Finite Element Analysis of Different Cube Type Vibration Fixture Made of Aluminum Alloys

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***Abstract*— A majority of consumer products or engineering equipments will meet a succession of complex vibratory environments of variable duration while in service. During these vibration tests, poor mechanical design will cause failures and customer dissatisfaction. This also causes increase in product cost and loss of credibility. The vibration trials form an integral part of the qualification and performance evaluation trials of any engineering equipment or end customer product that are subjected to vibration. Vibration is the most important modes of failure in avionic, electronic equipments. The intention of this work is to design and analyze a cube type vibration fixture used to conduct vibration trials of a variety of test items such as plates or plate sized assemblies, large electronic circuits etc. The size of the test items is roughly 300mm x 300mm. For example consider circuit like a motherboard of a desktop computer. Though a motherboard in service is not subjected to severe vibration levels up to 2000Hz, same size avionic panels inside an aircraft are! If a motherboard like circuitry is to be qualified for transport vibration, it is prudent to consider a vibration bandwidth of 0-2000Hz. Effort will be made to evolve a fixture capable of vibrating multiple such test items at one time. The analysis conducted on a motherboard like test item can be readily extended to a number of such electronic items like VLSI's, avionics equipment etc.**

Keywords*— *ANSYS, CATIA, Finite element analysis, Vibration fixture

I. INTRODUCTION

Customer is undoubting king of the market in 21st century. Every industry, organization, company, business or even individual strives hard to achieve customer satisfaction. This is a radical shift from old times when maximizing profit used to be the prime target of a business. In modern era, organizations are highly customer focused. Customers expect and demand products of high quality and reliability and are ready to pay more for it. In other words, the product should be defect free and should require least maintenance. To fulfill these requirements the customer products should undergo various types of tests during development stages or before it reaches the end user. The purposes of these tests are:

To simulate actual service conditions the product will experience in its lifetime.

To assess the functionality of a product under variety of environments, extreme conditions etc.

The types of tests that a product undergoes are broadly classified as follows:

Development tests: These tests are conducted during the design and development stages of the product and continue till design matures. These tests sometimes help evolve design specifications, and bring out design or manufacturing defects, flaws etc. and implement design changes, corrective actions. Development tests are important with a view to avoid failures during formal testing program, demonstration etc.

Qualification tests: These tests are performed to assess the functionality or survivability of the goods or product and are generally conducted against laid down test specifications.

Endurance tests: Endurance tests are conducted to bring out time dependent failures or fatigue failures. Estimation of useful service life is sometimes possible through this test. In many cases, it is impractical to continue Testing till the expected life of product is over and hence this test is accelerated in time so as to achieve same damage level in shorter period of time. This has direct impact on reducing the time of a product to reach market.

Reliability tests: These are done to evaluate reliability or material failure rates. The data of all tests mentioned above can be combined with this test to obtain statistical prediction of reliability.

II. FINITE ELEMENT ANALYSIS AND MODELING OF DIFFERENT CUBE TYPE FIXTURES.

A. Design 1:

A cube type fixture open from top side and '+' shaped ribs between the side faces is most commonly used one. Material of this fixture is aluminium mostly or magnesium in a few cases. The fixture is shown in Fig. 1. It is fixed to the shaker table by bolting the base of the fixture with shaker table. The threaded holes are provided on the shaker. A matching pattern of holes is produced on the fixture in a solid base at the bottom of about 50mm height. Rest of the height is a ribbed structure.

The structure can be made by welding plates to each other. Aluminium welding being a specialist job needs skilled welders.

