# Vibration Analysis of Open End Wind Tunnel by Using Experimental and FEA Technique.

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***Abstract*— The Wind Tunnel is the equipment used for testing different specimens. The models are of different types like symmetric and unsymmetrical aerofoil, Cylindrical shapes. The wind speed for this type of wind tunnel usually 20m/s. Flow of wind at such high speed creates vibration in the wind tunnel body. Another reason for vibration is the long structure with less and undamped support. This ultimately become a part of deviation in the test result also damaged the structure of the equipment. To reduce the vibrations use of various damping materials, introduction of additional support, change in the material, design change can be done. In this Paper main focus is on Damper Material and Additional Support for wind tunnel structure. Modal analysis and experimental test for assessing the vibrational performance i.e natural frequency and frequency response is carried out. The modal analysis of structure is carried out withoutdamper and with damper to minimize the vibration.**

***Keywords*- aerofoil, Damper, Frequencyresponse, modaltest, wind tunnel etc.**

## I. INTRODUCTION

Wind tunnels are an extremely useful tool to conduct aerodynamic tests on aircraft models and other related components of aircrafts. Wind tunnels are not just limited to aircraft design alone, they are also used in design of automobiles, wind turbines, buildings, bridges etc. They are a very integral part of testing and analysis when computational analysis is not feasible. Also, wind tunnels enable easy testing of scaled models of aircrafts so as to understand their behavior during various phases of flight, and at various flight speeds, before performing a flight test, so that any noticeable defects can be corrected, and the design can be improved. Wind tunnels give us the flexibility to vary the flow conditions like pressure, temperature, speed etc. for a wider range of tests that can be performed.

The purpose of this research is to analyze the vibration and reduced it by using damping material. For this there is requirement of addition of damping material at base and critical vibrating part. Thus the vibration pattern is observed before application of damper and after addition of damper. As per the requirement, the simulation of a model should be done using software. For that we follow two basic steps as modeling and then analysis. We do modeling in CREO 2.0 and analysis in 'ANSYS'. The main part of this project is to do analysis using 'ANSYS'. For this finite element analysis is required to study.Since last decade advent of powerful finite element analysis (FEA) have proven good tool to analyses the problem.

The Various complicated geometries can be analyzed by FEAinstead of doing analytical calculations. Optimized meshing And accurate simulation of boundary conditions along with the ability to apply complex load, provided by various FEM packages have helped the designer to carry vibration analysis with the investigation of critical stresses and contact stresses. FEM is used to find critical locations and quantitative analysis of stress distribution and deformed shape under loads. However detailed modeling and specialized knowledge of FEM theory are indispensable to perform these analyses with high accuracy. They also require complicated meshing strategies. Simulations of actual boundary conditions to equivalent FE boundary conditions have to be done carefully because a wrongly modeled boundary condition leads to erroneous results. The solution of such large scale FEM problem requires both large memory and disc space as computing resources.

## I. LITERATURE REVIEW

James H. Bell and Rabindra D. Mehta "Contraction design for small low-speed wind tunnels", Wind flow through tunnel would analyze for pressure distribution pattern and their corresponding impact on the experimental study. The effect of wind flow on the wall of tunnel in the form of pressure distribution is studied out and suggested an appropriate geometrical shape for contraction cone for smooth operation/experimental conduction to obtain the satisfy test result. The proposed polynomial geometrical shape of the contraction cone would satisfy all the operation requirements and need as per quoted by ISO design standards [1].

MillanValajinacinthe thesis report "Design, construction and evaluation of subsonic wind tunnel" given the correlation between optimized wind tunnel design and respective test result obtained (Feasible and Valid) are compared and discussed. Best and optimized design of wind tunnel best will be the respective test result obtained and supposed to valid, applicable and long reliable [2].

