Impact Factor (SJIF): 5.301

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444

Volume 6, Issue7, July 2019

Structural Dynamic Loading Simulation and Testing for Space Payload System

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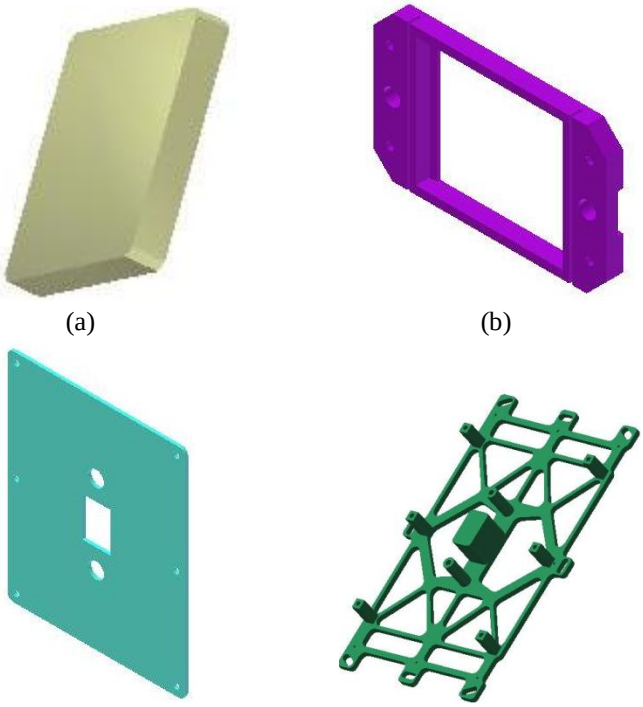
Abstract: *Detector Head Assembly (DHA) is a one of the most important assembly of the optical space payload. It consists of functional components namely detector, detector mount, PCB and DHA frame. Satisfactory functional performance of DHA under space dynamic loading environment can be ensured by structural dynamic simulation & testing. In this paper, DHA is characterized with dynamic simulation & testing. Random vibration of space environment levels are simulated & verified with the responses obtained at critical locations during vibration testing. We obtained natural frequencies and PSD response of DHA structure under the given dynamic loads using ANSYS software package. PSD responses of DHA along the normal (z axis) and parallel (x & y axis) to the mounting plane are prediction in simulation and in testing, responses are actually measured along normal to mounting plane at critical locations. The simulation results are correlated with the random vibration testing aspect.*

Keywords: *Detector Head Assembly, Detector, Detector Mount, PCB, DHA frame, PSD response, Natural frequency.*

I. INTRODUCTION

The detector along with its processing electronics, mechanical mounting and thermal control system is known as Detector Head Assembly (DHA) of an imaging system. DHA consists the detector, detector mount, PCB and DHA frame which are shown in figure1.



(a) (b) (c) (d)

Figure1. (a) Detector (b) Detector Mount (c) PCB (d) DHA Frame

Detector is an important part of the DHA and it may be an infrared based detector. DHA frame provide structural integrity and thermal balance. The detector mount is used to hold the detector. The PCB (Printed Circuit Board) is electronic circuit for operation of detector. Assembly of the components that is Detector Head Assembly (DHA) is shown in figure2.

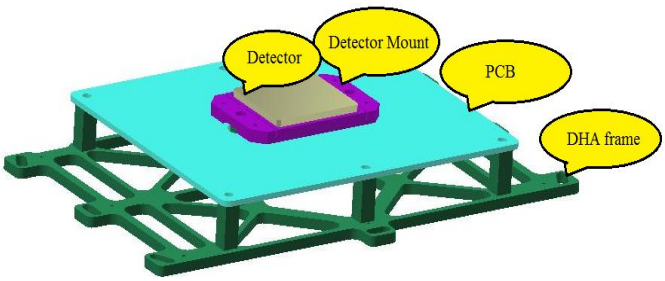


Figure2. Assembly of Components-DHA

DHA is an important part of the imaging system, performance of DHA has major impact on the quality parameters of the imaging system. The detector is placed at focal plane of the imaging system thus, it receive useful electromagnetic (light) signals and transforms it in an electronic charge & finally in digital format which is read by the detector electronics. Optics captures the signals in the form of light coming from planet surface.

