Study on Application of Double Closed Loop Control of Brushless Direct-Current Motor in Platform Screen Doors Control System

Cui Xiyou, Xu Yuanyuan, Zhang Zhengmao
(State Grid of China Technology College, Jinan 250002, Shangdong Province, China)

About the author: Cui Xiyou (1988-), Male, Graduate Student, Lecturer, Engaged in Power System and Automation Research.
E-mail address: 865309564@qq.com

Abstract: In order to enhance the stability of the metro platform screen doors (PSD), and to enable PSD to smoothly complete the process of closing and opening, this article proposed a control method based on the double closed loop speed regulating system of brushless direct-current (DC) motor. By means of double closed loop PI control of the motor speed loop and current loop, precise and stable control of brushless DC motor was realized, and the velocity curve of PSD was obtained, which could make PSD run smoothly. Finally, through the experimental analysis of the control system, the data curve satisfying the requirement of the control curve was acquired, which verified the reliability of the double closed-loop control of the brushless DC motor in the PSD control system.

1. Introduction
With the rapid development of China’s urban rail transportation industry, more and more attention has been paid to subway passengers’ safety. The PSD control system takes the task of protecting subway passengers’ safety, that has been a very important party of rail transportation industry. In subway daily running process, PSD open and close quite frequently, which requires a safe and stable control system of PSD. Motor control system, as a core control unit of PSD system, directly impacts PSD system operation on normally opening and closing. Therefore, based on the practical function demand of PSD system, combining the running characteristics of the doors, this article analyzed the requirement of control system and designed a PSD control system under double closed-loop control mode of brushless DC motor.

2. Velocity curve of control system
The PSD complete a movement cycle of opening and closing in required time, whose speed is different during the whole process. PSD control system driving brushless DC motor to open and close the doors, undergoes seven stages of starting with a low acceleration, running at a low and constant speed, high acceleration, running at high and constant speed, deceleration, running at low and constant speed, and barking. In this process, the speed of motor changes continuously, and the ideal velocity curve of PSD is shown as Figure 1.
In the velocity curve of PSD, the different stages follow the corresponding curve segments, which present as below:

- **Stage $t_0$-$t_1$:** The motor starting up with a low acceleration, and the doors slowly accelerating and closing.
- **Stage $t_1$-$t_2$:** The motor running at a constant speed for a distance, and the doors closing at a constant speed.
- **Stage $t_2$-$t_3$:** The motor running with a high acceleration, the doors accelerating and close.
- **Stage $t_3$-$t_4$:** The motor running at a constant speed, the doors opening at a constant speed.
- **Stage $t_4$-$t_5$:** The motor running with a low deceleration, the doors decelerating and opening.
- **Stage $t_5$-$t_6$:** The motor running at a low speed, the doors opening at a low speed.
- **Stage $t_6$-$t_7$:** The motor braking, the doors completely open.

To prevent the abrupt changes of the motor thrust, a smooth curve (S curve) was implemented in the controlling process of the motor drive module: in the process of acceleration and deceleration, actually the motor accelerated by a S curve instead of straight line, which meant the acceleration is a changing variable. Via a S curve acceleration, a gradually varied thrust to the doors could be achieved, rather than a sudden jump force to the doors. By adjusting the change rate of acceleration, in accordance with the mechanical cooperation of the synchronous belt and the motor, the synchronous belt could be effectively prevented from jumping, which reduced the system operating noise and greatly extended the lifetime of the motor and the mechanical components. The S curve is shown as Figure 2.
3. Double Closed Loop Control Principle of Brushless DC Motor

During the whole process of PSD opening and closing, the motor velocity of change continually is a dynamic process, which requires the motor possessing better speed control performance and fast response performance. Therefore, a brushless DC motor was selected as a PSD drive motor, with a shorter flywheel torque and a smaller transmission ratio that reduced the mechanical time constant in its working dynamic characteristics, obtaining good following features. In addition, deep analysis of the motor operation process, determination of the target velocity curve with relevant data, and the analysis of the velocity curves and stability of the motor starting, running and braking in the driving process, were carried out, to ensure a good performance of the control system. The control principle of brushless DC motor is displayed in Figure 3.

![Figure 3 Motor control principle diagram](image)

The controller of brushless DC motor processes the collected signal and send out control commands, and the rotor position is determined by pulse signals from the motor rotor position sensor, outputting appropriate and drive logic level to power drive circuit; According to the collected pulse signals in the position sensor, the processor calculates the current rotation speed and compares it with the set rotation speed of the motor; Current detecting circuit collects the current from the motor winding and compare it with the set value, and then the PI algorithm generates suitable electric current for the control winding of modulation signals. Since the speed of the brushless DC motor varies with the change of the electric current, as long as the current of the controller is under PWM control, the motor speed could be controlled. Therefore, in the control system, the motor is controlled by using the dual closed loop control of speed loop and current loop, so as to ensure the motor runs accurately in accordance with the pre-set curve.

