Military Technical College
Kobry El-kobbah,
Cairo, Egypt

5th International Conference
on Electrical Engineering
ICEENG 2006

PID and FLC Comparison Study on Position Control of Permanent Magnet Stepper Motors

Hamdy* A. M., M. Zaher**, A. B. Kotb***

Abstract

Stepper motors are found in three main types; Permanent Magnet, Variable reluctance and Hybrid stepper motors. This paper concerns with the study of response of the PM stepper motors using different two types of controllers. The position tracking of the PM stepper motor is investigated on open loop and then PID and FLC are used to modify the open loop response. The stepper motor is simulated with application of controllers using MATLAB software. Controller is used to improve the motor performance by reducing the rise time, minimize overshoots and eliminate the steady state error. The results show the advantages of FLC over the conventional PID controller.

1. List of symbols

V_a,V_b	Phase A and B stator voltages [V]	i_a, i_b	Stator phase currents [A]
i_f	Fictitious current of PM [A]	K_c	Machine emf constant [Nm/A]
T_l, T_{res}	Load and detent torques [Nm]	K_u	Scaling factor of output signal
L_a, L_b	Phase A and B self inductances [H]	R_a, R_b	Phase A and B resistances [Ω]
L_{ab}	Mutual inductance of phases [H]	N_r	Number of rotor teeth
θ	Motor angle position [Rad]	Ω	Motor speed [Rad/sec.]
J	Motor inertia [Kgm^2]	B	Friction coefficient [Nm.s/rad]
e(t)	Error signal	ce(t)	Change of error signal
u(t)	Output signal	K_p	Proportional gain of PID
K_d	Derivative gain of PID	K_i	Integral gain of PID
K_e	Scaling factor of error signal	K_{ce}	Scaling factor of change of ce(t)

* A. Lect., Al-Azhar University, E.mail: Hamdyshatla@hotmail.com, Tel: 0103584601.

** Professor, Electric Eng. Dept, Dean Of Alazhar Faculty of Engineering.

*** Professor, Electric Eng., Alazhar-University.

2. Introduction

A PM (Permanent Magnet) stepper motor converts digital information into a proportional mechanical position variation. Stepper motors are supplied by electric pulses from bipolar or unipolar drive circuits depending on the phase windings and motor ratings. Stepper motors are found in three main types; Permanent Magnet, Variable reluctance and Hybrid stepper motors. Stepper motors have many advantages such as; operation in open loop with precise positioning, high reliability and simple mechanical construction. The Permanent Magnet stepper motor usually consists of two phases each is supplied from different digital signals. The wound stator of the motor is fabricated from magnetic material and divided into certain number of poles. The rotor is a Permanent Magnet with two sections of attached to the two poles, shifted to each other by one half rotor teeth as shown in Fig. 1.

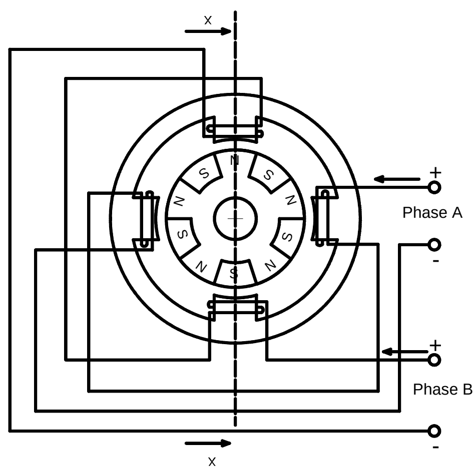


Fig. 1 (a): Stator and rotor teeth side view of PM stepper motor.

