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Free Vibration Studies of Woodpecker Inspired Layered Shock Absorbing Structure

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Abstract A woodpecker can drum the surface of a tree at a rate of 18 to 22 times per second with a deceleration of 1200g without experiencing any blackout or brain damage. A woodpecker is able to do this because of its unique head structure; beak, hyoid, spongy bone and skull bone with cerebrospinal fluid. Based on this concept, a bio inspired layered shock absorbing structure was fabricated. The three layer structure consists of steel as outer layer, aluminium as intermediate layer with viscoelastic material in between and a core containing gel/beads were used. The shock absorbing structure was then subjected to free vibration analysis by considering it as cantilever beam with fixed free boundary condition. The natural frequencies of the structure including the fundamental mode and higher modes were estimated using vibration measuring apparatus integrated with software. Experimental results of the shock absorbing layers were compared with numerical results estimated using commercial finite element package ANSYS. Noticeable variation in the frequency can be associated with the shell mode vibration of the cylindrical shape and delamination effect in the layered structure. The free vibration studies are useful in estimating the damping characteristics of woodpecker beak inspired layered structure and can find applications in hybrid shock absorber design.

Keywords: *free vibration, woodpecker beak, layered structure, natural frequency*

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1. Introduction

Nature through natural selection allows certain traits to become prominent and certain others traits that do not help in the survival of the species to become non-existent. This process has taken place over billions of years. Hence nature has some of the finest designs to tackle various real life problems. One such unique design is a woodpecker's beak (family Picidae, order Piciformes). Most woodpeckers can drum a tree at 20 times per second and a deceleration of 1200g without brain concussions or g-force induced loss of consciousness (G-LOC) [1]. Analyses conducted on woodpecker [2] showed that its unique endoskeleton features that help to protect its brain from shock impacts are beak, hyoid, spongy bone, skull with less space for cerebrospinal fluid(CSF), The beak which is made from elastic material reduces mechanical excitations from reaching the brain. Hyoid is a structure that connects the woodpeckers' tongue to the back of its head, during drumming the woodpecker extends its tongue in order to evenly distribute incident mechanical excitations from drumming, hyoid also helps to reinforce the head. A spongy bone, which is specially located at the contrecoup position from the beak evenly distribute incident mechanical excitations before they propagate to the brain [3]. Finally, woodpecker has a very narrow space for CSF between the skull bone and brain. This bird therefore has a relatively little CSF, thereby reducing the transmission of the mechanical excitations into the brain through the CSF. From studying a woodpecker's head a shock absorbing layered structure was designed [2] that could reduce physical damages to micromachined devices placed inside it from external mechanical excitations.

The present work focuses on the fabrication and modal analysis of the new layered structure which mimics woodpecker beak. The free vibration studies are useful in estimating the damping characteristics of woodpecker beak inspired layered structure and can find applications in hybrid shock absorber design. Free vibration studies were conducted experimentally for various geometric shapes with fixed-free boundary condition [3]. The natural frequencies of the structure including the fundamental mode and higher modes were estimated using vibration measuring apparatus integrated with software. Experimental results of the shock absorbing layers were compared with numerical results estimated using commercial finite element package ANSYS.

2. Fabrication of layered Structure

Layered shock absorbing structure was fabricated with materials shown in Table 1 which give an analogy between woodpecker and layered shock absorbing structure. These materials have similar properties to the mentioned features present in a woodpecker.

Table 1. Analogy between woodpecker and layered shock absorbing structure

Woodpecker	Layered shock absorbing structure
Beak	Metal (steel) enclosure I
Hyoid	Viscoelastic layer (foam)
Spongy bone	Silicone Gel
Skull bone with CSF	Metal (aluminium) enclosure II

The innermost layer of the shock absorbing structure was made from Silicone gel, this layer was followed by a layer of aluminium, then a viscoelastic layer of foam (polyurethane), and this was covered by a layer of stainless steel. The fabricated layered shock absorbing structure is shown in Figure 1. In order to study the effects of different layers, different specimens were made, a specimen with only steel layer, with only aluminium layer, a specimen with gel inside aluminium layer, a specimen with steel, foam and aluminium layers and last a specimen with steel, foam, aluminium and gel. Cylindrical and square geometric shapes were used for fabrication. The dimensions of each layers of cylindrical and square shaped layered shock absorbing structure are given in Table 2 and Table 3.