KenanYuce et al in the research paper titled "Vibration analysis and mistuned blade system", focused on the vibration impact produced under the phenomenon of the mistuning of blades would result in the blade failure in catastrophic manner under the effect of failure due to fatigue loading and hence elaborates the possibility of whole system collapse afterwards. Minimization the magnitude of vibration induced in tunnels blades will not only enhances the part reliability of the blade system but also restrict the induction of unwanted vibration effect that would divert the final test result by add them with unwanted error impact.[3]

Louis Cattafesta and Jose Mathewin there research paper titled "Fundamentals of Wind-Tunnel Design" stated Manual algorithms has been put forth to make an experimental investigation and to proposed new optimized design parameters for the sake of implementation by the time of designing the final wind tunnel system. The methodology basically consider the impact of all parameters those are supposed to be responsible and associates with the performance of wind tunnel which would be simply impossible to insert or considered by the time of analysis with methodologies like CFD or any standard computerized techniques. Manual effect of all the respective parameters those tending to impact the performance behavior of wind tunnel system are considered and hence helps to achieve the test result in most precise and appropriate way. [4]

Panda K. C., Dutt J. K. In their paper frequency dependent characteristics of the polymeric supports have been found by simultaneously minimizing the unbalanced response and maximizing the stability limit speed. Dutt, J.K. and Toi T. They used polymeric material in the form of sectors as bearing supports for improving the dynamic performance of rotor–shaftSystems, which often suffer from two major problems (a) resonance and (b) loss of stability, resulting in excessive vibration of such systems. Polymeric material in the form of sectors has been considered in their work as bearing supports.[5]

N. Venugopal, et.al. Applied Taguchi's concept of Orthogonal arrays for designing experiments to study the transmissibility ratio of viscoelastic materials and factors affecting it. Experiments are carried out with different process parameters like material, thickness, frequency. They used three viscoelastic materials namely Natural rubber, Neoprene rubber1, Neoprene rubber2. The results obtained are then analyzed using ANOVA (Analysis of Variance). Thus the factors to be given importance while choosing the viscoelastic material as damping media are identified and also laid down the procedure for the same by making use of Taguchi's Orthogonal array technique for Design of experiments and ANOVA.[6]

## II. Problem Statement and Objective

In the present study, effect of wind pressure on the vibrational behavior of the structure of the wind tunnel is the main objective of the study. Also to asseses the free and forced response of structure with and without the damper pad for different pad thickness and different materials of pad such PVC and glass etc.

### A. Specifications of Wind Tunnel

Type :- Open Wind Tunnel.
Test /Working section -
Material :- Acrylic Sheet 6mm thick.
Size :- 300mm x 300mm x 1000mm long.
Blower Fan :- 7 Blades,
D.C. Motor:- 7.5 H.P. 1500 RPM,
Excitation Voltage – 200 VDC,
Armature Voltage – 440 VDC ( Variable),
Make – Arwa Electronics
DC Variable (Thyristerised Control) Drive:-7.5 HP,
Output – Excitation – 200 VDC, Armature – 0 to 440 VDC,
Input: 3 Phase, 440 VAC supply, Make : Indus Electronics
Air Velocity In Test Section :- 3 to 30 m/sec.

### B.Dimensions Of Wind Tunnel.

| Parts | Dimensions |
|---|---|
| Contraction Section | $\phi$450 X 7200 mm |
| Test Section | 300X 300X 1000 mm |
| Divergent Section | 1000 X 1000X 1200 mm |

## III. SELECTION OF MATERIAL FOR TESTING:

The selection of viscoelastic material is based on the properties, installation, replacement and cost. As per the market survey rubber and flexible PVC is easily available material. Out of this two, natural rubber is used for several applications. Also flexible PVC is considered as good damping material.

Table 2.1: Comparison of Mechanical and Physical Properties of Viscoelastic Materials.

| Parameters | Flexible PVC | Natural Rubber |
|---|---|---|
| Density (g/ cc) | 0.9 | 0.95 |
| Thermal conductivity w/m-k | 0.14 | 0.17 |
| Yield strength(psi) | 1450-3600 | |
| Young's modulus | 1.4 Gpa | 4.5 Gpa |
| Damping ratio | 0.4 | 0.1 |
| Loss factor | 0.2 | 0.05 |
| Ultimate tensile strength | >= 27.6 MPa | 0.758- 24.8 MPa |
| Elongation at break | 50.0- 600 % | 500 % |
| Maximum Service Temperature, Air | 50.0- 190 °C | 50.0 °C |
| Hardness, Shore A | 74.1 | 30- 90 |

### C. Modal Analysis

It is also possible to test a physical object to determine its natural frequencies and mode shapes. This is called an Experimental Modal Analysis. The results of the physical test can be used to calibrate a finite element model to determine if the underlying assumptions made were correct (for example, correct material properties and boundary conditions were used).