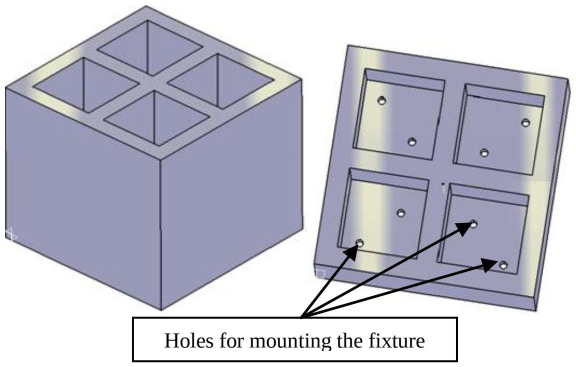


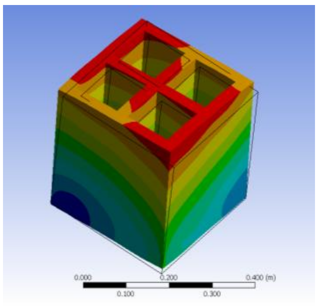
Fig. 1. Cube type fixture - Design 1

TABLE I. MODAL PARAMETERS OF CUBE TYPE FIXTURE - DESIGN 1

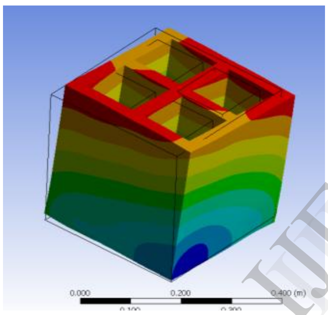
Design 1(49kg)	1st Mode	2nd Mode	3rd Mode	4th Mode
NF (Hz)	1170	1170	1532	2092

Natural Frequencies and Mode Shapes:

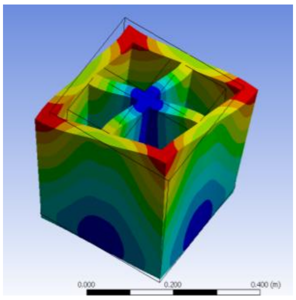
The natural frequencies (NF) and corresponding mode shapes are shown in Fig. 2. The un-deformed position is shown by wireframe lines.



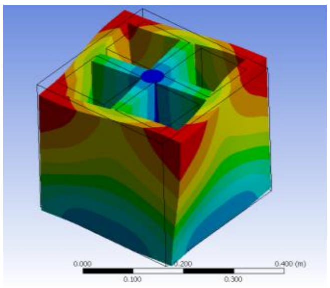
Mode 1: Bending, NF = 1170 Hz



Mode 2: Bending, NF = 1170 Hz



Mode 3: Stretching, NF = 1532 Hz



Mode 4: Twisting, NF = 2092 Hz

Fig. 2. Mode shapes of fixture - Design 1

Comments:

The first mode obtained is a simple bending mode like that of a beam. Second mode is a similar one with bending direction perpendicular to the first one. This mode is as expected since the fixture is symmetric about central axis in the direction of vibration. Such modes are called conjugate modes. Third mode is stretching of the material along the diagonal. Fourth mode is a twisting or torsion deformation type. If the test frequency range is up to 2000Hz, then it is seen that three modes are falling in the frequency bandwidth.

B. Design 2:

This is also a cube type structure but no open box from top, instead a solid one monolithic structure shown in Fig. 3. Material used is aluminium and is machined from a solid stock. Counter bore holes are drilled from top to insert holding bolts for the shaker.

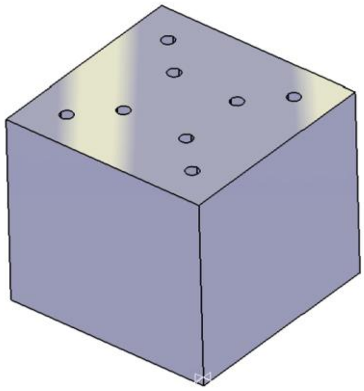


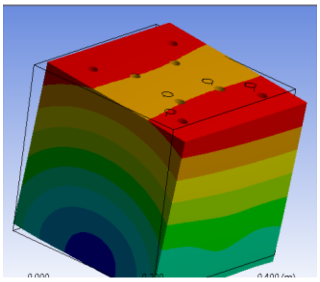
Fig. 3. Cube type fixture - Design 2

TABLE II. MODAL PARAMETERS OF CUBE TYPE FIXTURE - DESIGN 2

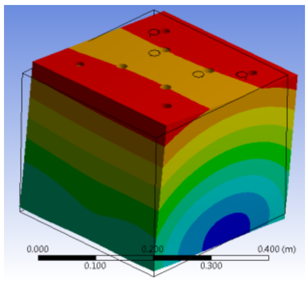
Design 2 (85kg)	1st Mode	2nd Mode	3rd Mode	4th Mode
NF (Hz)	1218	1218	2208	2742

Natural Frequencies and Mode Shapes:

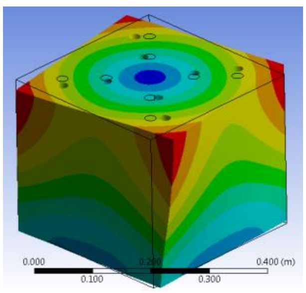
The natural frequencies (NF) and corresponding mode shapes are shown in Fig. 4.



