Research on Moment of Inertia Identification and PI Parameter Self-tuning of Speed Control System for the Permanent Magnet Synchronous Motor

Mengmei ZHU[1], Guangxu ZHOU[1], Jianhui MA[1*], Ningran SONG[1],Yongyun MU[1], Jia GAO[1], Yanliang XU[2]

1.Institute Of Automation
Qilu University of Technology (Shandong Academy of Sciences)
Shandong Provincial Key Laboratory Of Automotive Electronic Technology
Ji'nan Shandong, China
majialong@aliyun.com

2.College of Electrical Engineering
Shandong University
Jinan Shandong 250061, China

***Abstract*—The traditional PI controller parameters are mostly fixed, do not have online self-tuning ability, and it is difficult to satisfy the requirements of the speed control system for Permanent Magnet Synchronous Motor(PMSM). Moment of inertia is a very important parameter in controller parameter selfo-tuning. In this paper, the moment of inertia is identified in real time, combined with the relationship between the PI parameter of the controller speed loop and the moment of inertia, the appropriate control parameters are directly calculated to realize the online self-tuning of the controller parameters. The simulation model is built in Matlab/Simulink. The experimental results show that the proposed algorithm can realize the fast and accurate identification of the moment of inertia. At the same time, the controller PI parameter self-tuning can effectively reduce the system overshoot, the system response speed is fast, and the anti-interference ability is strong, greatly improving the performance of the speed control system.**

Keywords—PMSM; Moment of inertia; PSO; Parameter identification; PI self-tuning

I. Introduction

PMSM has the advantages of small size, high power density and high reliability, and is widely used in AC speed control systems [1]. The PMSM control system is affected by many factors during the actual operation, such as the disturbance of the load torque and the change of the moment of inertia, which will change the mathematical model of the control system. At this point, the fixed controller parameters cannot match the changed system and will inevitably affect the performance of the control system. To solve this problem, identify the parameters that have a large influence on the control system, and adjust the parameters of the controller online according to the parameters, so that the control system always runs in an optimal state[2].The speed loop reflects the mechanical performance of the entire system, and the most widely used control method is still the PI controller. Moment of inertia is one of the main external parameters affecting the performance of the motor control system. During the operation of the motor, the moment of inertia and other parameters will change. If the parameters of the PI controller are not adjusted in time, the control effect of the system may be reduced. It even caused instability in the entire control system. Therefore, the inertia identification and the tuning of the PI controller parameters are very important[3].

Many scholars have done a lot of research in the field of inertia identification.Inertia identification is mainly divided into offline identification and online identification. Existing offline identification algorithms, such as deceleration method, artificial trajectory method, etc. Although the algorithm is simple, its identification accuracy is low and the recognition time is long. Existing online identification algorithms, such as least squares method, model reference adaptive algorithm, etc, although some scholars have conducted related research, still can not produce satisfactory results.Reference [4] proposed a variable period least squares algorithm for online inertia identification, which broadened the scope of the identification algorithm and solved the problem of unrecognizability under low acceleration.Reference [5] used the recursive least squares identification algorithm based on forgetting factor to realize the identification of the moment of inertia. Reference [6] proposed an adaptive disturbance observer based on the moment of inertia identification. The disturbance observer can quickly and accurately realize the simultaneous identification of moment of inertia and disturbance torque. Online identification is still in the research stage and deserves in-depth study.

In this paper, we propose a PSO algorithm to optimize the model reference adaptive gain coefficient to realize the fast and stable identification of the moment of inertia, and directly calculate the appropriate control parameters based on the relationship between the controller's speed loop PI parameters and the moment of inertia.

II. Speed Loop Mathematical Model

The PMSM speed control system generally consists of two closed loop control systems: outer loop speed loop and inner

978-1-7281-4094-0/19/$31.00 ©2019 IEEE

loop current loop. If the viscous friction coefficient B is ignored, and the influence of friction torque and load torque is not taken into account, the current loop is simplified as an inertial link and regarded as a link in the speed loop. In this way, the speed loop is simplified as a second-order system with zero point. The simplified speed loop block diagram is shown in fig.1.

