Torque Control of DC Torque Motor Based on Expert PID

Xinyu Xu and Dazhai Li*  
Beihang University, Beijing, China  
*Corresponding author email: lidazhai@buaa.edu.cn

Abstract. Torque motor is a kind of special motor with a large number of poles, which can continue to operate at low speed or even when the rotor cannot rotate (that is, the rotor cannot rotate) without causing damage to the motor. In most cases, in order to meet the needs of industrial production and life, we need to torque motor for high-precision torque control. In this paper, we applied the expert PID control method to torque control. MATLAB simulation and experimental results show that the expert PID control has achieved good results in torque control of torque motor.

1. Introduction
The torque motor combines the characteristics of the servo motor and the drive motor, so it has the characteristics of low speed, large torque and simple control, and can work in the blocking state for a long time. DC torque motor is widely used in high precision position and speed control systems such as platform inertial navigation, radar and turntable due to its advantages of speed adjustment function, good mechanical characteristics, fast response speed and high operating accuracy [1].

With the development of torque motor, its control strategy is constantly changing. These control algorithms include PID control, self-adaptive fuzzy [2] control, intelligent control and adaptive control. Intelligent control and vector control are applied to more complex control. The control is precise and efficient, but the cost is high and the system stability is required.

With the purpose of controlling torque motor, this paper organically combines PID control and modern control to construct an expert PID control algorithm that is suitable for torque motor TKM106K control requirements.

2. PID Control
Please follow these instructions as carefully as possible so all articles within a conference have the same style to the title page. This paragraph follows a section title so it should not be indented PID control is an early technology which has many superior performances [3]. In engineering applications, the most widely used regulator control rules are proportional, integral, differential control, referred to as PID control[4]. PID control device has simple structure, reliable performance and easy to operate and is loved by most operators. PID has the dual function of PD and PI, which can improve the control performance of the system comprehensively.

(1):Proportional control, is to control deviation, deviation once produced, the controller that it works that adjusting control output, the accused of quantity changes in the direction of reduce the deviation, deviation reduce speed depends on the proportional coefficient \( K_p \), \( K_p \) reduce the faster, the greater the deviation, but it is easy to cause oscillation, especially in the case of delay link is larger, \( K_p \) decreases, and the possibility of oscillation is reduced, but the slow adjustment. But the simple proportional control has the disadvantage that residuals cannot be eliminated, so integral control is needed.
(2): Integral control: essentially, control the accumulation of deviations until the deviation is zero. The integral control always exerts a force to a given value, which is conducive to the elimination of residuals. The effect is not only related to the size of the deviation, but also to the duration of the deviation. 

(3): Differential control: it can sensitively calculate the variation trend of the error, can play the role of correcting the error before the appearance of the error signal, is conducive to improve the output response speed, reduce the overshoot and increase the stability of the system. However, the differential action is easy to amplify the high-frequency noise and reduce the signal-to-noise ratio of the system, so as to reduce the ability of the system to suppress interference. Therefore, differential control should be used with caution in practice. The PID control principle block diagram is shown in figure 1.

![Figure 1. The PID structure.](image)

Because the computer realizes its control algorithm by software, the analogy regulator must be discretized so that it can only calculate the control quantity according to the deviation value at the sampling time. Therefore, the integral and differential terms cannot be calculated directly and accurately, and can only be approximated by numerical calculation. Discrete difference equations are used instead of continuous differential equations. Digital PID overcome many shortcomings and shortcomings of the modular PID controller, can easily adjust the PID parameters, has a great deal of flexibility and strong applicability.

3. Expert PID Algorithm

Expert control is a branch of intelligent control, which combines the theory and technology of expert system with control theory, method and technology. In the absence of object model, it imitates the experience of domain experts to realize the control of controlled objects. And expert PID algorithm is the combination of expert system and PID algorithm and application optimization.

In general, the expert control consists of knowledge base and reasoning institution, which selects appropriate rules for reasoning output according to a certain strategy and realizes the control. Its basic structure is shown in figure 2.

![Figure 2. Expert control system.](image)

As shown in the figure above, the main factors affecting the control accuracy of expert controller are the accuracy of knowledge base expression and the correctness of inference engine. The completer and
more accurate the knowledge base, the more accurate will be the recognition of the state of the image you are accused of. Of course, the difference in the design of inference engine will also affect the control results.

Expert PID control is based on the controlled object and control law of all kinds of knowledge, and do not need to know the accurate model of the controlled object, the use of expert experience to design PID parameters.

The unit step response error curve of the system is shown in the figure 3.

Let $e(k)$ represents the error value of the discretized current sampling time. $e(k-1)$ and $e(k-2)$ represent the error values of the previous time and the previous two times, respectively. It’s obvious to define the change in error.

$$\Delta e(k) = e(k) - e(k-1)$$
$$\Delta e(k-1) = e(k-1) - e(k-2)$$

According to the error and its variation, the expert PID controller can be designed. The controller can be designed in the following four cases.

(1) $|e(k)| > M_2$: In this case, the absolute value of the error has exceeded the allowable range of the system. Regardless of the variation trend of the error, the maximum(minimum) output according to the output of the controller should be considered to quickly reduce the error. And the control effect is equivalent to the open-loop control. Neither integration nor differentiation should be introduced into the control system.

