Research on Dynamic Performance Simulation of In-wheel Motor Electric Vehicle Based on CarSim-Simulink

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Abstract. In order to reduce test costs and improve work efficiency, on the basis of the existing in-wheel-motor electric vehicle platform, CarSim software is used to establish a complete in-wheel-motor electric vehicle model that matches the actual vehicle. Based on Simulink, the dynamic model of the in-wheel motor is established. By defining the interface between the vehicle and the motor drive system, a joint simulation platform for in-wheel motor electric vehicles is established based on CarSim-Simulink, and simulation verification is performed on it. The results show that the established simulation model has high accuracy, can better simulate the existing experimental vehicle, accurately reflect the dynamic performance response of the vehicle, and provide a basis for further research and verification of control algorithms.

1. Introduction

In recent years, the global energy shortage and environmental pollution problems have become increasingly serious, which makes the development of future automobiles more inclined to pure electric vehicles [1]. Electric vehicles independently driven by in-wheel motors have attracted much attention due to their unique advantages such as compact design, simple structure, short power transmission chain, high transmission efficiency and rapid control response [2]. In-wheel motor electric vehicles, as a new form of vehicle architecture design, abandon the original traditional mechanical transmission mechanism, only by controlling the speed of the motor installed in the wheel hub to adjust the vehicle's motion state, the wheel torque can be distributed in any proportion within the range of motor characteristics [3]. The existence of this unique structure and control advantages gives it obvious dynamics advantages, and has greater technical space and development potential in terms of vehicle dynamics, stability and safety [4].

In order to further study the dynamic characteristics and control algorithms of in-wheel Motor Electric vehicles, it is necessary to establish a complete, accurate and practical simulation test model as a basis. Judging from the existing domestic and foreign documents, most of the simulation models are built based on MATLAB/Simulink module programming. As an authoritative and mature vehicle dynamics analysis software, Carsim software has the advantages of considering many degrees of freedom of movement, stable operation, and high simulation accuracy, which makes it special significance to establish an in-wheel motor electric vehicles test model and analyze its dynamic performance. However, since Carsim is currently mainly targeting traditional fuel vehicles and has not yet developed a dynamic simulation module for in-wheel motor electric vehicles, this paper modifies a certain fuel vehicle into an electric-wheeled vehicle based on the structure and characteristic
parameters measured and identified by the existing actual vehicle platform. The motor characteristic parameters are obtained through the motor loading and efficiency experiment, and the characteristic model of the hub motor is established based on Simulink. The two are combined to complete a simulation model of an in-wheel motor electric vehicle and verify its straight driving and steering capabilities. The whole modeling adopts a layered method, and the vehicle speed following controller and the driving torque distribution controller that generate the total driving force are designed, and finally verified by the simulation conditions. Design of vehicle test platform.

2. Vehicle dynamics model

2.1 Real vehicle test platform

The actual vehicle test platform of the in-wheel motor electric vehicle serves as the basis of the vehicle road test and dynamics research, and its role is self-evident [5]. At present, when most research institutions develop actual vehicle platforms, they use mainstream models in the market for comprehensive transformation. This article adopts independent design concepts to complete the model design and construction of a vehicle test platform based on simplified bodywork. The whole vehicle test platform uses a lead-acid battery pack to provide power, uses four-wheel motors for independent drive, uses an independent suspension structure, is equipped with EPS and EHB systems, and is designed with unique instrument functions, truly realized the "low noise, zero emission, and high efficiency" of vehicle driving [6]. In the early stage of the platform, the three-dimensional solid modeling software CATIA was used to complete the entire design process and to match and verify the assembly parts. The final model diagram is shown in Figure 1. With reference to the vehicle design platform, after the market selection of relevant components, they are assembled, processed and tested, and finally a complete real vehicle platform is obtained as shown in Figure 2.

