A New-Style Control System of Linear Induction Motor

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Abstract-To get higher control performance, the fuzzy control strategy is applied in the control system of linear induction motor(LIM). In accordance with the model of LIM based on vector control, the speed of LIM is controlled by fuzzy speed controller, the magnetic thrust and the magnetic flux are controlled by fuzzy magnetic thrust controller and fuzzy magnetic flux controller. Simulation and experiment have shown that this method brings better control effect than the drive system of LIM that based on PID adjustor control.

Keywords-linear induction motor; magnetic thrust; magnetic flux; fuzzy controller

I. INTRODUCTION

Linear motor is a kind of linear drive unit, which can convert electrical energy into mechanical energy without any other intermediate drive gearing[1]. Compared with traditional electrical locomotive, which is driven by rotating motor, the locomotive driven by linear induction motor(LIM), such as light rail, subway and maglev vehicle have the advantages of less fabrication cost, greater climbing capacity, without vibration, noise and pollution. And their reliabilities as well as security has been greatly improved. For now, these vehicles driven LIM are being applied widely in Canada, Japan and Germany. In our country, National Development and Reform Commission has regarded the orbit vehicle driven by LIM as an important project to realize the transportation modernization, which is one of the national great research items. No.4 and No.5 of Guangzhou subway will select LIM as their control-driven system for first time. Now, there is some fruit in this area in mainland, but it is still needed to do more things to one of its key technologies, the controllable system driven by LIM. And it is realistic and valuable[2].

Traditional PID adjustor is usually applied in Torque adjustor and Flux adjustor, which are part of AC asynchronous motor's control system, which is controlled by VVVF inverter control, based on vector control. But traditional PID adjustor depends on accurate mathematical model of controlled object. It is difficult for us to establish an accurate mathematical model for vehicle driven by LIM because of the peculiar end effect of LIM and its variational air gap for running LIM in draught subway and maglev train,. So the control effect of VVVF inverter controller based on PID is not very well.

The fuzzy control doesn't depend on an accurate mathematical model of controlled object, and it has satisfactory robustness. So it has been widely used in control fields. There are some papers report that fuzzy control has been successfully used in AC asynchronous motor's control system [3.4.5].

The strategy of fuzzy control based on the vector control of LIM is introduced in this paper[6.7]. And simulation system is established. Some simulation experiments about the LIM were done. The validity of theoretical analysis is proved from the experimental result. We could see the validity of theory.

II. MATHEMATICAL MODEL OF LIM FOR VECTOR CONTROL

A. *Equivalent circuit of LIM*

The end effect generates, because both the primary windings and iron core of LIM are off .The primary is limited ,leading to the first kind of vertical end effect primarily .It causes that air-gap magnetic field have not only positive traveling wave magnetic field ,but alternating oscillating magnetic field .The second kind of vertical end effect is owing to flux aberrance when secondary windings of the running LIM enter and leave primary fields ,causing additional power loss and low performance of LIM[8.9].

Eddy current opposite to exciting current is induced on the secondary conductor when primary and secondary windings are relatively stable. It can reduce exciting current.

Define variable $Q = {DR_2}/{(L_m + L_2)}$ (1)

Where D is the length of LIM, R_2 is secondary resistance, L_m is mutual inductance, L_2 is secondary leakage inductance conversion value to the primary.

The total eddy current loss of out secondary conductor is

$$P = I_m^2 R_2 \frac{1-e^{-Q}}{Q} \quad (2)$$

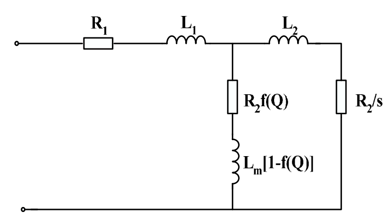

Fig.1.Equivalent circuit of LIM(Where S is rate of slide).

I_m is primary exciting current

$$\text{Define: } f(Q) = (1 - e^{-Q}) \tag{3}$$

T-equivalent circuit of the LIM is shown in Fig.1, considering dynamic longitudinal direction end effect.