Table 2. Dimensions of different layers of circular layered shock absorbing structure. *gel fills the entire space inside the aluminium layer

Layers	Outerdia (mm)	Thickness (mm)	Length (cm)
Steel	38	1.2	29.6
Aluminium	30	2	29.6
Foam(polyurethane)	35.6	5.6	29.6
Silicone Gel	26	*	29.6

Table 3. Dimensions of different layers of square cross sectioned layered shock absorbing structure. *gel fills the entire space inside the aluminium layer

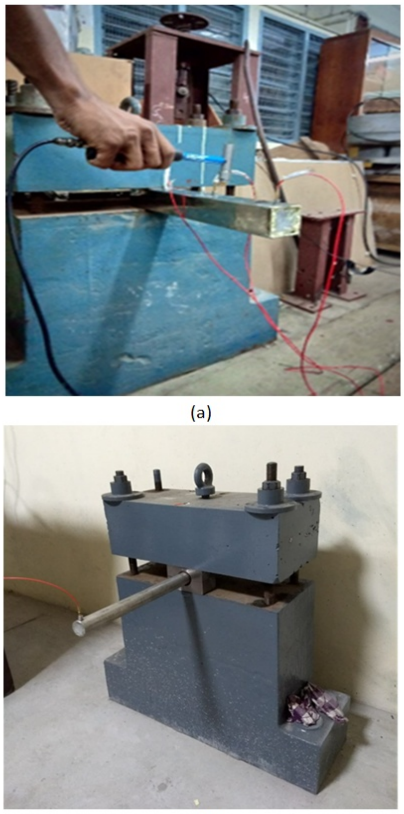
Layer	Side(mm)	Thickness (mm)	Length(cm)
Steel	50	1.5	35
Aluminium	38	2	35
Poly urethane foam	47	4.5	35
Silicone Gel (fill)	34	*	35

Figure 1. The fabricated layered shock absorbing structure with cylindrical and square geometry

3. Experiment Setup

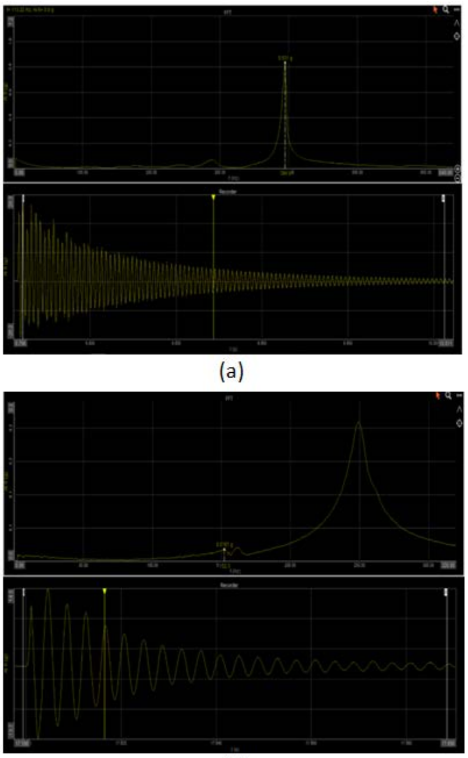
Free vibration studies of the two geometric shapes were carried out using fixed free boundary condition. Special fixtures were made to hold the cylindrical shape specimen. Experimental setup for square and cylindrical geometries was shown in Figure 2.

Excitation of the structure was made using an impact hammer. Accelerometers were placed on top of the beam to measure the displacements caused due to excitation of specimen. Using the integrated software of the vibration measuring apparatus results were extracted and frequency-amplitude graphs are plotted.



