Modeling and simulation design of an electromechanical integrated drive control system based on matlab models

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ABSTRACT

In order to address the lack of integrated simulation verification of control object and control strategy in the early design of most electromechanical integrated drive control systems as a reference for practical design, this paper proposes a modeling and simulation method for electromechanical integrated drive control systems based on Matlab models. This method combines the detailed parameter design of the control object with the design of the control strategy, and establishes an integrated simulation model in Matlab. Through system simulation analysis, it guides the design of the control object parameters and control strategies, and aims to use the simulation model as a reference for actual electromechanical integrated drive control system design.

Keywords: Matlab, drive control system, electromechanical integration, modeling and simulation

1. INTRODUCTION

The execution elements for spacecraft attitude control mainly include space inertial actuators, such as propulsion systems, reaction wheels (momentum wheels and reaction wheels), and control moment gyroscopes (CMGs) [1-2]. However, due to the limited fuel and imprecise jet control, propulsion systems are not well-suited for long-term high-precision attitude control [3]. In contrast, reaction wheels are primarily employed in small satellite platforms for attitude control purposes [4-5], whereas CMGs are widely used in larger aerospace vehicles, including space station systems and large satellites, due to their large output torque, high control accuracy, and fast dynamic response [6-9].

Space inertial actuators are an integral part of the spacecraft attitude control system, where their reliability and safety during extended orbital operation are crucial to the spacecraft's long-term performance. The performance of space inertial actuators directly impacts the spacecraft's attitude control accuracy, stability, and maneuverability. Therefore, the design of the space inertial actuator drive control system is a pivotal aspect of the overall spacecraft control system design, comprising two primary areas: the design of the inertial actuator control object and the design of the inertial actuator control system. The control object primarily consists of brushless DC motors and permanent magnet synchronous motors, and once designed, it cannot be easily modified [10]. Therefore, the performance of the control object and its compatibility with the entire drive control system are vital considerations that require careful attention in the early stages of the drive control system design. When designing the space inertial actuator control system, it is necessary to simultaneously consider the performance of the control object, the effectiveness of the control strategy, and the system's control accuracy, software and hardware costs, among other aspects.

Currently, in most cases, the design of the machine-electric integrated drive and control system is still relatively independent in the two aspects of control object body design and control system design. The common design process is to first design and optimize the control object according to the requirements of voltage, current, torque, speed, and other requirements, and then provide the control object design parameters or models to the control system design personnel for the design and verification of the entire system. The problem with this design process is that it cannot integrate the consideration and design of the control object and the control system in the early design stage, and the matching degree between the two is also difficult to ensure.

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Moreover, in the overall debugging stage of the control system, it mostly relies on experience and repeated experiments to achieve the desired control performance. To address this issue, this article proposes a Matlab model-based machine-electric integrated drive and control system design method. In the early design stage, the control object and the control system are integrated into a simulation model in Matlab. Through simulation analysis of different control object parameters and control strategies, the optimal control object parameter selection and control system design are sought, and the simulation model is used as a design reference to guide the design of the actual machine-electric integrated drive and control system.

2. SYSTEM SIMULATION MODEL CONSTRUCTION

The simulation model of the integrated electromechanical drive control system mainly consists of the following aspects:

(1) Controller model

(2) Control object model (Permanent Magnet Synchronous Machine)

(3) External disturbance model

(4) Vector pulse width modulation circuit model (Driver)

The overall simulation model of the system is shown in Figure 1.

