

Based on Brushless DC Motor of Fuzzy and PID Control System

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Abstract. The brushless DC motor (BLDCM) is a multi-variable and non-linear system. PID control and Fuzzy control have been used in the field of the BLDCM control. However, the design of the reference model is fix with structure, the tradition PID doesn't have from whole settle with artificial with experience modification PID parameter, PID control of the fuzzy controller are not satisfied. In this paper, PID fuzzy control system based on is presented so the controller is applied into the BLDCM control. In Matlab/Simulink, the simulation result showed that the correction by using fuzzy controller, to BLDCM system for real-time control, system stability improvement at the same time, response speed, feed system and raises the comprehensive performance. The validity of the model was verified and thus a new way was provided for further research of the motor.

1. Introduction

Brushless motor has many advantages such as small volume, light weight, convenient maintenance and easy control. It has been widely applied in aerospace, aviation, medical devices, instrumentation, household appliances, chemical industry and other fields, [1]. Many adaptive control algorithms have been widely applied in the control of BLDCM, but these algorithms are mainly for linear models, and are not applicable to control of nonlinear models. Fuzzy control is based on fuzzy set theory and fuzzy logic reasoning. Its advantage is to achieve intelligent control of objects by logical operation and logical reasoning, thus making up for the shortcomings of traditional control, [2]. The general PID control does not have self-tuning. It can only be determined by experienced technicians according to the step response curve of the controlled object, and the parameters of PID control object can be determined by a lot of experimental artificial methods. The above mentioned shortcomings can be overcome by self-tuning PID control. Fuzzy control is essentially a nonlinear control. The control object does not depend on the exact mathematical model and mathematical expression. It combines PID control with fuzzy control. It is an ideal control mode. In the aspect of fuzzy control, a lot of research work has been done about fuzzy control rules. Different fuzzy controllers are set up, such as fuzzy controller with self-adjusting factor, fuzzy self-tuning PID controller, adaptive controller and so on. [3-5] the research on self-tuning PID

control mainly focuses on the high precision, strong robustness and self-tuning of PID control, [6-8]. Document [9-46] proposes a method of designing model reference adaptive control system based on fuzzy set theory, but the structure is not suitable for online adjustment control. How to use self-tuning PID fuzzy control is a difficult and key problem of BLDCM control. However, there are many factors such as nonlinear and parameter changes in BLDCM's control system, which affect the control performance very much. It is impossible to set up the exact mathematical model accurately, while fuzzy PID control can meet the above requirements.

Based on the traditional PID control structure based on fuzzy PID control algorithm in combination with Matlab, change the PID parameters in a dynamic process with fuzzy reasoning method, and the fuzzy PID control system for a variety of complex visually constructed in the Simulink environment, observe the control effect, and provides a theoretical reference for the design and debugging of the actual control system. A BLDCM fuzzy PID control method is designed to control brushless motor. This model can improve system stability, zero overshoot and fast response speed, and improve the comprehensive performance of the system.

2. BLDCM model description

The voltage balance equation [10] of the BLDCM three-phase winding can be expressed as

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} + \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

In the form:

u_a, u_b, u_c - phase voltage of stator windings

i_a, i_b, i_c - phase current of stator winding

e_a, e_b, e_c - phase electromotive force of stator winding

L - Self-inductance of each phase winding

M - Mutual inductance between each phase winding

Electronic torque produced by stator winding

$$T_e = \frac{1}{\omega} (e_a i_a + e_b i_b + e_c i_c) \quad (2)$$

The formula (2) can be obtained, the BLDCM electromagnetic torque formula, the electromagnetic torque and the current amplitude are controllable torque, and the difference of 120° electric angle is required for the square wave current, and the motion equation is obtained.

$$J \frac{d\omega}{dt} = T_e - T_l - B\omega \quad (3)$$

In the form:

T_e - Electromagnetic torque

T_l - load torque

B - damping coefficient

ω - the moment of inertia of motor

J - the moment of inertia of motor

By the formula (1) ~ (3) shows that the existing speed signal of the system (nonlinear volume) and current signal (non exact amount) control BLDCM, the control structure is shown in Figure 1.

