Computer Life (CPL) ISSN: 1819-4818
DELIVERING QUALITY SCIENCE TO THE WORLD

Research on Control System of Permanent Magnet Synchronous Motor Based on Fractional Order PI$^{\lambda}$D$^{\mu}$

Minrui Hou

Department of Electrical Engineering, University of Shanghai Maritime, China.

hminrui@163.com

Abstract: This paper explores the basic structure and principle of permanent magnet synchronous motor, the mathematical modeling process of each module, and the application of traditional PID controller and fractional order PI$^{\lambda}$D$^{\mu}$controller in AC motor control system. Integer and fractional order control of current controller and speed loop controller are designed, and simulation model of AC motor control system based on fractional order PI$^{\lambda}$D$^{\mu}$ controller is established. IN the motor system, the traditional PID controller and fractional-order PI$^{\lambda}$D$^{\mu}$controller are used for speed control simulation experiments, and the response results are analyzed. It is concluded that fractional-order PI$^{\lambda}$D$^{\mu}$controller can strengthen the ability of the control system to resist external interference.

Keywords: PMSM; Fractional order PI$^{\lambda}$D$^{\mu}$; MATLAB.

1. INTRODUCTION

The permanent magnet synchronous motor (PMSM) control system is a dynamic change system, whose output can accurately track the input value and can change according to the input change, which is widely used in industrial production.As the motor is a nonlinear, strongly coupled and multivariable control system, the system will be affected by disturbances to varying degrees in actual operation. Therefore, it is necessary to explore the design of PMSM control system.Fractional order PI$^{\lambda}$D$^{\mu}$control is the extension and development of conventional integer order PID control. The dynamic system described by fractional order mathematical model is more accurate than that described by integer order model.In addition, the fractional order PI$^{\lambda}$D$^{\mu}$controller introduces differential, integral order λ and μ, and has two more adjustable parameters, so the setting range of controller parameters becomes larger, and the controller can control controlled objects more flexibly.The simulation results show that the anti-interference capability and robustness of the motor system based on fractional order PI$^{\lambda}$D$^{\mu}$ control are enhanced [2].

2. FRACTIONAL ORDER PIΛDM CONTROLLER

2.1 Fractional Calculus Theory

Fractional calculus is an arbitrary order differential and integral theory, which is unified with integral calculus. It is an extension of integral calculus. In mathematical operations, fractional calculus is often expressed by ${}_aD_t^{\lambda}$, in which fractional calculus order is λ, a and t respectively represent the upper limit and lower limit of fractional calculus operator.Fractional order differential calculation symbols are represented by ${}_aD_t^{\lambda}$ and fractional order integral operation symbols are represented by ${}_aJ_t^{\lambda}$.The definitions most commonly used in fractional calculus are listed below:

(1) Grünwald-Letnikov definition:

$$ {}_aD_t^{\lambda} f(t) = \lim_{h \to 0} h^{-\lambda} \sum_{j=0}^{[\frac{t-\lambda}{h}]} (-1)^j \binom{\lambda}{j} f(t - jh) \tag{2.1} $$

(2)Riemann-Liouville definition:

$$ {}_aD_t^{\pm\lambda} f(t) = \frac{1}{\Gamma(n-\lambda)} \frac{d^n}{dt^n} \int_a^t \frac{f(\tau)}{(t-\tau)^{\lambda+1-n}} d\tau \tag{2.2} $$

(3)Caputo definition:

Caputo's definition is similar to Riemann-Liouville's in many aspects. Either way, both are decomposed f (t) functions, and both give fractional derivative processes in the interval of order 0 to 1. The biggest difference between the two is only in the order of operations.

$$ {}_aD_t^{\alpha} f(t) = \frac{1}{\Gamma(m-\lambda)} \int_a^t \frac{f^{(m)}(\tau)}{(t-\tau)^{\lambda-m+1}} d\tau \tag{2.3} $$

Caputo defines that fractional calculus is usually set to 0 under any constant, and when defined by Riemann-Liouville, the result obtained by differential of fractional calculus under any constant is not 0.Therefore, Caputo is more suitable for practical application.In addition, the calculation process defined by Riemann-Liouville requires a large amount of basic information about the calculation object, including several fractional derivatives. The calculation results are very complex and difficult to obtain in the existing engineering design.

