ภาคผนวก ก

รายละเอียดของมอเตอร์

มอเตอร์ไฟฟ้ากระแสสลับที่นำมาใช้ในงานวิจัยนี้ เป็นมอเตอร์ไฟฟ้าแบบเหนี่ยวนำ (induction motor) ซึ่งตัวมอเตอร์ต่ออยู่กับชุดวัดระยะของเครื่องพับและตัดเหล็ก ในการควบคุมตำแหน่งและความเร็วของเครื่องพับและตัดเหล็ก จึงทำได้โดยการควบคุมที่ตัวมอเตอร์ดังกล่าว

ในการควบคุมมอเตอร์ จำเป็นต้องทราบรายละเอียดต่าง ๆ ของมอเตอร์ เนื่องจากต้องนำค่าที่เป็นค่าเฉพาะของมอเตอร์ มาใช้ในการจำลองการทำงานของมอเตอร์ จึงจะสามารถจำลองการทำงานของระบบได้ สำหรับรายละเอียดต่าง ๆ ของมอเตอร์นั้น สามารถหาได้จากคู่มือการใช้งานที่มาพร้อมกับมอเตอร์ แต่ถ้าเป็นมอเตอร์เก่า จำเป็นต้องทำการทดลอง เพื่อหาค่าเหล่านี้เอง ในงานวิจัยนี้ ทางผู้วิจัยได้ติดต่อกับทางบริษัทซีเมนส์ (SIEMENS) ซึ่งเป็นผู้ผลิตมอเตอร์ เพื่อขอข้อมูลการทดสอบมอเตอร์ที่สภาวะต่างๆ และนำมาค่าจากการทดสอบนั้นมาคำนวณหาค่าตัวแปรต่างๆ ของมอเตอร์ เพื่อนำมาใช้ในการจำลองการทำงาน ดังนี้

- rated power $P_n = 0.43$ kW.
- rated current $I_n = 1.02$ A.
- rated voltage $V_n = 460$ V.
- rated speed $\omega_n = 1670$ rpm.
- rated torque $T_n = 2.5$ Nm.
- rated frequency $f_n = 60$ Hz.
- pole pairs $n_p = 4$
- system inertia $J = 0.0008$ kg m2
- stator resistance $R_s = 27.55$ ohm.
- rotor resistance $R_r = 21.4$ ohm.
- stator and rotor inductances $L_s = L_r = 0.055$ H.
- magnetising inductance $L_m = 0.822$ H.

เนื่องจากค่าตัวแปรต่างๆ เหล่านี้ ได้ทำการทดสอบโดยต่อมอเตอร์แบบวาย (wye connection) ขณะที่การนำมอเตอร์ไปใช้งานจริงนั้น ได้ต่อมอเตอร์แบบเดลต้า (delta connection) แต่อย่างไรก็ตามแบบจำลองของมอเตอร์เหนี่ยวนำซึ่งสร้างขึ้นโดยใช้หลักการแปลงจากสามเฟสเป็น

สองเฟส หรือเรียกว่าการแปลง dq นั้น สามารถใช้ได้กับมอเตอร์ซึ่งต่อแบบใดก็ได้ โดยถ้ามอเตอร์ต่อแบบวาย ให้ป้อนแรงดันเฟสเข้ามอเตอร์ ขณะที่มอเตอร์ต่อแบบเดลต้า ให้ป้อนแรงดันสายเข้ามอเตอร์ เพื่อให้การแปลง dq เป็นไปอย่างถูกต้องตามวิธีการต่อมอเตอร์นั่นเอง

ในส่วนของรายละเอียดที่ได้จากการทดลองในห้องปฏิบัติการของบริษัทซีเมนส์ สามารถแสดงได้ดังนี้

SIEMENS

Werksprüfzeugnis (2.2) [1]

Prüfbescheinigung
nach EN 10 204 (DIN 50 049)

Seite 1 von 1

Hersteller: SIEMENS AG Bereich Automation & Drives, SD Geschäftsgebiet Niederspannugsmotoren Anschrift: Nádražní 25 CZ-789 85 Mohelnice	Besteller: [2] Kunde:
FID / Vreg.	Bz-Pos.

