Stability Analysis and Research of Permanent Magnet Synchronous Linear Motor

Rudong Du [a], Huan Liu [b]

School of Mechanical and Electronic Engineering, Shandong University of Science and Technology, Qingdao, 266590, China.

[a]2010397990@qq.com, [b]490329492@qq.com

Abstract

The linear motor has the characteristics of linear drive and quick response, especially in the high-speed feed system. In this paper, the plate-type ac permanent magnet synchronous linear motor is studied, and its internal working principle, structure and motion characteristics are analyzed in detail. On this basis, an effective control model is creatively proposed to improve the control stability of the linear motor. In addition, a mathematical analysis model was established for the motor. The servo control concept of linear motor was used to model and conduct electromagnetic field analysis. Vector control method was adopted to control the linear motor. Finally, the model was simulated and analyzed by Ansoft.

Keywords

Permanent magnet synchronous linear motor, stability, electromagnetic field analysis , ansoft.

1. Introduction

The future direction of the manufacturing industry will be intensive, modular and high-speed. In order to meet the requirement of high speed spindle pair machining, the fast feed servo system came into being as shown in figure 1 below. High speed feed system can be realized by the following two structures: ball screw and linear motor drive. Ball screw transmission mode, by rotating servo motor was carried out on the ball screw drive, the biggest only can realize the speed of 60 m/min, but this way, complex structure, high speed running, the friction between the components elastic deformation factors can cause movement lag, the working characteristic of the result in nonlinear error, the system inertial mass is bigger, can not quick response to control instruction[1].

The transmission mode of linear motor is to connect it directly with the worktable parts. There is no transmission link in the middle. The machine is driven directly by the motor, and the machining precision, rigidity and response speed of the system are greatly improved. The biggest characteristic of linear motor is to carry out linear motion. Because there is no mechanical contact, dc motor has small volume and relatively simple structure, few internal parts, smooth motion process, high repeatability precision and control precision, which can realize the control precision of submicron. Compared with the traditional rolling screw structure, the maintenance is simple, so the maintenance of the motor is easy and the life of the motor is long.

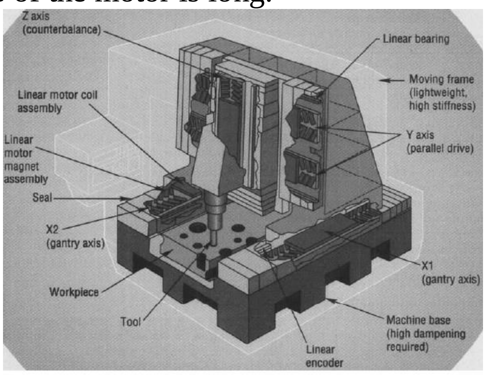

Fig.1 Fast feed system

2. Basic Structure of Ac Permanent Magnet Synchronous Linear Motor

2.1 Preliminary Structural Design

The primary structure of linear motor consists of iron core and armature winding. The structural function of the core is to reduce magnetic flux leakage, gather flux, increase thrust and air gap density. The coil is the most basic unit of winding. When pitch is the same as pitch, the winding is called interval winding, and when pitch is larger than pitch, it is called short distance winding. The winding in the linear motor cannot close the head and tail, so there will be end effect. In order to reduce the end effect, this paper selects the single-layer integral pitch concentrated winding structure [2]. The relative displacement of the stator and the moving line of the permanent magnet linear motor is corresponding to the position Angle of the rotating permanent magnet motor. Therefore, the gear groove force of the permanent magnet linear motor can be defined as the negative inverse of the magnetic field energy storage relative to the displacement, which is:

$$\alpha = \frac{2\pi x}{L}$$

$$F_{cog} = -\frac{\partial W}{\partial \alpha}\frac{\partial \alpha}{\partial X}$$

When the coil of the linear motor enters the current, the coil will generate an inductive magnetic pole, which will interact with the permanent magnet. Only when the force produced by each coil is in the same direction, the total net force produced by the coil is the largest, so there are definite rules for the sequence of three-phase winding. The motor studied in this paper USES the winding empty slot method to generate empty slots through the recombination of windings, and the original winding phase sequence remains unchanged. Among them, permanent magnet adopts permanent magnet material NdFe30. Permanent magnet, primary winding and iron core realize coupling through air gap. After electrification of primary winding, magnetic chain is generated. As one of the most basic parameters in motor design, the reverse electromotive force directly affects the thrust performance of motor. In the ideal case, the inverse electromotive force waveform is sinusoidal waveform. In this paper, the motor distance is 23.4mm, in which the width of magnetic steel is 18mm and the thickness is 3mm. The magnetic field in the direction of a straight line is a sinusoidal distribution, generating traveling wave magnetic field constantly shifting in one direction, as shown in figure 2 below：