B. Mathematical model of LIM for vector control system

In the rotor field directional coordinate system of rotating asynchronous motor, d axis is along side the direction of total rotor flux linkage vector λ_2, and rotor flux linkage has no component on the q axis direction, $\lambda_{2d} = \lambda_2, \lambda_{2q} = 0$. End effect only has effect on d axis , not on q axis. From the above analysis, voltage equation in the LIM synchronous reference axes coordinate is

$$\begin{cases} u_{1d} = R_1 i_{1d} + R_2 f(Q)(i_{1d} + i_{2d}) + \dfrac{d\lambda_{1d}}{dt} - \omega_1 \lambda_{1q} \\ u_{1q} = R_1 i_{1q} + \dfrac{d\lambda_{1q}}{dt} + \omega_1 \lambda_{1d} \\ 0 = R_2 i_{2d} / s + R_2 f(Q)(i_{1d} + i_{2d}) + \dfrac{d\lambda_{2d}}{dt} \\ 0 = R_2 i_{2q} / s + (\omega_1 - \omega_r)\lambda_{2d} \end{cases} \tag{4}$$

Flux linkage equation is

$$\begin{cases} \lambda_{1d} = [L_1 - L_m f(Q)] i_{1d} + L_m [1 - f(Q)] i_{2d} \\ \lambda_{1q} = L_1 i_{1q} + L_m i_{2q} \\ \lambda_{2d} = L_m [1 - f(Q)] i_{1d} + [L_2 - L_m f(Q)] i_{2d} \\ 0 = L_m i_{1q} + L_2 i_{2q} \end{cases} \tag{5}$$

Electromagnetic thrust and motional equation:

$$F_1 = \frac{3\pi}{2\tau}(\lambda_{1d} i_{1q} - \lambda_{1q} i_{1d}) \tag{6}$$

$$F_1 - F_{Load} = \frac{mdv}{dt} \tag{7}$$

Where m is mass of vehicle.

The conversion relationship between speed V of LIM and angular frequency ω is

$$V = \varpi\tau / \pi \tag{8}$$

From the above equation, Electromagnetic thrust can be expressed:

$$F_1 = \frac{3\pi}{2\tau} \cdot \frac{p}{2} \cdot \frac{L_m[1 - f(Q)]}{L_2 - L_m f(Q)} \left| \lambda_{2d} i_{1q} - \frac{L_2^2}{L_2 + L_m} \cdot \frac{f(Q)}{1 - f(Q)} i_{1q} i_{1d} \right| \tag{9}$$

The second item of (9) exists because of the end effect of LIM.

The basic theory of vector control is: the primary current can be divided into two non-coupling parts of field current component and armature current component through vector transformation matrix according to the fundamental thought of vector conversion control. To control the speed of LIM, both secondary flux and thrust are controlled by controlling i_{1d} and i_{1q}.

III. THE VECTOR CONTROL SYSTEM OF LIM BASED ON FUZZY CONTROL

A. Mathematical model of LIM for fuzzy control

Equation (7) shows that control electromagnetic thrust can control the speed of motor, and it can be obtained by transferring the three-phase current of primary coil. Not electromagnet torque, electromagnetic thrust is controlled of LIM comparing rotating motor.

From above analysis and mathematical model of LIM vector control, architecture diagram of LIM vector control system based on fuzzy control can be constructed. As illustrated in Fig 2.

FLC 1 is fuzzy speed controller , FLC2 is fuzzy magnetic flux controller, FLC3 is fuzzy electromagnetic thrust controller.

B. Design of fuzzy controller

As the length of this paper is limited, only given an example of fuzzy electromagnetic thrust controller design.

The input of fuzzy electromagnetic thrust controller is electromagnetic thrust error $e = F_1 - F_2$ and variance of