SIEMENS

3~Mot.
1LA7073 – 4AB

IP 55 **71M** **EN 60034** **ThCl F**

50 Hz **230 / 400 V D/Y**
0,37 kW **1,82 / 1,05 A**
cosf 0,78 **1370 / min**
220-240/380-420 V D/Y
1,89-1,87/1,09-1,08 A

60 Hz **460 V Y**
0,43 kW **1,04 A**
cosf 0,76 **1670 / min**
440-480 V Y
1,08-1,09 A

Messdaten	Mot –Nr.	Ständer [4] Frequenz [3] [Hz]	Ständer [4] Spannung [5] [V]	Ständer [4] Strom [6] [A]	Drehzahl [7] [1/min]	Leistung Aufn. P1 [9] [W]	Leistung Abgabe P2 [8] [W]	cos phi [-]	M [16] [Nm]	Eta [17] [%]	I_A/I_a [22]
Leerlauf [10]	**0000**	**50**	**400**	**0,868**	-	**125,1**	-	-	-	-	-
		60	**460**	**0,788**	-	**120,7**	-	-	-	-	-
Last [18]		**50**	**400**	**1,09**	**1345**	**602,1**	**370**	**0,795**	**2,63**	**61,5**	-
		60	**460**	**1,07**	**1648**	**660,5**	**430**	**0,776**	**2,49**	**65,1**	-
Anzug [19]		**50**	**400**	**3,60**	-	**2021**	-	**0,811**	**4,8**	-	**3,29**
		60	**460**	**3,98**	-	**2469**	-	**0,779**	**4,8**	-	**3,72**

Kurzschlußläufer [11] Ausführung: EN 60034 Teil 1, IEC 34-1 [12]

Widerstand zwischen Klemmen [13] [Ω]
U1-U2
V1-V2 **55,1**
W1-W2

Wicklungsprüfung bestanden [14]

Kühllufttemperatur max. 40°C [20]
bzw. nach Leistungsschildangabe [21]

English/Francais/česky

[1] Test report/Fiche d´essais/Osvědčeni o zkoušce
[2] Reference /Réference/Objednavatel
[3] Frequency/Fréquence/Kmitočet
[4] Stator/Stator/Stator
[5] Voltage/Tension/Napětí
[6] Current/Courant/Proud
[7] Speed r.p.m./Vitesse tr/min/Otáčky
[8] Output/Puissance nominale/Výkon
[9] Input/Puissance absorbée/Příkon
[10] No load test/Marche á vide/Naprázdno
[11] Squirrel-cage rotor/Rotor en court-circuit/Rotor nakrátko
[12] According to standard/Exécution selon prescription/Provedeni
[13] Resistance between terminals/Résistance entre bornes/Odpor na svorkách
[14] High-voltage test passed/L´essai diélectrique a donné satisfaction/Zkouška vinutí
[15] Number of poles/Nombres des póles/Polarita
[16] Torque/Couple/Moment
[17] Efficiency/Rendement/Účinnost
[18] Load/Mesure á..charge/Zátěž
[19] Locked rotor test/Test en court circuit/Zkouška nakrátko
[20] Cooling air temperature max...°C/Temp. de l´air de refroifdissement max...°C/Teplota okolí
[21] or indication on name plate/ou indiques sur la plaque/ pro údaj na výkonovém štítku
[22] Starting current related to rated current /courant rotor bloqué en proportion de courant assigné / poměrný proud nakrátko
[23] Starting torque related to rated torque / couple rotor bloqué en proportion de couple assigné / poměrný záběrový moment

A & D SD MM QS3 Datum: 2. 10. 2001 Unterschrift:

Josef Nejedlý
Leiter des Prüffeldes

ภาคผนวก ข

งานวิจัยที่ได้รับการตีพิมพ์

บทความที่ 1 ได้รับการตีพิมพ์ในงาน Information and Computer Engineering Postgraduate Workshop 2004 (ICEP 2004) ระหว่างวันที่ 22-23 มกราคม พ.ศ. 2547 จัดขึ้นที่มหาวิทยาลัยสงขลานครินทร์ วิทยาเขตภูเก็ต จ.ภูเก็ต ประเทศไทย ในหัวข้อชื่อเรื่อง "A Comparative Study of Induction Motor Position Control for Bending and Cutting Machine"

A COMPARATIVE STUDY OF INDUCTION MOTOR POSITION CONTROL FOR BENDING AND CUTTING MACHINE

Pramote Ariyadirek
Department of Computer Engineering
Faculty of Engineering
Prince of Songkla University
Hat Yai, Songkhla 90112 THAILAND
E-mail: apramote@ratree.psu.ac.th

Thanate Khaorapapong
Department of Computer Engineering
Faculty of Engineering
Prince of Songkla University
Hat Yai, Songkhla 90112 THAILAND
E-mail: kthanate@coe.psu.ac.th

ABSTRACT

In different scenarios, the comparison of the simulation results between fuzzy logic controller (FLC) for a position control with speed and that of without speed control loop is presented in this paper. The design of fuzzy logic controller is set up with simple rules that are derived from engineering and experimental results. At of constant positions, the measurement of results of fuzzy logic controller with and without speed loop are illustrated to see which has more advantages.

