Study on Design of a Novel Magnetic Field Modulation Linear Primary Permanent Magnet Synchronous Motor

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Background

Nowadays, linear induction motor(LIM) has been widely used in rail transit, but the efficiency and power factor of the LIM are rather low; linear permanent magnet synchronous motor has the advantages of high efficiency, high power density, small volume, good performance and so on, but the armature windings and PMs of traditional linear permanent magnet synchronous motor respectively arranged in different sides, which one of sides must be along with the track. Therefore, manufacturing and maintenance costs are high, and the applications in long distance rail traffic are limited.

Objectives

- Structure requirement: Both the permanent magnet and the windings are in the primary side.
- Performance requirement: Good no-load characteristics will be obtained.

Structure

Primary

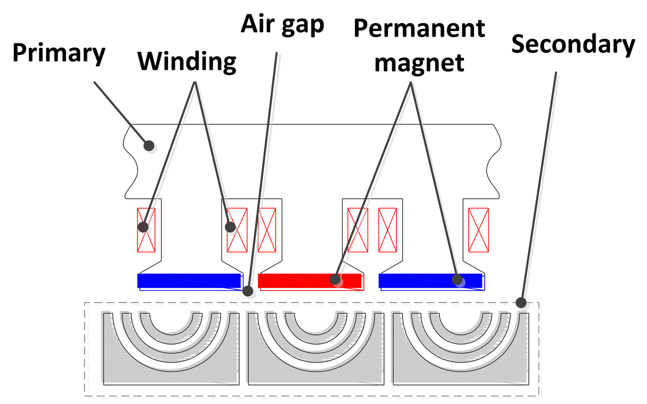

Fig. 1. Structure of LPPMSM

Fig. 2. Physical map of rail transit

The primary (Short side) consist of a primary core made of silicon steel sheets, three-phase armature windings and PMs. The pole number of the armature winding is 2q, the pole number of the permanent magnet is $2P_{PM}$, and the two magnetic fields are matched by different poles. In order to facilitate windings, the primary iron core is designed with a half closed slot, and the permanent magnet is attached to the surface of the primary tooth.

Secondary

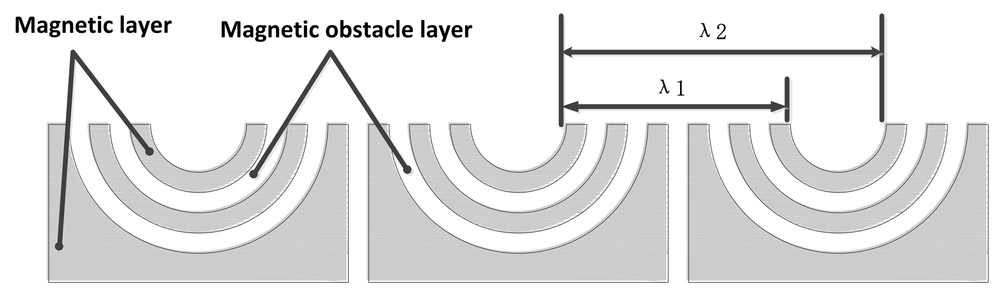

Fig. 3. Structure of secondary

The secondary are composed of magnetic layers and magnetic obstacle layers. This kind of secondary structure can cause flux to flow along paths conducive to electromechanical energy conversion.

The polar arc factor is defined as length lambda 1 divided by length lambda 2, and the electromechanical coupling ability of the motor can be adjusted by changing the pole arc coefficient.

Conclusion

- a novel magnetic field modulation linear primary permanent magnet synchronous motor (LPPMSM) has been proposed.
- In order to improve further capability of magnetic field modulation, the hybrid secondary structure has been used.
- The linear primary permanent magnet synchronous motor is carried out by 2D FEM, and the electro-magnetic characteristics of LPPMSM at no-load condition are obtained by 2D FEM.

Principle

formulas

The air-gap permeance can be approximately represented as:

$$\lambda_g(x,t)=\lambda_0+\lambda_1\cos[N_r\frac{2\pi}{L_a}(x-x_0-v_t t)] \quad (1)$$

In the formula(1), λ_0 is the mean value of air gap permeance, λ_i is i order harmonic amplitude, N_r is the number of secondary convex poles , L_a is primary length, and x_0 is initial position and V_t is the motor speed.

The magnetomotive force generated by the permanent magnet can be approximately represented as:

$$f_{PM}(x)=\frac{4B_r h_{PM}}{\mu_0\pi}\cos(p_{PM}\frac{2\pi}{L_a}x) \quad (2)$$

Where B_r is the residual magnetism of permanent magnet, h_{PM} is the thickness of permanent magnet, P_{PM} is the number of permanent magnet pole-pairs and μ_0 is vacuum permeability.