(a) (b)

Figure 2. Experimental set up for (a) Square geometry (b) Cylindrical geometry with special fixture



(a) (b)

Figure 3. Software integrated data acquisition for (a) Steel layer (b) steel, foam, aluminium and gel layers

Figure 3 shows the data extracted using the integrated software system for the steel layer and the bio inspired layered shock absorbing structure.

4. Natural Frequency Evaluation Using ANSYS

The natural frequencies found experimentally were validated using commercial finite element analysis package ANSYS [5]. Modal analysis was carried out and Block-Lancoz method was used for extracting the natural frequencies.

The properties of different materials used for fabricating the structure are given in Table 4. Using the above values and density, elastic modulus and Poisson's ratio given in Table 4, the fundamental and higher mode frequencies of the entire specimen were found.

Table 4. Properties of the materials used for the study.

Material	Density	Young's modulus	Poisons ratio	Reference
Stainless steel	7750 kg/m^3	1.93e11 Pa	0.3	Engineering data ANSYS
Aluminium	2710 kg/m^3	6.9e10 Pa	0.334	Engineering data ANSYS
Gel	1040 kg/m^3	52000Pa	0.32	Ref [6]
Foam	48 kg/m^3	1e8Pa	0.05	Ref [7]

The first mode of vibration of steel as well as bio inspired layered structure for cylindrical cross section is shown in Figure 4a and Figure 4b. The first mode of vibration of square cross section is shown in Figure 5a and Figure 5b.

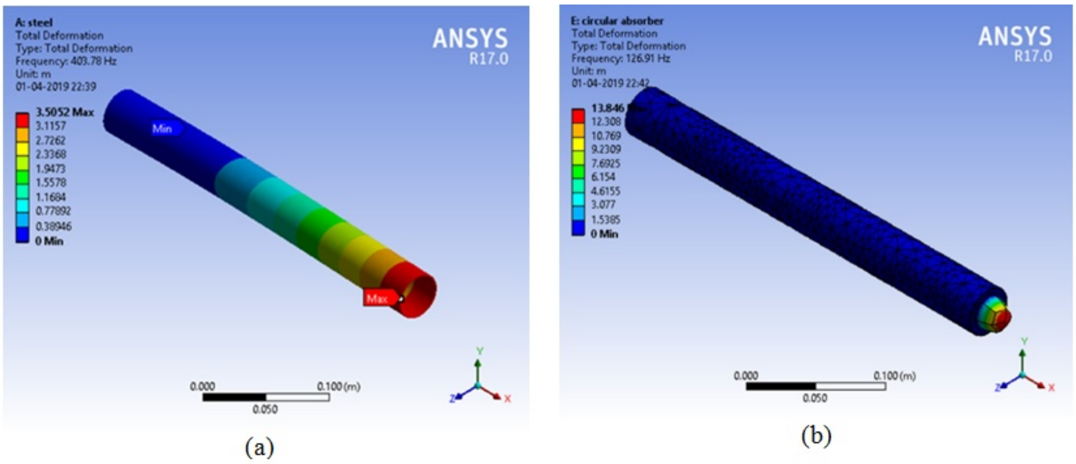


Figure 4. Cylindrical geometry ANSYS result for (a) steel layer (b) steel, foam, aluminium and gel

