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Structural Design Consideration and Performance Evaluation of Vibration Fixture for Power Cartridge Applications

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***Abstract*—The aim of this paper is to improve vibration testing of electromechanical components that is power cartridges which are used in avionics applications. Power cartridges are subjected to various induced forces during its service, transportation, handling and use. Due to this dynamic nature, vibrations are occurring in the cartridges. There are chances of failure of cartridges before its actual use, hence to know the acceptance and reliability of power cartridge vibration test is very important. The vibration is the Sample Under Test (SUT) where the cartridges mounted on to the vibration fixture. Electrodynamics force is transferred through the shaker coil to SUT via the fixture. The fixture design is most critical job due to resonance. This paper explained about an overview of design, manufacturing and its testing for this purpose guidelines regarding the design of vibration testfixtures has been developed. Modal analysis is done by using ANSYS 15 for aluminium, steel and manganese and resonance search method is performed on electrodynamic shaker for performance evaluation of fixture we compare experimental and software results it gives good correlation.**

***Index Terms*—Power cartridges, vibration fixture, resonance, Performance evaluation**

I. INTRODUCTION

A vibration fixture is a medium which interfaces the vibration generating machine and the Sample Under Test (SUT). The basic need of any fixture is that it should convey all possible forces produced by the shaker to the test component. It is impossible to locate a test component directly on to the shaker table. An ideal test fixture is one that has no any resonance effects over the frequency range of the test component. The fixture should be of less in weight and also cost effective for manufacturing. An ideal fixture is a structure having infinite stiffness at all frequencies with zero mass [1]. While designing the fixture one should consider the manufacturing process, time and cost involved in production of same. Now days, computer tools are available which helps in providing mode shapes, prediction of resonances and cross axial distortion models prior to final manufacture. The final proof of the suitable fixture can be confirmed by running a full rig assessment or modal analysis. Generally, vibration tests are performed to qualify the acceptability of specific component under certain environments. Shaker system is used to generate forces or accelerations which are same as that of real systems vibrations. All bodies with mass and elasticity are able to vibrate. A vibration is a periodic motion where a body or structure will move in alternating opposite directions around an equilibrium position. Resonant search method is performed to know the resonant and anti-resonant frequencies within test range. [1,9]

II. LITERATURE SURVEY

Pravin K. Aggarwal [1] Discussed in his paper various types of dynamic testing of structures are described, including vibration, acoustic and shock testing. Modal testing is discussed as it frequently complements dynamic testing and is part of the structural validation. Examples of dynamic and modal testing are presented as well as the common practices, procedures and standards employed. Also the test fixture design and testing discussed.

R. Hunter et al. [2] Done automation, which is based on a functional approach for the fixture design. For initial validation of the proposed methodology he developed the prototype knowledge-based application. Integrated design approach has been discussed.

Peter Avitabile, [3] Discussed dynamic coupling and resonant effects to overall response to the system and his effects on fixture design also explain the consideration for resonant free fixture design.

Perk Falk [4] has been discussed vibration testing of electrical and electromechanical component design methodology of modular fixture and performance evaluation.

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Hui wang et al.[5] Discussed in his paper fixture and its industrial applications, computer aided fixture design process its significance,approach and working principle to verify mathematical model and FEM used.

Nachiket Kulkarni et al. [6] Discussed natural frequency and stiffness analysis by using frequency response analysis he did his work on testing and analysis of fixture and post-processed through Altair Hyper Works software packages- Hyper Mesh, Optistruct and HyperView respectively.

The study of Dr. Yu Zheng [7] presents a method for finding form-closure locations with the enhanced immobilization capability. Fixtures are used in many manufacturing processes to hold objects. Fixture layout design is to arrange fixture elements on the object surface such that the object can be held in form-closure and totally immobilized.

T. Srinivas Reddy et al. [8] explained the design of a vibration fixture for space launch vehicles he discussed about dynamic characteristics of fixture material mechanical impedance and transmissibility performance is evaluated by using FEA tool.

