Magnetic Field and Thrust of Hybrid excitation Linear Synchronous Motor

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Abstract

A novel hybrid excitation linear synchronous motor(LSM) was introduced for applying permanent magnetic materials to linear synchronous electromagnetic excitation motor.Its air gap magnetic field and thrust was studied by FEM. The prototype motor was examined through contrastive experiments with normal electromagnetic excitation LSM. The results show the magnetic field of this novel LSM are adjustable and the thrust is high and flexible. This novel hybrid LSM combines the advantages of permanent magnet LSM and electromagnetic excitation LSM.

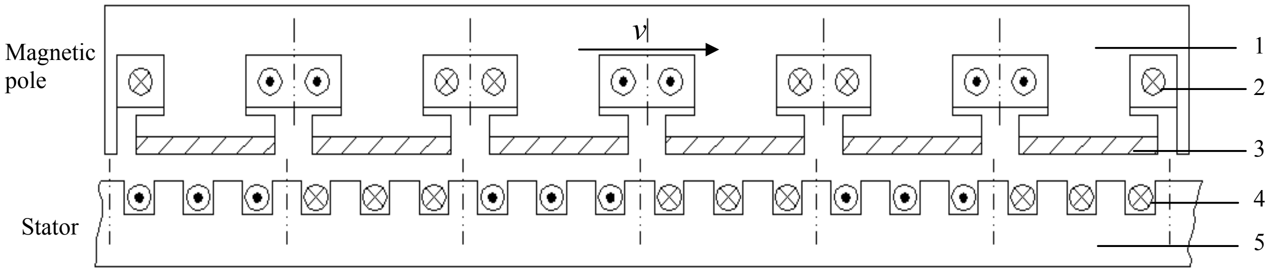
1 Introduction

In the past few years, tremendous interests have grown in developing Permanent Magnet (PM) Motor on account of its high efficiency and high torque characteristics. Moreover, besides its compact size, simple construction and efficient merits, Permanent Magnet Linear Synchronous Motor (PMLSM) can directly transform electric power into mechanical power without any intermediate gears, screws or crank shafts[1,2]. It has been widely used in many industries like manufacture, automation, transportation system etc. The maglev vehicles use the electromagnetic excitation LSM as driven and levitation part. It takes full advantage of the attractive force between stator and magnetic pole.

This paper is aimed to improve the performance of LSM in maglev. It can be realized by applying permanent magnet to the electromagnetic excitation of LSM. In American, some researchers have adopted this hybrid excitation LSM to drive the middle speed maglev vehicle as urban transportation system[3]. Let the permanent magnet and electromagnetic excitation provide magnetic flux in air gap together, the levitation force increases so that given air gap maybe can be improved. Now the air gap length of Germany maglev vehicle is about 10mm. If it can arrive 20mm, the requirement of road surface will decrease and the control system is much easier to realize. If the air gap still keeps 10mm, then the weight of vehicle can be increased and the thrust also improved. On the other hand, the adoption of permanent magnet decreases the power and volume of excitation system, so the weight of vehicle decreases and vehicle power will last long. Except in maglev vehicle, this hybrid excitation LSM also can be used in convey, automation system and other linear motion area. It is a valuable research objective.

Fig.1 shows a simple diagram of the hybrid excitation LSM. It includes a stationary part(call stator) and a moving part(magnetic pole). That stator consists of winding and core. It is much longer than magnetic pole, then it is also called long stator. The stator winding is divided into several sections on considering saving energy. Every section is connected with frequency-adjustable power. It is only switched on when the magnetic pole is running at this section. Magnetic pole is composed of the electromagnetic excitation winding, permanent magnet and magnetic pole core. This permanent magnet will provide the great mass of magnetic flux whilst the electromagnetic excitation winding is only as magnetic flux adjuster. The feature of this novel LSM is high thrust, flexible magnetic flux and high levitation force.

This paper introduces the construction of hybrid excitation LSM. As it is a novel LSM, some design outlines are expressed. A prototype motor is made after designing. The contrastive experiments are done in order to compare the thrust of this novel LSM with that of electromagnetic excitation LSM.



1.Magnetic pole core 2.Magnetic pole winding 3.Permanent magnetic 4.Stator winding 5.Stator core

Fig.1 Structure of hybrid LSM with permanent magnet and electrical excitation

2 Design

In order to know the advantage of this novel hybrid LSM, this paper designs and makes a motor. During the process of design, some outlines should be noticed because of big difference between this novel motor and typical motor. There are described as follows[4].

