Dynamic Analysis of Electric Vehicle with Battery Pack Swing Chassis

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Abstract
As the energy storage element of electric vehicle, battery has the characteristic of large volume and mass. It occupies a considerable part of the mass and moment of inertia of the vehicle, which has a negative impact on vehicle handling stability. However, eligible vehicle handling characteristics are the key to ensure traffic safety. A new type of chassis is presented wherein the battery pack with yaw-direction-suspension is mounted. A 3-DOFs linear mathematic model is established to simulate the dynamic characteristics of the vehicle with the presented chassis in steering wheel angle step input test as well as the frequency response of yaw rate. Then we compare the result to the traditional vehicle in terms of agility and stability and the improvement of handling stability and agility of new chassis is pointed out.

Key words: battery pack swinging chassis; handling stability; 3-DOFs model; agility dynamics.

Nomenclature

Abbreviation
DOF degree of freedom

Symbols

\(F_y\) lateral force
\(M_z\) moment of rotation around the Z-axis
\(I\) moment of inertia
\(m\) quality of the vehicle
\(\delta\) front wheel steering angle
\(a\) distance from center of mass to front axle
\(b\) distance from center of mass to rear axle
\(\omega\) yaw rate
\(K\) stiffness
\(D\) damping coefficient
\(u\) longitudinal velocity
\(v\) lateral velocity
\(\beta\) side slip angle
\(\theta\) turning angle

Subscript
\(b\) battery
\(zz\) parts of vehicle besides battery

Introduction

According to the study of vehicle handling dynamics, the moment of inertia is also a major factor affecting vehicle handling stability. It greatly restricts the improvement of handling stability and agility. If the moment of inertia can be reduced properly, the vehicle handling stability and agility will be greatly improved [1]. However, most of the electronic stability control systems used to improve vehicle handling stability are based on the design of braking system.[2] It can be seen that the main methods to improve the handling stability and agility in the automotive industry are to control the braking system and develop advanced control strategies [3]. So there is a lack of technology to improve vehicle handling stability and maneuverability by optimizing vehicle inertia.

Based on the current research on vehicle handling dynamics and agile dynamics, this paper proposes a method to reduce the influence of the rotational inertia of the battery pack on vehicle steering by swinging the battery pack horizontally. By modifying the 2-DOFs model of automobile steering, the mathematical model is established and analyzed.

Chassis instruction

We designed a new type of electric vehicle chassis, which consists of battery, battery pack shell and bottom plate. The battery is fixed in the battery pack shell, the battery pack shell is rotated and connected to the bottom plate, and four shock absorbers are arranged between the battery pack shell and the bottom plate to provide resistance to the rotation of the battery pack shell relative to the bottom plate. It cancels the rigid connection between the battery pack and the chassis and uses an elastic damping connection, so that the battery pack has the relative freedom of chassis rotation.

Vehicle model

In order to analyze the dynamic characteristics of vehicles, an effective and accurate vehicle dynamic model is need. In this paper, the linear 2-DOFs model of vehicle steering is modified to form the linear 3-DOFs vehicle model of battery pack swinging chassis.
We added the freedom of the battery pack rotation to the 2-DOFs model. From the graph, the resultant force of the 3-DOFs vehicle model along the Y-axis and the moment of rotation around the center of mass are as follows:

\[ \sum F_y = ma_y = F_{y1} \cos \delta + F_{y2} \]
\[ \sum M_z = I_z \omega_r = aF_{y1} \cos \delta - bF_{y2} + M_{zb} \]

The connection between the battery pack and the chassis is a spring damper. If the stiffness is \( K_b \) and the damping coefficient is \( D_b \), the torque of the battery pack is

\[ M_{zb} = I_b \dot{\omega}_b = K_b(\theta - \theta_b) + D_b(\dot{\theta} - \dot{\theta}_b) \]

According to the coordinate system, the absolute acceleration of the vehicle’s center of mass is \( a_y \) along the horizontal axis.

\[ a_y = \frac{dv}{dt} + u\omega_r \]

The three degree of freedom motion equation of the battery pack swinging suspension after finishing is as follows:

\[ \beta = -\omega_r + \frac{2[F_{yy} \cos(\beta - \delta) + F_{yy}]}{I_{zz}} \]
\[ \dot{\omega}_r = \frac{2aF_{yy} \cos \beta}{I_{zz}} - \frac{m_u}{I_{zz}} \omega_r + \frac{\omega_r}{I_{zz}} \]
\[ \dot{\omega}_{rb} = \frac{K_b(\theta - \theta_b) + D_b(\dot{\theta} - \dot{\theta}_b)}{I_{zb}} \]

**Model simulation and results**

We use Simulink to simulate vehicle steering angular step test. Angular step test is one of the important evaluation tests for vehicle handling stability, and yaw rate is one of the main evaluation of the angular step test [4][5]. The simulation result is shown behind.

From the figure, we can know that for the angular step condition, 90% response time of vehicle yaw angular velocity of battery pack swing chassis is 10% earlier than that of battery pack fixed model, and the peak response time is 20% earlier, the overshoot is almost completely eliminated.

In addition, the mathematical model is used to simulate the transient response of steering wheel to angular pulse input. The frequency response characteristics curve of yaw rate are shown behind.
Among them, the red line represents the original vehicle model and the blue one is the battery pack swinging chassis model. It can be seen that the resonance frequency point of the battery pack swinging chassis model is higher, so the corresponding pass-band is wider, which can ensure the necessary response speed. In addition, the phase lag angle ($f = 1$Hz) of the battery pack swinging chassis model is obviously smaller than that of the original vehicle model, which indicates that the response speed of the battery pack swinging chassis model is faster than that of the original model when the steering wheel is turned rapidly.

**Conclusion**

From the simulation, we can see that the response time is earlier and the overshoot is almost completely eliminated. It proves that the new chassis wherein the battery pack with yaw-direction-suspension is mounted can obviously reduce the impact of the battery's inertia on the steering. Therefore, by adding the degree of freedom of rotation between the battery pack and the chassis of the electric vehicle, we improve the response agility and handling stability of the vehicle when steering without affecting the volum and capacity of battery.

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**References**