The motor drive circuit feeds back the detected parameters of speed and current to the logic circuit, and then the logic circuit processes the detected data, which are used as a control variable to feedback control the motor. By adjusting the PI parameters of the set speed loop and current loop, the PI parameters that satisfy the control requirements are continuously optimized, to achieve precise control of the motor running parameters, so as to obtain a relatively ideal velocity curve. In the control system, the speed and current control regulators are set and cascade connected. The signals detected by the Hall position sensor of the rotor, were calculated to the motor speed by the processor and compared with the set speed, following by the adjustment of the speed PI controller and the output of current setting values; After that, the detected current is compared with the current setting value, flowing through the current PI controller, and output to the current of the motor. As regard to the structure of...
closed loop, the current loop is inside, as the inner loop, while the speed loop is outside, as the outer loop. The speed regulation is completed by two PI regulators, resulting in the double closed loop control of the motor, so as to accomplish the precise control of the PSD operation through the precise control of the motor.

4. Experimental Analysis of Control System
In order to verify the control effects of the control system on PSD, the changes of the position, speed, current, and voltage of PSD in the process of opening and closing were monitored. The monitored curve was compared with the expected one. By means of analyzing its performance with the data, double closed loop control system was constantly adjusted to achieve the purpose of stable control.

Through the calculation of the ratio coefficient of the electronic current loop and the speed loop, and the adjustment of the integral link parameters according to the system requirements, the requirement of system control was met.

The PI parameters of the current loop and speed loop in the control system were continuously adjusted, and after continuous experiments, the ratio coefficient of the current loop in PI regulator was decided as \( K_p = 60 \), while the integral coefficient was decided as \( K_i = 300 \); the ratio coefficient of the speed loop in PI regulator was decided as \( K_p = 36 \), while the integral coefficient was decided as \( K_i = 90 \).

In the continuous debugging process, the PI parameters of the current loop and the speed loop almost had reached the optimal values for controlling PSD opening and closing, at the moment the velocity curve of PSD was relatively smooth.

In the experiments of controlling PSD movement by the control system, the position, current, voltage and velocity curve of PSD were collected during the opening process. Figure 4 is the location curve of the door opening process, while the vertical axis shows the change of the current position. As can be observed in the figure, at the starting point the position is zero, and subsequently the curve varies smoothly, demonstrating the door is moving until it is completely open. The location curve of the door changes smoothly and its slope varies depending on the change of the motor speed, resulting in an outstanding control effect.

![Figure 4 The location curve of open the door process](image)

The current curve of the door opening process is shown as Figure 5, while voltage change curve of the process is displayed in Figure 6. When the control system receiving instructions to open the door, the brushless DC motor is controlled to positive rotation. The current and voltage are almost zero at the beginning and vary with the change of the motor speed. Finally, when the door opens completely, the current and voltage values nearly return to zero. In the process of opening the door, PSD moves at
different speeds under the control of the motor, undergoing continual changes of acceleration and deceleration, and finally accomplishing the door opening process.

![Figure 5 The current curve of open the door process](image)

![Figure 6 The voltage curve of open the door process](image)

The speed curve of the door opening process is presented in Figure 7. In the figure, with the target speed, feedback speed, and observed speed curve being monitored during the opening process, it is as shown the speed of the doors change constantly in the door opening process. Due to the friction of the belt, the door body and other components when the door running, some fluctuation of actual velocity emerges around the target value, which is reflected in the opening and closing movement and could be negligible, satisfying the demand for the speed curve of the control system.
Through the analysis of the position curve, current curve, voltage curve and speed curve monitored in the control system and the control of brushless DC motor, the door opening and closing can be controlled, so as to satisfy the requirement of PSD system. Through continuous optimization of control parameters and PI, a relatively stable working condition is achieved.

5. Conclusions
Aiming at the speed curve requirement of the control system applied to PSD, based on the double closed loop control of brushless DC motors, this paper put forward a control system for PSD opening and closing, designed a double closed loops control scheme, current loop and speed loop, and implemented the experimental analysis of double closed loops control. By verifying the reliability of the double closed loop control scheme of the brushless DC motor in PSD, the doors were ensured to work stably, the expected velocity curve was obtained, and the working requirements of PSD were met.

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