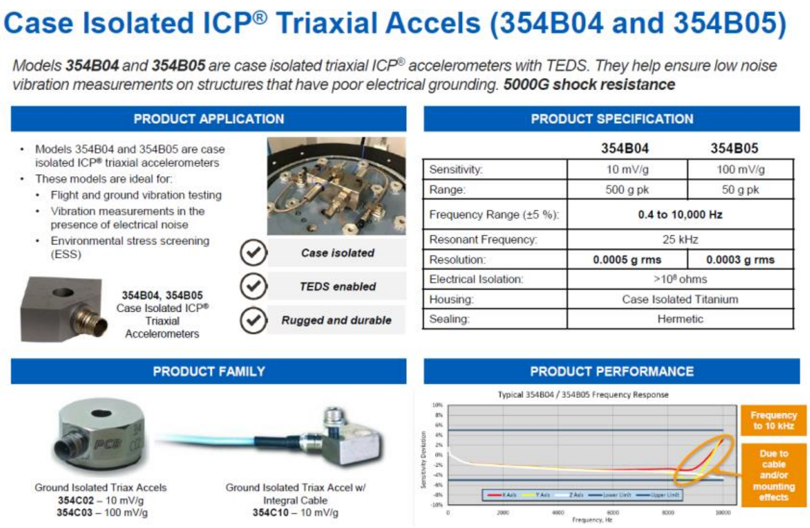
354B04

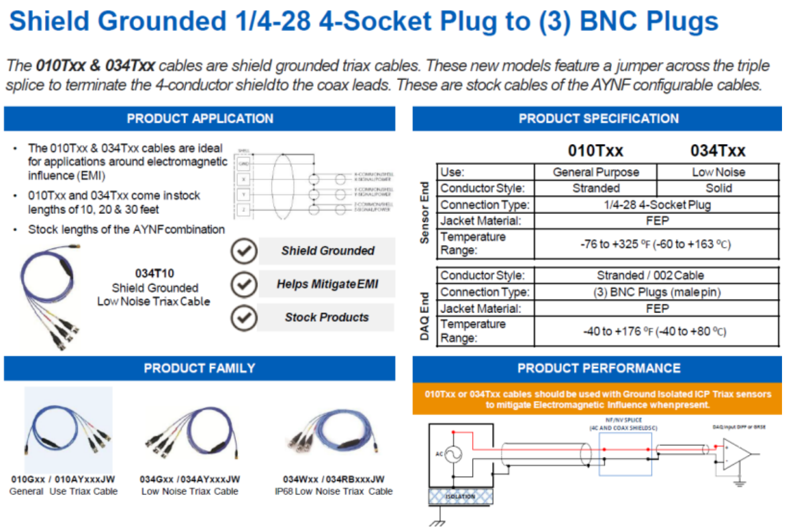
Case Isolated
Freq: 0.6-10k Hz +/- 5%
BB Resolution: 0.0005g rms

4. New accelerometers technologies for vibration testing

Shaker control accelerometers

PCB Model 354C04 and 354C05. This series of accelerometer has been designed also for such type of vibration stress screening and hereby we will evaluate the new benefits to such test with their new dedicated specifications: Case isolated with new T shielded grounded T cable to avoid any possible electromagnetic interference with fields created by shaker, amplifiers and surrounding environment. Through hole mount helps in such test the positioning of accelerometer is crucial especially in small shakers size. Other important specifications of these accelerometer models are: broadest frequency bandwidth, wide acceleration range and completely hermetic.