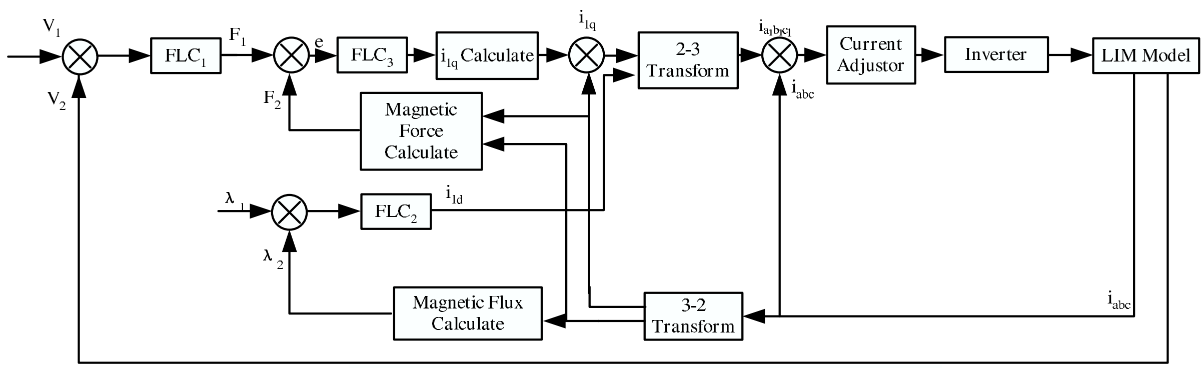

Fig.2.The scheme of fuzzy control based on vector control

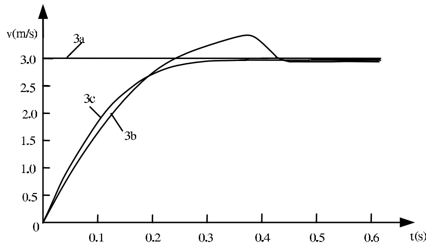

Fig.3.The speed emulation result comparison between the fuzzy control and the ordinary PID control.

3a.the present speed curve

3b.the speed curve with PID control

3c.the speed curve with the Fuzzy control

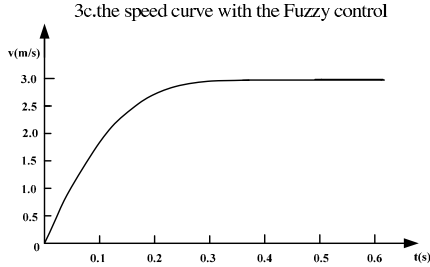

Fig.4.The experimental speed tracking of the Fuzzy control.

error Δe , i_{1q} is current reference signs of q axis by transferred from u , that is output of control variable. e , Δe , u correspond to the fuzzy variable E , EC , U of fuzzy controller ,the 7 subset of universe of discourse is followed: $\{NB, NM, NS, ZE, PS, PM, PB\}$, 13 grades of 7 subset is quantified $\{-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6\}$ Symmetrical, fold, nonuniform triangle membership function is chosen to variable E and EC. Symmetrical and uniform triangle membership function is chosen to variable U.

The analytic expression of fuzzy control rule is followed:

$$u = [\alpha E + (1-\alpha)EC],\ \alpha \in [0,1] \qquad (10)$$

Where, self adjusting formula of rule factor α is followed:

$$\alpha = \frac{1}{m}(\alpha_S - \alpha_0)|E| + \alpha_0$$

$$0 \le \alpha_0 \le \alpha_S \le 1 \ , \quad \alpha \in [\alpha_0, \alpha_S]$$

In the formula, m is quantified grade. In this design, m is equal to 6. α_0 and α_5 are upper limit and lower limit of rule factor .To improve the speed of simulation ,S-function of MATLAB is selected to implement the fuzzy control rule.

IV. THE RESULTS OF SIMULATION AND EXPERIMENT

According to the above analysis, MATLAB and it's SIMLINK module were adopted to simulate. The parameter of LIM as follows(model mumber:xy1809B-4.5CU2): secondary inductance : 0.03mH, primary inductance: 2.7H(count equal to 2.29H when U1=230V; count equal to 2.27H when U2=76V),mutual inductance: 0.034mH, secondary resistance: 0.05 ohm, primary resistance: 260 ohm, pole pitch: 4.5cm,number of pole pairs: 2,motor length: 88mm×95mm,start thrust: 8N,rated air-gap:2mm,frequency: 50Hz,synchronous speed: 4.5m/s.

Fig 3: the speed of response curves of PID control and fuzzy control when motor no load.

It is shown in figure 3b and figure 3c, the speed of response based on fuzzy control is rapid, both overshoot and error are smaller too, comparing to fuzzy control and PID control.

Fig 4: Experiment operation curve adopted fuzzy control algorithm. Comparing to figure 3c and figure 4, the result of experiment exactly inosculate to the result of simulation.

It is shown in the result of simulation and experiment: the system of LIM based on fuzzy control has better control effect than that based on PID control.

V. CONCLUSION

(1) The mathematical model of LIM by vector control is established according to the fundamental theory of vector change of revolving asynchronous motor, and considering end effect of LIM. LIM is controlled by fuzzy electromagnetic thrust controller and fuzzy magnetic flux controller. Fuzzy electromagnetic thrust controller and fuzzy magnetic flux controller are adopted by controlling LIM.

(2) LIM vector control system based on fuzzy control gains better control effect than traditional PID adjustor control system, according to the result of simulation and experiment. Static performance and dynamic performance of the whole system are improved.

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