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Design, Analysis and Testing of Multi-axis Vibration Fixture for Electronic Devices

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Abstract

Objectives: Any device required to operate under vibration environment has to be tested for the same. The mounting pattern of vibration shaker is fixed. Hence a fixture as adaptor is needed for mounting the Device Under Test (DUT). **Method/Analysis:** These fixtures are to be stiff (natural frequency > highest frequency of test spectrum) to avoid fixture resonance leading to amplification of loads. In the present study, two fixtures – 1) with single mount 3 orientation capability and 2) capable of for 3 axes simultaneous loading were designed, analysed (using ANSYS16) and developed with the aim of reducing time in a single test and effort during testing. **Findings:** The fixtures were tested by regular vibration shaker as well as a hand held analyser. The analysis and testing yielded good correlation for the natural frequency estimate (< 15% deviation).Using fixture-1, 4 units with 3 orientations can be tested simultaneously and each of the devices can be tested for the remaining orientations during the subsequent tests. With fixture-2 one can test the device for all 3 axes loading in a single test thus reducing the testing time when accounted across a number of devices. **Applications:** As most of the time and effort during vibration testing goes in change of orientation and arrangement of slip-table (assembly and dis-assembly of the fixture-DUT) the fixtures designed can go a long way in minimising the time and manual labour when accounted across many units.

Keywords: Frequency Response Function (FRF), GRMS, Modal Testing, Random Vibration, Vibration Fixture

1. Introduction

The interface plate or the fixture actually transmits the energy from the shaker to the DUT and is needed as an interface for the mounting-hole patterns of DUT and shaker head. The DUT is an airborne (military electronics) device Figure 1 to be tested for a random vibration spectrum.

The device has to be tested for frequencies ranging from 15 Hz to 2000 Hz. Thus the interface structure should have the first fundamental frequency more than 2000 Hz to avoid amplifications due to resonance[1]. Also in any vibration test the DUT is subjected to vibration in all 3 axes sequentially. This results in substantial amount of time in mounting and demounting the DUT for each orientation on the shaker and/or slip table. In this study two fixtures were to be designed for two different devices with the aim of reducing the time and effort of repetitive mounting and demounting. Fixture 1 is aimed at testing multiple DUTs of the same kind in more than one direction (3 axes) at the same time. Fixture 2 is aimed at exciting single DUT simultaneously in all 3 axes. Thus in both cases repetitive assembly and dis-assembly of DUT from the fixture is avoided thereby saving time and effort.

2. Design

Any electronic unit which is to be operated under vibration environment need to be qualified for vibration levels that the unit will undergo during its service life. In the present study the device is to be subjected to a random vibration specification of the 0.04 g^2/Hz starting from 15Hz to 1000 Hz and then the Powers Spectral Density (PSD) falling down by a slope -6 dB/Octave up to 2000 Hz

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as shown in Figure 2. The graph shown is plotted in log-log scale. The estimation of the G_{rms} value of the random vibration is important to decide the amount of payload/weight that the given shaker can support. In practice a given vibration shaker has only a limited capacity/rating of load that it can support. So the total mass including DUT, fixture and armature of the shaker should never exceed the rated capacity of the vibration shaker.

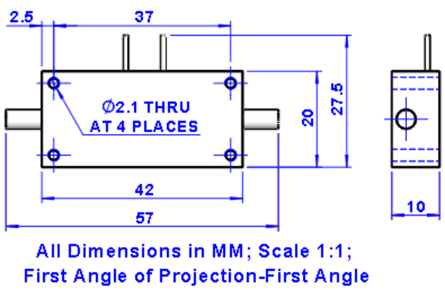


Figure 1. Dimensions of the Device under Test (DUT)

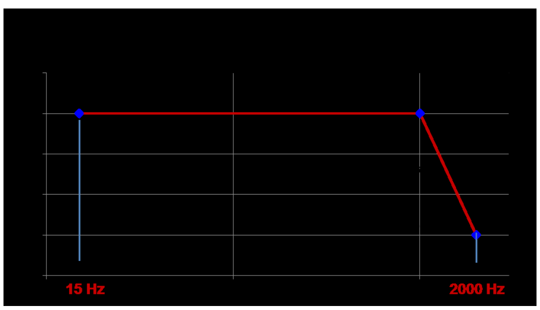


Figure 2. Random Vibration Specification

2.1 G_{rms} of Random Vibration Spectrum

The G_{rms} value can be calculated based on the equation given[2].

ln(P) = m*ln(f) + C; P=PSD, f=Frequency, C = Y intercept; for the curve shown in Figure 3.

