The Speed Control of Brushless DC Motor Based on Fuzzy Genetic Algorithm

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Abstract: In this paper, the speed control of brushless DC motor based on fuzzy Genetic Algorithm is discussed. The paper uses Genetic Algorithm to optimize the control rules, membership function and scaling factors of fuzzy control system. At last, the simulation of optimized fuzzy control system is carried out. The result of simulation indicated that the optimized control system could give a good control performance.

Key Words: BLDCM, Fuzzy control, Genetic Algorithm, MATLAB

1 INTRODUCTION

Brushless DC motor (BLDCM) has a series of advantages, such as simple structure, high reliability, convenient maintenance, high efficiency, no excitation loss and so on. So far, BLDCM has been widely used in aerospace, CNC machine tools, electrical equipment, mining, chemical and other fields. Therefore, well-designed high-performance BLDCM controller has important practical significance and practical value.

The BLDCM is a multi-variable, nonlinear, strong coupling and time-varying system, though the traditional PID controller is commonly used, it has failed to perform satisfactorily under non-liner conditions and parameter variations. In recent years some efforts have been made on the use of fuzzy logic controller (FLC). In a FLC, it does not need a detailed mathematical model; it can be applied to any complex and no-liner system. However, the membership functions and rules dependent on artificial. To overcome the above difficulties, this paper presents a fuzzy control based on Genetic Algorithm. The results of simulation show that the speed control of BLDCM system has good control effects.

2 THE MATHEMATICAL MODEL OF BLDCM

The induction electromotive force of BLDCM is a trapezoidal wave which contained a larger number of harmonics，so it is very difficult to precisely analysis the operation characteristics of BLDCM. Therefore，this paper makes the following assumptions:

(1)Windings of three-phase are symmetrical;

(2) The air-gap magnetic induction intensity in a trapezoidal (approximate square wave) distribution;

(3) Ignoring the influence of stator slot;

(4) Ignoring the influence of armature reaction on air gap flux;

(5) Ignoring the hysteresis and eddy current loss

Three-phase windings voltage balance equation of BLDCM:

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

In the equation, u_a , u_b , u_c are phase voltage of three-phase stator winding(V); e_a , e_b , e_c are Anti-electromotive force of three-phase stator winding(V); i_a , i_b , i_c are phase current of three-phase stator winding(A); r is phase resistance of three-phase stator winding(Ω); L is inductance of three-phase stator winding(H); M is mutual inductance of three-phase stator winding(H);P is differential operator(d/dt).

When phase AB are conducting and C is hanging， $i_c = 0$ ， under the condition of $i_a = -i_b = i_d$, we could get voltage balance equation:

$$u_a = e_a + i_a r + (L - M)\frac{di_a}{dt}$$

$$u_b = e_b + i_b r + (L - M)\frac{di_b}{dt}$$

$$u_d = U - 2 \cdot \Delta U_T = E + 2 i_d r + 2 \cdot (L - M)\frac{di_d}{dt} \quad (2)$$

In the equation, $u_d = u_a - u_b$ is the output voltage of the inverter, $E = e_a - e_b$ is Anti-electromotive force, U is power voltage, ΔU_T is voltage dropping of power tube.

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The equation of anti-electromotive force:

$$E = C_n \cdot n \tag{3}$$

The equation of electromagnetic torque:

$$T_m = C_m \cdot i \tag{4}$$

The equation of motion

$$T_e = J\frac{d\omega_m}{dt} + B\omega_m + T_L \tag{5}$$

C_n is coefficient of anti-electromotive force， C_m is coefficient of torque.

Transfer function:

$$\frac{\omega_m(s)}{u_d(s)} = \frac{C_m}{2\cdot J\cdot(L-M)s^2 + [2\cdot J\cdot r + 2\cdot B(L-M)]s + (2\cdot Br + C_m C_n)} \quad (T_L = 0) \tag{6}$$

3 THE DESIGN OF FUZZY CONTROLLER BASED ON GENETIC ALGORITHM

3.1 Fuzzy controller

This paper mainly discusses the speed control of BLDCM; the structure is shown in Fig.1.

