A Study of the Optimum Stator Winding Arrangement of LIM in Maglev Systems

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Abstract- **This paper describes the study of the stator-winding arrangement of the Liner Induction Motor (LIM) applied for the Magnetic Levitation (Maglev) systems. Considering that maximizing the magnetic flux density of the stator is essential for the large levitation force and trust, several patterns of the winding arrangements are shown and analyzed by simulations. The feasibility of each type is examined with the magnetic flux characteristics. From the results, an arrangement pattern, 2-3 model, is proven to be optimum for Maglev systems.**

I. Introduction

Maglev systems have been actively developed in many countries to solve technical problems in modern transportation systems such as noise, vibration, speed . Since they have an easy maintenance due to its contact-less structure between the rotor and stator winding, Maglev systems are expected to be applied into more industrial manufacturing systems [1]-[4].

From the viewpoint of the operation principle, linear motors in Maglev transportation systems are generally categorized into two types, i.e. Linear Induction Motor (LIM) and Linear Synchronous Motor (LSM). Out of them, LIM has an advantage due to the synchronization-free in starting and the comparably small scale in its system size over LSM, which results in the cost-reduction in manufacturing.

In addition to the structure, an arrangement of the stator winding also has a major impact on the magnetic force generated in the Maglev system. Although the idea of using LIM in the Maglev systems is not new, the previous works and the related research papers little focus on the arrangement of the stator winding.

The main objective of this paper is to investigate the optimum arrangement of the stator winding of LIM applied for Maglev systems. According to the number of the distributed winding and the coil pitch, several types of the arrangement model are introduced.

In order to investigate the feasibility of each model, the magnetic flux characteristics are examined by computation analyses. From the results, it is concluded that the 2-3 arrangement model has an optimum property in terms of the magnetic force as well as the cost-performance.

II. Design of CALCULATION Model

A. Analyzed Stator Model

The induced voltage E in LIM is expressed in (1), which is similar to the general form of the induction motor:

$$E = (B \cdot V) \cdot I \ , \qquad (1)$$

where B, V and I are the shifting magnetic field, its velocity and the induced current in the rotor, respectively. Then, from the relationship between B and I, the magnetic levitation force F is shown as follows:

$$F = (B \cdot I) \cdot L \ , \qquad (2)$$

where L is the length of the rotor in the horizontal direction.

Fig.1 shows the schematic diagram of the stator slot model for the analyses. In this model, the stator is composed of 70 slots based on layers of a grain-oriented silicon steel strip of 0.35m, and its relative permeability μ_r is 5000 H/m. In addition, the number of turns per coil is set to 25.

B. Stator Winding Patterns

Considering the practical stator configuration with increasing the magnetic force, a concentrated winding, two-distributed winding and three-distributed winding are compared and discussed. On the basis of the number of the winding and the coil pitch, thirteen types of winding arrangement are examined. Among them, several patterns and their equivalent circuits of the winding arrangement are illustrated as examples in Fig.2 and Fig.3, respectively. Here, the winding arrangement that has two series-winding per phase and three-coil pitch per pole is defined as 2-3

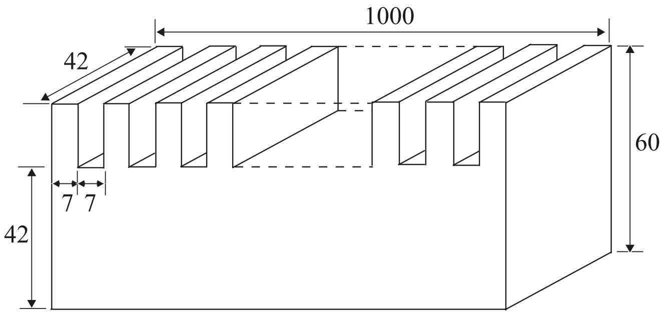

Fig.1 The analyzed stator slot model (unit :mm)

