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Research Article

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Dynamic modeling and simulation verification of electromagnetic direct drive steering-by-wire system

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Abstract With the progress of computer technology, the operation of various automobile simulation software is becoming more and more simple, in addition, they can also be combined with MATLAB/Simulink, LabVIEW and other software, so as to improve the simulation accuracy. The main task of this paper is to establish the dynamic simulation model of electromagnetic direct drive steerable by wire vehicle and conduct simulation verification. First of all, MATLAB/Simulink software is used to build the dynamics model of the electromagnetic direct drive steering-by-wire system designed above. Then, in the automotive dynamics simulation software CarSim, the dynamics model of the micro electric vehicle with the traditional mechanical steering system is set up according to the vehicle parameter table listed above. And the built SBW system model is embedded into the set CarSim car model through the S-function interface, so as to complete the establishment of the SBW vehicle model. Secondly, in order to effectively track the driver's turning intention, a fuzzy PID displacement tracking controller is designed to follow the driver's turning intention by controlling the line displacement of the steering transmission rod. Finally, the simulation was compared with the vehicle model provided by Carsim software to verify the correctness of the model.

Keywords Steering by wire system, Co-simulation of vehicle dynamics, Vehicle handing stability

1. Introduction

At present, the steering executive module of the steer-by-wire steering system mainly uses the permanent magnet synchronous motor and the reducer to provide power for the automotive rack and pinion steering device, and then drives the steering joint and the steering wheel to deflect in order to achieve steering. However, the design of the reducer should be carried out when the steering motor is selected, resulting in too long research and development cycle, and will also reduce the transmission efficiency of the steering motor. Therefore, this paper proposes an electromagnetic direct drive steering-by-wire system applied to micro electric vehicles, that is, the use of high-power density moving-coil electromagnetic linear actuator combined with the steering flange as a steering executive motor, through the steering transmission rod directly drive the wheel steering, eliminating the pinion and rack steering gear, traditional motor reducer and other motion conversion mechanism, shorten the power transmission route. The power transmission loss is reduced, and the response speed and working efficiency are improved [1][2].

This paper takes a new type of micro electric vehicle as the design object. First, MATLAB/Simulink software is used to build the dynamics model of the electromagnetic direct drive steer-by-wire system designed above. Then, in the automotive dynamics simulation software CarSim, according to the vehicle parameter table listed above, the dynamics model of the micro electric vehicle with the traditional mechanical steering system is removed, and the established SBW system model is embedded into the set CarSim vehicle model through the S-function interface, thus completing the establishment of the SBW vehicle model. Secondly, in order to effectively track the driver's turning intention, a fuzzy PID displacement tracking controller is designed to follow the driver's turning intention by controlling the line displacement of the steering transmission rod. Finally, the model is simulated and compared with the vehicle model of Carsim software to verify the correctness of the model[3][4].

2. Establishment of the dynamic model of the electromagnetic direct drive steering-by-wire system

2.1 Steering wheel assembly dynamics model

The steering wheel assembly of the electromagnetic direct-drive steering-by-wire system. The steering wheel assembly is mainly composed of a steering wheel, Angle sensor, steering column, torque sensor, worm gear reducer and road sense analog motor. The steering wheel assembly belongs to the second-order dynamic system. In this paper, Newton Euler method is adopted to establish the dynamics model of the steering wheel assembly. In order to improve the modeling accuracy, nonlinear functions are adopted to establish the friction model of the steering wheel assembly [5].

2.2Turn to perform assembly dynamics model

The steering actuator assembly is mainly composed of a steering actuator motor, a steering flange, a steering transmission rod, a displacement sensor, a steering tie rod, a steering knuckle and a steering wheel. In this paper, steering transmission rod, steering flange, steering tie rod, steering knuckle and left and right steering wheels are equivalent to steering execution components.

The steering actuator is a second-order dynamic system, so its dynamic model is established by Newton Euler method. The external input of the steering actuator is the horizontal component of the electromagnetic force acting on it by the steering actuator motor and the steering resistance acting on it by the steering knuckle. The steering actuator overcomes the inertia force, damping force and friction force of the steering actuator components, thereby generating linear speed and linear acceleration of the steering transmission rod and driving the left and right steering wheels to rotate [6].

3. Research on steering execution control strategy of electromagnetic direct drive steer-by-wire system

The electromagnetic direct drive steering-by-wire system cancels the mechanical connection between the steering wheel assembly and the steering executive assembly, and uses the electric control system to connect. In order to realize the steering according to the driver's intention, it is necessary to design the steering rod displacement tracking control algorithm of the steering executive assembly.

