FUZZY LOGIC CONTROL OF LINEAR INDUCTION MOTOR

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ABSTRACT

This paper presents fuzzy logic control for a Single-sided Linear Induction Motor (SLIM). In the last years, in the field of research on linear induction drives, a lot of efforts have been oriented to improve the dynamics performances of these machines by using fuzzy logic control (FLC). In order to insure a high transient behavior of the drive and to avoid the drawback of the parametric perturbations in the implemented control, the FLC is considered in this work.

I. INTRODUCTION

Linear motors (LMs) belong to the group of special electric machine that convert electric energy directly into mechanical energy of translatory motion [1]. LMs have nearly 165 years past and their areas have increased with fast progress in technology and shift necessity through different side by the day. Nowadays, LM systems have been come across in various applications; train, escalator, sporting equipment, elevator, Cd-rom, crank, printer, photocopier, robot…etc [2-5].

In this times, far too much effort have been continued to spent to improve dynamic performance of this types machines. We must observe care a choice of linear induction motor (LIM) control method to keep high transition behavior of LIM and also to prevent parametrical confuse, which arise from variation of LIM parameters, on implement control.

A goal of this paper is to realize LIM speed control with FLC.

II. LINEAR INDUCTION MOTOR

Due to the complexity of LIM's electromagnetic field theory, an analysis of the LIM's equivalent electrical circuit was undertaken, with alterations to the magnetizing inductance and a resistance representing the core loss [6,7].
Voltage and current ratings can be interchanged at will by the designer simply by changing the number of turns per primary coil and reconnecting coil groups in series or parallel as desired [8].

There are three phase winding consist of conductors laid in primary side chamfers in LIM primary side. Conductor numbers in other word winding numbers in each chamfer is the same. The windings, which form a phase, have been connected with series. Therefore, same current leaks from a phase.

In field theory, current, which leaks through LIM windings, is represented by current plate. However, as current is becoming dense discrete value, current plate is continuous and becoming dense value in fact. If both values of basic components of Fourier equations generate same sinusoidal magneto motor force, current of current plate becomes equal to winding current.

Primary currents:

$$i_1 = \sqrt{2} I_1 e^{jwt}\,,\ i_2 = \sqrt{2} I_2 e^{j(w-2\pi/3)t}\,,\ i_3 = \sqrt{2} I_3 e^{j(w-4\pi/3)t} \qquad (1)$$

Combine of three phase primary currents produces a magnetomotive force.

$$A_1 = \frac{3\sqrt{2}\,\mathrm{w}_1 k_{\mathrm{w}_1} I_1}{\pi \quad p_1} e^{j(wt-kx-\frac{\pi}{2})} \qquad (2)$$

$$k = \frac{\pi}{\tau} \qquad (3)$$

Current distribution on current plate:

$$j_1 = J_1 e^{j(wt-kx)} \quad \text{(A/m)} \qquad (4)$$

Producing magnetomotive force by the current distribution:

$$A_1 = \frac{J_1}{k} e^{j(wt-kx-\frac{\pi}{2})} \qquad (5)$$

Since A_1 in equation (2) is equal to A_1 in equation (5), J_1 can be obtained as shown below.

$$J_1 = \frac{3\sqrt{2}}{\pi}\frac{k\mathrm{w}_1 k_{\mathrm{w}_1} I_1}{p_1} = \frac{3\sqrt{2}\mathrm{w}_1 k_{\mathrm{w}_1} I_1}{p_1 \tau} \quad \text{(A/m)} \qquad (6)$$

Current distributions, which are determined in equation (4) and (6) is same in equivalence current plate, which produces sinusoidal magnetomotive force.

Secondary side of LIM is mostly made with homogeneous and conductive metal plates. That secondary side is made with homogeneous and nonmagnetic conductive plate is assumed.

STATOR

Stator design (pole number, stator length…etc) is limited by obtainable transformer iron plate dimensions. Each one transformer iron plate thickness is 0.5 mm and also length is 66 mm. Design LIM length is 264 mm. 200 unit transformer iron plates, which have dimensions given above, were used. Designed LM is shown in Figure 1.

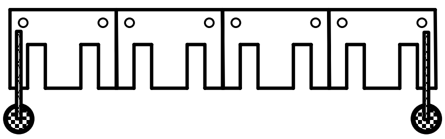

Figure 1. Designed LIM

STATOR WINDING ARRANGEMENT

Two bedded windings were used in SLIM stator side. The windings are series to decrease current consume. Pole gap 99 mm. stator winding arrangement is shown in Figure 2. There are 60 windings in each coil.

