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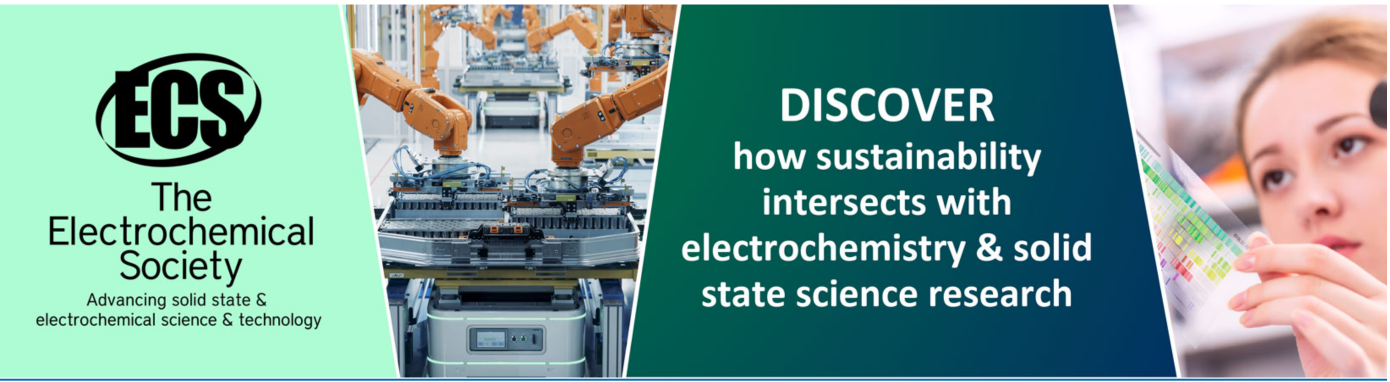

Research and Realization of Servo Control System Based on Medical Centrifuge

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Abstract. The power of the medical centrifuge is provided by the permanent magnet synchronous motor, so the AC control system of the permanent magnet synchronous motor directly determines the overall performance of the centrifuge. In this paper, the permanent magnet synchronous motor is the controlled object, the DSP28335 is used as the main control chip, and combined with the vector control strategy, the permanent magnet synchronous motor AC servo control system is designed. Finally, according to the design scheme, the soft and hard design of the motor control system is completed, and the system test is carried out. The test results show that the designed servo control system has fast response, good tracking performance, and stable operation, and has a certain market application prospect.

1. Introduction

Medical centrifuges are mainly used for the separation, purification and preparation of blood, and are basic equipment in the fields of medical and biological research. The rotation speed, response time and anti-interference ability of the centrifuge have a great influence on the experimental results and disease diagnosis. As the power output of the centrifuge, the permanent magnet synchronous motor determines the performance of the entire centrifuge[1]. Due to the nonlinearity and strong coupling of the permanent magnet synchronous motor mathematical model, traditional DC motor control strategies are often difficult to achieve high-precision and stable control of permanent magnet synchronous motor. At present, in engineering practice, there are two control strategies of permanent magnet synchronous motor, namely vector control strategy and direct torque control strategy. This paper compares the advantages and disadvantages of the two control strategies, and finally chooses the vector control strategy, and designs a permanent magnet synchronous motor AC servo control system with DSP28335 as the main control chip. The system tests show that the system has fast response, good tracking, and is relatively stable during operation, and has certain market application prospects[2].

2. Permanent Magnet Synchronous Motor Control Strategy

2.1 Choice of control strategy

In 1971, Blasehke F. proposed a vector control strategy. Its core idea is to simulate the permanent magnet synchronous motor as a DC motor for control by using the vector transformation method based on the mathematical model of the permanent magnet synchronous motor. The control strategy makes the whole control system have better dynamic and speed regulation performance. The commonly used vector control is the rotor flux oriented control. This method selects the rotor flux linkage as the reference coordinate, and uses the mutual transformation between the static coordinate system and the rotating coordinate system to decompose the stator current into excitation components and torque components[3]. The role of the excitation component is to generate flux linkage, and the role of the torque component is to generate torque. The excitation component and the torque component are independent of each other, so this method completes the decoupling of the mathematical model of the permanent magnet synchronous motor.