Shield Grounded 1/4-28 4-Socket Plug to (3) BNC Plugs

*The **010Txx & 034Txx** cables are shield grounded triax cables. These new models feature a jumper across the triple splice to terminate the 4-conductor shieldto the coax leads. These are stock cables of the AYNF configurable cables.*

PRODUCT APPLICATION

- The 010Txx & 034Txx cables are ideal for applications around electromagnetic influence (EMI)
- 010Txx and 034Txx come in stock lengths of 10, 20 & 30 feet
- Stock lengths of the AYNF combination

034T10
Shield Grounded
Low Noise Triax Cable

Shield Grounded
Helps Mitigate EMI
Stock Products

PRODUCT SPECIFICATION

		010Txx	034Txx
Sensor End	Use:	General Purpose	Low Noise
	Conductor Style:	Stranded	Solid
	Connection Type:	1/4-28 4-Socket Plug	
	Jacket Material:	FEP	
	Temperature Range:	-76 to +325 °F (-60 to +163 °C)	
DAQ End	Conductor Style:	Stranded / 002 Cable	
	Connection Type:	(3) BNC Plugs (male pin)	
	Jacket Material:	FEP	
	Temperature Range:	-40 to +176 °F (-40 to +80 °C)	

PRODUCT FAMILY

010Gxx / 010AYxxxJW General Use Triax Cable
034Gxx / 034AYxxxJW Low Noise Triax Cable
034Wxx / 034RBxxxJW IP68 Low Noise Triax Cable

PRODUCT PERFORMANCE

010Txx or 034Txx cables should be used with Ground Isolated ICP Triax sensors to mitigate Electromagnetic Influence when present.

DUT response accelerometers

Miniature accelerometers triaxial and single axis. These sensors are needed especially when measuring and mounting on very small objects such as CubeSats. PCB new Model 356A09: the smallest accelerometer (with only 6 mm cube size) now on the market with connector not only with integral cable. The benefit is the simple replacement of cable in case of cable breakage.

Small ICP® Triax Accel w/ Connector

High Overload Shock Limit

Wide Frequency Range

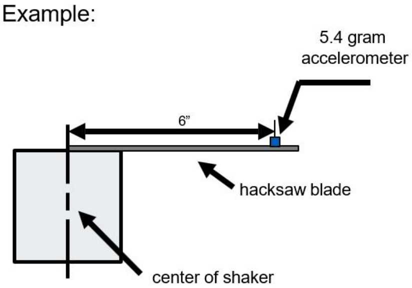
356A09 & 356A09/NC

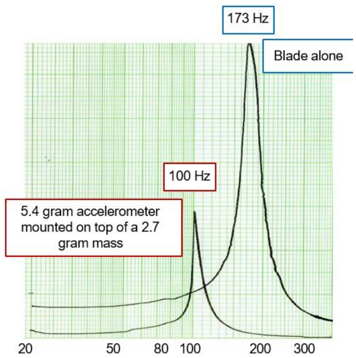
Sensitivity: (±20%)	10 mV/g
Measurement Range:	±500 g pk
Frequency Range (± 5%):	Y or Z axis – 2 to 8,000 Hz
Frequency Range (± 5%):	X axis – 2 to 5,000 Hz
Temperature Range:	-65 to +250 °F (-54 to +121 °C)
Overload Shock Limit:	±5,000 g pk
Weight:	0.04 oz (1.0 gm)
Size:	0.25 in (6.4 mm) cube
Electrical Connector / Mounting:	8-36 4-pin / Adhesive

Mass Loading Considerations.

How do you know if your sensor too heavy for the UUT? Typically one acquire FRF with a single accelerometer, then mount second accelerometer next to the first, re-acquire FRF. Then compare for measurable differences. The rule of thumb is: Target sensor mass less than 5% of UUT (unit under test).

Example:





5. Satellite testing sensors technologies

A satellite in general undergoes different tests depending on the type of requirement of the launcher or space rocket. Below we can mention some of them, a satellite in general undergoes different tests depending on the type of requirement of the launcher or space rocket. Below we can mention some of them, many of which use an accelerometer as a response transducer. This accelerometer will have different characteristics depending on the type of test to be performed:

- Vibration Test Qualification/ Environmental Stress Screening (ESS) is a general reliability testing term used to define the practice of exposing primarily electro-mechanical devices and delicate flight hardware to environmental stresses in an attempt to create failures and expose defects
- Structural, Modal Testing: Structural testing refers to specific dynamic tests on any given structure, small or large. These dynamic tests involve a test and measurement system composed of various types of sensors and a suitable acquisition system with related analysis software. We can divide these tests according to the purpose, but overall, we categorize them into two types according to measurement setup: modal analysis and operational modal analysis (OMA). Modal analysis involves the excitation of the structure with essentially two types of transducer technologies, while for operational modal analysis (OMA), external excitation is not required as the motion of the dynamic structure itself is analyzed during its normal operating conditions. In any case, the response of the system is detected by sensors that may utilize the same technology in both types of tests.
- Low Outgassing Solutions for TVAC (thermo-vacuum chamber test): low outgassing accelerometers and cables are designed for use in high-vacuum applications such as satellite ground testing and in space.
- Direct Field Acoustic Noise, or Reverberant Chamber Testing: It mainly uses measurement microphones but often also accelerometers to measure the vibration levels on the satellite under test as a result of the large acoustic stress to which it is subjected during this test to replicate the launch conditions inside the space launcher.
- Force Limited Vibration Testing (FLV): Due to the high cost, long development times, and uniqueness of sophisticated aerospace and other high-tech equipment, it is imperative to implement techniques that ensure their safety during vibration qualification testing. The PCB® Force Limited Vibration Testing System meets most requirements for limiting the reaction force between the shaker and unit under test in random vibration testing. The use of piezoelectric, 3-component force sensors facilitates easy and accurate measurement of the input force.
- Pyroshock, Stage Separation: Before launch, payloads and rockets must undergo rigorous environmental testing to simulate the extreme conditions they will face. This testing includes subjecting the equipment to extreme temperatures, vacuum, shock, vibration, and acoustic stress; all of which can potentially damage critical components.

In this work we have focused only on the vibration test accelerometers described above.

Examples of Sensors.

ICP and Piezoresistive Shock Sensors

- For stage separation, pyro-shock testing with ICP and Piezoresistive Mems technologies.

ICP Precision Condenser Microphones for Vibro-Acoustic Testing

- Up to 182 dB dynamic range, 70k Hz

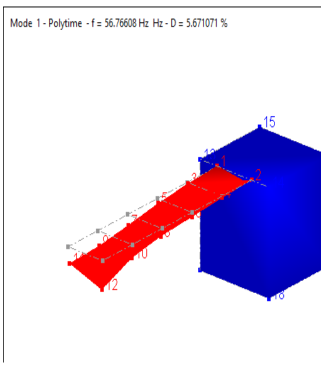
Piezoelectric Charge Mode and ICP Triaxial Force Rings/Links

- For Force Limited Vibration Testing (FLVT)

Dynamic Reusable Strain Sensors 740B02 & 740M04 for measuring dynamic strain

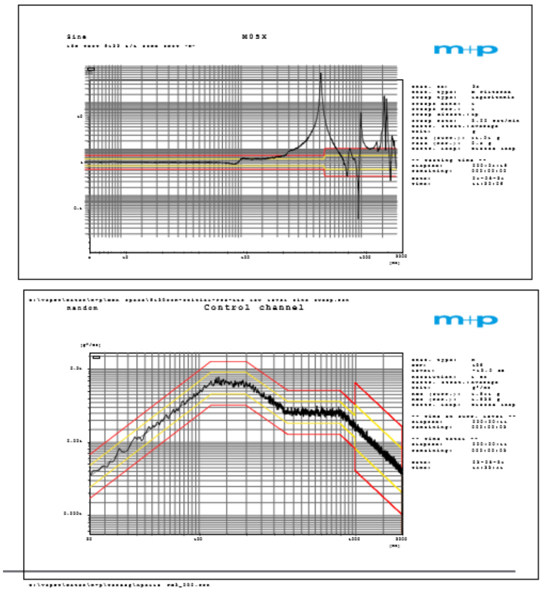
6. Vibration excitation system and Satellite vibration excitation. Basics of Satellite Vibration Testing

- Definition: Simulation of launch and operational conditions to ensure satellite durability.
- Objectives: Validate design, ensure durability, and predict performance under stress.
- Benefits: Reduces risk of in-orbit failures and improves design robustness.