For the most basic problem involving a linear elastic material which obeys Hooke's Law the matrix equations take the form of a dynamic three-dimensional spring mass system. The generalized equation of motion is given as

$$[M][\ddot{X}]+[C][\dot{X}]+[K][X]=[F]$$

Where [M] is the mass matrix, $[\ddot{X}]$ is the 2nd time derivative of the displacement [X] (i.e. acceleration), $[\dot{X}]$is the velocity, [C] is a damping matrix, [K] is the stiffness matrix, and [F] is the force vector. The general problem, with nonzero damping, is a quadratic eigen value problem. However, for vibrational modal analysis, the damping is generally ignored, leaving only the 1st and 3rd terms on the left hand side:

$$[M][\ddot{X}] + [K][X]=[0]$$

This is the general form of the Eigen system encountered in structural engineering using the FEM. To represent the free-vibration solutions of the structure harmonic motion is assumed, so that [Ẍ] is taken to equal λ[X] , where λ is an eigenvalue (with units of reciprocal time squared, e.g.S-2), and the equation reduces to

[M][X] λ +[K][X] = [0]

In contrast, the equation for static problems is:

[K][X] = [F]

This is expected when all terms having a time derivative are set to zero. In linear algebra, it is more common to see the standard form of an Eigen system which is expressed as:

[A][x] = [x] λ

Both equations can be seen as the same because if the general equation is multiplied through by the inverse of the mass, [M]-1, it will take the form of the latter. Because the lower modes are desired, solving the system more likely involves the equivalent of multiplying through by the inverse of the stiffness, [K]-1, a process called inverse iteration. When this is done, the resulting eigenvalues μ relate to that of the original by, μ= 1/ λ, but eigenvector are the same.

Modal analysis objective:

Modal analysis is performed to calculate natural frequency of setup with & without isolator. Controlling natural frequency provides one mean to control vibration. Here we are finding natural frequency of setup with & without isolator. Natural frequency of isolator model will compare with natural frequency of without isolator model. Model which gives less natural frequency than other two it will give low vibration. But this frequency must not near to resonance condition. The isolators used are natural rubber & flexible PVC. Stress comparative study was done with isolator & without isolator for Wind tunnel system.

## IV. Finite Element Analysis

Modal analysis of wind tunnel structure is performed by ANSYS 16.0 software to determine the natural frequency with isolator and without isolator is determined.

### *A. Solid modeling of* Wind Tunnel

Solid model of Wind tunnel is created by Creo 2.0 software which makes modeling so easy and user friendly. Fig.1shows a solid model of *Wind Tunnel*.

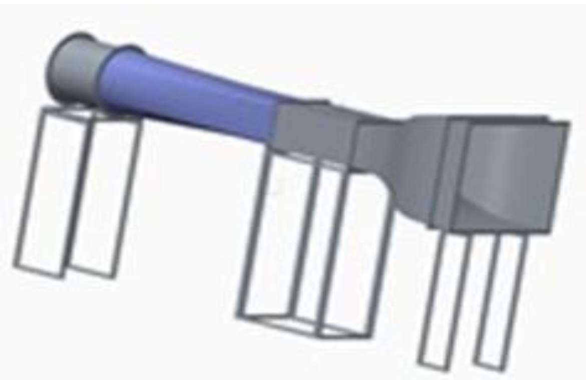

Fig.1 Solid model of Wind Tunnel

### *B. FEA Analysis*

Solid model of wind tunnel is created by Creo 2.0 software then this model is saving in IGES format and export into the FEA software ANSYS 16. The model without isolator and with isolator is analyzed in FEA software. Following steps are used to find analysis results,

1) Material properties
2) Geometry/Model
3) Meshing.
4) Loads and boundary condition.
5) Results

### *C. Mesh generation*

The meshing of wind tunnel without and with isolator was done in ANSYS 16(Workbench) software. Fig.2 shows themeshing of wind tunnel without isolator and Fig.3 shows the meshing of wind tunnel with damper.

