Identification of sound radiation in a GFRP plate

Myoung-Woon Kim\(^1\); Sang-Kwon Lee\(^1\);  
1 Department of mechanical engineering, Inha University, The Republic of South Korea

ABSTRACT

Weight lightening of a vehicle is one of big issues in the automotive engineering. The weight reduction of the structure in a GFRP plate yields the increase of vibration and noise because of effect of mass in vibroacoustics. Therefore, a new method is required to control the vibration and noise in a GFRP Plate. In order to control the vibration and noise in a GFRP plate, this paper developed a new method based on the optimal arrangement of the reinforced paper. The developed method is applied to the controlling the radiation noise and interior noise in a vehicle with GFRP plate roof. For this work, three GFRP plates with different arrangement of reinforced fiber are used for the acoustic and vibration analysis. From the results of this analysis, it is known that sound pressure radiated from plate is corresponded with vibration modes of plates. In addition, it is found that natural frequencies and vibration modes of plates was related to the arrangement of the reinforced fibers. Finally, the acoustics and vibration characteristics was controlled by the arrangement orientation of reinforced fiber.

Keywords: Glass fiber, Radiation, Plate  
I-INCE Classification of Subjects Number(s): 42

1. INTRODUCTION

Recently, in many fields, vessels, automobiles, aerospace and home appliances, weight lightening is a major research topic [1-2]. One method is to use a GFRP (Glass Fiber Reinforced Plastic) plate instead of metal because GFRP has lower density than metal and the strength of fiber direction is similar to the strength of metal [3]. Study on manufacturing, fracture and stress analysis on the GFRP has been proceeded continuously [3-4] but a study on the noise and vibration characteristic has relatively been preceded [5]. In this paper, the noise and vibration characteristic of the laminated GFRP is studied and the effect of orientation of reinforced fibers has been investigated to reduce the structure borne sound radiated from a CFRP plate. For this work, numerical method is employed.

2. Theory

2.1 Vibration of plates

The equation of motion for the vibration of GFRP plate is generally given [2],

\[
D_{11}\frac{\partial^4 w}{\partial x^4} + 4D_{16}\frac{\partial^4 w}{\partial x^2 \partial y^2} + 2(D_{15} + 2D_{16})\frac{\partial^4 w}{\partial x \partial y^3} + 4D_{26}\frac{\partial^4 w}{\partial x^2 \partial y} + D_{12}\frac{\partial^4 w}{\partial y^4} + \rho h \frac{\partial^2 w}{\partial t^2} = f(x, y, t)
\]

If a concentrated load with a harmonic function is applied at any points on the plate with fixed boundary condition, the dynamic response \(W(x,y)\) is expressed in terms of vibrational mode shape of the plate and is given by,

\[
W(x,y) = \sum_{k=1}^{n} \sum_{m=1}^{n} \int_{0}^{a} \int_{0}^{b} F(x,y)X_k(x)Y_m(y) dx dy \left( D_{11}I_{11} + 4D_{16}I_{12} + 2(D_{15} + 2D_{16})I_{16} + 4D_{26}I_{26} + D_{12}I_{12} \right) - \rho h \omega^2 X_k(x)Y_m(y)
\]

The natural frequency of the plate corresponding to the mode shape is expressed as follows:

\[
\omega = \sqrt{\frac{1}{\rho h} \left( D_{11}I_{11} + 4D_{16}I_{12} + 2(D_{15} + 2D_{16})I_{16} + 4D_{26}I_{26} + D_{12}I_{12} \right)}
\]
where \( m \) and \( n \) mean \( x \) and \( y \) directional modal lines respectively.

### 2.2 Acoustic radiation

If the geometric coordinate of a plate is given as shown in Fig.1, the sound pressure radiated by the vibration of the plate is expressed with the Rayleigh integral equation [3] and given by

\[
p(x, y, z) = \frac{j\omega \rho_0}{2\pi} e^{j\omega t} \sum s \frac{V(x', y', t)e^{-j|r-r'|}}{|r-r'|} ds
\]

where \( V \) is the vibration of plate.

### 3. Numerical analysis for vibration and sound

For this analysis, three GFRP plates with fiber orientation \( \pm 30^\circ \), \( \pm 50^\circ \) and \( \pm 70^\circ \) were fabricated as shown in Fig.2. At the first, the vibrational mode shapes and natural frequencies of a plate were obtained because the structure borne sound of a plate is related to them. The plate is excited by the impact hammer and the vibration of plate and sound radiated from the plate are measured simultaneously as shown in Fig.3. The transverse velocities over the surface of plates excited by the force were computed by numerical method. For the numerical calculation, the finite element model of a test plate is produced and the natural frequencies and mode shapes are calculated by a commercial software. The force vibration was also calculated and this result was used for the calculation of the sound radiated from plates. Finite element method (FEM) method was used for the vibration calculation and boundary element method (BEM) was used for the calculation of the sound pressure. The commercial software for these calculation is Virtual Lab is supplied by Siemens Company currently.
4. Results of experiments and numerical analysis

4.1 Mode

Natural frequencies and mode shape obtained by numerical method are listed in Table 1.

