DOI: 10.61782/fa.2025.0278

FORUM ACUSTICUM EURONOISE 2025

DESIGN OF VIBRATION ISOLATION SYSTEM FOR MULTIPLE NUMBER OF SPACECRAFTS TRANSPORTATION CONTAINER

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ABSTRACT

Program critical, high cost and delicate space hardware like Spacecraft built with pressurized tanks, sensitive optics, delicate electronics and hazardous chemicals need protection from various environmental (Mechanical, Climatic and Electric) hazards during transportation to launch base and also between various testing establishments. These environmental hazards include mechanical hazards such as shock, vibration and handling loads, climatic hazards such as temperature, humidity, rain, dust, differential pressure and electrical hazards like Electro Static Discharge, Electromagnetic interference(EMI), RF radiation etc. In order to offer protection to the spacecraft, multiple subsystems such as Shock & Vibration isolation system, Passive thermal control system, Gaseous nitrogen purge system, Passive Dehumidification System, Environmental control and Data Acquisition System are integrated inside the Container system.

This paper describes the detailed design of the container, its road vibration attenuation techniques for multiple number of Micro/Nano size spacecraft transportation simultaneously. Multiple number of Spacecraft accommodation in one container, avoids multiple trips of transportation for individual Spacecraft and associated expenses. The container is designed such a way to have proper envelope and dynamic clearances for multiple Spacecraft with respect to each other. The container Vibration isolation system is tuned in such a way that to avoid any dynamic coupling among Spacecrafts.

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Keywords: *mstc-multi spacecraft transportation container, wri- wire rope isolator, s/c- spacecraft, edas- environmental data acquisition system, rcp- recorder control parameters*.

1. INTRODUCTION

Spacecrafts are equipped with fragile components comprising pressurized tanks, reflectors, sensitive optics and electronics. Spacecraft is moved to launch base and also between various test establishments which include cleanroom airlocks, Thermovac lab, Anechoic Test Chamber, Vibration lab, Acoustic Test Facility and Large Space Simulation Chamber (LSSC) etc. During these movements, the spacecraft is required to be protected from various mechanical, climatic and electrical hazards. Spacecraft Transportation Container used to accomplish this requirement. These containers are designed based on Spacecraft envelope studies, compatibility checks, verification for dynamic characteristics based on mass properties of Spacecraft and its fragility, followed by test and validation of various systems of Spacecraft Transportation Container (STC) as per international standards available.

Spacecraft need protection from various environmental hazards during transportation by road and air. The physical hazards include shock, vibration and handling loads. The climatic hazards include temperature, humidity, rain, dust, differential pressure, fire, etc. Electro static discharge, Electromagnetic interference (EMI) and RF radiation are electrical hazards. These hazards lead to one or the other kind of damages like functional impairment, distortions, breakage, high stresses, condensation, corrosion, contamination and other forms of destruction.

In order to offer protection to the spacecraft, multiple subsystems such as Shock and Vibration Isolation System, Pressure Equalization and Rapid Decompression System, Passive Thermal Control System, Gaseous Nitrogen Purge System, Passive Dehumidification System, Environmental Control and Monitoring System, Handling Devices and Data Acquisition System are integrated in MSTC [Fig.1].

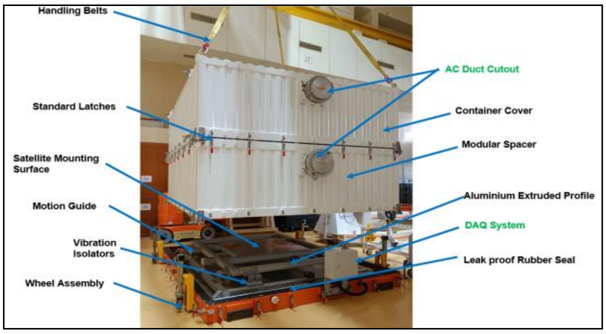

Figure 1. Typical Elements in MSTC

Appropriate grounding and all metallic construction forms the Faraday's cage to protect from electrical hazards. STC is dimensionally optimized for compatibility to accommodate itself inside commercially available cargo aircrafts and other constraints posed at assembly, integration and test (AIT) facilities.

This paper demonstrates on first of its kind Multi Spacecraft Transportation container (MSTC) and the modular approach of Vibration isolation system design. Fig.2 elaborates about putting Maximum five numbers of Micro-Satellite inside MSTC. Multiple number of Spacecraft putting in one container enable to avoid multiple trips of transportation for individual Spacecraft and associated expenses. MSTC is capable of accommodating, five numbers of Micro Satellite (Mass up-to 180 kg), two number of IMS2 bus Satellite (Mass up-to 450kg), or one number of IRS class satellite (mass up-to 900kg) for transportation. This approach of design brings modularity in number of satellite accommodation during transportation. Vibration isolation system for the MSTC shall be tuned on the basis of number or type of Satellite accommodation to achieve overall natural frequency of the system at 5-7 Hz [1].