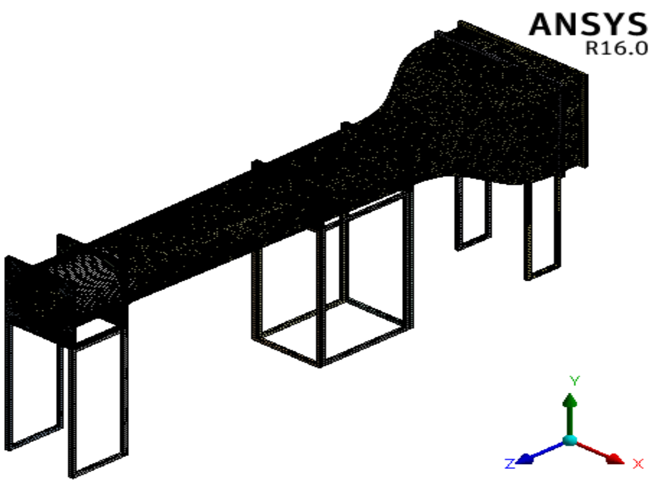


Fig. 2 Meshing of Wind tunnel

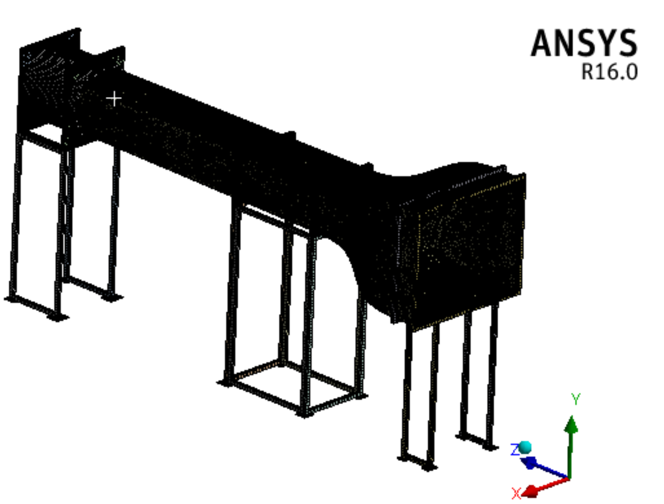


Fig. 3 Meshing of wind tunnel with damper

### *D. Boundary Conditions*

Modal analysis was performed to determine natural frequency of the structure by ANSYS software. For this boundary conditions are used: Fixed support

*E. Modal Analysis*

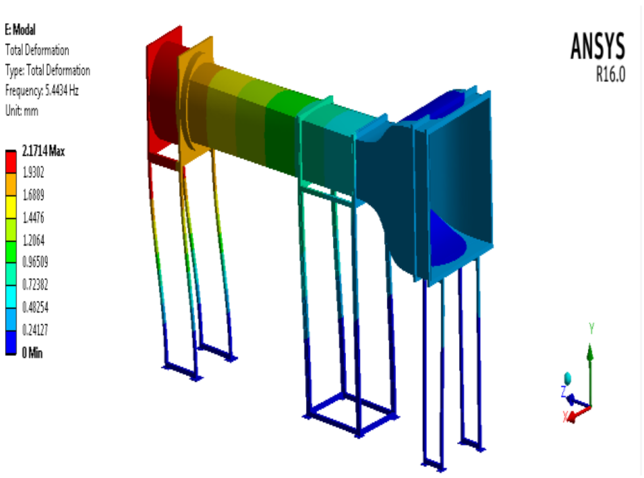


Fig. 4 First Mode Shape at lowest frequency of 5 Hz.

