Reduction of Vibration of DC motors in automobiles using sandwich metal composites

***Abstract* — The reduction of Noise, Vibration, and Harshness (NVH) in DC motor is one of the challenging task for car manufacturers. Methods to reduce NVH are found out and they do not prove to be too beneficial. In this paper, a cost effective and operational method has been analyzed. The use of sandwich metal composites using a viscoelastic core EC2216 and their characteristics has been investigated. It has been shown that the primary benefit of using a sandwich material is that the mass reduction of the entire system. The efficacy of damping of forced vibration by implementing sandwich material has been studied. The damping of vibrations and minimization of resonance is much effective by using sandwich material.**

Keywords—NVH; modal analysis; DC motor; sandwich material

I. INTRODUCTION

Use of motors is inevitable in various applications. Various types of motors are used in automobiles. In our current scenario, it is highly required that all vehicles must provide protection and comfort to the occupants, but there is one thing that the car manufacturers try to do without - NVH. NVH is the measure of how much unpleasant aural and tactile feedback car delivers as one drives. The primary and major source of NVH in cars and trucks are the noise and vibrations produced from large sized DC motors used to run the system apart from miniature applications of DC motors. Even very small levels of vibration across large panel areas can cause a significant increase in sound pressure in vehicle interior and potentially excite the cavities resonant modes of acoustic vibration. Hence proper research of functioning and optimization of motors is required. There are many methods to study the NVH of a system and Many modifications were proposed to reduce NVH, but none of the modifications was enough on its own to reach sufficient and reliable noise reduction [4]. Elimination of electrical noises are also studied [5]. One such analysis is presented in this paper regarding reducing the NVH in the motor under consideration.

Viscoelastic material has an inherent property to absorb excitations and converts it into heat energy thereby damping the vibrations. Such materials are extensively used various applications where damping of vibrations is required.

The causes for NVH in DC motors are electromagnetically induced vibrations, bearing vibrations, sliding contact vibration, imbalance vibrations, gear power transmission vibration, and undesirable forces, torques, and motions. Use of sandwich material which has a viscoelastic core is proposed and detailed analysis under free vibration and forced vibration conditions are made and compared with the actual motor casing which is made up of mild steel or aluminum.

A. Nomenclature

$[M]$ - *mass matrix*
$[\ddot{U}]$ - *second time derivative of displacement matrix*
$[U]$ - *displacement matrix*
$[\dot{U}]$ - *velocity matrix*
$[C]$ - *damping matrix*
$[K]$ - *stiffness matrix*
$[F]$ - *force vector*
ζ - *damping ratio*

II. PROBLEM DESCRIPTION

For a DC motor used in the car, the vibration levels must be reduced greatly and chances of resonance should be minimized. As the armature rotates in the

Suhas S, Isac Rajan, Preetam Kabade (B. Tech 3rd Year Mechanical Engineering)
suhasshekar27@gmail.com, isacrajan@gmail.com, preetamkabade@gmail.com
P Jeyaraj
Assistant Professor
pjeyaemkm@gmail.com
National Institute of Technology Karnataka (NITK), Surathkal

DC motor, mechanical or electrical imbalances generate vibrations inside the casing. Hence the response of the casing to forced vibration is to be studied, and methods to reduce that has to be found out. The objective of the proposed work is to show that the forced vibrations are effectively damped in SPS casing as compared to casing made of pure metal.

To check the reduction in weight due to use of sandwich material a mass analysis is performed.

III. Design Details

Every DC motor has six basic parts - axle, rotor (armature), stator, commutator, field magnets, and brushes. In most common DC motors, the external magnetic field is produced by high-strength permanent magnets. The stator is the stationary part of the motor - this includes the motor casing, as well as two or more permanent magnet pole pieces. The rotor rotates with respect to the stator. The rotor consists of windings, the windings being electrically connected to the commutator.