Detector is mounted on a specially designed mount made up of kovar material. As kovar has matching co-efficient of thermal expansion with alumina, it will minimize the thermal stresses caused by the temperature gradient. Detector with mount is directly fastened to the DHA frame at two lugs through mount. The power is controlled and

supplied to the detector by PCB card. The detector is connected to the PCB card by the kovar pins. The PCB card is then mounted on the DHA frame at six points. The frame acts as heat sink to remove heat from highly heat dissipating electronic components.

Boundary Condition:

Fixed support condition: The DHA frame is integrated the detector and PCB. The 32 faces of DHA frame are fixed supported which is illustrated in figure 3.

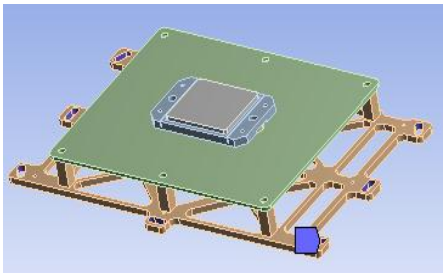


Figure3. Fixed Support Condition

Material Selection:

The material properties of DHA components are illustrated in table 1.

Table1. Material Properties

Components	DHA Frame	Detector Mount	PCB	Detector
Material	Al 6061 T6	kovar	FR4	alumina
Density in kg/m^3	2770	7850	1900	3960
Coefficient of expansion in $^{\circ}C^{-1}$	2.3E-5	5.8E-6	20E-6	5.6E-6
Modulus of elasticity in pa	7.1E10	2E11	15E10	37E10
Poison ratio	0.33	0.3	0.42	0.22
Yield Strength in Pa	2.8E08	2.5E08	2.5E07	2.8E08
Ultimate Strength in Pa	3.1E08	4.6E08	3.3E08	3.1E08

II. SIMULATION

(A) Modal Analysis

Modal analysis is a process whereby we describe a structure in terms of its natural characteristics which are the frequency, damping and mode shape- it's dynamic properties. Modal analysis refers to measuring and predicting the mode shapes and frequencies of a structure.

Frequency:

If a structure, after an initial disturbance is left to vibrate on its own, the frequency with which is oscillated without external force if known as its natural frequency.

The frequencies of DHA structure at different modes are illustrates in table 2.

Table2. Frequency Simulated Results at Mode

Mode	**Frequency(Hz)**
1	699.62
2	880.15
3	1010.9

Mode Shapes:

Structures vibrate in special shapes called mode shapes when excited at their resonant frequencies. Under normal operating conditions, the structure will vibrate in a complex combination of all the mode shapes. Deformation pattern of structure at the resonant frequency, these deformation patterns are referred as the mode shapes of structure. The modal analysis of DHA structure gives the different mode shapes at the resonant frequencies under the given boundary condition, which are illustrated at figure 4.

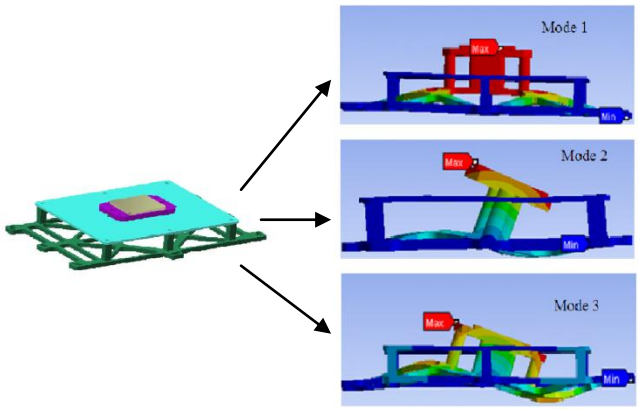


Figure4. Mode Shapes of DHA

(B) Random Vibration Analysis

Any motion that repeats itself after an interval of time is called vibration or oscillation. If a structure, after an initial disturbance, is left to vibrate on its own, the ensuring vibration is known as free vibration while system is subjected to an external force, the resulting vibration known as force vibration. Some case the excitation is nondeterministic or random; the value of the excitation at a given time cannot be predicted and resulting vibration is called random vibration.

Random vibration analysis is performed on the DHA for prediction of PSD (Power Spectral Density) response using mathematical models known as Finite Element Models. After defining the model and boundary conditions, the FEM software package computes the DHA structure's PSD response. PSD is the frequency response of a random or periodic signal that indicates the amplification of input dynamic loads.

