Comparison of Thrust Characteristics in Pencil Sized Cylinder-type Linear Motors with Different Magnet Arrays

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From a strong demand on the miniaturization of a chip mounter or a semiconductor device, the thrust improvement considering the magnets arrangement is studied. We accept a core stator with a Halbach type magnet array for a current linear motor. The thrust characteristics are compared with two kinds of mover, a NS magnet array and a Halbach magnet array.

Key Words: NS magnet array, Halbach magnet array, PCLM, FEA

1. Introduction

Although the size of the linear motor to be used in a semiconductor device or a chip mounter becomes small, it is not easy to obtain the desired thrust.

Because the volume (BIL low) defines the capacity of magnets and coils, the thrust also depends on this. In order to solve these problems, a lot of magnetic fields to a radial direction have been improved.

There are the following three methods.

(1) If a magnetic field is opposed and magnetic induction is very high, a magnetic induction is generated in a direction that is radial to the boundary of the magnetic induction generated by each opposed permanent magnet block group. (Improvement of inter-linkage magnetic field absolute value)

(2) The use of a magnetic core in a stator. (To lead the radial direction magnetic field to the coil)

(3) A Halbach magnet array allows us to use a well-controlled magnetic field inside the array. In contrast, it also produces undesired magnetic flux outside of the array. (To generate the inter-linkage radial direction magnetic field in the magnetize coil smoothly [1])

Unfortunately, thrust improvement is not easy to achieve if the volume becomes small.

Moreover, production is difficult. Concretely, the linear motor composed of stator core and the Halbach magnet in ϕ 10 or less is unexampled.

In this time, we make two type of stator structure, a core type and a coreless type and kinds of magnet arrangement, a NS magnet array and Halbach magnet array. The influence that each structure and arrangement exerted on the thrust characteristics was evaluated.

As a result, a comparison of the times and conditions above was obtained.

2. Proposed Design

2.1 Basic structure

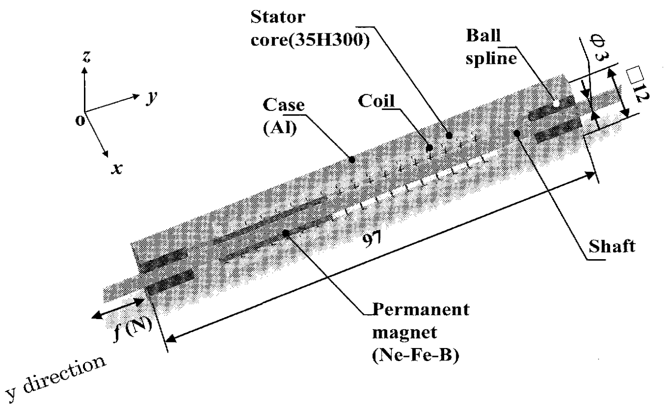

Fig. 1 Schematic structure of PCLM [units:mm].

A schematic structure of our pencil-sized, cylindrical linear motor (abbreviated as PCLM) is shown in Fig. 1 [2]. The units are in mm. The mover is composed of permanent magnets and a shaft. The shaft has ϕ 5 in the outer diameter. A rare earth Ne-Fe-B (Br = 1.29 T) type permanent magnet is used for the magnets. The NS magnet array has a shaft

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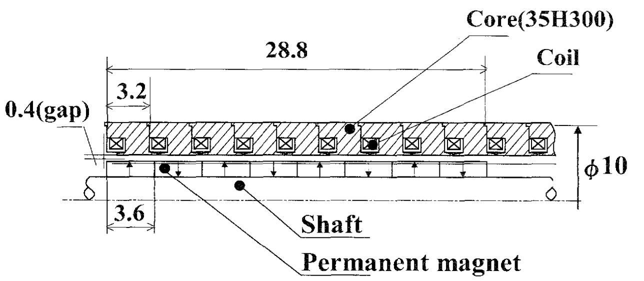
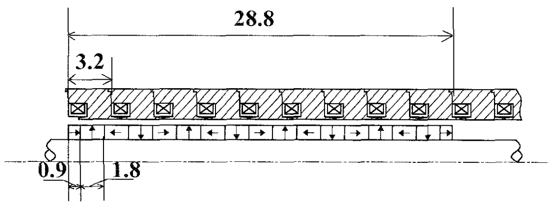
of a magnetic material, and the Halbach magnet array has a shaft made of a nonmagnetic material.

