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# Optimization of an Electric Vehicle Suspension System Using CAE

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**Abstract**

In this paper the dynamic analysis of an electric vehicle (EV) has been investigated. The vehicle suspension system was built using multi-body dynamics (MBD) software, Altair MotionView/MotionSolve. Using the model, the dynamic properties of a target vehicle with gasoline engine and an electric vehicle with motor and batteries were simulated. The kinematic simulation of the suspension system was also carried out to analyze their kinematic performance. This paper mainly focuses on the lateral acceleration, roll angle and yaw rate characteristic of the vehicle in step steer analysis. By using optimization software, Altair Hyperstudy, parameterized models of the front and rear suspension were assembled. Then the optimization of dynamic properties of the electric vehicle suspension system was carried out.

*Keywords：electric vehicle, multi-body dynamics, optimization*

## 1 Introduction

In recent years, the price of oil has risen dramatically. Also, air pollution of earth is increasing. As a result, development of the electric vehicle has become important. One way to quickly bring an electric vehicle to market is to substitute motor for engine for an internal combustion engine vehicle. However, when the engine is substituted for an electric motor and batteries, the weight and the center-of-gravity position of the vehicle will be affected. This will affect the dynamic properties of the vehicle, so the characteristic of the vehicle suspension system must be modified in order to maintain similar dynamic performance. In this paper the characteristic of the vehicle suspension system was adjusted by using optimization software, Altair Hyperstudy and the simulation model was built by using muti-body dynamics (MBD) software, Altair MotionView. The dynamic properties analysis of a vehicle with gasoline engine was simulated first, as a baseline vehicle. A kinematic simulation of the suspension system was also carried out to analyze their kinematic performance.

## 2. Modeling of the vehicle suspension system

The simulation of the original vehicle with Macpherson front suspension and leaf spring rear suspension was built using MotionView, shown as figure 1. It was assembled with an engine as the power system and simulated first using a step steer analysis. Another simulation model of electric vehicle was built by replacing engine system with motor/battery system is shown as figure 2. The difference between original engine car and original EV car is the weight and the center-of-gravity position of sprung mass. After changing the power system, the electric vehicle increased 20kg in the front axle and 140kg in the rear axle. This changes the dynamic properties of the vehicle,

This paper mainly focuses on the lateral acceleration, roll angle and yaw rate of the vehicle in step steer analysis. The input data of the step steer analysis is illustrated as table 1. The initial velocity of the vehicle is 38.9mph. The steering wheel starts to turn at 2 seconds and stops at 2.2 seconds. A total of 61 degrees of steering wheel angle were input over 0.2 seconds using a sine or function. Total time of the simulation is 6.2 seconds. The steering angle curve changes is shown as figure 2. Altair Hyperstudy was used to tune the suspension parameters to modify its properties to make them closer to the original baseline vehicle. The objective functions are the change of the lateral acceleration, roll angle and yaw rate of the vehicle between original car (target car) and electric car. The goal was to attempt to match these to the baseline simulation. The design variables of the optimization model are illustrated as table 2. There are three design variables in the optimization analysis, including the diameter of front stabilizer bar, the stiffness of coil spring and the thickness of each rear leaf spring. There are four leaves in the rear suspension. Their gauge increased or decreased simultaneously. The change range of the design variables was limited by lower bound and upper bound, which are shown as table 2. Finally, a gradient method multi-objective in Hyperstudy was selected to solve the problem. So the objective functions can be minimized at the same time by changing the design variables.

