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Moment of Inertia Identification based on Particle Swarm Optimization Model Reference Adaptive for Permanent Magnet Synchronous Motor

Moment of Inertia Identification based on Particle Swarm Optimization Model Reference Adaptive for Permanent Magnet Synchronous Motor

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Abstract. In order to improve the dynamic performance and robustness of permanent magnet synchronous motor (PMSM) servo system, the moment of inertia identification based on model reference adaptive algorithm is studied. According to the problem that the stability and convergence response speed of the model reference adaptive identification (MRAI) algorithm can not be combined at the same time, the particle swarm optimization (PSO) algorithm is used to optimize the model reference adaptive gain coefficient to realize the fast and stable identification of the moment of inertia. The simulation results showed that the method has strong optimization ability, fast convergence speed, small oscillation amplitude and good stability.

1. Introduction

The AC PMSM servo control system is widely used in high precision and high performance applications. However, the dynamic performance of the servo system is affected by internal motor parameters, external disturbance torque and some non-linear factors[1] . Since the moment of inertia has a great influence on the control performance of the servo system, it is very important to quickly and accurately identify the moment of inertia of the entire servo system.

At present, researchers at home and abroad have done a lot of research on the method of identification of moment of inertia. The method of moment of inertia identification can be divided into two categories: offline and online. The offline moment of inertia identification method is a parameter self-tuning performed before the system is operated, using the relationship between electromagnetic torque and moment of inertia, the acceleration and deceleration time, the speed change value and the average electromagnetic torque in the acceleration section or deceleration section are measured, and then the moment of inertia is calculated[2]. The offline identification method needs to store and calculate a large number of data without real-time performance and poor identification precision, which limits the scope of its application in high-performance control system. With the development of modern control theory and computer technology, online identification has been better applied in the field of servo control. The commonly used identification methods for online moment of inertia are: least square method, observer method and MRAS. Reference [3] proposed a method to identify the online moment of inertia by least square method, which requires the cooperation of high order filters and increases the complexity of the system. Reference [4] proposed an adaptive disturbance observer based on the recognition of moment of inertia, which can realize the identification of moment of inertia. Reference [5] was improved on the basis of classical MRAI, and the moment of inertia was quickly identified by dichotomy. In reference [6] , different adaptive gains were selected in MRAI by stages. These methods improve the dependence of the identification model on the gain parameters to some extent.

In this paper, by analyzing the influence of adaptive gain coefficient in MRAI system on the convergence speed and parameter stability of PMSM moment of inertia identification, proposed PSO algorithm to optimize the model reference adaptive gain coefficient to achieve fast and stable moment of inertia identification.

2. Moment of Inertia Identification based on MRAI

2.1. Principle of MRAI

The model-based reference adaptive identification method is based on the actual system as a reference model, establish an adjustable model containing the parameters to be identified. These two models have the same physical meaning of input and output. The two models work at the same time, the error of the two models' output is used to form a suitable adaptive control law to adjust the parameters of the adjustable model in real time. When the output of the adjustable model approaches the output of the reference model, it is considered that the parameter in the adjustable model is the true value of the parameter to be identified in the actual system. The principle of MRAI is shown in figure 1.

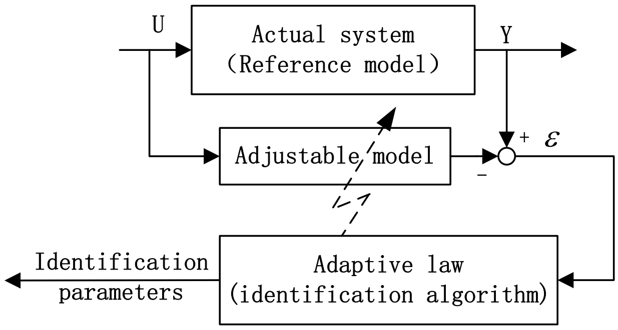

Figure 1. Block diagram of MRAI.

2.2. Moment of inertia identification

The mechanical kinematics equation of PMSM is

$$T_e - T_l = J d\omega / dt + B\omega \tag{1}$$

Where ω is rotor mechanical angular velocity, J is the sum of the moments of inertia of the motor and the load, B is viscous friction coefficient, T_e is electromagnetic torque, T_l is load torque.