2.2 Vehicle model based on Carsim

According to the structure and characteristic parameters of the above-mentioned actual vehicle test platform, a CarSim vehicle model is designed based on the actual vehicle platform. However, because there are only some complete vehicle models of traditional cars in CarSim software, the power output route of traditional cars is from the engine to the transmission system to the wheels,, while the power of the in-wheel motor electric vehicle studied in this paper is directly generated by the in-wheel motor. Therefore, it is necessary to modify a traditional car model in CarSim, modify its power system, cut off the power transmission between the transmission system and the wheels, and change from the built-in engine drive to the external power drive, which is directly driven by the motor torque is loaded into the wheels to achieve [7]. In addition, in order to complete the cross-platform co-simulation with Simulink, it is necessary to pre-define the input and output interfaces of the above-mentioned CarSim vehicle model. The correct setting of the interface is critical to the accuracy of the entire model, especially for the co-simulation process. Table 1 shows the specific interface settings.
TABLE 1. Co-simulation input/output interface settings

| Input/output variable name | Physical meaning |
|---------------------------|------------------|
| IMP_MYUSM_L1             | Left front wheel torque |
| IMP_MYUSM_R1             | Right front wheel torque |
| IMP_MYUSM_L2             | Torque of left rear wheel |
| IMP_MYUSM_R2             | Right rear wheel torque |
| Vx-Target                | Target speed |
| Vx                        | Actual speed |

3. Motor dynamics model based on Simulink

3.1 Motor selection calculation

In the pre-design and development of the in-wheel motor electric vehicle, it is necessary to formulate the power performance parameters of the designed vehicle, and select the motor drive system according to the power requirements. Table 2 below shows the target performance parameters of the actual vehicle platform design. The primary selection of the motor is mainly based on the maximum speed of the car to determine its power $P_{el}$, and then the highest demand power $P_{el}$ of the motor is checked according to its acceleration and climbing index requirements, and the peak power of the motor is determined with reference to the highest power of the motor [7]. The specific power calculation is as follows: 1 and 2, where $f$ is the rolling resistance coefficient, $\eta$ is the mechanical efficiency, and the other parameters are shown in Table 2. After the above-mentioned motor selection calculation, and considering the working performance of the motor and other factors, the permanent magnet brushless DC motor is selected as the vehicle motor, and according to the matching calculation results, a motor is selected. Its main parameters are shown in Table 3.

$$P_{el} = \frac{1}{\eta} \left( \frac{mg f v_{max} + C_p A v_{max}^3}{76140} \right)$$

$$P_{el} = \frac{1}{\eta} \left( \frac{mg f \cos \alpha_{max} + \sin \alpha_{max}}{3600} v_a + \frac{C_p A}{76140} v_a^3 \right)$$

TABLE 2. Vehicle performance parameter table

| Vehicle quality $m$ /kg     | 1220       |
| Wheelbase $L$ /m            | 2.33       |
| Wheelbase $d$ /m            | 1.48       |
| Wheel radius $r$ /m         | 0.33       |

Coefficient of air resistance $C_p$ 0.3
Frontal area $A$ /m$^2$ 3
Maximum speed $v_{max}$ (km/h) 150
Maximum grade $\alpha_{max}$ /\(^\circ\) 20

TABLE 3. Matched motor parameters

| Motor parameters | Numerical value |
|------------------|-----------------|
| rated power $P_e$/kw | 10 |
| Peak power $P_e$/kw | 30 |
| Rated speed $n_e$/rpm | 400 |
| Peak speed $n_e$/rpm | 1200 |
| Rated torque $T_e$/(N.m) | 150 |
| Peak torque $T_e$/(N.m) | 220 |
3.2 Motor modeling

As the core component of the in-wheel electric vehicle, the motor system is a key step in the establishment of the in-wheel electric vehicle simulation model. Taking into account the advantages of simple structure, small size, convenient control and better efficiency of the permanent magnet brushless DC motor, the driving system of the electric vehicle real vehicle platform uses four high-power permanent magnet brushless DC hub motors. The permanent magnet brushless DC motor is composed of three-phase stator winding, permanent magnet rotor, voltage inverter, rotor position detector, etc. To simplify the establishment of the model, the cogging effect, motor core saturation and damping effects are ignored. Excluding the armature reaction, the numerical model is as follows:

