Control of Permanent Magnet Synchronous Motor Based on Active Disturbance Rejection Control

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Abstract. For the control of permanent magnet synchronous motors, the proportional integral controller has the characteristics of simple structure and strong versatility, and has been widely used. However, in some occasions with the higher requirements for anti-interference, the proportional integral controller cannot fully meet the control requirements. Therefore, it is proposed to apply active disturbance rejection controller to control permanent magnet synchronous motors to achieve the purpose of improving the control performance of the system. The models of the proportional-integral controller and active disturbance rejection controller were built using MATLAB, and compared with each other under the premise of ensuring that both parameters were optimal. The situation proves that the permanent magnet synchronous motor with applying active disturbance rejection controller has better anti-interference performance in the interference environment.

1. Introduction
In the field of motor control, the proportional integral controller, as a mature controller, has been widely used for its excellent control effect and strong versatility [1]. This controller has a very good corresponding speed and good steady-state performance in a relatively ideal control environment, but in the application scenarios where the disturbance is large, the noise is large, and there are sudden signals, the control effect of simple proportional integral controller is insufficient. To meet our requirements, we need new controllers.

With the continuous development of the field of automatic control, new control theories have been continuously proposed [2-4]. Most of the theories is optimized based on the original to improve the control performance, and the active disturbance rejection controller (ADRC) proposed by Han Jingqing [3] is an innovative algorithm for the purpose of anti-disturbance. It promotes the essence of PID control and absorbs the achievements of modern control theories. It is summarized in the results of computer simulation experiments and can replace proportional integral controller in some fields. ADRC is a control algorithm with strong anti-interference ability, and the algorithm is simple and easy to implement. It has great research value in the field of permanent magnet motor control.

2. Control Object Model and Controller Model

2.1. Control object
This paper builds a synchronous permanent magnet motor based on Simulink simulation software, and its parameters are: phase armature resistance $R=0.5\Omega$, Torque constant $K=2.83N\cdot m/A(rms)$, Electrical time constant $t=19s$, Moment of inertia $J=0.00341kg\cdot m^2$. In this
In the case, the speed-torque control is a closed-loop control and controlled by PI controller and ADRC. After the parameters are turned, we get the closed-loop equivalent inertial link, $T = 0.38461s$. Then, it is brought into Eq. 1 to get the control model.

$$G(s) = \frac{k}{s(Ts + 1)}$$

(1)

In the formula, $k$ can be equivalent to the controller, and only has the function of zooming in and out. In order not to lose the generality, it is normalized to 1.

2.2. Controller model

As a comparison with the ADRC controller, the traditional proportional-integral controller (hereinafter referred to as PI controller) has the following form:

$$C(s) = K_p(1 + \frac{K_i}{s})$$

(2)

In the formula, $K_p$ and $K_i$ are proportional and differential coefficients, respectively. It is a control method that corrects the output of the controller based on the error and the integral of the error. PI has the characteristics of fast steady-state speed, good steady-state performance, simple parameter tuning, and is widely used.

The active disturbance rejection controller proposed by Mr. Han Jingqing is a control method developed by absorbing the advantages of PID control technology and adding many new elements, which is an efficient nonlinear robust controller [5]. Compared with PID controller, it has many advantages. It has been controlled by the industrial field, and has been used in many fields and achieved good control results. [6]. Active disturbance rejection controller consists of tracking differentiator (TD), extended state observer (ESO), nonlinear state error feedback control law (NLSEF). TD enables the system to be immune to sudden changes in the input signal. NLSEF has a better effect than the linear control. ESO can compensate for disturbances and increase the system's immunity. It is the key of the ADRC [7]. As more and more fields such as intelligent robots [8], medical [9], aircraft trajectory control [10-11] and ship [11-14] have begun to apply ADRC control, it is also constantly being improved and matured. The block diagram model of ADRC is shown in Figure 1.

![Figure 1. Block diagram of the third-order ADRC controller](image)

The entire control block diagram is very clear, and the parameter optimization method has been continuously improved [15], which can already be easily applied to the field of permanent magnet synchronous motor control and quickly set parameters.

