

# Self-tuning of Controller Parameters of Servo System based on Variable Step Size Iteration Method

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**Abstract.** In this paper, we study the self-tuning method of the controller parameters of the servo system based on variable step size iteration method. We first introduce the basic knowledge of two degrees of freedom, the design of the initial value of the initial value of two degrees of freedom, and the selection of the objective function and variable step two degree of freedom iteration parameter setting method. And then we study a variable step two degree of freedom iterative self-tuning method. In order to prove the validity of the two degree of freedom iteration method based on the variable step size for the PI controller parameters of the speed loop of the permanent magnet servo system, we conducted a simulation analysis, and we got two degree of freedom before and after iteration speed waveform figure (Figure 3), 2 times rotating inertia speed waveform figure (Fig. 4) and sudden and anticlimax torque waveform figure (Figure 5). And the obtained simulation results are analyzed, and the simulation results show that the PI controller parameters can be effectively adjusted by the method of variable step size two degrees of freedom based on the frequency domain method.

## 1.INTRODUCTION

Servo system is also known as the servo system, and it is a kind of automatic control system, which is controlled by position, angle and speed. Its main function is to achieve the implementation of the implementation of the location, angle or speed command tracking. At present, permanent magnet synchronous servo system is widely used in PI controller which is simple in structure and easy to implement, and improper parameter setting of PI controller will directly affect the control performance of the servo system [1]. In the actual engineering, the uncertainty of the load inertia and the model parameters may deteriorate the control effect of the servo system. Based on this, the servo system can adjust the parameters of PI controller to get better control performance.

Many domestic and foreign scholars have put forward a method of setting the parameters. According to whether the algorithm depends on the servo system model, the parameter tuning method can be divided into PI parameter tuning method based on the model and PI parameter tuning method based on the rule. Based on the models of the PI parameters tuning method is the precise mathematical model of the system is first established [2]. Then it under reasonable assumptions simplifies analysis of mathematical model of system. Finally it is to control the expected performance index of the system for target acquisition system controller parameters. Ziegler-Nichols (Z-N) setting method, relay feedback setting method [3], frequency domain tuning method are all based on the model of PID parameter tuning method. Mathematical model of PI parameter tuning method without system based on rule. In the system, the control parameters are updated by some kind of search optimization method, and the optimal control parameters are found to be the optimal control parameters [4, 5]. Two degree of freedom of the parameter self-tuning method by comparing the objective function values after the two degrees of freedom to modify the PI parameters, until a certain PI parameters to obtain the optimal objective function. The parameter self-tuning method based on the model is very fast, but it is not satisfied with the system model; the satisfactory result can be obtained by the method of parameter self-tuning based on rules, but the rapidity of the parameter setting is not satisfactory. So some scholars put forward the combination of the model based on the rules and the rules of the parameter setting.

In this paper, we study the parameter self-tuning method based on the combination of the model and the rule and the variable step size two degree of freedom. The method is used to calculate the parameters of the initial PI controller by frequency domain method, and then the ITAE is used as the evaluation function to find the optimal PI controller parameters by the method of variable step size two degree of freedom.

## 2. RESEARCH CONTENTS

### 2.1 Two degree of freedom iterative parameter tuning method

The speed loop of permanent magnet synchronous servo system is mainly composed of current loop, servo motor, load and feedback [6]. The current loop is the inner loop, and its control performance is generally related to the electrical parameters of the control system, which is not affected by the change of the moment of inertia of the load [7]. Because the current loop controller parameters are not required to be adjusted before the commissioning of the factory, it is necessary to adjust the parameters of the speed loop PI controller.

The so-called two degree of freedom iteration parameter self-tuning method is the whole set of PI parameters when the P and I two parameters was separated from the whole set to obtain the optimal objective function value of the PI parameters. The controller can be used for setting any two independent parameter controller without knowing the specific setting algorithm. In the two degree of freedom iteration parameters of the speed loop, the  $w^*$  is a given rotational speed,  $w$  is the actual speed,  $(K_{ps}, K_{is})$  is the parameter of the speed loop controller. The  $(k + 1)$  PI parameters of the two degree of freedom iteration method are shown in the formula (1) and type (2):

$$\begin{cases} K_{ps}(k+1) = K_{ps}(k) + \Delta K_{ps}(k) \\ K_{is}(k+1) = K_{is}(k) + \Delta K_{is}(k) \end{cases} \quad (1)$$

$$\begin{cases} K_{ps\min} \leq K_{ps}(k) \leq K_{ps\max} \\ K_{is\min} \leq K_{is}(k) \leq K_{is\max} \end{cases} \quad (2)$$

In the above formula:  $K_{ps}(k)$  and  $K_{is}(k)$  are the  $k$  PI parameters;  $\Delta K_{ps}(k)$  and  $\Delta K_{is}(k)$  are the second iteration steps of  $K$ . In order to prevent the output oscillation, the formula (2) is the range of PI parameters. After Park transformation, the flux linkage and torque equations are obtained in the d-q rotating coordinate system.