The voltage balance equation of the three-phase winding:

\[
\begin{bmatrix}
u_a \\ u_b \\ u_c
\end{bmatrix} = 
\begin{bmatrix}
r & 0 & 0 \\ 0 & r & 0 \\ 0 & 0 & r
\end{bmatrix}
\begin{bmatrix}
i_a \\ i_b \\ i_c
\end{bmatrix} +
\begin{bmatrix}
0 & L - M & 0 \\ L - M & 0 & 0 \\ 0 & 0 & L - M
\end{bmatrix}
\begin{bmatrix}
i_a \\ i_b \\ i_c
\end{bmatrix} +
\begin{bmatrix}
e_a \\ e_b \\ e_c
\end{bmatrix}
\] (3)

Among them, \(u_a, u_b, u_c\) is the stator phase winding voltage; \(i_a, i_b, i_c\) is the stator phase winding current; \(e_a, e_b, e_c\) is the stator phase winding electromotive force; \(L\) is the self-inductance of each phase winding; \(M\) is the mutual inductance between every two-phase winding; \(p\) is the differential operator.

Electromagnetic torque equation:

\[
T_e = \frac{e_a i_a + e_b i_b + e_c i_c}{\omega}
\] (4)

The motion equation of the motor:

\[
T_e - T_L = J_w \frac{d\omega}{dt} + B\omega
\] (5)

Among them, \(T_e\) is electromagnetic torque; \(\omega\) is rotor angular velocity; \(T_L\) is load torque; \(J_w\) is motor moment of inertia; \(B\) is viscous friction coefficient. However, the above-mentioned mathematical model is more complicated, and it is transformed and described here and expressed as the following formula. Where: \(K_x\) is the torque coefficient; \(K_c\) is the back electromotive force coefficient; \(E\) is the input voltage; \(r\) is the armature resistance.

\[
T_e - T_L - B \cdot \omega = J_w \cdot \dot{\omega}
\] (6)

\[
T_e = K_m \cdot i_a
\] (7)

\[
E - K_e \cdot \omega - r \cdot i_a = L_m \cdot \dot{i}_a
\] (8)

When the in-wheel motor electric vehicle is actually running, the vehicle control system receives the target drive torque signal of the accelerator pedal and sends instructions to the motor controller to output electromagnetic torque to drive the wheels. Because the motor is directly connected to the wheels, this article assumes that the transmission process excluding the torque loss, the transmission efficiency is 100%. Therefore, according to the digital-analog formula 6-formula 8, a motor model based on torque PI control is established in Simulink. Among them, the expression of the torque PI control is shown in equation 9. The voltage at the input terminal of the motor is generated by PI calculation through the difference between the target torque and the actual torque. The required motor physical parameters are mainly provided by the actual vehicle motor manufacturer. However, since the target torque determined by the decision may exceed the peak torque of the motor, it is necessary to consider the torque limit at this speed, and combine the characteristic data obtained in the motor experiment in the previous chapter to establish a look-up table module, which is obtained through the look-up table the maximum torque that the motor can output at the current speed is compared with the calculated torque required by each wheel. If the calculated driving torque is small, the calculated torque
will be output; on the contrary, if the calculated torque is large, the maximum rotation of the motor will be output. Figure 3 is a torque PI control motor model based on a characteristic look-up table established by Simulink.

\[ E_{ij} = K_p(T_{ed_{ij}} - T_{ei_{ij}}) + K_i \cdot \int (T_{ed_{ij}} - T_{ei_{ij}})dt \]  

(9)