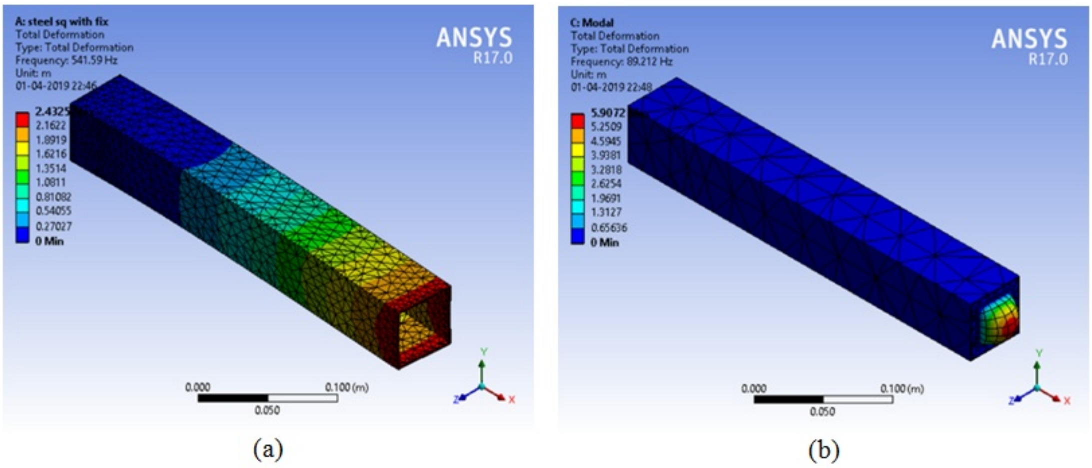


Figure 5. Square geometry ANSYS result for (a)steel layer (b)steel, foam, aluminium and gel

Table 5. Comparison of ANSYS and experimental results.

SPECIMEN	1st mode from ANSYS (Hz)	1st mode from experiment (Hz)
Steel square prism	541.59	473.83
Aluminium square prism	426.45	371.00
Square prism with steel, foam & aluminium	499.79	489.26
Square prism with aluminium & gel	89.34	90.04
Square prism with steel, foam, aluminium and gel	89.21	79.88
Steel cylinder	403.78	394.90
Aluminium cylinder	314.39	236.51
Cylinder with steel, foam & aluminium	175.79	349.10
Cylinder with aluminium & gel	126.35	150.51
Cylinder with steel, foam, aluminium and gel	126.91	249.3

5. Results and Discussion

Free vibration test was conducted on all the specimens using the experimental set up shown in Figure 2. Natural frequencies obtained experimentally and using ANSYS software are given in Table 5.

Figure 6 shows the frequency response curve for steel cylinder obtained from free vibration test. The first mode frequency was seen at 394.9Hz. From ANSYS software first mode was obtained at 403.78Hz.

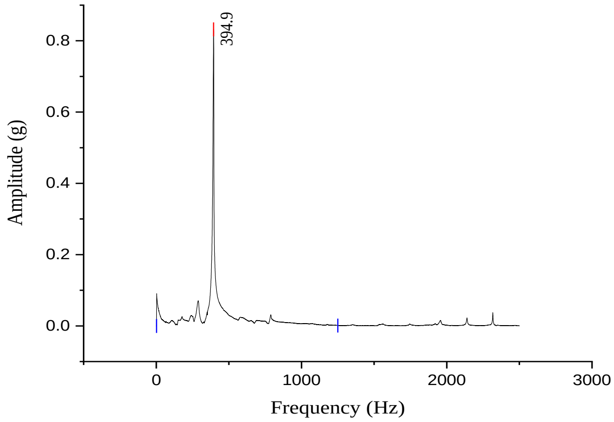


Figure 6. Experimental results for steel layer (circular cross section)

Figure 7 shows the frequency response curve for the layered cylindrical structure with steel, foam, aluminium and gel layers. The first mode frequency from the graph can be seen at 249.33Hz. First mode frequency obtained from ANSYS software was at 126.91Hz, the noticeable variation in the frequency can be attributed to the shell modes of vibration [8] associated with the cylindrical shape of the test specimen. The experimental fixed boundary condition of the structure due to lack of precise fixture and the delamination effect in the layered fabricated structure are other reasons for the significant variation in first mode frequencies.