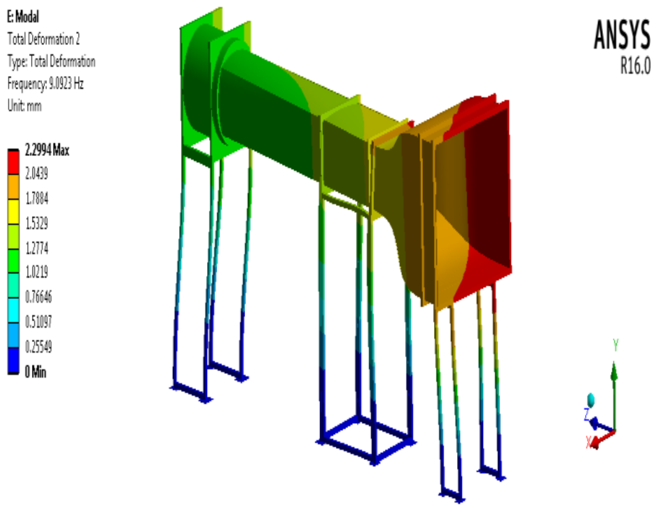


Fig. 5 Second Mode Shape at frequency of 8.30 Hz.

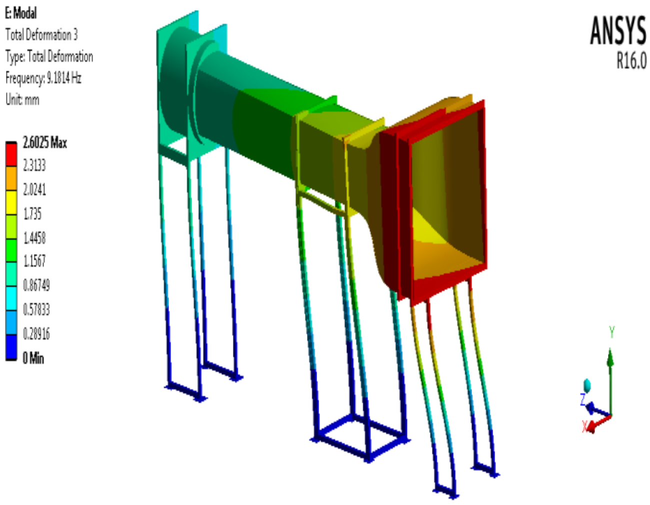


Fig. 6 Third Mode Shape at frequency of 9.18 Hz

## V. Experimental Result

To verify the vibrations of wind tunnel experimentally we have taken readings with the help of FFT analyzer. For this we have considered both conditions i.e. without damper and with damper. The readings from the machine are used to verify with the Finite element analysis results.

In experimentation we can get results on FFT analyzer directly. The wind tunnel setup is as shown in the Fig.Vibrations are induced in the setup due to wind at high velocity. The three conditions of damper namely Natural Rubber and PVC with different thickness are considered. Thedampers are placed between Foundation and base of setup.
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Fig. 7 Experimental setup

Fig.8 Experimental setup

Specification of FFT analyzer

1. Range: Route measurements: DC to 80 kHz (GX-R:80 kHz)
2. Averaging type: RMS, Time, Peak Hold, ExponentialMeasurement parameters: Acceleration, velocity, displacement, Temperature, phase, voltage, user specified
3. Measurement types: Overall, spectrum, time waveform, cross phase, orbits, shaft centreline Multi-point
4. Accuracy: ±2.5% of full scale range
5. Data display: Single and dual channel spectrum, single and dual channel time, phase table, process, orbit, Simultaneous spectrum, time waveform,
6. peak hold averaging Up to 12 bands (fixed or order base) downloadable from host software

*A.Experimental Test*

For experimental results readings were taken with the help of FFT analyser and Wind tunnel Setup.This is carried out at 600 rpm of fan.Diffrent readings with and without Isolater.The readings at supports are taken by using acceleromenter.These readings are interpreted with the help of display device like Computer.The following results are obtained given in the table 4.1.The readings are in $m/s^2$.

Table 4.1: Experimental results

| Stage | Without Isolator | 3mm Rubber | 3mm PVC | 6mm Rubber | 6 mm PVC | 9mm Rubber | 9mm PVC |
|---|---|---|---|---|---|---|---|
| Support 1 | 13.8 | 10.75 | 8.35 | 7.85 | 7.36 | 6.41 | 5.95 |
| Support2 | 13.5 | 10.58 | 8.25 | 7.13 | 6.85 | 6.33 | 5.85 |
| Support3 | 4.02 | 3.28 | 2.68 | 2.43 | 2.22 | 1.71 | 1.56 |
| Support4 | 3.76 | 3.35 | 2.74 | 2.81 | 2.43 | 1.93 | 1.64 |

## VI. Results and Discussion

| Factor | Level | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Material | Natural Rubber | PVC | - |
| Thickness (mm) | 3 | 6 | 9 |

To find optimised result mix level taguchi method of DoE is used.

