Hamiltonian Method in the Application of Permanent Magnet Linear Motor Control

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***Abstract*-Ac motor control system is complex nonlinear system which contains many factors such as multi-variable, strong coupling, time-varying and uncertainty parameters, it is very complicated to adopt the traditional control method to control this system. First this paper established the mathematical model of permanent magnet synchronous linear motor from the perspective of energy shaping, and then according to the principle of the realization of feedback dissipative Hamiltonian, designed the motor speed controller, constructed a feedback dissipative Hamiltonian control system of permanent magnet synchronous linear motor, at last carried the simulation research on the system. The simulation result verified the accuracy and effectiveness of the control law, shown that it could achieve the control of permanent magnet linear motor by the use of this method.**

Keywords-pmlsm; hamiltonian system; energy; shaping; feedback dissipative

I. INTRODUCTION

In recent years, the linear motor as a kind of electromagnetic transmission device, it does not require any intermediate conversion which can achieve directly converting electrical energy into mechanical energy. It also have some advantage such as simple construction, can do high-speed linear motion, obtain a higher acceleration and easy to control, so that it is widely used in industrial production. However, AC servo system itself is a complex nonlinear system, there must be some outside interference factors to affect the normal running of the system and system parameters' change, load disturbance's existence increase the difficulty of control, therefore it need to build a reasonable control system, select effective control strategy, restrain system disturbances, let the system to be a stable state. Traditional control strategies have vector control, direct thrust control method, with the development of modern control theory, there has been an adaptive control, fuzzy intelligent control method and neural network control. [1] used a method of direct thrust control, has fast response and good robustness.[2] combined the vector control with the neural network, made asynchronous motor speed control system achieved optimal adjustment of the control parameters on-line, and improved the performance of the control system. So each control strategy has its own advantage, generally they could be combined with each other to achieve a better control effect. However, this paper from the perspective of energy shaping, change a nonlinear servo system into a dissipative Hamiltonian system by set the appropriate feedback control rate. and its controller structure is simple, easy to implement, can realize the requirements.

II. ESTABLISH THE PERMANENT MAGNET SYNCHRONOUS LINEAR MOTOR MATHEMATICAL MODEL [3]

First, in order to simplify the analysis, we can make the following assumptions:

(1)The three-phase stator windings is symmetrical, each phase winding has the same number of turns, the same resistance value, each phase winding axes are spaced 120 degrees, ignore the effect of the longitudinal end portions;

(2)ignore the impact of core saturation and temperature on electrical parameters;

(3)Conductivity of permanent magnet material is zero, the magnetic field generated by the permanent magnets is constant, ignoring the eddy current loss, hysteresis loss.

Then PMLSM stator voltage equations in the synchronous rotating d-q coordinate.

$$u_d = R_s i_d + p\psi_d - \omega\psi_q \quad (1)$$
$$u_q = R_s i_q + p\psi_q + \omega\psi_d \quad (2)$$

ω is permanent magnet linear motor which is converted into translational speed of rotation of the motor electrical angular velocity, $\omega = \frac{\pi}{\tau}v$; R_s is stator resistance; ψ_d, ψ_q,is d axis flux, q axis flux.

Flux equation is

$$\psi_d = L_d i_d + \psi_f \quad (3)$$
$$\psi_q = L_q i_q \quad (4)$$

L_d is d axis inductance; L_q is q axis inductance; ψ_f is mover magnet flux coupled to the stator. Electromagnetic force and mechanical movement equations in d-q coordinates.

$$F_e = \frac{3\pi \cdot n_p}{2\tau}\left[\psi_f i_q + (L_d - L_q) i_d i_q\right] \quad (5)$$
$$M\frac{dv}{dt} = F_e - F_l - Bv \quad (6)$$

N_p is number of pole pairs； F_e is electromagnetic force； F_l is load force：Bis viscous friction coefficient.

III. FEEDBACK DISSIPATIVE HAMILTONIAN REALIZATION

There is a nonlinear system

$$S:\ \begin{cases} \dot{x} = f(x) + G(x)u \\ y = h(x) \end{cases} \quad (7)$$

u is control variables, $x \in R^n, u \in R^n$.

If there is a feedback control law u enables the system to meet

$$f(x) + G(x)u = [J(x) - R(x)]\frac{\partial H(x)}{\partial x} \qquad (8)$$

and

$$G'(x)\left\{f(x) - [J(x) - R(x)]\frac{\partial H(x)}{\partial x}\right\} = 0 \quad (9)$$

$J(x) = -J^T(x)$, reflects within the system interconnect structure. $R(x)$ is semi-definite diagonal matrix, on behalf of additional resistive structure on the port. $G'(x)G(x) = 0$. So there is a feedback dissipative Hamiltonian realization for system (7). For a Dissipative Hamiltonian system[4] such as

$$\dot{x} = [J(x) - R(x)]\frac{\partial H(x)}{\partial x} \qquad (10)$$

When we select the desired positive Hamiltonian function to be Lyapunov function, it can be proved $\frac{dH(x)}{dt} = \frac{\partial^T H(x)}{\partial x}\cdot\frac{dx}{dt} = \frac{\partial^T H(x)}{\partial x}\cdot[J(x) - R(x)]\frac{\partial H(x)}{\partial x} \le 0$.

Therefore, according to Lyapunov stability principle, the system can be in stable state at the desired balance point.