Considering that the speed sampling frequency of the identification algorithm is high enough and frictional resistance is ignored, the motion equation of the PMSM can be discretized as

$$T_e(k-1) - T_L(k-1) = J[\omega(k) - \omega(k-1)]T_s^{-1} \tag{2}$$

The identification algorithm has a short control period. In the actual motor operation, the load is less likely to change drastically in one cycle. Therefore, it can be considered that the load does not change in one identification period Ts,

$$T_l(k-1) = T_l(k-2) \tag{3}$$

Collation (2) and (3) , obtained:

$$\omega(k) = 2\omega(k-1) - \omega(k-2) + \Delta T_e(k-1)b(k) \tag{4}$$

Where $\Delta T_e(k-1) = T_e(k-1) - T_e(k-2), b(k) = T_s J^{-1}$.

Taking equation (6) as the reference model, the equation of the adjustable model can be obtained:

$$\hat{\omega}(k)=2\omega(k-1)-\omega(k-2)+\Delta T_e(k-1)\hat{b}(k) \tag{5}$$

The deviation between the reference model and the adjustable model output is

$$\varepsilon(k)=\omega(k)-\hat{\omega}(k) \tag{6}$$

According to the discrete time iterative parameter identification mechanism proposed by Landau [7] , the adaptive algorithm is designed as follows:

$$\hat{b}(k)=\hat{b}(k-1)+\beta\frac{\Delta T_e(k-1)}{1+\beta\Delta T_e(k-1)^2}\varepsilon(k) \tag{7}$$

β is an adaptive gain greater than 0, The selection of β has an effect on the convergence time of the identification results and the fluctuation of the identification results. The higher the adaptive gain is, the faster the parameter identification speed is and the shorter the convergence time is. On the contrary, the smaller the gain, the slower the identification speed, but the smaller the identification fluctuation, the higher the identification accuracy. In order to have fast identification convergence rate and high identification precision, it is necessary to design adaptive gain reasonably. In this paper, PSO algorithm is proposed to optimize adaptive gain.

3. PSO Adaptive Gain Coefficient

3.1. Principle of PSO algorithm

PSO is an effective global Optimization algorithm, which was first proposed by Kennedy and Eberhart in the United States in 1995. In a D-dimensional target search space, there is a group of N particles, and each particle is regarded as a point in space, and the i-th particle is denoted as $x_i=[x_{i1},x_{i2},...x_{iD}]$, The individual optimal solution of the i-th particle (the solution corresponding to the minimum adaptation value of the i-th particle) is expressed as $p_{besti}=[p_{besti1},p_{besti2},...p_{bestiD}]$. The global optimal solution (the solution of the minimum fitness of the whole particle swarm in the past search process) is expressed as $g_{best\,i}=[g_{i1},g_{i2},...g_{iD}]$. The speed iteration formula is:

$$v_{id}(k+1)=wv_{id}(k)+c_1r_1(p_{besti}(k)-x_{id}(k))+c_2r_2(g_{besti}(k)-x_{id}(k)) \tag{8}$$

The position iteration formula is:

$$x_{id}(k+1)=x_{id}(k)+v_{id}(k+1) \tag{9}$$

Where $i=1,2,...N$, $d=1,2,...D$, k represents the number of iterations, w is the inertia weight, r_1,r_2 is a random number between [0, 1], c_1,c_2 as learning factor.

3.2. PSO algorithm for adaptive gain parameters

According to the problem of adaptive identification of moment of inertia for the model studied in this paper, the adaptive gain was determined as the parameter to be optimized. The selection of fitness function directly affects the convergence speed of PSO and whether the optimal solution can be found. In the control field, integral time absolute error (ITAE) is a performance evaluation index of control system with good engineering practicability and selectivity [8] . The system designed by ITAE has the advantages of small overshoot, moderate damping and good dynamic performance. In this paper, the ITAE sum of velocity deviation and moment of inertia deviation is used as the fitness function of PSO algorithm

$$F=s_1\int_0^{\infty}t\left|\Delta w(t)\right|dt+s_2\int_0^{\infty}t\left|\Delta J(t)\right|dt \tag{10}$$

In the formula, s1 and s2 are weighting coefficients, which respectively determine the proportion of the rotational speed deviation and the rotational inertia identification deviation in the ITAE. $\Delta\omega(t)$ indicates the deviation between the speed reference and the speed feedback. $\Delta J(t)$ indicates the difference between the current moment and the previous moment's identified moment of inertia.