The design procedure of the two degree of freedom iteration parameter auto tuning method is as follows:

(1) Establish the mathematical model of the speed loop of the servo system, based on the frequency domain method to calculate the initial PI controller parameters.

(2) Select the objective function, and calculate the value of the objective function under different PI parameters;

(3) The minimum value of the objective function is selected as the target, and selects the minimum value corresponding to the PI parameter for the next iteration of the initial value. Repeat (2), (3), until the two selected PI parameters are the same.

### 2.2 Design of initial value of two degrees of freedom

In permanent magnet synchronous servo system, the bandwidth of the current loop is much higher than the open loop cutoff frequency of the speed loop, so the current loop can be equivalent to a first order inertial link [8]. The simplified velocity loop structure is shown in Figure 1. A is the speed feedback filter time constant; B is the speed detection feedback coefficient; B is the current loop closed loop bandwidth; B is the torque coefficient; B is the moment of inertia; B is the load torque; B is the electromagnetic torque.



Fig.1 Structure diagram of speed loop of servo system

The transfer function of the speed regulator ASR in Figure 1 is:

$$G_s(s) = K_{ps} \left(1 + \frac{K_{is}}{s}\right) \quad (3)$$

Therefore, the speed loop open loop transfer function is:

$$G_{so}(s) = K_{ps} \left(1 + \frac{K_{is}}{s}\right) \left(\frac{w_{cb}}{s + w_{cb}}\right) \left(\frac{K_T}{J_s}\right) \left(\frac{K_{sf}}{T_{sf}s + 1}\right) \quad (4)$$

In the permanent magnet synchronous servo system, the current loop closed loop frequency  $w_{cb}$  is much faster than the speed loop  $w_{sc}$ , and the speed feedback filtering time parameter  $T_{sf}$  is often very small. So the speed loop filter has a great influence on the high frequency band, and the influence of the low frequency band and the middle frequency band can be ignored. Therefore, in the low frequency band and the middle frequency band, the  $w_{sc} / w_{cb}$  and  $T_{sf} \bullet w_{sc}$  can be ignored.

The adjustment coefficient of the velocity loop phase margin is  $u = \frac{w_{sc}}{K_{is}}$ .

We can adjust the velocity loop phase margin by adjusting the U value. In order to ensure that the speed loop PI controller after the correction of the servo system has a larger phase margin, we select the value of the coefficient u is 5. Accordingly, the parameters of the speed loop controller can be further simplified as:

$$\begin{cases} K_{ps} = \frac{Jw_{sc}}{K_T K_{sf}} \\ K_{is} = \frac{w_{sc}}{5} \end{cases} \quad (5)$$

### 2.3 Select objective function

The parameter design of the speed loop controller based on frequency domain method is heavily dependent on the ideal mathematical model of the servo system and some simplifying assumptions of the model. In the actual servo system, there are no ideal parameters such as parameter perturbation, load disturbance, friction and so on [9]. Therefore, the frequency domain method of the PI controller parameters cannot make the servo system to achieve the best state, and it needs further optimization [10].

The objective function is the key to optimize the parameters of the servo system. The more common objective functions are: square error integral (ISE), absolute error integral (IAE), time and absolute error product integration (ITAE).

(1) Square error integral (ISE)

$$ISE = \int_0^{t_i} (y(t) - y_{sp}(t))^2 dt \quad (6)$$

(2) Absolute error integral (IAE)

$$IAE = \int_0^{t_i} |y(t) - y_{sp}(t)| dt \quad (7)$$

(3) Time and absolute error product integral (ITAE)

$$ITAE = \int_0^{t_i} t |y(t) - y_{sp}(t)| dt \quad (8)$$

Among them,  $y(t)$  represents a given value;  $y_{sp}(T)$  represents the actual value;  $t_i$  indicates the step response to a given duration. The error between the given value and the actual value of the target function in the response process of the servo system is also given.

### 2.4 Variable step two degree of freedom iteration parameter setting method

According to the iterative optimization principle, we can know that the convergence rate of the iterative optimization is dependent on the initial value and the iteration step. Under normal circumstances, when the initial value is the same, the iteration step is growing up, and the target function value tends to the optimal value; the iteration step is small, and the objective function value tends to the optimal value. However, the optimal value of the objective function is usually better than the optimal value of the objective function, which is the short iteration step, which can make the servo control system get better performance.

