Structural Design Method of a Control Arm with Consideration of Strength

Jong-kyu Kim, Seung Kyu Kim, Hwan-Jung Son, Kwon-Hee Lee, Young-Chul Park*
Mechanical Engineering
Dong A University
Busan,
Korea
*parkyc67@donga.ac.kr.

Abstract: Recently developed automotive components are getting lighter providing a higher fuel efficiency and performance. In this research, the shape of upper control arm was determined by applying the optimization technology. This study considers the static strength in the optimization process. In this study, the kriging interpolation method is adopted to obtain the minimum weight satisfying the static strength constraint. Optimum design of static strength is obtained by the in-house program. MSC.fatigure is used for assessment of the durability life, which is one of the most important criteria in automotive industry. In addition, the real experiments on 1/4 car is conducted to validate the FEM analysis. At last, the correlation of each case about durability life is obtained.

Key-Words: Control Arm, Shape Optimization, Kriging, 1/4 car module, Weak Model, VPG (Virtual Proving Ground)

1 Introduction
For related auto parts industry, modularization and weight reduction of chassis subassembly are one of the main goals in order to achieve fuel efficiency and lower production cost. Additionally, auto makers also require that the part manufacturers to provide a subassembly unit defined by modularization. Some parts are developed with their target weight predetermined in units of gram-force during proto design stage exemplifying the importance of lightweight design. In this study, a lightweight design of upper control arm is presented by applying optimization technique, considering a static strength performances.

Upper control arm is a structural component that pivots in two places. One end of control arm is attached to the body frame while the other end is attached to the steering knuckle. Upper control arm is a critical part of vehicle's suspension system since it plays an important role in riding comfort and handling performances. In this study, a forging part made of aluminum material is being investigated for the structural design.

This study proposes the optimal structural design of an upper control arm, considering a static strength performance. The inertia relief method for FE analysis is utilized to simulate the static loading conditions. One of the most important the assessment of automotive components is the durability criterion. Generally, for the suggested optimum design considering only static strength, the prediction of the fatigue life is needed to check the criterion. In this study, a 1/4 car module for numerical analysis and a full car for experiment are conducted to examine the fatigue strength of the control arm. In case of 1/4 car module, both fatigue analysis and experiment are performed. In case of part model and full car, only fatigue analysis is performed. For the analysis of the full car model, VPG program is used. Comparing the results of the 1/4 car module and full car, the correlation about each case is found. Besides, the weak model is used in the experiment, since the experiment costs too much time.

2 DURABILITY ASSESSMENT OF THE CONTROL ARM

2.1 Fatigue analysis of control arm

The suggested optimum design considering static strength is investigated again to examine durability performance. In this study, the strain method, Neuber's rule, SWT (Smith-Watson-Topper) method and Miner damage rule built in MSC Fatigue (8) are adopted to predict the fatigue life of the control arm. Table 5 shows three cases for the durability analysis. Each case has its own life cycle criterion, which is represented as C1, C2 or C3. We obtained the results that all the life cycles satisfy the criteria.
The durability performance was assessed for the optimum design considering static strength. The durability criterion is shown Table 5. The durability life of the optimum design is \( N = 1 \times 10^{20} \) for all three cases, which is thought to be the permanent life, in general. Therefore, it is difficult to assess the durability performance of the control arm.

### 3.2 Assessment of the control arm considering SWT index

SWT (Smith-Watson-Topper) index is a durability index using durability life and material data of structure. Assessment of the control arm is applied Z company’s equivalent load and criteria. The equation of SWT index is represented as

\[
SWT = \frac{\sigma_{\max}}{2} \left( \left( \frac{\sigma'}{\sigma} \right)^2 (2N_f)^{2b} + E \sigma' \varepsilon' (2N_f)^{b+c} \right) \tag{5}
\]

Index of fatigue durability

\[
\text{Index of fatigue durability} = \left( \frac{\text{SWT}_{\text{target}}}{\text{SWT}_{\text{analysis}}} \right)^{0.5} \tag{6}
\]

where \( N_f \) is durability life, others values are \( \varepsilon \)-N material data. And (SWT)target is SWT index of object durability life and (SWT)analysis is SWT index of through the analysis. If the Index of fatigue durability is higher than 1.0, the structure is thought to be safe

For the optimum design considering static strength, SWT index of approximate 1.0 is obtained. Initial model is optimum design model of static strength for durability analysis, and decrease the variables for find the model of reduced life. Table 6 shows the durability model and analysis result by using the trial-error method.

**Table 1 : Specifications for durability assessment**

<table>
<thead>
<tr>
<th>Static analysis</th>
<th>Load time histories</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st case1</td>
<td>1 constant</td>
<td>C1</td>
</tr>
<tr>
<td>case2</td>
<td>+1 - -1 Sine</td>
<td></td>
</tr>
<tr>
<td>2nd case1</td>
<td>1 constant</td>
<td>C2</td>
</tr>
<tr>
<td>case3</td>
<td>+1 - -1 Sine</td>
<td></td>
</tr>
<tr>
<td>3rd case4</td>
<td>+1 - 0 Sine</td>
<td>C3</td>
</tr>
</tbody>
</table>

