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A study of speed control algorithm of IPMSM for Railway vehicle with improved PID Controller

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Abstract: *Recently, due to the increasing adoption of energy-saving policy, IPMSM (Interior Permanent Magnet Synchronous Motor) is used as machinery, home appliance, automotive and robotic applications. The features of IPMSM are high power, high efficiency and high performance. To obtain a high performance in a direct vector controlled IPMSM, it is essential to obtain robust control system of railway vehicle. Two degree of freedom controller is applied to IPMSM in order to resist disturbance, error of system. The proper control scheme possesses a prominent aspect in that it can force the systems to follow the desired reference model. The proposed method utilizes the combination of PID controller and PD controller. This simulation is composed of several blocks. Those are IPMSM, PWM three-phase inverter, current controller and speed controller. The validity of proposed technique is verified through the MATLAB/SIMULINK simulation results*

Keywords: IPMSM; PID-PD; Robust Control; Railway Vehicle; Speed Control

1. INTRODUCTION

Due to the energy saving policy, the motor used as a driving source in machinery, household appliances, automobiles and robot application industries is composed of an Interior Permanent Magnet Synchronous Motor (IPMSM), which has characteristics of high output, high efficiency and high performance compared to conventional motors) Has been increasingly adopted, and attempts to improve the performance of the product have been actively conducted. Therefore, there is a high demand for low noise and low vibration of the motor. The IPMSM has the characteristics of operating at high speed or low speed and high torque and requires high output density. Therefore, it is possible to obtain a good effect by selecting a permanent magnet synchronous motor as well as an induction motor which is mainly used. In this paper, This paper propose a control method that is robust against frequent speed changes or sudden changes in load on a railway vehicle through 2-DOF controller.

As a speed controller which is mainly used, there is a problem that the response overshoot of the motor speed to the step change of the speed command is small and the recovery time of the torque response to the step change of the load torque is also short.

In order to solve this problem, the controller parameter values in the conventional speed PID control need an flexable tuning method. Designing the PID controller for Robust speed control to noise is quite complicated because there are many parameter values to consider. Therefore, the complexity of this design is solved using a 2-DOF controller. This paper proposes a control method which is robust to the change of speed or the rapidly changing load by applying the control method to the interest induction type while maintaining the controller type in the existing PID which is familiar to the engineers. This IPMSM and PWM 3-phase inverter current controller and speed controller simulation models were constructed through MATLAB / Simulink program and the results were derived

2. IPMSM MODEL AND CURRENT CONTROLLER DESIGN

2.1 IPMSM Modeling

Fig. 1. shows the speed control system of the embedded type permanent magnet motor. Speed Controller is designed by PD controller for PID velocity control algorithm of existing embedded type Permanent Magnet Motor and implement a system that generates optimal current command according to speed. Therefore, the stator equation of IPMSM can be expressed as follows on the synchronous coordinate system.

$$v_d = R_s i_d + pL_d i_d - P\omega_{rm} L_q i_q \quad (1)$$

$$v_q = R_s i_q + pL_q i_q + P\omega_{rm} L_d i_d + P\omega_{rm}\phi_f \quad (2)$$

v_d , v_q : d-axis and q-axis voltage

i_d , i_q : d-axis and q-axis current

R_s : Stator resistrance

L_d , L_q : d-axis and q-axis stator inductance

ω_{rm} : Machinery angular velocity of Rotor

ϕ_f : Flux linkage

p : Differential operator

P : Pole pair

2.2 Current Controller

In the design of the current controller, eq(3) and eq(4)

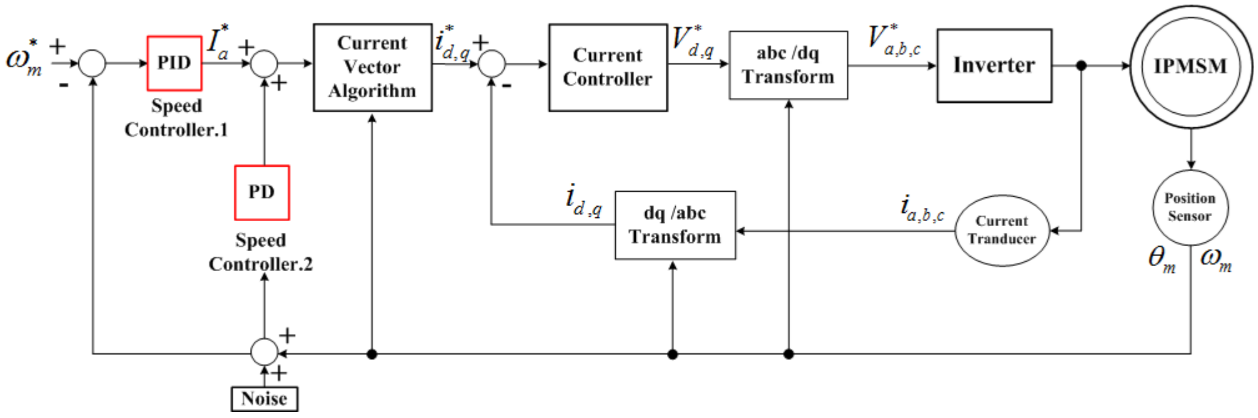

Fig. 1. Topology of Independently Rotating Wheelsets System

can be constructed by eq(1) and eq(2)