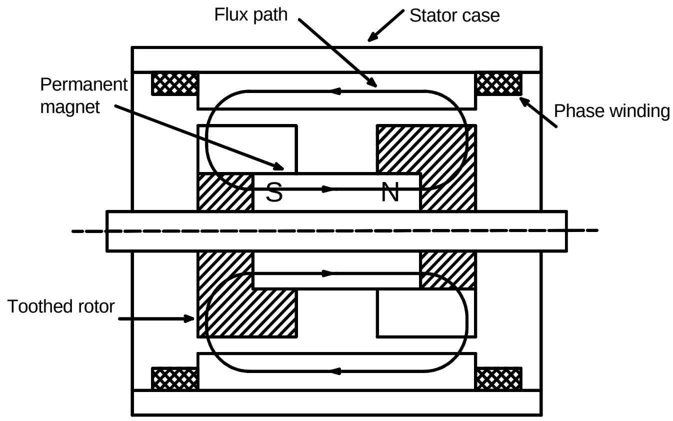


Fig. 1 (b): Cross-section side view at X-X of PM stepper motor.

Large number of poles results in small step angle but this is limited to the size of the motor and the manufacturing capabilities. Application of electric pulse on one stator phases results in a step angle while, application of pulse to two phases produces half step angle of the motor. S. E. Lyshevski established approximate model of the PM stepper motor operated in servo mechanism [1]. H. Melkote performed the nonlinear control of Variable reluctance stepper motors and concerned with the fundamental fictitious current of the permanent magnet [2]. More advanced researchs deal with the modeling of the stepper motors considering more assumptions to linearize the motor model [3].

The application of artificial intelligence (AI) control algorithms are adopted for the position control of Permanent Magnet stepper motors such as; Fuzzy Logic and Neural Networks [4], [5], [6]. Adaptive Fuzzy Logic control is used to have self-tuned scaling factors of the FLC instead of manual tuning.

3. Mathematical Model of PM Step Motor

The permanent magnet stepper motor parameters are used to obtain an approximate representation model of the motor. Assumptions of the motor equations are held to simplify the model and to obtain more linear equations. Assumption are such as; neglect the mutual effect between stator phases and concern the fundamental component of the fictitious PM current on stator phases. Also the variations of the stator phases self inductances with the rotor position are neglected.

The expression of the phase A current is [7]

$$\frac{di_a}{dt} = \frac{1}{(L_{aa}L_{bb} - L_{ab}L_{ba})}\left\{\begin{aligned} & -L_{bb}v_a - L_{ab}v_b - R_aL_{bb}i_a + R_bL_{ab}i_b \\ & -L_{bb}\ \Omega\left(i_a\frac{dL_{aa}}{d\theta} + i_b\frac{dL_{ab}}{d\theta} + i_f\frac{dL_{af}}{d\theta}\right) \\ & +L_{ab}\ \Omega\left(i_a\frac{dL_{ab}}{d\theta} + i_b\frac{dL_{bb}}{d\theta} + i_f\frac{dL_{fb}}{d\theta}\right) \end{aligned}\right\} \quad (1)$$

and that of phase B is given by equation (2)

$$\frac{di_b}{dt} = \frac{1}{(L_{aa}L_{bb} - L_{ab}L_{ba})}\left\{\begin{aligned} & -L_{ba}v_a + L_{aa}v_b + R_aL_{ba}i_a - R_bL_{aa}i_b \\ & +L_{ba}\ \Omega\left(i_a\frac{dL_{aa}}{d\theta} + i_b\frac{dL_{ab}}{d\theta} + i_f\frac{dL_{af}}{d\theta}\right) \\ & -L_{aa}\ \Omega\left(i_a\frac{dL_{ab}}{d\theta} + i_b\frac{dL_{bb}}{d\theta} + i_f\frac{dL_{fb}}{d\theta}\right) \end{aligned}\right\} \quad (2)$$

The motor electromagnetic torque expression is

$$T_e = \frac{1}{2}[i_a \quad i_b \quad i_f]\frac{\partial}{\partial\theta}\left\{\begin{bmatrix} L_{aa} & L_{ab} & L_{af} \\ L_{ba} & L_{bb} & L_{bf} \\ L_{fa} & L_{fb} & L_{ff} \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_f \end{bmatrix}\right\} \quad (3)$$