In this paper, PID control algorithm is used to design the displacement tracking control algorithm of steering actuator assembly. In order to make the displacement tracking control more robust, fuzzy control strategy is introduced to adjust the proportional gain coefficient, integral gain coefficient and differential gain coefficient of PID controller.

3.1 PID control principle

PID (Proportional Integral Derivative) control is widely used in industrial control systems because of its advantages of simple structure, good stability, reliable operation and easy adjustment. The PID controller takes the variation obtained by the difference operation as the input and the output value is processed by the proportion, integral and differential operation as the input of the control object, so as to achieve the target control.

3.2 The principle of fuzzy control

Fuzzy Logic Control (Fuzzy Logic Control) is a nonlinear intelligent control method based on human control experience and common sense, based on fuzzy set theory, fuzzy language variables and fuzzy logic reasoning. It is suitable for complex control systems that are difficult to build mathematical models or have no mathematical models. The method and process of simulating manual control convert accurate digital signals into fuzzy language discourse domain, form language rules by utilizing mature experience and knowledge of experts in related fields, and realize the entire control process through fuzzy reasoning and clarity [7].

The functions of each link of fuzzy controller are as follows:

(1) Fuzzification refers to converting the input into the corresponding subset of the fuzzy domain through the input membership function, and setting the language value representing the degree, so that the fuzzy scale has richer information connotation. The membership function which is widely used is S type, Z type, symmetric type and so on.

(2) (2) The core of fuzzy reasoning is to establish a suitable fuzzy rule knowledge base. Fuzzy statements that make up fuzzy rules correspond to language variables in fuzzy categories through linguistic values and semantic rules.

(3) Clarity is the conversion of an ambiguous quantity into an exact value. The output is generally two or more sets of fuzzy membership values and output elements, which are combined with the output union and the output membership function to obtain the final control.

3.3 Design of fuzzy PID displacement tracking controller

Fuzzy PID control system is a combination of fuzzy controller and PID controller, using fuzzy rules to achieve self-tuning of PID parameters [8].

The CarSim vehicle model inputs the steering resistance into the dynamic model of the electromagnetic direct drive steer-by-wire system, and the electromagnetic direct drive steer-by-wire system dynamic model inputs the left and right wheel angles into the CarSim vehicle model.

In this paper, the difference E_r between the actual and the expected displacement of the steering lever, the differential dE_r of the steering lever displacement and the fuzzy set of ΔK_p, ΔK_i and ΔK_d are set as {NB, NS, ZO, PS, PB}, that is, {negative large, negative small, zero, positive small, large}. The fuzziness domains of E_r and dE_r are set to [-5, 5] mm and [-0.5, 0.5] m/s, respectively. The fuzziness domains of ΔK_p, ΔK_i and ΔK_d are set to [-3, 3], [-0.4, 0.4] and [-0.1, 0.1], respectively.

Figure 1, Figure 2 and Figure 3 show the three-dimensional surface of proportional coefficient adjustment value ΔK_p, integral coefficient adjustment value ΔK_i and differential coefficient adjustment value ΔK_d with the displacement difference E_r and differential dE_r of the steering transmission rod, respectively.