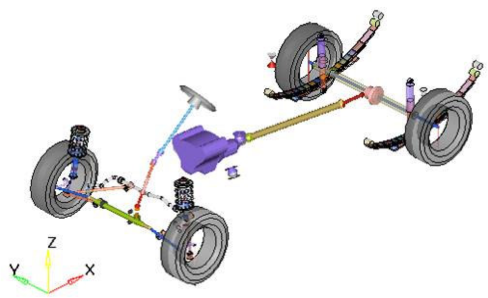


Figure 1: Assembled Model of the original vehicle suspension system

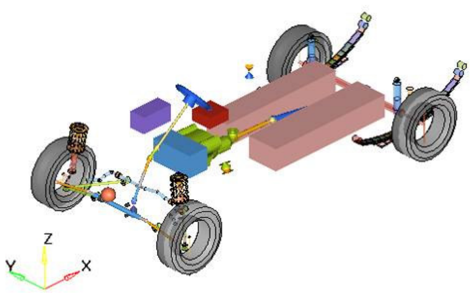


Figure 2: Assembled Model of the electric vehicle suspension system

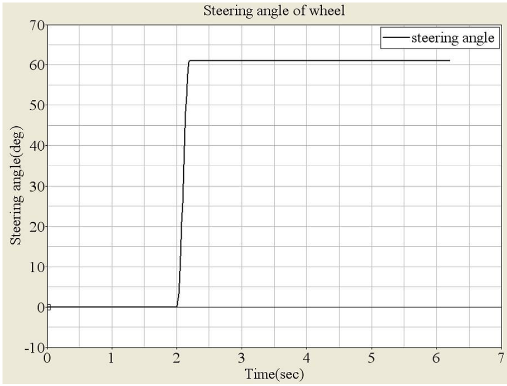


Figure 3 : Steering angle of the vehicle

Table 1: List of step steer input data

| **Step steer input data** | |
|---|---|
| Vehicle velocity(mph) | 38.9 |
| Steering input start time(sec) | 2 |
| Steering input end time(sec) | 2.2 |
| Steering input type | angle |
| Max steering value(deg) | 61 |
| Function type | sine |

Table 2: List of optimization design variables

| optimization design variables | | | |
|---|---|---|---|
| Items | *Stabilizer bar OD-mm* | *front Coil spring k-N/mm* | *leaf 1~4 thickness increased -mm* |
| min | 20 | 25 | -0.5 |
| max | 30 | 30 | 0.5 |
| Nom | 24 | 28 | 0 |

# 3 Result

## 3.1 Optimization of the vehicle

The lateral acceleration, roll angle and yaw rate responses of the original engine car and EV car are evaluated via step steer analysis. Figure 4 shows the iteration diagram of the response through the optimization. The stabilizer bar OD, front Coil spring stiffness and leaf 1~4 gauge increment are design variables of the objective response functions. After 7 iterations through the optimum calculation, the responses were converged and the design variables were found.

The final design values of the modified EV car are illustrated as table 3. All the design values are larger in comparison with the design values of the original engine car. The diameter of the front stabilizer bar increased 3.96%, front Coil spring stiffness increased 0.79% and the gauge of the rear leaf 1~4 increased 0.06 mm. According to the optimization results, it is more effective to adjust the diameter of stabilizer bar to meet the dynamic properties of the original vehicle.

Table 4 and figure 5~ figure 7 show the response results of the original engine car, original EV car and modified EV car. Comparing the responses of original engine car and the original EV car with each other, it shows that the roll angle increased 2.94% and the lateral acceleration and yaw rate only decreased. By using the optimization software, the roll angle of the modified EV car was decreased to close to the value of the original engine car and the variations of the lateral acceleration and yaw rate between two cars were still kept small. So the optimization method can be used to modify the performance of the electric vehicle suspension system.

Besides, the step steer analysis also be simulated with the velocity of the vehicle was change to 46.6mph. The results of these analysis are showed as table 5 and figure 8~figure10. It shows that the roll angle of the modified EV car still approaches to the roll angle of the original engine car. Besides, the differences of roll angle and yaw rate between the original engine car and the modified EV car are still small. So these design value are still suitable for 46.6mph velocity.

