Design and Simulation of DC Motor Controller Based on the Fuzzy Control

Jianwei Li
Automotive Engineering Department, Zibo Vocational Institute, Zibo, Shandong, 255314, China
*Corresponding author’s e-mail: 10874@zbvc.edu.cn

Abstract. The motor fuzzy controller was designed by the application of the principle of fuzzy logic based on the research of DC motor model. The simulation analysis of traditional control and fuzzy control were conducted by MATLAB simulation module, which illustrates the better control performance of fuzzy control method by comparison.

1. Introduction
DC servo motor is widely used in numerical control machine tool and process control. It avoids the brush maintenance and reduces the installation dimensions. Due to the motor parameter and model that is influenced by the application environment, the conventional PID control will be unreliable when the motor parameters changes. However, the fuzzy control can overcome the nonlinear factors and has strong robustness to the changes of controlled parameters. Because it doesn’t need accurate mathematical model and the control rules are constructed according to the practical experience, it can avoid the influence of model and loads on the system, improve the dynamic performance and achieve good control effect.

2. The mathematical model of DC servo motor
The control object is DC motor which is used commonly. The equivalent circuit is shown in figure 1, where $M_e$ is the electromagnetic torque of DC motor, $M_L$ is the external load driven by DC motor, $n$ is the speed of external load driven by DC motor.

According to the figure 1, the differential equation can be expressed as:

\[
V_f = R_i + L_f \frac{di}{dt}
\]

\[
V = R \cdot i(t) + L \cdot \frac{di(t)}{dt} + e(t)
\]

The transform function of armature current and voltage can be obtained by Laplace transform as follows:

\[
\frac{I(s)}{V(s) - E(s)} = \frac{1}{R} \frac{1}{T_I s + 1}
\]
In addition, the dynamics equation of external load driven by motor can be expressed as:

\[ i - i_L = \frac{T_m}{R} \cdot \frac{de}{dt} \]  

(4)

Where \( T_m \) is the constant of mechanical time.

The transform function of Counter electromotive force and current can be obtained by Laplace transform as follows:

\[ \frac{E(s)}{I(s) - i_L(s)} = \frac{R}{T_m s} \]  

(5)

The transfer function relationship between the speed and current can be expressed as:

\[ \frac{n(s)}{I(s) - i_L(s)} = \frac{1}{T_i \bar{s}} \]  

(6)

Where, \( T_i \) is the constant of integral time.

According to the relationship between the transfer function above, the dynamic structure of DC motor can be drawn in figure 2.

Figure 2. The dynamic structure of DC motor.

### 3. Design of fuzzy controller of DC servo motor

#### 3.1. The determination of fuzzy controller input and output parameters

The fuzzy controller of DC motor has two input parameters and one output parameter. The speed deviation of the motor shaft and the variation of the deviation are the input parameters, the output parameter is the voltage of the armature. The control model is shown in figure 3.

The speed deviation of input shaft is fuzzed into variables. The fuzzy subsets which are defined in the domain are negative big (NB), negative small (NS), zero (Z), positive small (PS), positive big (PB).

According to the control range of speed deviation from -3000r/min to 3000r/min, subordinate function of speed deviation is shown in figure 4, as well as the subordinate function of the variation of speed deviation in figure 5.
3.2. The select of control rules and reasoning method

When the armature voltage is selected by fuzzy controller, the principles should be followed. The armature voltage should increase or reduce as soon as possible when the speed deviation and variation of speed deviation change greatly. Otherwise, the armature voltage should change slowly or be constant. Then some reasonable rules are formed according to the human opinions. For an example, the deviation is positive big and the variation is positive big too, which shows that the output has been overshoot and tends to increase continually, so the output should be lowered to negative big to reduce output quickly to the expectations. The form of statements is expressed as:

\[ \text{If } E = \text{PB} \text{ and } EC = \text{PB} \text{ then } U = \text{NB} \]  \hfill (7)

There are many ways to choose reasonable methods. The Mamdani method is selected based on the rule of fuzzy synthetic relationship.

3.3. The establish of rule table

According to the principle of control rule, the control rule of DC motor is shown in table 1.
Table 1. The control rule table of DC motor.

| E   | NB | NS | ZE | PS  | PB |
|-----|----|----|----|-----|----|
|     | NB | PS | PB | PB  | NB |
| NS  | PS | PS | PB | PB  | NB |
| ZE  | PB | PS | ZE | NS  | NB |
| PS  | PB | NS | NS | NS  | NB |
| PB  | PB | NB | NB | NB  | NB |

According to the fuzzy control rule, the fuzzy rules editor is used to edit the rule table so as to control the system, which is shown in figure 6. The input and output surface of the fuzzy controller is shown in figure 7. There are 25 control rules in the fuzzy controller according to the former analysis.

Figure 6. The setting of fuzzy rules.

4. Simulation analysis

According to the DC motor model built in front, taking $C_e = 0.2 \text{min/r}$, $R = 1.0 \Omega$, $T_1 = 0.17s$ as an example, the simulation analysis of traditional control and fuzzy control are carried. The simulation analysis model of traditional control and fuzzy control are shown in figure 8. The simulation results of ideal curve, traditional control curve and fuzzy control curve is shown in figure 9 when the speed is 1000 r/min.
Figure 7. The input and output surface of the fuzzy controller.

(a) The traditional control model  
(b) The simulation model of fuzzy control

Figure 8. The simulation model of DC motor.
(a) The traditional control model  
(b) The simulation model of fuzzy control
According to the results, the system had slow response and large overshoot when the traditional control model was adopted. Adversely, the fuzzy control model had quick response, no overshoot, good anti-interference ability and excellent dynamic and static performance.

5. Conclusion
The model of DC motor presents certain nonlinear by the effect of load, friction force and the external environment. The conventional controller design methods can’t adapt to the kind of changes. The fuzzy set is an important tool of nonlinear mapping, the adaptive fuzzy controller will obtain when it is applied to DC motor control. The fuzzy controller doesn’t depend on the specific mathematical model and the motor has good output response in various cases.

Acknowledgements
The author is grateful for the reverent help of technical staff or financial support provided by Department of Automotive Engineering, Zibo Vocational Institute.

Reference
[1] Xu, S., Hao, X., Zhang, Z. (2003) Fuzzy Control and Simulation of Direct Current Servo System. Journal of Henan University of Science and Technology (Natural Science), Vol 24:64-67.
[2] Cai, B. (2005) Small Power Direct Current Torque Motor Servo System Based on Fuzzy Control. Journal of Xinyang Normal University (Natural Science), Vol 18:95-98.
[3] Hou, J. (2005) Design and Simulation of Fuzzy Controller for DC Servo Motor. Journal of Heilongjiang Institute of Science and Technology, vol 15:221-224.
[4] SHIEH M Y. Design of integrated Fuzzy controller for servo motor [M]. Mechatronics, 1998.