With the assumptions mentioned before, the motor phases self inductances L_{aa} and L_{bb} are replaced by L_a and L_b respectively when neglecting the variation of self inductances with rotor position. Taking into account only the fundamental component of the mutual inductances, equations (1), (2) and (3) are modified to the following

$$\frac{di_a}{dt} = \frac{1}{L_a}\{v_a - R_ai_a + K_C\ \Omega\ sinN_r\theta\} \quad (4.a)$$

$$\frac{di_b}{dt} = \frac{1}{L_b}\{v_b - R_bi_b - K_C\ \Omega\ cosN_r\theta\} \quad (4.b)$$

$$\frac{d\Omega}{dt} = \frac{1}{J}\{K_ci_b\cos N_r\theta - K_ci_a\sin N_r\theta - T_{res-T_l}\} \quad (4.c)$$

$$\Omega = \frac{d\theta}{dt} \quad (4.d)$$

The motor dynamic equations 4.(a), (b),(c) and (d) are used to simulate the motor in open loop. Equations are represented using the **MATLAB** software with certain required motor position. The motor speed and position are shown in Fig. 2 and 3 respectively. Fig. 2 shows rotor position over shoots and high settling time and normally these oscillations appear in the speed response of the motor. It is proposed to reduce these over shoots and eliminate the steady state error by introducing a rotor position control loop.

The position control is achieved by the conventional PID controller and FLC with a comparison between them.

4. Fuzzy Logic Controller (FLC)

Fuzzy control is based on fuzzy logic technique. The fuzzy logic mimics the human thinking which does not always follow crispy logic, (Yes-No logic) but often deal with uncertain problems. The problems of load disturbance or parameters variation usually requires an artificial intelligence control technique. FLC is advantageous to PID control as it is reliable and doesn't require the complete mathematical model of the plant to be known. FLC is very useful for non-linear control systems. Fuzzy Logic control is described by IF-THEN production rules.

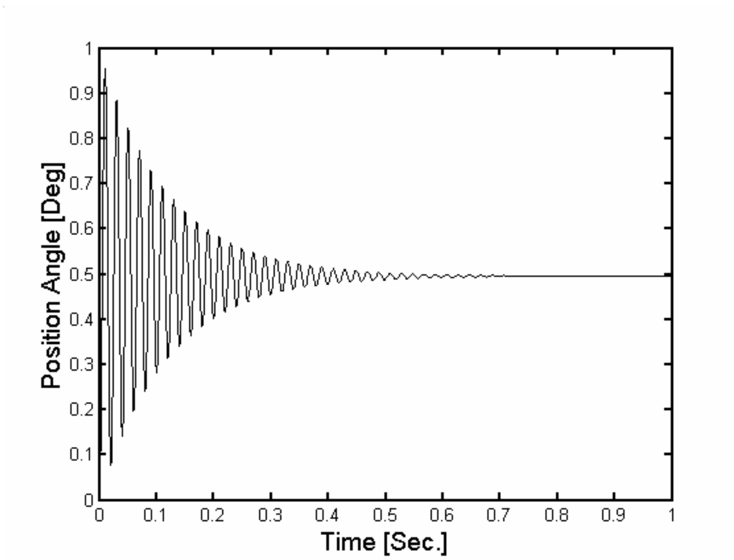


Fig. 2: PM stepper motor position in deg.