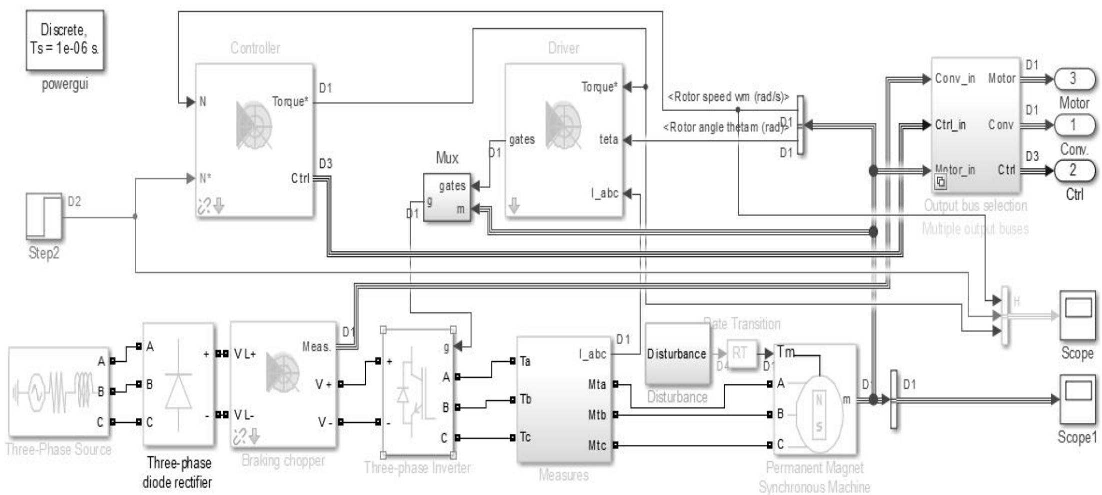

Figure 1. Simulation model of mechatronic integrated drive control system

2.1 Control strategy simulation model

The control strategy simulation model is mainly used to verify the effectiveness of different control strategies in the entire drive control system. As shown in the simulation model in Figure 1, the Controller module is the simulation model for the control strategy of the inertial actuator drive control system. The Controller module shown is a encapsulated block model of a specific control strategy. Opening the module will reveal the specific control strategy model, parameter configuration, and connection relationship, as shown in Figure 2.

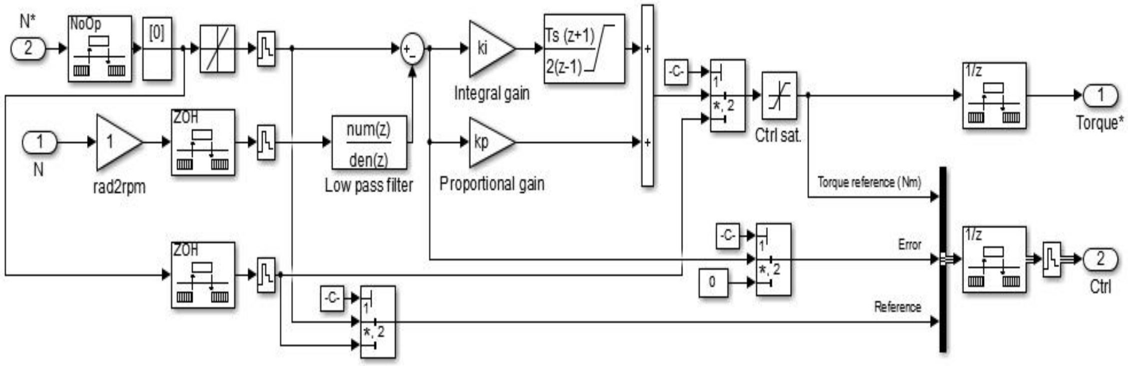

Figure 2. Specific simulation model of control strategy

The establishment of the control strategy model can select different control algorithms according to actual needs, and then encapsulate them into a sub-module. The control strategy model can be both continuous and discrete. In this control strategy, the discrete PID model is taken as an example and a discrete low-pass filter is added. The advantage of the discrete control model is that it can make the simulated control closer to the actual control, and the sampling time and holding type can be flexibly selected.

2.2 Control object simulation model

The modeling of the control object and its integrated simulation verification with the entire drive control system has important design guidance significance. The control object used in this mechatronic integrated drive control system is a permanent magnet synchronous motor, and the parameters that need to be considered in the control object design are basically included in this model, which is different from the transfer function model that only focuses on individual key parameters. This control object model can conveniently modify any parameter without modifying other modules, and can easily analyze the influence of changes in a certain parameter on the performance of the entire drive control system, thus guiding the actual design of the control object. The encapsulated block model of the control object (Permanent Magnet Synchronous Machine) and the detailed parameter modification interface of this mechatronic integrated drive control system are shown in Figure 3.