$$v_d^* = v_d' - P\omega_{rm} L_q i_q \quad (3)$$

$$v_q^* = v_q' + P\omega_{rm}\left(L_d i_d + \phi_f\right) \quad (4)$$

d and q-axis are subjected to non-interference control. If the d-axis current and the q-axis current act independently of each other, the currents of the d-axis and q-axis are proportional to the values of v_d' and v_q', respectively, amplified by the integral controller.

$$v_d' = \frac{K_{pd}s + K_{id}}{s}\left(i_d^* - i_d\right) \quad (5)$$

$$v_q' = \frac{K_{pq}s + K_{iq}}{s}\left(i_q^* - i_q\right) \quad (6)$$

Here, v_d^*, v_q^* are command values of the values of v_d, v_q. eq(1) to eq(6), i_d, i_q can be obtained through closed-loop control. The gain values of the current controller are determined by the following equations.

$$K_{pd} = \omega_c L_d \quad (7)$$

$$K_{id} = \omega_c R \quad (8)$$

$$K_{pq} = \omega_c L_q \quad (9)$$

$$K_{pq} = \omega_c R \quad (10)$$

This is the cut-off frequency for current control. Thus, the stability of the current control system can be ensured and each current can be independently controlled.

3. SPEED CONTROLLER DESIGN

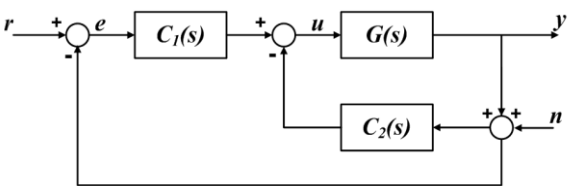

Fig. 2. Modified PID Controller

Fig. 2. shows the structure of the modified PID controller. Fig. 1, PID and PD velocity controllers, and the controller formulas discussed in this paper are as follows.

$$PID-PD: C_1(s) = C_{PID}(s) = K_{p1}\left(1 + \frac{1}{T_{i1}s} + T_{d1}s\right)$$

$$C_2(s) = C_{PD}(s) = K_{p2}\left(1 + T_{d2}s\right) \quad (11)$$

The closed-loop transfer functions of the PID, PI-PD, and PID-PD control systems are eq(12), eq(13), and eq(14), respectively.

$$G_{pid}(s) = \frac{C_{pid}(s)G(s)}{1 + C_{pid}(s)G(s)} \quad (12)$$

$$G_{pd}(s) = \frac{C_{pd}(s)G(s)}{1 + C_{pd}(s)G(s)} \quad (13)$$

$$G_{pidpd}(s) = \frac{C_{PID}(s)G(s)}{1 + \left(C_{PID}(s) + C_{PD}(s)\right)G(s)} \quad (14)$$

Convex set C is defined by [4] as follows.

① $C \subseteq R^n$ in set C, if $x_1, x_2 \in C$ and $0 \le m \le 1$, it is $mx_1 + (1-m)x_2 \in C$.

② $mx_1 + (1-m)x_2$ is located between x_1 and x_2 point.

This is also applied to the time domain response of the system, and the unit step response of eq(15) system satisfying eq(15) is shown as a boundary between the two responses of the right side.

$$G_m(s) = mG_1(s) + (1-m)G_2(s) \quad (15)$$

This characteristic has been proven in Haitham [4] and has been applied to controller design. However, since this controller is dependent on the two systems constituting the convex set, there is a problem that the order and the form of the controller are not constant. This paper proposes the most widely used PID controller to solve this problem. The convex set between the PID control system and the PI-PD control system can be represented by the PID-PD control system

4. SIMULATION RESULT AND ANALYSIS

Table 1. Specifications of IPMSM parameter

Parameter	Value
Power rating[kW]	**410**
Phase Current rating[Apk]	**188**
Phase Voltage rating[Vpk]	**1760**
R_s [mΩ]	**81.61**
L_d [mH]	**9.85**
L_q [mH]	**35.63**
Flux linkage [Wb]	**2.57**
Inertia [kg · m²]	**1.39**
Pole	**4**

The parameter values used in the simulation are the parameter values used in the high-speed railway vehicle as targets in [5] and they are shown in Table 1.
The mathematical modeling of the controller presented in this paper derives the transfer function of the controller in eq(14).