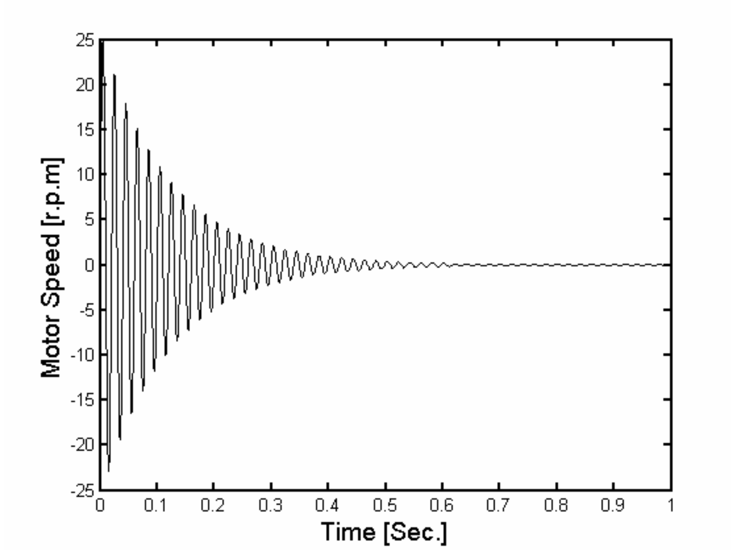


Fig. 3: PM stepper motor speed in (r.p.m).

The main limitation of FLC is the lack of systematic procedure of design and analysis. The block diagram representing the construction of the FLC is shown in Fig. 4.

Now both conventional PID controller and FLC are used to improve the motor performance. The control loop includes a signal of the motor position which is compared with the reference position. The tuning of the PID control is achieved either by ZIEGLER-NICHOLS method or by trial and error.

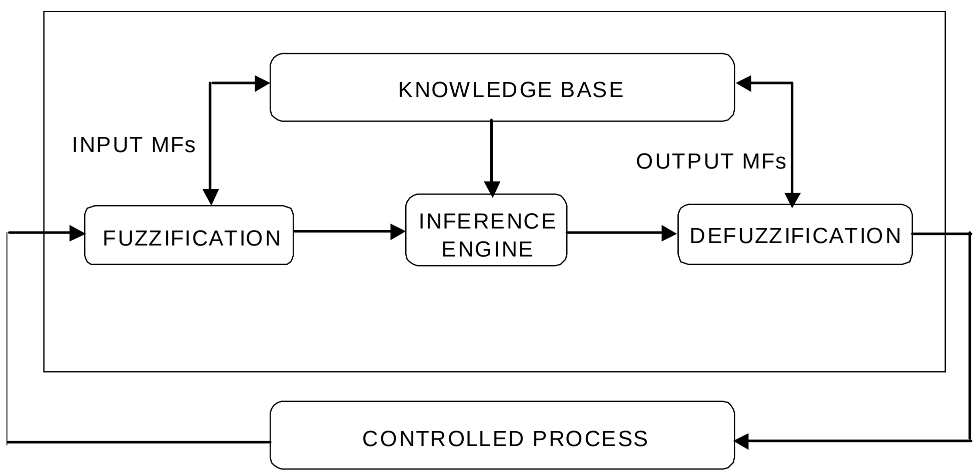


Fig. 4: FLC block diagram construction.

The PID controller gain is defined by

$$f(e) = K_p e(t) + K_d \frac{de(t)}{dt} + K_I \int e(t)dt \quad (5)$$

The FLC representation includes the definition of the input and output process control. In our work the inputs are error and change of error signals while, the output is the actuating signal applied to the system.

The equations describing the FLC process of control variables are

$$e(t) = \theta_r - \theta(t) \quad (6)$$

$$ce(t) = e(t) - e(t-1) \quad (7)$$

$$u(t) = \Delta u(t) + u(t-1) \quad (8)$$

The FLC application is associated with the choice of five symmetrical triangular membership functions used to describe inputs and outputs as shown in Fig.5.