3. Design of Active Disturbance Rejection Controller

3.1. Designing the transition process TD

The entire control block diagram is very clear, and the parameter optimization method has been continuously improved [15], which can already be easily applied to the field of permanent magnet synchronous motor control and quickly set parameters.
The purpose of arranging the transition process TD is to decompose the input signal into the following signal of the input signal and the differential signal of the input signal. Compared with the traditional method of obtaining the differential signal by using adjacent quantities to make a difference, this method can reduce the interference of noise on micro components to obtain a more reasonable and stable differential signal than the traditional differentiator. At the same time, it can avoid the sudden change of the signal to disturb the system and resolve the contradiction between the response speed and the overshoot that the classical system cannot solve. The design of TD is as follows:

\[
\begin{align*}
\dot{v}_1 &= v_2 \\
\dot{v}_2 &= v_3 \\
\dot{v}_3 &= \text{fhan}(v_1 - v_2, v_3, r)
\end{align*}
\]  

(3)

\text{fhan(\text{\footnotesize *})} is the fastest tracking differentiator, which is used to quickly track the input signal \(v(t)\), and generates transition signals without mutations. The fastness of the system is determined by \(r\), but when \(r\) is too large, it will bring problems such as large overshoot and long stabilization time.

3.2. Design of ESO

The extended state observer (ESO) is the core part of the ADRC. It can analyze and simulate the size of the disturbance and offset it to ensure that the disturbance is compensated in real time. The system is linearized into an integrator series structure through NLSEF to make the control object easy to control and improve performance. The control law is as follows:

\[
\begin{align*}
\dot{e} &= z_1 - y \\
\dot{z}_1 &= z_2 + (z_2 - \beta_1 e) \\
\dot{z}_2 &= z_3 - \beta_2 \text{fal}(e, 0.5, d) \\
\dot{z}_3 &= z_4 - \beta_2 \text{fal}(e, 0.5, d) + b_d \mu \\
\dot{z}_4 &= -\beta_2 \text{fal}(e, 0.125, d)
\end{align*}
\]  

(4)

In the formula, the function of \(\text{fal(\text{\footnotesize *})}\) is to control the gain of the system, \(z_1, z_2, z_3\) are the state components of each order of the tracking object, \(z_4\) is the disturbance amount predicted by the system, and \(\beta_1, \beta_2, \beta_3, \beta_4\) are the main parameters of ADRC that determine the phase and amplitude of the entire system [15].

3.3. Design of NLSEF

The role of NLSEF is to suppress the difference part of the compensation amount to a certain extent, and combine the components non-linearly instead of linearly which can bring better control effect. The following control laws can be used:
In formula (5), $b_0$ determines the performance of error compensation, and determines the system adjustment speed. NLSEF has $\beta_1$, $\beta_2$, $\beta_3$ and $a_1$, $a_2$, $a_3$ six main parameters, the former is used to balance the adjustment speed and the overshoot, the latter mainly determines the nonlinear shape.

4. Simulation

Build simulation model based on ADRC and PI controller principle. In the simulation model, we used the same transfer function to simulate two DC permanent magnet synchronous motors with the same conditions, we output the control effects of the two controllers to the same oscilloscope, and applied different interference signals to simulate the actual motor Various interferences received in the control situation, as well as changing the transfer function used to simulate the motor to represent the parameter changes caused by the aging of the motor. The follow-up performance of the two controllers was tested and recorded, and each parameter was calculated for the system to compare the pros and cons of the two.