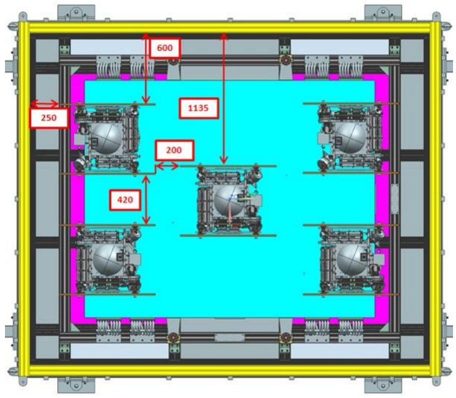

Figure 2. Multi S/c accommodation inside MSTC

2. Design of Shock & Vibration Isolation system:

The transportation of the Spacecrafts by road or air is always a challenge and requires adequate protection from shock and vibration. Metallic wire rope isolators are used for isolating the spacecraft inside MSTC from the destructive effects of Shock & Vibration [2]. These isolators behave linear for vibration inputs and nonlinear for any transient shock input events.

Table-1 Shows the properties of the helical isolators used in present work.

Table 1. Properties of Wire Rope Isolators

Parameter (Single Isolator)	Max Static Load (KN)	Max. Deflection (mm)	K_v (Vibration Stiffness, KN/m)	K_s (Shock Stiffness, KN/m)
Value	1.15	81.28	43.67	13.84

The MSTC is designed for multiple number of Satellite accommodation from one spacecraft to maximum five number of Spacecrafts. Fig.2 explains about five number of Satellite transportation configuration by using eight/twelve number of helical isolators depending on individual satellite mass, to tune natural frequency of the total suspension system at 5-7 Hz. For the requirement of only two satellite transportation the number of isolators will be eight on the basis of Satellite mass. Table.2 explains about modularity in tuning of natural frequency of the container for various isolator configuration. This method enables the modularity in accommodation for the multiple number of Satellite in the single transportation container.

Table 2. S/c modular accommodation in MSTC

Parameter	Values		
Satellite Physical parameter	05 Micro S/c-180 Kg each	02 IMS-2 Bus S/c, 270kg each	01 IRS S/c type, 900 kg
Number of Isolators	12	08	08
Tuned Natural Frequency(Hz)	5	6	6.8

MSTC system may be modelled as a single degree or two degree of freedom system depending on relative stiffness of the Satellite and Isolators. Present system is majorly designed for Small Satellites with high bending stiffness compare to suspension frame stiffness, therefore MSTC is modelled as a single degree of freedom system.

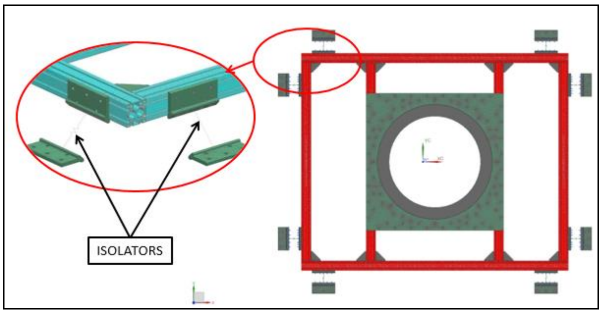

Figure 3. FEM Simulation for Suspension Frame

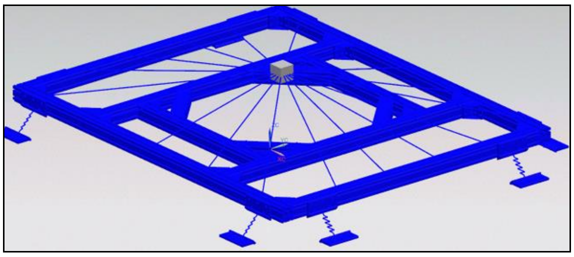

Figure 4. SDOF simulation of MSTC system

The concept of vibration isolation in MSTC may be modelled as shown in Figure 3 & 4 as a single degree of freedom system with linear spring element and damping parameter of the isolators. The Satellite is constrained to move only in vertical direction by using linear motion guide, and so from the basic dynamics of the system, the equation of motion is given by:

$$M\ddot{x} + C\,(\dot{x} - \dot{y}) + k(x - y) = 0$$

$$M\ddot{x} + C\,\dot{x} + kx = F(t)$$

$$Where, F(t) = C\dot{y} + ky$$

$$Tr = \frac{\sqrt{1 + \left(2\varepsilon\,\frac{\omega}{\omega_n}\right)^2}}{\sqrt{\left(1 - \left(\frac{\omega}{\omega_n}\right)^2\right)^2 + \left(2\varepsilon\,\frac{\omega}{\omega_n}\right)^2}}$$

The ratio of force transmitted to the satellite to excitation force is derived by T_r.

