Simulation of Cornering with Steer Release and Optimization of Vehicle Steering Stability

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Abstract. According to the principle of multi-body dynamics, using ADAMS module of ADAMS/CAR to form a complete vehicle model, and by using INSIGHT module used to design suspension hard point, the simulation analysis was carried out. Controllability and stability of the vehicle is to make evaluation and analysis by the experiments cornering with steer release. Ordinal optimization of before and after the optimization model, the results were analyzed, it demonstrated that optimized score significantly higher than before optimization.

Introduction

Vehicle handling and stability has been one of the hot issues in the research of automotive experts and scholars. In 1995, Milliken and William\textsuperscript{1}, who published the vehicle dynamics theory and analysis method of the article, provides an important reference for the study of handling stability. In 2002, Caviasso\textsuperscript{2} introduced the design of suspension optimization. In 2005, Coello\textsuperscript{3} proposed a multi-objective optimization algorithm of evolutionary algorithm.

In 2007, Pang\textsuperscript{4} analysis and improved the research scheme of the suspension kinematics and elastic kinematics sensitivity. The problems and the research of vehicle are corrected. In 2007, Guo\textsuperscript{5} found that the rubber bushing affect vehicle handling and stability of factors. In 2011, Cai, Yang, et al\textsuperscript{6} used screw theory in the research of multi-link suspension motion. In 2013, Pan\textsuperscript{7} pointed out that using multi-body dynamics theory analyzed vehicle to the problem of excessive and modified the original vehicle wheel alignment parameters.

About the evaluation of vehicle handling and stability, which was written by Moat\textsuperscript{8}, the German, introduces the test and evaluation of the performance of the vehicle. German automotive expert made a complete analysis of the suspension in the "automotive suspension", from the various components of the suspension designing. According to the standards of Criterion thresholds and evaluation of controllability and stability for automobiles (QC/T 480-1999), Controllability and stability analysis should be from Steering transient response, steady rotation, pylon course slalom, et al. The simulation analysis of cornering with steer release is carried out.

The Establishment of Vehicle Model

The Establishment of the Model of Front Suspension

The structure of the suspension is characterized by the two unequal length of the A cross arm. The excellent performance of lateral stiffness and vertical stiffness is the outstanding characteristic of this kind of suspension. Front wheel alignment parameters can be controlled by the two arms of the suspension. When the driving direction is changed, the lateral force of the tyre can be absorbed by the double A shaped arm. When the driving direction of the vehicle is changed, the control arm of the double arm type is better than other types in resisting lateral inclination. When the length of the
control arm is not equal, the front wheel can be changed in the course of motion, and the change of the front wheel spacing can be reduced by changing the camber angle at any time. In this way, the service life of the tire can be prolonged, and the strain capacity of the road surface is enhanced. Make the contact surface of the tire and the ground becomes larger, and the working performance of the wheels is excellent. Figure 1 is the front suspension structure model.

![Figure 1. The front suspension structure model.](image)

Steering system is a necessary component to correct or maintain the orientation of vehicle movement. This car adopts the gear rack connection mode. The vehicle steering system basically consists of a steering wheel, turning axis, turning column et al. The steering system can transfer the torque of the steering wheel to the lateral movement of the lateral transfer arm or the lateral movement of the gear rack. And the torque can be obtained when the tire steering is greater than the torsion force of the human output. Direction twisting mechanism is usually mounted on the frame or body. The force of the output can change the transmission direction when the direction changed after the steering mechanism changed. The component can output the torque and the rotation state of the driver to the steering wheel. This will make the two wheels in accordance with a certain change in the way to reverse.

**The Establishment of Rear Suspension Model**

The automobile rear suspension adopts a multi-link structure. This type of suspension can adjust the position of the angle of the main pin. A greater degree of reduction comes from the front and rear forces of the road surface, thereby increasing the comfort of the braking and acceleration. When the car drives along the straight road, the rear suspension can play a good guarantee of the stability to the straight line. In the process of braking or turning, the multi-link suspension can make the front beam of the rear wheel be positive, and the control performance of the vehicle is enhanced, and the angle amplitude of the steering wheel is reduced. When multi-link suspension in forced motion, the connecting rod active to the link point (hard point) position adjustment to change the wheel state, keeping the rear wheels on the ground to achieve the best grip. Because the design of the freedom degree of the suspension is relatively large, we can aimed at the vehicle in the motion state of the former beam angle and the camber angle for correction. It can make the rear wheel to obtain a certain steering angle and greatly improve the control limit of the vehicle. Figure 2 is rear suspension structure model.

