The Speed-Adjustment System of Brushless DC Motor Based on Grey PID

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Abstract **- As brushless DC motor (BLDCM) is a multi-variable and non-linear system, using conventional PID control can not obtain satisfied control effect. In this paper, a grey PID controller model based on grey theory is presented, and the controller is applied into the BLDCM speed control. In this system, if only use classic PID controller, cannot overcome the shortcomings of parameter uncertain. So we use grey PID controller, divide the motor model into two parts: certainty section and uncertainty section. The uncertainty section can be estimated by grey predictor. The simulation illustrates that excellent flexibility and adaptability as well as high precision and good robustness are obtained by the proposed strategy.**

Index Terms - Brush-less DC motor; Grey theory; Grey PID Control

I. Introduction

As Brushless DC motor (BLDCM) using permanent magnetic rotor, with high energy density and efficiency. Brushless DC motor adopts the electronic reversing device instead mechanical device. It can overcome commutation spark and noise of the dc motor. In the same time, it has the advantage of good reliability and good speed control performance. Because the dynamic characteristics of Brushless DC motor are complex, so it is difficult to reach no static error station by conventional PID control. Model reference adaptive control and variable structure with sliding mode can improve the efficiency of operation performance [1-2].Recently, intelligent control is widely applied in the control system of Brushless DC motor. Neural network can approach to any nonlinear function, and have the ability of self-learning to adapt environment change. The literatures [3-5] propose a speed control method by neural network. It can improve the dynamic performance of system, but control algorithm is complex. Fuzzy control is an intelligent method that can imitate human thinking, and solve control problem of parameter uncertain. The literature [6] proposes adaptive control based on fuzzy genetic algorithm combine fuzzy logic control with genetic algorithm, genetic algorithm can optimize fuzzy control rule and improve the performance of controller.

Grey system theory and fuzzy control are effective methods to deal with uncertainties problem. But fuzzy control cannot solve "small sample, little information" uncertainties problem, and controller parameters lack of self-regulation.Grey control doesn't exist the problem above mentioned, and algorithm is simple. The object of grey system theory study on is uncertainties system, which is partly unknown and partly known. It accord to the known information to generate new information. When brushless dc motor is in operation, parameters change and load disturbance cannot accurately described by mathematical model. So it can be regarded as a grey system.

Grey control strategy is determined by predict the future states, it's a pre-control mode. The literature [7] proposes a grey PID controller, but only gives general algorithm, simulation waveform is not presented. This paper based on grey system theory, establish grey model GM(0, N) for uncertainty section of the system. We can predict the rotor speed of Brushless DC motor by grey model. The simulation result shows that the rotor speed is smooth on the grey PID, and smaller overshot, stronger robustness and rapid adjustment in addition.

II. Grey PID Control Theory

A. Grey System

The system can be divided into black, white and grey system according to its information clear degree. The grey system refers to the system in which some information is clear and some information is unclear. It is different from the white system in which all information is completely clear and different from the black system in which all information is completely unclear. To one system, it's difficult to accurately describe the relationship and structure by mathematics. And when system is in operation, noise is often occurred. Grey theory is an effective method which study on this system. Grey theory regard random variable as grey variable which changes at a certain range, and also regard random process as grey process. Model building of grey system doesn't use primitive date sequence, but uses generating data. Before the model is established, deal with primitive data first to make it present certain regularity. There are several methods to deal with primitive data, such as, accumulated generating · inverse accumulated generating ' average generation. This paper adopts Accumulated Generating Operation (AGO).

Its basic formula can be expressed as

$$x^{(1)}(k) = x^{(r)}(k-1) + x^{(r-1)}(k) \qquad (1)$$

Accumulated generating operation can make any non-negative and pendulum data conversion to non-reducing and increasing data.

B. Grey PID Algorithm

Grey system theory is an effective method to deal with uncertainty section, it needs little information and calculation convenient. This paper adopts grey control method; establish grey model for uncertainty section. This grey model can make grey variable convert to white variable. So it can improve control quality and robustness.