In order to fix the axis, a ball spline is installed. The stroke distance of the linear motor is 28.8 mm. The core of the stator is made of silicon steel (35H300), and the number of poles is eight. The excitation coil is a three-phased structure. The number of windings in one slot is 24 turns for the core type, and 55 turns for the coreless type. The sectional structures are shown in Fig. 2. The units are in mm. There are two kinds of magnet arrays, an NS magnet array and a Halbach magnet array.



(a) NS magnet array.



(b) Halbach magnet array.

Fig. 2 Sectional structure of PCLM [units :mm].

2.2 Principle of operation

Fig. 3 explains the principle of operation of the linear of the Halbach magnet array type. The magnets are so arrayed that the direction of magnetization is shifted by 90 degrees, and that the magnetic flux is generated in the direction *B* of Fig. When the current goes though the coil, the electromagnetic force is generated by Fleming's law to the right in the coil part, while the reaction force comes to the movable part because the coil part is stationary, thus, PCLM obtains thrust drive to the left. Consequently, when the coil is excited oppositely, thrust is generated to the other direction.

Thrust in the same direction can be obtained at any time by switching the current to be applied with respect to the position of the moving part.

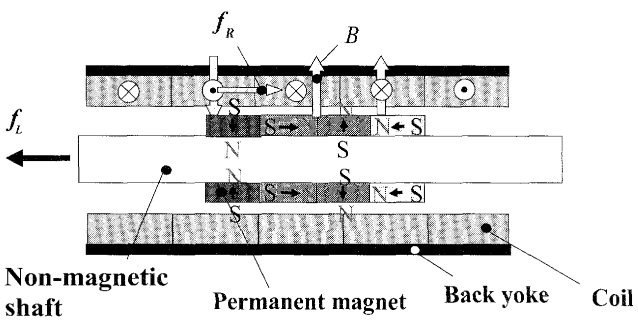


Fig. 3 Principle of operation.

2.3 Motor constant density

The motor constant density expressed as Eq. (1) is used as an index to evaluate the stator composition and the difference of magnet arrays, which influence the thrust [3].

$$G = \frac{F_{max}^{\ 2}}{P \cdot V_m} \quad [\mathrm{N}^2/(\mathrm{W} \cdot \mathrm{m}^3)] \tag{1}$$

Where, G is the motor constant square density, F_{max} is the maximum thrust, P is the input electric power and V_m is Volume of the linear motor.

3. Finite Element Analysis of PCLM

3.1 Model of finite element analysis

To estimate the thrust of the models, we performed a finite element analysis using commercial software (ANSYS/EMAG, Cybernet systems). Our model of the PCLM is shown in Fig. 4. The magnetic properties take into account the nonlinearity of the magnetic material and are approximated by approximate curves with

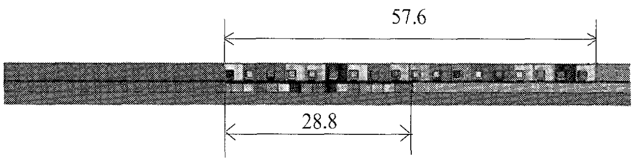
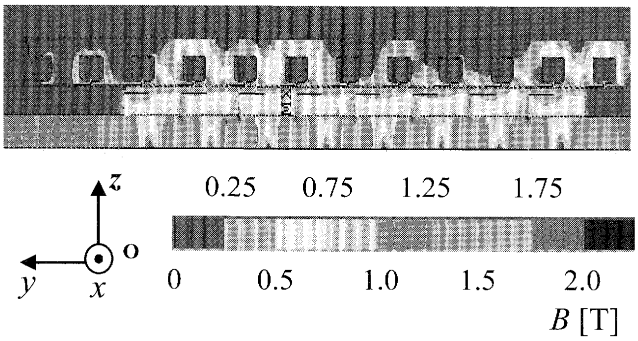


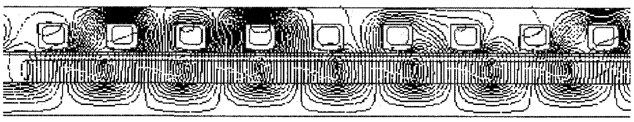
Fig. 4 PCLM model.

Table 1 FEM conditions of the PCLM.