KEYWORDS

Fuzzy logic controller, Position control, Speed control, Induction motor, Bending and Cutting machine.

INTRODUCTION

Induction motors are widely used in industrial applications for example, handling devices, electrical traction and robotics because they are less cost but more rugged and reliable than DC motors. Though induction motors have a few advantageous characteristics, they also possess nonlinear and time-varying dynamic interactions.

By using conventional PI controller, it is very difficult and complex to design a high performance induction motor drive system. We cannot obtain the good responses for the changes of the load torque and load inertia moment from the system, we observe the overshoot and oscillation of the motor response, the oscillation of the torque and the long settling time [1-3]. The fuzzy logic controller is attractive approach, which can accommodate the motor parametric variations and difficulty in obtaining an accurate mathematical model of induction motor due to rotor parameter and load time constant variations. It employs the strategy adopted by the human operator to control complex processes and gives superior performance than the conventional PI controller [4-6]. In order to have the robustness against speed variation and external perturbations, fuzzy logic controller is a recent control technique, which permits the control of nonlinear system such as induction motor. It has three main characteristics. 1) the fuzzy controller a linguistic controller it is not necessary to find the precise and accurate mathematical model of the controlled object 2) the FLC is an ideal flexible nonlinear type controller, it can overcome the influence of only nonlinear variations 3)the FLC has a strong robustness, as it is not sensitive to parametric variations of the controlled process.

In this paper, the application of fuzzy logic to control an induction motor drive is investigated. First, fuzzy logic control principle is considered for the design of the position controller. Then with help of the MATLAB/Simulink, we propose the fuzzy controller, which is suitable for position control with and without speed control loop of induction motor drives. Thirdly, we simulate the whole system and discuss the performance of the position control system with and without speed control loop by considering the position response under the constant loads.

INDUCTION MOTOR DYNAMICS AND CONTROL STRUCTURE

This paper presents the position control of induction motor for Bending and Cutting Machine. The control system is shown in Fig. 1, which composes of induction motor, ball screw and the encoder to feedback the position of motor to the controller.

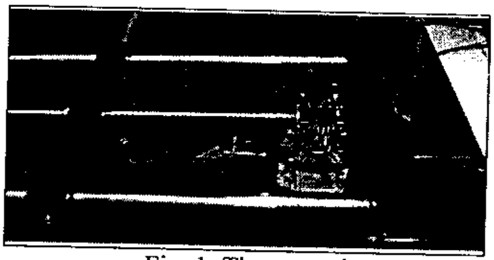


Fig. 1. The control system.

A block diagram of an induction motor position control with and without speed control loop are shown in Fig. 2 and Fig. 3 respectively. The reference position is compared with the actual position and the error is fed to the fuzzy logic controller. To determine the set-point speed of the system, the controller employs the error and change of error as fuzzy inputs. In Fig. 2, the set-point speed is compared with the actual speed of induction motor in the speed controller and gets the frequency to control inverter. In Fig. 3, the set-point speed is transformed to frequency into inverter.

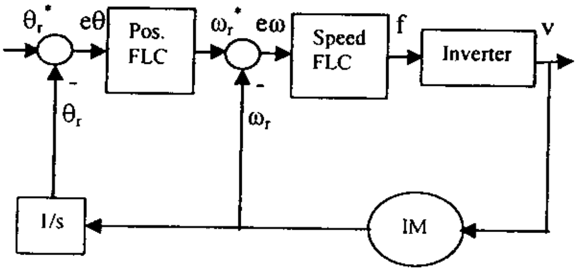


Fig.2 Block diagram of an induction motor position control with speed control loop using fuzzy logic control.