The hypothesis of system uncertainty section accord with matching condition, it can be expressed as $D(x,t)$, $D(x,t)$ includes two parts: one part is in proportion to state x, the other is not related to state. The formula can be described as follows:

$$D(x,t) = V_1 x_1 + V_2 x_2 + \cdots V_n x_n + f(t) \tag{2}$$

where: $V = (V_1 V_2 \cdots V_n)$, $x^T = (x_1 x_2 \cdots x_n)$.

Assume V_i (i =1, 2…n) and $f(t)$ are slow time-variable, so V_i and $f(t)$ can be regarded as constant. If we can obtain the values of V_i and $f(t)$,we get the relationship of $D(x, t)$ and $x_1, x_2, \ldots, x_n$. Then we can estimate the uncertainty section $D(x, t)$, which corresponds to the state x.

Set $x^{(0)}$ be primitive discrete time function.

$$x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \cdots x^{(0)}(n)) \tag{3}$$

If

$$x^{(1)}(k) = \sum_{m=1} x^{(0)}(m) \tag{4}$$

Then called $x^{(1)}(k)$ is accumulated generating operation of $x^{(0)}(k)$, it can be expressed as follows:

$$\text{AGO}\, x^{(0)} = x^{(1)} \tag{5}$$

As results of accumulated generating operation, we can establish grey model GM (0, N) for uncertainty section $D(x, t)$, and the discrete time function is consequently as following:

$$\begin{cases} D^{(0)} = (D(1)D(2)\cdots D(N)) \\ f^{(0)} = (D(1)f(2)\cdots f(N)) \\ x^{(0)} = (x_1(1)x_1(2)\cdots x_1(N)) \\ x_2^{(0)} = (x_2(1)x_2(2)\cdots x_2(N)) \\ \vdots \\ x_n^{(0)} = (x_n(1)x_n(2)\cdots x_n(N)) \end{cases} \tag{6}$$

Under the assumption of $D^{(1)}$, $f^{(1)}$, $x_i^{(1)}$ (i=1,2,Ξn) is accumulated generating Operation sequence of $D^{(0)}$, $f^{(0)}$, $x_i^{(0)}$ (i=1,2,Ξn). The grey model of uncertainty section $D(x, t)$ is expressed as follows:

$$D^{(1)}(x,t) = V_1 x_1^{(1)} + V_2 x_2^{(1)} + \cdots V_n x_n^{(1)} + f^{(1)} \tag{7}$$

For slow time-varying part, it can be expressed as follows:

$$\begin{cases} f^{(1)}(1) = f(1) = f \\ f^{(1)}(2) = 2f(1) = 2f \\ f^{(1)}(N) = Nf \end{cases} \tag{8}$$

Let $\hat{V}^T$ be the estimation of V

$$\hat{V}^T = (\hat{V}_1 \hat{V}_2 \cdots \hat{V}_n \hat{f})^T \tag{9}$$

$$B = \begin{bmatrix} x_1^{(1)}(2) & \cdots & x_n^{(1)}(2) & 1 \\ x_1^{(1)}(3) & & x_n^{(1)}(3) & 2 \\ \vdots & & \vdots & \vdots \\ x_1^{(1)}(N) & & x_n^{(1)}(N) & N-1 \end{bmatrix} \tag{10}$$

According to least square method, if $(B^T B)$ is reversible, then

$$\hat{V}^T = (B^T B)^{-1} D_N^{(1)} \tag{11}$$

$$D_N^{(1)} = (D^{(1)}(1) D^{(1)}(2) \cdots D^{(1)}(3))^T \tag{12}$$

At last, Generating data convert into primitive data, we can obtain the estimation model:

$$\hat{D}(k) = \hat{V}_1 x_1(k) + \hat{V}_2 x_2(k) + \cdots + \hat{V}_n x_n(k) + \hat{f} \tag{13}$$

III. The Design Of Loop-Closed Speed Adjusment System Based On Grey Pid

A. The MathematicalMmodel of Brushless DC Motor

The hypothesis of three-phase symmetry voltage of brushless dc motor, in the same time, armature reaction is neglect.