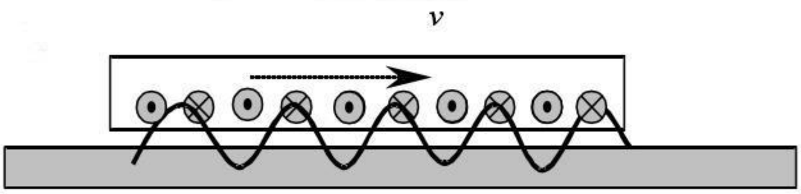

Fig. 2 Traveling wave magnetic field in air gap of ac linear motor

2.2 Physical Model of Linear Motor

The linear motor is different from the rotary motor and has its unique mechanical and electromagnetic coupling characteristics. By virtue of the coordinate system (d-q coordinate system) in the rotating motor, it is assumed that the linear motor has the same coordinate system. After coordinate transformation of stator current I, two components are obtained, namely thrust current and excitation current. By controlling the two phases and amplitudes separately, the coupling between the magnetic chain and the thrust can be reduced and decoupling can be realized.

$$u_d = R_S i_d + L_d\frac{di_d}{dt} - \omega L_q i_q = R_S i_d + \frac{\varphi_d}{dt} - \omega\varphi_q$$

$$u_q = R_s i_q + L_q\frac{di_q}{dt} + \omega L_d i_d + \omega\varphi_{pm} = R_s i_q + \frac{\varphi_d}{dt} + \omega\varphi_d + \omega\varphi_{pm}$$

In the above equation, R_S is the rotor winding resistance, L_d and L_q are respectively the inductance values of d axis and q axis, v is the motor motion displacement and $u_d u_q$ are respectively the voltage values of q axis of d axis of the motor. $\varphi_d\varphi_q$ is the magnetic flux component of d axis, q axis, and φ_{pm} is the excitation flux. Ideally, electromagnetic thrust is calculated by the following formula:

$$P_e = u_a i_a + u_b i_b + u_c i_c = \frac{3}{2}(u_d i_d + u_q i_q)$$

Substitute in:

$$P_m = Fv = \frac{3\pi}{2\tau} v(\varphi_d i_q - \varphi_q i_d) + \frac{3\pi}{2\tau} v\varphi_{pm} i_q$$

Through the above equation, we get the relationship between current and electromagnetic thrust, and the output power of electromagnetic external thrust. By controlling the current, the electromagnetic thrust can be controlled and the speed can be controlled. The motion of the linear motor follows the above equation.

3. Modeling and Electromagnetic Analysis of Linear Motor

3.1 Create the Motor Geometric Model

In order to carry out the simulation and verification of permanent magnet synchronous linear motor, the first step is to model the linear motor. The permanent magnet synchronous linear motor model is built by Ansoft with its own drawing function. According to the actual structural size of each part required in the permanent magnet synchronous linear motor servo system, the overall simulation model of the permanent magnet synchronous linear motor is formed. As shown in the figure 3:

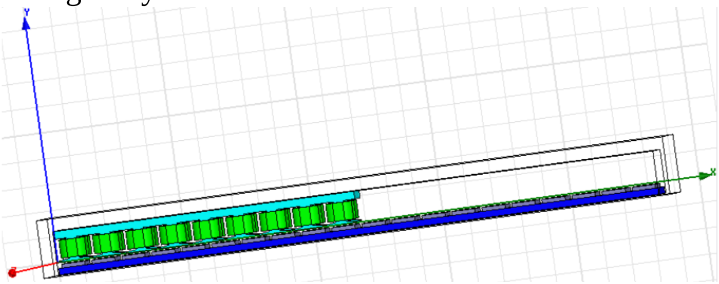

Fig. 3 Geometric model of flat plate permanent magnet synchronous linear motor

After the model is built, the excitation is set and the coil winding is closed. Therefore, the direction of the source needs to be specified when the excitation source is loaded. This requires setting the direction of the Section surface and selecting the established winding[3]. After set up the solution domain, geometric model of the air gap has surrounded the entire motor face domain, open circuit, linear motor as core can produce end magnetic flux leakage, therefore, to impose boundary conditions can cause the error of calculation, surrounded by establishing linear motor the whole solution domain geometry model of magnetic field, in the use of balloon boundary can be very good simulating the actual magnetic field of linear motor. In parameter setting, force and torque can be calculated, inductance can be calculated, residual can be solved, and mesh size can be divided.

3.2 Analysis of Simulation Results

Finite element analysis model, load, boundary, solution were set up, after the completion of execution of the Validation check command, self-inspection of pop-up dialog, when all set up correctly, start the solving process, the solving process, process display box alternating progress information display system calculation process, such as refinement of subdivision, solving matrix and computing power, user can interrupt according to need to solve, after solving, information dialog box will pop up message accordingly. Execute the Solution data command, and the Solution observation dialog box will pop up. By various operations of this dialog box, the Solution can be observed.

As can be seen from the figure below, the relationship between the triangle element and the number of convergence is expressed. When selecting the Convergence option at the top of the dialog box, the Convergence information can be observed. In this case, the system has completed four adaptive processes, and the results tend to converge. By default, the convergent data is displayed as a table, but it is graphically straightforward by selecting the Plot item in the dialog box. In the graphical display dialog box, the relationship between triangular elements and convergence times, total energy and convergence times, energy error percentage and convergence times, magnetic field force and convergence times can be directly expressed.