The casing protects the parts and is used to fix the motor in its position by constraining all degrees of freedom. As the power of the motor increases the

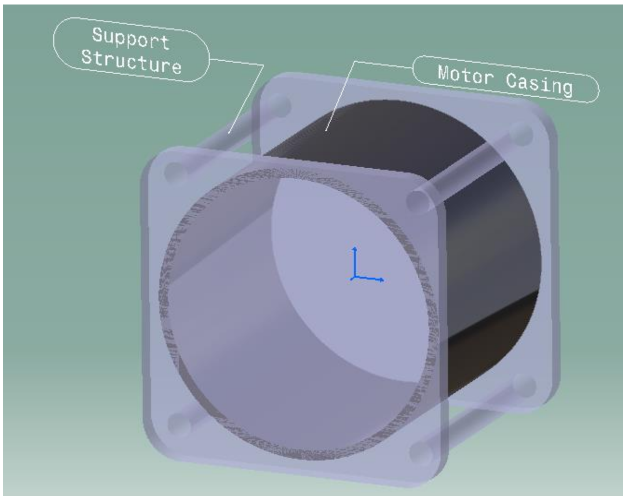

Figure 1: Motor Casing Model

dimensions of the casing also increases. In this paper, we study the free and forced vibration analysis of DC motor casing that is popularly used in electric cars. The power specification of the motor is considered around 20 to 30 kW. The voltage specification of the motor is around 96 to 120 volts. The motor dimensions were obtained from a commercial motor. The outer diameter of the casing was taken 300 mm and the axial length of the motor was taken to be 250 mm. The thickness of the casing is 10 mm. The casing of the motor was modelled in CATIA V5. It is clamped on both ends by the support structure as shown in Figure 1.

Two cases are considered here. Once the casing is considered to be made of pure metal - aluminum or mild steel. In the other case, viscoelastic core is introduced with metal layer enveloping it. Sandwich Plate Structure (SPS) is chosen as the structural composite material with two metal layers of equal thickness enclosing a light-weight polyurethane elastomer EC2216 [3]. The dimensions of the casing for different cases are presented in Table I. The material properties are shown in Table II.

TABLE I. DIMENSIONS

Casing	*Diameter (mm)*	*Length (mm)*	*Thickness (mm)*
Metal	300	250	10
Sandwich	300	250	Outer layer = 2 Core = 6 Inner layer = 2

TABLE II. PROPERTIES OF MATERIALS

Material	*Young's Modulus (GPa)*	*Poisson Ratio*	*Density (kg/m^3)*
Mild Steel	210	0.3	7850
Aluminum	68.9	0.33	2700
EC2216 [1,2]	1.34	0.3	1340

IV. Analysis Details

The basic approach to solve the problem is depicted in Figure 2.

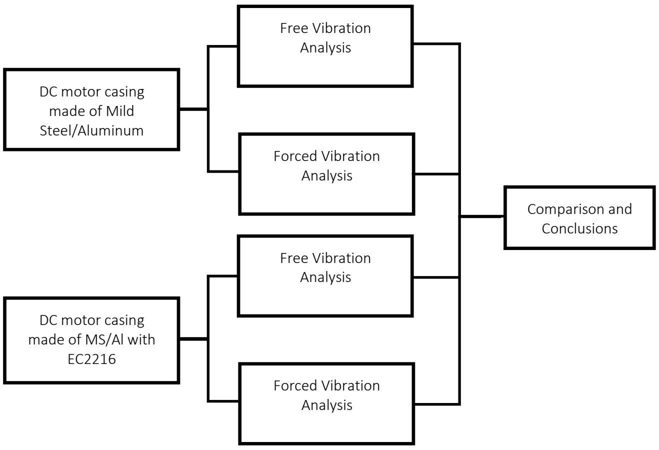

Figure 2: Flowchart

Suhas S, Isac Rajan, Preetam Kabade (B. Tech 3rd Year Mechanical Engineering)
suhasshekar27@gmail.com, isacrajan@gmail.com, preetamkabade@gmail.com
P Jeyaraj
Assistant Professor
pjeyaemkm@gmail.com
National Institute of Technology Karnataka (NITK), Surathkal

A. Modal Analysis

The goal of modal analysis is to determine the natural mode shapes and frequencies of an object or structure during free vibration. FEM is used to perform this analysis. For FEM eigenvalue modal analysis problem for a linear elastic material, the matrix equations take the form of dynamics three-dimensional spring mass system. The generalized equation of motion is given as:

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

In this analysis, the value of damping ratio ζ for Mild Steel is taken as 0.01 and for sandwich structure it is taken as 0.1 [6].