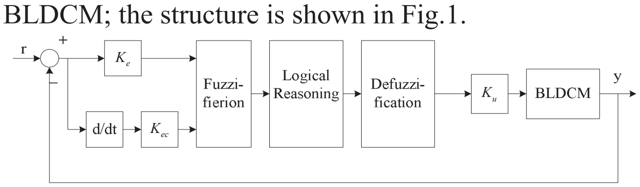

Fig.1 Fuzzy control system

Seven triangular fuzzy sets have been used to partition the input and output spaces: negative large(NB), negative medium(NM), negative small(NS), zero(ZO), positive small(PS),positive medium(PM), positive large(PB). Fuzzy domain is [- 3,3], fuzzy domain of error, error variation, output are respectively[-3,3],[3,3],[0,6],the actual domain respectively are $[-x_e, x_e]$,$[-x_c, x_c]$,$[0, y_u]$, the quantification factor $K_e = 3/x_e, K_{ec} = 3/x_{ec}, K_u = y_u/6$.

Fuzzy reasoning using the Mandam inference method of max-min synthesis. The centre of area method is used for the defuzzification. Fuzzy control rules are shown in Table 1

Table 1 Fuzzy control rules

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

3.2 Fuzzy controller based on Genetic Algorithm

Genetic Algorithm is based on the theory of nature selection and work on generating a set of random solutions and making them compete in arena where only the fittest survive. Each solution in the set is equivalent to a chromosome. Flowchart are shown in Fig.2

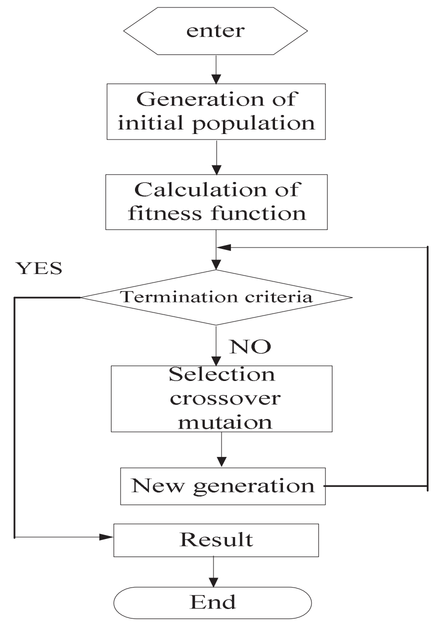

Fig.2 Flowchart of Genetic Algorithm

The genetic algorithm coding use integer and float hybrid coding. The parameters to be optimized including: 49 control rules, NB,NM,NS,ZO,PS,PM,PB respectively by 1~7.Triangular membership function, its shape can be determined by 3 parameters shown in Fig.3, factors K_e, K_{ec}, K_u ,so this article needs to optimize 61 parameters. The algorithm then uses three basic genetic operators: reproduce, cross over, mutation.

The optimal objective function：

$$J = \int_0^{\infty}[\omega_1|e(t)| + \omega_2 u^2(t) + \omega_4 ey(t)]dt + \omega_3 \cdot t_u \tag{7}$$

$[\omega_1, \omega_2, \omega_3, \omega_4]$=[0.99,0.001,2.0,20]

The selection fitness function：

$$F = 1/(J + 10^{-10}) \tag{8}$$

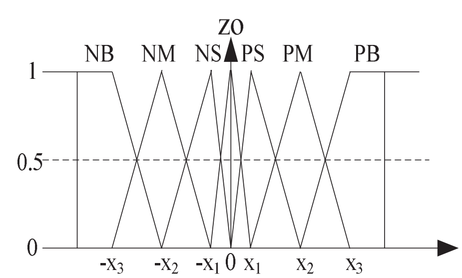

Fig.3 Schematic diagram of fuzzy partition

Probability of population crossover:

$$P_c = \begin{cases} K_1(f_{\max} - f_c)/(f_{\max} - f_{avg}) & f_c \geq f_{avg} \\ K_1 & f_c < f_{avg} \end{cases} \quad (9)$$