2.2 Fractional order PI$^{\lambda}$D$^{\mu}$ controller

The application of fractional order PI$^{\lambda}$D$^{\mu}$controller is essentially to broaden the research of integer domain PID controller. It has more integral terms λ and differential terms μ in parameters than traditional PID controller. Its control structure frame can be illustrated in Figure 2.1 below.

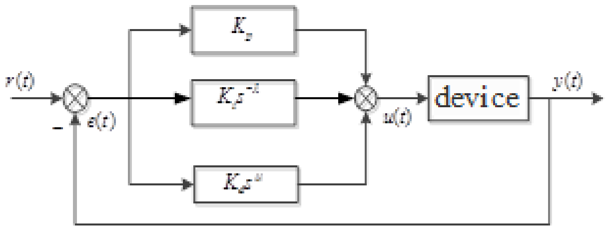


Fig. 2.1 Structure of fractional order PIλDμ controller

For a controller with input e(t) and output u(t), the expression of its time domain is,

$$ u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \tag{2.4} $$

The expression form in the frequency domain is,

$$ G(s) = K_p + \frac{K_i}{s} + K_d s \tag{2.5} $$

In the above formula, Kp, Ki and Kd are the three adjustable parameters of the controller. The proportional coefficient Kp is used to improve the response speed of the system, but too large will cause a certain overshoot of the system and deteriorate its stability.The integral coefficient Ki is used to eliminate the steady-state error of the system, and at the same time excessive assembly will cause integral saturation in the response process of the system.The differential coefficient Kd can predict and suppress the variation of errors, and has the function of improving the dynamic performance of the system.

The order λ of the integral term of the fractional order PIλDμcontroller, like the order μ of the differential term and other parameters, determines the performance of the controller.Proper adjustment of various parameters can provide different correction angles for the controller, making the controller more flexible.

3. MODELING AND ANALYSIS OF PMSM SYSTEM

3.1 Vector Control of PMSM

PMSM control consists of motor body, controller, position sensor, etc. Magnetic field oriented vector control and Direct Torque Control (DTC) are the most common control methods of PMSM. It can be well implemented in digital controller and has many advantages, such as stable waveform of output parts, high efficiency of voltage output, etc. This control method is adopted in this paper. The control principle diagram of permanent magnet synchronous motor system based on this method is shown in Fig. 3.1.

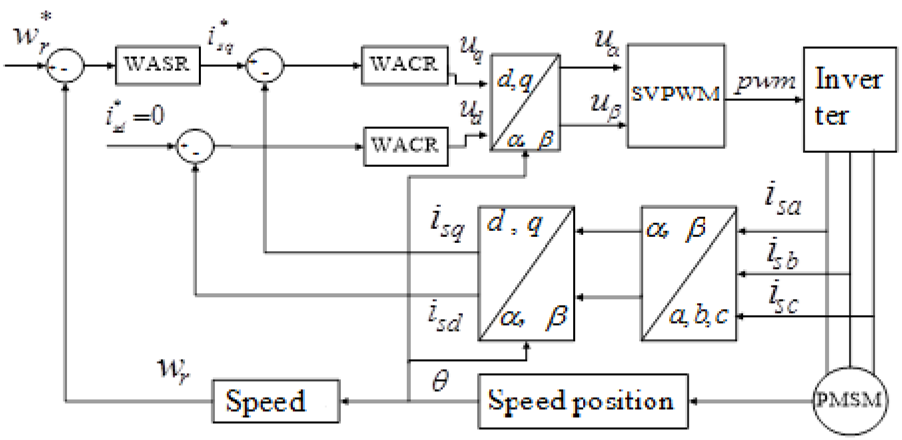


Fig. 3.1 Vector control schematic diagram of PMSM

Where WASR represents a rotational speed controller and WACR represents a current controller.

3.2 Permanent Magnet Synchronous Motor Modeling

In the MATLAB/Simulink environment, a permanent magnet synchronous motor model based on fractional order $PI^{\lambda}D^{\mu}$control can be established, as shown in Fig.3.2.