Types of Vibration Tests

- Sinusoidal Vibration Testing: Simulates low-frequency vibrations to test structural integrity.
- Random Vibration Testing: Applies high- frequency, broadband vibrations to ensure robustness.
- SRS Shock Testing: Applies transient, high level shock impulse to verify conformance to required Shock Response Spectrum requirements.
- Acoustic Testing: Replicates the noise environment during launch to test for acoustic loads.



Testing Procedures

- Pre-Test Preparations: Calibration, setup, and safety checks to ensure accurate testing.
- Test Execution: Running tests according to predefined protocols to simulate conditions.
- Data Collection and Analysis: Recording and interpreting results to validate satellite performance

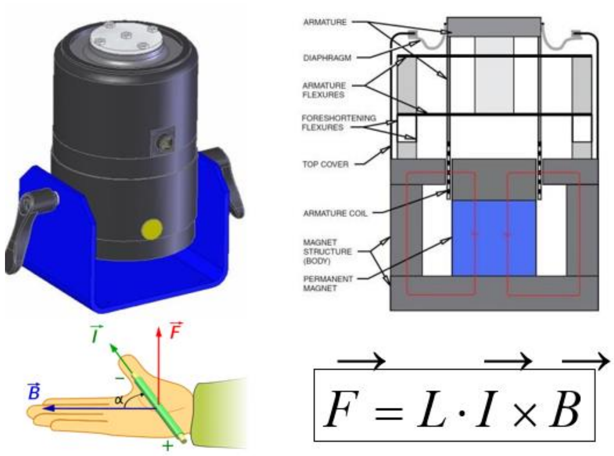
Photo Courtesy of Cal Poly CubeSat Laboratory

Equipment and Facilities Used

- Shakers and Controllers: Simulate various vibration profiles to test satellite integrity.
- Test Fixtures: Secure satellites and vibration accelerometers to measure responses to vibrations.
- Measurement Sensors: accelerometers, strain sensors, force sensors

7. Electrodynamic shaker

The shaker is like a transducer but while a sensor transforms a physical quantity such as vibration into an electrical signal (such that it can be appropriately analyzed by a suitable acquisition and analysis system and software), the shaker is an actuator, therefore it transforms an electrical signal into a vibration suitable for appropriately stimulating the object under test. This force or vibration can be analyzed as acceleration, velocity or displacement. The shaker is also known by different names: electrodynamic exciters, electromagnetic, shakers, actuators, etc. We can divide shakers into small or large. Small shakers are usually permanent magnets while large shakers use field coil for generating the electromagnetic field. Shakers are great tool to provide controlled and/or measurable vibration input into a test article, test object, or test structure.

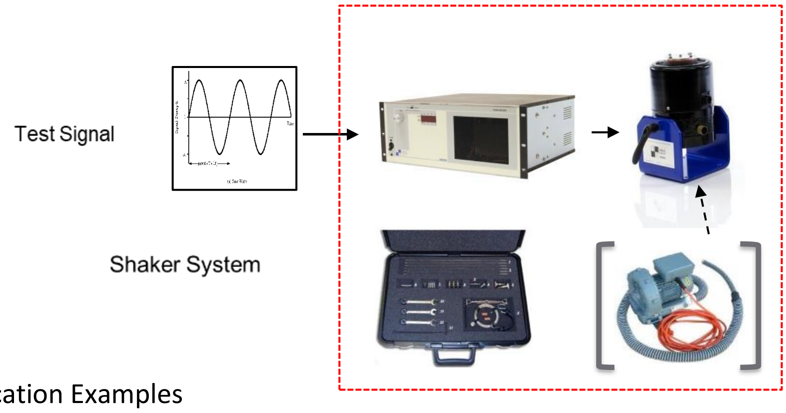


$$\vec{F} = L \cdot \vec{I} \times \vec{B}$$

Force on a current-carrying wire

Shaker Systems

The shaker is always part of a more or less complex system composed of Shaker with relative amplifier, cable, accessories, cooling. The shaker can be electrodynamic / electromagnetic, the amplifier can be linear amplifiers or switching amplifiers, the cooling can be air Cooling (cooling vacuum) or water cooling (very large shakers). Furthermore, the system includes a series of useful accessories such as cables, trunnion base, slip table, mounting accessories (inserts, etc.).