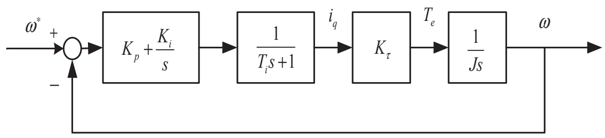

Fig. 1 Speed loop equivalent block diagram

Where ω^* is the speed of a given motor, K_p is the proportional coefficient of the speed loop, and K_i is the integral coefficient of the speed loop. $T_i = LR_s^{-1}$ is the closed-loop time constant of the current loop, $K_\tau = 1.5 p_n \psi_f$ is the torque factor of the motor, J is the system moment of inertia. From the equivalent block diagram of the speed loop, the open loop transfer function of the system can be obtained as

$$G(s)=\frac{K_\tau\left(K_p s+K_i\right)}{Js^2\left(T_i s+1\right)} \tag{1}$$

$$K=\frac{K_\tau K_i}{J},T_s=\frac{K_p}{K_i} \tag{2}$$

Then equation (1) can be expressed as

$$G(s)=\frac{K\left(T_s s+1\right)}{s^2\left(T_i s+1\right)} \tag{3}$$

As can be seen from the transfer function, this is a typical Type II system, and its open-loop Bode diagram is shown in fig.2 below.

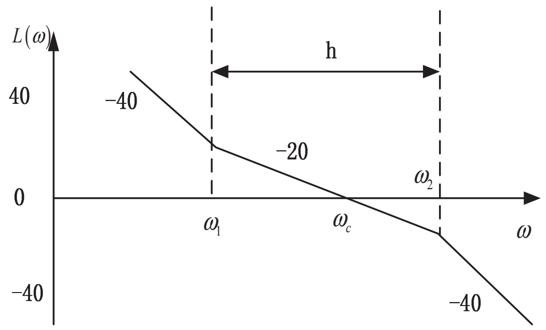

Fig. 2 Amplitude-frequency response of a typical Type II system

Where ω_1 is the turning frequency, ω_2 is the cutoff frequency, h is the mid-band width. For a fixed h value, there is one and only one cutoff frequency ω_c such that the system satisfies the following parameter relationships:

$$\frac{\omega_c}{\omega_1}=\frac{h+1}{2} \tag{4}$$

$$\frac{\omega_2}{\omega_c}=\frac{2h}{h+1} \tag{5}$$

Common engineering design methods of controller include minimum resonance peak method(minimum Mr Criterion) and third-order optimal design method (maximum phase Angle margin criterion). In the minimum Mr Method, the starting point of the adjustment parameter selection is to make the closed-loop system corresponding to equation(3) have the minimum Mr Value, and at the same time consider the requirements on the response speed and disturbance rejection performance of the system. The third-order optimal design method is basically the same as the minimum Mr Design method. The starting point of the selection of adjustment parameters is to enable equation(3) to obtain the maximum phase Angle margin and to select the parameters of the regulator with the fastest response speed possible. In this paper, the minimum Mr Method is used to design the PI parameter of velocity loop.

The parameter selection formula is

$$T_s=hT_i, K=\frac{h+1}{2h^2T_i^2} \tag{6}$$

That is, the parameters of the PI regulator are

$$K_p=\frac{J(h+1)}{2hT_iK_\tau}=\frac{J(h+1)R_s}{3hLp_n\psi_f} \tag{7}$$

$$K_i=\frac{J(h+1)}{2h^2T_i^2K_\tau}=\frac{J(h+1)R_s^2}{3h^2L^2p_n\psi_f} \tag{8}$$

For the typical Ⅱ model system, the smaller the h value, the better the immunity of the system, but when the value of h is too small, the number of system oscillations will increase. Considering all indexes of the system's tracking performance and disturbance rejection performance comprehensively, we take h according to experience. Usually, the minimum Mr design is h=5. In summary, the PI parameter self-tuning function of the controller can be achieved only by identifying the value of the moment of inertia and adjusting the parameters of the controller in real time.

III. Moment of Inertia Identification Based on PSO Optimization Model Reference Adaptive Algorithm

Among various online identification methods, the model reference adaptive algorithm is mostly used. The main idea is that the equations containing the parameters to be estimated are used as reference models, and the equations without unknown parameters are used as adjustable models. The input and output of the two models are the same.The error of the output of the two models is used to adjust the adjustable model in real time, and finally realize the identification of system parameters. In the classic model reference adaptive parameter identification method, the adaptive gain coefficient is a fixed value. If a larger adaptive gain coefficient is selected, the system identification speed is faster and the identification time is shorter, but it will cause larger fluctuations. If the adaptive coefficient selection is smaller, the system is slow to recognize and the fluctuation is small. Based on this case, this paper proposes a method of optimizing model reference adaptive coefficient based on PSO to achieve the optimal design of adaptive gain coefficient and improve the rapidity and stability of model reference adaptive identification.