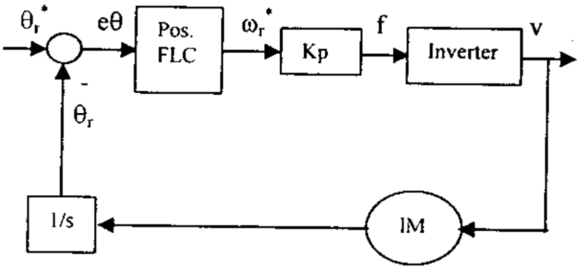


Fig.3 Block diagram of an induction motor position control without speed control loop using fuzzy logic control.

The most popular induction motor model derived from the equivalent circuit is Krause's model detailed in [7]. According to his model, an induction motor model can be represented in the state-space form as follows [8-9]:

$$\frac{dF_{qs}}{dt} = \omega_b\left[v_{qs} - \frac{\omega_e}{\omega_b}F_{ds} + \frac{R_s}{X_{ls}}\left(\frac{x_{ml}^*}{x_{lr}}F_{qr} + \left(\frac{x_{ml}^*}{x_{ls}} - 1\right)F_{qs}\right)\right]$$

$$\frac{dF_{ds}}{dt} = \omega_b\left[v_{ds} - \frac{\omega_e}{\omega_b}F_{qs} + \frac{R_s}{X_{ls}}\left(\frac{x_{ml}^*}{x_{lr}}F_{dr} + \left(\frac{x_{ml}^*}{x_{ls}} - 1\right)F_{ds}\right)\right]$$

$$\frac{dF_{qr}}{dt} = \omega_b\left[-\frac{(\omega_e - \omega_r)}{\omega_b}F_{dr} + \frac{R_r}{X_{lr}}\left(\frac{x_{ml}^*}{x_{ls}}F_{qs} + \left(\frac{x_{ml}^*}{x_{lr}} - 1\right)F_{qr}\right)\right]$$

$$\frac{dF_{dr}}{dt} = \omega_b\left[\frac{(\omega_e - \omega_r)}{\omega_b}F_{qr} + \frac{R_r}{X_{lr}}\left(\frac{x_{ml}^*}{x_{ls}}F_{ds} + \left(\frac{x_{ml}^*}{x_{lr}} - 1\right)F_{dr}\right)\right]$$

$$\frac{d\omega_r}{dt} = \left(\frac{n_p}{2J}\right)(T_e - T_L)$$

When d: direct axis
q: quadrature axis
s: stator variable
r: rotor variable
F_{ij} is the flux linkage(i=q or d and j=s or r)
v_{qs}, v_{ds}: q and d-axis stator voltages
v_{qr}, v_{dr}: q and d-axis rotor voltages
R_r: rotor resistance
R_s: stator resistance
X_{ls}: stator leakage reactance ($\omega_b L_{ls}$)
X_{lr}: rotor leakage reactance ($\omega_b L_{lr}$)
X_m: magnetizing leakage reactance ($\omega_b L_m$)

$$\boxed{X_{ml}^* : 1\Big/\left(\frac{1}{X_m} + \frac{1}{X_{ls}} + \frac{1}{Xlr}\right)}$$

n_p: number of poles
J: moment of inertia
T_e: electrical output torque
T_L: load torque
ω_e: stator angular electrical frequency
ω_b:motor angular electrical base frequency
ω_r: rotor angular electrical speed

DESIGN OF FUZZY CONTROLLER FOR INDUCTION MOTOR

The function of a fuzzy controller is to convert linguistic control rules based on expert knowledge into control strategy. Fuzzy logic appears to be very useful when systems are too complex for analysis by conventional control techniques. Therefore, no exact mathematical model for induction motor is required.

The fuzzy controller accomplishes four elementary functions: Fuzzification, Fuzzy Rule, Fuzzy Inference and Defuzzification. Fig. 4 describes the fuzzy logic controller.