Thus, the air gap flux density can be expressed as:

$$B_{ag}(x,t)=f_{PM}(x)\cdot\lambda_g(x,t)=\frac{4B_r h_{PM}\lambda_0}{\mu_0\pi}\cos(p_{PM}\frac{2\pi}{L_a}x)+\frac{2B_r h_{PM}\lambda_0}{\mu_0\pi}\cos\left[(p_{PM}+N_r)\frac{2\pi}{L_a}(x-\frac{N_r v_t t+N_r x_0}{p_{PM}+N_r})\right]+$$
$$\frac{2B_r h_{PM}\lambda_0}{\mu_0\pi}\cos\left[(p_{PM}-N_r)\frac{2\pi}{L_a}(x+\frac{N_r v_t t+N_r x_0}{p_{PM}-N_r})\right] \quad (3)$$

The third term in the formula(3) is chosen as the effective harmonic component of the LPPMSM .

The pole-pairs of the armature winding is

$$q=|P_{PM}-N_r|$$

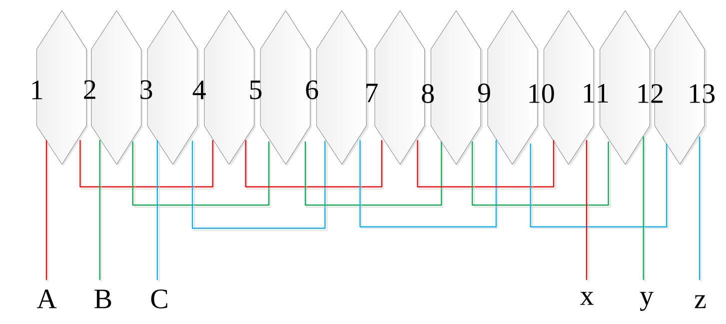

Fig. 4. Winding connections

Table 1 Key design data

Itmes	Value
Number of PM poles	6x2
Number of primary teeth	12
Number of Primary slot	13
Phase number	3
Primary side length/mm	1500
Air-gap length/mm	1

Results

Study of secondary structure

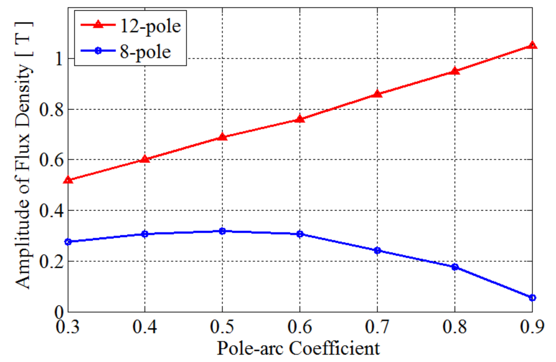

Fig. 5. Amplitude of flux density with different pole-are coefficient

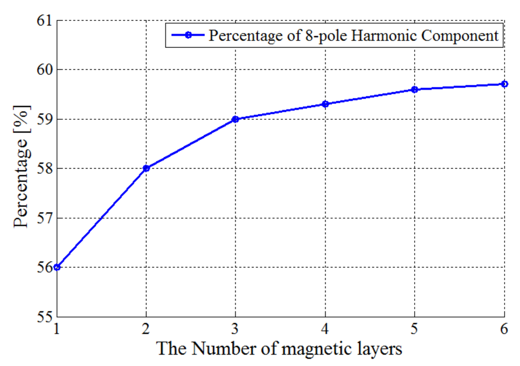

Fig. 6. Percentage of 8-pole harmonic component

By changing the secondary polar-arc coefficient, the 12 and 8 harmonic components in the air gap are obtained.

By changing the number of magnetic layers, the percentage of harmonic content is obtained.