ITEM	CONDITION
CPU	ATHLON 1.0GHz
SOFTWARE	ANSYS
ANALYTICAL TECHNIQUE	FINITE ELEMENT METHOD
NONLINEAR LIBERATING	NEWTONRAPSON METHOD
ANALYTICAL TYPE	FOUR-NODE TETRAHEDRON
MATERIAL CHARACTERISTIC	NONLINEAR OF B-H IS CONSIDERED
ELEMENT TYPE	FOUR-NODE TETRAHEDRAL ELEMENTS
NUMBER OF ELEMENTS	110,000

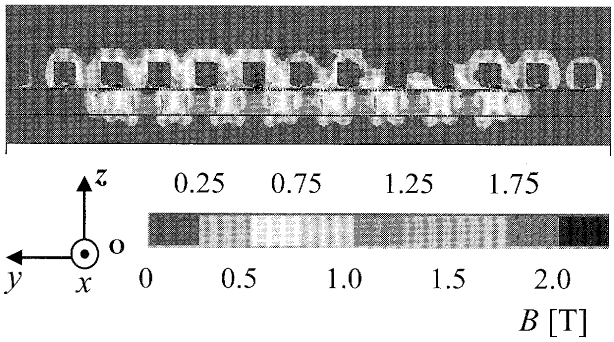


(a) Magnetic flux density.

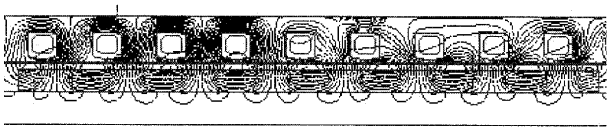


(b) Magnetic flux line.

Fig. 5 Calculated results of the NS array model.



(a) Magnetic flux density.



(b) Magnetic flux line.

Fig. 6 Calculated results of the Halbach array model.

interpolating points. The number of points is 12 for the permanent magnet, and 25 for the core material 35H300. The pitch of the magnetic poles is 3.6 mm.

The size of the air area (surrounding control area) is twice larger than the model. The conditions of the analysis are summarized in Table 1. The number of elements was about 110,000.

3.2 Calculated results

First of all, we calculate the distributions of the magnetic flux density at which the thrust becomes the maximum value. The calculated results are shown in Figs. 5 and 6. These models are of the core type. It is found that the flux concentration in the radial (z) direction of the Halbach arrays model is higher than that of the NS arrays model. Next, we compared the thrust curves of the NS magnet array type with that of the Halbach array type. Fig. 7 shows the result of the cored type, and Fig. 8 shows the results of the coreless type. From this it can be seen that the Halbach array model has better results.

The magnetic flux density of the gap, for the Halbach magnet array, it is 0.75 T and for the NS magnet array it is 0.5 T. The magnetic flux density of the stator is about 1.5 T.

4. Experimental Results

A linear motor was produced with the NS magnet array and the Halbach magnet array respectively, and thrust was measured in a linear motor of the coreless and core type. Experimental setup is shown in Fig. 9.

A linear motor was arranged in the measurement system. The mover of the linear motor was pulled with direct current impressed between U-VW of the coil. Thrust generated at that time was measured.

5. Conclusion

Fig. 10 shows the thrust characteristic result. For core type, thrust is improved by 10 % in the Halbach array when compared to the NS array. For coreless type, thrust is improved by 20 % in the Halbach array when compared to the NS array. The Halbach magnet array became a high result in the motor constant density. And thrust was able to be raised as shown in Table 2.

However, compared with the analytical result, core type was 20 % low and coreless was 30 % low.

It became a low value compared with □32.

In the calculation result, the motor constant density is actually closer to the □32 value (the value in parentheses). The cause is as follows.

It is enumerated to have become 1.04 T since the magnet is actually produced though the reference residual magnetization of the magnet was assumed as 1.29 T when analysing it as this factor. The factor that is most capable of raising thrust will be thoroughly investigated in the future. Examples include changing the size of the stator and the size of the magnets.

Finally, it is planned to examine a pencil sized linear motor of $\phi 10$ fitted with a sensor by developing linear sensor.