Vibration Testing Application Examples

Examples of Vibration Testing Application are not only large satellites but also CubeSat testing and generally any component level testing. These last two types of DUT are regulated by a specific standard normally followed for the execution of such tests on CubeSats: NASA GEVS (GSFC-STD-7000) which for example reports a test level up to 14.1 G rms and indicates the CubeSats to be tested in all orientations (XYZ).

Shaker Selection – Vibration Testing

The selection of a suitable shaker system always starts from Newton's 2nd Law: F = M*a

Where:

F = required force. Shaker rated force must be greater than the required test force

M = Total Mass = m1 + m2 + m3+…+ mi. These masses are: Shaker armature effective mass, SUT (specimen under test) mass, Test fixture mass

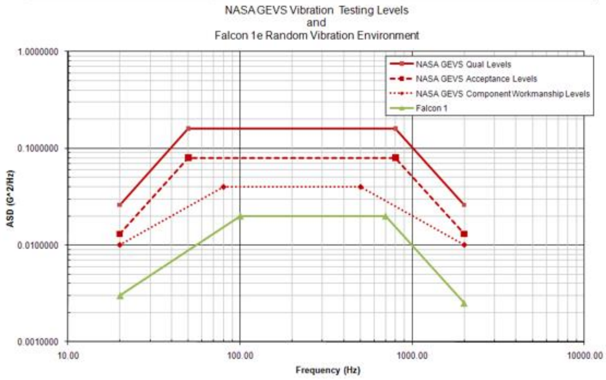
a = required test acceleration

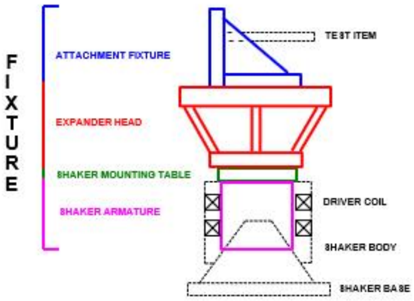
Required information to select proper shaker system:

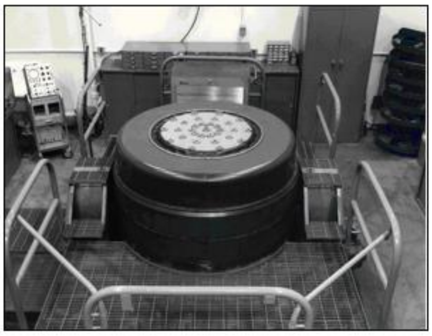
- What is the CubeSat size (size & weight)
- Frequency Range or Testing Frequencies
- Vibration mode: sine (pk), random (RMS)
- Required vibration acceleration or Test Specifications or Vibration Profile:
    - Sine testing: Max g_{pk} requirements
    - Random testing: Max g RMS, PSD profile (g^2/Hz) g_d = acc density Df = frequency bandwidth
- Required vibration displacement

Table 2.4-3
Generalized Random Vibration Test Levels
Components (ELV)
22.7-kg (50-lb) or less

Frequency (Hz)	ASD Level (g^2/Hz)	
	Qualification	Acceptance
20	0.026	0.013
20-50	+6 dB/oct	+6 dB/oct
50-800	0.16	0.08
800-2000	-6 dB/oct	-6 dB/oct
2000	0.026	0.013
Overall	14.1 G_{rms}	10.0 G_{rms}







8. Vibration Testing and Stress Screening | Model 2500E.

The Modal Shop’s Model 2500E 500 lbf vibration shaker, it is a shaker with low costs and dimensions, easy to transport when needed but above all suitable for the particular needs of CubeSats and related fixtures.