Probability of population mutation:

$$P_m = \begin{cases} K_2(f_{\max} - f_m)/(f_{\max} - f_{avg}) & f_m \geq f_{avg} \\ K_2 & f_m < f_{avg} \end{cases} \quad (10)$$

3.3 The optimized results

The optimized results:

{2 3 3 1 3 3 4 1 2 1 1 1 3 3 2 1 3 3 3 4 4 3 3 6 5 6 5 3 3 2 3 6 7 5 5 6 4 7 5 4 6 7 7 4 7 7 4 6 6 0.9657 1.9194 2.6785 0.5925 1.4115 2.9574 3.7624 4.6700 5.0337 2.9591 0.011 9.6762 0.1865}

Decoded fuzzy control rules are shown in Table 2.

Table 2 Decoded fuzzy control rules

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

Optimized membership function of error e is shown in Fig.4.

Optimized membership function of error variation e_c is shown in Fig.5.

Optimized membership function of output u is shown in Fig.6.

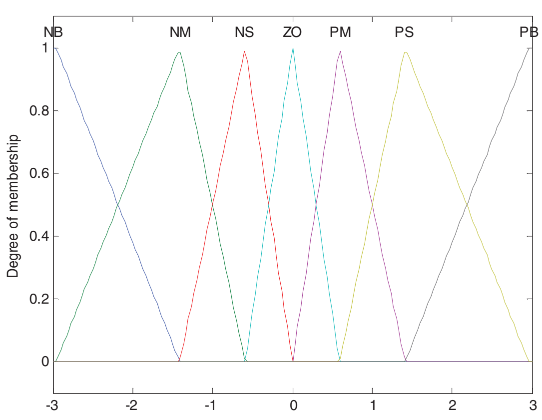

Fig.4 Optimized membership function of error e

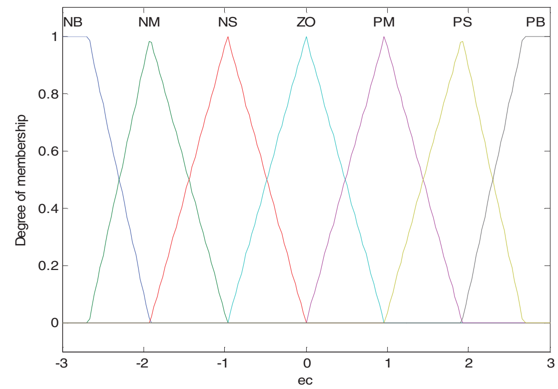

Fig.5 Optimized membership function of error variation e_c

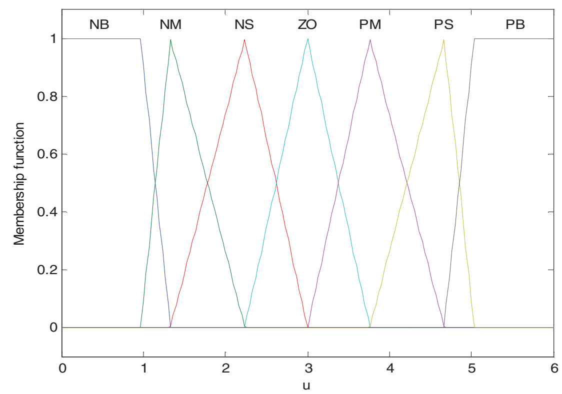

Fig.6 Optimized membership function of output u

Optimized quantization factor::

$K_e = 2.9591$

$K_{ec} = 0.011$

Optimized scaling factor:

$K_u = 9.6762$

4 SIMULATION RESULT AND ANALYSIS

The BLDCM discussed is produced by Shanghai Si Zhuang Electric Company; its model is 57ZWN98-2430, its parameters are shown in Table 3.

Table 3 Parameters of BLDCM

output power	80W	rated current	6A
rated voltage	24V	Rated speed	2000r/min
Rated torque	0.4N.m	no-load speed	3000r/min
no-load urrent	300mA	Pole number	2

Transfer function:

$$G(s) = \frac{23.15}{0.000137s^2 + 0.028s + 1}$$

According to the fuzzy controller designed in the paper, simulation is carried out by using MATLAB. Fig.7 shows the performance of fuzzy control. Fig.8 shows the performance of fuzzy control based on Genetic

Algorithm.