B. Boundary Conditions

The ends of the motor casing were given the fixed support boundary condition.

C. Mass Analysis

The mass of Mild Steel casing with the dimensions given in Table I is calculated to be 17.88 kg.

If the sandwich material is used as the casing with Mild Steel as the enveloping layer the mass of the casing comes out to be 8.983 kg. It can be noted that it is nearly 50% reduction in the weight of the casing.

The mass of Aluminum casing with the said dimensions is 6.15 kg.

Again, if sandwich material with aluminum as the enveloping layer is employed the mass of the casing comes out to be 4.291 kg. It is notable that a mass reduction of around 30% is obtained.

Hence it can be concluded from mass analysis that the reduction in mass of the casing is remarkable and this can be very much advantageous in terms of cost and efficiency of the vehicle.

V. Results

A. Free Vibration Analysis

Free vibration occurs when a mechanical system is set in motion with an initial input and is allowed to vibrate freely. The mechanical system vibrates at one or more of its natural frequencies and damps down to motionlessness.

Table III shows the convergence study for five mode shapes carried out in ANSYS Modal Analysis workbench module for Mild Steel casing.

TABLE III. CONVERGENCE STUDY FOR METAL CASIING

Element Size	Natural Frequencies (Hz)				
	1	2	3	4	5
10mm	2374.8	2374.8	2604	2604.3	2791.8
7.5mm	2370.3	2370.4	2600.5	2600.6	2788.3
6mm	2370.2	2370.3	2600.4	2600.5	2788.2
5mm	2369.8	2369.8	2600	2600	2787.9
4mm	2369.5	2369.6	2599.7	2599.7	2587.7

The same study done for casing with sandwich material with EC2216 viscoelastic carried out is given in Table IV.

TABLE IV. CONVERGENCE STUDY FOR SANDWICH CASIING

Element Size	Natural Frequencies (Hz)				
	1	2	3	4	5
15mm	1841.3	1841.3	2032.5	2032.5	2118.1
12.5mm	1841.3	1841.3	2032.8	2032.8	2118
10mm	1839.7	1839.7	2029.8	2029.9	2117.2
7.5mm	1840.1	1840.1	2031.2	2031.2	2117.2
6mm	1840.3	1840.3	2031.9	2031.9	2117.2

The simulation results for free vibration analysis is shown in Figure 4.

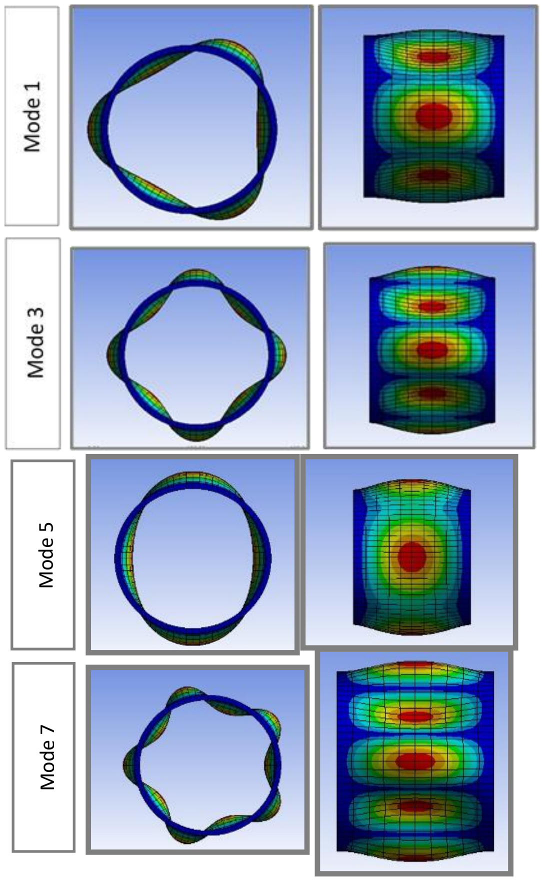

Figure 3: Mode shapes 1, 3, 5, and 7

Suhas S, Isac Rajan, Preetam Kabade (B. Tech 3rd Year Mechanical Engineering)
suhasshekar27@gmail.com, isacrajan@gmail.com, preetamkabade@gmail.com

