Electromechanical Coupling Modelling of High Speed EMUs with Rotor Field Oriented Control

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Abstract. According to the theory of vehicle system dynamics and rotor flux-oriented control (RFOC), an electromechanical coupling simulation model of transmission system of high-speed EMUs is established considering the effect of mechanical and electrical characteristics. Firstly, an EMUs multi-body system (MBS) model including is developed by Simpack software based on the structure and parameters of a high-speed EMUs, and a RFOC simulation model of traction transmission system is also built by the Simulink platform. Then two types of models are linked by Simpack co-simulation interface model. Consequently, the electromechanical coupling model of EMUs is developed. The computer simulation method is adopted to simulate the coupling system with RFOC. Simulation results indicate that the proposed model can effectively reveal the change of electrical performance of the high-speed EMUs, the coupling system has a good anti interference performance and robustness.

1. Introduction

The vibration problems arising from the driving-transmission system of high-speed EMUs were researched by traditional methods, and the effects of electromechanical coupling to EMUs were mostly neglected [1-5]. In recent years, field-oriented control (FOC) can achieve the decoupling between rotor flux and speed by coordinate transformations, which can improve the dynamic performance, and achieve decoupling between rotor flux and speed control [4-5].

In the early modelling of vehicle system, the influence of motor driving on vehicle dynamics is not very obvious. Therefore, the motor driving system is rarely modeled as an independent unit. The general processing method is to equivalent the transmission system to wheel set, frame or car body, without profound study to driving and transmission system. However, with the increase of speed, the dynamic response in the high-speed running state has changed greatly. Compared with that in the low-speed running state [6-7], the influence of the vibration characteristics of the motor driving system on the vehicle system dynamics can not be ignored.

At present, research on EMUs is usually carried out in different disciplines, where electrical scholars raily consider the vehicle system model, and vehicle scholars seldom consider the electrical characteristics and control strategy of traction system. To consider the influence of motor driving on EMUs, a MBS model of EMUs is established, then the Simulink simulation model of RFOC system of the motor driving is developed. The types of models are connected by the interface module to realize electromechanical coupling. Meantime, the simulation examples are given so as to verify the coupling system performance.
2. MBS model of high-speed EMUs
For convenience of MBS modelling, the frames and car bodies are assumed to be rigid, elastic deformation of rail and component are also ignored. Based on the structure and parameters of a type of EMUs, a simplified MBS model established by Simpack is illustrated in Figure 1.

The traction motor is fixed on the power bogie frame, while both the axle boxes and gearboxes are connected by joints on the wheelset, and there is one DOF to rotate around the wheelset. The driven gear is mounted on the wheelset shaft in the form of interference fit, and it has the same DOF as the wheelset. For the MBS analysis, components are connected each other by joints, constraints and force components.

![Figure 1. MBS model of high-speed EMUs](image1)

3. Electromechanical coupling model of high-speed EMUs

3.1. Traction characteristics of high-speed EMUs
The traction characteristics of EMUs refer to the relationship between traction forces and speed during the EMUs starting, operation and braking. Figure 2 shows the traction characteristics curve of high-speed EMUs. If \( v \) and \( M \) represent the speed and weight of the EMUs separately, the calculation formulas of traction forces \( F \) and basic resistances \( W \) are as follows:

\[
F = \begin{cases} 
-0.285v + 300 & v \leq 119 \text{ km/h} \\
31500 / v & v > 119 \text{ km/h} 
\end{cases} \\
W = (7.75 + 0.062367v + 0.00113v^2)M
\]  

(1)

For the MBS model, torques of traction motor are given as

\[
M (1) = 300 - 0.285VX (S_M \_wheel, S_M \_sys) \\
M (2) = \frac{31500}{VX (S_M \_wheel, S_M \_sys) \times 3.6}
\]  

(2)

3.2. RFOC of electric drive system
In actual design of electric transmission system, RFOC is used for traction motor windings, and the airgap flux linkages of motor windings can be obtained by identification and radial displacements of the rotor use negative feedback control method. The ROFC configuration is shown in Figure. 3, and the Simulink model of RFOC can also be built.

![Figure 2. Traction characteristics curve](image2)
3.3. Electromechanical coupling model of the EMUs

Based on the joint simulation platform of Simpack and Simulink, the mechatronics coupling model is established as shown in Figure 4. Based on the parameters of traction motor, the Simulink model of RFOC is adopted to calculate and provide the electromagnetic torque of the motor and the resistance of high-speed EMUs.

4. Simulation results

The main parameters of traction motor are given as follows: power is 560 kW, rated voltage 2750V, rated frequency 138Hz, intermediate DC voltage 3200V and pole pairs 4. Assuming that the EMUs is running on a straight track, the track irregularity is not considered, and the simulations are based on no-load condition and variable speed constant load of traction motor.
Figure 5. Motor speed control curve under no-load condition

Figure 6. Electromagnetic torque control curve under no-load condition

Figure 7. Motor speed control curve under variable speed constant load

Figure 8. Electromagnetic torque control curve under variable speed constant load
As shown in Figures 5-6, for the RFOC simulation of motor speed and electromagnetic torque, the coupling system has overshoot, but rise time is fast, and steady-state error is smaller. In Figures 7-8, the motor speed is variable, the system also has overshoot, but rise time is very fast, steady-state error is very small, and tracking performance is better, hence the electro-mechanical coupling system has a good anti-interference performance and robustness.

5. Conclusions
Based on the joint simulation platform of Simpack and Simulink, a full electro-mechanical coupling model of the driving-transmission system of a type of high-speed EMUs is developed. Simulation results of RFOC indicate that the proposed coupling model can effectively reveal the change of electrical performance of the high-speed EMUs, and the coupling system has a good anti interference performance and robustness.

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