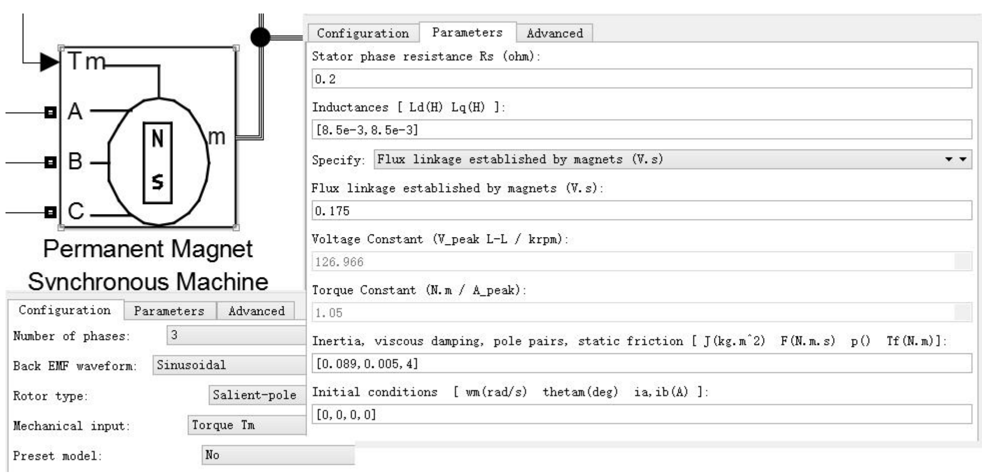

Figure 3. Control object simulation model and parameter interface

2.3 External interference model

The external disturbance model is an essential component of a complete drive control system simulation model. By designing disturbance models of different types and magnitudes, it is possible to simulate external disturbances in the actual control system and verify the effectiveness of the designed control strategy and parameters. The sine disturbance model with white noise (Disturbance) as shown in Figure 4.

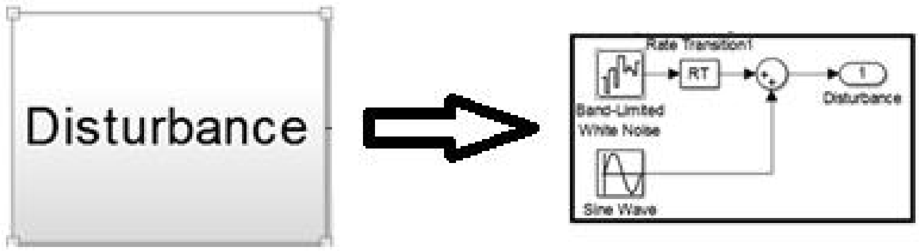

Figure 4. Model of sinusoidal interference with white noise

2.4 Vector pulse width control circuit model

The simulation model of the vector pulse width modulation (PWM) circuit plays an important role in guiding the design and selection of the actual vector PWM circuit and the switching frequency. It also helps to validate the impact of different switching frequencies on the performance of the control system. The internal design of the vector PWM circuit encapsulated in the Driver module is shown in Figure 5.

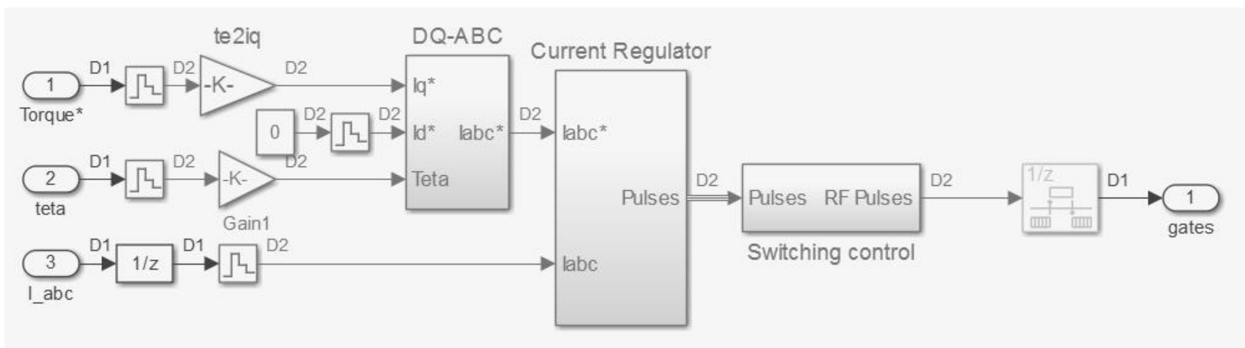

Figure 5. Simulation model for a vector pulse width control circuit

3. SYSTEM SIMULATION AND ANALYSIS

This section mainly focuses on the simulation of the integrated electromechanical drive control system. By analyzing the effects of different design parameters in the control strategy (including external disturbances), control object, and vector pulse width modulation model on the overall system performance, it aims to guide the design and implementation of each specific module in practice. Due to space constraints, only a few parameters are analyzed as examples in this paper.

3.1 Simulation analysis of control strategy parameters

Modifying the control strategy is relatively easy in both the early and late stages of the system design, including replacing the overall control strategy or modifying certain parameters within the control strategy. For a given control strategy, analyzing the control parameters through simulation can clearly show the impact of parameter changes on system performance, thus effectively determining the direction of system design and debugging.