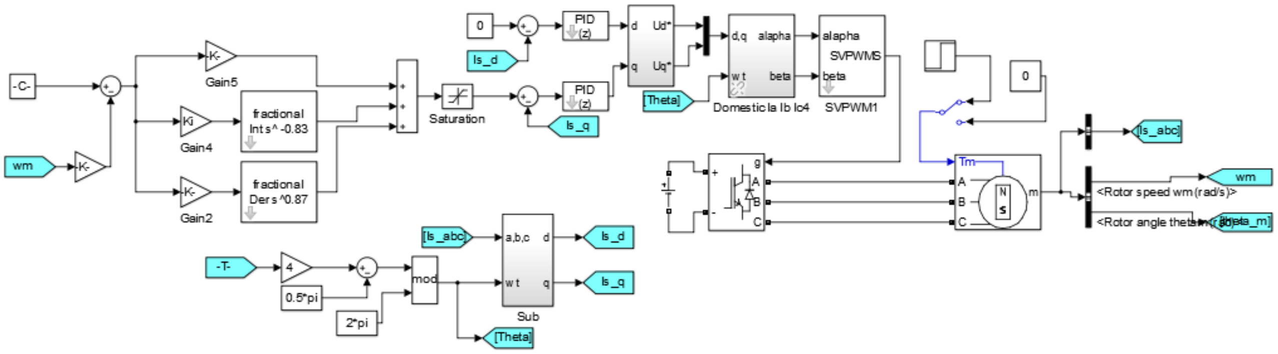
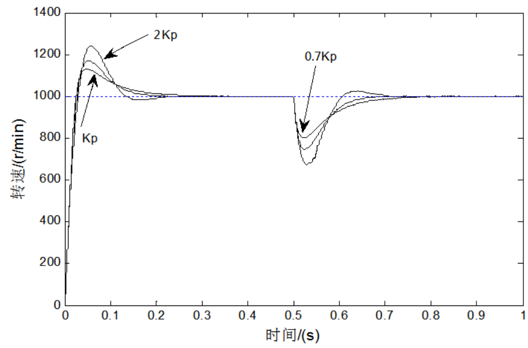


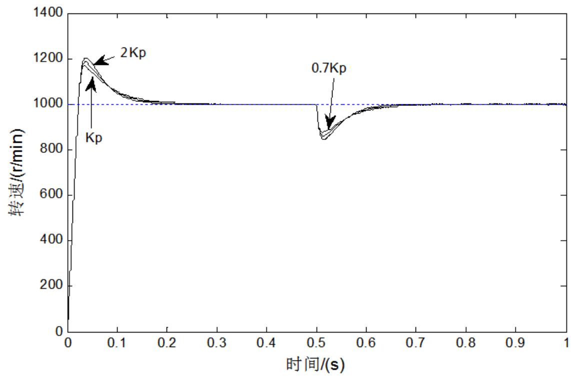
Fig. 3.2 Simulation model of motor control system

This is a typical double closed loop system. The outer loop is a speed loop and the inner loop is a current loop. id=0 control method is adopted. According to the design of each part in section 3.3, the parameters of each part are obtained by ta King Tl=1ms, h=5, ψm=π/4, ωc=80rad/s, and Kp, ki and Kd of the d-axis and q-axis PID controllers of the current loop are set to 8.35, 700 and 0.75 respectively. According to the calculation, the fractional order controller parameters of the speed loop can be obtained, Kp=2.2836, Ki=9.9122, Kd=0.7632, λ=0.5939, μ=0.4332.

The speed control simulation experiment is carried out on PMSM. Set the parameters as above. First, apply a rotating speed of 1000r/min to the system to start it when there is no load. Change the Kp parameters of traditional PID controller and fractional order controller. Compare the speed response diagram with the following Fig.3.3:



(a) The speed response of PID control when the parameter Kp is changed

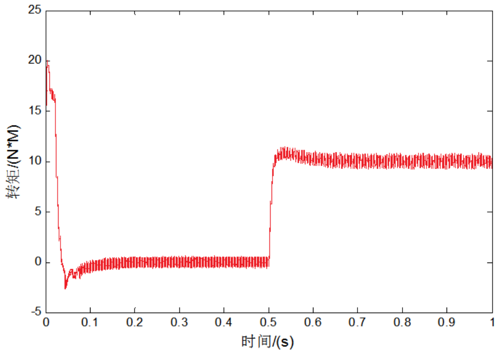


(b) The speed response of fractional order PIλDμ when the parameter Kp is changed