The model reference adaptive gain coefficient is set as β, according to the popov superstability theory and the discrete formula of the mechanical motion equation of PMSM, the model reference adaptive law of the moment of inertia is obtained.

$$\hat{b}(k)=\hat{b}(k-1)+\beta\frac{\Delta T_{\mathrm{e}}(k-1)}{1+\beta\Delta T_{\mathrm{e}}(k-1)^2}\varepsilon(k) \tag{9}$$

Where Te is the electromagnetic torque, $\varepsilon(k)=\omega(k)-\hat{\omega}(k)$ is the speed estimation error, the formula for calculating the moment of inertia is as follows.

$$J(k)=T_s/\hat{b}(k) \tag{10}$$

Where T_s is the identification cycle.

PSO is a global Optimization method for random search.The basic steps of particle swarm optimization algorithm are as follows: determine the parameters to be optimized, compare fitness values to judge the merits of particles, update particle swarm and output the optimal solution.

The optimization parameter in this paper is the model reference adaptive gain coefficient.The fitness function selects integral time absolute error (ITAE) that is widely used in the control field [7].

$$ITAE=\int_0^{\infty}t\left|e(t)\right|dt \tag{11}$$

In actual operation, in order to improve the speed and real-time performance of the algorithm, the above formula is improved. Take N-time cumulative sum of the absolute value of the deviation and the product of time as the fitness function, the two deviations are the deviation of the speed reference and the speed feedback, the deviation of the current identification value of the moment of inertia and the previous identification value.

$$F=s_1\Delta t\sum_{j=1}^{N}t_j\left|\Delta w(j)\right|+s_2\Delta t\sum_{j=1}^{N}t_j\left|\Delta J(j)\right| \tag{12}$$

Where s1 is a weight coefficient of the deviation of the speed, and s2 is a weight coefficient of the deviation of the moment of inertia identification value. $\Delta\omega(j)$ is the speed deviation, $\Delta J(j)$ is the moment of inertia identification value deviation.

The flow chart for PSO optimization model reference adaptive algorithm is shown in fig.3.