In order to improve the convergence rate of the iterative self-tuning and guarantee the optimal control performance, we introduce the step attenuation coefficient. The variable step size method is adopted to make the iteration step size exponentially decaying.

$$\begin{cases} \Delta K_{ps}(k) = \alpha K_{ps}(k-1) \\ \Delta K_{is}(k) = \alpha K_{is}(k-1) \end{cases} \quad (9)$$

In the formula:  $0 < \alpha < 1$  indicates attenuation coefficient; K indicates the number of

According to the different stages of the parameters of the servo control system, the variable coefficient method can shorten the iteration time and achieve the goal of parameter self-tuning.

The framework of permanent magnet synchronous servo system based on a control strategy is shown in Figure 2. The parameters of the servo system are shown in table 1.

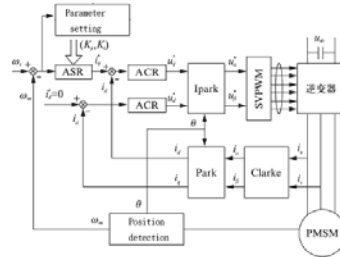


Table 1 Parameters of permanent magnet synchronous motor

In the MATLAB/Simulink simulation environment, we construct a PI controller parameter self-tuning model based on the variable step two degree of freedom iteration method based on Figure 2. Among them, the parameter auto tuning module is implemented by S function. In the experiment, the speed loop cutoff frequency is 200 Hz. Table 2 is the number of iterations required for the convergence of the objective function and the convergence value for the different values of the alpha.

From the Table 2, we can find that the convergence of the objective function becomes smaller when the iterative step size is gradually increased. Because the coefficient is big, the iteration step size is also big, and the optimum scope can increase correspondingly. Because of the exponential decay of the iteration step length, the range of the step size and the PI parameter is small in the 7 step of iteration, and the objective function value tends to be stable. In the convergence of the objective function, the smaller iteration step can achieve a better convergence value, so it is generally better to converge in the small step length.

The speed waveform of the parameters based on frequency domain method to calculate and the PI parameters of two degree of freedom iteration is shown in figure 3. Figure 4 is the initial value of the above PI parameters and the iteration of the PI parameters of the speed waveform contrast. Suddenly loading and unloading torque waveform is shown in Figure 5.

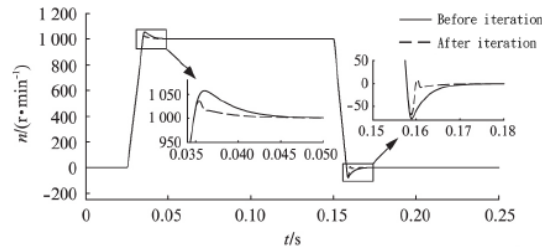


Fig.3 Two degrees of freedom before and after the speed waveform.

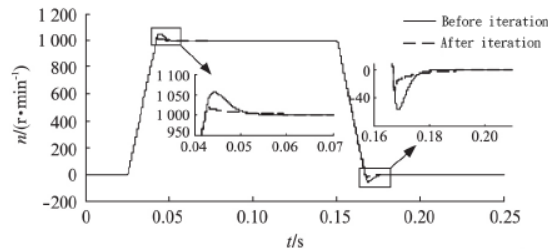


Fig.4 Two times the rotational inertia speed waveform

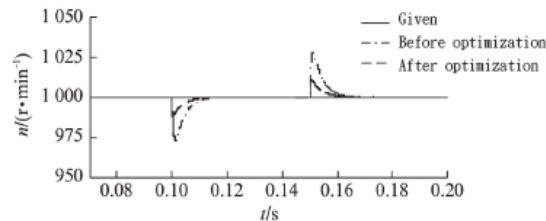


Fig.5 Sudden increase and sudden reduction of torque waveform

As can be seen from Figure 3, in the speed start and stop stage, the speed overshoot of the variable step size two degrees of freedom after the optimization was reduced by 38.6% and 11.8% respectively than before optimization. Assuming that the inertia of the motor is 2 times of the inertia of the servo system, the inertia of the system is not allowed to identify the inertia of the system, so the initial value of the iteration is calculated by the moment of inertia. Because the inertia identification is not accurate, which leads to identification of inertia is one times of inertia. So the initial value of iteration is calculated by 1 times of inertia. Figure 4 is the initial value of the above PI parameters and the iteration of the PI parameters of the speed waveform contrast. The observation figure 4 shows that the iterative parameter tuning method can be very good to solve the problem because of the inaccurate identification of the model error caused by the model error. The analysis of figure 5 shows that the maximum value of the fall and rise of the rotating speed after the iteration is significantly reduced by nearly 50% compared with the value before optimization.

#### 4. CONCLUSIONS

In the high performance servo system, the parameters of the speed loop controller are very important. In this paper, we use the iterative self-tuning method as the basis, and use the variable step two degree of freedom iteration method to adjust the parameters of the PI loop controller. The experimental results show that the PI controller parameters can be effectively adjusted by the method of variable step size two degrees of freedom based on the frequency domain method.

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