**Fig. 3. Wheel hub motor model**

### 4. Modeling and simulation of in-wheel motor electric vehicles

#### 4.1 Design of Drive Controller Based on Speed Following

After completing the modeling of the in-wheel motor electric vehicle based on CarSim, since the internal power system of the modified vehicle has been cut off, it is necessary to design the drive controller in an external way. The control process obtains the total drive force according to the vehicle speed demand, and then after a certain algorithm, it is assigned to the four in-wheel motors to drive the vehicle. In this paper, considering that the PID control algorithm is simple, easy to use, adaptable, and robust, so in the design of the drive controller to obtain the required total driving force, a PID control-based vehicle speed following controller is used, so that it can carry out stable and adaptive tracking to the set target speed in real time [8]. The controller takes the deviation $e$ between the driver's target vehicle speed $V_{ref}$ and the actual feedback vehicle speed $V$ as input. After the PID control module's solution, the controller outputs the total drive torque $T_d$. The control process is shown in Figure 4. The calculated total drive torque input to the torque distribution module, then output the target torque command to the motor control system to drive the wheels.

**Fig.4. Vehicle speed follows PID control process**

#### 4.2 Co-simulation model establishment and verification

Based on the vehicle dynamics model and the in-wheel motor model established above, combined with the developed driving strategy based on speed following control, a co-simulation model of the in-wheel motor electric vehicle is established based on CarSim-Simulink. In order to verify whether the steering stability of the in-wheel motor electric vehicle under normal driving conditions is good, it is necessary to conduct a simulation test on its steering stability during steering. In order to verify the vehicle's handling stability under steady state, this paper selects a typical handling stability test condition: increasing sine condition, vehicle speed 80km/h, road adhesion coefficient 0.85. And the results are shown in Figure5 and Figure 6. In order to facilitate reference and comparison, the CarSim traditional car model with the same structure and parameters is selected as the reference car and some parameters
are compared and measured. It should be noted that although there are differences in the power system between the two, the same overall structure and working condition parameter settings have little effect on the stability parameter response of its driving under steady state, and the CarSim reference car is used as the model validated by actual tests is obtained when it is created, and the performance indicators reflected can provide a reference for the simulation results of the in-wheel motor electric vehicle.

![Fig. 5. Simulation results of increase sine condition](image)

It can be seen from the results in Fig. 8 that the driving trajectory, yaw rate, center of mass side slip angle, and lateral acceleration of the in-wheel motor electric vehicle under increased sinusoidal conditions are all close to the verified CarSim reference vehicle, indicating that the overall compliance performance Claim. Although there is a slight deviation, it is mainly because the suspension system and other models of the in-wheel motor electric vehicle are different from the reference car. When encountering a certain yaw motion, the yaw stability of the two cars also shows a little difference. The
driving speed curve in Figure 5(b) shows that both vehicles have a better ability to follow the target speed (80km/h), but due to the difference in the power system and speed control method of the two vehicles, a certain deviation is caused.

![Figure 5](image)

![Figure 6](image)

Fig. 6. The response characteristics of the motor

It can be seen from Figure 6(a) that the torque change curve of the motor under working conditions shows that the actual torque of the motor basically coincides with the target torque, indicating that the established motor model based on torque PI control follows the torque accuracy of performance is relatively high; from the speed curve in Figure 6(b), the speed of the four wheels is basically the same at the beginning of driving at the initial speed of 80km/h. After sinusoidal steering, the speed of the outer wheel (right) is always greater than that of the inner wheel (left) Speed, which fits the actual situation. The motor current change curve in Figure 6 (c) is consistent with the torque change trend, which is consistent with the linear relationship between the motor current and torque in reality; Figure 6 (d) shows the motor control voltage obtained by the torque difference PI calculation. It can be seen that at the beginning of the vehicle driving, the voltage is increasing. With the increase of vehicle speed and steering change input, the voltage also shows certain fluctuations.

5 Conclusion

In this paper, the whole vehicle model of the in-wheel motor electric vehicle is established based on the CarSim software platform, and then the dynamic model of the in-wheel motor is established based on Simulink. Then the software cross-platform interface was defined, and the simulation modeling of the in-wheel motor electric vehicle was completed based on CarSim-Simulink, and carried out the simulation verification of its driving ability. Verified by simulation data, the built model is accurate, effective, and highly accurate, which can provide a solid foundation for the later research on vehicle control algorithms.
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