Performance analysis of low-speed and large-thrust cylindrical linear motor with double-layer fractional-slot winding

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Abstract. For low-speed and large-thrust situations, the single-layer winding permanent magnet linear motor is inefficient because of its large distance, and the thrust fluctuation is large. In order to solve this problem, a finite element analysis model of cylindrical permanent magnet linear motor is established in a cylindrical permanent magnet linear motor, and the Ansoft software simulation is used to ensure the positioning force and thrust of the double-layer winding motor and single-layer winding motor under the same key parameters. The performance of double-layer winding motor and Single-layer winding motor at different frequencies is compared and analyzed. The simulation results show that the cylindrical linear motor with double-layer fractional-slot winding structure is more suitable for occasions with low speed and large thrust, and has higher operation efficiency.

1 Introduction

The permanent magnet linear synchronous motor with fractional-slot concentrated winding has the advantages of small size, quick response, low loss, large thrust, low thrust fluctuation and low installation cost[1-3]. Lu Qinfen, College of Electrical Engineering, Zhejiang University, who based on finite element method, took the 12-groove / 11-pole structure and 12-groove / 11-pole structure for example, and analyzed the influence of structural parameters of unilateral and bilateral motors on motor performance[4]. Wang Hao, the Institute of mechanical and vehicle engineering of Beijing Institute of Technology, had adopted a new method of nonlinear magnetic circuit model, and obtained the essential rule of the longitudinal end effect. At the same time, he applied this method to reducing the

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positioning force of the integer slot motor and the positioning force of the fractional-slot motor[5].

A new design method of low speed and high efficiency cylindrical permanent magnet linear motor is presented in this paper. Duplex winding technology is applied to the design of cylindrical permanent magnet linear Motor[6-7]. Taking 15 slot /16 pole dual winding and 15 slot /16 pole Single-layer winding for example, this paper analyzes the matching of the number of pole slots for dual winding and permanent winding of cylindrical permanent magnet linear motor. The finite element analysis model of a cylindrical permanent magnet linear motor is set up. Through the Ansoft software, the cylinder type Single-layer winding and dual winding linear motor are simulated, and the performance of the two kinds of structural motors at different frequencies are compared. Through comparison and analysis, it is proposed that a linear structure be suitable for the low speed and high thrust density occasion which provides a basis for optimal design of this motor type.

2 Finite element simulation of double-layer winding motor

In actual motor production and design, it is necessary to have low loss, high efficiency, low noise, low torque fluctuation, high winding coefficient and installation flexibility[8-10]. Therefore, the design of the fractional-slot permanent magnet linear motor is first considered by the pole slot coordination problem of the motor. This paper takes fractional-slot linear motor as an example.

2.1 Finite element modeling of two types of winding motor

Finite element analysis is to mathematically solve practical problems and to obtain approximate solutions. The essence is to simplify the problem, and its modeling steps are shown in Fig. 1.
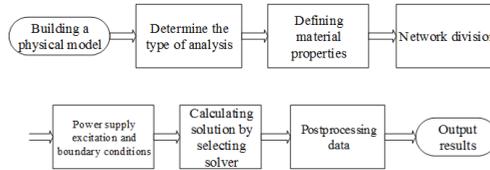

Fig. 1. Ansoft modeling steps.

The finite element analysis model of cylindrical linear motor is established by Ansoft software, as shown in Fig. 2 and Fig. 3.
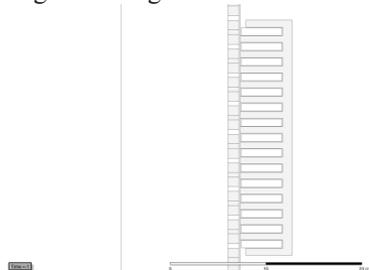

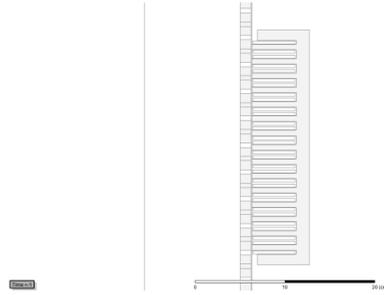**Fig. 2.** Single-layer winding linear motor simulation model.

Fig. 3. Dual winding linear motor simulation model.