Taking the feedback signal sampling time in the system closed-loop control as an example, and adding white noise sinusoidal external disturbances to the system, simulation analysis of the system speed step response under different sampling times is performed, as shown in Figure 6.

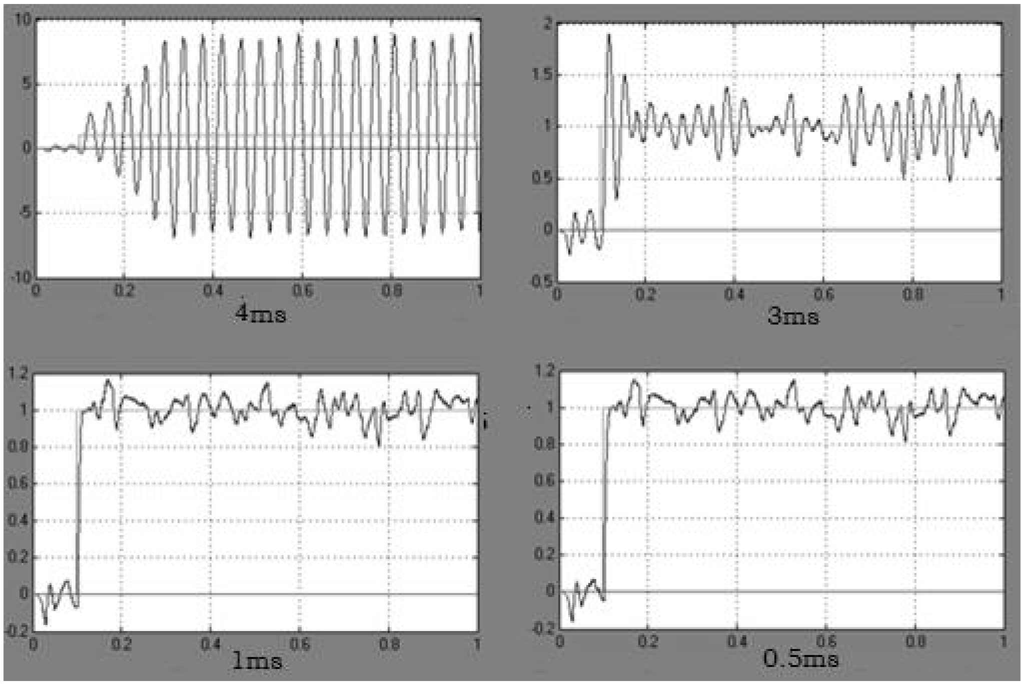

Figure 6. Impact of different sampling times on system control performance

Through simulation, it is known that when the sampling time is set to 4ms, the system speed is out of control and in an oscillating and divergent state, indicating that the 4ms sampling time does not meet the stability requirements of the system. When the sampling time is set to 3ms, the system speed can be stable, but the fluctuations are large, and the performance is poor. When the sampling time is set to 1ms, the system speed is still stable and the performance is significantly improved. When the sampling time is set to 0.5ms, the system speed performance is basically not improved compared to the 1ms sampling time, indicating that further reducing the sampling time has little effect on improving the system performance. Therefore, selecting a sampling time that is too large or too small is not appropriate. A sampling time that is too large can cause the system to be unstable and divergent, while a sampling time that is too small increases the design difficulty and wastes software, hardware resources, and costs. Through simulation, the minimum sampling time range that satisfies both system speed stability and improves system performance can be obtained. Therefore, in the actual control system design, including the upper-level control strategy and lower-level signal acquisition chip selection, guidance can be obtained through simulation to avoid imprecise design and cost waste caused by empirical design or blindly pursuing high sampling rates.

3.2 Simulation analysis of control object parameters

The main control objects of the electromechanical integrated control system are mainly permanent magnet synchronous motors and brushless DC motors. Here, we take the permanent magnet synchronous motor as an example for analysis. The permanent magnet synchronous motor is a parameter-multivariable, nonlinear, and strongly coupled control object. The design parameters that affect the system performance mainly include: the number of motor poles, the installation method of magnetic poles, the stator resistance, the stator inductance, the magnetic flux of the permanent magnet, the torque coefficient, the moment of inertia, the viscous damping, the static friction positioning torque, etc. All of these parameters can be set and modified in the control object model. The following analysis takes the different sizes of the permanent magnet flux and stator inductance as examples to analyze their effects on the system performance. As shown in Figure 7, when the magnetic flux is designed to be 0.2V.s, the system speed fluctuates about 10% more with a magnetic flux of 0.4V.s. While under the same 0.2V.s magnetic flux condition, the system speed performance is not significantly affected when the stator inductance is designed to be 2mH or 4mH, as shown in Figure 8.