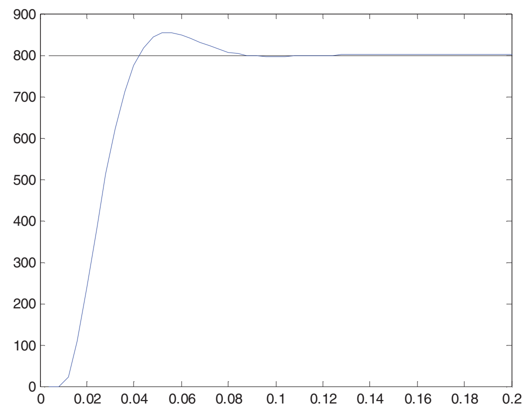

Fig.7 The performance of fuzzy control

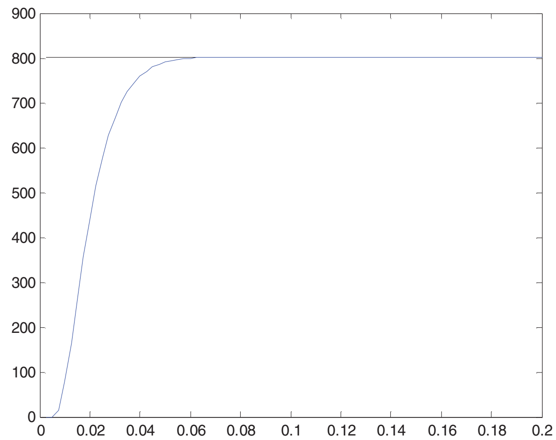

Fig.8 The performance of GA-fuzzy control

Adding a 10 pulse disturbance when time is 0.12 seconds .Disturbance response curve of fuzzy control is shown in Fig.9. Disturbance response curve of fuzzy control based on Genetic Algorithm is shown in Fig.10.

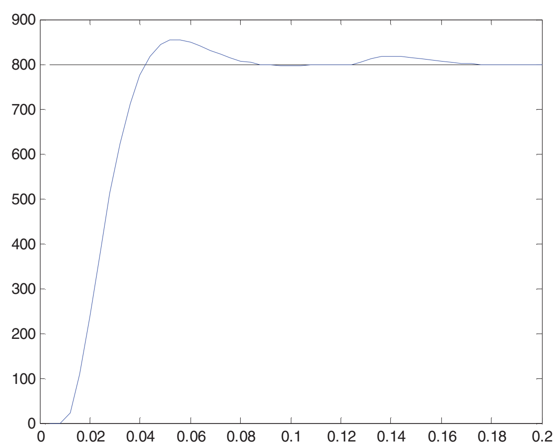

Fig.9 Disturbance response curve of fuzzy control

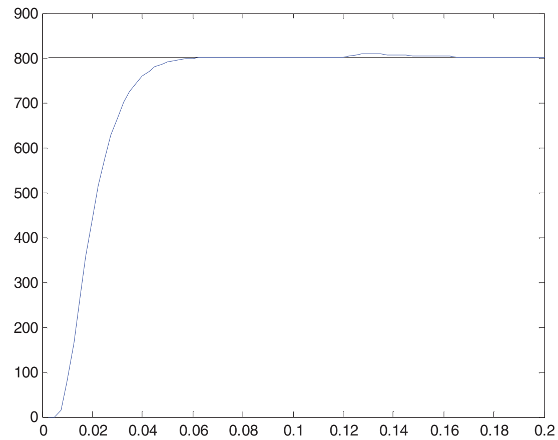

Fig.10 Disturbance response curve of fuzzy control based on Genetic Algorithm

5 CONCLUTION

The proposed fuzzy control based on Genetic Algorithm has been successfully implemented and it overcoming the drawbacks of the Fuzzy controller. Through the simulation results we can see: compared with the fuzzy control, the fuzzy control based on Genetic Algorithm response more quickly and has stronger anti-interference ability. It is more suitable to control brushless DC motor.

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