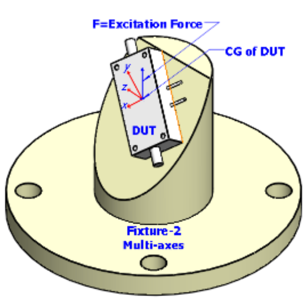


Figure 3. Fixture-2 (simultaneous 3 axes loading)

Thus the actual equation becomes, $P = Cf^m$; and

G_{rms} = sqrt (A); A = Area under the curve

Area under the curve can be calculated as follows,

$$A = A_1 + A_2 = \int_{f1}^{f2} C_1 f^{m1} df + \int_{f2}^{f3} C_2 f^{m2} df$$

$$C_1 = \frac{P_1}{f_1^{m1}};\ C_2 = \frac{P_2}{f_2^{m2}};$$

In the present study, $P_1=P_2=0.04\ g^2/Hz$ and $f_1=15Hz$; $f_2= 1000$ Hz; $f_3=2000$ Hz. Here m1=0 (horizontal line) and m2 = -6dB/Octave. One Octave refers to doubling of the frequency and 1 dB = $10\log_{10}(P_{out}/P_{in})$. Hence the slopes can be read from the Table 1.

Table 1. Slope of the PSD curve

Slope	P_o/P_i	ΔY	ΔX	Slope	
			Octave	m=tanθ	θ
0dB	2^0	0	2	0	0
3dB	2^1	2	2	1	45
6dB	2^2	4	2	2	63.4
9dB	2^3	8	2	4	76.0

From the above, $A_1 = 39.4\ g^2$; $A_2 = 20\ g^2$; $A = 59.4\ g^2$.

Thus Grms = sqrt(A) = 7.7g

2.2 Maximum Permissible Fixture Weight

The mass of the device is 100gms. The shaker which is going to be used for the testing of the DUT is rated for 450kgf capacity for random vibration. Table 2 indicates the weight budgeting and the safe operation of the shaker and the following equation in other terms estimates the maximum value of the mass of the fixture.

Table 2. Maximum fixture weight calculation

Components		Weight
Armature Weight	Ma	8 Kg
Expander Weight	Me	15Kg
Text Unit Weight	Mu	0.1Kg
Vibration Fixture Weight	Mf	0.75Kg
Total Weight	M=Ma+Me+mu+Mf	23.85Kg
Grms of the Vibration Profile	G	7.7 g
Net Weight	W=M*G	183.645 Kgf
Maximum Capacity of Shaker	Ws	450 Kgf

Requirement	W<WS	Requirement Satisfied

$$\frac{Ws}{Ma + Me + Mu + Mf} \geq GRMS$$

The equation gives the maximum allowable fixture weight to be 35.3kg. As the DUT has considerably small dimensions and weight one could have a huge margin for weight of the fixture. But for larger and heavier devices the vibration fixture design within the weight limitation of the shaker capacity will be even more challenging.

2.3 Fixture 1

The first fixture (Fixture-1) is designed with an aim of testing 4 devices at the same time in 3 different orientations Figure 4. Here a fixture with 4 mounting points (M10 screws) to the shaker with a perpendicular plate for DUT in the orthogonal direction is designed. The fixture is designed with provision to mount the DUTs both in the horizontal and the vertical plane, with 2 orientations in the vertical plane (X and Y). Thus the fixture can be used to test 4 DUTs in any of the 3 orientations. The fixture was designed using aluminium alloy 6061 T6 to keep the mass (750 g) as minimum as possible with the natural frequency more than 2000 Hz[3]. Fixtures with similar plate dimensions and varying support structures were designed and the best out of the lot, the one which fulfilled the above specifications was chosen[4]. Table 3 lists the design, mass, natural frequency (ANSYS modal analysis results), fundamental mode shape along with advantages and disadvantages of each of the design. Case 5 with two opposite side supports/ribs was chosen because it provided the maximum advantage. That is 4 DUTs could be fixed and tested for the given vibration specifications for 3 different (orthogonal) axes at the same time. In this design however the aspect to be noted is that even though the fixture facilitates testing of 4 DUTs in three different orientations at the same time, the test load acting, on a DUT per test, is still a uniaxial load. For example take a DUT whose X-axis is parallel to the vertical axis of the shaker, the excitation, due to the test load will be predominantly on the X-axis of the DUT. To study the effects of multi-axial loading conditions on the DUT another fixture, fixture 2, has been designed.

