NVH Characterization of Composite Material for Commercial Vehicle Frame Components

Sagar V. Vispute¹, A. P. Tadamalle²

¹PG Scholar, Department of Mechanical Engineering, Sinhgad College of Engineering, Vadgaon (Bk), Pune, INDIA
²Associate Professor, Department of Mechanical Engineering, Sinhgad College of Engineering, Vadgaon (Bk), Pune, INDIA

ABSTRACT

The purpose of this paper is to study NVH (Noise Vibration and Harshness) characterization of composite material component use in commercial vehicle by using finite element software. Noise and vibration is considered as an important aspect in development of vehicle. Composite materials are becoming famous in automobile sector as they have high strength, damping and low mass density, although they are relatively costlier. Moreover composite properties can be changed by tuning material composition, fiber orientation angle and layer thickness. Front cage model is evaluated for its modal and dynamic response. Simulation is carried out using 2D PCOMP element of HYPERMEH and NASTRAN. Predicted modal and dynamic responses are validated with experimental results. Composite component shows considerable weight saving with improved performance over sheet metal.

Keywords—Front Cage, Carbon Composite, Experimental Modal Analysis, Zone Based Composite Modeling, NVH Performance.

I. INTRODUCTION

Nowadays, development in technology demands engineering design field to be competitive and creative to meet the challenging competition. Transportation is major sector contributing CO₂ emission. The challenge faced by automotive industry is to reduce CO₂ emission and use of eco-friendly components at competitive vehicle cost. Composite materials are becoming famous in automobile sector as they have high strength, damping and low mass density, although they are relatively costlier. Moreover composite properties can be changed by tuning material composition, fiber orientation angle and layer thickness. Noise and vibration is considered as an important aspect in development of vehicle. Resonance of systems, subsystems is main cause of noise and vibration in vehicles. NVH performance of components or systems can be cascaded down to modal parameters, dynamic responses (VTF/NTF) for various transfer paths.

Composite materials are light in weight and have good energy absorption capacity but use of composite in replacement of sheet metal needs change in component design and manufacturing process, it restricts use of composite in automobiles [1, 2]. Modal parameters like natural frequency, dynamic stiffness are highly depend on geometrical parameters as fiber orientation angle, fiber length, material composition and stacking sequence [3, 5]. Composite parts failure like delamination, micromechanical changes and fiber pullout are depends on fiber angle and fiber length [4].

Finite Element Analysis is very famous to mathematically model and numerically solve complex structural and fluid problems [6]. FEA software package helps in cost and time saving in studying economic design and study on various materials and its properties under variable lodes [9]. To estimate best combination of layer thickness, stacking sequence and orientation angle modal and dynamic response analysis is required. Finite Element Analysis is chosen for analysis in this work.

Front cage is experimentally tested for its modal and dynamic response to predict modal parameters. Simulation is carried out using 2D PCOMP element of FEA software HYPERMEH and NASTRAN. Model is divided in to finite zones based on similarity in number of layers and fiber orientation angle. Simulated modal and dynamic responses are compared with experimental results in free- free boundary condition.

II. COMPOSITE MATERIAL
Compositematerials are made from two or more constituent materials (matrix and reinforcement) with significantly different physical or chemical properties, when combined, produce a material with characteristics different from the individual one. The individual components remain separate and distinct within the finished structure. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. Mostly fibers are used as the reinforcing phase and are much stronger than the matrix and the matrix is used to hold the fibers intact. Examples of such composites are an aluminum matrix embedded with boron fibers and an epoxy matrix embedded with glass or carbon fibers. As composites are multi-layered, they are much stronger and break resistant than single layer sheet metals.

A. Fabrication Process

The reinforcing and the matrix elements undergo a molding method, in which these materials are combined and compacted. There are various types of molding methods, including autoclave molding, vacuum bag molding, and resin transfer molding, among others. In automobile engineering, tooling materials used for the manufacture of composites include invar, aluminum, carbon fiber, steel and reinforced silicon rubber. Here UD HM CFRP (Uni-Directional High module Carbon Fiber Reinforced Polymer) material with injection molding process has been selected for front cage.

B. Fundamental Property Relationship

The physical properties of composite materials are orthotropic. When a unidirectional continuous-fiber lamina or laminate is loaded in a direction parallel to its fibers (0°) the longitudinal modulus $E_{11}$ can be estimated from its constituent properties by using the rule of mixtures:

$$E_{11} = E_f V_f + E_m V_m$$

(1)

The longitudinal tensile strength $\sigma_{11}$ also can be estimated by the rule of mixtures:

$$\sigma_{11} = \sigma_f V_f + \sigma_m V_m$$

(2)

When the lamina is loaded in the transverse (90° or 22-direction), the fibers and the matrix functions in series, with both are carrying the same load. The transverse modulus of elasticity $E_{22}$ is given as:

$$\frac{1}{E_{22}} = \frac{V_f}{E_f} + \frac{V_m}{E_m}$$

(3)

Poisons ratio can be found out by following equation 4,

$$\mu_{12} = \mu_f V_f + \mu_m V_m$$

(4)

While these micromechanics equations do not yield sufficiently accurate values for design purposes and are useful for a first estimation of lamina properties when no data are available. For design purposes, basic lamina and laminate properties should be determined using actual mechanical property testing.

C. Composite Over Traditional Material

The physical characteristics of composites and metals are significantly different. Table 1 compares some properties of composites and general purpose steel (GPS). Because composites are highly anisotropic, their in-plane strength and stiffness are usually high and directionally variable, depending on the orientation of the reinforcing fibers. Properties that do not benefit from this
reinforcement are comparatively low in strength and stiffness. Metals typically have reasonable ductility, continuing to elongate or compress considerably when they reach a certain load (through yielding) without picking up more loads and without failure. Because of this ductility, metals have a great capacity to provide relief from stress concentrations when statically loaded also it provides great energy-absorbing capability. As a result, when impacted, a metal structure typically deforms but does not actually fracture. In contrast, composites are relatively brittle.