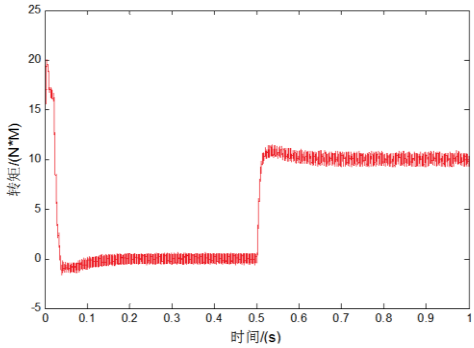
Fig. 3. 3 Speed response of the system changing Kp parameters under different controls

From the simulation results in Fig.3.3 above, it can be seen that the overshoot and adjustment time of the traditional PID control increase when the parameter Kp is changed, while the fractional order $PI^{\lambda}D^{\mu}$ control is less affected when the parameter Kp is changed.

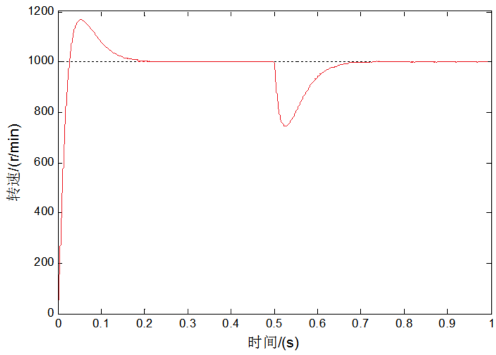
At the time of 0.5s, a load torque of 10N·M is applied to the system, and the torque response, rotational speed response and single-phase current obtained after the system runs for 1s are compared with the traditional integer order PID, as shown in the following Fig.3.4:



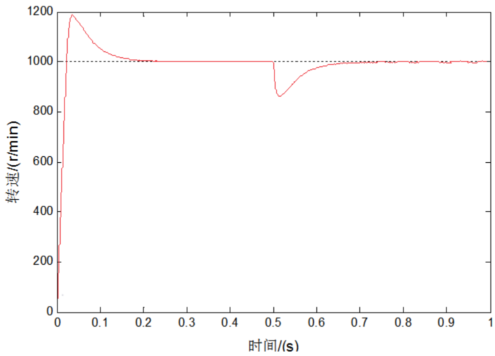
(a) System torque response based on PID control



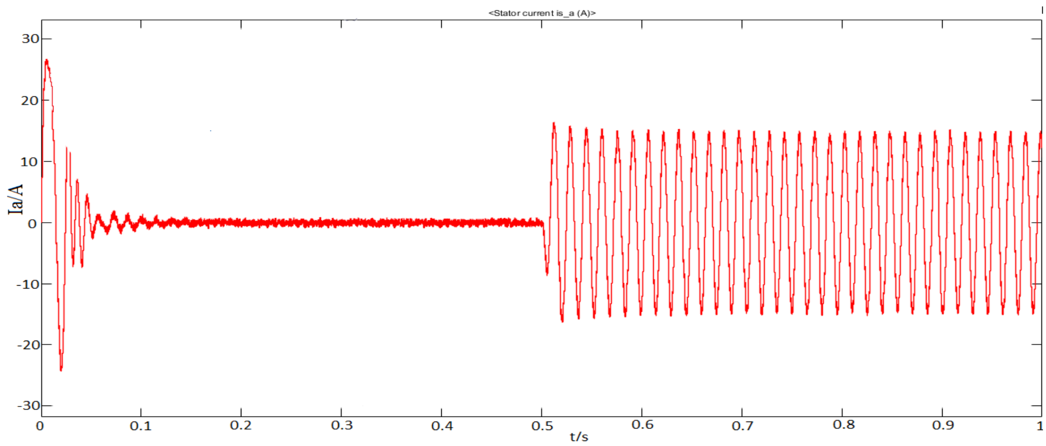
(b) System torque response based on fractional order PIλDμ control