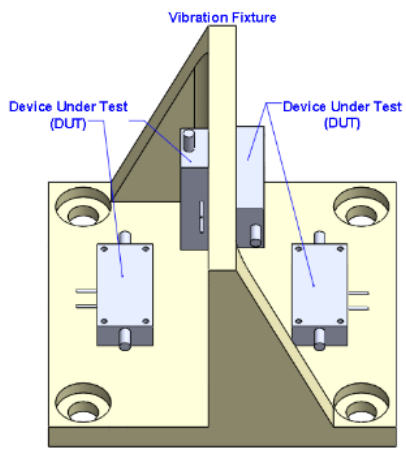
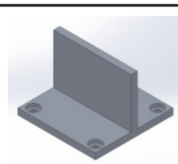
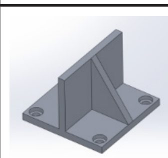
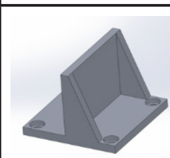
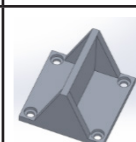
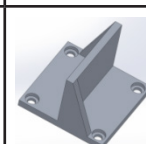
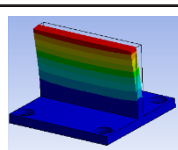
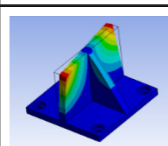
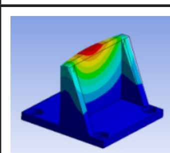
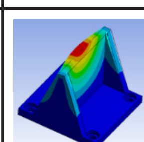
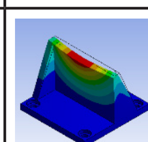


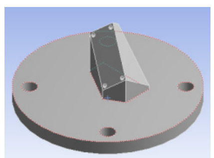
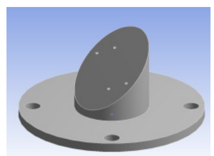
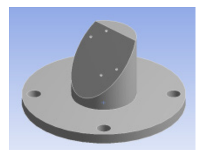
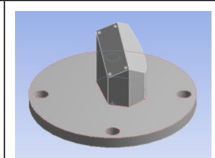
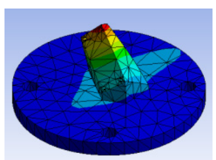
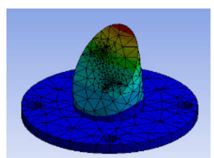
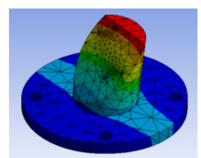
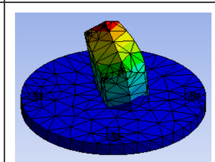
Figure 4. Fixture-1 (4 units - 3 orientations)

Table 3. Summary of design of fixture-1

Parameters	Case 1	Case 2	Case 3	Case 4	Case 5
Structural Feature	Horizontal & Vertical plane	Vertical Plane stiffened with rib at middle	Stiffness doubled with 2 ribs	Further stiffening with 4 ribs	2 ribs at opposite sides
CAD Model					
Fundamental Mode Shape					
First Frequency (Hz)	1275	2400	2598	3098	2466
Mass (kg)	0.67	0.74	0.75	0.83	0.75