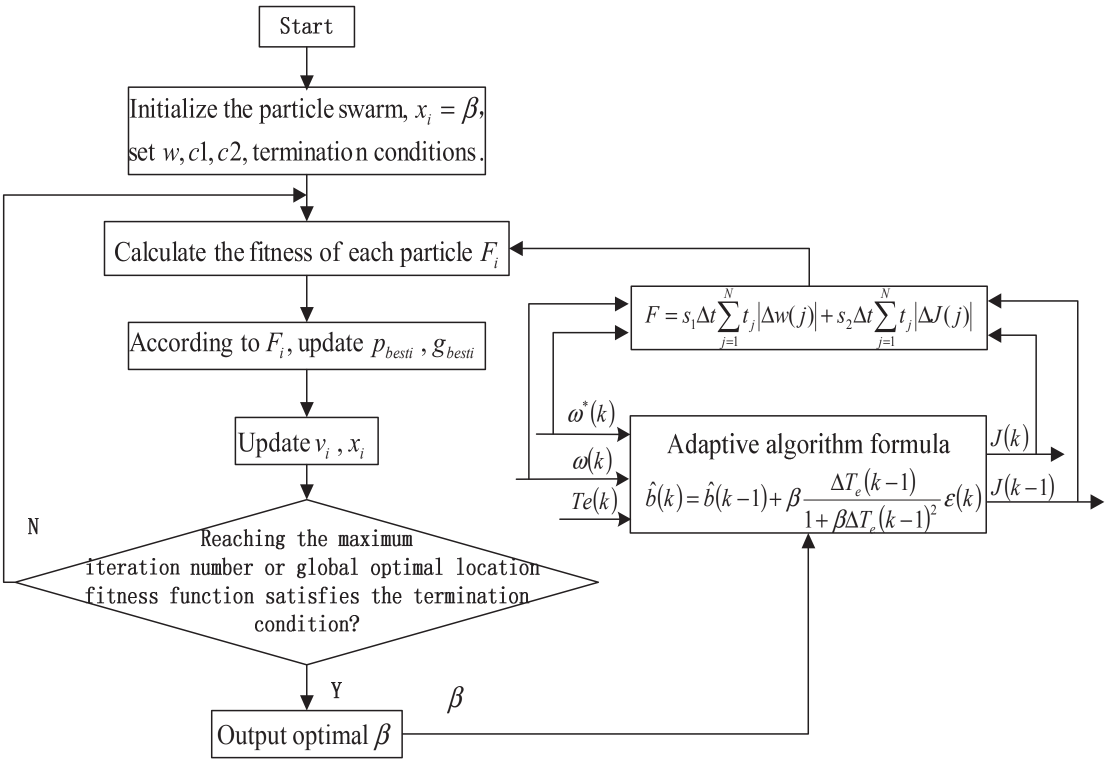

Fig.3 Flow chart for PSO optimization model reference adaptive algorithm

IV. SYSTEM SIMULATION

The simulation experiment platform of PMSM control system is established in Matlab/Simulink simulation environment. Based on the simulation experiment platform, the MRAS module based on PSO algorithm optimization model reference adaptive algorithm gain coefficient identification moment inertia is designed. The speed loop PI parameter self-tuning regulator is designed according to the identified moment of inertia.The whole simulation system consists of three parts[8].

The first part is the PSO program written by MATLAB m file. The PSO program calls the function handle of the simulation model through the feval function, and transfers the optimized adaptive gain to the PSO_PI file.The specific function calling program is as follows:

```
Obj Fun = @PSO_PMSM
f Swarm(j,:)=feval(Obj Fun,Swarm(j,:))
```

The second part is the program connecting PSO optimization program and simulation model, ie PSO_PI.m.

```
unction z=PSO_PID(x)
assignin('base','Beta',x(1));
[t,x,y_out]=sim('PID_Model',[0,200]);
z=y_out(end,1);
```

The PSO_PMSM file assigns the optimized parameters of PSO to the parameters of the model through assignin function, and then starts the simulation through sim function, and finally returns the simulation result, i.e. the value of fitness function, to the PSO program, and keeps the loop operation until the iteration condition is satisfied.

The third part is the simulation model of PMSM control system built in Simulink. The control system simulation diagram (PSO_PMSM) as shown in fig.4.