The PSO adaptive gain parameter schematic diagram is shown in figure 2 .

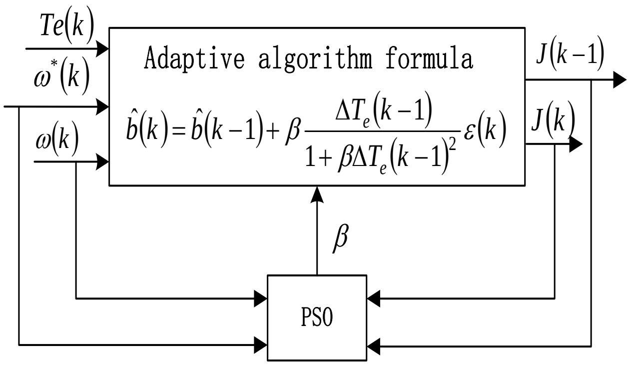

Figure 2. Principle diagram of PSO adaptive gain coefficient.

4. Simulation Analysis

The moment of inertia identification is simulated in MATLAB according to figure 2. According to the motor speed and the output torque, the moment of inertia is adaptively identified by the model reference. At the same time, according to the deviation between the deviation of the speed and the deviation of the current moment of inertia and the previous moment identification result, the adaptive gain coefficient β is optimized by PSO algorithm. In the PSO algorithm, the number of initial particle groups is 30, the number of iterations is 50, the inertia coefficient w is gradually reduced from 0.8 to 0.2 with the number of iterations of the particle swarm, the learning factor $c_1 = c_2 = 1$, and the weighting coefficient of the fitness function is $s_1 = 0.7$, $s_2 = 0.3$.

The simulation uses PSO to optimize the gain coefficient and the fixed gain coefficient ($\beta = 20$, $\beta = 0.5$) for comparative analysis. The initial moment of inertia of the system is $1.854 \times 10^{-4} \, \mathrm{kg} \cdot \mathrm{m}^2$, which is stepped to $2.854 \times 10^{-4} \, \mathrm{kg} \cdot \mathrm{m}^2$ at one second.

The moment of inertia identified by $\beta = 20$ is shown in figure 3, and figure 4 is the partial enlargement of identification results.

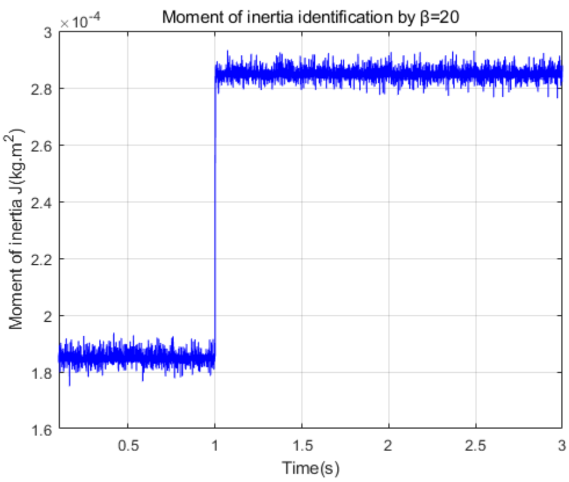

Figure 3. The moment of inertia identified by $\beta = 20$.