D. Ravi Prasad et al.[9] Discussed dynamic characteristics of structural material using modal analysis in which he finds out the dynamic property natural frequency, Mode shape, Damping of structural material by using FEA and FFT and FRF were obtained by using Vibration analyzer. He did his analysis for steel,copper, brass aluminum

III. Methodology

a) Materials for fixture

The strength and fatigue properties of materials seldom need to be considered in fixture work. Stiffness required for high-frequency performance dictates fixtures that are so rugged that they seldom fail. Since the weight of a fixture is often its most critical parameter, aluminum and magnesium most commonly use materials. For a given size of metal, aluminum is $1/3^{rd}$ heavier than magnesium while steel is five times heavier. Some alloys of aluminum and magnesium have better damping properties than steel and are cheaper to machine. The controlling factor for natural frequencies is the ratio E/ρ, where E is Young's Modulus and is ρ density. This ratio is approximately 2.5×10^7 N m/kg for most metals [11].

b) Method of manufacturing

There are various ways to manufacture a fixture, amongst them, one-piece fixture manufacturing, casting, bolting together several pieces to form an assembly, building up an assembly by laminating strips of material together, and welding. Amongst all, this one-piece manufacturing from solid stock is preferable for power cartridges fixture due to all metal removal operations can be done at a maximum speed of the machines. Milling, boring, drilling and tapping operations can be performed at speeds unattainable in any other tooling metal, about 20% faster than the aluminum and three times as fast as with steel. One-piece machining avoids mating and preload problems that arise when a fixture is made of parts that must be bolted together. Of course, multiple parts may be needed in order to load the test item into any fixture [11].

c) Types of fixture.

The knowledge of the dynamic behavior of structures has been often of primary importance in the field of aerospace and mechanical design. The fixture is designed in such a way that it should accommodate all shapes and sized components with attachment points. A bad fixture results in isolation at attachment points and a good fixture transmits the input with precision. A good fixture which having no resonance at frequency range. Location of center of gravity of the shaker, slip-table with the SUT has to be as close as possible to mitigate overturning moment concerns. Vibration testing generally requires a fixture which is an intermediary structure to interface with the specimen and the vibration generating equipment (vibration shakers). The types of fixtures constructed for use may include Box fixtures, T-type bolted and L-type book end fixtures, welded or adhesive bonded fixtures and cast fixtures also adapter plate, cube type and hemispherical designs also considered. The type will be influenced by the cost of manufacture, the complexity and the material used. All fixtures require having a very high tolerance of flatness and often skimming or milling techniques are required post manufacture. One should avoid poor build techniques such as riveting or bolting sections. [11]

d) Design philosophy

The proposed model of fixture is prepared in CATIA V5.

1) Dimensions of the fixture:
   (a) Maximum Diameter: ϕ240 mm.
   (b) Thickness : 130mm.
2) Other details of the fixture:
   (a) Material : Aluminum Alloy IS : 733
   (b) Fabrication method: Machining from solid stock.
3) Type of Fixture: Cube Type
4) Resonant frequency of the Shaker : 1000 Hz
5) Frequency of circular base plate F_{BP}-

$$f_{bp} = \frac{\lambda^2}{2\Pi r^2}\sqrt{\frac{D}{\rho m}} \tag{1}$$

$$D = \frac{Eh^3}{12(1-\upsilon^2)} \tag{2}$$

F_{BP} = 1932.26 Hz

6) Frequency of fixture body

$$\lambda^2 = 5.33 + 3.55\,(b / L)^2 + 5.33(b / L)^4 \tag{3}$$
$$= 5.33 + 3.55\,(218 / 110)^2 + 5.33\,(218 / 110)^4$$
$$= 40.2041$$
$$\lambda = 6.34$$

and frequency of fixture body is

$$f_B = 23.5 \times 10^4\,(h / b^2)\,\lambda \tag{4}$$
$$= 23.5 \times 10^4(100 / 218^2) \times 6.34$$
$$f_B = 3135.04 \text{ Hz}$$

