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—pmblsm; 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 some outside interference factors to affect the normal running of the system and system parameters' change, and then adopt the traditional control method to control the system. So each control strategy has its own control parameters on-line, and improved the performance of speed control system achieved optimal adjustment of the control parameters.

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.

\[ \begin{align*}
    u_d &= R_d i_d + p \psi_d - \omega \psi_q \\
    u_q &= R_q i_q + p \psi_q + \omega \psi_d
\end{align*} \]  

(1)

\( \omega \) is permanent magnet linear motor which is converted into translational speed of rotation of the motor electrical angular velocity, \( \omega = \frac{2\pi}{T} \); \( R_s \) is stator resistance; \( \psi_d, \psi_q \) is d axis flux, q axis flux.

Flux equation is

\[ \begin{align*}
    \psi_d &= L_d i_d + \psi_t \\
    \psi_q &= L_q i_q
\end{align*} \]  

(3)

(4)

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

\[ \begin{align*}
    F_e &= \frac{2\pi n_p}{2} [\psi_q i_d + (L_d - L_q) i_d i_q] \\
    M \frac{dv}{dt} &= F_e - F_l - Bv \\
    N_p &= \text{number of pole pairs} \quad F_e \quad \text{is electromagnetic force} \quad F_l \quad \text{is load force} \quad B \quad \text{is viscous friction coefficient.}
\end{align*} \]  

(5)

(6)

III. FEEDBACK DISSIPATIVE HAMILTONIAN REALIZATION

There is a nonlinear system

\[ \begin{align*}
    S: \{ \dot{x} &= f(x) + G(x)u \\
    y &= h(x)
\end{align*} \]  

(7)

\( u \) is control variables, \( x \in \mathbb{R}^n, u \in \mathbb{R}^n \).
If there is a feedback control law $u$ enables the system to meet

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

and

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

$$[f(x) - R(x)]\frac{\partial H(x)}{\partial x} = 0$$

We select the desired positive Hamiltonian function to be Lyapunov function, it can be proved that:

$$\frac{\partial H(x)}{\partial x} - R(x) \leq 0$$

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

$$H(x) = \frac{1}{4l_d^2} (x_1 - x_{10})^2 + \frac{1}{4l_q^2} (x_2 - x_{20})^2 + \frac{1}{2R} (x_3 - x_{30})^2$$

$$\frac{\partial H(x)}{\partial x} = \frac{1}{l_d} (x_1 - x_{10}) \frac{\partial H(x)}{\partial x_1} + \frac{1}{l_q} (x_2 - x_{20}) \frac{\partial H(x)}{\partial x_2} + \frac{1}{R} (x_3 - x_{30}) \frac{\partial H(x)}{\partial x_3}$$

$$\frac{\partial H(x)}{\partial x_1} = -k_{d1}x_1 - k_{d2}x_2 + v_1$$

$$\frac{\partial H(x)}{\partial x_2} = -k_{q1}x_1 + k_{q2}x_2$$

$$\frac{\partial H(x)}{\partial x_3} = -k_{l1}x_1 - k_{l2}x_2 - F_1$$

FIGURE 1. THE SIMULATION OF MOTOR SPEED CONTROL SYSTEM.

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

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.

REFERENCES