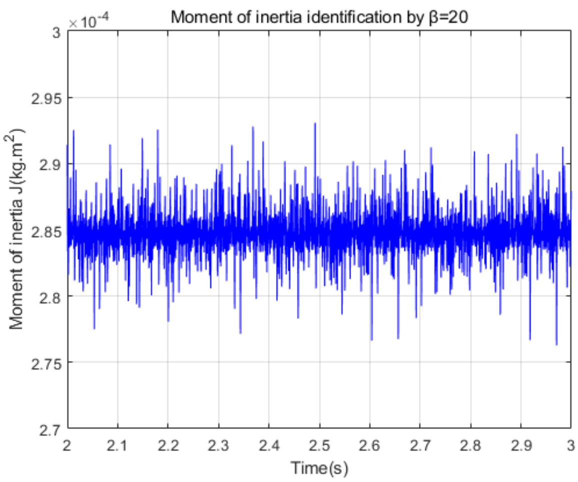

Figure 4. Partial enlargement of the identification result by .

The convergence time of the moment of inertia identification is about 0.01s, and the identification error is about 14.5%.

The moment of inertia identified by $\beta = 0.5$ is shown in figure 5, and figure 6 is the partial enlargement of identification results.

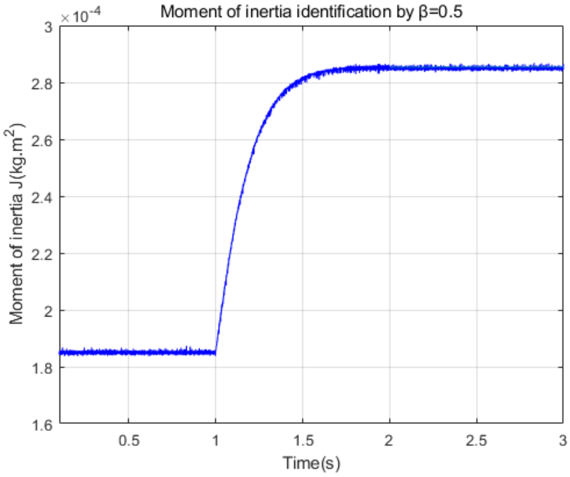

Figure 5. The moment of inertia identified by $\beta = 0.5$.

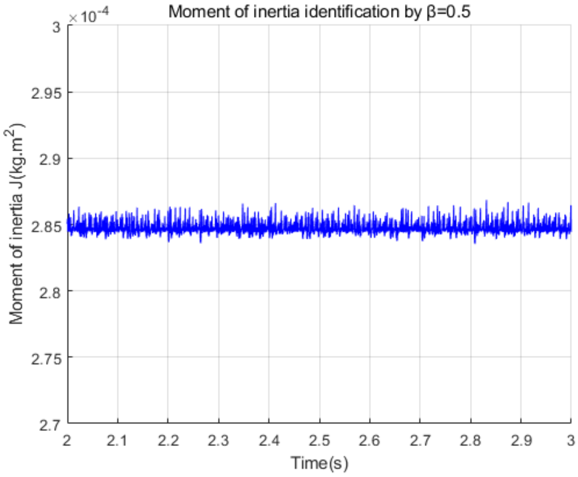

Figure 6. Partial enlargement of the identification result by $\beta = 0.5$.

The convergence time of the moment of inertia identification is about 0.75s, and the identification error is 2.1%.

The moment of inertia identified by PSO optimization β is shown in figure 7, and figure 8 is the partial enlargement of identification results.

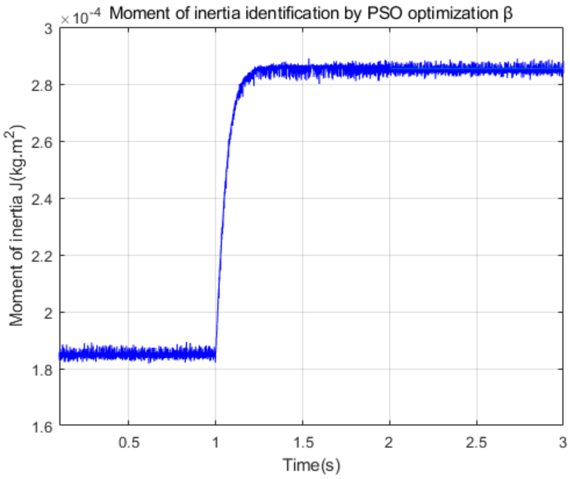

Figure 7. The moment of inertia identified by PSO optimized gain coefficient.