P Jeyaraj
Assistant Professor
pjeyaemkm@gmail.com

National Institute of Technology Karnataka (NITK), Surathkal

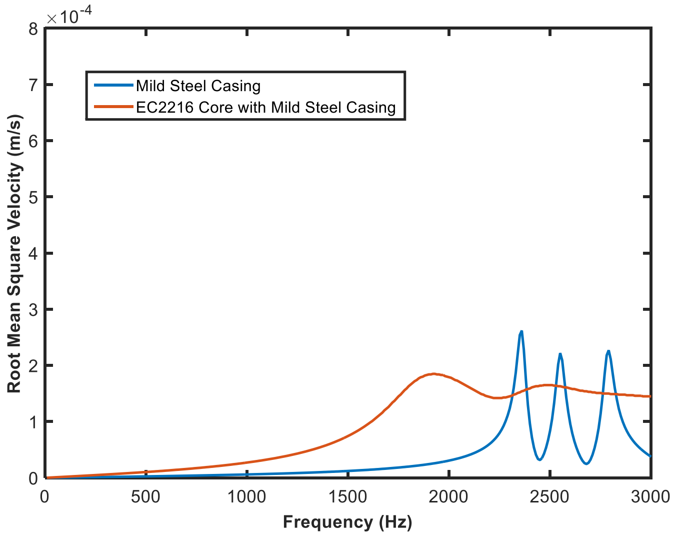

Figure 4: Vrms - Frequency for Mild Steel and SPS

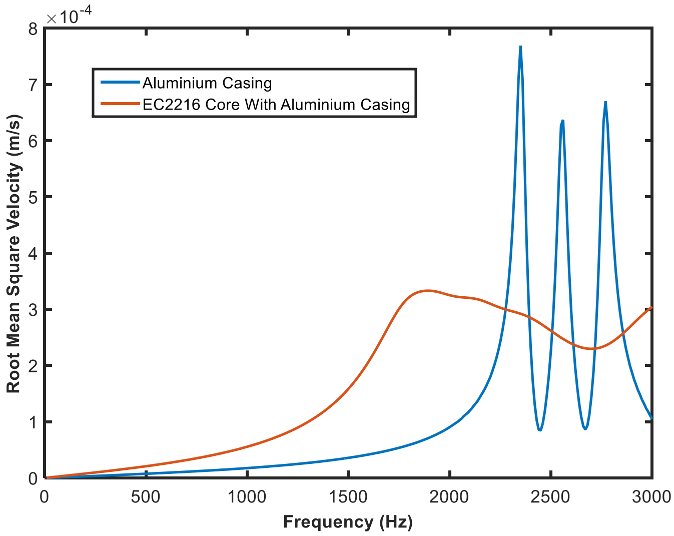

Figure 5: Vrms - Frequency for Aluminum and SPS

B. Forced Vibration Analysis

The variation of root mean square velocity of every nodes in the system is averaged and is plotted against input frequencies from 0 to 3000 Hz for the input force of 1 newton on the casing. This explains at what frequency is resonance is attained. This is to study the response of the structure to forces with different frequencies. The peaks are very sharp as shown in Figure 4 and Figure 5 at resonance for Mild Steel and Aluminum.

It can be noted that the by using sandwich material the amplitude of velocity is reduced drastically and the effect of resonance is minimized. The resonance does happen but the change of amplitude is smooth and it has less effect on the overall system.

VI. CONCLUSIONS

From the above analysis, we can conclude that sandwich material is suitable replacement in place of pure metal casing to reduce vibration. The similar study can be extended for acoustic (noise) and its harshness. On comparison of Mild Steel sandwich with Aluminum sandwich it can be stated that due to damping, weight reduction factor, structural strength and stability Mild Steel EC2216 sandwich material is more preferable.

VII. REFERENCES

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suhasshekar27@gmail.com, isacrajan@gmail.com, preetamkabade@gmail.com

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