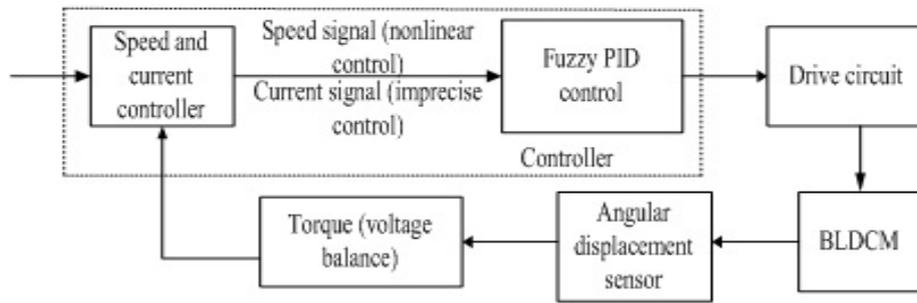


Figure 1. System structure with BLDCM of fuzzy and PID control

Aiming at the BLDCM system controlled by nonlinear quantity and inexact quantity, a fuzzy PID control BLDCM system is presented in this paper. BLDCM control is realized by fuzzy PID controller, and the controller performance is improved by adjusting the controller parameters online.

3. Design of fuzzy PID control

3.1. Fuzzy PID control model

The fuzzy PID controller takes the error E of the controlled object's feedback value and the target value as the input and the error change rate EC as input, and adjusts the parameters K_p , K_i and K_d of PID with the method of fuzzy reasoning. Using the fuzzy rules to modify the PID parameters online, the fuzzy PID controller is formed. The structure of the control system is shown in Figure 2.

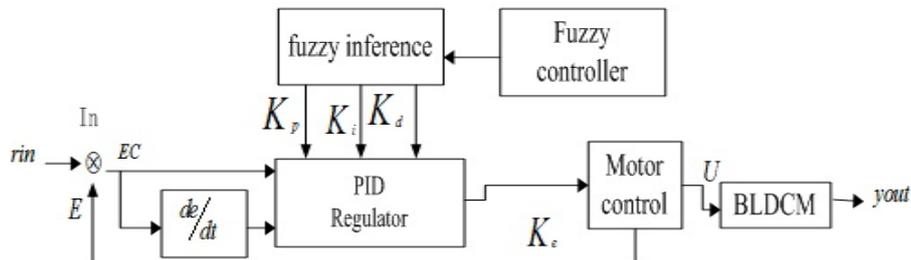


Figure 2. Block diagram of fuzzy and PID control

Fuzzy PID control is to find out the relationship between fuzzy PID and three parameters E and EC , through continuous detection of E and EC in the operation, according to the principle of fuzzy control can be adjusted on line 3 parameters, E and EC are to meet the different requirements for different control parameters, the object has a good dynamic and static performance. The algorithm for the PID controller used by the system is

$$u(k) = K_p E(k) + K_i \sum_{j=0}^k E(j) + K_d EC(k) \quad (4)$$

In the formula, K_p , K_i and K_d represent the ratio coefficient, the integral coefficient and the differential coefficient respectively.

3.2. Design of fuzzy PID control

1) Determine the input and output of the controller

The input error E and error change EC of the fuzzy controller are EC . In order to calculate the input error of the sampling value at the time of K , the error of the input error E is $E(k)$, and the EC error is $EC(k)$. It is defined as

$$\begin{cases} E(k) = y(k) - y_m(k) \\ EC(k) = E(k) - E(k-1) \end{cases} \quad (5)$$

2) Fuzzy control rules

The fuzzy controller selects two dimensional input and three dimensional output, and its fuzzy universe is divided into 7 linguistic variables, such as large NB = " Negative Small ", NM = " Negative Small ", NS = " Negative Large ", ZO = " Zero ", PS = " Negative Small ", PM = "median", PB = "Postion longer". The analysis method can be referred to [11].

If E is A_i and EC is B_j , then ΔK_p is C_{ij} , ΔK_i is D_{ij} , ΔK_d is E_{ij}
 $i = 1, 2, 3, \dots, m, j = 1, 2, 3, \dots, n$

Among them, $A_i, B_j, C_{ij}, D_{ij}, E_{ij}$ is a fuzzy set on the domain of $\Delta K_p, \Delta K_i$ and ΔK_d which define error, error change rate and PID parameter respectively.

In this paper, in consultation with senior expert fuzzy control and engineering and technical personnel of actual debugging and verification on the basis of revising for the establishment of electric hydraulic servo position control system is mainly aimed at the fuzzy rule table $\Delta K_p, \Delta K_i$ and ΔK_d three parameter control table, table (1) ~ (3) shown.