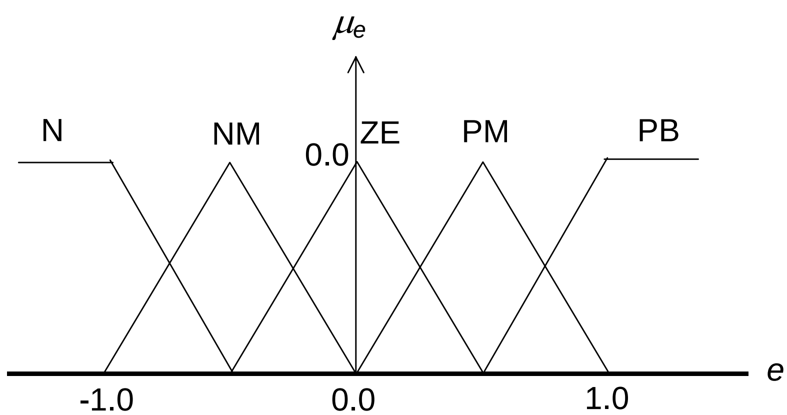


Fig. 5: Five triangular symmetrical fuzzy membership functions.

The normalized universe of discourse for both error and change of error is from –1.0 to 1.0, and from 0.0 to 2.0 for the output. The steady state point is located in the middle of the discourse for all signals. The applied fuzzy rules are given in Table 1. Abbreviated fuzzy sets are used in Table 1 such as; NB (Negative Big), NM (Negative Medium), ZE (Zero) and PB (Positive Big).

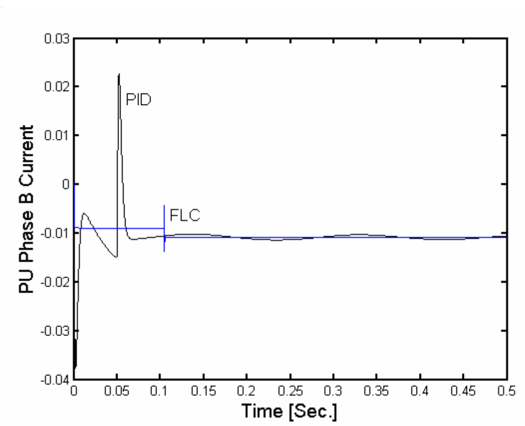
Table 1: Fuzzy sets rules table

CE\E	**NB**	**NM**	**ZE**	**PM**	**PB**
NB	*NB*	*NB*	*NB*	*NM*	*ZE*
NM	*NB*	*NB*	*NM*	*ZE*	*PM*
ZE	*NB*	*NM*	*ZE*	*PM*	*PB*

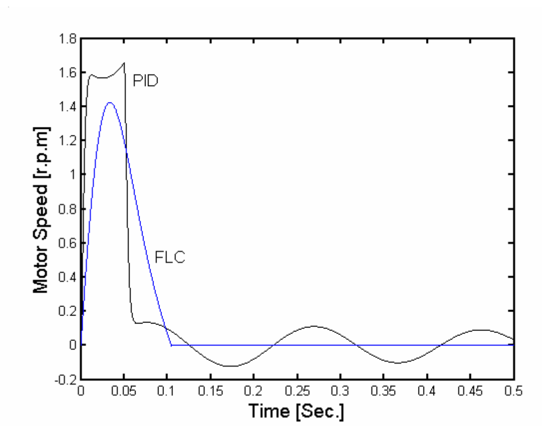
PM	*NM*	*ZE*	*PM*	*PB*	*PB*
PB	*ZE*	*PM*	*PB*	*PB*	*PB*

Scaling factors are used to normalize the input and output values obtained directly from equations (6), (7) and (8). The scaling factors named K_E, K_{CE} and K_U for error, change of error and actuating signals respectively.

The PM stepper motor position response with PID controller and FLC is shown in Figures 6(a), (b), (c) and (d). The motor overshoots are minimized as shown in Fig. 6.c and the rise time is decreased when comparing Fig. 3 and Fig. 6.c.