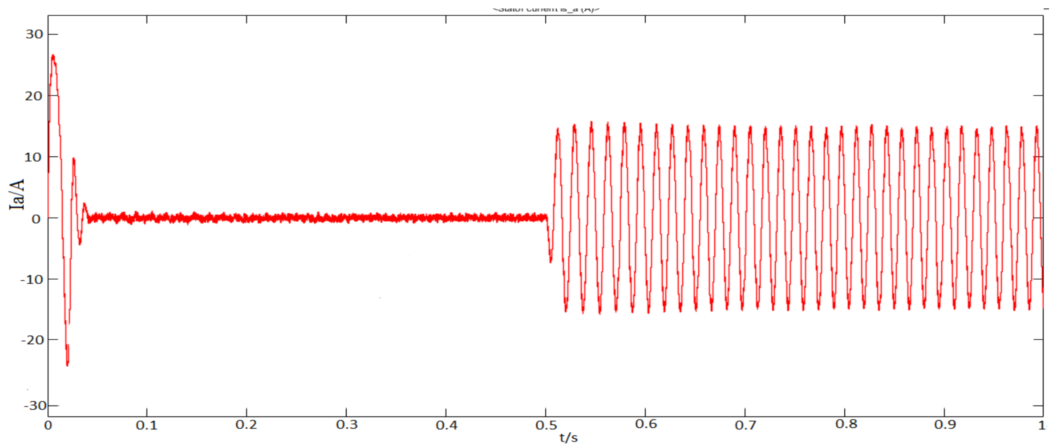
(c) System speed response based on PID control



(d) System speed response based on fractional order $PI^{\lambda}D^{\mu}$ control



(e) Single-phase Current Response of System Based on PID Control



(f) Single-phase current response of the system based on fractional order $PI^{\lambda}D^{\mu}$ control

Fig.3.4 System Output Response under Different Control Strategies

As can be seen from Fig.3.4, compared with the traditional PID, the control performance has been greatly improved. as can be seen from figs. (c) and (d), the initial overshoot of the fractional order $PI^{\lambda}D^{\mu}$control system is slightly higher than that of the integer order PID, but when external disturbance is added after 0.5 seconds, the fluctuation of the rotational speed is relatively small and relatively stable, its quantization value is 13%, and the torque comparison of (a) and (b) and the current comparison of (e) and (f) show that the disturbance variation is small, thus the robustness of the system is improved. this paper studies PMSM.

4. CONCLUSION

This paper introduces the fractional order $PI^{\lambda}D^{\mu}$principle and controller, combines the vector control principle of PMSM, SVPWM technology and the design and modeling of PMSM double closed-loop system. finally, the simulation mathematical model of PMSM control system is built on Simulink. The simulation experiment compares the speed control performance of traditional PID control and fractional order $PI^{\lambda}D^{\mu}$control in AC control system. The simulation compares the changes of motor speed, torque and single-phase current as well as the fluctuation when sudden external interference is added,so as to compare the influence of different controllers on the control performance of the system.The above simulation experiments prove that the anti-interference capability and robustness of the motor system based on fractional order $PI^{\lambda}D^{\mu}$control are enhanced.

REFERENCES

[1] Li Rugui, Single Beam, Li Xiaochun, et al. Digital Realization of Fractional Order Control Algorithm in AC Servo System [J]. Journal of Electrical Technology, 2014 (S1): 177-183.

[2] Duanyuan Bai, Chunyang Wang. Parameter Calibration and Simulation of Fractional PID Controller for Hydraulic Servo System. In Proc. of the 28st the Chinese conference Decision and Control conference (CCDC), YinChuan, China in May 28-30, 2016:1704-1708.

[3] N.N.Praboo, P, K.Bhaba. Simulation work on fractional order PIγ control strategy for speed control of DC motor based on stability boundary locus method[J].International Journal of Engineering Trends and Technology, 2013, 4(8):3404-3409.

[4] Wang Lina, Zhu Hongyue, Yang Zongjun. Parameter Setting Method of PI Controller for Permanent Magnet Synchronous Motor Speed Regulation System [J]. Journal of Electrical Technology, 2014, 29 (5): 104-117.