7) Frequency of fixture body side block F_{SB}

$$\lambda = 0.37$$
$$f_{SB1} = 23.5 \times 10^4\,(h / b^2)\,\lambda$$
$$= 23.5 \times 10^4(100 / 58^2) \times 0.37$$
$= 2584.72$Hz, same as that of side block

$$f_{SB2} = 2584.72 \text{ Hz}$$

8) Estimation of Cumulative Frequency

The cumulative frequency of the fixture is the combined effect of circular base plate and fixture body is calculated by Dunkerley's equation.

$$1/F^{2} = 1/f_1^2 + 1/f_2^2 + 1/f_3^2 + \ldots 1/f_n^2 \quad (5)$$

The total cumulative frequency of the vibration fixture is F = 1500 Hz

IV. Experimental Set up

An experimental setup for testing samples on the shaker is shown in Fig. 1. It consists of the shaker & sample mounted on it to simulate the forces acting on it. Vibratory motion, both the input motion of a shaker and the response motion of the fixture and test items, is converted into an electrical signal which can be remotely measured and analyzed by the accelerometer. The electrical output is proportional to the instantaneous input acceleration. Most of the accelerometers used are of piezoelectric or crystal units. Shakers are rated by the force they produce. Shakers are varying in size, from one ton to ten tons and are used to vibrate satellites and other large structures.

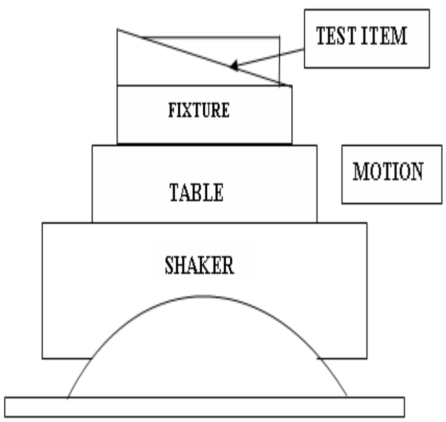

Fig. 1 Experimental Setup for Vibration test

There are three ways to place test specimen, on fixture by means of a thin metal rod (stinger); on top of the shaker table; or by a slip table and vibrates in the horizontal direction. Near the attachment points of structure accelerometer is mounted which is used to measure the input force. Load cell placed on the stinger measures the excitation force in some cases.

The electrodynamic transmission force proportional to the current applied to its voice coil which is used forperformance evaluation, stress and deflection, squeak-and-rattle testing and modal analysis. The shaker system may be driven by sinusoidal, random or transient signals according to user's area of interest and driven by an audio-frequency power amplifier and may be used "open loop" as in most of the modal testing cases or in closed-loop control there is servo control input is given to achieve a desired motion level in the SUT.[12]

A) Need of Testing

High quality and reliability is the basic need of customer. After design for fulfillinguser's requirements, it should undergo various qualification tests. In these qualification tests vibration is one of the stringent test in which the component should undergo vibrations as same as that will induced during its working, transportation and use. Vibration tests are mainly performed on the test components due to following symptoms due to vibration.

- Scraped wiring.
- Loose connection of fasteners/components.
- Electrical contacts mismatch.
- Deformed seals.
- Optical or mechanical misalignment.
- Cracked and/or broken structures.
- Migration of particles and failed components.
- Particles and failed components lodged in circuitry or mechanisms.

C) Transmissibility

The fixture must be as strong as possible so that it is not deflected by the applied force and transfers input motion to test component is called transmissibility. This is a comparison of both input force and output deflection. At a transmissibility of 1.0, the output is directly proportional to input. Ideally, a dynamic test fixture transmits the motion of the test machine to the component to be tested with zero distortion. At all amplitudes and frequencies, there is an identical motion to fixture input and output. For no resonance effect the natural frequency of fixture is always kept as high as possible and kept a transmissibility of 1.0 [12].