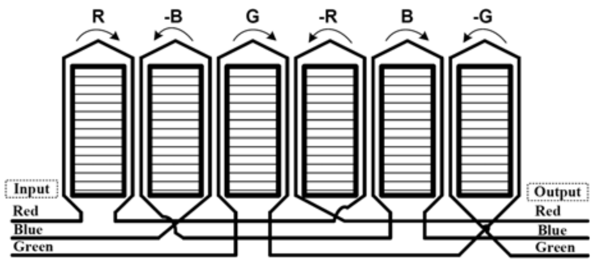

Figure 2. Stator winding arrangement (upper sight)

REACTION PLATE DESIGN

Reaction plate takes from solid or layer plates. To improve performance reaction plate is covered by aluminum or copper conductive plate. Secondary side is an important piece of LIM magnetic circuit in SLIM design. If the reaction plate is solid instead of layer or ladder plate, SLIM performance decreases quite [9,10]. Eddy currents are carried by layer plates in layer type reaction plate and resistive loss occurs. The resistive loss can be neglected. Thrust amplitude depends on the permeability of LIM's reaction plate. Since low permeability there are low thrust and also weak power factor. Changes in thrust amplitude can be observed by using different material in a reaction plate. An equivalent circuit model of LIM is given below.

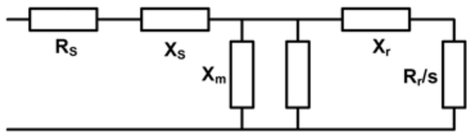

Figure 3. LIM equivalent circuit

The mathematical modeling of LIM in d-q form and parameters values of LIM, at its simplest, are given by the equations and table in Appendix [7, 11, 12].

III. FUZZY LOGIC

Fuzzy logic (FL) is suitable method to show input on output through system. That system has a determined characteristic tendency is not important. If a problem in system can be defined clearly, there is no necessary to use a FL. When a problem is complexity an also there are uncertain sides of problem, a fuzzy implication helps system act, which stem form state between input and output to be understood.

For complex and non linear systems, a fuzzy logic controller the best suitable is emphasize in many studies [13]. General fuzzy logic control system scheme is shown in Figure 4.

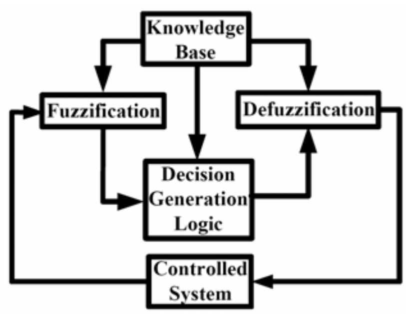

Figure 4. Fuzzy logic control system scheme [14]

A FLC consists of four main parts. These are Fuzzification, Knowledge Base, Decision Generation Logic and Defuzzification [15-17].

MEMBERSHIP FUNCTIONS

A membership function is a characteristic function of a fuzzy group. The member function gives membership degree to each member in value interval. x-axis indicates breaking points of variables. y-axis indicates membership values for linguistic variables. The forms, which are often used for membership functions, are monotonous, triangular, trapez or bell shapes. Membership functions are decided with user experiments, viewpoint, culture…etc by the user. Membership functions can be different in same problem for two users [18]. In this paper, 5 rules triangular membership function was used. In Figure 5, negative big(NB), negative small(NS), zero(ZE), positive small(PS) and positive big(PB), which are defined in certain variable space and also fuzzy membership functions, were constituted. A rule table, which belongs to membership functions, is given in Table I.

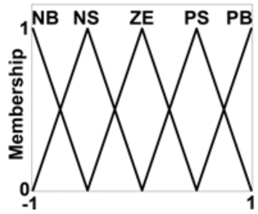

Figure 5. Five rule triangular membership function

Table I. Rule table

e \ de	NB	NS	ZE	PS	PB
NB	NB	NB	NS	NS	ZE
NS	NB	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PS
PS	NS	ZE	PS	PS	PB
PB	ZE	PS	PS	PB	PB

In most control systems, FLC input variables are error signals and derivatives of error signals or integrals of error signals.

After fuzzy logic controller is added, a new system block diagram is shown in Figure 6.