Pros	3 axes possible; Easy to realise	f_n improved	f_n further improved	f_n improved substantially	f_n> required; 4 units in 3 axes test possible
Cons	f_n<required	Only 2 DUTs can be tested at the same time	Only 2 DUTs can be tested at the same time	Connectors of DUT inaccessible for electrical connection	f_n not as high as Case 4 but certainly more than required
Case 5 was selected as the design yielded natural frequency more than required as well as space for fixing 4 units and test in 3 axes simultaneously					

Table 4. Summary of design of fixture-2

Parameters	Case 1	Case 2	Case 3	Case 4
Structural Feature	Circular base with predominant milling	Pure turned part with very little milling	Even reduced milling	Increased milling compared to Case-1
CAD Model				
Fundamental Mode Shape				
Mass (kg)	0.42	0.56	0.55	0.45
First Frequency (Hz)	12076	7071	6529	7174
Pros	Least weight; Highest f_n	Easy to fabricate	Even simpler to fabricate	Relatively lighter
Cons	More material removal in manufacture	Refinement needed to avoid thin cross-section at top	f_n not as high as Case-1	More material removal in manufacture
Case 3 was selected as the design yielded natural frequency more than required with minimum fabrication effort for simultaneous 3 axes excitation				

2.4 Fixture 2

This fixture Figure 3 is designed for loading a device in all 3 axes in the same test thus avoiding the necessity of multiple tests on the same device for the other orientation loading. The design of the fixture is carried out so as to machine the fixture from a single block of aluminium alloy 6061 T6 to achieve the desired stiffness/natural frequency more than 2000 Hz with mass being least with 4 Nos. of M10 mounting screws. Table 4 lists the design, mass, natural frequency (ANSYS modal analysis results), fundamental mode shape along with advantages and disadvantages of each of the design.

2.5 Design for 3 Axes Simultaneous Loading

When the shaker vibration load is F and the direction is perpendicular to the base of the fixture. The angle between the inclined plane Figure 5 and the bottom of the fixture is α whereas the angle of mounting on this inclined plane Figure 6 is β. When the CG of the DUT is located along the centre of the fixture, the calculation is as follows[5]:

1. Load perpendicular to the inclined plane=Fz= $F\cos(\alpha)$
2. Along inclined plane, load along mounting direction= Fy = $F\sin(\alpha)\cos(\beta)$
3. Along inclined plane, load perpendicular to mounting direction= Fx = $F\sin(\alpha)\sin(\beta)$

4. For uniform/equal loading in all 3 axes=> Fx = Fy = Fz

From equations (2), (3) and (4)

Fsin(α)cos(β)=Fsin(α)sin(β) => cos(β) = sin(β) =>**β** = 45°

From equations (1), (2) and (4)

Fcos(α) = Fsin(α)cos(β) => tan(α) = sqrt(2) =>**α = 54.73°**

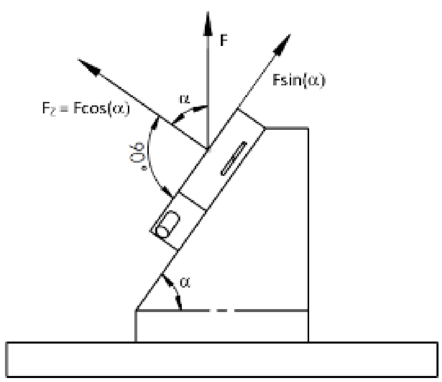


Figure 5. Side view - 3 axes loading

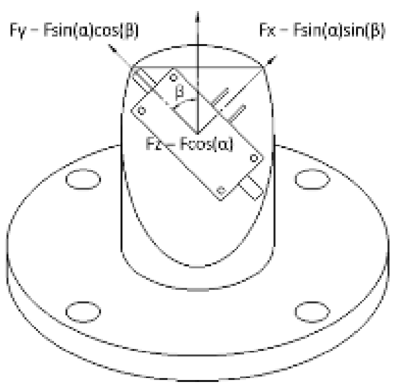


Figure 6. Front view - 3 axes loading

But in this design of fixture DUT will be subjected to an overall excess loading,

$$F = \sqrt{F_x^2 + F_y^2 + F_z^2} = \sqrt{3}F_x = 1.7F_x$$

Table 5. FE analysis details

Parameters	Fixture-1	Fixture-2
Element Type	Solid 187 (with mid-side nodes) – Suitable for irregular meshes	
Number of Elements	57710	35619
Number of Nodes	91411	60663

Table 6. Material properties

Material	Density (ρ)	Young's Modulus (E)	Poisson's Ratio (υ)
Aluminium Alloy 6061 T6	2710 kg/m^3	70.3 GPa	0.346

3. Finite Element Analysis

The fixture is modelled in 3D CAD package SolidWorks2015 and analysed using the FEM tool ANSYS16. The details of the analysis are summarized in Table 5 and 6.