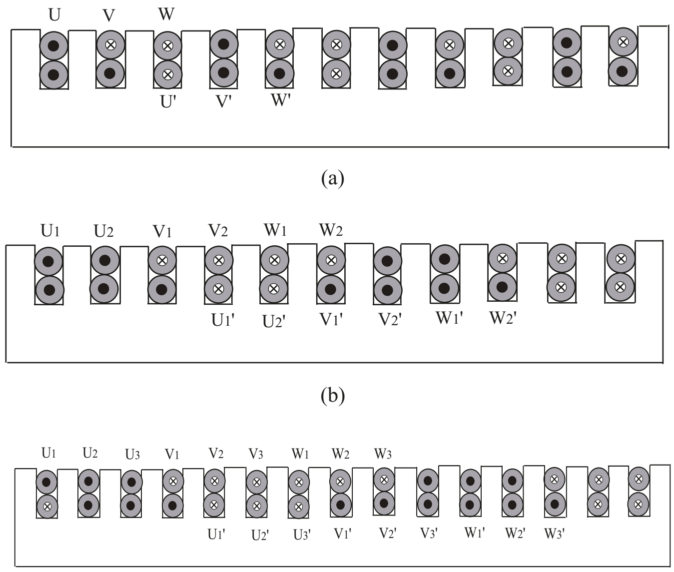

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Fig.2 Stator winding arrangement patterns (a) 1-2 model, (b) 2-3 model, (c)3-4 model.

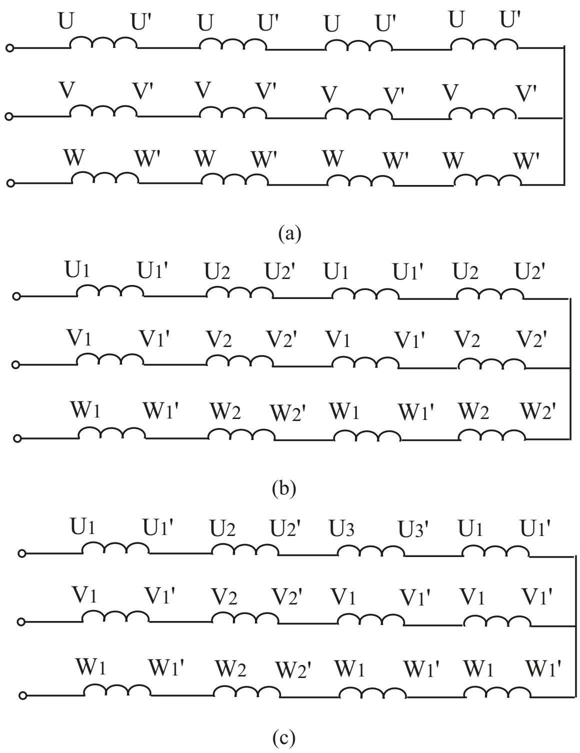

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Fig.3 Equivalent circuits of the winding patterns (a) 1-2 model, (b) 2-3 model, (c)3-4 model.

model, and so are 1-2 and 3-4, respectively. Furthermore, the coils of all models are positioned by means of double layer winding so as to increase the magnetic flux density.

III. Simulation Analyses and Results

A. Simulation Set-Up

In order to evaluate the magnetic levitation force generated in each winding pattern, the characteristics of the magnetic flux density (B_m) are analyzed by simulations. In particular, the vertical component of the magnetic flux density at 3 mm above the surface of the stator is focused in the analyses to evaluate the thrust. The simulator used in the calculations is JAMG-Studio. Additionally, all of the calculations are implemented in the two-dimension electromagnetic field based on Finite Element Method.

In the simulations, in order to examine the magnetic characteristics in the rotating magnetic field, distributions of B_m are also measured according to the phase position of the 3 phase balanced current. The tested 3 phase current is 10 A in rms.

Additionally, the stator length L is set to 315mm for easy calculation.