The Modal Shop’s Electrodynamic Shaker Model 2500E is a 500 lbf pk (2.2kN) sine force shaker designed for general-purpose vibration testing of small components, as well as stress screening of electronic and mechanical sub-assemblies. It is designed to re-create field vibration in a controlled laboratory setting and can be used in a variety of R&D, reliability, and quality assurance applications within the automotive, aerospace & defense, and consumer electronics sector.

Model 2500E offers a large 6 in (152 mm) diameter specimen mounting table, making it easy to adapt to almost any test requirement with a minimum of fixturing. The table provides multiple internally threaded attachment points, making the shaker assembly ideally suited for applications such as production screening, reliability acceptance testing, and product engineering evaluation. The composite materials used for the armature suspension and guidance system provide a high degree of lateral and rotational restraint while maintaining maximum compliance in the axis of motion to permit full 1.0 in (25 mm) peak to peak stroke. The shaker and trunnion base assembly allow a variety of operating positions ranging from a standard vertical orientation to a rotation of 90° to interface with horizontal tables.

Model 2500E has an inherently low stray magnetic field, which is minimized even further by the use of a built-in degauss coil. Safety features include over travel switch protection, air-cooling flow interlocks, and safe start in mute mode associated with the Model 2050E12-7 Digital Power Amplifier. Optional accessories are available such as special vibration isolation mounts, metric inserts for specimen mounting, and a magnesium head expander.

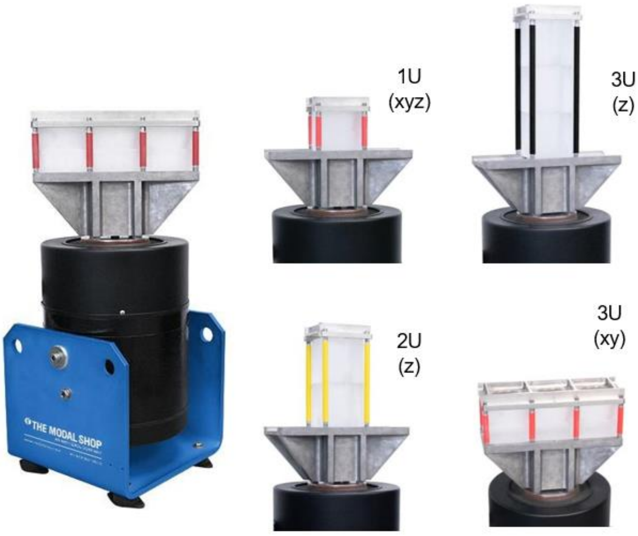
9. New shaker fixture for CubeSat

Importance of the Test Fixture

The connection between the shaker and the DUT is made through a specially designed fixture. This fixture becomes an integral part of the test system and is different depending on the specific characteristics of the DUT, i.e. the satellite or its component to be tested. The basic idea with any fixture is that it should transmit uniformly the forces produced by the vibration exciter to the test object. It is generally impossible to fix a test object directly to the shaker table itself, and the fixture acts as a transition piece between the two.

Scope of CubeSat fixture:

- Pre-Test on dummy payloads
- Securely holds CubeSat
- Allows for 3 axes (x, y, z) testing
- Minimize unwanted resonances to ensure accurate launch simulation



For such small components as CubeSats, a dedicated fixture is often not compatible for a fast and reliable installation especially on large shakers such as those used in space qualification laboratories. Therefore, a first challenge was to design a fixture suitable for the different modular dimensions of CubeSats and the following challenge to design an electrodynamic exciter capable of having small dimensions suitable for CubeSats and related fixtures.