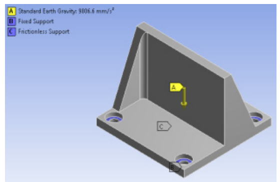
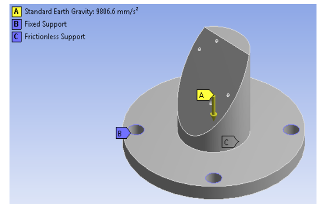
The boundary conditions – the model is fixed at the mounting whole curved surface area and a frictionless support is given at the bottom surface of the horizontal base plate. The Preconditioned ConjuGate (PCG) Solver is used for the modal analysis in ANSYS. The mesh sensitivity was carried out to refine the mesh to obtain mesh independent results. The mesh sensitivity hart shows the variation in the 1st mode frequency with respect to number of elements and the associated time taken for the solver to complete the solution. The refinement is continued till the convergence (change < 1%) of the 1st mode frequency is obtained as shown in the Table 7.

4. Testing

The fabricated Fixture-1 was tested in the conventional vibration shaker with two piezoelectric based accelerometers as sensors. One accelerometer was mounted on the shaker (for controlling input) and the other was mounted on the vertical plane of the fixture (for measuring the output/response). The sine sweep is programmed in the range 10 – 2000 Hz with 1g as input. The fixture was tested in order to find its resonance frequency.

Same fixture was tested using a hand held analyser, with equipment specifications as mentioned in Table 8, as this test is less time consuming compared to the conventional shaker method. In this test the fixture is mounted on the shaker (or any rigid surface) and the accelerometers are located on the fixture horizontal plane (Channel-1) as well as the vertical plane (Channel-2). At this condition a blow with a mallet is imparted to the horizontal plane and the response is captured by the accelerometers. The hand held analyser converts the time domain data into frequency domain data. The frequency response function (Channel-2/Channel-1) shown in Table 8, gives the peak

Table 7. Summary of the analysis

<table>
<tr><th></th><th>Fixture 1</th><th>Fixture 2</th></tr>
<tr><td>Boundary conditions</td><td>
</td><td>
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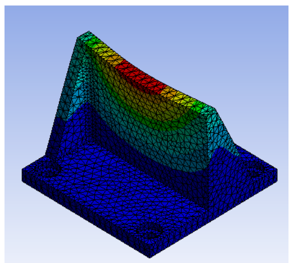
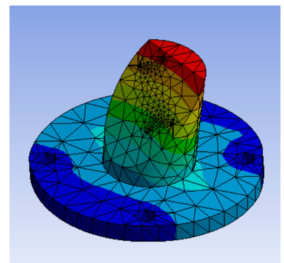
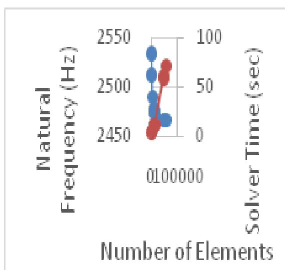
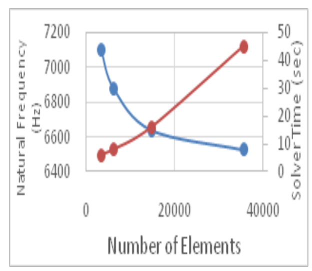
<tr><td>Modal analysis</td><td></td><td></td></tr>
<tr><td>Mesh sensitivity chart</td><td>
</td><td>
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at the natural frequency of the structure being tested. In Table 9, the pictures on the left hand column show the mounting setup and Frequency Response (FRF) chart for fixture 1, with FRF chart, whereas the right hand column shows the test setup and FRF chart for fixture 2.