Input Specifications:

A random response analysis is performed on the DHA structure for the dynamic loads for normal to mounting plane (z axis) and parallel to mounting plane (x & y axis) mentioned in analysis specifications which illustrated in table 3 and figure 5.

Table3. Input Specifications in Tabular form

Frequency(Hz)	PSD Acceleration (g^2/Hz)
	Qualification Level
10	0.00885
100	0.044
700	0.044
2000	0.0155

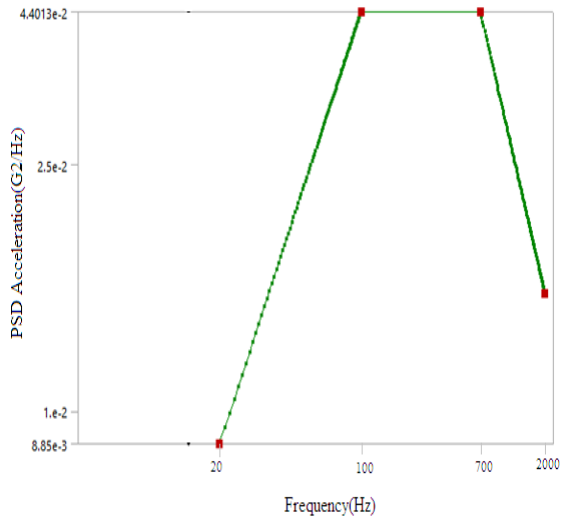


Figure5. Input Specification in Graphical form

PSD Response:

There are two points on DHA where the PSD response was carried out one on detector and second on detector mount along x, y and z axis.

(1) PSD Response on Detector

Point on detector where PSD response is carried out which illustrated in figure 6.

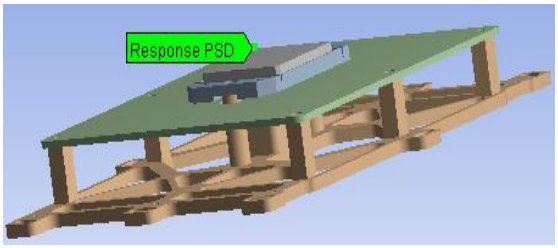


Figure6. Point on Detector

(a) Z-Axis (Normal to Mounting Plane):

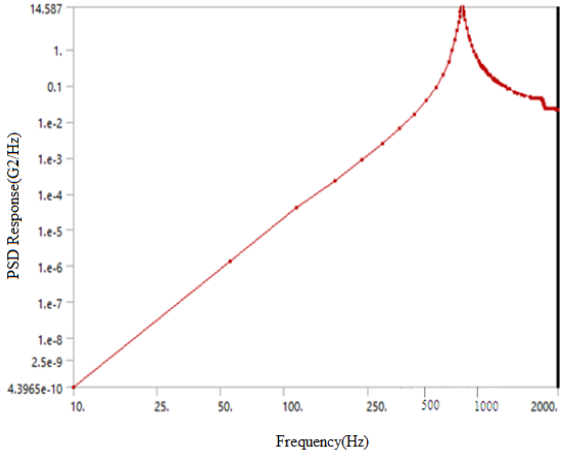


Figure7. PSD Response on Detector in Z-Axis

PSD response on detector in z axis is 14.587g^2/Hz and overall rms value is 31.154g.

(b) X-Axis (Parallel to Mounting Plane):

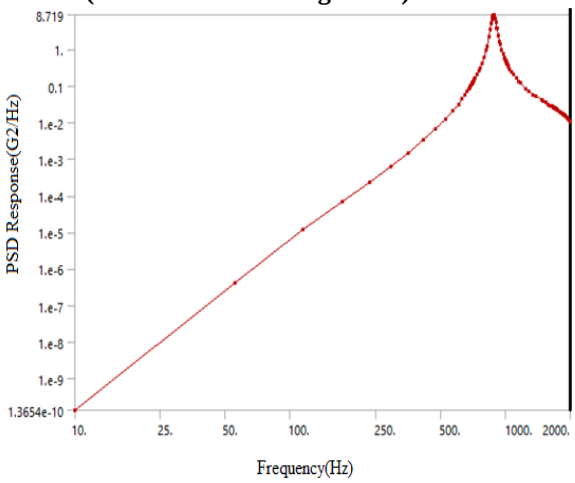


Figure8. PSD Response on Detector in X-Axis

PSD response on detector in x axis is 8.719g^2/Hz and overall rms value is 26.901g.