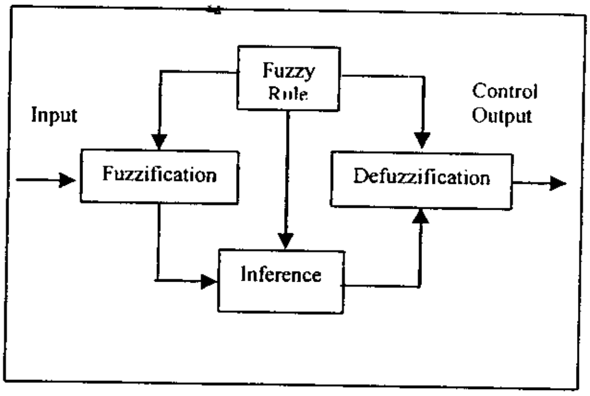


Fig. 4 Fuzzy Logic Controller

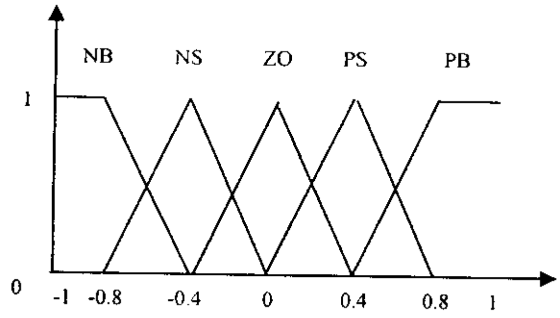
A. Fuzzification

Input variables of fuzzy controller are the position error e(k) and its derivative ce(k). At a sampling point k, e(k) and ce(k) are expressed as

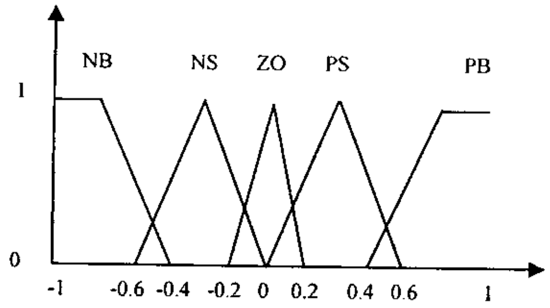
$$e(k) = \theta_r^*(k) - \theta_r(k)$$
$$ce(k) = e(k) - e(k-1)$$

where $\theta_r^*(k)$ and $\theta_r(k)$ are the position command and the actual position of induction motor, respectively.

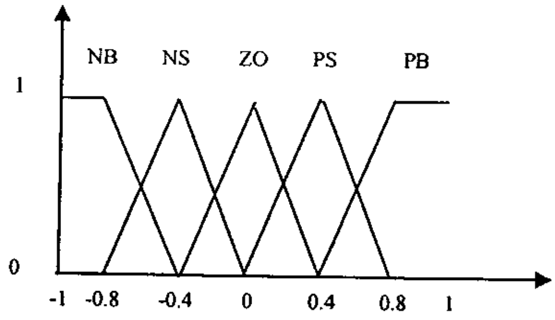
The next step is to decide the appropriate shape of the membership functions for e(k) and ce(k). Since it is easier to see the influence of e(k) on the value of cωr as compared to ce(k), five fuzzy sets are assigned to e(k) and ce(k). Consequently, if the number of fuzzy sets in a particular universe of discourse in increased to infinity, then all fuzziness will be lost and it will be equivalent to a conventional input domain. To simplify mathematical computations, the shape of the fuzzy sets on the two extreme ends of the respective universe of discourse is taken as trapezoidal whereas all other intermediate fuzzy sets are triangular. This is illustrated in Fig. 5.



(a) Error



(b) Change of error



(c) cωr*

Fig. 5 Membership function of Input, Output variable

The input variables are quantized to 13 levels as shown in Table 1. We adapt nonlinear quantization to ensure a good performance of the proposed controller.

Table 1 Quantization of input variable

Error Position (E, mm.)	Change of error position (CE,mm.)	Quantized value
E>=21	CE>=0.6	6
17.5<=E<21	0.5<=CE<=0.6	5
14.0<=E<17.5	0.4<=CE<=0.5	4
10.5<=E<14	0.3<=CE<=0.4	3
7<=E<10.5	0.2<=CE<=0.3	2
3.5<=E<7	0.1<=CE<=0.2	1
-3.5<=E<3.5	-0.1<=CE<0.1	0
-7<=E<-3.5	-0.2<=CE<-0.1	-1
-10.5<=E<-7	-0.3<=CE<-0.2	-2
-14<=E<-10.5	-0.4<=CE<-0.3	-3
-17.5<=E<-14	-0.5<=CE<-0.4	-4
-21<=E<-17.5	-0.6<=CE<-0.5	-5
E<-21	CE<-0.6	-6

B. Fuzzy Rule

To obtain the better system dynamic response, we have used the fuzzy control rules as shown in Table 2. Control rule is obtained from regularized linguistic expression based on sign and size of e(k) and ce(k). This table is composed from applying full boundary of input variables.