Table 8. Testing equipment specifications

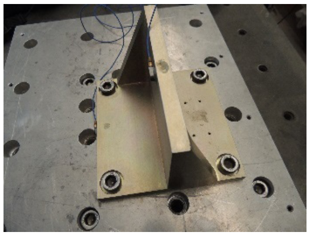
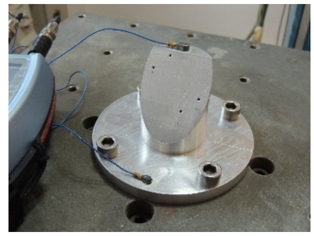
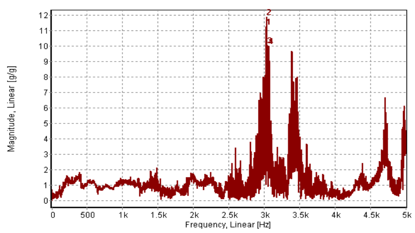
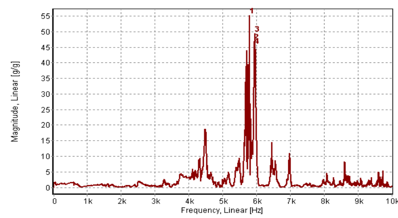
Hand Held Analyser Details	
Max frequency band	0 – 40000 Hz
Shaker specifications	
Rated force	480 Kgf (random)
Operating frequency range	5 – 3000 Hz
Max displacement stroke	30 mm
Max Velocity	1.5 m/sec

Accelerometer details		
Parameters	CH 1	CH2
Sensitivity	5.76 mv/SU	9.19 mv/SU
Sensor/Display unit	Gs	
Input voltage	10 V	
Coupling type	ICP	

5. Results

The first mode natural frequency of the Fixture 1 was estimated as 2466 Hz through analysis. The tests revealed the natural frequency of fixture 1 to be 3026 Hz, whereas for Fixture 2 the analysis predicted a fundamental frequency to be 6529 Hz and the test yielded a value of 5806 Hz. The natural frequency of the both the fixtures were well above

Table 9. Modal testing picture and FRF chart

	Fixture 1	Fixture 2
Modal test setup		
FRF chart		

the requirement of 2000 Hz. The test results for fixture 1&2 are summarized in Table 10.

Table 10. Modal analysis, vibration shaker and hand held analyser test results for fixture 1&2

Results (Hz)	Fixture-1	Fixture-2
Analysis	2466	6529
Testing – Vibration Shaker	2700	Not carried out
Testing – Hand held Analyzer	3026	5806

6. Conclusion

Two variants of vibration fixture has been designed, developed and tested towards random vibration testing of an airborne electronic device for the given vibration shaker and the given spectrum. The analysis and the test results of the fixture showed good correlation (<15% deviation). Vibration fixtures are designed to minimise the time and effort during testing. Using fixture 1, 4 units with 3 orientations can be tested simultaneously and each of the devices can be tested for the remaining orientations during the subsequent tests thus reducing the testing time when accounted across a number of devices. With the second fixture one can test the device for all 3 axes loading in a single test thus saving time and effort.

7. References

1. Rao SS. Mechanical Vibrations. 5th edition, Prentice Hall, 2010.
2. Dave Steinberg. Vibration Analysis of Electronic Equipment, 3rd Edition, John Wiley and Son, 2000.
3. Ong JH, Lim GH. Simple Technique for maximizing the Fundamental Frequency of Vibrating Systems. *The American Society of Mechanical Engineers Journal of Electronics Packaging*. 2000 Feb; 122(4):341-349.
4. Kara Buckley, Lee Chiang. Design Principles for Vibration Test Fixtures, MIT Lincoln Laboratory, 2011, p. 1-32.
5. Fuqiang Sun, Xiaoyang LI, Tongmin Jiang, Wei Zhang. A Multi Axis Vibration Fixture Based on Electromagnetic Shaker. *IEEE Proceedings of 8th International Conference on Reliability, Maintainability and Safety (ICRMS)*. 2009 Jul, p. 1183-1186.