Direct torque control. In 1985, Depenbrock M proposed a direct torque control strategy. This method does not need to decouple the mathematical model of the permanent magnet synchronous motor, so it does not need to carry out complex coordinate transformation. The core idea of the direct torque control strategy is to regard the motor and the inverter as a whole. In the stator coordinate system, the space voltage vector pulse width modulation technology is used combined with the mathematical model of the permanent magnet synchronous motor to calculate the stator flux linkage and torque， and finally, the PWM waveform generated by the main control chip is used to control the switching state of the inverter, thereby directly controlling the torque.

Compared with the vector control strategy, the direct torque control strategy has certain shortcomings, such as greater noise when the motor speed is low, and it is also difficult to control the torque and flux linkage. During the operation of the system, the system using the direct torque control strategy has large current and torque ripple, and the switching frequency of the inverter is not constant. Therefore, this paper adopts the vector control strategy for the control of the permanent magnet synchronous motor[4].

2.2 Basic Principles of Vector Control

The transformation of the three-phase stationary coordinate system ABC to the two-phase stationary coordinate system αβ is called Clarke transformation, and the transformation formula is

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} \tag{1}$$

The transformation of the two-phase stationary coordinate system αβ to the two-phase rotating coordinate system dq is called Park transformation, and the transformation formula is

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{2}$$

The corresponding Park inverse transformation is

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} \tag{3}$$

Where:i_A, i_B, i_C are stator A, B, C phase currents.i_α, i_β are the components of the stator current on the α and β axes. i_d and i_q represent the components of the stator current d and q axes.

The system vector control structure diagram is shown in Figure 1. First, measure the currents $i_A$andi_B with a current detection device, and obtain the current i_C according to Kirchhoff's law. Then, i_d and i_q can be obtained through Clark and Park transformations. At the same time, the position detection device detects the angle θ rotated by the rotor of the motor, and calculates the actual angular velocity ω of the motor. Use ω to compare with the given angular velocity ω_{ref} to get the velocity deviation.The speed deviation is input to the speed PI controller to obtain the given q-axis current i_q.Compare the actual dq-axis current i_d, i_q with the given values a and b to obtain the dq-axis current deviation, and input the current deviation to the current PI control to obtain the given dq-axis voltage U_{dref}, U_{qref}.Using Park inverse transformation, the stator voltages $U_{\alpha ref}$ and $U_{\beta ref}$ can be obtained and input to the SVPMW module. The SVPMW module outputs six complementary PWM waveforms to drive the IPM three-phase inverter. The entire vector control system forms a closed loop[5].

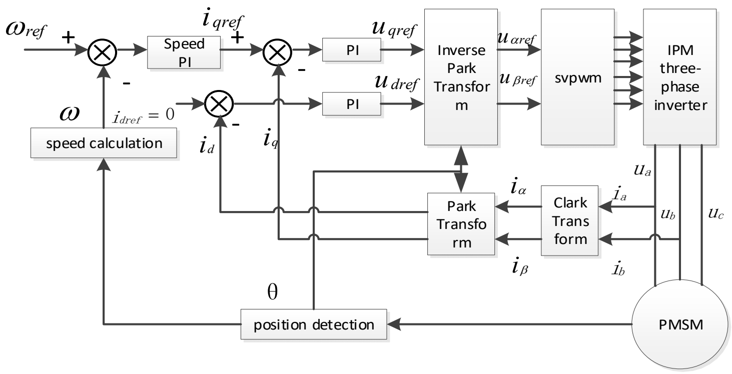

Figure 1. The system vector control structure diagram

3. Hardware Design

The hardware of the servo control system based on medical centrifuge designed in this paper consists of the following parts: permanent magnet synchronous motor, main power module, current detection circuit, position and speed detection circuit, DSP main control unit, protection circuit, etc. The servo motor adopts PMSM produced by American Kollmorgen Company, the model is M-205-B, and its main parameters are shown in Table 1. The main control chip selects the DSP produced by American TI Company, the model is TMS320F28335, and the overall hardware structure block diagram of the system is shown in Figure 2.