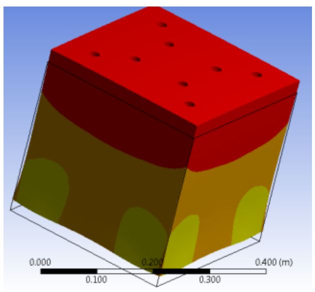
Mode 1: Bending, NF = 1218 Hz



Mode 2: Bending, NF =1218 Hz



Mode 3: Stretching, NF = 2208 Hz



Mode 4: Twisting, NF = 2742 Hz

Fig. 4. Mode shapes of fixture - Design 2

Comments:

It is evident that this fixture is slightly stiffer one as compared to design 1 and has only two conjugate modes falling within a test bandwidth of 0Hz-2000Hz. Weight of this fixture is much higher about 85kg as compared to 49kg (with aluminium) of design 1. It is remarkable that increasing weight of the fixture would not always reduce the stiffness and reduce the NF consequently.

C. Design 3:

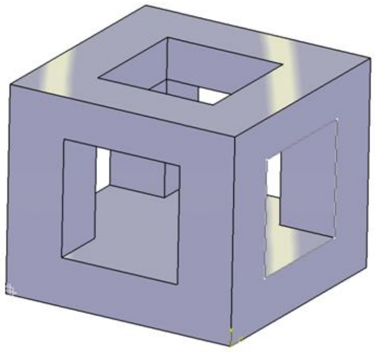


Fig. 5. Cube type fixture - Design 3

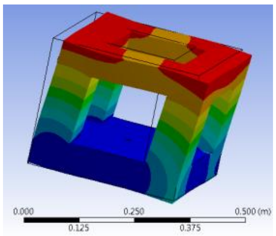
This design is shown in Fig. 5 is a much lighter structure and is very advantageous for vibration testing of small circuits. But following modal survey checks its suitability for an electronic module of size 300mm x 300mm approximately.

TABLE III. MODAL PARAMETERS OF CUBE TYPE FIXTURE - DESIGN 3

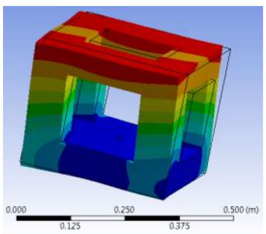
Design 3 (52kg)	**1st Mode**	**2nd Mode**	**3rd Mode**	**4th Mode**
NF (Hz)	727	727	1015	1664

Natural Frequencies and Mode Shapes:

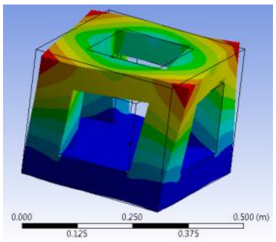
The natural frequencies (NF) and corresponding mode shapes are shown in Fig. 6.



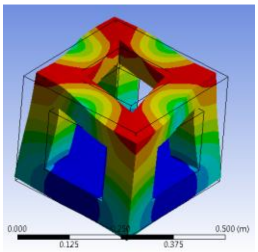
Mode 1: Bending, NF = 727 Hz



Mode 2: Bending, NF = 727 Hz



Mode 3: Stretching, NF = 1015 Hz



Mode 4: Twisting, NF = 1664 Hz

Fig. 6. Mode shapes of fixture - Design 3

Comments:

The natural frequency has dropped considerably. There are 4 or more modes in the test range. Such modal parameters are not acceptable and fixture is faulty.

D. Design 4:

This is a spherical type of fixture from which rectangular working surfaces are obtained by cutting the original spherical structure and is shown in Fig. 7.

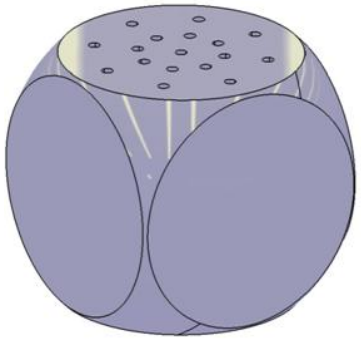


Fig. 7. Spherical fixture with flat surfaces –Design 4

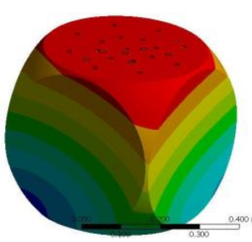
The radius of flat circles is about 209mm adjusted such that it is possible to mount a rectangular plate of size 300mm x 300mm on the same. This has resulted quiet a heavy fixture with mass of 200kg.