**Table 2 : Analysis results using trial-error method**

<table>
<thead>
<tr>
<th>Opt.</th>
<th>95%</th>
<th>90%</th>
<th>85%</th>
<th>81%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>( 1 \times 10^{20} )</td>
<td>( 1 \times 10^{20} )</td>
<td>( 4.23 \times 10^{20} )</td>
<td>( 1.13 \times 10^{20} )</td>
</tr>
<tr>
<td>2nd</td>
<td>( 1 \times 10^{20} )</td>
<td>( 1 \times 10^{20} )</td>
<td>( 4.23 \times 10^{20} )</td>
<td>( 4.24 \times 10^{20} )</td>
</tr>
<tr>
<td>3rd</td>
<td>( 1 \times 10^{20} )</td>
<td>( 1 \times 10^{20} )</td>
<td>( 4.94 \times 10^{20} )</td>
<td>( 2.68 \times 10^{20} )</td>
</tr>
<tr>
<td>Index</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>7.56</td>
<td>7.56</td>
<td>7.56</td>
<td>1.31</td>
</tr>
<tr>
<td>2nd</td>
<td>7.41</td>
<td>7.41</td>
<td>7.41</td>
<td>1.29</td>
</tr>
<tr>
<td>3rd</td>
<td>7.56</td>
<td>7.56</td>
<td>7.56</td>
<td>1.33</td>
</tr>
</tbody>
</table>

**Table 3 : Comparison of analysis results between the part model and the 1/4 car module**

<table>
<thead>
<tr>
<th>Assessment</th>
<th>The part model</th>
<th>The 1/4 car module</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>( 1.13 \times 10^6 )</td>
<td>( 2.66 \times 10^7 )</td>
</tr>
<tr>
<td>C2</td>
<td>( 4.24 \times 10^6 )</td>
<td>( 1.00 \times 10^{20} )</td>
</tr>
<tr>
<td>C3</td>
<td>( 2.68 \times 10^6 )</td>
<td>( 1.00 \times 10^{20} )</td>
</tr>
</tbody>
</table>
3.2 Production of a weak model and its analysis and experiment

The prediction durability life of the control arm considering SWT index put in too much time the experiment. Therefore, in this study, for a fast experiment, the control arm is changed into a weak model. The weak model represents the model of further decreased durability life. Figure 9 shows the production of the weak model. First, draw a straight line from the ball joint center to the bush center. Then, the durability life of the control arm is analyzed by control the position of the line. For the fast experiment, selected the result of fatigue analysis life is N=5×10^4. The durability life of the part model is approximately N=5×10^4 at the length of L=60.5 mm, and the 1/4 car module's analysis result is N=6.67×10^7. The criteria of assessment is C2.

![Figure 2: The method which the weak model](image)

![Figure 3: Weak model and experiment equipment](image)

The weak model is shown in figure 10(a). Figure 10(b) shows the assembly of the 1/4 car test machine with the weak model. The assembly contains four arms, one shock-absorber and one damper-spring. Load is applied at the wheel-patch by the hydraulic machine. The experiment of 1/4 car module is performed, however the control arm is not broken in the range of the durability life of the weak model. This indicates that the true durability life given by the 1/4 car experiment, which is related to the analysis result of the 1/4 car module. Unfortunately, the prediction durability life of the 1/4 car module applying the weak model takes too much time. Therefore, for the experiment of the 1/4 car module, applied prediction life is changed from the part model's life to 1/4 car module's analysis result. To control the input load of the 1/4 car module, obtained the durability life of N=4.34×10^4. The experiment of the 1/4 car module is carried out based on the analysis load.

The prediction and experiment durability life of the weak model are shown in table 8. Two samples are used in the 1/4 car test. Results show that the durability lives between the analysis and experiment are very close. Figure 11(a) and 11(b) show the predicted and experimental fracture locations, respectively. The fracture location of the experiment does coincide with that of the analysis.

![Table 8: Comparison of 1/4 car simulation and experiment](image)

3.3 Analysis of control arm using full car model by VPG program

Finally, the full car model is analyzed by using VPG program, since the analysis of the full car model is more reliable. The composition of the front wheel drive system is Macpherson Strut type, and the rear wheel drive system is Multi-link system. The analysis model of the control arm is that introduced in section 3.2. The control arm is assembled in rear part. Analysis model of the full car is shown in figure 14. Analysis result of the full car simulation is shown in table 9. The durability lives of 1/4 car module and the full car are obviously different.
Conclusions

This study presents the design process of a control arm to reduce the weight satisfying the imposed requirements. The following conclusions can be made from this study.

1. By performing the kriging interpolation method, the weight of control arm is reduced by 16% from the initial design. On the contrary, when in-house program is utilized, the weight of upper control arm decreases additionally by around 2%.

2. The optimum design of static strength’s durability life has permanent life. Therefore, it is difficult to judge the durability of the control arm. To find the durability characteristic of the control arm, design values of optimum design is reduced, and fatigue analysis is performed.

3. To compare the durability of the control arm, the analysis and experiment of the control arm attached in the 1/4 car module was carried out. Analysis results show significant differences between part model and 1/4 car module, and relative small difference between the experiment and analysis of 1/4 car module. However, the tendency of fracture position is similar to each other.

4. The fatigue analysis result of the full car using VPG program is different from that of 1/4 car module’s. Future work will examine the relation between the durability experiment of 1/4 car module and the full car simulation.

References:


Acknowledgement

This research was financially supported by the Ministry of Education, Science Technology (MEST) and Korea Industrial Technology Foundation (KOTEF) through the Human Resource Training Project for Regional Innovation.