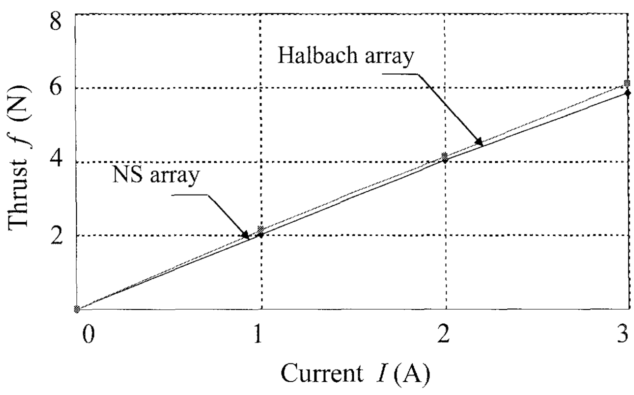


Fig. 7 Calculated thrust curves for the core type.

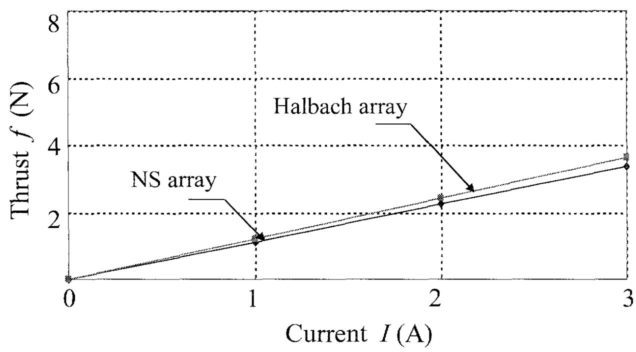
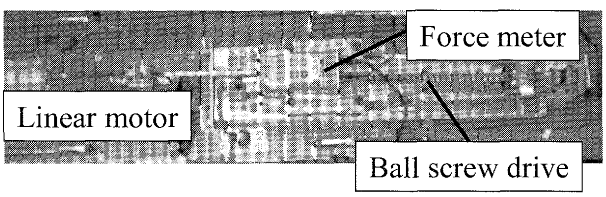
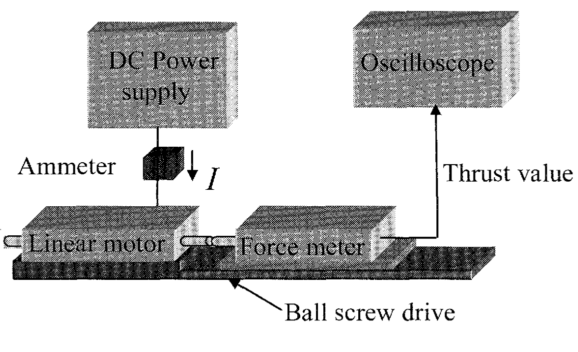


Fig. 8 Calculated thrust curves of coreless type.



(a) Thrust measurement system.



(b) Characteristics measurement system.

Fig. 9 Thrust measurement treatment system.

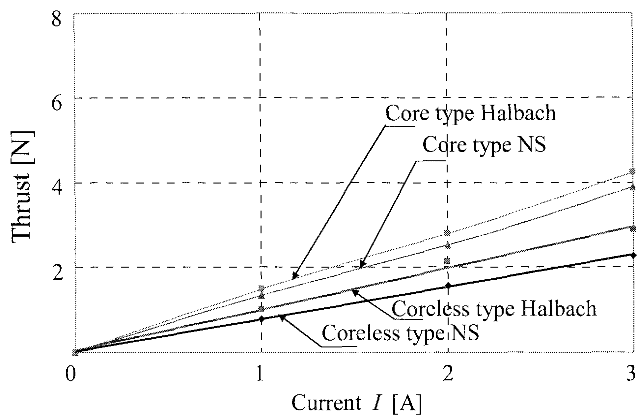


Fig. 10 Current-Thrust characteristic of a NS magnet array and a Halbach magnet array (measured).

Table 2 Motor performance.

Item(Unit)	Symbol	□32	core type		coreless	
			NS	Halbach	NS	Halbach
Maximum thrust(N)	F_{max}	18	3.88	4.23	2.27	2.88
Thrust density constant($N^2/W \cdot m^3$)	G	0.21×10^{-6}	0.09×10^{-6} (0.20×10^{-6})	0.11×10^{-6} (0.23×10^{-6})	0.03×10^{-6} (0.08×10^{-6})	0.05×10^{-6} (0.09×10^{-6})

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