(c) Y-Axis (Parallel to Mounting Plane):

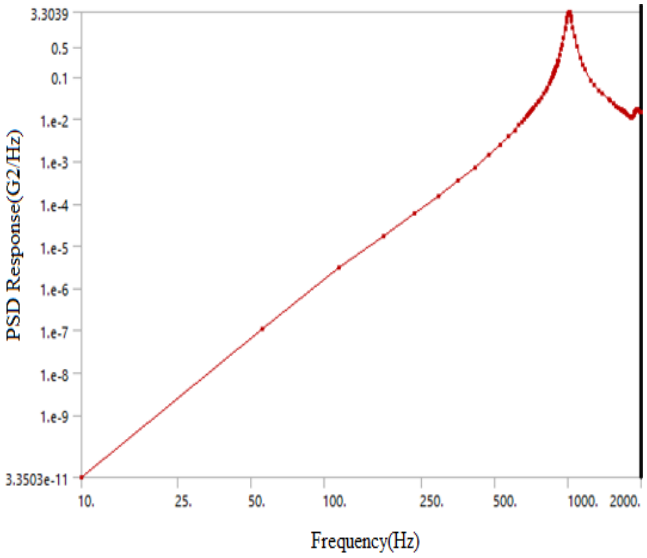


Figure9. PSD Response on Detector in Y-Axis

PSD response on detector in y axis is 3.3039g^2/Hz and overall rms value is 17.754g.

(2) PSD Response on Detector Mount

Point on detector mount where PSD response is carried out which illustrated in figure 10.

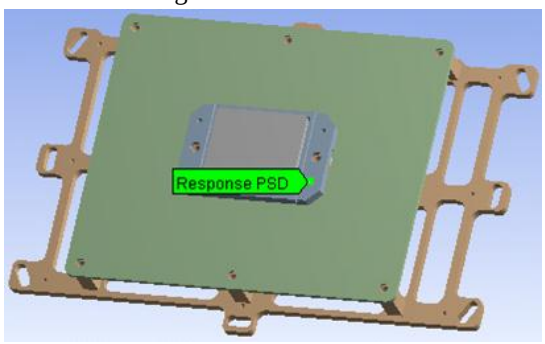


Figure10. Point on Detector Mount

(a) Z-Axis (Normal to Mounting Plane):

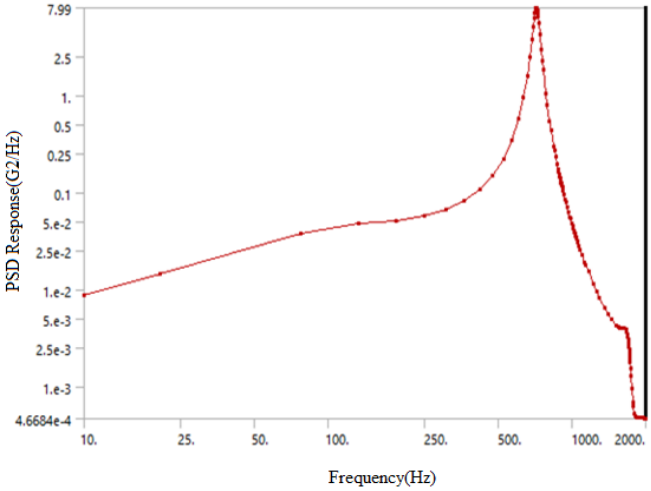


Figure11. PSD Response on Detector Mount in Z-Axis

PSD response on detector mount in z axis is 7.99g^2/Hz and overall rms value is 26.5214g.

(b) X-Axis (Parallel to Mounting Plane):

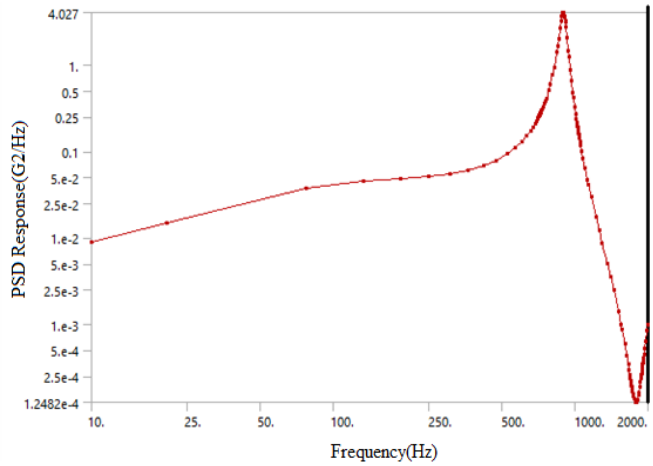


Figure12. PSD Response on Detector Mount in X-Axis

PSD response on detector mount in x axis is 4.027g^2/Hz and overall rms value is 21.647g.