Wire rope Isolators usually possess nonlinear behavior. In the isolation of vibration displacement amplitude is small so behavior is more linear, whereas in the isolation of shock, nonlinearity tends to be more important because of large deflections as shown in isolator deflection curve Figure 5.

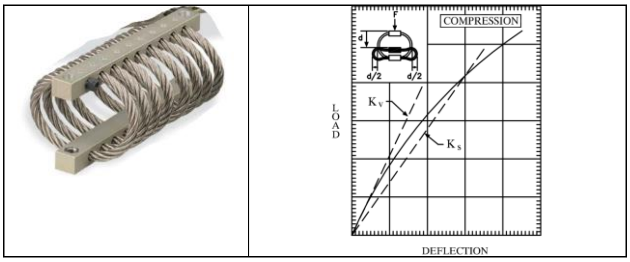

Figure 5. Wire Rope Helical Isolator

In such cases, an isolator that is relatively stiff at small deflections, but gets softer at higher deflections is more beneficial [2]. This allows the isolator to store more energy in the same amount of deflection, as compared to linear isolator. The WRI is a type of passive isolator, consists of standard wire rope held between two metal retainer bars and the metal wire rope is made up of individual wire strands that are in frictional contact with each other, hence, it is a friction type of isolator. The application of vibration isolation system requires an understanding of the vibration control components, namely Source, Path and receiver of the vibration. Since the shock and vibration so often occur together, an isolator must have two seemingly incompatible properties to counteract forces effectively.

3. Data acquisition for Vibration Isolation performance verification.

Shock and vibration input levels to the satellite is a function of road conditions, speed, suspension system of vehicle, sprung and un-sprung mass of vehicle, suspension system of MSTC & S/C physical properties. Environmental Data Acquisition System (EDAS) is useful for the validation of suspension systems for various loads and road conditions. EDAS is a multi-channel digital waveform recording system [3]. It has inbuilt tri axial accelerometer sensor, temperature humidity sensors to measure shock, vibration, temperature and humidity condition that occurs during the transportation. DAQ and Various mounting location of external accelerometer is shown in Fig.6. EDAS uses piezo-resistive accelerometers, which offers superior low frequency response to record transportation vibration accurately. Trigger based mode operation is selected for acquiring maximum severe events. RCP (Recorder Control Parameters) defines the editable control parameters like sampling rate, trigger level, no. of samples per window, pre-trigger & post trigger samples and memory modes.

The test results obtained from EDAS are used for tuning the isolator stiffness of the MSTC. The suspension system supporting satellite consists of Aluminium extruded profiles having high stiffness to mass ratio, which enables suspension system own natural frequency high to avoid coupling with Satellite own fundamental frequencies. During transportation all the elements are rigidized through fasteners for appropriate torque value to establish the system integrity and performance of system under dynamic load conditions. Isolation performance verification is carried out by monitoring acceleration levels along with associated frequency data at various locations on the suspension system.

4. Experimental validation for Vibration Isolation: Fig.6 elaborates about the test setup for MSTC isolation performance. Four number of DAQ units having tri-axial data acquisition capability is used to acquire shock and vibration events during entire test.

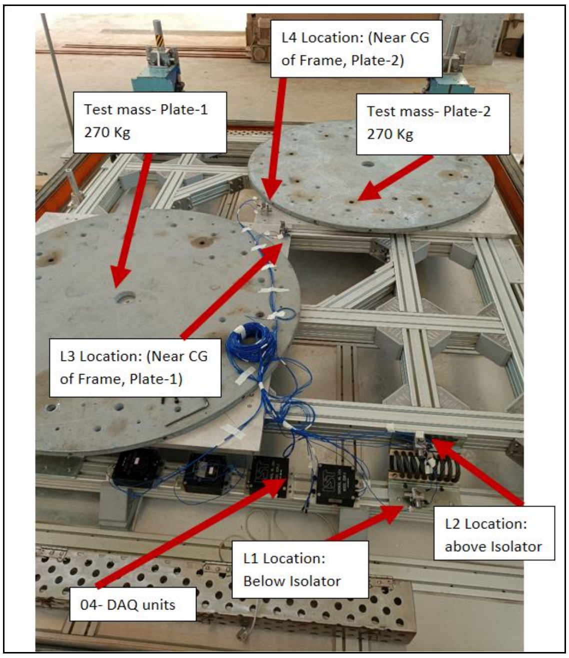

Figure 6. MSTC Isolator Experimental Details

Four locations are selected (L_1- L_4) to mount external accelerometer in tri-axial configuration and connected with DAQ using wires. Location L_1 represents base excitation before isolator, location L_2, L_3, L_4 corresponds to accelerometer location after isolator, near base of S/c (test mass). Programming of the DAQ is made as per **Table.3**, which provides parameters and its values used on the recorder to measure vibration levels in the various sections of distributed environment.

