Study on Design of the whole vehicle test platform and Modeling simulation for In-wheel motor electric vehicles

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Abstract—In order to meet the needs of actual vehicle research, the whole vehicle test platform for in-wheel electric vehicles is designed based on the idea of modularity. On the basis of the vehicle test platform, a joint simulation platform for in-wheel motor electric vehicles is established based on CarSim-Simulink, and simulation verification is carried out. The results show that the designed real-vehicle platform scheme is feasible, and the established simulation model has high accuracy, which can simulate the experimental vehicle well, accurately reflect the dynamic performance response of the vehicle, and provide a basis for further control algorithm research and verification.

1. INTRODUCTION

In recent years, electric vehicles independently driven by in-wheel motors have attracted attention due to their unique advantages such as compact design, simple structure, short power transmission chain, high transmission efficiency and rapid control response. As a brand-new vehicle architecture design form, it abandons the original traditional mechanical transmission mechanism, and only adjusts the vehicle's motion state by controlling the motor speed installed in the wheel hub, so that the wheel torque can be distributed in any proportion within the range of the motor characteristics. 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, handling stability and safety.

In order to further study the dynamic characteristics and control algorithms of in-wheel motor electric vehicles, it is necessary to design and establish a complete, accurate and practical real vehicle platform and simulation test platform as a basis. Therefore, based on the modular design concept, this paper completed the model design of the vehicle test platform based on the simplified body, and based on the structure and characteristic parameters of the designed vehicle platform, based on a certain fuel vehicle model built in CarSim, the structure Modifications are made to electric vehicles with in-wheel motors. According to the characteristic parameters of the in-wheel motor, the dynamic model of the in-wheel motor is established based on Simulink. By setting the interface connection, the two are combined to complete the simulation model of the in-wheel motor electric vehicle, and its driving ability is verified.

2. DESIGN OF VEHICLE TEST PLATFORM

2.1 Motor drive system
The motor drive system is the heart of the in-wheel motor electric vehicle, which determines the driving power of the vehicle. Before model design, the electric drive system is selected and calculated according to the driving power parameters required by the whole vehicle to complete the design...
matching. The performance parameters required by the test platform design are shown in Table 1. The primary selection of the motor is mainly based on the maximum speed of the car to determine its power, and then the highest required power 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. The specific power calculation is as follows: 1 and 2, where is the rolling resistance coefficient, is the mechanical efficiency, and the other parameters are shown in Table 1.

After the selection and calculation of the motor, the permanent magnet brushless DC motor is selected as the motor used in the vehicle test platform. According to its mechanical structure, the three-dimensional design model of the in-wheel motor system is completed as shown in Figure 1.

\[ P_{el} = \frac{1}{\eta_t} \left( \frac{mgf}{3600} v_{max} + \frac{C_p A}{76140} v_{max}^3 \right) \]

\[ P_{ez} = \frac{1}{\eta_t} \left( \frac{mg f \cos \alpha_{\text{max}} + \sin \alpha_{\text{max}}}{3600} v + \frac{C_p A}{76140} v^3 \right) \]

**TABLE I. Vehicle performance parameter table**

| Parameter                  | Value  |
|----------------------------|--------|
| Vehicle quality m/kg       | 1220   |
| Coefficient of air resistance \( C_p \) | 0.3    |
| Wheelbase L/m              | 2.33   |
| Frontal area A/m²          | 3      |
| Wheelbase d/m              | 1.48   |
| Maximum speed \( V_{max} \) (km/h) | 150    |
| Wheel radius r/m           | 0.33   |
| Maximum grade \( \alpha_{\text{max}} \) (°) | 20     |

### 2.2 Power battery system

According to the requirements of the working voltage of the motor system, in order to reduce the cost and meet its requirements, the power battery system is designed to use 9-12V lead-acid batteries, and the total voltage of the battery packs in series is 108V. In addition, according to the initial concept, the test platform is required to have a continuous mileage of 40km after being fully charged. In order to make the power battery system more reasonable layout on the whole vehicle, the battery system and its box have been designed in three dimensions. The three-dimensional model is shown in Figure 2.

![Figure 1. Three-dimensional model of motor](image1)

![Figure 2. Three-dimensional model of battery](image2)
2.3 Steering and brake system
The in-wheel motor electric vehicle has no engine assembly, which makes the traditional hydraulic power steering system unable to be used normally. Therefore, it is considered that the driver can better control the direction of the car when the in-wheel motor actual vehicle platform is built later. Power steering EPS system. The steering gear adopts a popular rack and pinion steering system. According to its mechanical structure, a three-dimensional model is designed. The model is shown in Figure 3. In the design of the brake system of the vehicle test platform, it is considered that the vacuum pump provides energy to the servo chamber in the vacuum booster. The vacuum pump uses 24V on-board DC power supply. After it works, it provides vacuum assistance for the test platform. The three-dimensional model design of the system is shown in Figure 4.

![Figure 3. Three-dimensional model of steering system](image3.png)

![Figure 4. Three-dimensional model of brake system](image4.png)

2.4 Vehicle test platform
On the basis of the design of each subsystem, after three-dimensional matching, verification and assembly, the three-dimensional model design of the test platform is completed, as shown in Figure 5. The test platform uses lead-acid battery packs as the power source of the vehicle, uses four-wheel hub motors to independently drive, design independent suspension structure, installs electric power steering EPS system, and integrates unique instrument design functions, thus truly realizing the driving of the vehicle "High efficiency, low noise and zero emissions".