(c) Y-Axis (Parallel to Mounting Plane):

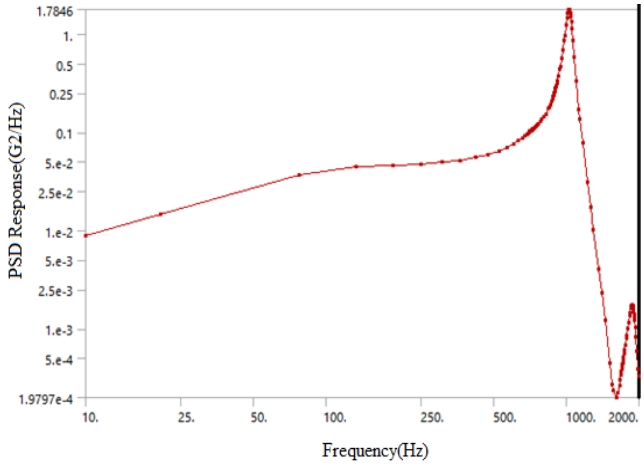
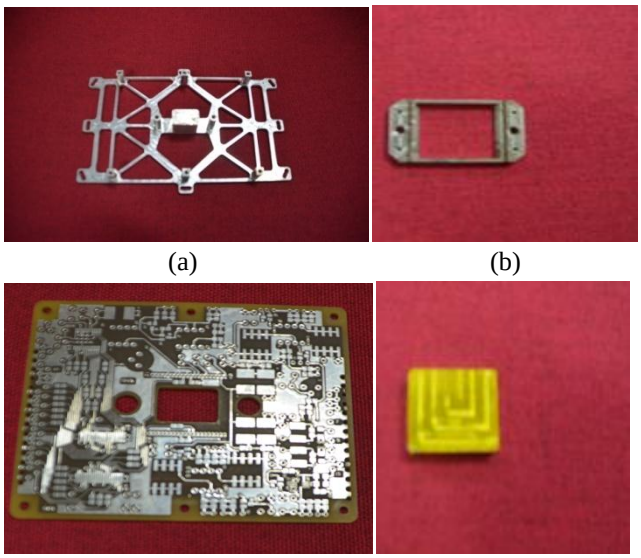


Figure13. PSD Response on Detector Mount in Y-Axis

PSD response on detector mount in y axis is 1.7846g^2/Hz and overall rms value is 16.256g.

III. REALIZATION & TESTING

Realization of DHA components are illustrated in figure 14.



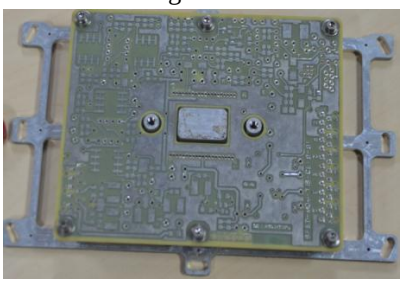
(a) (b)

(c) (d)

Figure14. (a)DHA Frame (b) Detector Mount (c) PCB (d) Detector

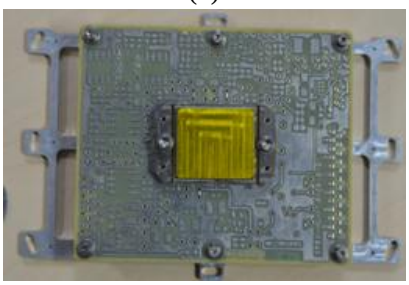
Assembly of Components

It is required to maintain proper assembly sequence for DHA which illustrated in figure 15.



(a)

(b)



(c)

Figure15. Assembly of Components-DHA (a) PCB Fixed on DHA Frame (b) Detector Mount Fixed (c) Detector Glued on Detector Mount

Testing Setup

Block diagram of vibration testing setup illustrated in figure 16.