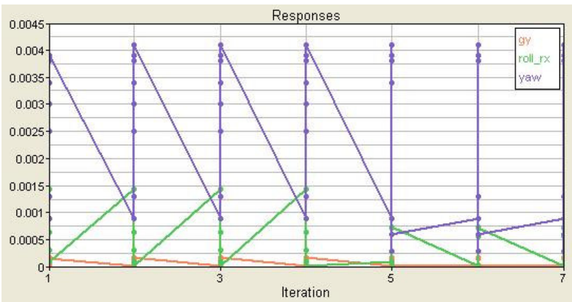


Figure 4 Iteration diagram of optimization

Table 3: Design variables comparison

| Items | Stabilizer bar OD-mm | front Coil spring k-N/mm | leaf 1~4 gauge increased -mm | EV add. mass-kg |
|---|---|---|---|---|
| orig. Engine car | 24 | 28 | 0 | 0 |
| orig. EV car | 24 | 28 | 0 | 160 |
| modified EV car | 24.95 (+3.96%) | 28.22 (0.79%) | 0.06 | 160 |

Table 4: Response comparison for 38.9 mph velocity

| Items | orig. Engine car | orig. EV car (diff %) | modified EV car (diff %) |
|---|---|---|---|
| Lateral acceleration (g) | - 0.4547 | -0.4523 (-0.53%) | -0.4545 (-0.04%) |
| Roll angle (deg) | - 2.2573 | -2.3238 (+2.94%) | -2.2565 (-0.04%) |
| Yaw rate (deg/sec) | 14.692 9 | 14.6215 (-0.49%) | 14.6926 (-0.002%) |

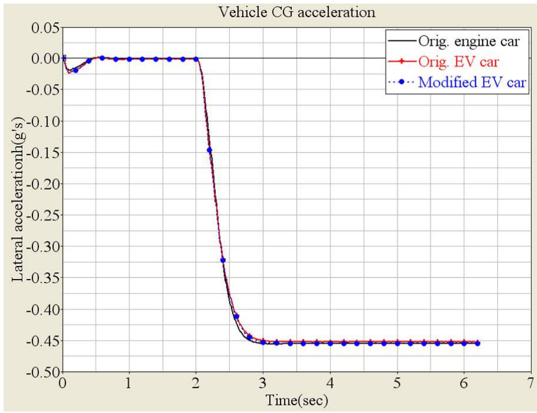


Figure 5 Lateral acceleration of the vehicle for 38.9mph velocity

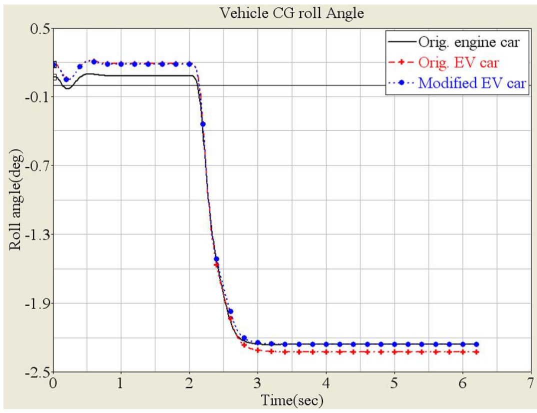


Figure 6 Roll angle of the vehicle for 38.9mph velocity

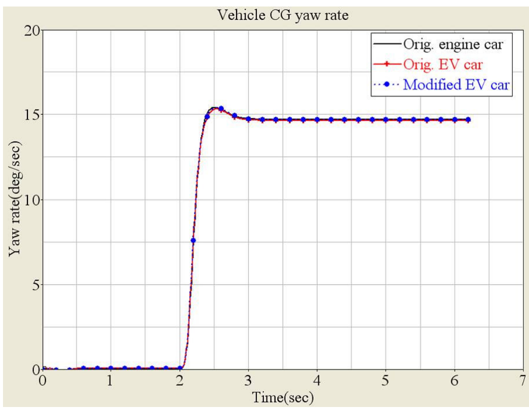


Figure 7 Yaw rate of the vehicle for 38.9mph velocity

Table 5: Response comparison for 46.6 mph velocity

| Items | orig. Engine car | orig. EV car (diff %) | modified EV car (diff %) |
|---|---|---|---|
| Lateral acceleration (g) | -0.5845 | -0.5801 (-0.75%) | -0.5801 (-0.75%) |
| Roll angle (deg) | -2.9368 | -3.0335 (+3.29%) | -2.9313 (-0.18%) |
| Yaw rate (deg/sec) | 15.773 | 15.646 (-0.80%) | 15.649 (-0.78%) |