![Figure 5. Three-dimensional model of the whole vehicle](image5.png)
3. SIMULATION MODEL ESTABLISHMENT

3.1 Vehicle modeling

According to the parameters of the actual vehicle platform designed above, a vehicle model consistent with the actual vehicle platform of the in-wheel electric vehicle is completed based on CarSim. The establishment of the CarSim vehicle model is mainly carried out from seven parts, namely the car body, aerodynamics, power system, braking system, steering system, suspension and tires, as shown in Figure 6 below. From the perspective of these seven components, except for the power system, the modeling of the rest of the systems is similar or the same as that of the traditional car. Therefore, in the process of modeling the whole vehicle, except for the power system, the modeling of the other systems is based on real. Except for the vehicle platform parameters, the default values are used without modification. The focus is mainly on the rectification of the power system model. Since the power output route of the traditional car built in CarSim is the engine-transmission system-wheels, 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 certain traditional car model in CarSim, modify its power system, cut off the power transmission between the transmission system and the wheels, and change the built-in engine drive to an external interface to connect power to it. Provide driving force, which is then directly loaded into the wheels by the motor torque. Among them, the input/output interface settings are shown in Table 2.

Figure 6. CarSim vehicle model structure composition

| 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              |

3.2 Motor system modeling

According to the results of the matching calculation during the actual vehicle design, the selected permanent magnet brushless DC motor parameters are shown in Table 3.

| Motor parameters | Numerical value |
|------------------|-----------------|
| rated power $P_e$/kw | 10              |
| Peak power $P_a$/kw    | 30              |
| Rated speed $n_e$/rpm  | 400             |
| Peak speed $n_a$/rpm    | 1200            |
| Rated torque $T_e$/N.m   | 150             |
| Peak torque $T_a$/N.m    | 220             |
Considering that the focus of this article is mainly to establish the complete vehicle dynamics model of the in-wheel motor electric vehicle, and the accuracy of the motor dynamic model is not too high, some simplifications have been made in the process of modeling the in-wheel motor, but still it can ensure that it reflects the actual characteristics of the motor well. Therefore, a look-up table method is used to model the motor system. Get the maximum torque that the motor can output at the current speed by looking up the table, and compare it with the calculated torque required for each wheel. If the calculated driving torque is small, the calculated torque will be output; otherwise, if the calculated torque is large, the output will be the maximum torque of the motor. Figure 7 below shows the in-wheel motor model based on MATLAB/Simulink platform.

![Figure 7. In-wheel motor dynamic model](image)

3.3 Co-simulation model

After completing the modeling of the in-wheel electric vehicle based on CarSim, since the internal power system of the modified vehicle has been cut off, the drive controller needs to be designed by an external method. 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 vehicle speed following controller based on PID control is used. Enabling it to carry out stable and adaptive tracking of the set target vehicle speed in real time [6]. The input of the controller is the error between the target vehicle speed and the actual vehicle speed, and the output is the total driving force required, as shown in the following equation 3. Among them, are the proportional, integral, and differential coefficients in PID control.

$$T_d(t) = k_p \cdot e(t) + k_i \int e(t)dt + k_d \cdot \frac{de(t)}{dt}$$  \hspace{1cm} (3)

Based on the vehicle dynamics model and in-wheel motor model established above, combined with the established driving strategy based on vehicle speed following control, a co-simulation model of the in-wheel motor electric vehicle is established based on CarSim-Simulink, as shown in Figure 8.

![Figure 8. Co-simulation model](image)

3.4 Simulation verification

After the modeling is completed, for the follow-up algorithm research, the accuracy of the model needs to be effectively verified. Therefore, the straight-driving ability and steering ability of the model during driving under the set road conditions are simulated and verified.
3.4.1 Direct driving ability verification
In order to verify the straight driving ability of the car, it is necessary to ensure that the driving torques of the four wheel hub motors of the whole vehicle are synchronized. Therefore, the driving torque of 100N.m is set for the four wheels, and the road adhesion coefficient is set to 0.85 to simulate the straight driving ability of the vehicle under straight-line and uniform acceleration. In this process, the vehicle accelerates from a standstill. The simulation time is set to 20s, and the corresponding results are shown in Figure 9 below. From the driving trajectory of Figure 9(a) and the wheel angle curve of Figure 9(b), it can be seen that the deviation of the car after 20s of driving is only 0.013cm, and the deflection angle of each wheel is relatively small, which is basically close to 0 degree. The above data shows that the car has good straight driving ability.

3.4.2 Steering ability verification
In order to verify the steering ability of the car, when the vehicle is running for 5 seconds, a 5-degree step angle signal is set for the steering wheel to make it steer and travel in a circle. The road adhesion coefficient is set to 0.85, and the target vehicle speed is set to 60km/h, and the simulation result is shown in Figure 10.
Figure 10(a) shows the change of the front wheel angle during driving, and Figure 10(b) shows the trajectory of the vehicle driving. It can be seen from the curve in the figure that the front wheel angle of the vehicle has changed to a certain extent. However, it is basically not much different from the given input, that is, it is close to the 5 degrees set under the open loop condition, which meets the requirements of the angle input, and it can be seen from the driving trajectory that it meets the Ackerman steering characteristics. The above data shows that the built model has good steering performance.

4. CONCLUSION

This paper first designed a three-dimensional model of the in-wheel motor electric vehicle test platform based on the CATIA platform, and then, based on the parameters of the actual vehicle platform, the simulation modeling of the in-wheel motor electric vehicle was completed in conjunction with CarSim-Simulink, and the driving ability was simulated and verified. The results show that the designed real-vehicle platform scheme is feasible, and the built simulation model is accurate, effective and high-precision, which can provide a solid foundation for the later research of vehicle control algorithms.

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