2.1 Permanent Magnet

Although the price of permanent magnet is cheaper than before, we still need use permanent magnet as economically as possible in order to decrease the cost. The type and size of permanent magnet is decide by motor rated data and technical requirement. Popular permanent magnet NdFeB N35SH is adopted in this design because the price is low and the performance is suitable. Assumed remanence magnetic flux density of 20℃ keeps constant, its value of operational temperature is

$$B_r = [1 + (t - 20)\frac{\alpha_{Br}}{100}]B_{r20} = 1.13\text{T}. \tag{1}$$

where B_{r20} is remanent magnetic flux density of 20℃. α_{Br} is reversible temperature coefficient of remanence magnetic flux density, the values is -0.12% K^{-1}, t is operational temperature, the estimated value is 75℃.

The coercivity of same operational temperature is

$$H_c = [1 + (t - 20)\frac{\alpha_{Br}}{100}]H_{c20} = 847\text{kA/m} . \tag{2}$$

where H_{r20} is coercivity of 20℃.

The relative recoil permeability is

$$\mu = \frac{B_{r20}}{\mu_0 H_{c20} \times 10^3} = 1.1 \cdot \tag{3}$$

where μ_0 is magnetic permeability of free space.

The size of permanent magnet in this design is 35mm×50mm×3mm. The magnetic flux density is supplied by permanent magnet and electromagnetic excitation together, so we need check whether the operational condition is always along given recoil line.

2.2 Electromagnetic Excitation system

Since the electromagnetic excitation system is only as an airgap magnetic flux density adjuster, its capacity is decided by adjustable range. The electromagnetic excitation system is planned to provide half MMF of permanent magnet. The MMF of electromagnetic excitation system is

$$F_a = \frac{1}{2} H_c h_{Mp} = 1270.7 \text{ A.Turns} . \quad (4)$$

where h_{Mp} is the magnetization length of permanent magnet.

According to the capacity of excitation power, the maximum current is 3.2A. The number of turns is also known.

2.3 Leakage inductance calculation

Since the stator is much longer than magnetic pole, a part of stator is uncovered by moving magnetic pole. The corresponding flux linkage isn't used for energy conversion. We call it outside main leakage magnetic flux. In motor equivalent circuit, a main leakage reactance represents this field. Assumed the magnetic energy of one pole keeps constant, then an equivalent air gap length is

$$\delta_{ef} = \frac{\tau_1}{\pi} . \quad (5)$$

where τ_1 is pole pitch of stator.

At this time, the main inductance calculation formula is still useful, only this equivalent air gap length appears

$$L_\sigma = 2\mu_0 \frac{m(NK_{dp1})^2 b_E}{\pi(p_1 - p_r)} . \quad (6)$$

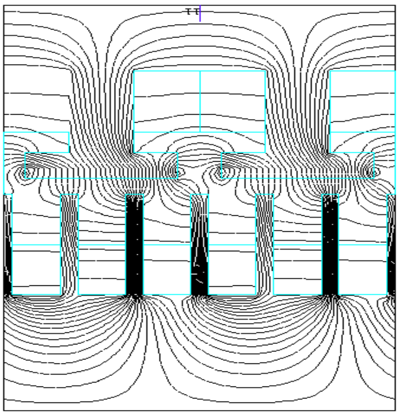
where p_1 - total poles of one session stator winding, p_r - total poles of magnetic poles, NK_{dp1} - the number of effective turns per phase, b_E - the width of primary stack, m - the number of phases.

To linear motor, there exits transverse end effect and longitudinal end effect. The equivalent coefficient is a nice way to consider these two effects, which is a traditional way. Now FEM is widely used to obtain precise results. In this design, some parameters are calculated by FEM.

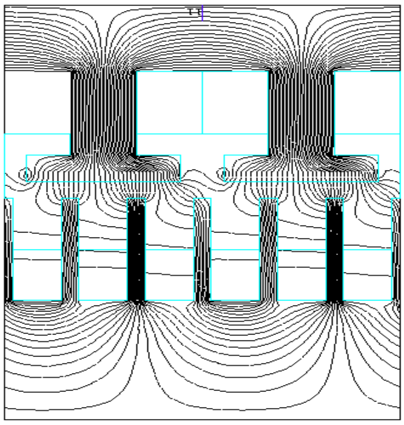
Some parameters of this novel hybrid excitation LSM are listed as follows: the length of long stator is 6m, the rated voltage is 380V, the rated stator current is 3.8A, the stator pole pitch is 45mm, the width of stator stack is 50mm, the number of magnetic pole pairs, the number of turns of stator winding is 163, the number of turns per magnetic pole is 395, the maximum excitation current is 3.2A[5].