10. CubeSat Vibration Testing with Modal-Pod™

Standardized Vibration Test Fixture | Model 2000X15

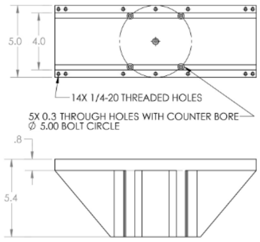
Streamline your CubeSat vibration testing with Modal-Pod™ Model 2000X15, a CubeSat test fixture which provides a broader standard mounting fixture to meet the standardized sizing of 1U, 2U, and 3U CubeSats. With the common fixture base that is built to interface directly with The Modal Shop's Model 2500E 500 lbf vibration shaker, the user can quickly mount up to 3U size satellites in horizontal or vertical configurations for critical vibration qualification and acceptance testing based on NASA or other standards to ensure survivability during launch. Installing and configuring the Modal-Pod from Model 2500E shaker is easy using included screws and tools. The simple removal also allows the shaker to easily be used for testing of sub-assemblies mounted either directly to the shaker, via Model 2000X14 head expander, or with optional slip table for additional component level vibration testing.

Highlights

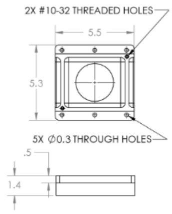
Supports the mounting of various size CubeSats (up to 3U) to the shaker in different orientations

Includes lightweight magnesium mounting fixture, dummy payloads, mounting accessories, and a heavy-duty case

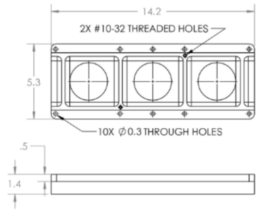
Simplifies qualification testing of CubeSats to NASA testing or other standards



Model 2000X15 - Base
Dimensions in inches



Model 2000X15 - 1U Top Plate
Dimensions in inches

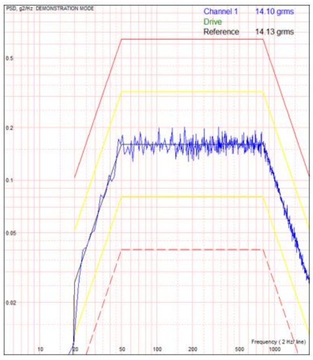


Model 2000X15 - 3U Top Plate
Dimensions in inches

Specifications		
Weight		
Base	9.25 lb	4.18 kg
1U Top Plate	0.75 lb	0.33 kg
3U Top Plate	1.94 lb	0.87 kg

11. Running the test

The aim of this experimental test was to perform the test with two different systems: the first one using a large electrodynamic exciter in a large test laboratory and another test to be performed in any environment with the shaker just introduced. Finally compare the results obtained with the two configurations. The setup could be similar, but always considering that the smaller shaker of the second case also had the fixture adapted and studied as already introduced, dedicated to CubeSats thus making the test setup phase much easier. The two tests were obviously performed with the same setup in terms of excitation mask as can be seen from the figure in accordance with the standard.