Table 2 Fuzzy rules

e Δe	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NB	NS	ZO	PS
ZO	NB	NS	ZO	PS	PB
PS	NS	NS	PS	PS	PB
PB	ZO	PS	PB	PB	PB

C. Fuzzy inference and Defuzzification

Many defuzzifiers have been presented in fuzzy logic literature [10]; however, there is no scientific or mathematical bases for the preference of any of them. Consequently, defuzzification is considered as an art rather than simplicity. The most popular defuzzification method is the centroid method where

$$c\omega_r^*(k) = \frac{\sum_{i=1}^{n} \mu\left[(c\omega_r^*)_i\right](c\omega_r^*)_i}{\sum_{i=1}^{n} \mu\left[(c\omega_r^*)_i\right]}$$

The reference speed $\omega_r^*(k)$ that is applied to the vector control system is computed by integrating $c\omega_r^*(k)$:

$$\omega_r^*(k) = \omega_r^*(k-1) + c\omega_r^*(k)$$

SIMULATION RESULTS AND DISCUSSTION

The control performance of the described FLC is evaluated by simulation using MATLAB / Simulink with the parameters indicated in Appendix and is tested under the constant load. The simulation results compare the trajectory control under several position tracks of position control with and without speed control loop.

Fig. 6 shows the position response of the system under constant load at 10 mm. The position control with speed control loop's response has less rise time, settling time and is smoother so it is better than without one.

Fig. 7 shows the position response of the system under constant load at 20 mm. The comparative results are the same as Fig. 6. But the position control with speed control loop's response is as smooth as without one.

Fig. 8 shows the position response of the system under constant load at 30 mm. The position control with speed control loop's response has more rise time and settling time than without one, so it is slightly worse than without one.

.Fig. 9 shows the position response of the system under constant load at 40 mm. The position control with speed control loop's response has more rise time and settling time than without one so it is worse than without one.

Fig. 10 shows the position response of the system under constant load at 100 mm. The position control with speed control loop's response has much more rise time and settling time than without one so it is much worse than without one.

The results above show that the position control with speed control loop's response is better than without one when the reference position is short. On the contrary, those responses interchange together when the reference position is longer. From the simulation results, the position control without speed control loop has been implemented in the laboratory because of simplicity and economy.

CONCLUSION

The paper has presented a comparative study of fuzzy logic position controller for controlling an induction motor for Bending and Cutting Machine. The simulation results obtained have confirmed the very good dynamic performance and the robustness of the controller. Furthermore, we can compare both of proposed control's simulation results and lead to implement the proposed position control without speed control loop in our laboratory.

APPENDIX

Induction motor parameters:

- rated power $P_n = 0.43$ kW.
- rated current $I_n = 1.02$ A.
- rated voltage $V_n = 460$ V.
- rated speed $\omega_n = 1670$ rpm.
- rated torque $T_n = 2.5$ Nm.
- rated frequency $f_n = 60$ Hz.
- pole pairs $n_p = 4$
- system inertia $J = 0.0008$ kg m2
- stator resistance $R_s = 27.55$ ohm.
- rotor resistance $R_r = 21.4$ ohm.
- stator and rotor inductances $L_s = L_r = 0.055$ H.
- magnetising inductance $L_m = 0.822$ H.

REFERENCES

[1] T.S. Radwan.and M.A. Rahman, "Performances of Novel Fuzzy Logic Based Indirect Vector Control for Induction motor Drive," Industry Applications Conference, 2000, Conference Record of the 2000 IEEE, vol.2, pp. 1225-1231, 2000.

[2] Ichiro Miki, Naoshi Nagai, Sakae Nishiyama, and Tetsuo Yamada, "Vector Control of Induction Machine with Fuzzy PI controller," IEEE IAS Annual Meeting Conf. Rec.,pp. 341-346, 1991.

[3] Minh Ta-Cao, J.L. Silva Neto, and Hoang Le-Huy, "Fuzzy Logic Based Controller for Induction Motor Drives," Proceedings of the Canadian Conference on Electrical and Computer Engineering, Calgary, Canada, vol. 2, pp. 631-634, May 1996.

[4] L.A. Zadeh, "Fuzzy Sets," Inform. Contr., vol. 8, pp. 338-353,1965.

