Mass Optimization of Decklid Subsystem for Passenger Vehicles

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Abbreviations:  
FEA - Finite Element Analysis  
DESVAR - Design Variables  
DESOBJ - Design Objective  
DCONSTR - Design Constraints

Keywords: Decklid, Mass, Optimization, Aluminum, Hinge assembly

Abstract
This paper highlights the work done on the optimization of decklid subsystem for weight reduction of passenger vehicles. The existing steel hinges are replaced by aluminum hinges with minor geometry modifications. Hinge assembly consists of hinge brackets, goose neck tubes and U-channel brackets which are of approximate 3.4 kg in weight. Size optimization technique is applied to decklid assembly to get the effective thickness of hinge assembly. Proposed hinge assembly is of light weight aluminum material which is virtually validated for different criteria such as static and dynamic performance. There is approximate 35% weight reduction achieved without deviating from required decklid performance. Results are compared for aluminum and steel hinges.

Introduction
Now a days, using light weight structural material is a trend in automotive industries which will benefit fuel economy and power to weight ratio of the vehicle. This work highlights the size optimization of decklid subsystem for mass reduction, thickness of the Hinge assembly is considered as design variable. Stiffness and frequency are considered as design constraints. The existing components are all of steel with respective grades and are satisfying the static and dynamic load conditions. In order to reduce the weight, the existing hinge assembly of steel material is replaced by aluminum material and performed the size optimization technique available in HyperWorks® OptiStruct to get the effective thickness for hinge assembly to meet the required criteria.

Methodology
1.0 Geometry and FE Model
Decklid assembly consists of inner panel, outer panel, hinge reinforcement, latch reinforcement and the hinge assembly as shown in figure 1. All components are modeled (FE Model) with shell elements. Outer and inner panels are connected with adhesive. Hemming is done along the edge of the outer and inner panels. Hinge reinforcement is connected with inner panel through spot welds. Hinge assembly is sub assembly of decklid system consists of hinge bracket, gooseneck tube and U-channel bracket as shown in figure 2. Hinge assembly is bolted to inner panel and hinge reinforcement. Hinge pivot is modeled in such a way that decklid rotates freely about hinge axis.

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2.0 **Purpose of the Decklid Gooseneck Strap**

a) The main purpose of the gooseneck strap is to attach the decklid to the body. The strap and pivot determine the swing motion of the decklid.

b) To provide lateral stiffness to the open lid and to maintain gaps and flushness of a closed lid.

c) To mount the check stop, thus providing a positive stopper for the opened decklid.

d) To provide a mount for counterbalance (torque rods, extension springs) which assists in opening and closing of the decklid.

Hinge assembly as shown in *figure 2* is considered for size optimization as it is critical and affects the decklid performance.

**3.0 Process Flow:** Steps for size optimization is described in as shown in *figure 3*.

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Figure 3: Process flow chart for design methodology
4.0 Definition of Optimization Parameters:
In this analysis, size optimization technique is selected in order to get the optimal thicknesses for significant weight reduction. Mathematically the problem is defined as

\[
\text{Find } X \\
\text{Which minimize } F(X) \\
\text{Subjected to constraints } g(x) \leq 0, h(x) < 0, k(x) > 0 \\
\text{And } X_{lb} \leq X \leq X_{ub}
\]

Where \( X \) is the design variable i.e. thickness of hinge bracket, goose neck tube and U channel bracket which are defined by DESVAR card and are related to individual PSHELL properties, can be defined by design variable property relationship card. The objective function \( F(X) \) of the present work is to minimize the weight of hinge assembly which can be defined by DESOBJ card. Deflections and frequency responses are created through response card. \( g(x) \), \( h(x) \) and \( k(x) \) are design constraints which can be defined by DCONSTR card. Thickness of the hinge assembly is varied from 4 mm to base thickness. Base thickness is taken as hinge assembly thickness with steel material. Problem definition for size optimization is described in the table 1 for each load case.