Table 5.1: Experimental Results

| Thickness | Material | Support 1 | Support 2 | Support 3 | Support 4 |
|---|---|---|---|---|---|
| 1 | 1 | 10.75 | 10.58 | 3.28 | 3.35 |
| 1 | 2 | 8.35 | 8.25 | 2.68 | 2.74 |
| 2 | 1 | 7.85 | 7.13 | 2.43 | 2.81 |
| 2 | 2 | 7.36 | 6.85 | 2.22 | 2.43 |
| 3 | 1 | 6.41 | 6.33 | 1.71 | 1.93 |
| 3 | 2 | 5.95 | 5.85 | 1.56 | 1.64 |

Table 5.2: FEA Results

| Stage | Without Isolator | 3mm Rubber | 3mm PVC | 6mm Rubber | 6 mm PVC | 9mm Rubber | 9mm PVC |
|---|---|---|---|---|---|---|---|
| Support1 | 11.85 | 9.58 | 8.34 | 7.40 | 7.31 | 6.74 | 5.92 |
| Support2 | 11.41 | 9.24 | 8.15 | 7.13 | 6.97 | 6.64 | 5.70 |
| Support3 | 3.52 | 3.08 | 2.87 | 2.65 | 2.47 | 2.07 | 1.77 |
| Support4 | 3.45 | 3.12 | 2.95 | 2.92 | 2.48 | 2.14 | 1.67 |

From above results it is observed that Flexible PVC with thickness 9mm reduced the vibrations significantly. Socomparison between without isolator and with flexible PVC isgiven in the table 5.2

Table 5.2: Result Analysis of cases without isolator and with isolator

| Result Analysis between without isolator and with 9 mm PVC | | | | |
|---|---|---|---|---|
| **Sr.No** | **Stage** | **Without Isolators** | **With 9 mm PVC** | **% Reduction** |
| **Experimental Analysis** | | | | |
| 1 | Support 1 | 13.8 | 5.95 | 56.88 |
| 2 | Support2 | 13.5 | 5.85 | 56.67 |
| 3 | Support3 | 4.02 | 1.56 | 61.19 |
| 4 | Support4 | 3.76 | 1.64 | 56.38 |
| **FEA Analysis using ANSYS** | | | | |
| 1 | Support 1 | 11.85 | 5.925 | 50.00 |
| 2 | Support2 | 11.417 | 5.7083 | 50.00 |
| 3 | Support3 | 3.5229 | 1.7742 | 49.64 |
| 4 | Support4 | 3.4576 | 1.6754 | 51.54 |