The fixture is used to test the cartridges at one ton vibrating force. The transmissibility should be higher for high test reliability of good testing of component transmissibility should be 1

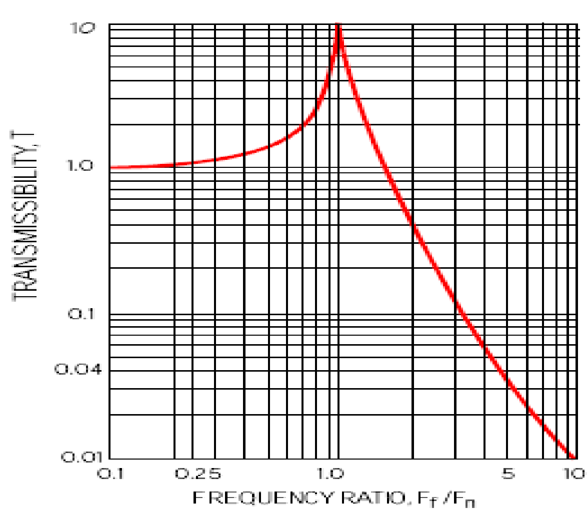

Fig. 2 Transmissibility curve for single degree of freedom [8]

B) Resonance search Method

The Resonance search method is carried out on electrodynamic shaker in which sine sweep test is performed in the frequency range 70 to 3000 Hz for 10 Sec Q limit 1 to 10, During sine testing, energy is output at a single frequency. A sine sweep test is a useful to find out the resonant and anti-resonant frequency within test range of a product. The resonance, or natural frequency, is the point where small vibration levels cause the system to exhibit high amplitude levels. Dwelling at the resonance point is a common practice to determine if a product can withstand a higher level of stress [12].

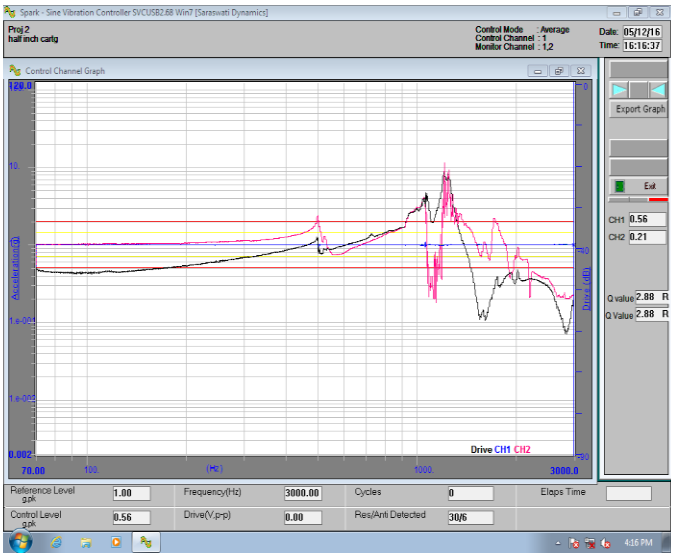

Fig. 3 Acceleration verse frequency graph of resonance search method

Table I MODAL ANALYSIS FOR DIFFERENT COMPOSITION

Material	Aluminum			Magnesium			Steel		
Mesh size	4	5	6	4	5	6	4	5	6
Mode 1	1460	1468	1470	1445	1453	1456	1436	1444	1446
Mode 2	1535	1542	1544	1515	1523	1524	1514	1520	1522
Mode 3	2437	2469	2472	2431	2443	2446	2419	2430	2433
Mode 4	3109	3117	3122	3064	3072	3077	3071	3079	3084
Mode 5	4095	4107	4111	4046	4058	4063	4036	4047	4051
Mode 6	4119	4130	4135	4070	4082	4086	4059	4069	4074

V. RESULT AND DISCUSSION

Modal analysis is a best tool for obtaining the vibration characteristics of mechanical structure or components which are undergone vibration in its service. By doing it one can easily find out the modal parameters, that can be analyzed for further conclusion. The modal parameters (frequency, damping and mode shapes) of a structure or components are a function of its physical properties (mass, damping and stiffness). [9]

Performance of manufactured fixture is evaluated by doing FEM analysis of Fixture. In which by taking three different material, aluminum, steel and Magnesium modal analysis is done on ANSYS 15 for different mesh size and results are tabulated which find better correlation in between them