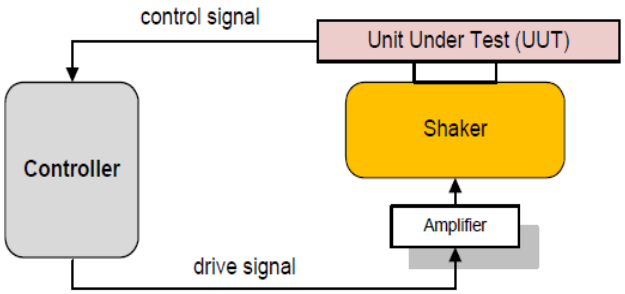


Figure16. Basic Vibration Testing Setup

Vibration testing is accomplished by introducing a forcing function into a structure, usually with some type of shaker. UUT (Unit Under Test) is attached to the table of shaker. Vibration testing is performed to examine the response of a UUT to a defined vibration environment. Vibration control system is a computer system that can conduct close-loop control for vibration shaker system. It generates an electronic signal that drives the amplifier which then provides the drive signal to either a hydraulic or electro-dynamic (ED) shaker, or an acoustic driver. The response on the UUT is fed back to the VCS (Vibration Control System) as a feedback control signal. The response is usually measured with one or more accelerometer.

Vibration shaker tables are capable of performing many different tests that specify sine, random, shock, sine-on-random, random-on-random etc.. According to capacity there are number of shaker table are available like 8T (tone), 4T, 2T etc. In testing work we used 4T shaker table which is illustrated figure 17.

Figure17. 4T Shaker Table

In addition to acting as a mounting interface between the shaker and the product to be tested, a vibration fixture needs to be rigid and light weight. The vibration fixture should be also transmitting a uniform distribution of energy from the armature to the test item. Specialized vibration fixture designs permit the fixture to be rotated for testing in the x, y and z axis. It is common to find the weight of a fixture to be two or three times heavier than the products to be tested. Interface plate as fixture used in random vibration testing of DHA which is illustrated in figure 18.

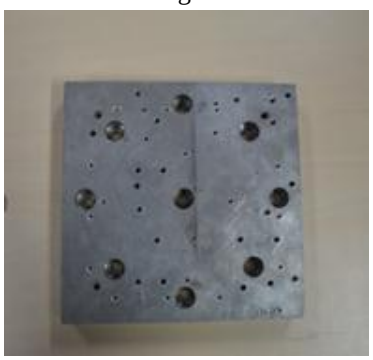


Figure18. Interface Plate

Here PSD responses of DHA structure are measured along the normal to the mounting plane direction (z axis) because it is critical and out plane axis. Also the simulation results indicate that the random response of structure is higher in normal direction rather than parallel to the mounting plane direction. So perform testing only z axis for validate simulation results.

Proper assemble DHA and interface on armature of shaker is illustrated in figure 19.