(2) $e(k) \Delta e(k) > 0$: In this case, the error is changing in the direction of the increase in the absolute value, or the error is a constant value and is not changing. If $|e(k)| > M_2$, the error is large. In order to realize the direction of the error change and make the error change towards the direction of the absolute value decrease, and reduce the absolute value of the error rapidly, the strong control effect is considered. The output of the controller is:

$$u(k) = u(k-1) + \alpha[k_p \Delta e(k) + k_i e(k) + k_d \{e(k) - 2e(k-1) + e(k-2)\}]$$

And if $|e(k) \leq M_2$ this shows that the absolute value of the error itself does not exceed the allowable range. The controller outputs a small control quantity so that the absolute value of the error changes in the direction of decreasing:

$$u(k) = u(k-1) + \beta[k_p \Delta e(k) + k_i e(k) + k_d \{e(k) - 2e(k-1) + e(k-2)\}]$$

(3) $e(k) \Delta e(k) < 0, \Delta e(k) \Delta e(k-1) > 0$ or $e(k) = 0$: In this case, it indicates that the absolute value of the error changes in the direction of decreasing, or has reached an equilibrium state, so the output of the controller should be kept unchanged.

Figure 3. Error curve.
In this case, the absolute value of the error is very small, so the integral step should be introduced to eliminate the steady-state error.

Notation:
- \( u(k) \): Controller output at time \( k \)
- \( u(k - 1) \): Controller output at time \( k - 1 \)
- \( \alpha \): Gain amplification factor, \( \alpha > 1 \)
- \( \beta \): Control coefficient, \( 0 < \beta < 1 \)
- \( M_1, M_2 \): The default margin of error, \( M_1 > M_2 \)
- \( \varepsilon \): The allowed error

As shown in figure 3, the error is going to go in the direction of the decrease in the absolute value in region of I, III, V, VII... And the output of the controller should be unchanged. The error is going to go in the direction of the increase in the absolute value in region of II, IV, VI... At this time, the output of the controller should be changed according to the error size to reduce the error.

4. Mathematical Model of Torque Motor

DC torque motor work must follow the voltage balance equation and torque balance equation\(^5\).

\[
\begin{align*}
U_m - i_m R_m - L_m \frac{d}{dt} i_m - K_e \omega_m &= 0 \\
K_T i_m - J_m \frac{d}{dt} \omega_m - B_m \omega_m - T_L &= 0
\end{align*}
\]

Notation:
- \( U_m \): The motor input voltage
- \( i_m \): The motor current
- \( R_m \): The armature winding resistance
- \( L_m \): The motor inductance
- \( \omega_m \): The motor rotation angular speed
- \( K_e \): The motor anti-electromotive force constant
- \( K_T \): The motor torque coefficient
- \( J_m \): The motor inertia
- \( B_m \): The motor damping coefficient
- \( T_L \): The actual output torque in the system

The parameters of TKM106K are shown in the following table 1:

| Parameter | Value          |
|-----------|----------------|
| \( R_m \) | 4.23 (\(\Omega\)) |
| \( L_m \) | 5 (mH)         |
| \( K_e \) | 4.37 (V·s/rad) |
| \( K_T \) | 5.78 (N·m/A)   |
| \( J_m \) | 0.12 (kg·m\(^2\)) |
| \( B_m \) | 0.232 (m s/rad) |

5. Results and Discussion

In the simulation experiment, it is expected that the overshoot of response speed is small and the response process is as smooth and fast as possible. The expert PID algorithm is used to adjust the PID parameters, and the system step response graph is obtained. The value of parameter \( M_1 \) and \( M_2 \) is calculated according to the extreme value of each region in figure 5. The result after setting is \( M_1 = 8 \) and \( M_2 = 0.6 \).
As shown in Figure 4, compared with PID controller, the control effect of expert PID controller is improved obviously. The control process is smooth, fast and the overshoot is small. Compared with the traditional PID algorithm, the expert PID algorithm reduces the error by about 30% to compare Figure 5 and Figure 6. The experimental results show that the output torque of the torque motor can be controlled quickly and steadily by the expert PID controller.

6. Conclusion
Aiming at the problem of torque motor system, this paper studies the expert PID control method of torque motor output torque. A simple expert PID control method is presented, which has a strong
adaptability to torque motor. Through the simulation experiment, compared with the ordinary PID control method, the proposed expert PID control method is efficient and has good control effect, and is easy to be realized by the lower grade single-chip microcomputer and other devices, which provides an optional control method for the application of torque motor.

References
[1] Mansoor, AZ, Salih, TA, Abdullah, FS 2013 Speed control of separately excited D.C. motor using self-tuned parameters of PID controller. Tikrit Journal of Engineering Sciences 20(1): 1–9.
[2] Kandiban, R, Arulmozhiyal, R 2012 Design of adaptive fuzzy PID controller for speed control of BLDC motor. International Journal of Soft Computing and Engineering 2(1): 386–391.
[3] Fengjiao Z and Hong L 2015 Study on improvement method of PID controller Isa. Trans.22 425
[4] Haiyu Ji, Zhijian Li, Keda Pan, Zongjun Zhang. "Shipborne Radar Servo Control based on Neural Sliding Mode Variable Structure", 2018 IEEE 3rd Advanced Information Technology, Electronic and Automation Control Conference (IAEAC), 2018
[5] Paul Krause, Oleg Wasyuenzuk, Scott, Sudhoff, Steven Pekarek. "Analysis of electric machinery and drive systems(The third edition)."