Modeling and Simulation of Vehicle Handling Stability Control Based on Tire Pressure

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Abstract: In order to study the influence of tire pressure change on the control of vehicle handling stability, the seven-degree-of-freedom theoretical model of automobile dynamics and tire theoretical model considering tire pressure were established. Considering the double lane conditions, the control stability of automobile is simulated, and the influence of tire pressure change on the control stability of automobile is analyzed. The simulation results show that when the tire pressure is too high or too small, the yaw rate of the vehicle in the process of high speed steering cannot be stable, which reduces the vehicle handling stability.

1. Introduction
With the development of automobile industry, people have higher and higher requirements for vehicle handling and stability. Tire pressure has varying degrees of influence on the rolling resistance coefficient, water-slip phenomenon, tire standing wave phenomenon and sideswipe stiffness of the wheel, thus affecting the handling stability of the vehicle. Cho’s research results show the relationship between the critical velocity of water slide and tire pressure, and it is found that the critical velocity of water slide is proportional to the 1/2 power of tire pressure [1]. Ong found that the critical velocity of water slide increased with the increase of its load and tire pressure [2]. With the increase of tire pressure, the drainage capacity of tread increases, and water slip is not easy to occur. With the decrease of the tire pressure, the drainage capacity of the tire tread is weakened, and the water in the pattern is not discharged in time, and the water-slip phenomenon is more likely to occur. Tire sideslip characteristics are the basis of vehicle handling stability. In a certain range, the lateral stiffness increases with the increase of tire pressure, and the lateral stiffness decreases when the tire pressure reaches the rated value. Kasprzak analyzed the influence of tire on vehicle lateral force and righting moment, and found that tire pressure on wheel lateral force was closely related to vertical load [3-4]. The longitudinal and lateral forces of the tire are the most important external forces in the driving of the automobile. This mechanical characteristic has an important influence on the handling and stability of the automobile.

At present, most domestic scholars do not consider the influence of tire pressure when studying vehicle handling and stability control. In this paper, based on the “magic formula” empirical formula, the experience of the tire pressure tire model is established, and set up seven degrees of freedom vehicle model by simulating the car tires driving conditions, respectively, considering four tires are in a different level of tire pressure influence on vehicle handling stability simulation analysis. The analysis results of this paper have a certain guiding significance for the research of vehicle handling stability.
2. Vehicle system dynamics model

2.1. Seven degrees of freedom vehicle dynamics model

In order to analyze the influence of different tire pressure levels on vehicle handling stability, a seven-degree-of-freedom vehicle dynamics model was established. As shown in Figure 1 below, the model considers longitudinal motion along the X axis, lateral motion along the Y axis, yaw motion around the Z axis, and rotation motion of the four wheels. In order to simplify the model, the effects of air resistance and tire rolling resistance are ignored.

![Seven degrees of freedom vehicle dynamics model](image)

The seven-degree-of-freedom dynamic motion differential equation of the vehicle includes longitudinal, lateral and yaw motion equations [5]. The differential equation of vehicle longitudinal motion can be expressed as:

\[ m(u-vr) = \sum F_x = (F_{x1} + F_{x2}) \cos \delta - (F_{y1} + F_{y2}) \sin \delta + F_{x3} + F_{x4} \]

(1)

The differential equation of vehicle lateral motion can be expressed as:

\[ m(v+ur) = \sum F_y = (F_{x1} + F_{x2}) \sin \delta + (F_{y1} + F_{y2}) \cos \delta + F_{y3} + F_{y4} \]

(2)

The differential equation of vehicle yaw motion can be expressed as:

\[ I_r = [(F_{y1} + F_{y2}) \cos \delta + (F_{x1} + F_{x2}) \sin \delta] \cdot a - (F_{x3} + F_{x4}) \cdot b + \\ (F_{y1} - F_{y2}) \sin \delta + (F_{x2} - F_{x1}) \cos \delta] \cdot \frac{D_r}{2} + (F_{x4} - F_{x3}) \cdot \frac{D_r}{2} \]

(3)

2.2. Tire model considering tire pressure effect

The influence of tire pressure on vehicle handling stability was analyzed by establishing a tire model including tire pressure. Based on the tire model with “magic formula”, this paper introduced the tire pressure change rate to extend the tire pressure as the input of the tire model [6-8]. Among them, tire pressure, vertical load variation, lateral stiffness and adhesion coefficient, tire longitudinal slip stiffness and adhesion coefficient, tire drag, tire lateral force and longitudinal force are mainly considered in the model.

(1) The variation of tire pressure and vertical load can be expressed as:

\[ dp_t = \frac{P_t - P_{t0}}{P_{t0}} ; \quad df_z = \frac{F_z - F_{z0}}{F_{z0}} \]

(4)

(2) The lateral stiffness of the tire is:

\[ K_y = p_{y1} \left(1 + p_{y2} dp_t\right) \cdot F_{z0} \cdot \sin \left[ p_{y4} \cdot \arctan \left( \frac{F_z}{p_{y2} \left(1 + p_{y2} dp_t\right) F_{z0}} \right) \right] \]

(5)
(3) The longitudinal slip stiffness of automobile tires is:

\[ K_{sk} = F_x \left( p_{kx1} + p_{kx2} \frac{df_x}{dp} \right) \exp \left( p_{kx1} \frac{df_x}{dp} + p_{kx2} \frac{dp}{dp} \right) \]  

(6)

(4) The tire side-slip force is:

\[ F_y = D_y \sin \left[ C_y \arctan \left( B_y \alpha_y - E_y \left( B_y \alpha_y - \arctan \left( B_y \alpha_y \right) \right) \right] + S_y \]  

(7)

(5) The tire longitudinal force is:

\[ F_x = D_x \sin \left[ C_x \arctan \left( B_x K_x - E_x \left( B_x K_x - \arctan \left( B_x K_x \right) \right) \right] + S_x \]  

(8)

3. Vehicle handling and stability control model

3.1. Simulation model

According to the vehicle powertrain model and the stability control strategy based on yaw moment control, the model was built in the Matlab/Simulink environment. The vehicle handling and stability control model includes a tire model with tire pressure (as shown in Fig. 2) and a vehicle dynamics model with seven degrees of freedom. Vedyna is used to provide real-time speed and steering wheel angle.

Fig. 2 Vehicle handling stability simulation model based on tire pressure

3.2. Results and Analysis

In the simulation of vehicle handling stability considering the change of tire pressure, the dual lane condition under typical driving conditions was selected for simulation analysis. The influence of different tire pressure levels was studied, three levels of tire pressure, namely low (1.8 bar), standard (2.3 bar) and high (2.8 bar), were taken for simulation analysis. The simulation results are shown in Figure 3. It can be seen that the curves of vehicle yaw rate are different under the three tire pressure conditions. When the tire pressure is 1.8 bar and 2.8 bar, the vehicle yaw angular velocity follows the working condition well before 14s, and after 14s, the vehicle yaw rate presents a large oscillation jump and gradually becomes stable. When the tire pressure is 2.3 bar, the yaw rate follow-through performance is very good.
4. Conclusion
In this paper, a vehicle system dynamics model is built to simulate the control of vehicle handling stability. The influence of tire pressure on vehicle handling and stability control is analyzed. (1) The seven-degree-of-freedom dynamics theoretical model of the vehicle was built, and the influence of tire pressure variation was considered to establish the tire theoretical model. (2) Based on the established vehicle dynamics model, the simulation study of vehicle handling stability control considering tire pressure changes was carried out.

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