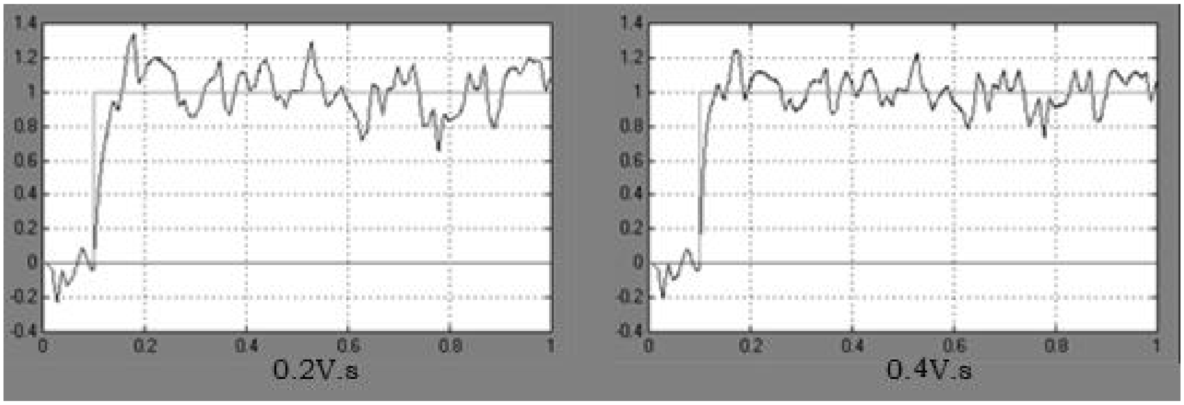

Figure 7. The Impact of Different Magnetic Fluxes on Control Performance of the System

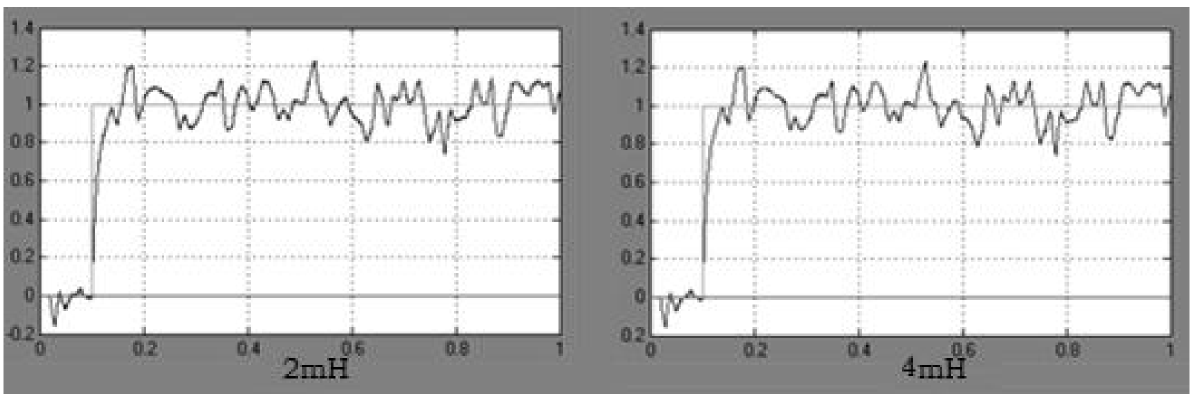

Figure 8. The impact of different stator inductances on the control performance of the system

Based on the simulation results above, it can be seen that different types of design parameters of the mechatronic system control object have a large difference in the degree of influence on system performance, and as a complex control object, different parameters also have mutual constraints and influences. Meanwhile, different application scenarios will inevitably have different requirements for control performance. For example, some scenarios only pursue transient high torque output, while others may focus more on steady-state speed accuracy. Therefore, in actual control system design, designers can use the different system impacts of the parameters provided by the system simulation model as a design reference, and appropriately bias the parameters that have a greater impact on specific system performance. By selecting various model parameters based on specific needs, the overall performance of the driving control system can be considered during the initial design of the control object, achieving the goal of optimal coordinated design.

