Novel Linear Motor for High Precision Stage of Semiconductor Lithography System

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I. Introduction

Stages used in semiconductor lithography system must satisfy needs of high precision positioning. The needs are high speed and high accuracy. The accuracy is about several nm and the speed is about 100msec of settling time for 20mm step. In addition to the needs, the stage must be able to move over the long stroke of 300mm, which is wafer size of next generation. Typical configuration of the stages is presented in Fig. 1.

Brushless permanent magnet linear motors offer significant advantages that can satisfy the mentioned requirements. The linear motor inherently has infinite stroke and resolution if guide mechanism can be selected ideally. We construct the linear motor symmetrically and it is guided by air bearing as depicted in Fig 2. Translation motion of the motor is delivered directly. The air bearing enables the system move smoothly for it has no friction. In addition to the smoothness, the symmetry of the two motors in both side of the bearing makes the system robust to environment such as heat, humidity and etc. and the attracting force between the stator and the mover diminished. The guide mechanism and the linear motor makes the stage simple, light, and smooth so the system can be controlled simply and moved rapidly.

In this paper we propose a novel multi-pole permanent magnet array. The magnet array has trapezoidal magnets. To design the linear motor, we propose a modeling method that describe magnetic filed of magnets and coil of the motor more accurately and effectively. Using this method, accurate design will be obtained and batch process can be easily applicable to perform, for example, optimal design, dynamic simulation and etc.

III. Linear motor with multi-segmented trapezoidal magnet array

Conventionally, salient-poles are used to maximize magnetic flux density in air gap where stator coil is wounded, however, the saliency can cause force ripple originated from the variation of reluctance between stator and mover. The force ripple is detrimental to precision positioning of the motor. Non-salient stator can be adopted to remove the force ripple, however, actuation force of the motor is not sufficient for it has lower magnetic flux density than salient motor. The alternative to remove the ripple and to improve the actuation force of linear motor is introducing multi-segmented permanent magnet array. Using the magnet array, the magnetic flux density can be so highly confined to stator winging that actuation force of the motor can be high. The principle of the multi-segmented magnet array is shown in Fig. 3. [1,2]

In this paper we propose a novel multi-segmented permanent magnet array. The magnet array has trapezoidal magnets as depicted in Fig. 4. Magnetization of the magnets has equal magnitude and direction that advances by 180/N deg. from one magnet to the next. N is segment number of magnets per pole pitch of the array. Using the magnet array, the magnetic flux density can be highly confined to stator winding. Actuation force of the motor with proposed and conventional magnet array is compared under condition of same volume and power of motor.

III. Modeling and design of the motor

To design the linear motor, we propose a modeling method that describe magnetic filed of magnets and coil of the motor more accurately and effectively. We can model magnet array with more complicated shape and magnetization direction and account end effect of mover precisely.

Firstly, the filed due to a single magnet in free space has been calculated using the method proposed by Halbach in the following equation. [1] In the equation, z* means conjugate of z and integration path is along the surface of the magnet.

$$B^*(z_0) = -\frac{B_r}{4\pi i}\oint \frac{dz^*}{z_0 - z} \qquad \text{where } B_r = B_{rx} + iB_{ry},\ z_0 = x + iy \tag{1}$$

If the stator has infinitely permeable, long and thick, the magnetic flux is normal to the upper surface of the stator. To meet this boundary condition, the image magnet with same magnitude of magnetization is introduced in the opposite side of the surface at same distance with the real magnet. The magnet has identical y-directional but opposite x-directional magnetization. Superposing the field by the real and image magnet, we can obtain the field due to a single magnet above the stator yoke. After obtaining the field of the each magnet in Fig. 4, the field by the magnet array can be calculated by superposing the field. For 2-segmented magnet array with trapezoidal magnet, the calculation is verified by the finite element method in Fig. 5. The field due to the stator coil can be calculated in similar way. Using the field, we can calculate the force, back emf or inductance of the motor.

This modeling can be used as a general design tool for non-salient brushless permanent magnet DC motor. Using this method, accurate design will be obtained and batch process can be easily applicable to perform, for example, optimal design, dynamic simulation and etc.