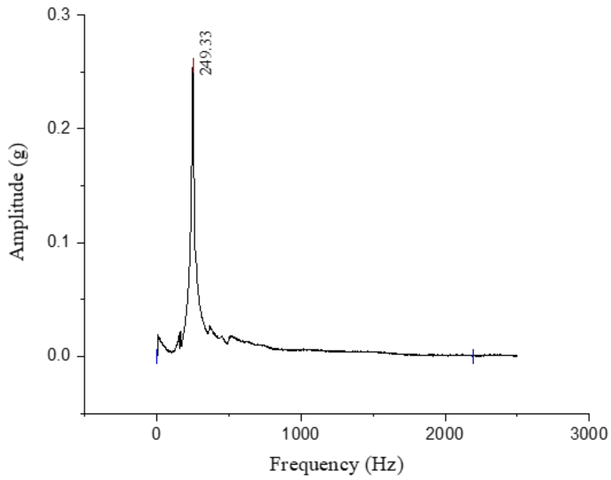


Figure 7. Experimental results for steel, foam, aluminium and gel layers (circular cross section)

Figure 8 show the frequency response curve for steel square cross section, first mode frequency can be seen at 473.83Hz. From ANSYS software first mode was obtained at 541.59Hz.

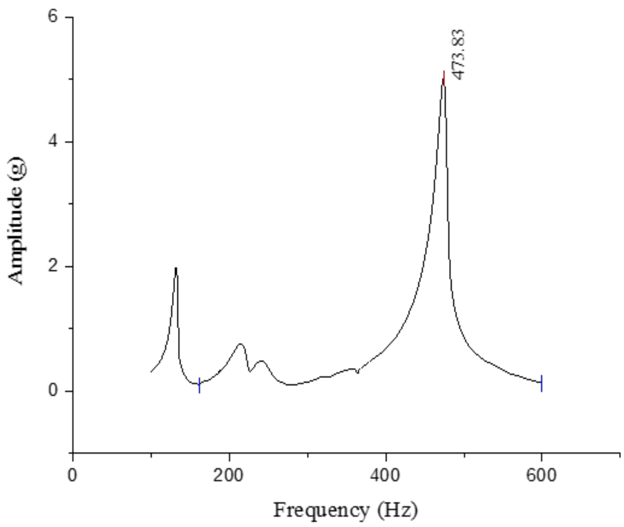


Figure 8. Experimental result for steel layer (square cross section)

Figure 9 shows the frequency response curve for cylinder with steel, foam, aluminium and gel layers, first mode can be seen at 79.88Hz. From ANSYS software first mode was obtained at 89.21Hz. The noticeable variation can be attributed to the experimental fixed boundary condition and the delamination effect in the layered fabricated structure.

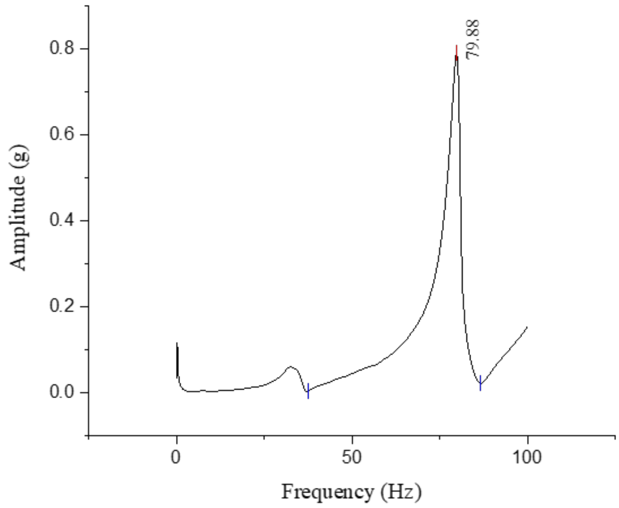


Figure 9. Experimental results for steel, foam, aluminium and gel layers (square cross section)

6. Conclusion

Woodpecker inspired layered shock absorber structure was fabricated. Free vibration experiment was conducted on individual layers as well as combination of layers. Natural frequencies were thus found out experimentally and using ANSYS software. Considering the low repeatability of free vibration experiments values were found to be in reasonable agreement. Noticeable variation in the frequency can be associated with the shell mode vibration of the cylindrical shape and delamination effect in the layered structure. The free vibration studies are useful in estimating the damping characteristics of woodpecker beak inspired layered structure and can find applications in hybrid shock absorber design.

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