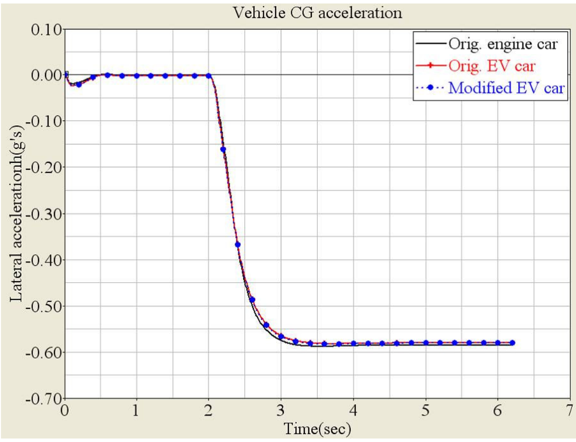


Figure 8: Lateral acceleration of the vehicle for 46.6mph velocity

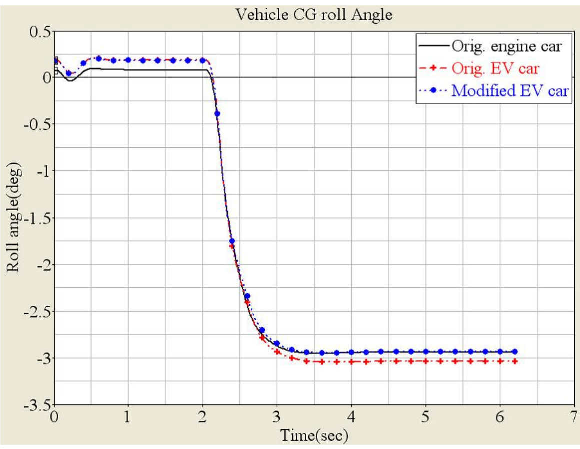


Figure 9: Roll angle of the vehicle for 46.6mph velocity

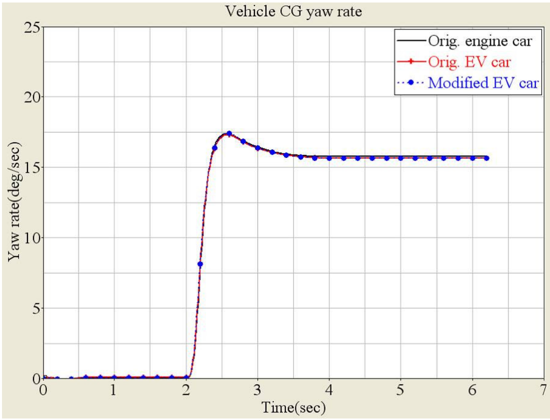


Figure 10 Yaw rate of the vehicle for 46.6mph velocity

## 3.2 kinematic simulation of the suspension system

Comparisons of the front spring rate and rear spring rate between different cars are shown as Table 6 and figure 11~figure 14. According to the comparison results, it shows that the front suspension roll rate increases 7.34% due to the increment of the front stabilizer diameter. Also, the ride rate and roll rate of the rear suspension increase at the same time due to the increment of the rear leaf 1~4 gauge.