B. Simulation Result and discussion

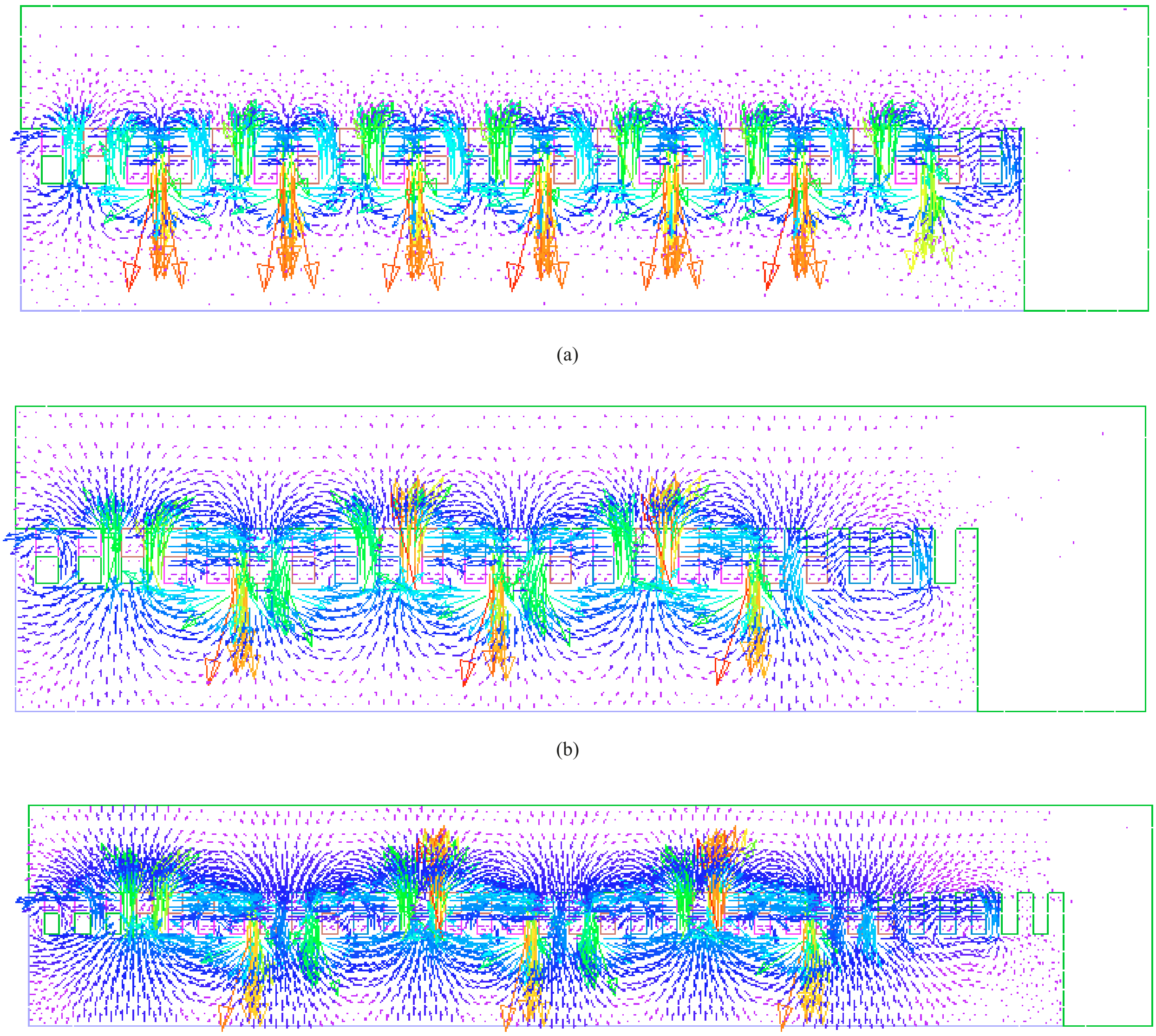
The magnetic flux density distributions of 1-2, 2-3 and 3-4 are shown in Fig.4.

In the concentrated winding type, 1-1, 1-2 model are analyzed. By comparing the calculation results in Fig.5, it is confirmed that 1-2 has the better distribution characteristics.

In the two-distributed winding type, five models of 2-1, 2-2 2-3, 2-4 and 2-5 model are tested. By comparing the distributions in Fig.6, it is proven that 2-3 model generates the greater flux density the others, which results in the larger magnetic flux.

Similarly, in the three-distributed winding type, six patterns of 3-1, 3-2, 3-3, 3-4, 3-5 and 3-6 model are tested. By comparing the results in Fig.7, it is confirmed that 3-4 model shows the best magnetic flux distribution.

Next, in order to identify the best arrangement, the characteris-



(a)

(b)

(c)

Fig.4 The graphical view of the magnetic flux density distribution (a) 1-2 model (22 slots), (b) 2-3 model (22 slots), (c)3-4 model (33 slots).

tics of 1-2, 2-3 and 3-4 model are compared in Fig.8. From the results, it is explicitly seen that 2-3 and 3-4 model generate the better flux distributions than 1-2 model, respectively. On the other hand, there is no major distinction between 2-3 and 3-4 model in terms of the total magnetic flux. However, 2-3 model explicitly has advantages over 3-4 model from the viewpoint of the cost to construct the winding arrangement.