TABLE IV. MODAL PARAMETERS OF CUBE TYPE FIXTURE - DESIGN 4

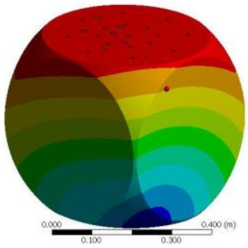
Design 4 (200kg)	**1st Mode**	**2nd Mode**	**3rd Mode**	**4th Mode**
NF (Hz)	726	726	1477	2076

Natural Frequencies and Mode Shapes:

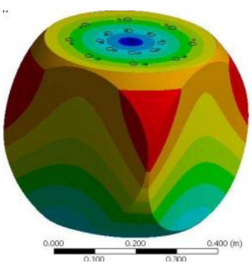
The natural frequencies (NF) and corresponding mode shapes are shown in Fig. 8.



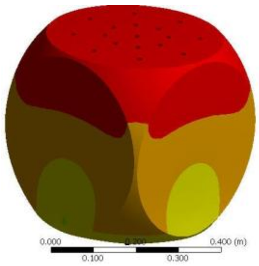
Mode 1: Bending, NF = 726 Hz



Mode 2: Bending, NF = 726 Hz



Mode 3: Stretching, NF = 1477 Hz



Mode 4: Twisting, NF = 2076 Hz

Fig. 8. Mode shapes of fixture - Design 4

E. Newly design fixture:

The size of the electronic module which is being vibrated is 300mm x 300mm shown in fig. 9 is the area of the 'working' surfaces of the fixture. This generates a fixture of envelope dimensions 300 x 300 x 300.

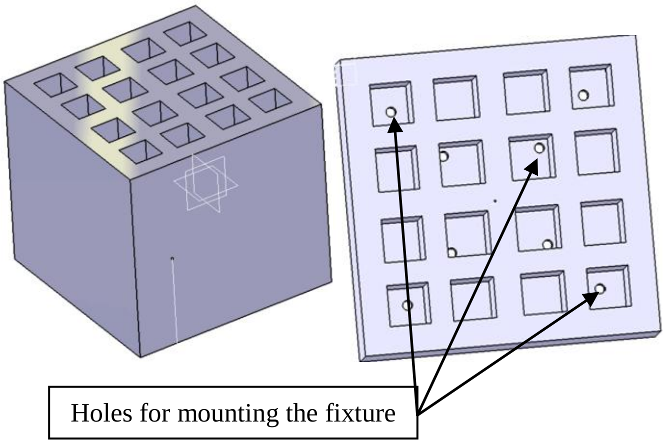


Fig. 9. Cube type fixture - Newly design

With a view to evolve a much stiffer vibration fixture with comparatively less weight, a structure shown in Fig. 9. The attachment points on the shaker match with the holes drilled in the base of the fixture. Provision for mounting accelerometer stud is made on the top surface of the fixture via matching tapped holes.

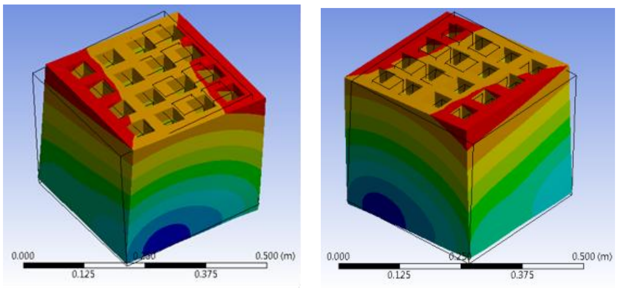
Overhanging the shaker table is avoided. The thickness of rib is 25mm. To avoid very thin sections a rib thickness in the range of 10mm is not recommended. Increasing the thickness improves modal parameters. The limiting case is a solid fixture (design 2). The rib thickness of 25mm gives first NF very close to that of design 2 i.e. 1202Hz. Rib more than 25mm thick improves NF very marginally but weight substantially. Hence 25mm is thought to be an optimal value.