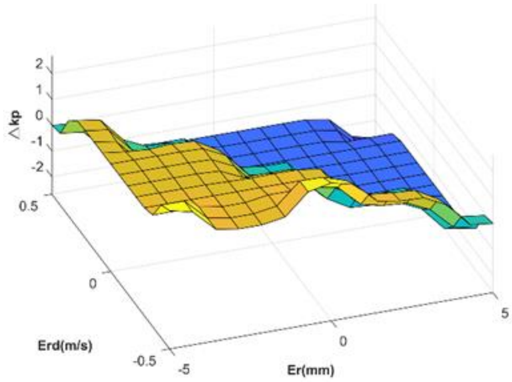

Figure 1: ΔK_p variation surface

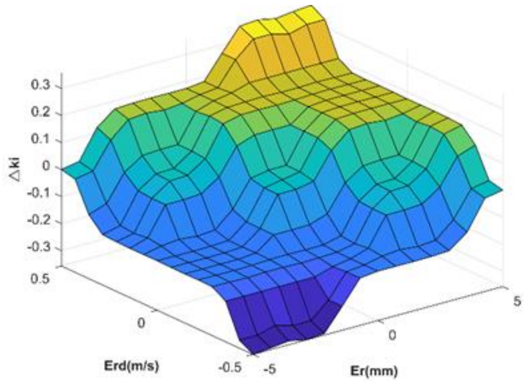

Figure 2: ΔK_i variation surface

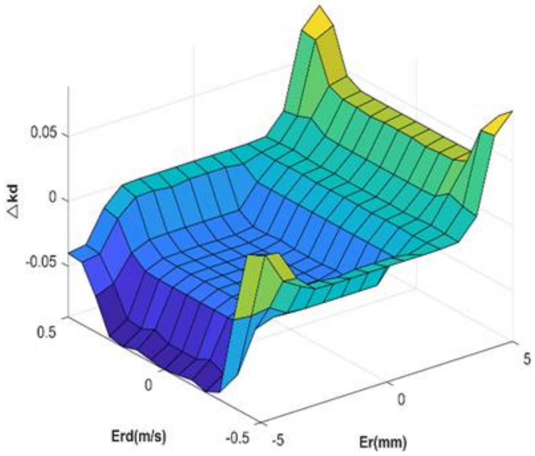

Figure 3: ΔK_d *variation surface*

4. Construction of joint simulation model of electromagnetic direct drive steering-by-wire vehicle based on CarSim

The Simulink simulation model of the electromagnetic direct drive steer-by-wire system and the fuzzy PID displacement tracking controller have been introduced in the previous section. Based on the original CarSim vehicle model, the Simulink model of the steer-by-wire system is used to replace the original mechanical steering module and improve the vehicle model. Thus, the whole vehicle model of steer-by-wire is established, and the whole vehicle equipped with steer-by-wire system is simulated and verified, and the vehicle model is compared with that of traditional steering system.

4.1 Introduction of CarSim simulation platform

The working interface of CarSim software is shown in Figure 4 and 5, which mainly consists of four parts: vehicle parameter setting module, road setting module, model solving setting module and post-processing module of simulation results.