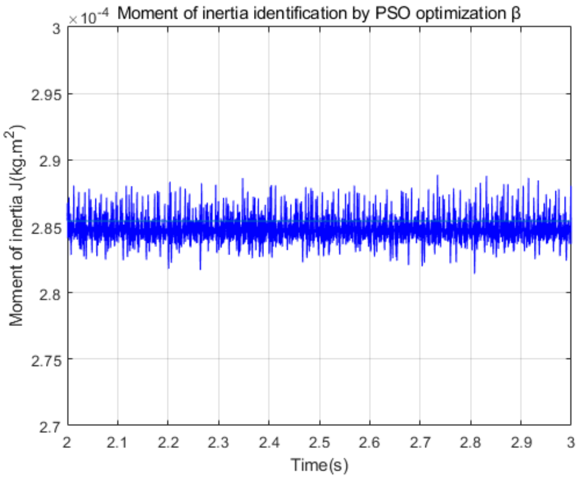

Figure 8. Partial enlargement of the identification result by PSO optimized gain coefficient.

The convergence time of the moment of inertia identification is about 0.4s, and the identification error is 6.8%.

For obvious comparison, the identification results of the three gain coefficients are placed in the same figure, as shown in figure 9. Figure 10 is the partial enlargement of the identification result by three gain coefficients.

When $\beta = 20$, the convergence of the inertia identification results is faster, but the waveform oscillation amplitude is larger. The waveform oscillation amplitude is smaller when $\beta = 0.5$, but the convergence speed is not good. The identification method of PSO optimization gain coefficient balances the convergence speed and stability, has a good identification effect.

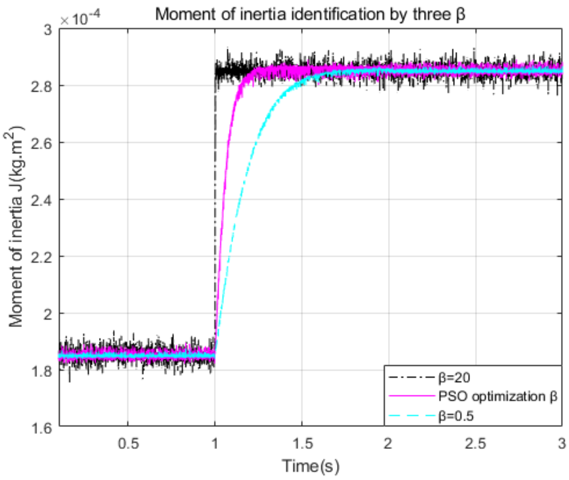

Figure 9. PSO optimized gain coefficient and fixed gain coefficient identification results.

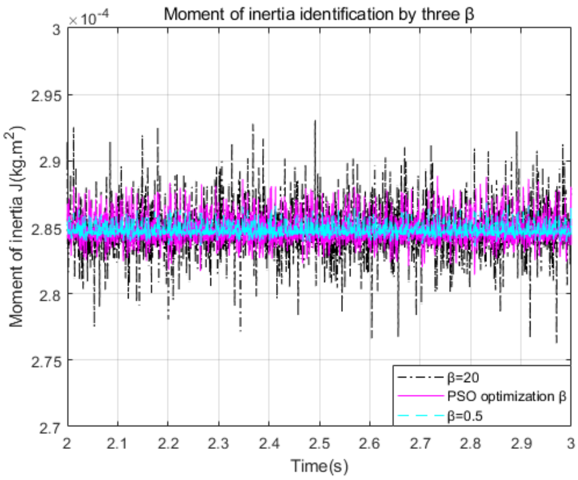

Figure 10. Partial enlargement of the identification result by three gain coefficients

5. Conclusion

Based on the analysis of MRAI moment of inertia identification, the selection of adaptive gain has great influence on convergence time and identification result. It is proposed to optimize the model reference adaptive gain coefficient by particle swarm optimization. The simulation results show that the identification method has strong searching ability and fast convergence speed, and the parameter identification result has small oscillation amplitude and good stability.

Acknowledgments

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