Table 1 Main parameters of the motor

The main parameters	Numerical value
P	1.6 kW
R_s	1.24Ω
L_d	7.2 mH
L_q	19 mH
J	0.00343 kg·m^2
K_T (1.5pn ψ_r)	0.601 Nm/A
P_n	2

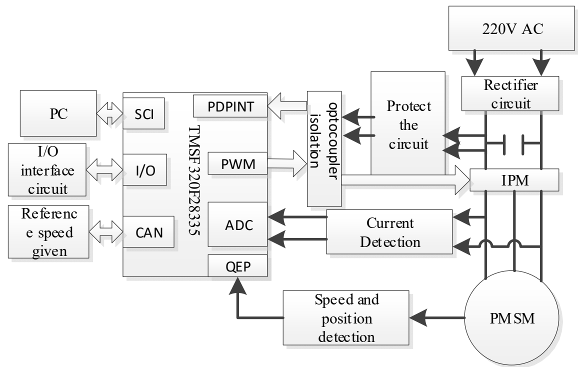

Figure 2. The overall hardware structure block diagram of the system

3.1 Current detection circuit

The purpose of vector control is to control the torque or dq axis current, so it is very important to accurately detect the stator current for real-time control of the motor. The control system designed in this paper adopts closed-loop Hall sensor to realize the detection of A-phase and B-phase current. The current sensor selects CSNE151-100 from Honeywell Company. The current detection circuit is shown in Figure 3.

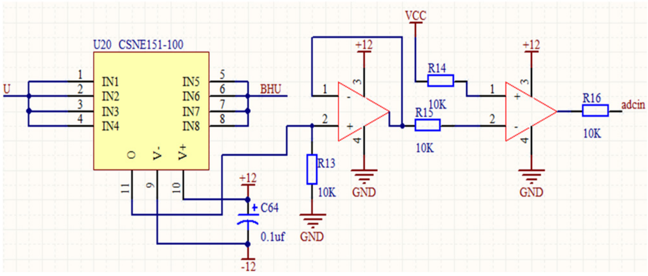

Figure 3. The current detection circuit

The current signal detected by the Hall sensor cannot meet the input conditions of the I/O port of the DSP. Here, the current signal needs to be converted to between -1.5V and +1.5V through the sampling resistor. Since the A/D input voltage range of the DSP is 0V-3V, an offset voltage of 1.5V needs to be superimposed on the voltage converted by the sampling resistor. The voltage after the current detected by the Hall sensor passes through the sampling resistor is recorded as V_i, denote the final input voltage to the DSP as V_{adcin}, if $R_3 = R_4$, V_c =0.75V, $V_{adcin} = 2 \cdot V_c - V_i$=1.5-$V_i$. Let the stator current of the motor be I and the transmission coefficient of the current sensor to be K_{sen}, so we have $V_i = IR_1 / K_{sen}$ combine the two formulas, we have $V_{adcin} = 1.5 - IR_1 / K_{sen}$.

Through the above analysis, it is found that to complete the detection of the stator current, it is necessary to select an appropriate sampling resistor, and the connection method of the sensor is also particularly important.

3.2 Position and speed detection circuit

The core component of this position and speed detection circuit is the photoelectric encoder ESP3806-001.The photoelectric encoder ESP3806-001 is easy to install, occupies a small space in the system, and has strong anti-interference ability. It has a total of eight effective outputs, namely A, A-, B, B-, Z, Z-, 0V, +5V. When it is working, in order to enhance the stability of the signal and improve the anti-interference ability, the A, B, Z signals are reversed and superimposed on the A, B, Z three-phase. When the motor rotates once, it can output 2048 pulses, of which the Z-phase signal outputs one pulse, which is used to indicate the initial position of the motor. Phase A and phase B differ by90°. By comparing the two phases, which is in front and who is behind, the forward and reverse rotation of the motor can be judged. The position and speed detection circuit is shown in Figure 4.