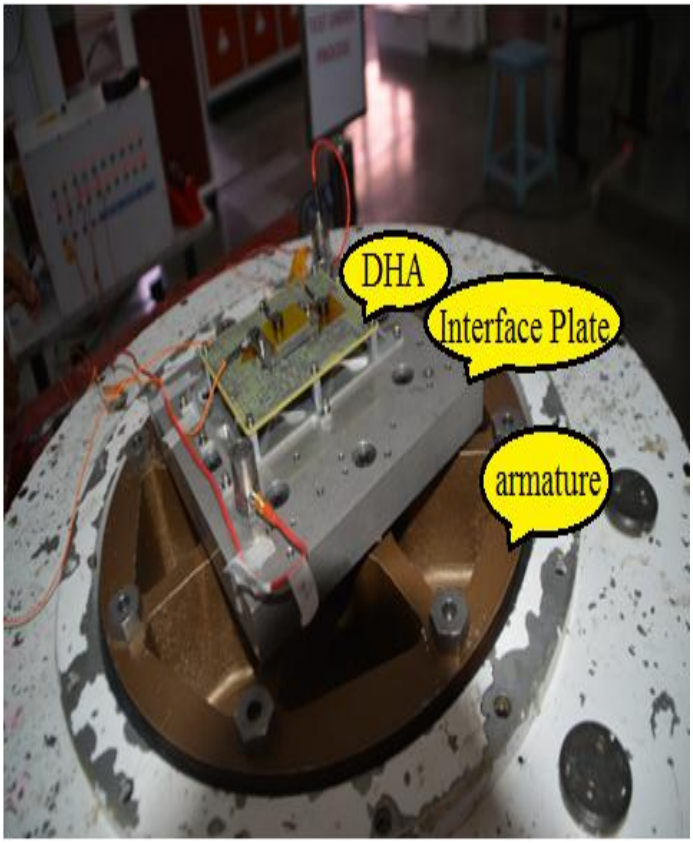


Figure19. Assemble DHA and Interface Plate on Armature

Figure20. Testing Under Process

Output Results

Natural frequencies and PSD response of DHA structure are carried out according to input specifications

(a) Natural Frequency

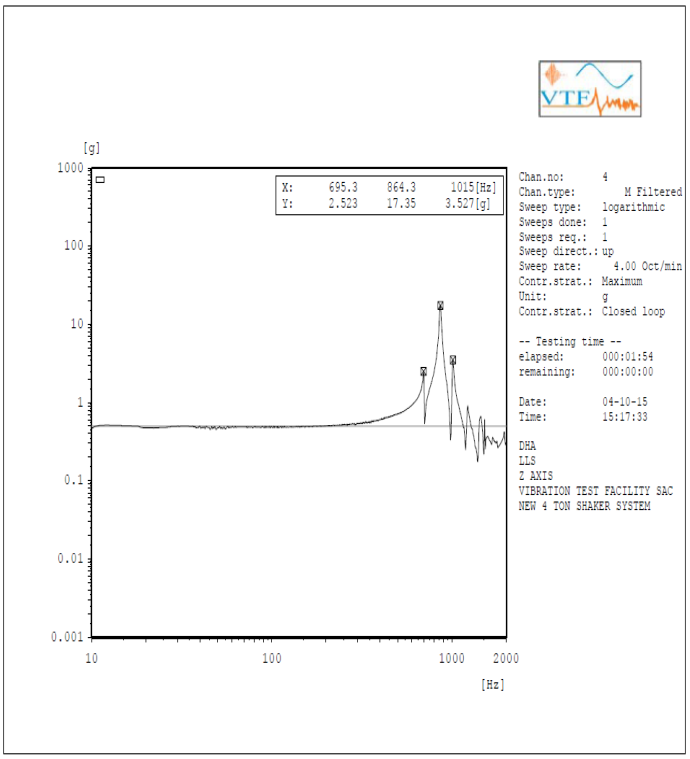


Figure21. Natural Frequencies Results

(b) PSD Response

PSD response carried out in z direction based on input dynamic loads on detector and detector mount of DHA.