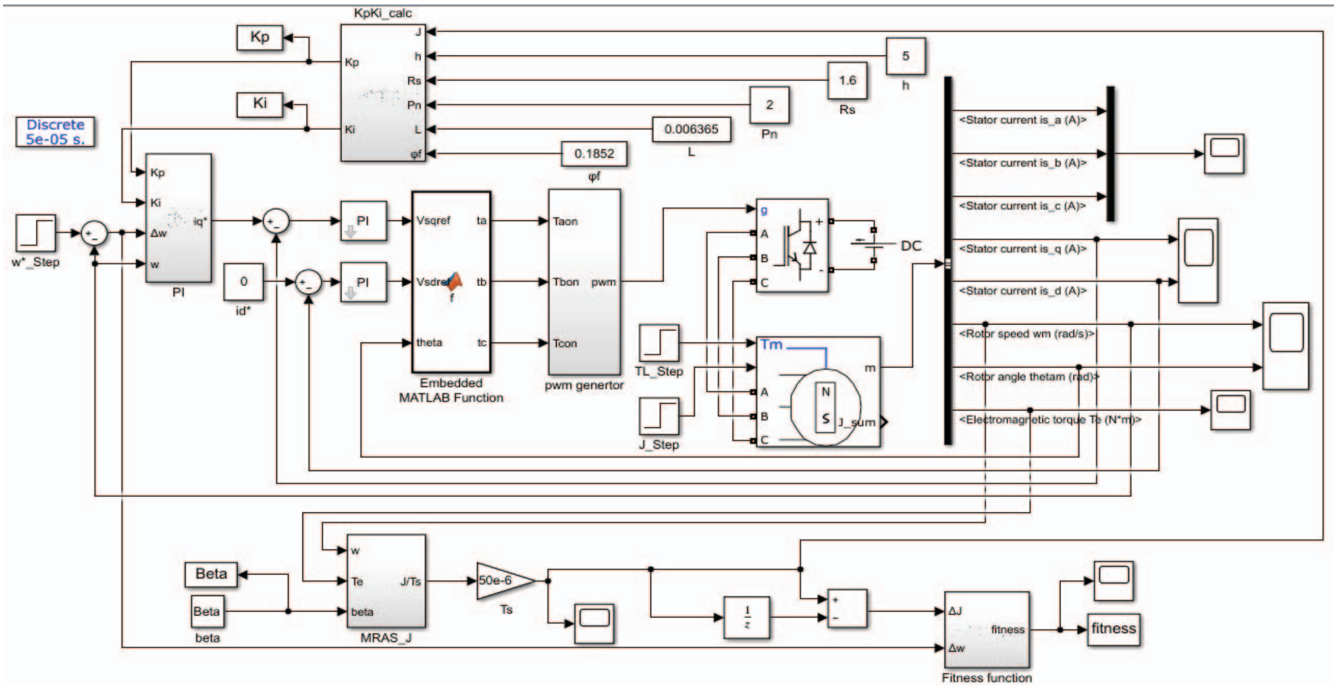

Fig.4 Control system simulation diagram

V. EXPERIMENTAL RESULT

In the PSO model reference adaptive adaptive moment of inertia parameter adaptive gain coefficient algorithm, the population size is selected as 30, considering the calculation amount of PSO and the calculation time of the algorithm, the maximum number of iterations is selected as 50. coefficient of inertia is selected as 0.6. In the fitness function, the speed deviation weighting coefficient $s_1 = 0.7$, and the moment of inertia identification value deviation weighting coefficient $s_2 = 0.3$. The control system adopts ID=0 control mode, the algorithm period is 50us, the given speed is 500rpm, and the motor moment of inertia is 0.0001854kg.m^2. Add 0.00001kg.m^2 moment of inertia at 0.2s, and add 2Nm load at 0.3 seconds, the simulation results are as follows.