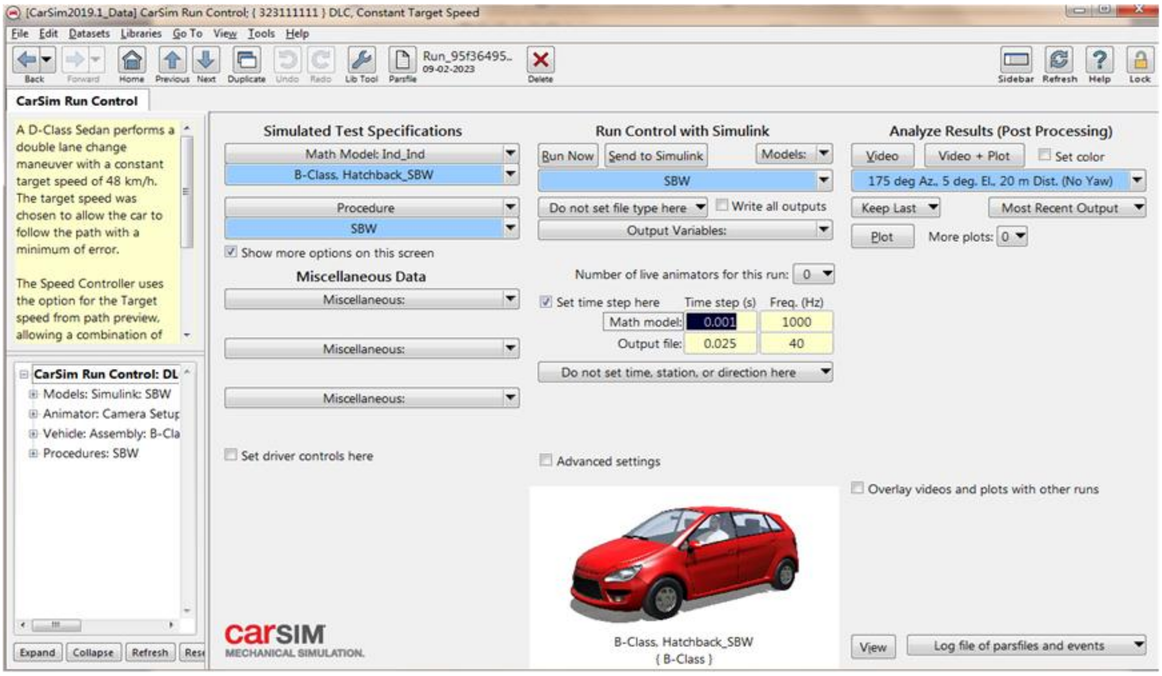

Figure 4: CarSim working interface

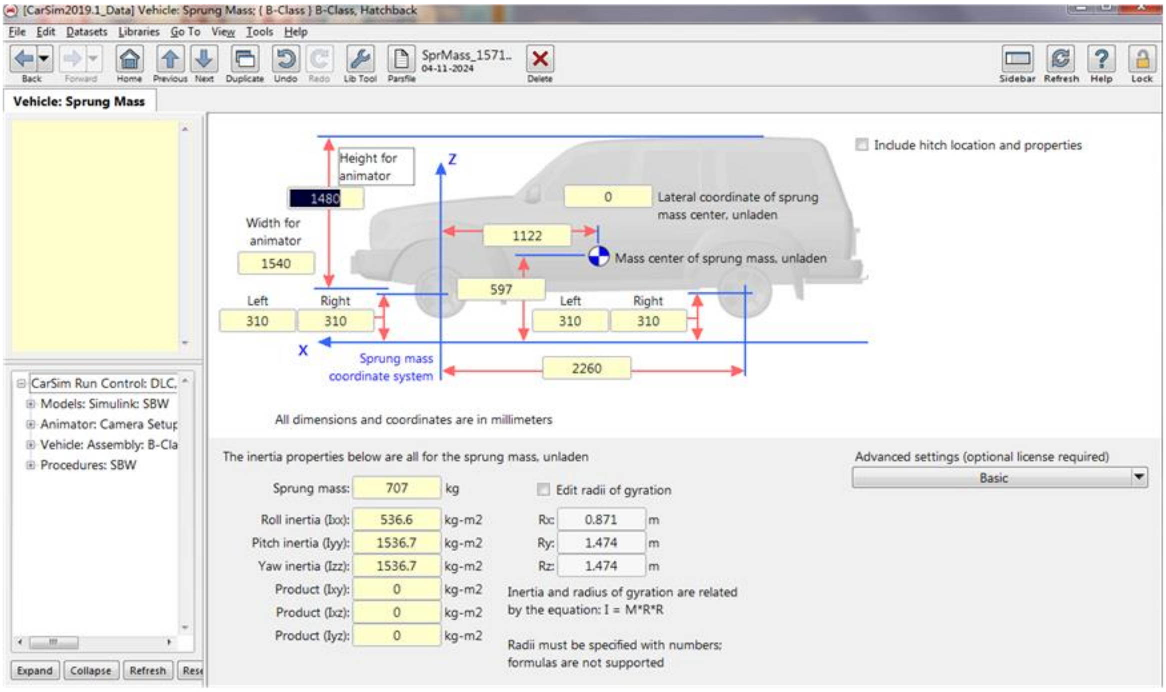

Figure 5: Main parameter setting of car body

5. Simulation test verification

In order to verify the correctness of the established dynamic model of electromagnetic direct drive steering-by-wire and fuzzy PID displacement tracking controller, this paper uses figure-eight simulation conditions to compare the established dynamic model of electromagnetic direct drive steering-by-wire system and the influence of fuzzy PID displacement tracking controller on vehicle control performance compared with traditional mechanical steering.

5.1 Eight-figure winding condition

In order to verify the influence of the established electromagnetic direct drive steering-by-wire system on the steering performance of the vehicle at low speed and large Angle, this paper uses the eight-figure winding condition for comparison and verification. Set the speed to 20km/h, so that the vehicle follows the set track curve.

Finally, the comparison curve of driving trajectory, yaw Angle velocity and lateral acceleration are obtained. It can be seen from the simulation results that the trajectory and yaw velocity response characteristics of the steer-by-wire vehicle dynamics model and the mechanical steer-by-wire vehicle model are basically the same, while the lateral acceleration curve of the steer-by-wire vehicle model is larger. It can be seen that the established steering-by-wire system has little effect on the performance of vehicle steering at low speed and large Angle.

6. Conclusion

In this chapter, simulation experiments verify that the designed electromagnetic direct drive steering-by-wire system has little influence on the steering performance of micro-electric vehicles, and the designed electromagnetic direct drive steering-by-wire vehicle dynamics model provides a simulation experiment platform for the research of intelligent vehicle drive-by-wire chassis. Firstly, MATLAB/Simulink software is used to establish the simulation model of electromagnetic direct drive steering-by-wire control model designed above, and CarSim vehicle dynamics simulation software is used to establish the whole vehicle dynamics model of mini electric vehicles. By setting the interface between Simulink and CarSim vehicle dynamics model, the co-simulation model of vehicle dynamics was established. Secondly, in order to effectively track the driver's turning intention, a fuzzy PID displacement tracking controller is designed to follow the driver's turning intention by controlling the line displacement of the steering executive motor. At last, the effectiveness of the established electromagnetic direct drive steering-by-wire vehicle dynamic model is verified by using the double shift condition, the steering center condition and the eight-figure loop simulation condition.

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