Thus following those analyses, the characteristics of the 2-3 model are explored further in terms of the rotating field of the 3 phase current. In Fig.9, the average B_m of 2-3 model is shown for each phase position. From the results, it is proven that 2-3 model invariably has the larger magnetic flux through the whole rotating field. This ensures that 2-3 model can generate the greater magnetic force and thrust in LIM.

IV. Conclusion

This paper has explored the optimum stator winding arrangement of LIM applied for Maglev systems. The thirteen arrangement patterns were tested and analyzed by simulations. Considering the magnetic flux density and the cost to realize the winding arrangement, the pattern of two-distributed winding per phase with three-coil pitch per pole is concluded to be the optimum arrangement.

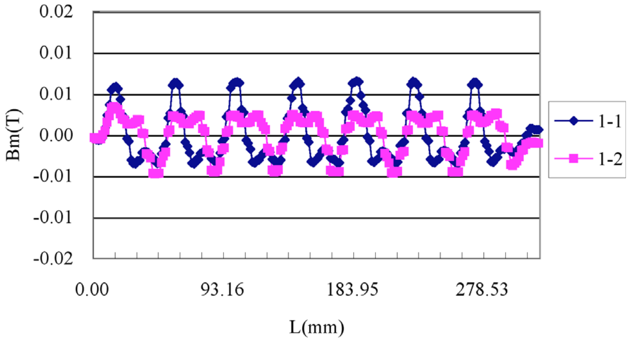
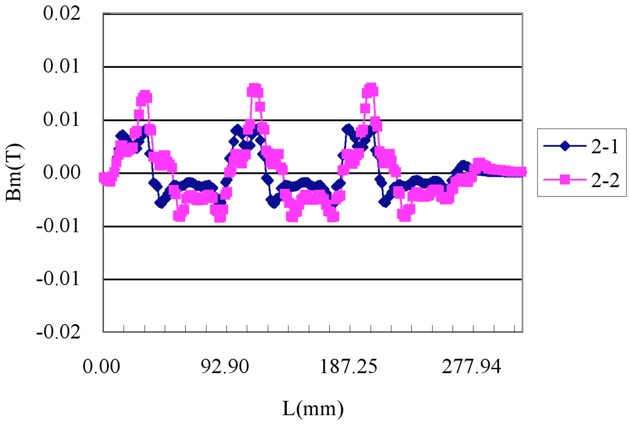


Fig.5 Average magnetic flux densities of the concentrated winding models.



(a)

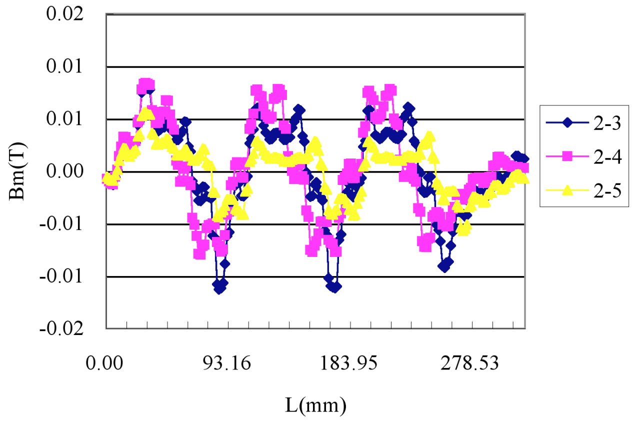


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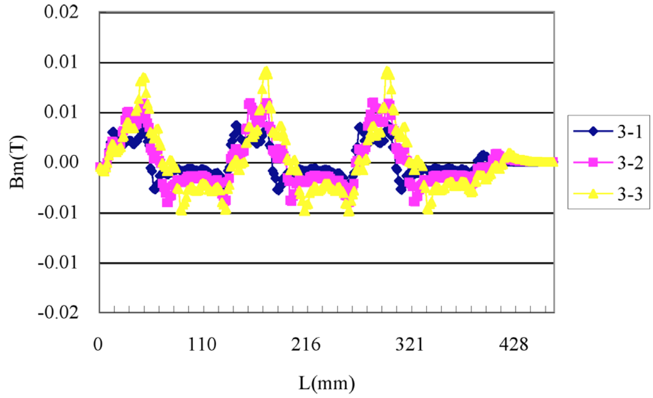
Fig.6 Average magnetic flux densities of the two-distributed winding models (a) 2-1 and 2-2, (b) 2-3, 2-4 and 2-5 model.