[5] L.A. Zadeh, "Outline of a new approach to the analysis of complex systems and decision processes," IEEE Trans. On System, Man, and Cybemetics, vol. SMC-3, no.1, pp. 28-44, January 1973.

[6] C.C. Lee, "Fuzzy Logic in Control System: Fuzzy Logic Controller Part I,II," IEEE Trans. On System, Man, and Cybernetics, vol. 20, no.2, pp. 404-435, 1990.

[7] P.C. Krause, "Analysis of Electric Machinery," McGraw-Hill Book Company, 1986.

[8] BIMAL K. BOSE, "Modern Power Electronics and AC Drives," 1st edition. Prentice Hall, New Jersey, 1986.

[9] Burak Ozpineci, Leon M. Tolbert, "Simulink Implementation of Induction Machine Model- A Modular Approach," International Electric Machines and Drives Conference, 2003.

[10] Hellendoorn H., C. Thomas, "Defuzzifications in Fuzzy Controllers," Intelligence and Fuzzy Systems, vol.1, pp.109-123, 1993.

[11] YASKAWA ELECTRIC COPORATION, "Σ Series SGME/SGDE (for speed/torque control) USER MANUAL," November 1996 96-111.

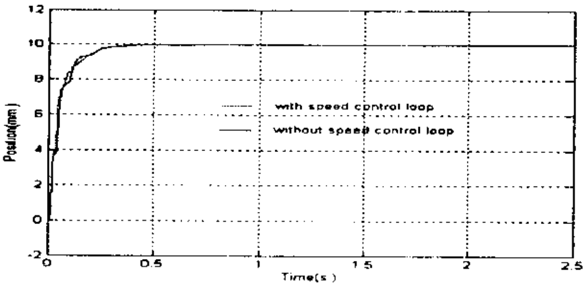


Fig. 6 Position response of the system under constant load at 10 mm.

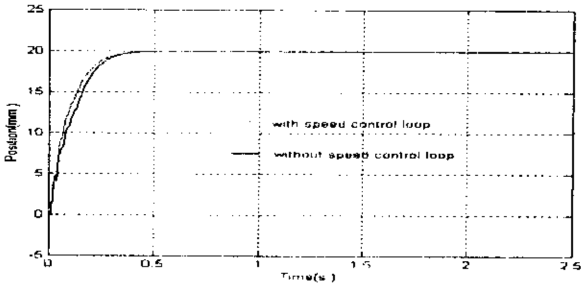


Fig. 7 Position response of the system under constant load at 20 mm.

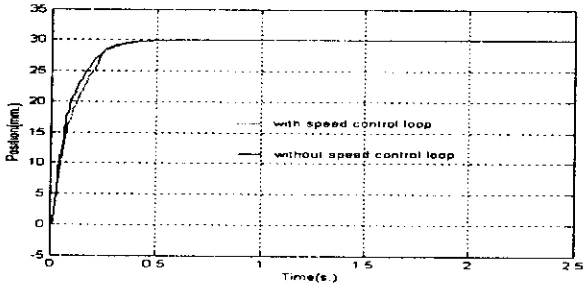


Fig. 8 Position response of the system under constant load at 30 mm.

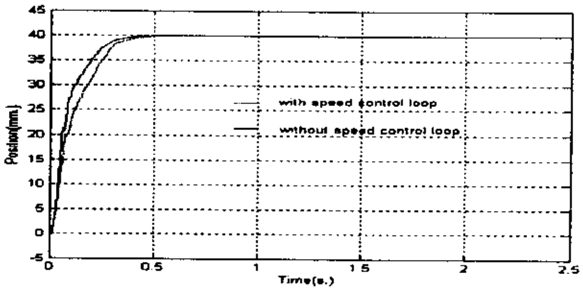


Fig. 9 Position response of the system under constant load at 40 mm.

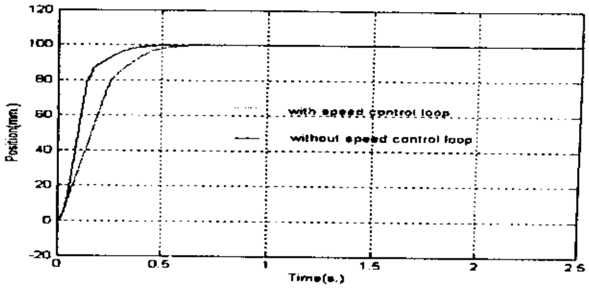


Fig. 10 Position response of the system under constant load at 100 mm.