3 Magnetic field

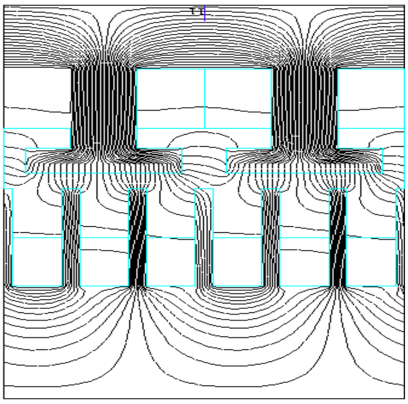
The airgap magnetic field is decided by permanent magnet, electromagnetic excitation system and armature reaction. Since its distributing is complex, FEM is a more suitable way to study than magnetic circuit method. In the world, there are many mature commericial FEM softwares. Among these softwares, ANSYS is a popular one. This paper use it to study 2-D magnetic field of hybrid excitaiton LSM under different electromagnetic excitation current I_f [5]. It positive value means the airgap magntic field increased by electromagntic exictation field. Contrariwise, the airgap magnetic field is decreased. Fig.2 shows the results of FEM. The airgap magnetic field changes with electrical excitation current. When I_f makes airgap magnetic field weaken, the effect is quite apparent. While I_f makes airgap magnetic field enhance, the effect is lowered. It is caused by the saturation of iron core. The calculation thrust by FEM are listed in Table.1. Apparently, the thrust varies continously along with electrical excitation current.



a) $I_f = -2$ A



b) $I_f = 0$ A



c) $I_f = 2$ A

Fig.2 The airgap magnetic field of one pole pair

Table 1 The calculation thrust of FEM

I_f /A	Thrust /N
2	186
1	167
0	145
-1	121
-2	97

4 Experiment results

To test its performance and compare with electromagnetic excitation LSM, the prototype motors of this novel hybrid LSM and electromagnetic excitation LSM were made. These two motors are of same construction. Fig.3 is a picture of prototype motor.

A series of experiments were carried out on these two motors under same conditions. The contrastive experimental results are shown in Fig.4. It can be found the FEM and experiemtnal results of hybrid exictaiton LSM are almost same. The thrust can vary continuously along with variation of electromagnetic excitation current. Its adjustable performance is strong and flexible.Additionaly, the novel hybrid excitation LSM can produce much higher thrust than electromagnetic excitation LSM by experimental results.

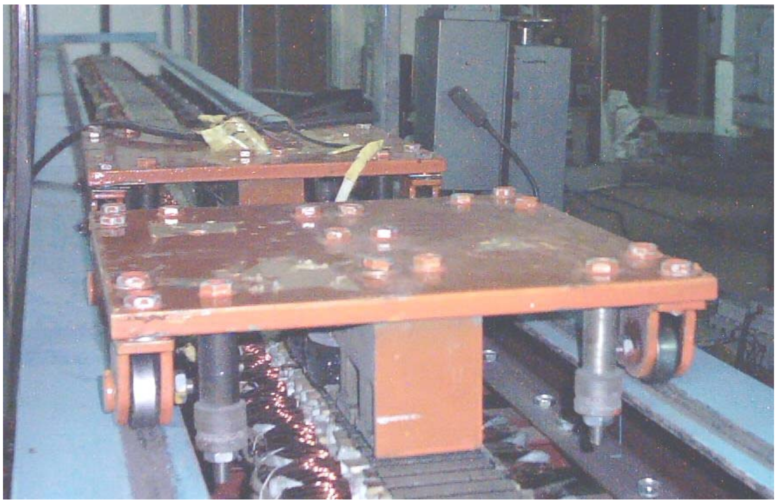


Fig.3 Picture of prototype motor

5 Conclusions

The novel hybrid excitation LSM can produce not only high thrust but also adjustable thrust. Both FEM analysis results and experimental results verify this conclusion very well. It is worth study because its good performance. The further work is focused on research of control system and dynamic feature.

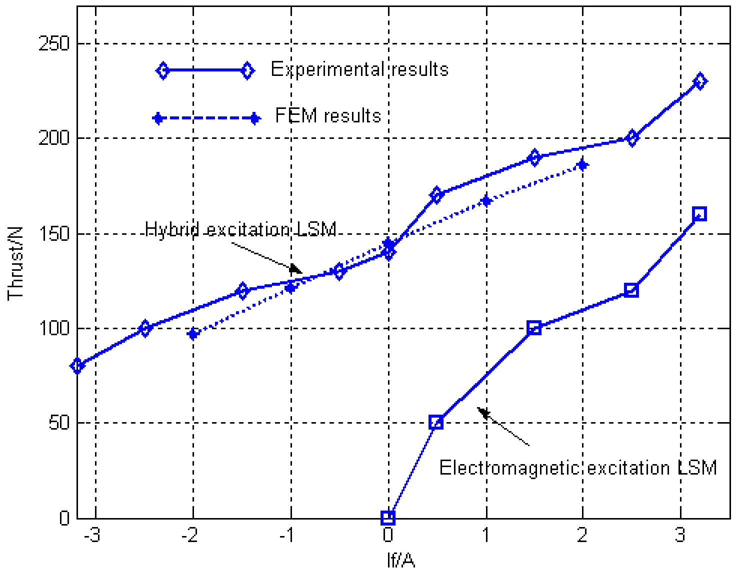


Fig.4 Thrust-electrical excitation current characteristic curves

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