2.2 Positioning force simulation analysis of two types of winding motor

When the linear motor has no excitation source, the curves of the relationship between the dynamic force and the time are calculated by the calculation of the Anosft. No current flow in the motor coil is shown in Fig. 4 and Fig. 5. At this time, the undulation of the motor's no-load thrust is attributable to the effect of the cogging force and the end force of the motor.
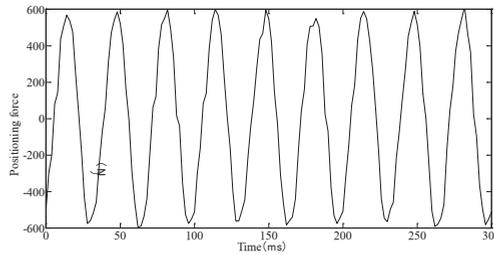

Fig. 4. Thrust curve of Single-layer winding motor without excitation.

As can be seen from Fig. 4, when no excitation source is applied, the thrust of a Single-layer winding motor fluctuates between -625N and 625kN due to the action of cogging force and end force.
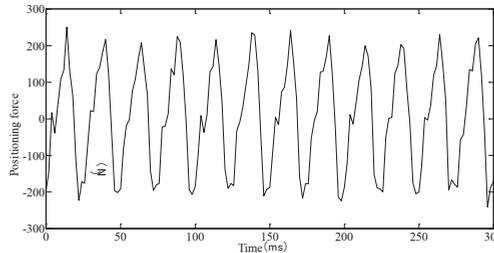

Fig. 5. Thrust curve of Double-layer winding motor without excitation.

It can be seen from Fig. 5 that when there is no excitation source, the thrust of the dual winding motor fluctuates between -240N and 240kN due to the action of the cogging force and the end force.

According to the fluctuation of the positioning force in Fig. 4 and Fig. 5, it can be seen that the positioning force of the Single-layer winding motor is far greater than the positioning force of the dual winding motor under the same gear distance. This is due to the characteristics of the double-winding structure of the motor, the side end slot of the

double-winding structure is half groove, which is different from the side end slot of the Single-layer winding structure of the motor.

2.3 Thrust simulation analysis of two types of winding motor

Above, two models of structural motors were established, and the range of thrust fluctuation without excitation source was calculated. Next, current source excitation is added to study the range of thrust fluctuation of two structural motors. In order to make the thrust result comparable, it is necessary to ensure that their key parameters are the same, especially to ensure that the rated power and synchronous speed of two kinds of structural motors are the same. The circuit parameters of the two types of motors are shown in Table 1.

Table 1. The parameters of Double-layer winding of PMLM.

Parameters	Single-layer winding motor	Double-layer winding motor
Rated power	7.5KW	7.5KW
Synchrono-us speed	0.45m/s	0.45m/s
Frequency	15Hz	15Hz

When the 7.5KW Single-layer winding motor is coupled with current excitation, the relationship between the force and time of the motor is shown in Fig. 6.
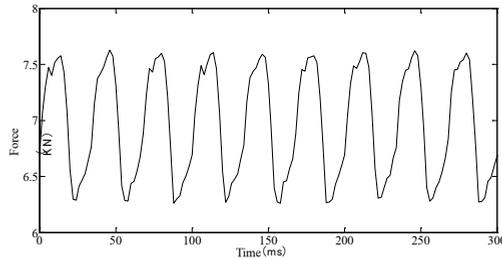

Fig. 6. Thrust curve of Single-layer winding motor with excitation.

When the current excitation is added to the 7.5kW dual winding motor, the relationship between the force and time of the motor is shown in Fig. 7.
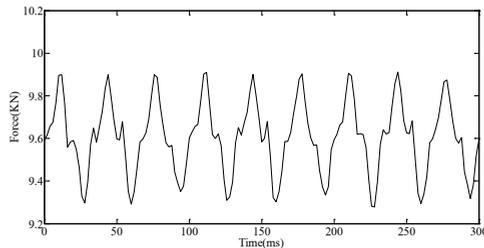

Fig. 7. Thrust curve of Double-layer winding motor with excitation.

As can be seen from Fig. 6 and Fig. 7, obviously, under the same condition, the dual winding structure motor is far superior to the Single-layer winding motor in thrust size and percentage of thrust fluctuation.

3 Conclusion

In this paper, the finite element analysis model of a cylindrical permanent magnet linear motor is established, and the single and dual winding linear motor are analyzed by the simulation of Ansoft software. Through the comparison of two kinds of structure motors, the following conclusions are reached. It proved that the dual winding pole slot matching method has obvious effect on the thrust fluctuation of the motor. Under the condition of the excitation source, the dual winding motor is more suitable for the high thrust density and high precision environment.

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