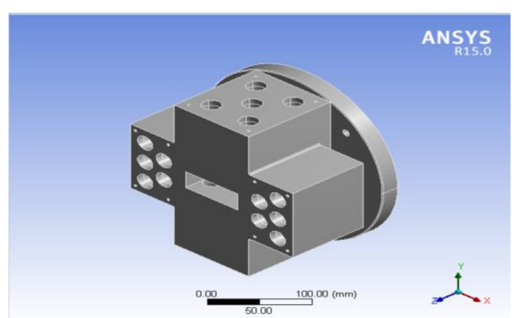

Fig. 4 Imported CATIA model of Fixture Body

For manufacturing of vibration fixtures generally Stainless Steel, Aluminum, Magnesium are considered having similar E/ρ ratio (ratio of Young's modulus to density) not affecting the natural frequency of the fixture. Magnesium is a lighter metal & there is a fabrication issues and availability of indigenous fabrication techniques. Hence Aluminum alloy is preferable material. When choosing the material, it needs to be considered the test frequency range, overall mass and the cost. For low level vibration test a frequency range is 20 Hz to 100 Hz may find that a wooden or plastic fixture is adequate. Whereas for high level typically frequencies greater than 500 Hz will require a much stiffer material. In most of the cases fixtures mass many times greater than the SUT, this will affect the force capability of the shaker. The materials like duralumin, magnesium or aluminum having good stiffness-to-mass ratio. Another characteristic of a material is its damping properties, e.g. the hysteretic damping of aluminum is approximately four times greater than that for steel. [7]

Steel is avoided for the manufacturing due to heavy, it rings, it is difficult to work with the resonances are of high Q and it is expensive.[10]

Modal Analysis is done for three Material aluminium, steel and Magnesium for different mesh size and results are tabulated in table I which gives better correlation between all the material but we select aluminium for manufacturing to above stated reasons.