Table 1 – Results according to the fiber arrangement angle [Hz]

<table>
<thead>
<tr>
<th>Angle</th>
<th>±30°</th>
<th>±50°</th>
<th>±70°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode 1 Mode shape</td>
<td><img src="image.png" alt="Mode 1 Mode shape ±30°" /></td>
<td><img src="image.png" alt="Mode 1 Mode shape ±50°" /></td>
<td><img src="image.png" alt="Mode 1 Mode shape ±70°" /></td>
</tr>
<tr>
<td>Frequency</td>
<td>38.2</td>
<td>43.3</td>
<td>49.3</td>
</tr>
<tr>
<td>Mode 2 Mode shape</td>
<td><img src="image.png" alt="Mode 2 Mode shape ±30°" /></td>
<td><img src="image.png" alt="Mode 2 Mode shape ±50°" /></td>
<td><img src="image.png" alt="Mode 2 Mode shape ±70°" /></td>
</tr>
<tr>
<td>Frequency</td>
<td>68.2</td>
<td>65.8</td>
<td>63.9</td>
</tr>
<tr>
<td>Mode 3 Mode shape</td>
<td><img src="image.png" alt="Mode 3 Mode shape ±30°" /></td>
<td><img src="image.png" alt="Mode 3 Mode shape ±50°" /></td>
<td><img src="image.png" alt="Mode 3 Mode shape ±70°" /></td>
</tr>
<tr>
<td>Frequency</td>
<td>86.0</td>
<td>100.7</td>
<td>90.2</td>
</tr>
<tr>
<td>Mode 4 Mode shape</td>
<td><img src="image.png" alt="Mode 4 Mode shape ±30°" /></td>
<td><img src="image.png" alt="Mode 4 Mode shape ±50°" /></td>
<td><img src="image.png" alt="Mode 4 Mode shape ±70°" /></td>
</tr>
<tr>
<td>Frequency</td>
<td>110.4</td>
<td>105.8</td>
<td>127.2</td>
</tr>
<tr>
<td>Mode 5 Mode shape</td>
<td><img src="image.png" alt="Mode 5 Mode shape ±30°" /></td>
<td><img src="image.png" alt="Mode 5 Mode shape ±50°" /></td>
<td><img src="image.png" alt="Mode 5 Mode shape ±70°" /></td>
</tr>
<tr>
<td>Frequency</td>
<td>121.5</td>
<td>131.0</td>
<td>129.0</td>
</tr>
<tr>
<td>Mode 6 Mode shape</td>
<td><img src="image.png" alt="Mode 6 Mode shape ±30°" /></td>
<td><img src="image.png" alt="Mode 6 Mode shape ±50°" /></td>
<td><img src="image.png" alt="Mode 6 Mode shape ±70°" /></td>
</tr>
<tr>
<td>Frequency</td>
<td>157.2</td>
<td>146.8</td>
<td>142.0</td>
</tr>
</tbody>
</table>

According to this result, mode shape tends to occur perpendicular to the fiber arrangement direction because of the relatively small stiffness for perpendicular to the fiber directions the fiber in a direction.
4.2 Vibration and sound radiation

![Graph 1: ±30°s result for vibration and sound radiation](image1)

Figure 4- ±30°s result for vibration and sound radiation

![Graph 2: ±50°s result for vibration and sound radiation](image2)

Figure 5- ±50°s result for vibration and sound radiation

![Graph 3: ±70°s result for vibration and sound radiation](image3)

Figure 6- ±70°s result for vibration and sound radiation
Fig 4–6 show the results of vibration and acoustic for laminated GFRP plate. Vibration results are the frequency response function (FRF). Acoustic results are the sound pressure level normalized by the excitation force. Since the sound pressure is determined by the vibration speed of the plate, the peak sound pressure level should be corresponded with that of vibration. If the mode shape is symmetric, as shown in the table, sound radiation does not occur. For this case, the larger the angle of the fiber arrangement tends to increase the frequency of the primary mode affecting the overall sound pressure level.

5. CONCLUSIONS

It is known that vibration and acoustic character of a GFRP plate is changed by the arrangement of the orientation of reinforce fiber in a GFRP plate. The arrangement of the fiber can be used for the control of sound radiated from a GFRP plate.

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