IV. Design Speed Controller

According to the mathematical model of permanent magnet synchronous linear motor, Select system variables x, feedback control variables u.

$$x = (x_1, x_2, x_3)^T = (L_d i_d, L_q i_q, Mv)^T, u = (u_d, u_q)^T$$

Redefined equation coefficients and simplified equations, then the equations can change into

$$f(x) = \begin{cases} \dot{x}_1 = -k_1x_1 + k_2x_2x_3 \\ \dot{x}_2 = -k_3x_2 - k_2x_1x_3 - k_4x_3 \\ \dot{x}_3 = k_5x_1x_2 + k_6x_2 - k_7x_3 - F_l \end{cases} \quad G = \begin{Bmatrix} 10 \\ 01 \\ 00 \end{Bmatrix} \quad u = \begin{Bmatrix} u_d \\ u_q \end{Bmatrix} \quad (11)$$

Steady-state balance point of the system: in order to ensure the asymptotic stability of the system, when we study rotating motor, often use the maximum torque/current way to achieve electromagnetic torque control. For linear motors, can be seen from the electromagnetic force equation, when under ideal conditions, consider the linear motor symmetrical three-phase winding, air gap magnetic field distribution, the same axis inductance, electromagnetic force has a linear relationship with i_q, we can consider $i_d = 0$ vector control mode. Therefore, under conditions known load force we can obtained for a desired balance point of the system by calculating.

$$x_0 = (x_{10}, x_{20}, x_{30})^T = (L_d i_{d0}, L_q i_{q0}, Mv_0)^T$$

When

$$u = \begin{Bmatrix} u_d \\ u_q \end{Bmatrix} = \begin{Bmatrix} k_1x_1 - k_2x_2x_3 + v_1 \\ k_3x_2 + k_2x_1x_3 + k_4x_3 + v_2 \end{Bmatrix} \qquad (12)$$

The equation (11) can covert into $\dot{x} = f(x)' + Gv$

$$f(x)' = \begin{Bmatrix} 0 \\ 0 \\ k_5x_1 + k_6x_2 - k_7x_3 - F_l \end{Bmatrix}, v = \begin{Bmatrix} v_1 \\ v_2 \end{Bmatrix} \qquad (13)$$

Because of the conversion between mechanical energy and electrical energy in motor speed control system, by setting the desired balance point of system.

$$x_0 = (x_{10}, x_{20}, x_{30})^T$$

Then we can construct Hamiltonian for this system

$$H(x) = \frac{1}{2L_d}(x_1 - x_{10})^2 + \frac{1}{2L_q}(x_2 - x_{20})^2 + \frac{1}{2M}(x_3 - x_{30})^2 \qquad (14)$$

$\frac{\partial H}{\partial x} = \left\{\frac{1}{L_d}(x_1 - x_{10}), \frac{1}{L_q}(x_2 - x_{20}), \frac{1}{M}(x_3 - x_{30})\right\}^T$, according to (8), solved the equations we can get

$$J(x) = \begin{Bmatrix} 0 & 0 & -k_5L_dx_2 \\ 0 & 0 & -(k_6 + k_5x_{10})L_q \\ k_5L_dx_2 & (k_6 + k_5x_{10})L_q & 0 \end{Bmatrix}, R(x) = \begin{Bmatrix} r_1 & 0 & 0 \\ 0 & r_2 & 0 \\ 0 & 0 & B \end{Bmatrix}$$

$$v_1(x) = -r_1\frac{\partial H(x)}{\partial x_1} - k_5L_dx_2\frac{\partial H(x)}{\partial x_3},$$

$$v_2(x) = \; = -r_2\frac{\partial H(x)}{\partial x_2} - (k_6 + k_5x_{10})L_q\frac{\partial H(x)}{\partial x_3}$$

Put the above results into formula (12), we could get the feedback control variables u of the system finally.

V. Simulation and Analysis

Figure.1 is the simulation model of the control system in Matlab/Simulink[5].

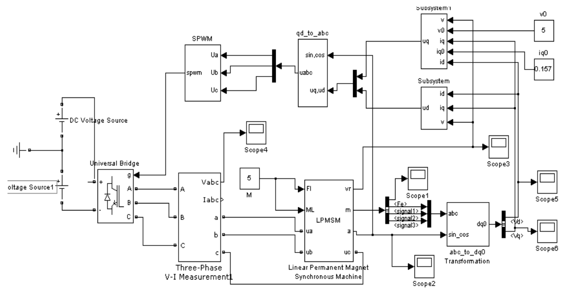

FIGURE 1. THE SIMULATION OF MOTOR SPEED CONTROL SYSTEM.

When $r_1 = r_2 = 1$, $r_1 = r_2 = 3$, $r_1 = r_2 = 5$, motor speed curve is shown in Figure.2 by adjusting the parameters of the controller can change the system overshoot, response speed.

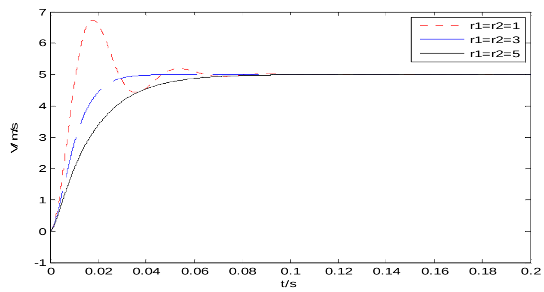

FIGURE 2. THE PMLSM SPEED CURVE.

VI. Conclusions

Form the study we can see that it is more convenient to design the system controller in a feedback dissipative Hamiltonian system. and controller requires less amount of tuning parameters. When parameter values is small, the system has a more rapid response and a larger overshoot, When parameter values is large, overshoot quantity turn small, but it cost a lot time to achieve a stable state. So parameter switching method or the parameters optimization algorithm can be considered to make the system be better with fast response and stability. In addition, when the load force disturbance is unknown, the system need to introduce load force observer load force in real time observation.

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