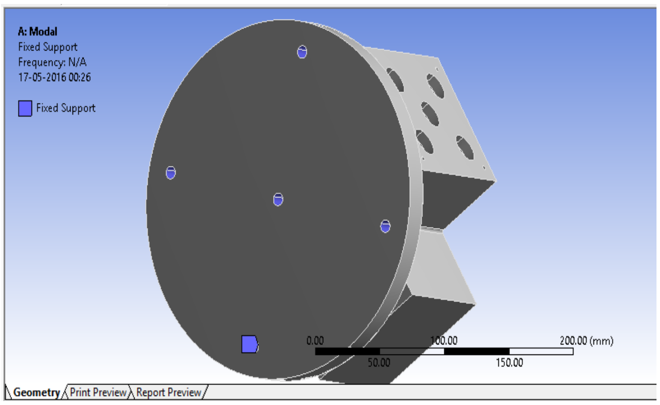

Fig. 5 Fixed boundary condition

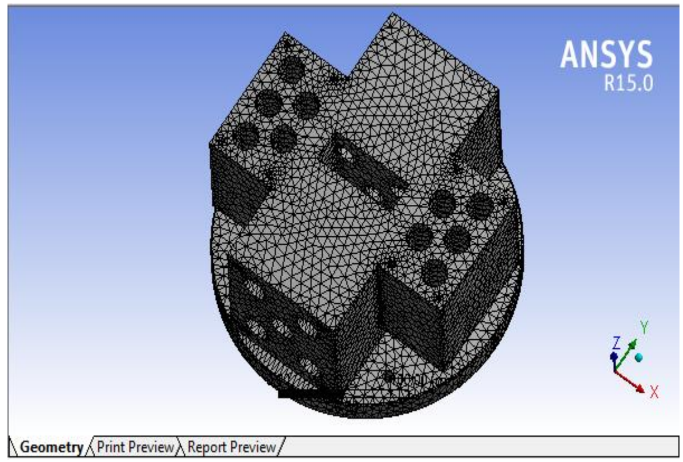

Fig. 6 Meshed Model of Fixture Body

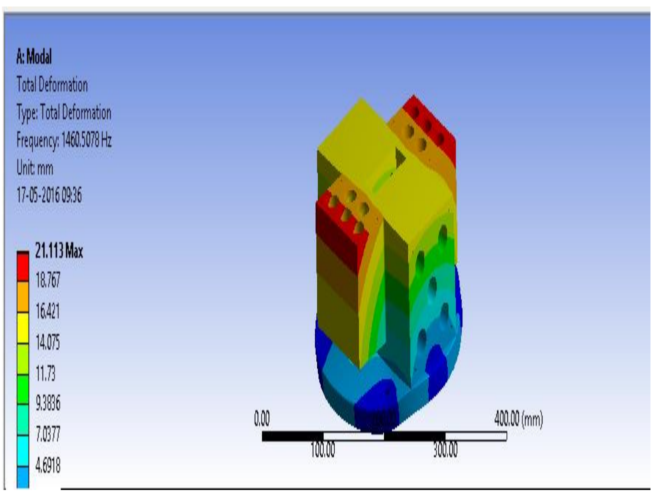

Fig. 7 Mode shape 1

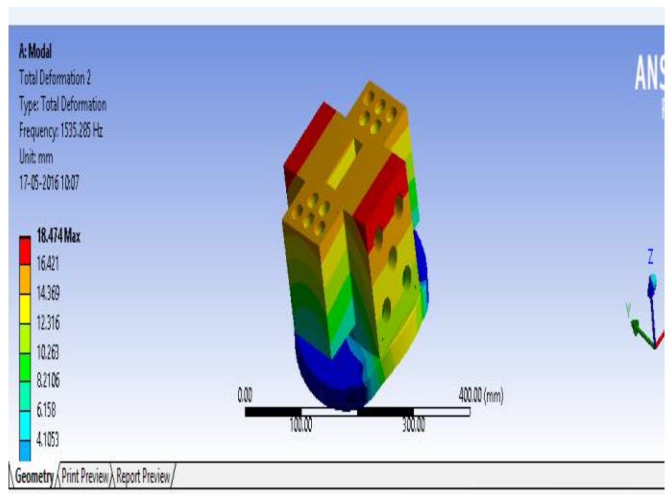

Fig. 8 Mode shape 2

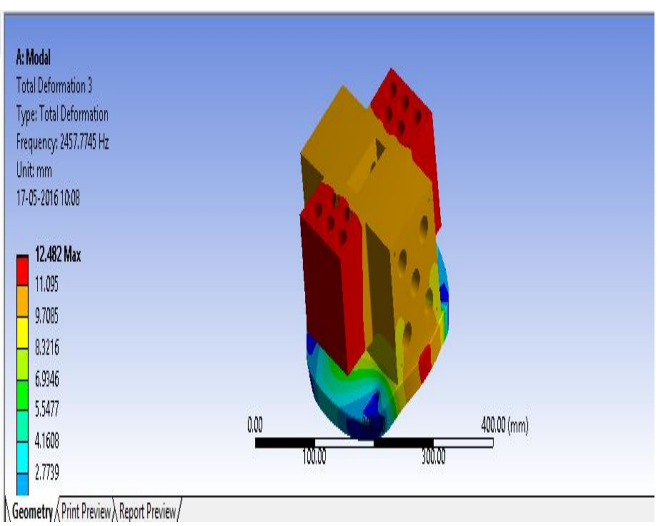

Fig. 9 Mode shape 3

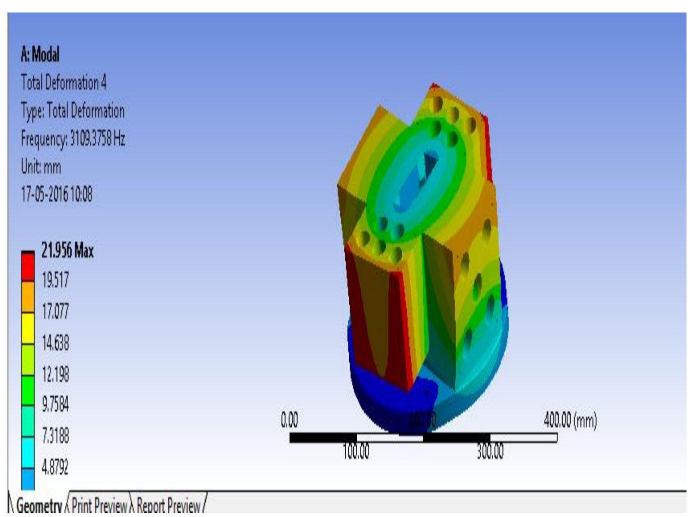

Fig. 10 Mode shape 4

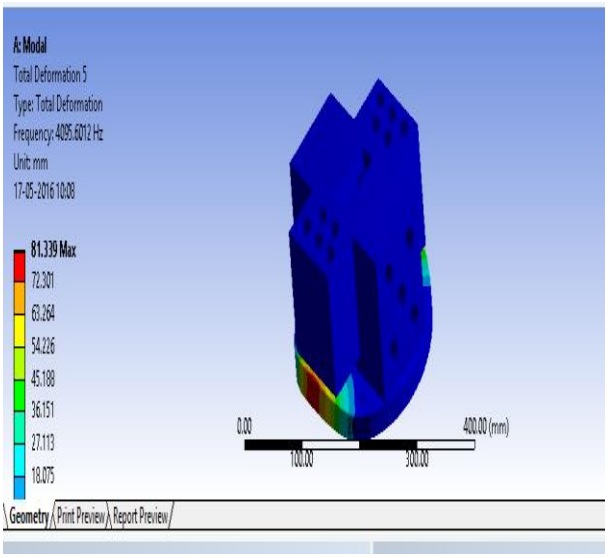

Fig. 11 Mode shape 5

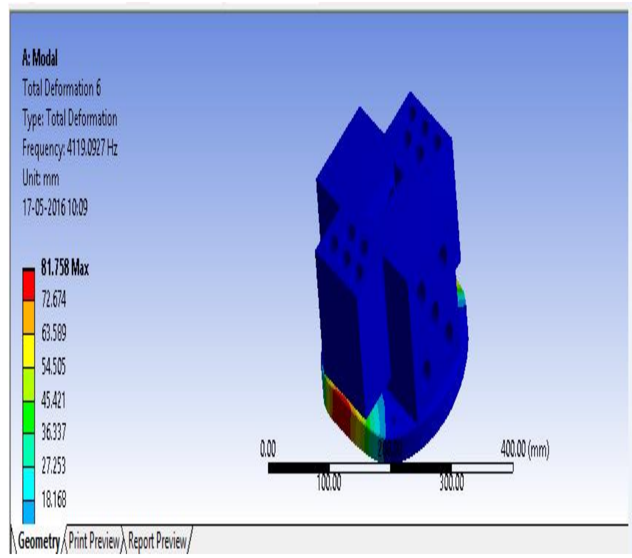

Fig. 12 Mode shape 6

VI. CONCLUSION

After conducting experiment with various configuration of the vibration fixture, the following conclusions can be drawn.

An aluminum material is selected, having material property i.e. E/ρ is 2.5×10^{7} Nm/kg which is compared with other material. The specification of Al material is IS:733, which is selected for manufacturing of vibration fixture.

A good vibration fixture avoids under-test or over-test of the test specimen. This has its implications on timely completion of the test program and further development activity as a whole.

Finite Element analysis was carried out using ANSYS tool. Evaluation was carried out using 1 Ton shaker system. The control mechanism of vibration shaker works best for the properly designed vibration fixture.

The first natural frequency of the fixture from FE analysis was worked out 1460 Hz. From theoretical calculation 1500Hz, it was observed that the natural frequency of vibration fixture is more than that of the resonant frequency of shaker which gives good correlation.

The Resonant frequency search method is performed and generated graph which not include the first fundamental frequency hence the above prediction is validate experimentally.

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