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Design Variables</th>
<th>Gage Range</th>
<th>Responses</th>
<th>Design Constraints</th>
<th>Objective Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modal</td>
<td>Hinge Assembly Thicknesses</td>
<td>4 mm to Base Thickness</td>
<td>1\textsuperscript{st} Mode Frequency and Volume</td>
<td>1\textsuperscript{st} Mode Frequency ( \geq ) Natural Frequency</td>
<td>Minimize the Volume</td>
</tr>
<tr>
<td>Torsion</td>
<td>Hinge Assembly Thicknesses</td>
<td>4 mm to Base Thickness</td>
<td>Z-Deflection @ Load Point and Volume</td>
<td>Z-Deflection &lt; 16 mm</td>
<td>Minimize the Volume</td>
</tr>
<tr>
<td>Lateral</td>
<td>Hinge Assembly Thicknesses</td>
<td>4 mm to Base Thickness</td>
<td>Y-Deflection @ Load Point and Volume</td>
<td>Y-Deflection &lt; 3.6 mm</td>
<td>Minimize the Volume</td>
</tr>
<tr>
<td>Combined (Model + Torsion + Lateral)</td>
<td>Hinge Assembly Thicknesses</td>
<td>4 mm to Base Thickness</td>
<td>1\textsuperscript{st} Mode Frequency, Z-Deflection, Y-Deflection and Volume</td>
<td>1\textsuperscript{st} Mode Frequency ( \geq ) Natural Frequency, Z-Deflection &lt; 16 mm and Y-Deflection &lt; 3.6 mm</td>
<td>Minimize the Volume</td>
</tr>
</tbody>
</table>

*Table 1: Problem definition for size optimization*

5.0 Results & Discussions:
Size optimization is performed separately for modal, torsion and lateral load cases. This study tells which component thickness is critical for each load cases. Thickness values for hinge assembly are shown in table 2. Figure 4 shows the element thickness plot for separate torsion, lateral and modal load cases. For modal analysis optimized thickness values are nothing but the initial thickness values. Hence further thickness change is not required. For torsion load case hinge bracket thickness is critical and for lateral load case gooseneck tube thickness is critical. Hence Size optimization for combined load conditions is performed and effective thickness values are shown in table 2. There is almost 35 % weight reduction in the hinge assembly using aluminum material without deviating the decklid performance.
Table 2: Thickness values with steel and aluminum material for all load cases

<table>
<thead>
<tr>
<th>Hinge Components</th>
<th>Steel</th>
<th>Aluminum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current Design</td>
<td>Modal</td>
</tr>
<tr>
<td></td>
<td>Gage, mm</td>
<td>Gage, mm</td>
</tr>
<tr>
<td>Hinge bracket</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Goose neck tube</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>U Channel bracket</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

| Hinge weight per Vehicle | 3.4 kg       | 1.2 kg    | 1.7 kg   | 2.1 kg   | 2.1 kg   |
| % weight Reduction      | 0            | 64.7 %    | 49.2 %   | 36.4 %   | 36.7 %   |

Figure 4: Element thickness plot for torsion, lateral and modal load cases

Figure 5 shows the element thickness plot for combined load case. Gooseneck thickness is the critical for combined load case and thickness values are shown in table 2.

Figure 5: Element thickness plot for combined load case

Figure 6 shows the mass convergence with design iterations for combined load case and figure 7 shows the thickness variation for hinge assembly with design iterations. Performance values of steel hinge and aluminum hinge are compared in table 3.

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6.0 Conclusions & Remarks:

- A new methodology has been developed for size optimization in order to get the effective thickness values with material change of structural components.
- Size optimization technique is implemented to decklid subsystem and effective thickness values are proposed for combined load case.
- Using size optimization technique, there is an approximate 35% of weight reduction in the decklid hinge assembly without deviating the decklid performance.
- Using size optimization there is not only saving in weight but also increased the overall performance of decklid for specified load cases and these are useful for the future projects.
- Proposed aluminum hinge assembly is slightly costlier than steel hinge assembly, but cost to weight ratio is more for aluminum hinge assembly.

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