Air-gap magnetic flux density and FFT

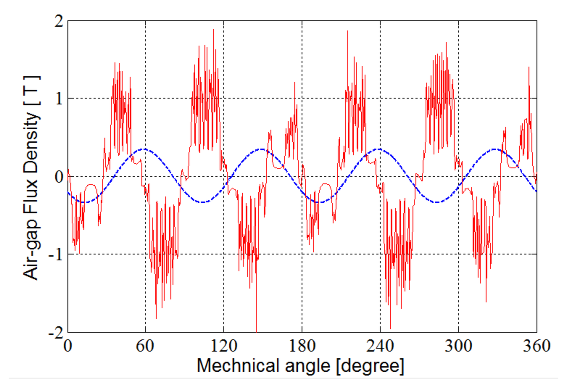

Fig. 7. Air-gap magnetic flux density

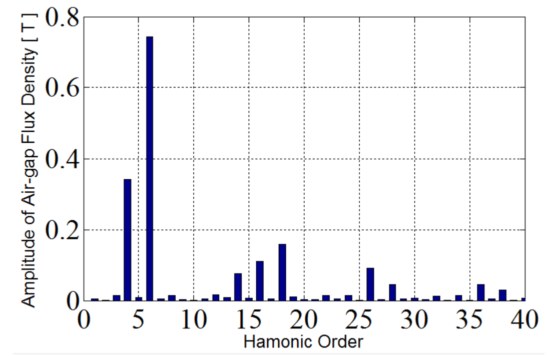

Fig. 8. Air-gap magnetic flux FFT

Magnetic density and magnetic force line

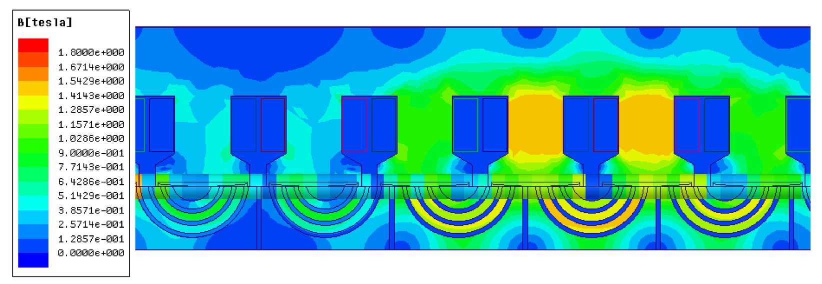

Fig.9. No-load magnetic density distribution

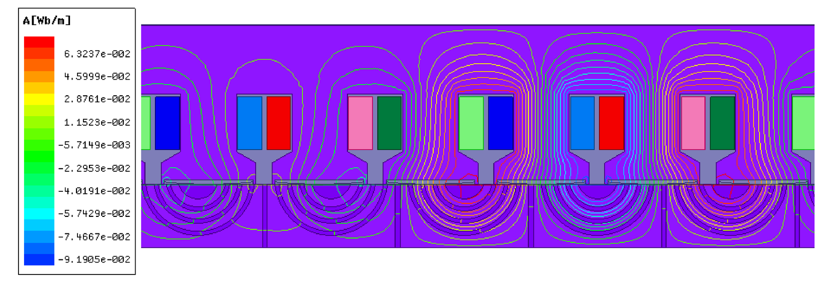

Fig.10. The Magnetic force line distribution

Induced EMF of LPPMSM

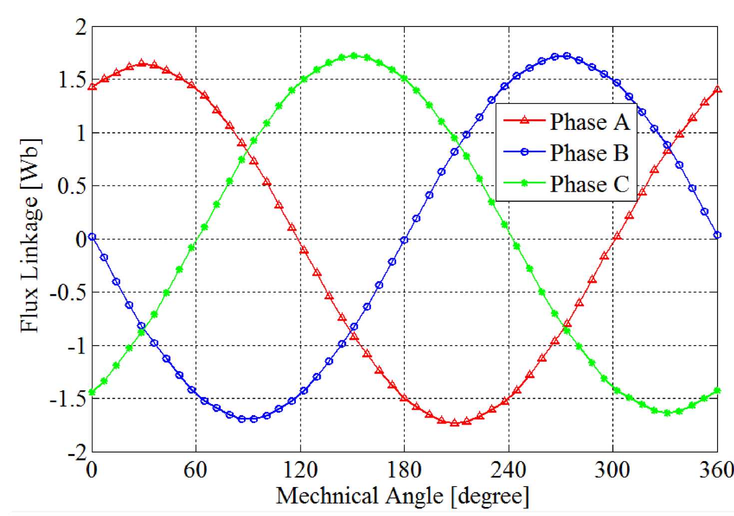

Fig. 11. Flux Linkage

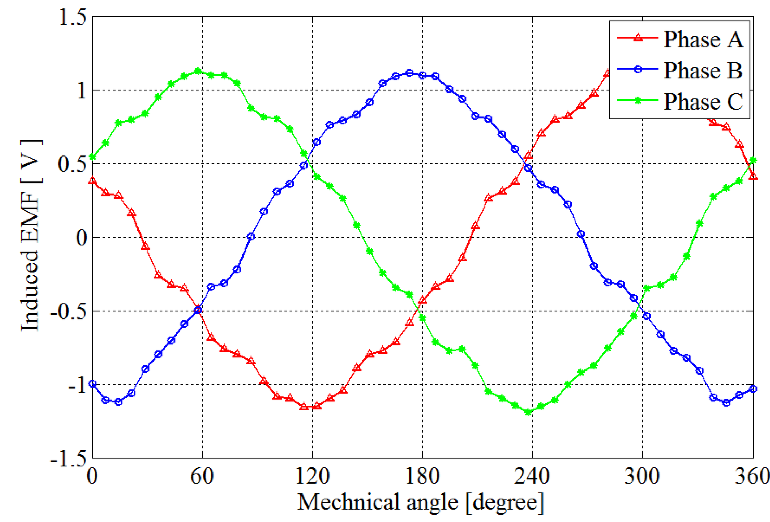

Fig. 12. Induced EMF

According to the simulation results, it is determined that the number of magnetic layers is chosen as 3, and the polar arc coefficient is chosen as 0.6.

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