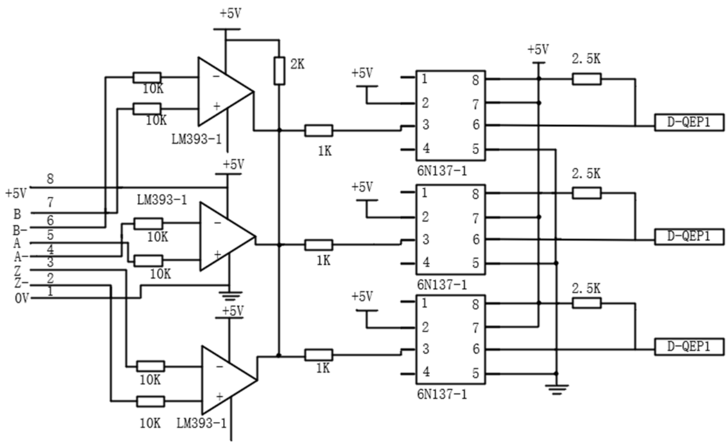

Figure 4. The position and speed detection circuit

4. Software Design and Algorithms

4.1 Speed loop control algorithm

A linear controller consisting of three basic control elements: proportional gain (P), integral gain (I), and differential (D) gain is called a PID controller. The discrete PID control law is

$$u(k) = K_p e(k) + K_i \sum_{j=0}^{k} e(j) + K_d [e(k) - e(k-1)] \tag{4}$$

where u(k) is the output of the controller at time k; K_P, K_i, K_d are the proportional coefficient, integral coefficient and differential coefficient respectively, e(k) is the deviation at time k, and e(k-1) is the deviation at time k-1. Since the differential term reduces the anti-interference ability of the system, this system removes the differential term in the above formula and adopts PI control.

In order to prevent the integral saturation caused by the excessively large digital integral term of the traditional digital PI regulator, the speed loop adopts the PI control algorithm to weaken the integral when it encounters a limit. Its basic idea: When calculating u(k), according to whether the control amount u(k-1) at the previous moment exceeds the limit range, if it exceeds, decide whether to accumulate the integral term according to the deviation, when u(k-1) is positive saturation When, only the negative deviation is accumulated, and when u(k-1) is negatively saturated, only the positive deviation is accumulated. The introduction of the PI control algorithm that weakens the integral when encountering a limit can not only maintain the integral action, but also reduce the overshoot, which greatly improves the control performance. The limit weakened integral PI control algorithm is an improvement to the traditional digital PID control algorithm. This algorithm solves the problems of large overshoot, multiple oscillations, and long overshoot caused by integral saturation in the traditional PID. The follow-up experimental research in this paper has verified the stability of the algorithm. The current loop interrupt service subroutine is shown in Figure 5.

4.2 Interrupt subroutine flow

The interrupt subroutine is mainly used to calculate and process the speed loop and the current loop. The timing interruption period of the speed loop is 1ms, and the timing interruption period of the current loop is 0.1ms. The speed loop interrupt service subroutine is shown in Figure 6.