Table 1. Rule-base of ΔK_p fuzzy controller

EC	E						
	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PB	PB	PM	ZO	ZO
NM	PB	PB	PB	PB	PM	ZO	ZO
NS	PM	PM	PM	PM	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NM	NM	NM	NM
PM	ZO	ZO	NM	NB	NB	NB	NB
PB	ZO	ZO	NM	NB	NB	NB	NB

Table 2. Rule-base of ΔK_i fuzzy controller

EC	E						
	NB	NM	NS	ZO	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NM	NM	NM	NS	ZO
NS	ZO	NS	NM	NM	NS	NS	ZO
ZO	ZO	NS	NS	NS	NS	NS	ZO
PS	ZO						
PM	PB	ZO	PS	PS	PS	PS	PB
PB	PB	ZO	NM	NB	PS	PS	PB

The variation range of the system error E and the error change rate EC is defined as the domain on the fuzzy set.

3.3. Fuzzy reasoning

The general $A_i \times B_j$ to the K_{pij} 's Fuzzy R relationship is described, as an example of K_p , assuming $K_p = K_{pij}$, According to the Fuzzy mathematical theory, the fuzzy inference rules are calculated

According to the Fuzzy mathematical theory, the fuzzy inference rules are calculated

$$(K_p) = \vee \left((E, EC, K_p) \wedge (E) \wedge (EC) \right) \tag{6}$$

K_p Parameter adjustment calculation formula

$$K_p = K_{p0} + \{E, EC\} K_p = K_{p0} + K_{up} \times \Delta K_p$$

Methods according to the literature [12] with fuzzy reasoning for K_p , K_p is the parameters of PID controller, K_{p0} is the initial parameters of K_p , ΔK_p and K_{up} respectively adjust the amount and proportion factor, through the on-line calculated E , EC , to complete the adjustment of K_p controller parameters, such as type (6) ~ (7) shown). In the same way, we can find K_i , K_d as shown in the following formula (8).

$$\begin{cases} K_p = K_{p0} + K_{up} \times \Delta K_p \\ K_i = K_{i0} + K_{ui} \times \Delta K_i \\ K_d = K_{d0} + K_{ud} \times \Delta K_d \end{cases} \tag{7}$$

4. Simulation and analysis of fuzzy PID control system

On the basis of the above model, the simulation experiment of the motor running state is carried out. The parameters of BLDCM are set as shown in Table 4. A simulation of a fuzzy PID control in Matlab and a comparison of the original curve in Simulink is shown in Figure 4.

On the BLCD experimental platform, we use the Simulink and Fuzzy toolbox in Matlab environment to bu

Table 3. Motor simulation parameters

Simulation parameters	parameter values	Unit
Polar logarithm	2	
Stator winding resistance	0.435	Ω
Stator winding inductance	0.004	mH
Rotor winding resistance	0.816	Ω
Leakage inductance of rotor winding	0.004	mH
Rotor winding acceleration	0.19	Kg.m ²
Inverter DC power supply	510	V
torque	0.87	N.S



Figure 3. Control platform

On the basis of the above model, the simulation experiment of the motor running state is carried out. The parameters of BLDCM are set as shown in Table 4. A simulation of a fuzzy PID control in Matlab and a comparison of the original curve in Simulink is shown in Figure 4.

Table 4. BLDCM simulation parameters

Simulation parameters	Parameter values	unit
Polar logarithm	Three phase 4 pole	
Moment of inertia	0.0015	kg·m ²
Rated speed	820	r/min
Rated rotor distance	10	Nm
Winding resistance	3.4	Ω
Self-feeling	0.00389	H
Anti-electric type	0.5187	V/r.min