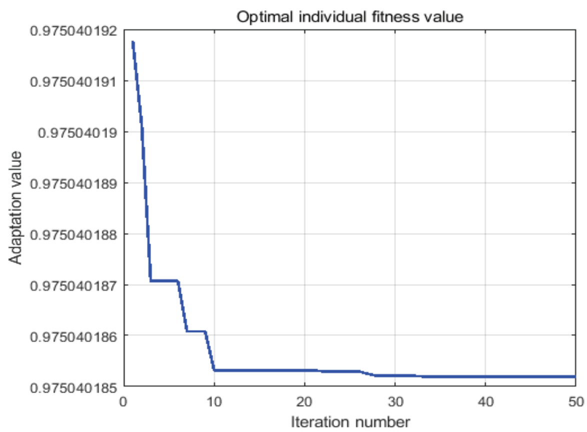

Fig.5 Fitness curve

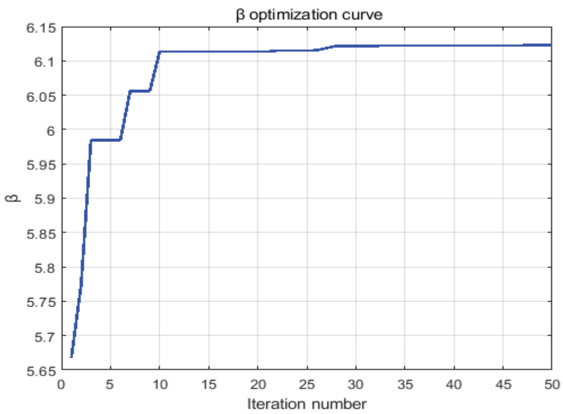

Fig.6 β Beta optimization curve

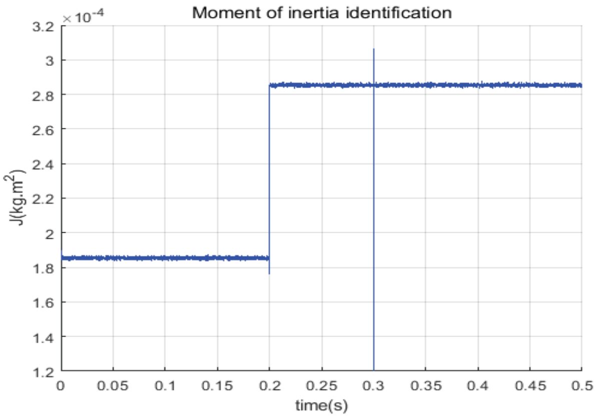

Fig.7 Moment of inertia identification results

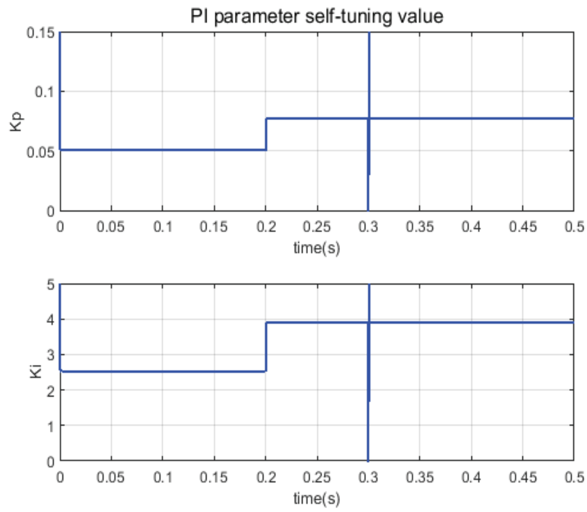

Fig.8 Speed loop PI parameters

As shown in fig.5-8, the parameter β obtained by PSO is 6.122575, and the identification result of the moment of inertia is J=0.00018542kg.m^2, and the stable value after 0.2 seconds is 0.0002854kg.m^2. The stability value of the PI regulation parameter of the speed loop regulator is K_p=0.0503, K_i=2.5303. After the system's moment of inertia increases after 0.2 seconds, the stability of the PI parameter is K_p=0.0775, K_i=3.895.

The simulation results of the system's speed step response are shown in fig.9. The given speed is 500rad/s, and the actual speed overshoot is stabilized to 500rad/s after 0.1 seconds. The system suddenly adds 2N.m load at 0.3 seconds, and the speed drops slightly, and then stabilates to 500rad/s after 0.05 seconds.

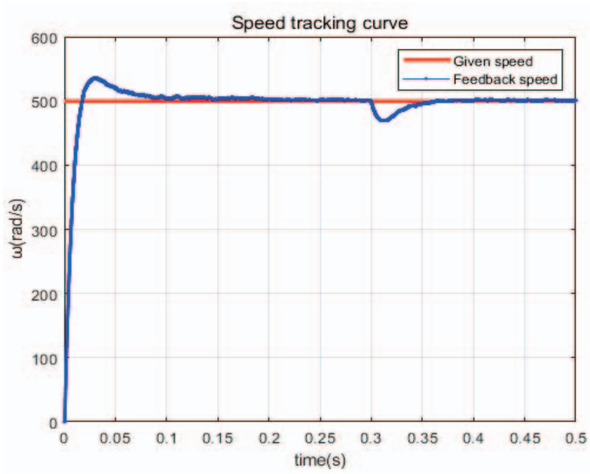

Fig.9 Speed tracking curve

Three-phase current is shown in fig.10.The first 0.3 seconds motor was loaded with 1N.m, the phase current amplitude was small, and the sinusoidal type was poor. With a load of 2N.m, the phase current waveform is nearly sinusoidal, the current amplitude is 5.8A.

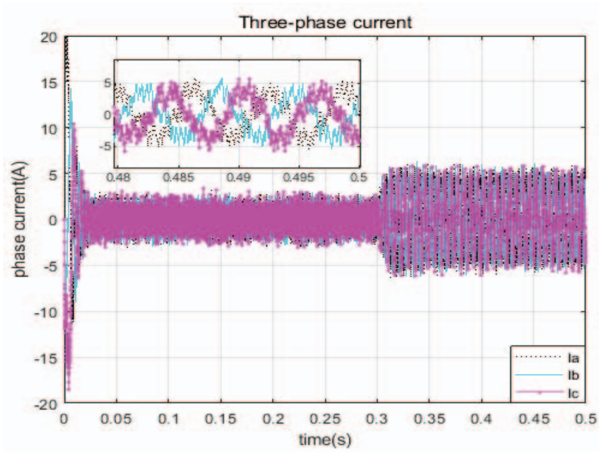

Fig.10 Three-phase current

The dq axis current is shown in fig.11. D-axis current fluctuates around zero, q-axis current in the first 0.3 seconds, due to the light load and small amplitude, the output torque of the motor increases after the load is increased, and the current Iq of axis q is proportional to the electromagnetic torque, so the current of the cross axis increases.