$$G_{pidpd}(s)=\frac{\left(K_{p1}+\frac{K_{i1}}{s}+K_{d1}s\right)G(s)}{1+\left(K_{p1}+\frac{K_{i1}}{s}+K_{d1}s+K_{p2}+K_{d2}s\right)G(s)} \quad (16)$$

This can be expressed as eq(16) where p gain and d gain are bound together, and if the sum has a constant gain value, then a value of m can be set.

$$K_p = mK_{p1}+(1-m)K_{p2} \quad (17)$$

$$K_d = mK_{d1}+(1-m)K_{d2} \quad (18)$$

eq(17) and eq(18), respectively. One control system, the simulation was carried out at the command speed of 5000rpm and at the speed of 3000rpm.
First, the command speed of 5000 rpm is shown in Fig. 3. shows that the PID controller is used only for m = 1, and PID and PD are used for m = 0.5, and only the PD controller is used for m = 0. The settling time was in the order of PID-PD, PD, PID, when the oscillating value reached 5100rpm within 2% of the steady-state value. In other words, in the accelerated state, it was the best when using the PID-PD controller.

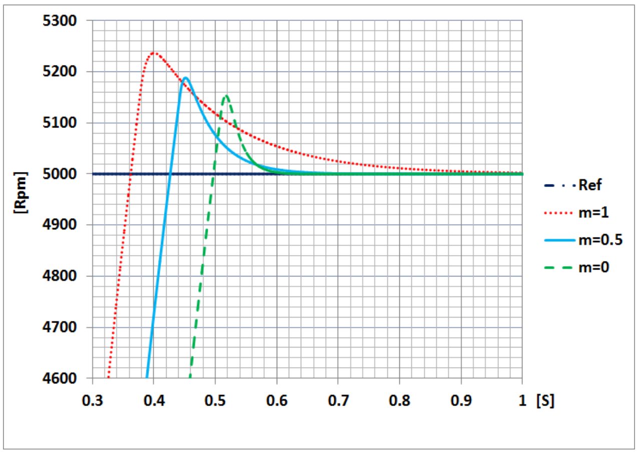

Fig. 3. 2 Degree of freedom controller simulation result (command velocity= 5000rpm)

Table 2. Results of Fig.3

Parameter	PID	PID-PD	PD
Settling time [s]	0.52	0.48	0.53
Rising time [s]	0.33	0.38	0.45
%Overshoot	104.8	103.9	103

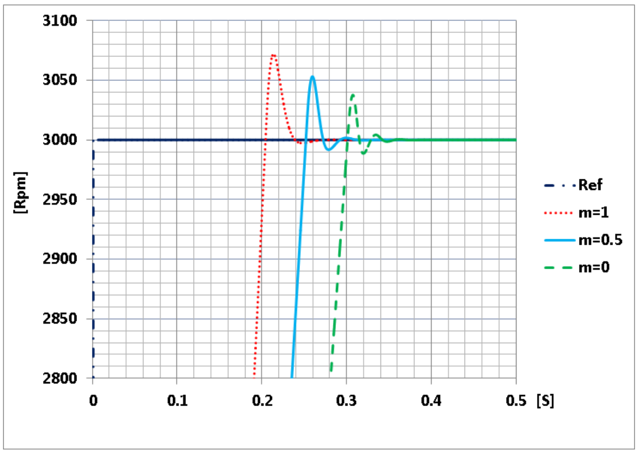

Fig. 4 2 Degree of freedom controller simulation result (command velocity= 3000rpm)

Table 2 Results of Fig.4

Parameter	PID	PID-PD	PD
Settling time [s]	0.22	0.26	0.31
Rising time [s]	0.17	0.20	0.25
%Overshoot	102.4	101.7	101.4

Fig. 4., the rise time or overshoot result is similar to the above result, but the settling time is faster at the PID than the previous result. And the modified PID controller can be used as a favorable system according to various conditions through the change of m value. This allows the m value to be used in railway systems with frequent speed changes and rapidly changing loads

5. CONCLUSION

PID control is still widely used because of its superior performance in control of the system and its simplicity of design. However, Using PID control cannot provide sufficient performance. Therefore, modified PID control with internal feedback has been proposed and studied. This paper proposes a method to use the characteristics of the convex shape set for the controller design by setting the PID-PD controller, which is a form of this modified PID controller, to constitute the convex set of the closed loop transfer function at the boundary between the PID controller and the PD controller. In addition, design variables and time - domain relations can be easily predicted through the characteristics of the convex set, which is a design advantage that can easily cope with changes in design specifications. In order to implement two controllers, there are several parameter values to be considered, but it is possible to select a desired controller by using one parameter change through a two degree of freedom method.

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