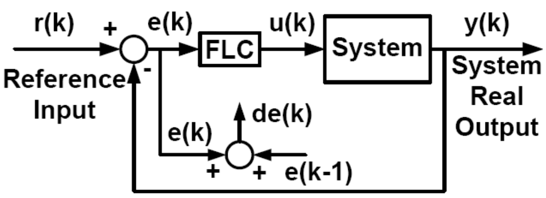

Figure 6. System with FLC block diagram

Certain inputs of FLC are error, which occurs during system runs and error variation.

FLC certain inputs can be obtained by equation (7) and (8). In these equations, k is a sampling step, r(k) is a reference input, y(k) is a real system output

$$e(k) = r(k) - y(k) \tag{7}$$

$$de(k) = e(k) - e(k-1) \tag{8}$$

Steps, which are necessary to be used in controller design, are summarized by topics in Figure 7.

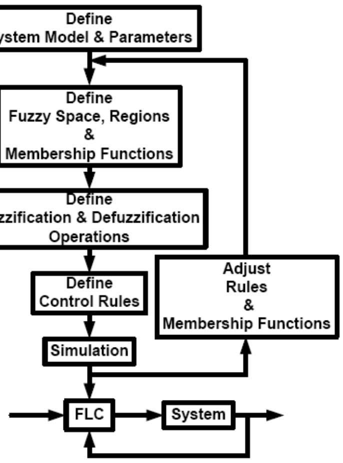

Figure 7. Fuzzy design flow diagram

VI. RESULTS

In this part, we do system numerical simulation with different conditions. We use SLIM characteristics listed in Table II and mathematical modeling given in Appendix.

The motor behavior without control is illustrated in Figure 8 and 9. The motor reaches maximum speed and the thrust goes to zero nearly in 7th seconds.

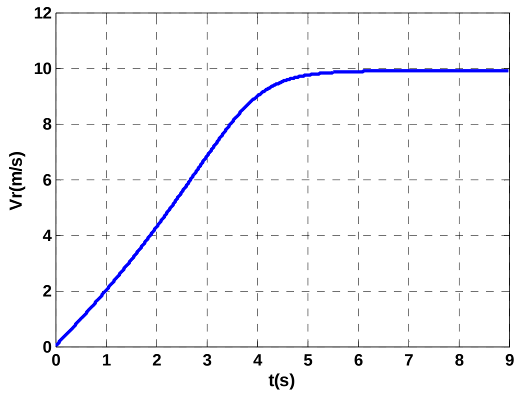

Figure 8. Speed variation in time without control

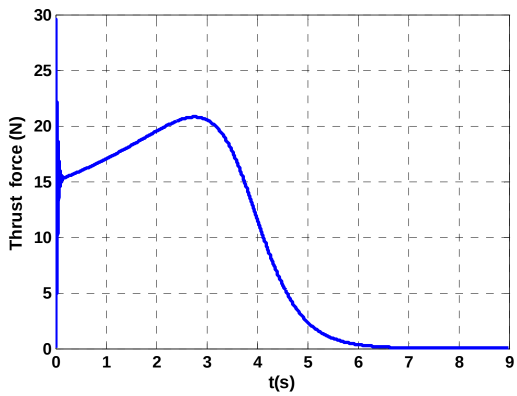

Figure 9. Thrust force without control

The numerical simulation results concerning FLCs are given in Figure 10-13. In Figure 10 and 11, there is only one speed reference 9.9 m/s during the simulation. The system reaches the reference speed under 0.2 seconds.

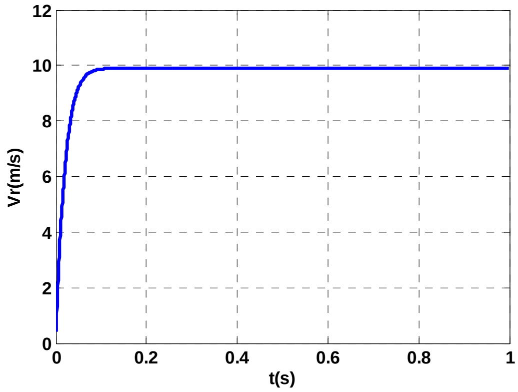

Figure 10. Speed variation with FLC (V_{ref} = 9.9 m/s)

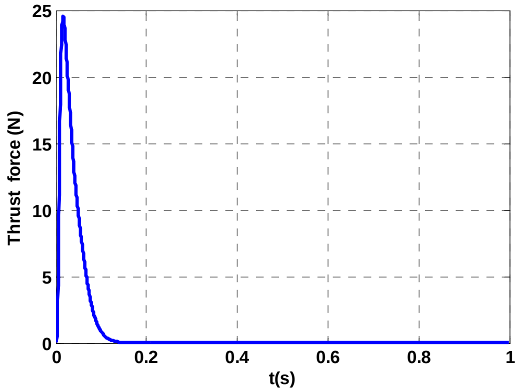

Figure 11.Thrust force with FLC (V_{ref} = 9.9 m/s)