![Figure 2. Rear suspension structure model.](image)
Integrated Model of Vehicle

By using the function of ADAMS/CAR components, the components are assembled and the whole vehicle model is built. The vehicle simulation model mainly consists of 6 parts, the front suspension component model, the rear suspension component model, the vehicle body model, the steering system model, the tire model and the power transmission system model. As shown in Figure 3.

Figure 3. Vehicle simulation model.

ADAMS/INSIGHT Optimization Design

Experiment can be used to carry out experimental analysis of multiple parameters. Selecting the spatial coordinate parameters of steering knuckle lower ball hinge point C in the balance position, lower control arm rear point A, lower control arm front point B, steering knuckle upper ball hinge point F in the balance position, upper control arm rear point D, upper control arm front point E, steering tie rod inside and outside points (set to N and M) are used as design variables:

\[
X\{x_a, x_b, x_c, x_f, x_d, x_e, x_n, x_m\}
\]

\[
Y\{y_a, y_b, y_c, y_f, y_d, y_e, y_n, y_m\}
\]

\[
Z\{z_a, z_b, z_c, z_f, z_d, z_e, z_n, z_m\}
\]

(1)

The range of variation of the selected parameters is influenced by the structural design, and the variation range of the selected parameters is ±15mm.

In the optimization process of front suspension, the front wheel position parameters mean positioning parameters of the front axle and kingpin axis formation in space. It includes the front wheel toe angle, camber angle, caster angle and kingpin inclination angle. Selecting camber angle(\(\gamma\)) of the front wheel, toe angle(\(B\)) of the front wheel and caster angle(\(\beta\)) are used as test targets. The variation of the hard point parameters will be affected camber angle, toe angle and caster angle. This paper analyzes the change of the three, and objective function is:

\[
\gamma_{\min} \leq \gamma \leq \gamma_{\max}
\]

\[
B_{\min} \leq B \leq B_{\max}
\]

\[
\beta_{\min} \leq \beta \leq \beta_{\max}
\]

(2)

After iterative calculation, a set of three target changes are selected in the smallest amount of data. The design variables that are less affected by the impact of the target are ignored (steering knuckle lower ball hinge point C in the balance position). The rest of the optimization of the design variables are gathered statistics, and finally getting the optimized data as shown in Table 1. After the optimization of the suspension assembly, it can be optimized before and after the optimization of the vehicle analysis and comparison.

<table>
<thead>
<tr>
<th>Hard point</th>
<th>x/mm</th>
<th>y/mm</th>
<th>z/mm</th>
<th>Hard point</th>
<th>x/mm</th>
<th>y/mm</th>
<th>z/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(before)</td>
<td>467.3</td>
<td>-451.15</td>
<td>158.12</td>
<td>D(optimized)</td>
<td>516.8</td>
<td>-491.1</td>
<td>551.21</td>
</tr>
<tr>
<td>A(optimized)</td>
<td>467.3</td>
<td>-451.15</td>
<td>181.37</td>
<td>E(before)</td>
<td>364.18</td>
<td>-447.2</td>
<td>552.189</td>
</tr>
<tr>
<td>B(before)</td>
<td>67.23</td>
<td>-401.19</td>
<td>180.48</td>
<td>E(optimized)</td>
<td>364.18</td>
<td>-447.2</td>
<td>547.17</td>
</tr>
<tr>
<td>B(optimized)</td>
<td>67.23</td>
<td>-401.19</td>
<td>174.52</td>
<td>N(before)</td>
<td>467.11</td>
<td>-401.27</td>
<td>332.89</td>
</tr>
<tr>
<td>F(before)</td>
<td>665.8</td>
<td>-446.32</td>
<td>178.9</td>
<td>N(optimized)</td>
<td>467.11</td>
<td>-401.27</td>
<td>321.71</td>
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</tbody>
</table>
Simulation of Cornering with Steer Release

Cornering with steer release means when the vehicle is running on the circular trajectory, the driver suddenly let up on the steering wheel. At the same time, the yaw rate and the lateral inclination angle of the vehicle are recorded. The research of cornering with steer release is a key experimental analysis of vehicle transient response analysis.