Voltage equation can be expressed as follows:

$$u = L\frac{\mathrm{d}i}{\mathrm{d}t} + Ri + e \tag{14}$$

Motion equation can be expressed as follows:

$$J_m \frac{\mathrm{d}\omega}{\mathrm{d}t} = T_m - T_L - b_m \omega \tag{15}$$

Back EMF equation can be expressed as follows:

$$e = K_e \omega \tag{16}$$

u is phase voltage of brushless dc motor, L is inductance of stator winding, e is back EMF. J_m is moment of inertia, T_m is electromagnetic torque, T_L is load torque, b_m is damping coefficient, K_e is back EMF coefficient, K_t is electric torque coefficient.

The above three equation can be converted into as follows:

$$\frac{\mathrm{d}i}{\mathrm{d}t} = -\frac{R}{L}i - \frac{K_e}{L} + \frac{1}{L}u \tag{17}$$

$$\frac{d\omega}{dt} = -\frac{b_m}{J_m}\omega + K_t i \qquad (18)$$

We can obtain the state equation of brushless dc motor.

$$\begin{bmatrix} \dot{X}_1 \\ \dot{X}_2 \end{bmatrix} = \begin{bmatrix} -\frac{b_m}{J_m} & K_t \\ -\frac{k_e}{L} & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{L} \end{bmatrix} u \qquad (19)$$

where: $X_1 = \omega$, $X_2 = i$.

According to grey control theory, we can divide the brushless dc motor into two parts: one part is the certainty section, it can be expressed by state equation. The other is the uncertainty section, it consists of parameter uncertainty and disturbance. it can be described as follows:

$$D(x,t) = V_1 x_1 + V_2 x_2 + \cdots + V_n x_n = Vx + f(t) \qquad (20)$$

B. Controller Design

This system adopts double closed-loop drive. The speed control in external loop use grey PID control, the current control in internal loop use conventional PID control.

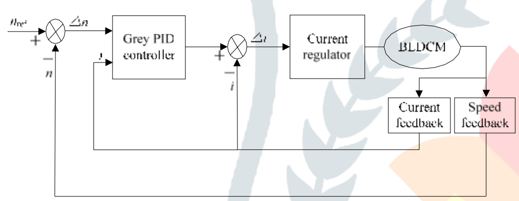

Fig. 1 structure of BLDCM based on grey PID

Fig. 1 presents the structure of double closed-loop speed adjustment system of BLDCM based on grey PID. When motor starting, conventional PID control is adopted, we estimate the parameters *V* of uncertainty section by grey predictor. Then compensated energy will be in action.

IV. RELSULTS AND ANALYSIS

Simulation runs on MATLAB platform, and the parameters of the motor module are as follows:

Rated voltage: 500V; rated torque: 3N·m, rated speed: 3000r/min, effectiveinductance: 8.5mH, phase resistance: 2.875ö, friction coefficient: 1×10^{-3}N·m·s, rotational inertia0.8×10^{-3} kg·m^2, pairs of poles: 4.

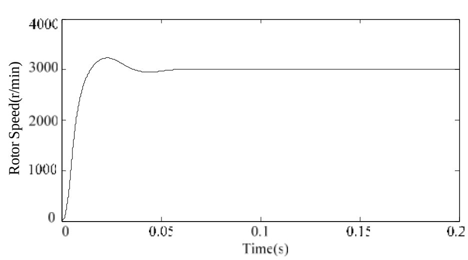

Fig. 2 Speed response curve on conventional PID control

Fig. 2 is the speed response curve on conventional PID control. It can be observed that the speed of motor comes to the reference of 3000r/min after about 50ms. It hits the max value of 3100r/min before being stable, and the overshot is beyond 3%.

Fig. 3 is the speed response curve on grey PID control. The extremely short rising time is shown in the fig, without even overshot. By comparison, the following conclusion can be drawn: compared with conventional PID control, the grey PID control perform much faster rotor speed response with no overshot.