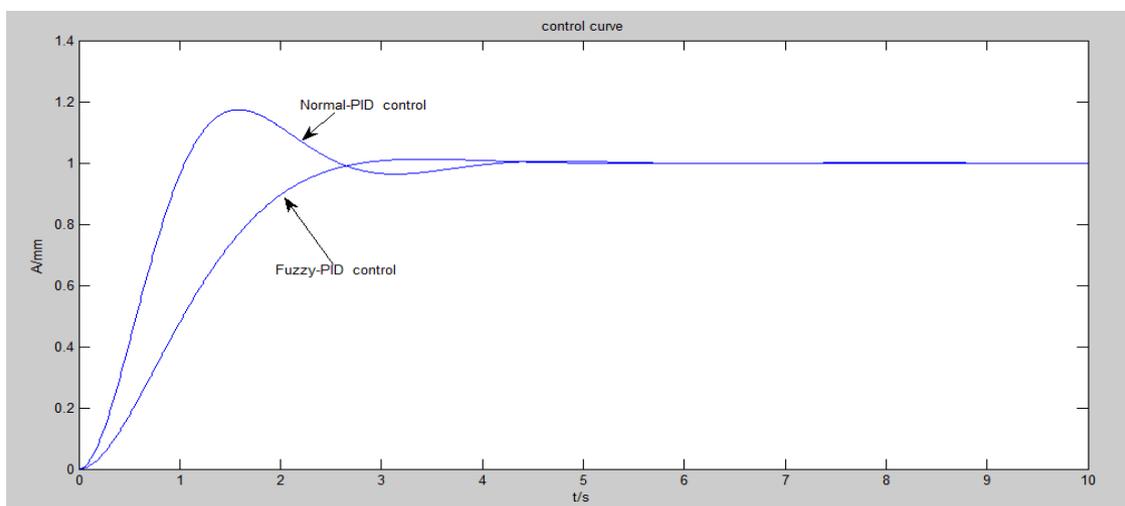


Figure 4. Self-turning and fuzzy control of k_i charts

We can see from Figure 4, the system uses fuzzy PID control curve and original curve compared to the curve transition time is more than 30s, the overshoot is greater than 30%, compared with the electric control system of precision control, quality control is not satisfactory, the fuzzy PID control parameters need to be applied, to reduce debugging time, reduce the overshoot is the system is more stable and accurate transition. A simulation comparison diagram is shown when the parameters of the controlled object occur at 30%, as shown in Figure 5.

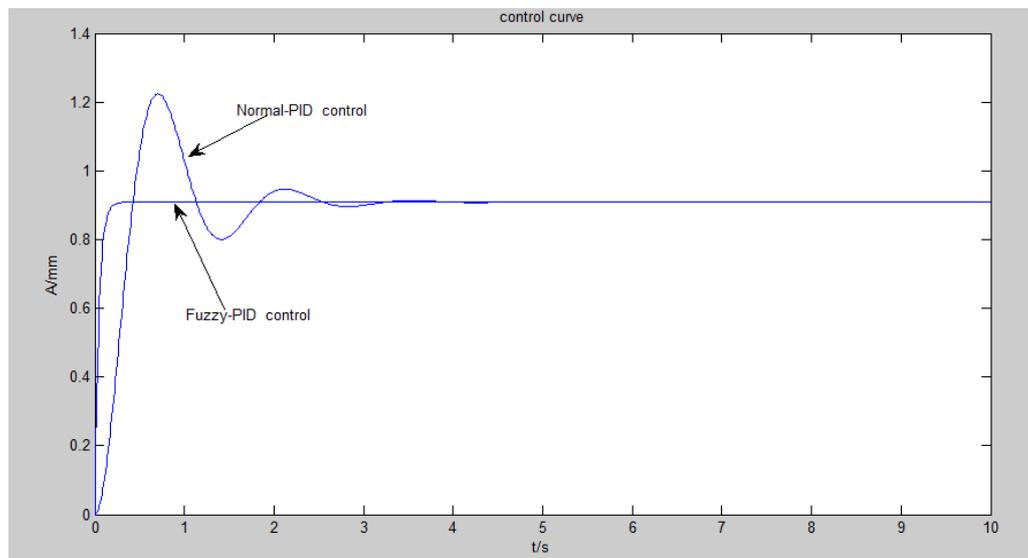


Figure 5. Fuzzy PID control charts

Through the simulation analysis of fuzzy PID control, it is found that the overshoot of the system output is smaller than that of the general PID control, and the adjustment time is faster. The performance of the system is improved to meet the requirements of high precision and stable performance control. It can enhance the performance of the system, reduce the time of the system to modify and debug repeatedly, and realize the purpose of the efficient development and utilization of the system.

5. Summary

The fuzzy PID control model of brushless motor is established in this paper, and Matlab simulation is used. The simulation results show that:

1) Using fuzzy control, the curve rises gently before the system reaches stability and has no concussion, and the requirement of the system's overshoot is zero. The model has strong adaptability and can be easily modified for functional modules. It provides a new method for the future analysis of this kind of motor and its control strategy, and has a strong reference for BLDCM research.

2) Fuzzy PID control is a simple design and control rule optimization control method. It has good dynamic performance and anti-interference ability. It is suitable for nonlinear and PID parameter adjustable control system, which is highly adaptive. It is generally better than the conventional PID control.

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