(1) PSD Response on Detector

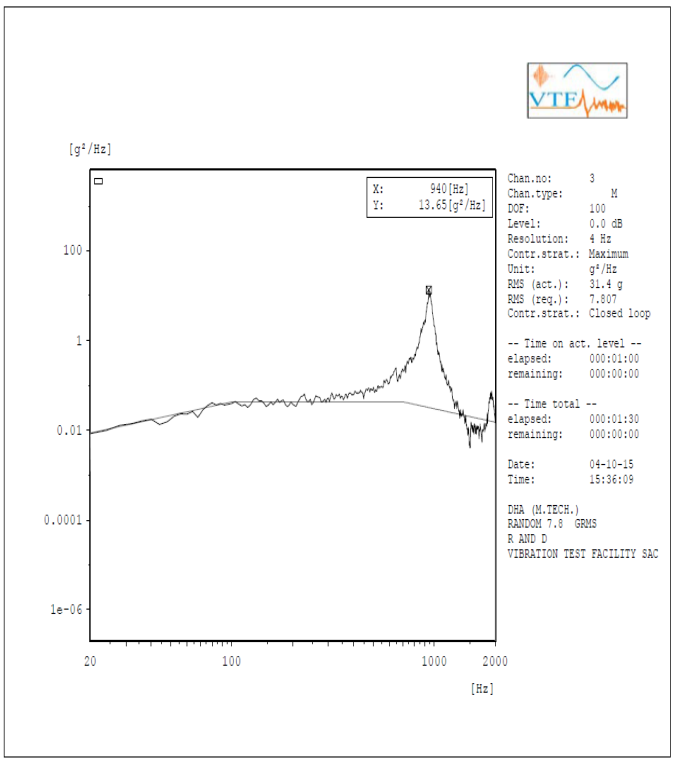


Figure22. Response on Detector

Acceleration response on detector is 13.65g^2/Hz and overall rms value is 31.4g

(2) PSD Response on Detector Mount

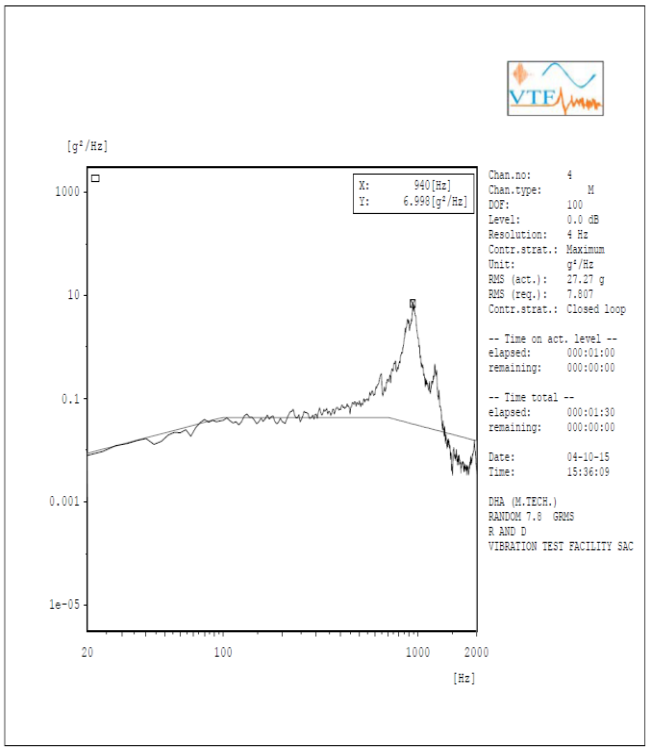


Figure23. Response on Detector Mount

Acceleration response on detector mount is 6.998g^2/Hz and overall rms value is 27.27g.

IV. RESULTS & DISCUSSION

Structural validation and characterization of DHA is done by the structural dynamic loading simulation and dynamic testing. The natural frequencies and random PSD response of the DHA structure carried out by both analysis and experimental aspect.

The natural frequencies results of DHA are illustrated in table 4.

Table4. Comparison of Natural Frequencies Results

Natural Frequencies(Hz)	
Analysis Results	**Experiment Results**
699.62	695.3
880.15	864.3
1010.9	1015

In strucsture dynamic loading simulation, the PSD response of DHA carried out in x, y and z axis. The random vibration response simulation results are illustrated in table 5.

Table5. Simulation Results of Random Response

		Analysis Results		
		X Axis	**Y Axis**	**Z Axis**
PSD Response on Detector	Response in g^2/Hz	8.719	3.309	14.587
	Overall rms in g	26.901	17.754	31.154
PSD Response on Detector Mount	Response in g^2/Hz	4.027	1.7846	7.99
	Overall rms in g	21.647	16.256	26.521

In dynamic testing, the PSD response of DHA carried out in z axis only. The comparison of the simulation and testing results of PSD response in z axis illustrated in table 6.

Table6. Comparison of PSD Response in Z-Axis

		Analysis Result	**Experiment Result**
PSD Response on Detector	Response in g^2/Hz	14.587	13.65
	Overall rms in g	31.154	31.4
PSD Response on Detector Mount	Response in g^2/Hz	7.99	6.998
	Overall rms in g	26.5214	27.27

The above comparison results indicate that the analysis results of natural frequencies and random response of the DHA structure are found to be in closely agreement with experiment work results.

V. CONCLUSION

Structurally validation of DHA carried out by the structural dynamic simulation and dynamic testing under the dynamic loads. Work-men ship and structurally integrity of DHA observe by the random vibration simulation and testing. Modal analysis of DHA gives the natural frequencies and mode shapes of DHA. Natural frequencies of DHA found by analysis are closely agreement to experiment work. Natural frequencies of DHA are 695.3Hz, 864.3Hz and 1015Hz at mode 1, 2 and 3 respectively. Higher frequencies of structure indicate structure becomes a stiff.

PSD response on detector and detector mount are gives the amplification of input dynamic loads in x, y and z axis and also found the overall rms values. The random response

testing carried out only in z axis because it is critical & out plane axis for validation of simulation results.

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