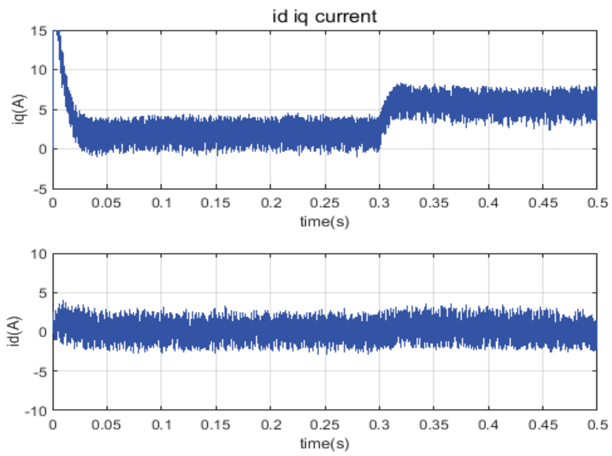

Fig.11 Id iq current curve

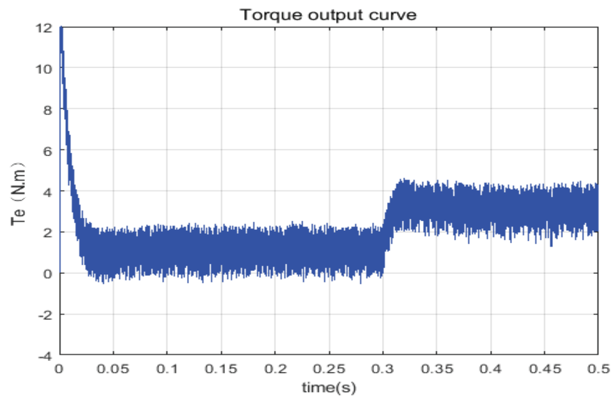

Fig.12 Torque output curve

The torque output is shown in fig.12. The system suddenly adds 2N.m load at 0.3 seconds, the torque output fluctuates around 1N.m in the first 0.3 seconds, increases rapidly at 0.3 seconds, and then stabilizes around 3N.m, and the electromagnetic torque reaches equilibrium with the load torque.

VI. Conclusion

In this paper, the PSO algorithm is used to optimize the model reference adaptive gain coefficient to identify the moment of inertia, based on the identification result, the parameters of the rotational speed loop controller are self-tuning according to the engineering design method of minimum Mr. The simulation proves that the inertia of the reference adaptive identification based on PSO optimization model is accurate and the error is small. At the same time, the speed loop controller PI parameters can be self-tuned without manual adjustment. The self-tuning control system has a fast response speed, can effectively reduce the system overshoot, steady state no static difference, has certain anti-interference ability to load disturbance, greatly improve the performance of the speed regulation system.

Acknowledgment

This work was supported by the Key Research and Development Planning Project of Shandong Province (2019GGX104099; 2019GGX104012), and Major Science and Technology Innovation Project of Shandong Province (2017CXGC0906; 2018CXGC0505).

References

[1] ZHANG Hao-ming, SUN Yu-kun. Reasearch on Parameter Identification and PI Self-adjusting of AC Speed Control System for the Permanent Magnet Motor. China Rural Water and Hydropower, No.5, pp.121-123, 2008.

[2] YU Le-hua, LIU Min. Design of Parameters Self-tuning Controller Based on Particle Swarm Optimization Algorithm. Mechatronics. No.10, pp.69-72, 2012.

[3] LIU Xin. Moment Inertia Identification Method Research for Permanent Magnet Synchronous Motor. Donghua University.2016.

[4] Yang Ming;Qu Wanying. On-Line Inertia Identification of Servo System Based on Variable Period Recursive Least Square and Kalman Observer. Transactions of China Electrotechnical Society. Vol.33 Sup.2 pp.367-376. 2018

[5] Xun Qian, Wang Peiliang, LiZuxin, et al. PMSM parameter identification based on recursive least square method[J]. Transactions of China Electro- technical Society, 2016, 31(17): 161-169.

[6] Chen Wei, Guo Zhaosheng, Xia Changliang, et al. Design of adaptive disturbance observer for AC servo system with inertia identification[J]. Transactions of China Electrotechnical Society, 2016, 31(16): 34-42.

[7] MENG Qingkuan, Navigation System of Agricultural Vehicle Based on Fuzzy Logic Controller with Improved Particle Swarm Optimization Algorithm. Transactions of the Chinese Society for Agricultural Machinery, Vol.46, No.3, pp.29-58, 2015.

[8] Wang Yanghua. Fuzzy PID Control of Boiler Main Steam Pressure Based on PSO. Journal of Hunan University of Technology. Vol.26 No.5, pp.62-66, Sep. 2012.