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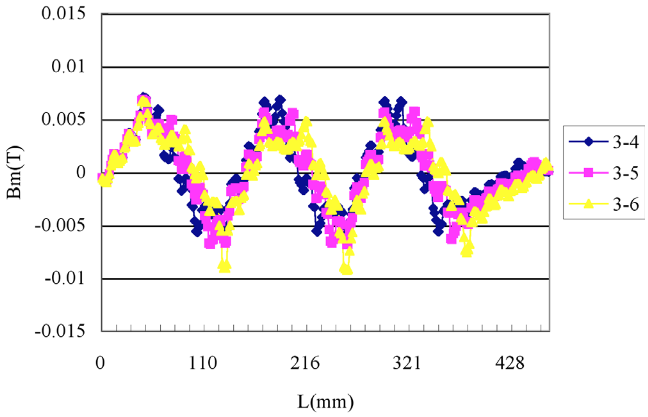

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Fig.7 Average magnetic flux densities of the three-distributed winding models (a) 3-1, 3-2 and 3-3, (b) 3-4, 3-5 and 3-6 model.

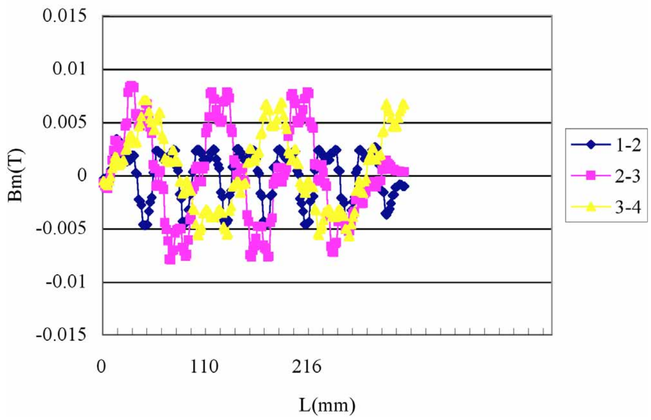

Fig.8 Comparison of the average magnetic flux densitis.

The next objectives of this research are to investigate the characteristics of the optimum arrangement by experimental works using a laboratory-prototype Maglev system and prove the feasibility of the proposed winding arrangement.

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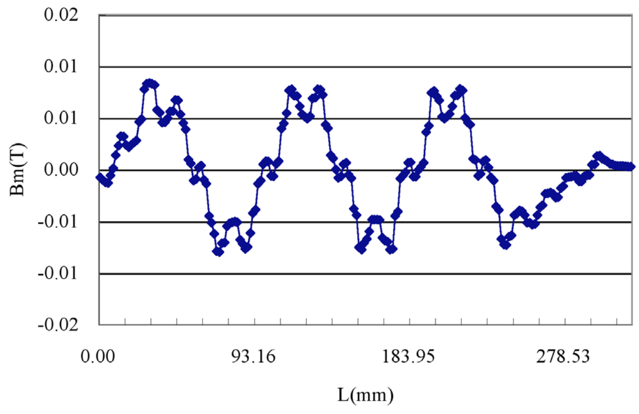

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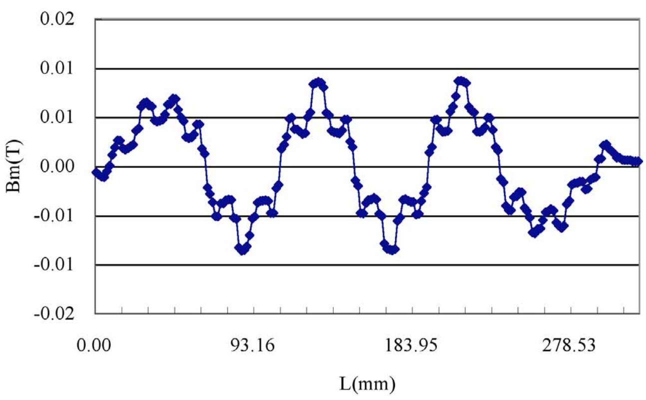