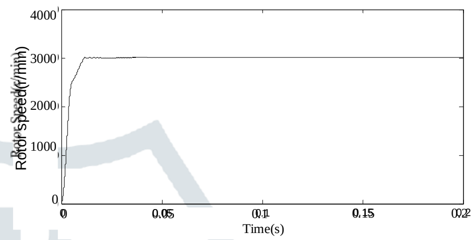

Fig. 3 Speed response curve on grey PID control

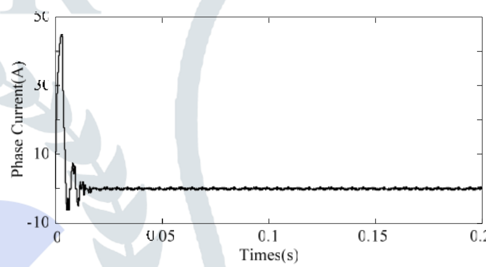

Fig. 4 Phase current curve on grey PID control

Fig. 4 is the waveform of phase current on grey PID control. At the startup, phase current rises up and falls down sharply. The current is so large that the rotor could be motivated to the reference speed within very short time of about 10ms.

Fig. 5 is the electromagnetic torque curve on conventional PID control. Fig 6 is the electromagnetic torque curve on grey PID control.

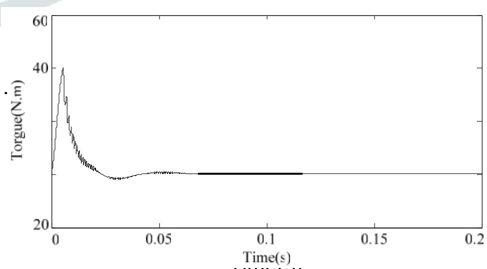

Fig.5 Electromagnetic torque curve on conventional PID control

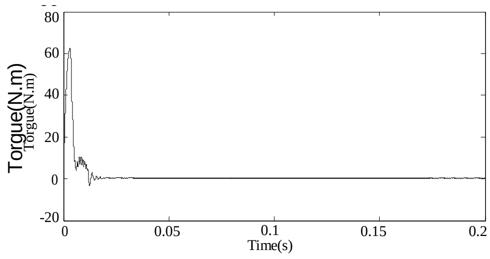

Fig 6 Electromagnetic torque curve on grey PID control

Through comparison, we know torque response faster, and come to stability in a shorter time on grey PID control.

Fig. 7 and Fig. 8 are speed curves under load disturbance in 0.1 seconds, respectively on conventional PID and Grey PID control. Fig8 is the corresponding current waveform of Grey control.

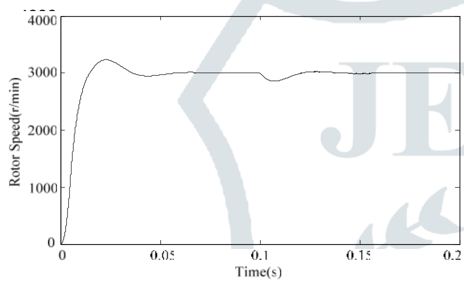

Fig.7 Speed response curve under the condition of load disturbance in 0.1 seconds, adopt conventional PID control

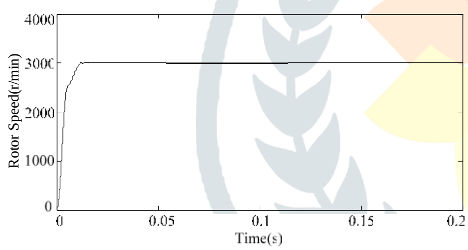

Fig 8 Speed response curve of grey PID control under load disturbance in 0.1 seconds

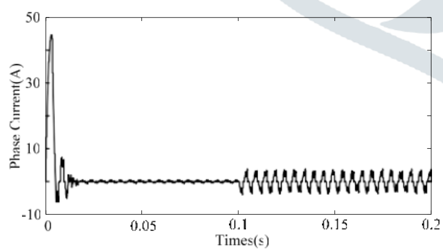

Fig 9 Speed response curve of grey PID control under load disturbance in 0.1 seconds

Above all, both in tracing reference and rejecting load disturbance, Grey PID control is superior to conventional PID control. The reason should be owed to its strong predication ability. By sampling a quantity of rotor speed data during initial period of motor operation, the Grey control algorithm can properly predicate status of whole system by AGO because it eliminates most random factor.

V. Conclusion

Grey PID control presented in this paper doesn't need much input information, in the same time the algorithm is simple and effective. A new speed-adjustment system of brushless DC motor based on grey PID controller is designed in this paper. The simulation results show that the system has well dynamic and static performance its rotational speed variation is smoothing, and oscillation time is short. It also restraints the speed fluctuation caused by load disturbance effectively.

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