TABLE V. MODAL PARAMETERS OF CUBE TYPE FIXTURE - NEWLY DESIGN

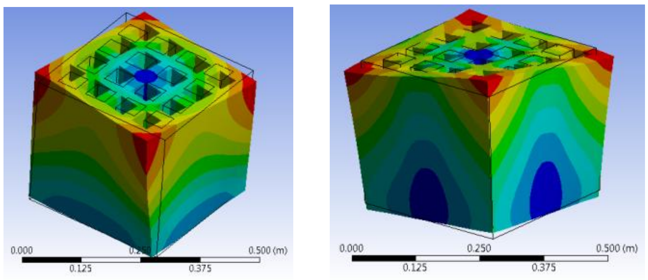
Newly design (63kg)	1st Mode	2nd Mode	3rd Mode	4th Mode
NF (Hz)	1202	1202	2122	2628

Natural Frequencies and Mode Shapes:

The natural frequencies (NF) and corresponding mode shapes are shown in Fig. 10.



Mode 1: Bending, NF=1202Hz   Mode 2: Bending, NF=1202Hz



Mode 3: Stretching, NF = 2122Hz   Mode 4: Twisting, NF = 2628Hz

Fig. 10. Mode shapes of fixture - Newly design

Comments:

Following are the noteworthy design features of this fixture:

i. The fixture is a bit heavy than old design 1 of 49kg.
ii. It has more ribs in between outer walls as compared to design 1 although is lighter than design 2.
iii. The fixture is symmetric about vertical central axis thus giving CG on the axis of the shaker and vibratory movement which is very desirable feature.
iv. But improvement in vibration characteristics is prominent. Its first resonant mode occurs well above 1000Hz thereby satisfying the design criteria. Increase in NF from 1170Hz to 1202Hz is achieved. It is at par with design 2 i.e. monolithic block of 85kg.
v. The structure is much lighter that design 2 but has comparable modal parameters. This is achieved by increasing stiffness with addition of mid ribs. Hence a ribbed structure is much stiffer than a solid structure of same mass.
vi. There are only two conjugate modes falling within test band of 0Hz-2000Hz.
vii. The structure is not easy to realize. However a one-time fabricated fixture can serve lifelong to accomplish rational vibration tests.

III. COMPARISON OF MODAL PARAMETERS OF VARIOUS FIXTURES

TABLE VI. PERFORMANCE OF VIBRATION FIXTURES COMPARED BY MODAL PARAMETERS

Parameter	Weight (kg)	NF 1 Hz	NF 2 Hz	NF 3 Hz	NF4 Hz
Fixture					
Design 1	50	1170	1170	1532	2092
Design 2	85	1218	1218	2208	2742
Design 3	52	727	727	1015	1664
Design 4	200	726	726	1477	2076
Newly design	63	1202	1202	2122	2628

Above data shows that 1st NF is highest in case of design 2 i.e. solid cube fixture with no ribs in between. But it is quite a heavy fixture with weight 85kg. Newly design fixture matches closely with design 2 having 1st NF at 1202Hz. It is advantageous for handling and other such activities being much lighter than design 2. Design 1 is also a satisfactory one but has 3 frequencies falling within test band of 0-2000Hz which may lead to overtest. Fixtures 3 and 4 are clearly ruled out for vibration application. Therefore the newly design fixture is the most satisfactory one and is recommended for vibration qualification testing.

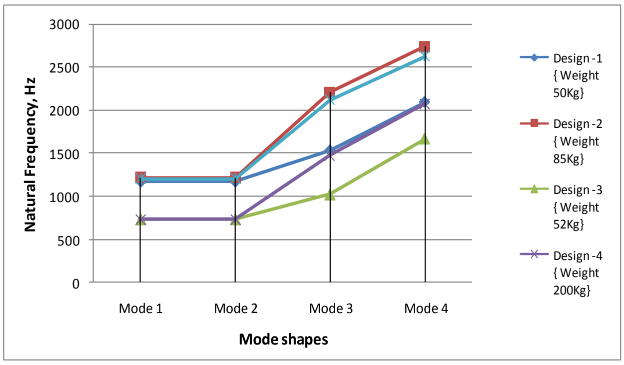


Fig. 11. Graph between Natural frequency and mode shapes of different types of cube fixtures.

IV. CONCLUSIONS

The modelling, analysis and comparison of various types of cube fixtures has been carried out. A review of the reported cube type fixtures was taken and their vibration characteristics were investigated. A new design was evolved taking into account the advantages and disadvantages of earlier fixtures. Modal analysis of all the fixtures was completed. A comparative study shows that the newly design fixture is most satisfactory one. The finite element analysis with ANSYS is a very useful tool for evaluating diverse options and conduct much iterations before finalizing the design. It also helps quick optimization of the design with respect to input requirements.

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