12. Testing at a Test Lab

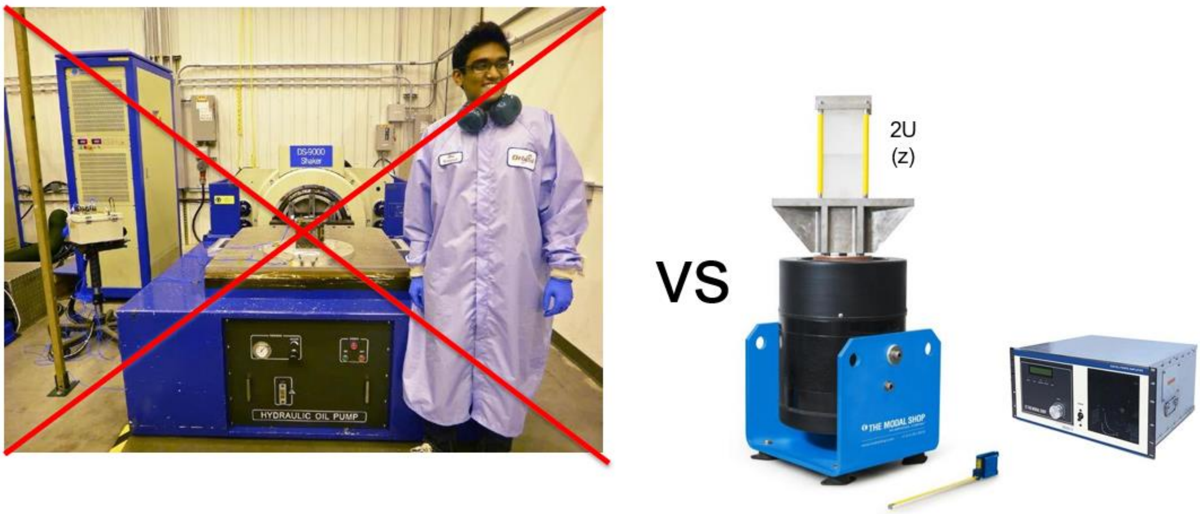
The test performed in the large environmental testing laboratory involved the use of a large shaker with a large amplifier. This system is commonly used for any small or large test article, making the tests similar in terms of cost and setup complexity between a large test article, such as a large satellite, compared to a small one such as a CubeSat. Therefore, there is no substantial difference between the two types of test articles in terms of setup complexity and test execution, and unfortunately also in terms of cost. This last factor makes it uncompetitive, although necessary, to perform these types of vibrational tests on a CubeSat.

Ref.: https://www.nasa.gov/wp-content/uploads/2017/03/nasa_csli_cubesat_101_508.pdf - page 63

Cal Poly lab uses 2000 pounds and 6000 pounds shakers

13. Testing In-house

Instead, in the second case, the shaker described above was used with the relative fixture specifically designed for testing on CubeSats with the consequent extreme flexibility of the various units (U) as can be seen from the images. In this case, bringing the test in-house can drastically reduce the costs and execution times of the test. Furthermore, the shaker size better matched to the test article and test requirements. Finally, test equipment is available at all times, whenever test needs to be repeated (ex: due to a fix, update design)



14. Conclusions.

In this article we have given an overview of the various components of a satellite test system, focusing on 2 main technological developments for CubeSat testing. These developments have concerned the excitation system, now composed of a shaker with much smaller dimensions and costs, as well as a fixture designed exactly for the various units (U) of the CubeSats, thus making it possible to carry out tests that until now were prohibitive in terms of time and costs, crucial factors in the development of a CubeSat. These developments have also grouped two new accelerometers (among many others) that will allow us to obtain very precise results for CubeSats as well as for traditional satellites, with the advantage of being able to carry out assembly even on small-sized DUTs such as CubeSats.

Author:

Carmine Salzano, Dr. Ing., holds a Mechanical Engineering degree from University of Napoli (Italy). He was a professor at University of Salerno (Italy) in the Mechanical and Aerospace Engineering Department (2003), teaching noise and vibration control. Carmine has worked for over 35 years in the market of sensors and instrumentation and over the last 20 years he has written numerous papers, presented at many international conferences and held dozens of seminars around the world every year. Presently and for 20 years, his title is International Manager at PCB Piezotronics, Inc. (U.S.A.), Aerospace & Defense and Test Sector.

References

[1] P. Avitabile, M. Peres. Shaker excitation. IMAC 27 - Orlando, FL - 2009

[2] C. Salzano, Dynamic Strain Sensors and Accelerometers for Structural Testing. Cases of Measurements on a Civil Structure and on the GVT of an F-16 Aircraft. IOMAC International Operational Modal Analysis Conference Proceedings. Napoli 2024.

[3] M+P publication: Safe vibration testing with M+P software

[4] Technical Data from www.pcb.com

[5] Technical Data from www.modalshop.com

[6] M. Maze (PCB Piezotronics), M. Peres (Modal shop) and J. Churchill (M+P). Presentation at Small Sat conference USA 2024.

[7] B. Metz (PCB Piezotronics). Optimizing 3-Component Force Sensor Installation for Satellite Force Limited Vibration Testing