5. Testing and analysis

5.1. Without interference

(Dotted line in the figure is the following effect of the PI controller, and solid line is the following effect of the ADRC controller, the same applies below)

![Figure 2. Comparison of control effect without interference](image)

Table 1. Comparison of response performance indicators

| Index         | Rise Time | Adjustment time | Peak time | Steady-state error | Overshoot |
|---------------|-----------|-----------------|-----------|--------------------|-----------|
| ADRC controller | 0.92s     | 1.7s            | 1.25s     | 0.1%               | 0.5%      |
| PI controller  | 0.5s      | 2.5s            | 0.8s      | 0.2%               | 32%       |

From Figure 2 and Table 1, it can be seen that under the condition of no interference, the ADRC has a very smooth system response due to the TD. It has superior performance. The PI controller has
the faster rise time, but there is a large amount of overshoot. So the final adjustment time is also longer than the ADRC. Both of them can guarantee the final waveform is stable and distortion-free, and generally there is no large performance difference.

5.2. Under white noise interference

It can be clearly seen from Figure 3 that the PI controller has a more obvious waveform distortion when white noise is applied. Although the ADRC also generates slight fluctuations, the overall waveform is relatively smooth. It can be seen that under the interference of white noise, ADRC has a significantly better control effect.

5.3. Comparison of effects under step disturbance

From the comparison of the follow-up effect of Figure 4, we can clearly see that the ADRC has a very strong anti-interference ability in the case of step disturbance. In the figure, almost no overshoot caused by step disturbance is observed, but the PI controller's anti-interference ability for step disturbance is relatively mediocre, the overshoot is obvious, and it takes a long time to restore stability. Therefore, ADRC has better performance indicators under step disturbance.
5.4. Performance comparison under slight changes in motor parameters

In the process of use, the motor inevitably has mechanization problems. After the motor parameters are slightly changed, whether the controller can adapt to this change and maintain a relatively stable control effect is also an important performance indicator. So we slightly change the simulated motor parameters. The test results are shown in Figure 5 and Table 3.

![Figure 5. Comparison of control effects after motor parameters change](image)

**Table 3. Comparison of response performance indicators after motor parameters change**

| Controller     | Rise Time | Adjustment time | Peak time | Steady-state error | Overshoot |
|----------------|-----------|-----------------|-----------|--------------------|-----------|
| ADRC controller| 0.92s     | 2.5s            | 1.12s     | 0.4%               | 8%        |
| PI controller  | 0.5s      | 5.4s            | 0.8s      | 0.6%               | 50%       |

It can be clearly seen from Figure 5 that compared to the initial state, the following effect of the PI controller after the motor ages has more obvious fluctuations. According to the performance parameters measured in Table 3, the adjustment time and the overshoot are much larger than the ADRC. The indicators of the controller show that the ADRC has strong adaptability under the condition of motor aging, which is in line with the principle of robustness of automatic control.

5.5. Performance comparison under pulsed disturbance

![Figure 6. Comparison of control effects under spike disturbance](image)

**Table 4. Comparison of performance indicators for spike disturbance**

| Controller     | Time to restore stability | Overshoot | Steady-state error | Whether distortion |
|----------------|---------------------------|-----------|--------------------|--------------------|
| ADRC controller| 1.1s                      | 2.8%      | 0.4%               | no                 |
| PI Controller  | 3.7s                      | 6.2%      | 0.6%               | no                 |
It can be seen from Figure 6 that under the interference of sharp pulses, the waveform change of the PI controller is more obvious than that of the ADRC, and it causes a large overshoot and also takes more time to return to the stable state. It can be considered that the ADRC has a better control effect under pulse interference.

6. Summary
In this paper, for the control problem of DC permanent magnet synchronous motors, through the simulation tool of Simulink, a simulation model of the ADRC and PI controller to control DC permanent magnet synchronous motors is established. By comparing the response waveform diagram and measuring the specific performance parameters of both, we can find that although a simple PI controller is sufficient to obtain a good control effect in the absence of interference, when the simulation introduces some interference which would occur in the real environment, the ADRC due to the existence of the differential tracker and the extended state observer can estimate in advance, extract interference, and act in a timely manner. Therefore, no matter under the condition of spike interference, step interference or white noise interference, ADRC has the better performance than PI controller. It is verified that the ADRC can replace the PI controller to control the permanent magnet synchronous motor under the non-ideal conditions with interference.

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