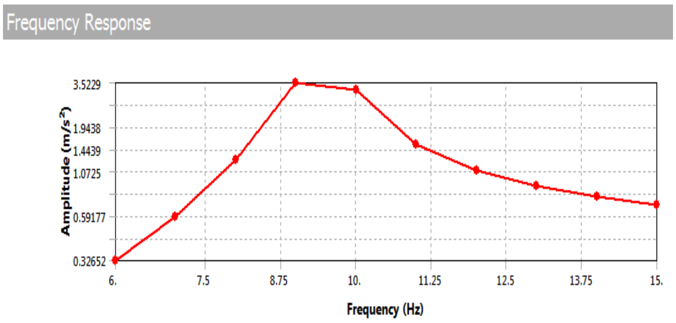


Fig. 9 Frequency response Curve For Support 1 without isolater

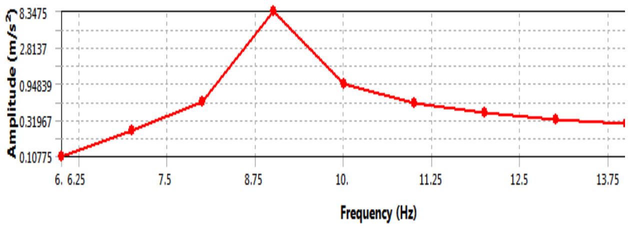


Fig. 10 Frequency response Curve For Support 2 without damper

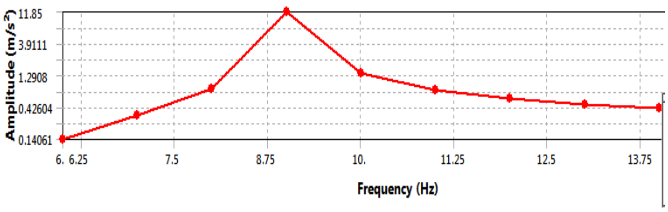


Fig. 11 Frequency response Curve For Support 3 without damper

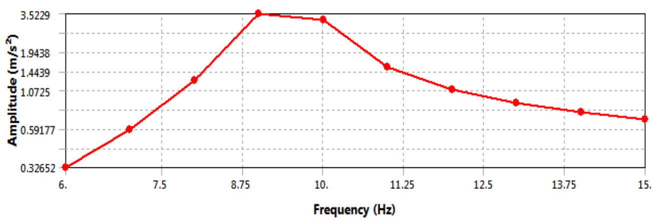


Fig. 12 Frequency response Curve For Support 3 without damper

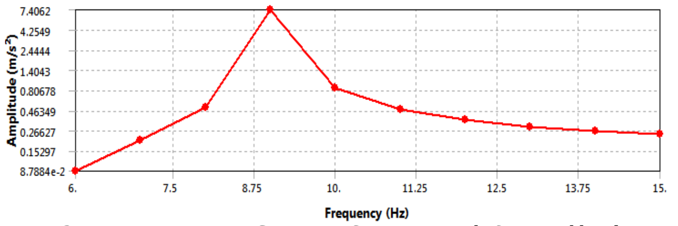

Fig. 13 Frequency response Curve For Support 1 with 6mm Rubberdamper

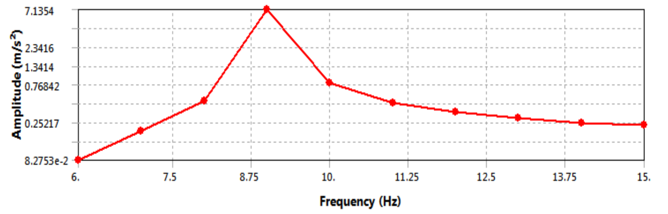

Fig. 14Frequency response Curve For Support 2 with 6mm Rubber damper

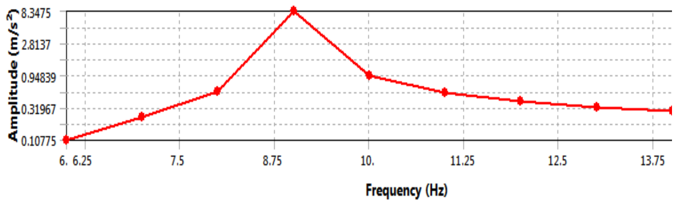

Fig. 15 Frequency response Curve For Support 1 with 6mm PVC damper

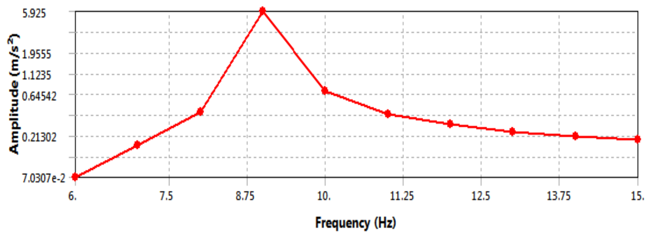

Fig. 16 Frequency response Curve For Support 1 with 9mm PVC damper

The acceleration in the system is reduced by around 55% by the use of 9mm PVC. Thus it is showing that the vibrations in the systemare reduced. Thus the results are obtained are much more accurate.

## VII. Conclusion

In the present work, attempt is made to assess the free modal response and harmonic response by using numerical tool (i.e. Ansys) and experimental test.The resonance frequency by FEA was found to be 5 Hz and 9.18 Hz by experimental test.Also the effect of varying the material of damper pad and thickness on frequency response of the structure. Amplitude decreases with increase in thickness of the pad.PVC pad is found to be good damper material as compared to Natural rubber.

## Acknowledgment

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