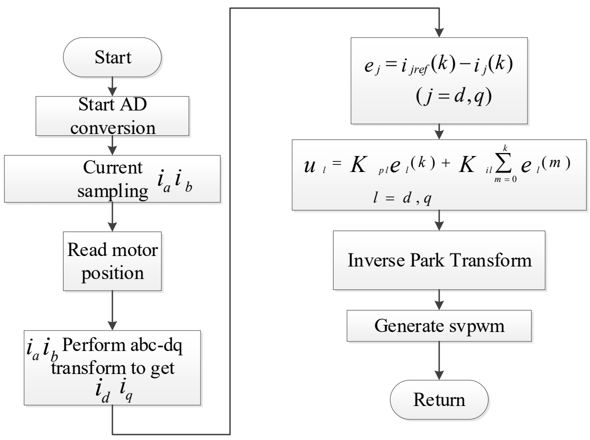

Figure 5. The current loop interrupt service subroutine

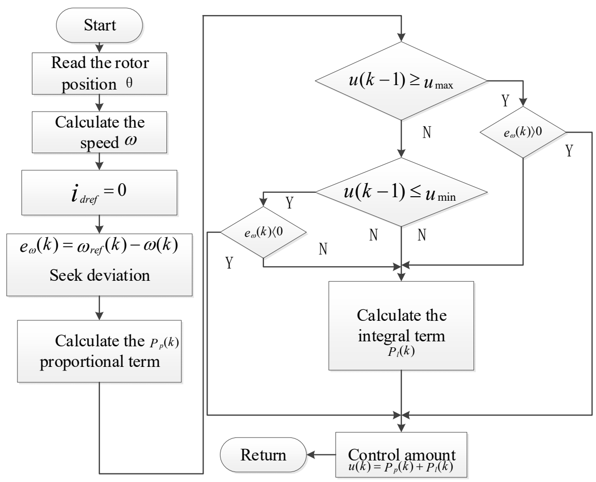

Figure 6. The speed loop interrupt service subroutine

5. Experimental Study

The software and hardware joint debugging of the servo control system of the medical centrifuge designed in this paper is completed and the experiment is carried out. The experimental platform of the system is shown in Figure 7. During the operation of the system, the motor monitoring system is used to observe the system parameters. The operation interface of the motor monitoring system is shown in Figure 8.

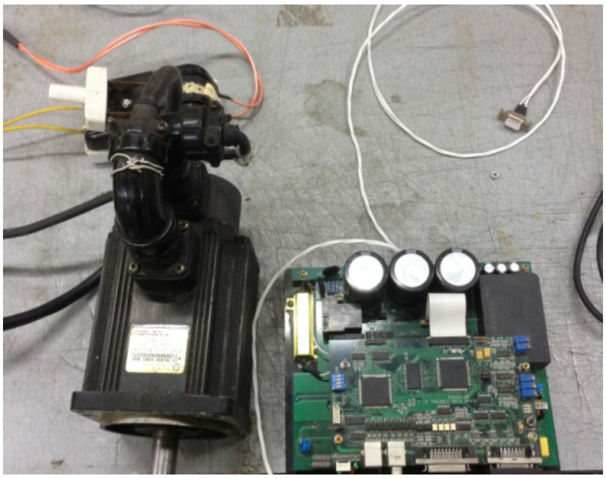

Figure 7. The experimental platform of the system

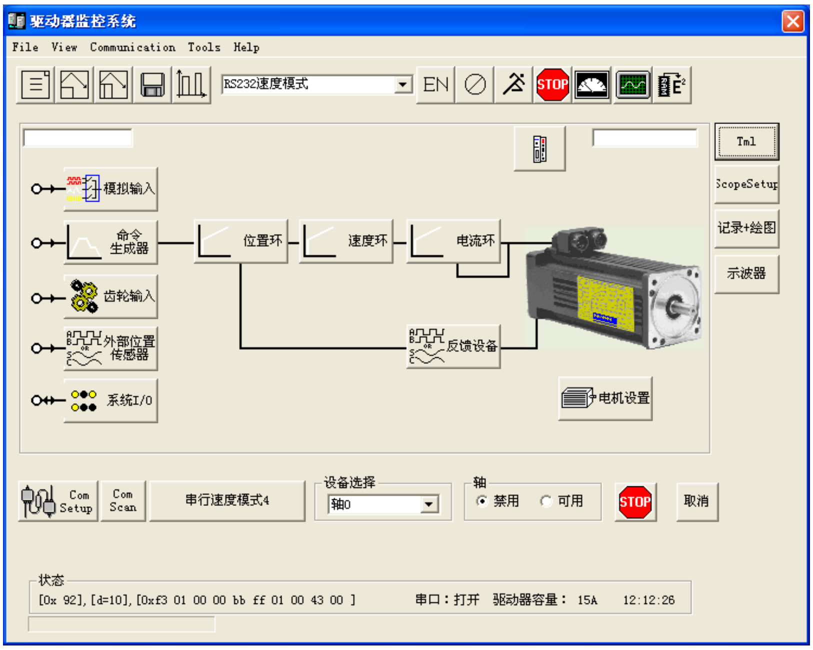

Figure 8. Monitoring system interface

The speed response curve of the motor and the voltage waveforms of phases A, B and C under the operation of 3000rpm are shown in Figure 9. It can be seen from the figure that the motor does not start to work immediately after the start command is given to the whole system. This is because the motor power is relatively large, so the start-up time is slightly longer, which is usually called the dead time. After a short delay, the voltage on the three-phase stator gradually increases, and at the same time, the speed rises rapidly. After a period of time, the speed and the three-phase stator voltage enter a steady state value, and remain at a steady state until the system receives a braking signal Figure 10 shows the speed response curve and the voltage waveforms of A, B and C phases when the motor brakes at 3000rpm. As can be seen from the figure, when the system receives a braking signal, after a short delay, the speed begins to decrease, and the three-phase stator voltage decreases until it decreases to zero.