Table 3. EDAS RCP Information

Amplitude Trigger Threshold(g)	0.2
Sampling Rate (Samples/second)	1024
Pre-Trigger Samples	512
Post Trigger Samples	1536
Sample Size (Sample per Window)	2048
Recording Window (Second)	2

Experimental validation is proposed for two S/c configuration. Equivalent test mass of 270kg is mounted and hard fastened symmetrically on the suspension frame. This mass is selected for simulating IMS2 bus satellite mass.

MSTC after mounting the simulated test mass and programming of EDAS is put on low bed trailer and fastened at various locations using lashing belts to avoid any relative motion between container and trailer during movement. Dynamic loads on the MSTC is simulated by running the Trailer on the road for various rough patches and sudden brake conditions.

Entire shock and vibration data is processed and presented in terms of SRS plot for all three directions, as shown in Fig.7. Anti-aliasing filter is applied to acceleration signal X(t) before it is sampled so that the frequency components above the Nyquist frequency are removed from the measurement. The signal then is sampled to discrete sample for the selected sampling frequency. Discrete signal is then multiplied with window function w(t) to remove leakage and followed by FFT operation. Shock response spectrum (SRS) is then derived for entire events till 100Hz frequency band. Fig.7 explains about SRS response comparison, before isolator and after isolator for all three direction of MSTC- Travel, Lateral and Normal to road ground.

Suspension system along test mass natural frequency is observed to be 6.8 Hz, with reference to catalogue calculated value of 6Hz (Table.2). It is observed from the plot that after natural frequency of the suspension system a good isolation is observed for entire frequency band of dynamic disturbance, hence prove for an effective isolation in MSTC.

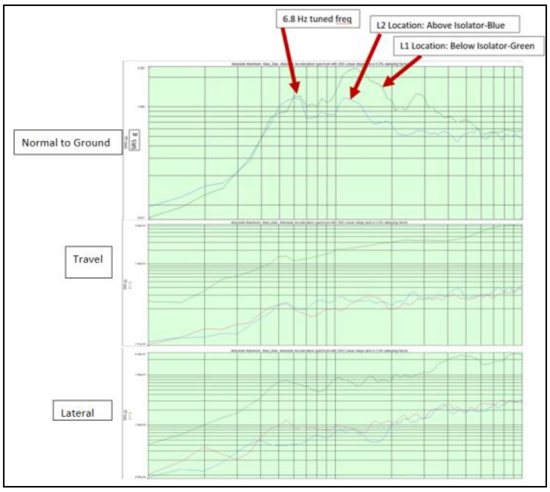

Figure 7. SRS Plot for all three Directions

5. CONCLUSION

Spacecrafts need protection from various environmental hazards during transportation by road and air. This paper described the detailed design of the container, its road vibration attenuation techniques for multiple number of Micro/Nano size spacecraft transportation simultaneously. Multiple number of Spacecraft accommodation in one container, avoids multiple trips of transportation for individual Spacecraft and associated expenses. Helical isolators used for the container suspension for single or multi Spacecraft configuration demonstrates a good isolation performance. Two numbers of IMS2 bus Spacecrafts are transported successfully using newly designed MSTC system as shown in Fig.8.

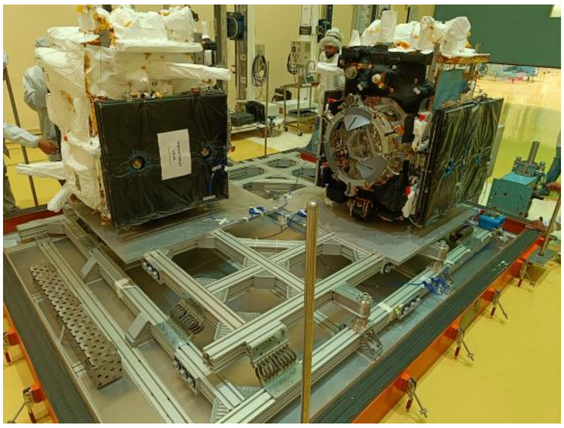

Figure 8. Two number IMS2 S/c transportation

6. REFERENCES:

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