Table 6: Spring rate comparison

| Items | orig. Engine car | modified EV car | Difference (%) |
|---|---|---|---|
| Front suspension ride rate (N/mm) | 28.99 | 29.08 | 0.31% |
| Front suspension roll rate(N-m/deg) | 1043.03 | 1119.6 | 7.34% |
| Rear suspension ride rate(N/mm) | 58.97 | 60.13 | 1.96% |
| Rear suspension roll rate(N-m/deg) | 587.17 | 597.24 | 1.71% |

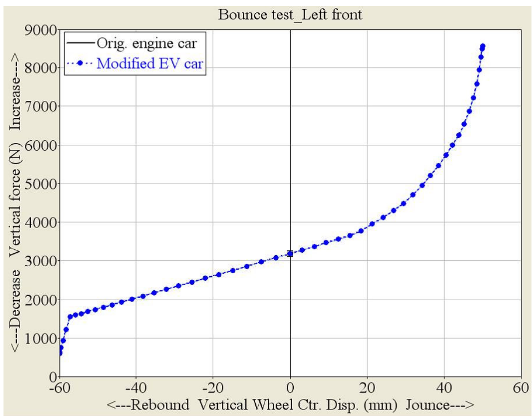


Figure 11: Spring Rate curve of front suspension in bounce test

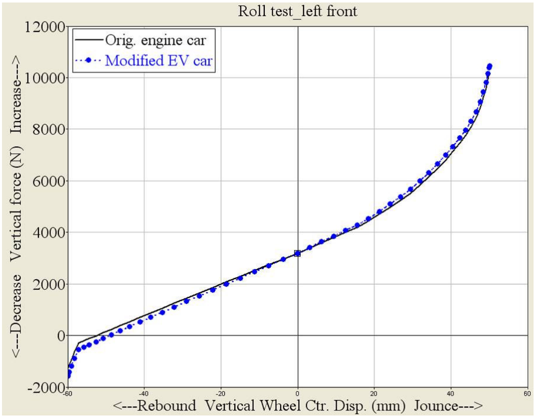


Figure 12: Spring Rate curve of front suspension in roll test

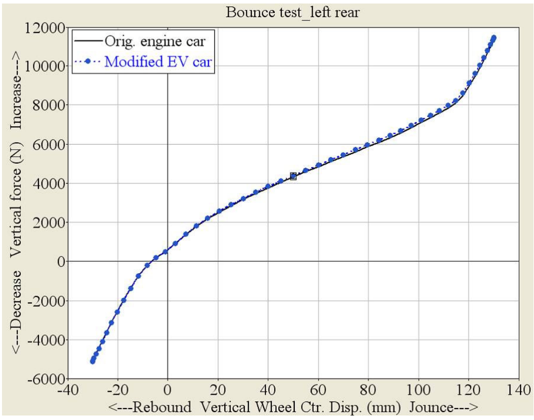


Figure 13: Spring Rate curve of rear suspension in bounce test

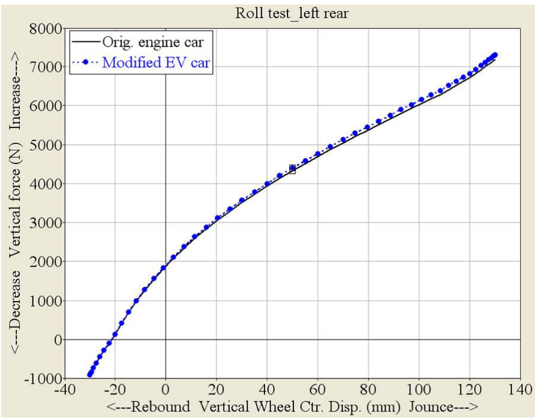


Figure 14: Spring Rate curve of rear suspension in roll test

## 4 Conclusion

When the engine is replaced with an electric motor and batteries, the lateral acceleration and the yaw rate of the vehicle will decrease slightly for a fixed steering wheel angle. Roll angle will increase due to the increase in vehicle weight. By using optimization software, the solution to adjust the lateral acceleration, roll angle and yaw rate of the EV car to meet similar performance of the original engine car is to increase the spring rate of front and rear suspension and the diameter of stabilizer bar, especially the diameter of stabilizer bar. Also, the adjustment of the design variables makes the roll rate of rear suspension increase. So the optimization method can be used to modify the performance of the electric vehicle suspension system in the step steer analysis and other analysis applications.

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Mr Coker has over 18 years of experience with Mutibody Dynamics analysis, with primary focus on vehicle dynamics simulation, suspension design, and optimization.

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