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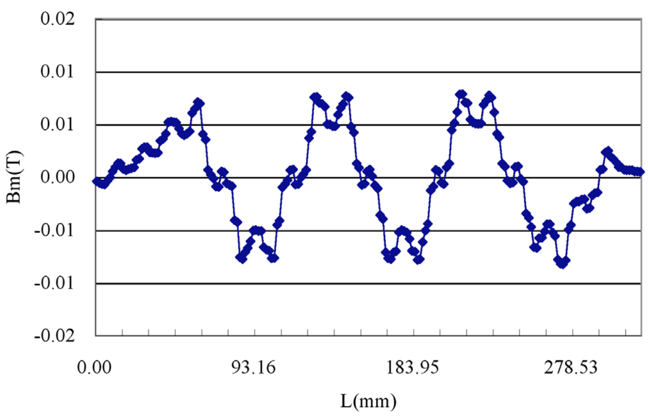

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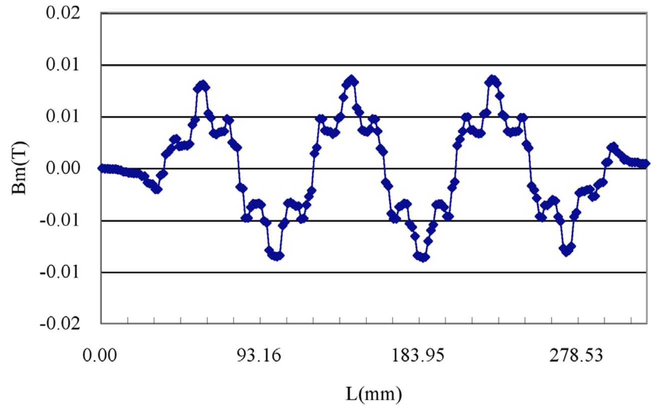

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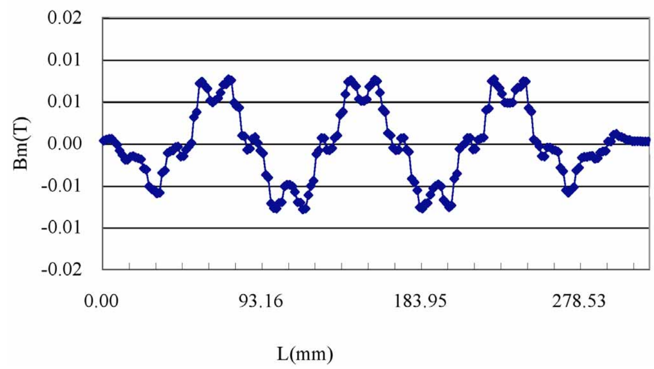

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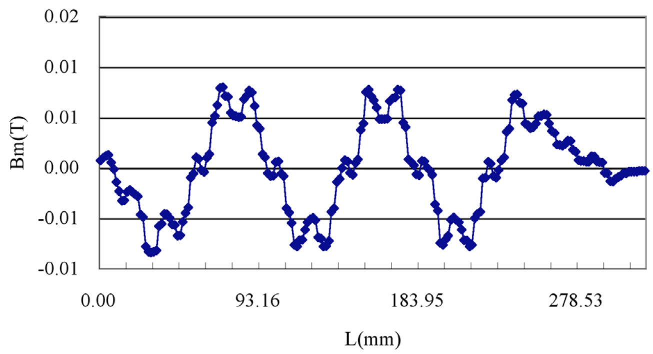

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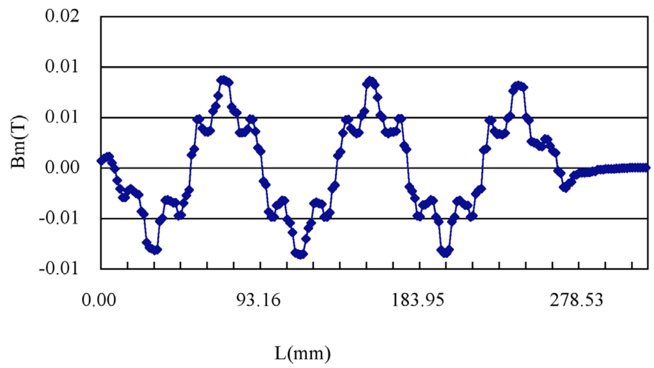

(g)

Fig.9 Characteristics of the average magnetic flux density in 2-3 model (a) 0°, (b)30°, (c)60°, (d)90°, (e)120°, (f)150°, (g)180°.