In accordance with the relevant standards, the vehicle with a diameter of 30m circular track uniform motion at the beginning of the experiment, and the lateral acceleration of the vehicle cannot be less than 4m/s². When the above conditions are achieved, immediately give up the control of the steering wheel, the absolute value of the angular velocity of the yaw rate after 3 seconds ($\Delta r$) and the total variance of yaw rate ($E_r$) are evaluated.

In ADAMS, the experimental data is set as: orbital path radius of 15m, when the initial lateral acceleration reached 0.41g (g represents the acceleration of gravity) let go of the steering wheel, the process of letting go keep 3 seconds. Simulation results are shown in Figure 4.

![Figure 4. Yaw velocity - Time curve.](image-url)

(Solid line is before optimization, the dotted line is optimized)

Analysis of Figure 4, the curve before and after optimization, the trend is basically the same. After optimization of the vehicle, when the acceleration reaches 0.41g, its yaw rate is lower than the optimization (before optimization is 28.7°/s, optimization is 26.1°/s), 3 seconds (18s) residual yaw angular velocity is lower than before optimization (before optimization is 0.47°/s, optimization is 0.35°/s). The data of this experiment is evaluated and scored:

1. In this experiment, the method of evaluating the residual yaw rate of 3s (eighteenth seconds in a graph) at the end of the test:

   $N_{\Delta r} = 60 + \frac{40(\Delta r_{60} - \Delta r_{100})}{\Delta r_{60} - \Delta r_{100}}$

   $N_{\Delta r}$ represents the score of the residual yaw rate.

   $\Delta r$ represents the emulational score of the residual yaw velocity (before optimization is $0.47^\circ$/s, optimization is $0.35^\circ$/s); $\Delta r_{60}$ and $\Delta r_{100}$ respectively represent the lower and upper values of the residual yaw rate.

2. Evaluation of the total variance of yaw rate:

   $N_{E_r} = 60 + \frac{40(E_{r60} - E_r)}{E_{r60} - E_{r100}}$

   $N_{E_r}$ represents the score of the total variance of yaw rate; $E_r$ represents the emulational score of the total variance of yaw rate. $E_{r60}$ and $E_{r100}$ respectively represent the lower and upper values of the total variance of yaw rate.

3. $N_{\Delta r}$ represents the comprehensive evaluation of the experiment of cornering with steer release. Data are summarized as shown in Table 2:
\[ N_H = \frac{N_{\Delta \psi} + N_E}{2} \]  

(5)

Table 2. Experimental parameters and evaluation of cornering with steer release.

<table>
<thead>
<tr>
<th>Index</th>
<th>Not optimized</th>
<th>Optimized</th>
<th>Index</th>
<th>Not optimized</th>
<th>Optimized</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta \psi )</td>
<td>2</td>
<td>2</td>
<td>( E_r )</td>
<td>0.33</td>
<td>0.31</td>
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<tr>
<td>( \Delta \psi_{100} )</td>
<td>0</td>
<td>0</td>
<td>( N_{\Delta \psi} )</td>
<td>90.6</td>
<td>93.0</td>
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<tr>
<td>( \psi )</td>
<td>0.47</td>
<td>0.35</td>
<td>( N_E )</td>
<td>96.0</td>
<td>98.7</td>
</tr>
<tr>
<td>( E_{\psi,60} )</td>
<td>0.6</td>
<td>0.6</td>
<td>( N_H )</td>
<td>93.30</td>
<td>95.85</td>
</tr>
<tr>
<td>( E_{\psi,100} )</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Through analysis table 2, After the optimization, the vehicle showed good performance in the experiment of cornering with steer release. Evaluation score is high (before optimization is 93.30, optimization is 95.85). In the process of turning, passengers feel more comfortable and comfortable. After the turn of the vehicle, the car's ability to get a straight line is improved.

Conclusions

The ADAMS/INSIGHT module is used to optimize the front and rear suspension, several positioning parameters of the suspension are analyzed and modified. Controllability and stability test procedure for automobile is to make evaluation and analysis by cornering with steer release experiments. The score before optimization is 93.30 points, after optimization is 95.85 points. The operating stability of the overall performance has been improved.

References