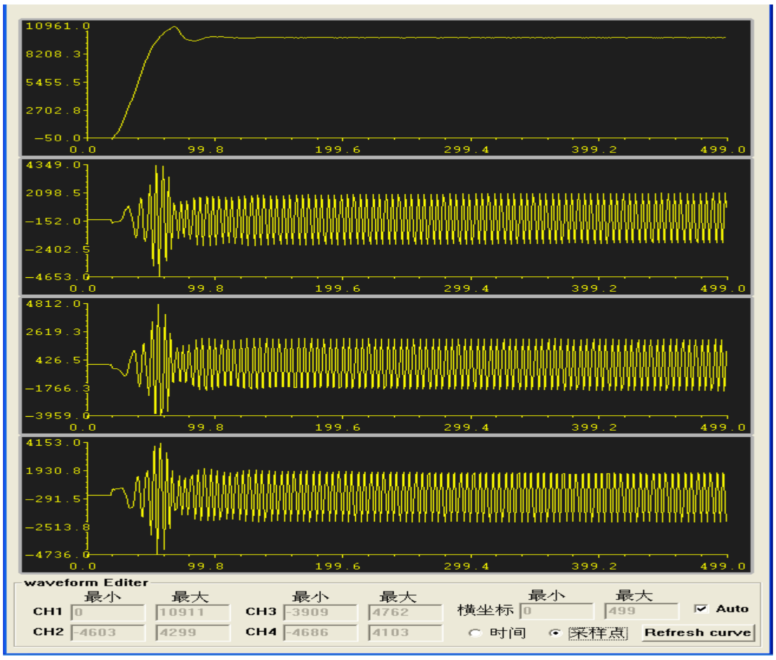

Figure 9.Motor start experiment curve

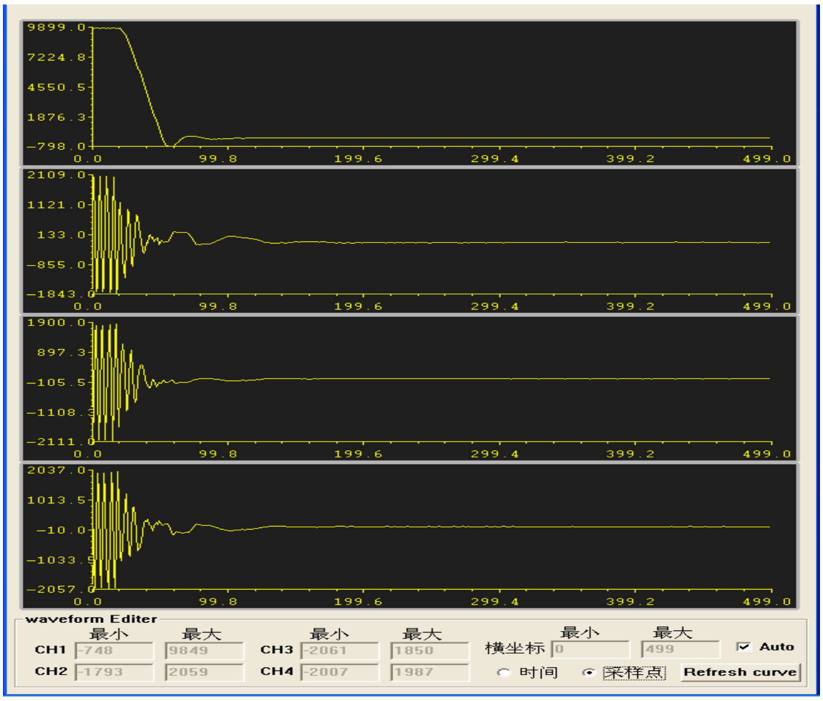

Figure 10.Motor braking experiment curve

6.Conclusion

From the experimental research results, the medical centrifuge servo control system designed in this paper has fast response speed, small overshoot, stable system operation, strong anti-interference ability and strong robustness, and has certain market application prospects. On the basis of this research in the future, the current loop PI controller can be improved, and the combination of fuzzy and fractional PID can be considered to further improve the system control accuracy.

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