3.3 PWM chopping frequency simulation analysis

The vector pulse width modulation (PWM) is the most widely used PWM modulation method in current mechatronic control systems. When using PWM modulation, the PWM frequency is an important parameter. A low PWM frequency will cause a decrease in control performance, while a high frequency will bring high-frequency interference and switch losses of power transistors, especially for high-power driving circuits, where the switch losses of power transistors are much greater than the thermal resistance losses [3]. However, currently in system design, there is not much theoretical analysis or simulation verification for the selection of PWM frequency, mostly relying on empirical selection. Figure 9 shows the simulation results of the influence of different PWM frequencies on system performance under the same control object and the same control parameters. PWM frequencies of 3kHz, 5kHz, 10kHz, and 15kHz were selected.

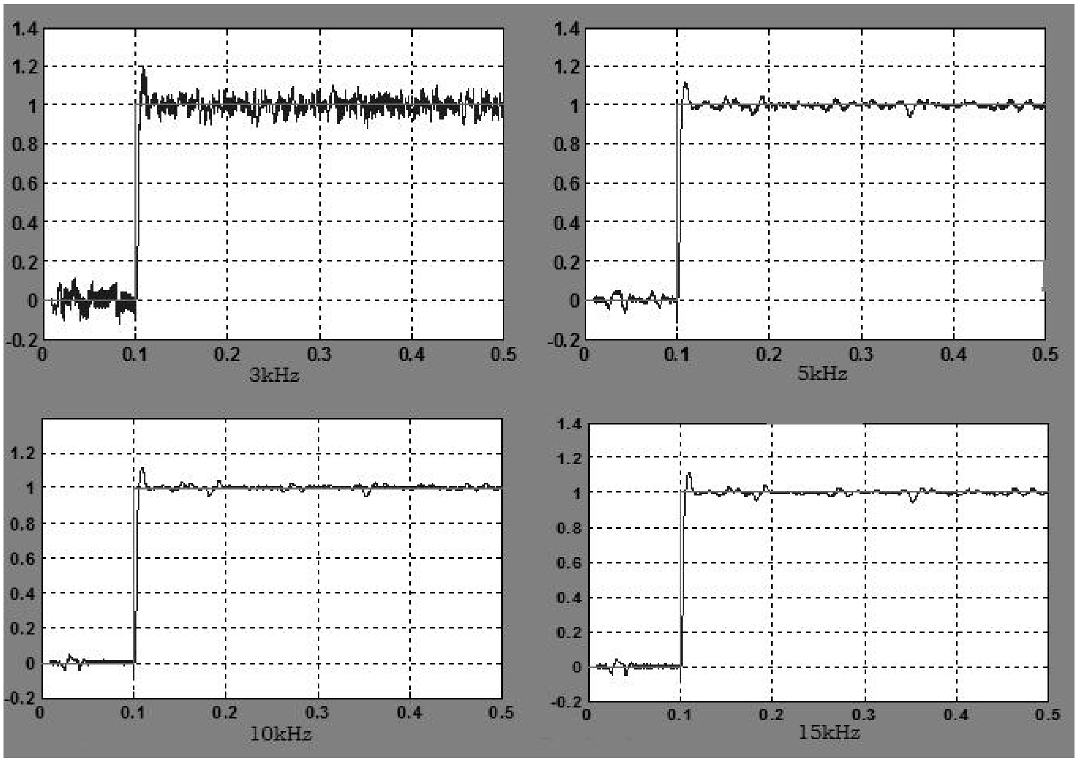

Figure 9. The impact of different PWM switching frequencies on the control performance of the system.

According to the simulation results, it can be seen that when the PWM frequency is selected at 3kHz, the system speed fluctuates greatly. When the frequency is increased to 5kHz, the speed fluctuation is significantly reduced. When the frequency is further increased to 10kHz, the speed fluctuation is further reduced. Continuing to increase the frequency to 15kHz, the increase in frequency has little effect on the speed fluctuation. Therefore, for this system, the optimal PWM frequency is around 10kHz. Therefore, for a system to be designed, obtaining the optimal PWM frequency through simulation analysis has great engineering practical value for improving system performance and reducing high-frequency interference and power loss.

4. CONCLUSION

This article proposes a modeling and simulation design method based on Matlab models for the current shortcomings in the design of integrated electromechanical drive control systems. This method integrates the design of the control object's main body and control strategy design through simulation. From the establishment of the simulation model to the analysis of simulation data, this article illustrates the practical value of this design method through several typical parameter analyses. It provides a good reference for the integrated design of electromechanical drive control systems and similar control systems in the early stage of development.

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