Table I  
**Comparison between GPS and Composite**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Composite</th>
<th>GPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load-strain relationship</td>
<td>More</td>
<td>Less</td>
</tr>
<tr>
<td>Static Notch sensitivity</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Fatigue sensitivity</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Transverse properties</td>
<td>Weak</td>
<td>Strong</td>
</tr>
<tr>
<td>Mechanical properties</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Fatigue strength</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Hydrothermal Sensitivity</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Sensitivity to corrosion</td>
<td>Much less</td>
<td>High</td>
</tr>
</tbody>
</table>

### III. Modal Analysis

The modal analysis is a field of measuring and analyzing dynamic response of the structure or fluid under vibration. The dynamic analysis is performed to determine modal parameters as undamped natural frequencies and mode shapes of the structure. These results characterize the basic dynamic behavior of the structure and are an indication of how the structure will respond to dynamic loading. Natural frequencies and mode shapes are functions of the structural properties and boundary conditions.

#### A. Experimental Modal Analysis

The purpose of experimental modal analysis is to find modal parameters of a component in free-free boundary condition. During experiment component geometry is assume to be symmetric and maintained during free-free boundary condition. Component is excited with unit force with help of hammer and output is measured at multiple accelerometer locations. Dynamic signal analyser computes the FRFs (Frequency Response Function). FRF is defined as ratio of the Fast Fourier Transformation of Response/Excitation. FRF is property of linear dynamic system and does not depend on magnitude or nature of excitation force.

![Figure 2: Experimental test set-up for front cage](image)

Experimental test set-up for front cage is shown in figure 2. Cage is horizontally suspended using four elastic bungee cables. Seven tri-axial accelerometers are connected by multichannel Data Acquisition system. Cage is excited on twenty five measurement points in X, Y and Z direction by plastic tip hammer as shown in figure 2. More measurement points more accurate, smooth and clear will be the mode shapes. Hammer response obtained from accelerometers are sends to LMS SCADA digital signal analyzer and FRFs are stabilized by stabilization techniques. Peaks in stabilization diagrams are related to mode of vibration with specific resonant frequency.

![Figure 3: Stability index diagram for front cage](image)

Figure 3 shows stability index diagram for front cage in frequency domain. Red curve indicates frequency response; each peak corresponds to natural frequency. Green curve shows phase change for a particular mode corresponding to that of natural frequency. During experiment eleven natural resonant frequencies observed out of which first six are considered for comparison.

#### B. FEA Model Building and Simulation

The FEA modeling of composite involves surface modeling and meshing. Composite part is complicated in modeling as it consists of many layers with variable thickness. Composites are either orthotropic or anisotropic. Part is divided into finite zones with similar number of
plies and stacking sequence. Simple CAD model is prepared in CATIA V5. CAD model contains only surface geometry, no any data about type of material, property and stacking sequence. This CAD model (.igs) is then imported in Altair HYPERMESH 13. Then model is mesh with 2D 1st order elements, quad and triangle. Model is divided in eight zones based on composite layers. Table 2 shows layer details for front cage.

<table>
<thead>
<tr>
<th>Zone</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front cage</td>
<td>8</td>
<td>13</td>
<td>12</td>
<td>25</td>
<td>7</td>
<td>38</td>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>

Zones are divided on basis of similarity in number of layers, stacking sequence, fiber angle, layer thickness, material orientation vector and element normal. Material orientation vector orients modulus of elasticity of fiber in a particular direction. Figure 4 shows front cage model.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Card</td>
<td>MAT8</td>
</tr>
<tr>
<td>Property Card</td>
<td>PCOMP</td>
</tr>
<tr>
<td>Modulus of Elasticity for Matrix (E₂)</td>
<td>30E3 N/mm²</td>
</tr>
<tr>
<td>Modulus of Elasticity for Fiber (E₁)</td>
<td>400E3 N/mm²</td>
</tr>
<tr>
<td>Poison’s Ratio (μ₁₂)</td>
<td>0.2</td>
</tr>
<tr>
<td>Mass Density (ρ)</td>
<td>3.2E-9 Tones/mm³</td>
</tr>
<tr>
<td>Layers thickness t₁</td>
<td>0.25mm</td>
</tr>
</tbody>
</table>

**IV. RESULTS AND DISCUSSION**

The comparison between simulated and experimental results shows that FEM models are well suited for calculating the frequencies and modes of different composite parts. The maximum frequency difference of 5% is obtained at first (67.53 Hz) and the fifth (254.2 Hz) mode and less than 10% for modes two, three and six. Maximum frequency difference of 17.8% obtained at fourth (228.3 Hz) mode for front cage as shown in figure 5 below. The simulation results are in good correlation with that of experimental modal performance of composite cage component.

**V. CONCLUSION**

The results of the equivalent model presented in this analysis are obtained with good accuracy which presents an efficient approach during the development of the composite parts leading into the reduction of the cost and the time of analysis. Hence modeling approach use in current work is suitable to model composite material. The present work can be evaluated to analyze effect of geometry parameter and change of material on NVH performance of composite front cage.

**VI. ACKNOWLEDGMENT**
It is precious moment to acknowledge the various individuals who helped us during completion of this paper. I am thankful to NVHCAE team, ERC TATA MOTORS Ltd. for their contribution to successful completion of this work.

REFERENCES