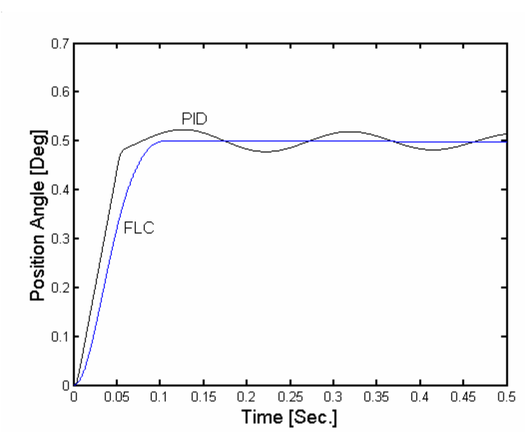


(a): Motor phase current

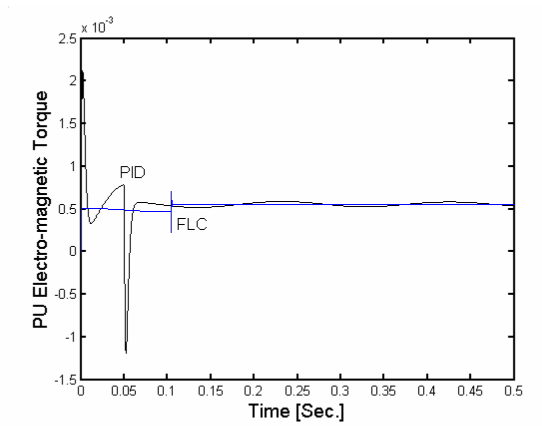


(b): Motor speed

Fig. 6 (a) and (b) : Motor phase current and speed with PID and FLC



(c): Motor position angle



(d): Motor electromagnetic torque

Fig. 6 (c) and (d) : Motor position and electromagnetic torque with PID and FLC

5. Conclusions

The FLC operates on nonlinear systems and there is no need for the mathematical model as it uses if the rules. The application of FLC is helpful in reducing the motor overshoots and minimizing the steady state error and the rise time is decreased with the control algorithm. Fuzzy logic control is useful for complex processes and it gives superior performance than the conventional control (PID). Scaling factors are tuned to improve the motor response. The output scaling factor affects on system overshoots and rise time. The error and change of error scaling factors affect mainly on the steady state error and are responsible for reducing the rise time of the motor. The limitation for increasing the membership functions is the computation time taken for the practical implementation of the system. Lower number of fuzzy sets may make the control to loose data points of the system. The use of triangular membership functions is useful in control systems rather than its ease representation in simulation programs. Other fuzzy sets (trapezoidal, Sigmoidal) require higher calculation time although they give higher performance

6. References

[1] Sergey Edward Lyshevski, "Motion Control of Electromechanical Servo-devices with Permanent-Magnet Stepper Motors", DEE, Purdue Univ., USA, 1997.

[2] Hemant Melkote, "Robust Adaptive Control of Variable Reluctance Stepper Motors", IEEE trans. On Control, Vol. 7, 1999.

[3] F. Khorrami, P. Krishnamurthy, H. Melkote, "Modeling And Adaptive Nonlinear Control Of Electric Motors", ISBN 3-540-00936-1, Springer-Verlag, Berlin Heidelberg, 2003.

[4] S. Rajasekaran, G. A. Vijayalakshmi Pai, "Neural Networks, Fuzzy Logic, and Genetic Algorithms", Prentice-Hall, ISBN-81-203-2186-3, Second Edition, 2003.

[5] Chih-Min Lin, Yi-Jen Man, "Hybrid Adaptive Fuzzy Controllers With Application To Robotic Systems", Dept of EE, Yuan-Ze Univ., Rep. of China, 2002.

[6] Leonid Reznik, "Fuzzy Controllers", Newnes, ISBN 0-7506-3429-4, 1997.

[7] W. Marrtinez, L. Parra. J. L. Peres, " Software Simulation of Fuzzy Logic Controller Applied to A Hybrid Stepper Motor", Journal of Mexican Society of Instrumentation, 1995.

[8] M. N Uddin, " Fuzzy Logic Based Position Control of Permanent Magnet Synchronous Motor", CCECE 2002.

[9] Junhong Nie, Derek Linkens, "Fuzzy-Neural Control", Prentice-Hall, ISBN-81-203-1368-2, 1995.