During the simulation, which results are obtained in Figure 12, 13, the speed reference has changed, as follows: between 0 and 0.2 second, the reference is 5.0 m/s, from 0.2 to 0.5 second, the reference is equal to 9.9 m/s, which is the nominal value of speed, from 0.5 to 0.7 second, the reference is 7.0 m/s, between 0.7 and 1 second, the reference is 3.0 m/s.

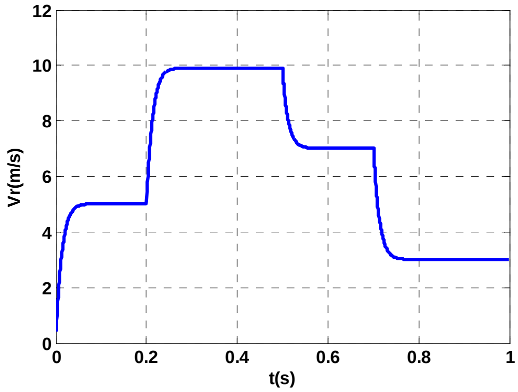

Figure 12. Speed variation in time with FLC with different speed references

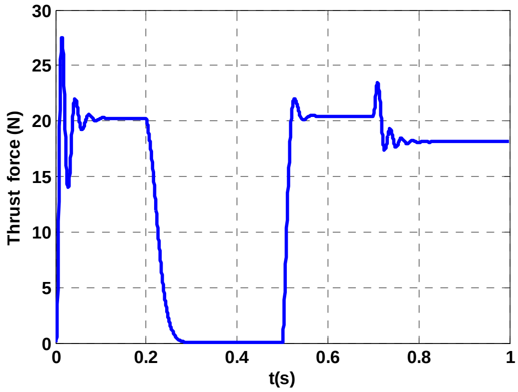

Figure 13. Thrust force with FLC with different speed references

V. EVALUATION

In this paper, a FLC of LIM was realized. The system output behavior was observed with using five rule triangular membership functions. Since the fuzzy logic controller has flexible rules, the control can be done easily.

Firstly, system behavior should be observed efficiently. And then membership functions and control rule table are obtained with taking error and error variations into account.

If thrust, current or flux control are required fuzzy logic can be used as a control method.

At work, since LIM's parameters are more variable than conventional induction motor's parameters, a control method, which will be used must response to variations in system in shortest period so a FLC can be more useful than conventional control methods.

APPENDIX

Table II. SLIM characteristics

Stator Resistance	R_s	7.2 Ω
Stator Impedance	X_s	9.26 Ω
Rotor Impedance	X_r	0 Ω
Rotor Resistance	R_r	2.68 Ω
Magnetizing Impedance	X_m	16.55 Ω
Nominal Voltage (phase)	V_n	60 V
Weight	m	8 kg
Pole Pitch	τ	0.099 m
Nominal frequency	f	50 Hz
Winding Configuration		wye
Number of phases		3

$$\frac{d}{dt}\begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} = \frac{1}{L_r L_s - M^2}\begin{bmatrix} -L_r r_s & \left[M^2\left(\omega_e - \frac{\pi}{\tau}V_r\right)\right] & M r_r & -M L_r \frac{\pi}{\tau} V_r \\ -\left[M^2\left(\omega_e - \frac{\pi}{\tau}V_r\right) - L_r L_s \omega_e\right] & -L_r r_s & L_r M \frac{\pi}{\tau} V_r & M r_r \\ M r_s & M L_s \frac{\pi}{\tau} V_r & -L_s r_r & \left[M^2 \omega_e - L_s L_r\left(\omega_e - \frac{\pi}{\tau}V_r\right)\right] \\ -L_s M \frac{\pi}{\tau} V_r & M r_s & -\left[M^2 \omega_e - L_s L_r\left(\omega_e - \frac{\pi}{\tau}V_r\right)\right] & -L_s r \end{bmatrix}\begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} + \frac{1}{L_s L - r - M^2}\begin{bmatrix} L_r & 0 & -M & 0 \\ 0 & L_r & 0 & -M \\ -M & 0 & L_s & 0 \\ 0 & -M & 0 & L_s \end{bmatrix}\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix}$$

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