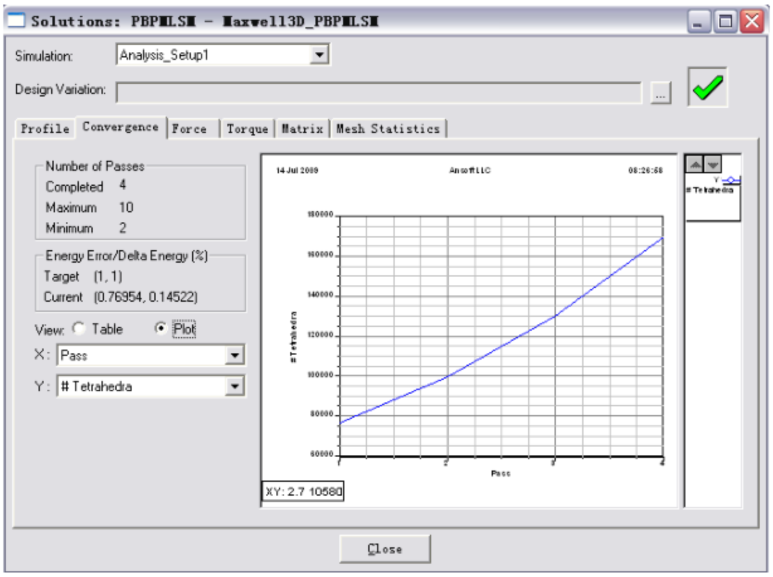

Fig. 4 Convergence times and force information of the motor

Selection dialog at the top of the Force and Toque options, as shown in the above parameters can be observed from the information, the resulting Force and torque of the motor, in this case, only contains a motor bearing information[4]. As shown in figure 4 Force information including by X Y component in two directions and the total Force, torque information in Ansoft software is the direction for the physical coordinate system is the direction of figure in numerical minus sign in front of the Force, Force exerted on behalf of the motor for the opposite direction to coordinate direction.

Then select the stator in the model window and execute the B_Vector command. In the post-processing field diagram display interface, you can change the name of the drawn post-processing field diagram[5]. Finally, in the generated vector magnetic field map, the result can also be optimized, the display style and color ratio can be changed to make the whole more consistent with the results. After a series of adjustments, the final display effect is shown as follows figure 5:

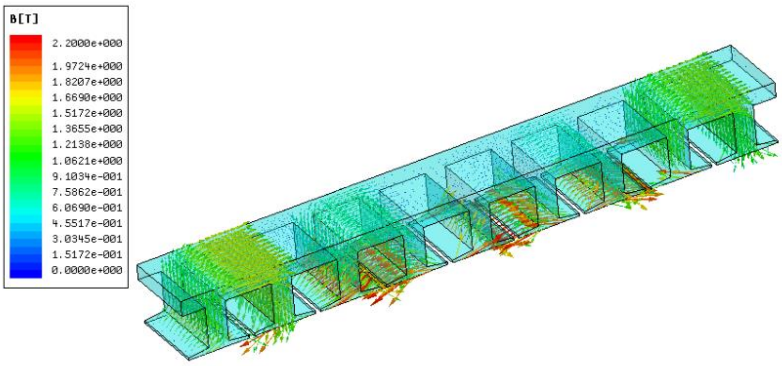

Fig. 5 Fagnetic density field diagram of moving vector

Through the simulation and analysis of the permanent magnet linear motor and its servo control system, the permanent magnet synchronous linear motor is shown by its high precision and large thrust. Stability and reliability can be further improved by optimizing mechanism design and improving control methods. Through software analysis, the mechanism of linear motor can be optimized to reduce the influence of thrust fluctuation, harmonic component and end effect on the stability of linear motor[6].

Based on the hardware structure of the linear motor, based on the analysis of the linear motor primary structure and secondary structure, and optimize the mechanical structure of the linear motor, the primary structure of the distributed winding and single layer from the concentrated winding, a positioning pin hole on each base design, simple optimization in the design of the structure to reduce the factors affecting the stability of the linear motor.

4. Summarizes

In this paper, the velocity stability of PMSM under the condition of torque and convergence is analyzed, and the electromagnetic thrust, inductance and flux components of PMSM are derived and calculated. By Ansoft software, the simulation experiment and the linear motor servo system of vector magnetic field is analyzed, finally the theory and simulation results validate each other, this paper put forward the thrust fluctuation of permanent magnet linear motor selection of the appropriate dynamic sub polar distance, the cogging force of the motor can be effectively weakened, winding induction electromotive force exists phase difference, which can realize the equivalent distribution of each phase winding, can effectively weaken the no-load harmonic content in the counter electromotive force, the purpose of suppressing the motor thrust ripple.

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