IV. Discussion and conclusion

We perform optimization of the motor to maximize the force per volume of the motor under the geometrical, electrical constraints. Usually, active constraint is the power of the electrical circuit. Investigating the optimization results, the 4-segmented magnet array can produce maximum force per volume of the motor. This is in contrast in Marinescu's results. Marinescu studied multi-segmented rectangular magnet array and insisted that the 3-segmeted one can produce more force. [3] However, if the thickness of the magnet is not limited and the gap is large compare to magnet thickness, 4-segmeted one can produce more force for same volume of the motor. The optimization results are compared in Table 2.

To apply the system to stage of semiconductor lithography, the motor most be able to carry enough load and move with high speed. The motor can move the load 15 kg with acceleration of 2.5m/s^2.

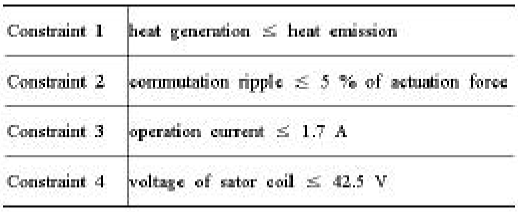
Reference

[1]. K. Halbach, "Design of Permanent Multipole Magnets with Oriented Rare Earth Cobalt material", Nuclear Instruments and Methods, Vol. 169, No. 1, pp. 1-10, 1980.

[2] J. Ofori-Tenkorang and J. H. Lang, "A Comparative Analysis of Torque Production in Halbach and conventional Surface-Mounted Permanent-Magnet Synchronous Motors", IEEE IAS Annual meeting, Oct. 8-12, 1995, pp. 657-663.

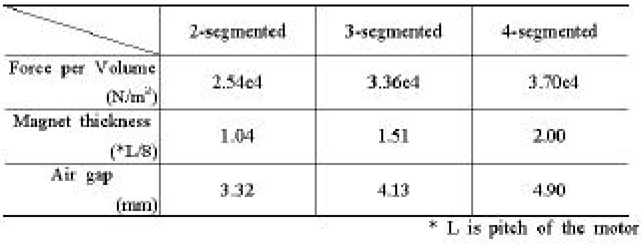
[3] M. Marinescu and N. Mrinescu, "New Concept of Permanent Magnet Excatiation for Electrical Machines. Analytical and Numerical Computation", IEEE Transactions on Magnetics, Vol. 28, No. 2, March 1992, pp.1390-1393.

Table 1 Constraint of optimization



Constraint 1	heat generation ≤ heat emission
Constraint 2	commutation ripple ≤ 5 % of actuation force
Constraint 3	operation current ≤ 1.7 A
Constraint 4	voltage of sator coil ≤ 42.5 V

Table 2 Comparison of optimization results



	2-segmented	3-segmented	4-segmented
Force per Volume (N/m^2)	2.54e4	3.36e4	3.70e4
Magnet thickness (*L/8)	1.04	1.51	2.00
Air gap (mm)	3.32	4.13	4.90

* L is pitch of the motor

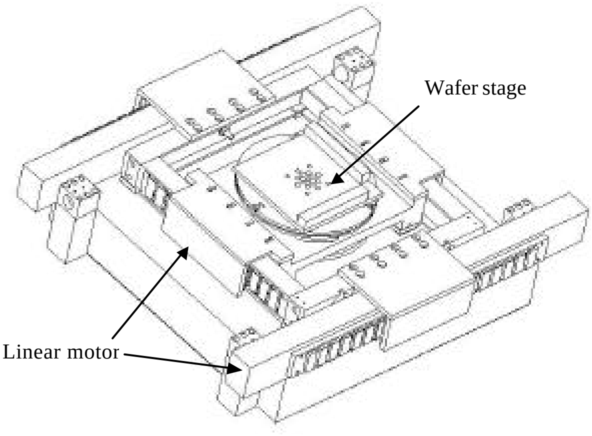


Fig. 1 A wafer stages of semiconductor lithography system

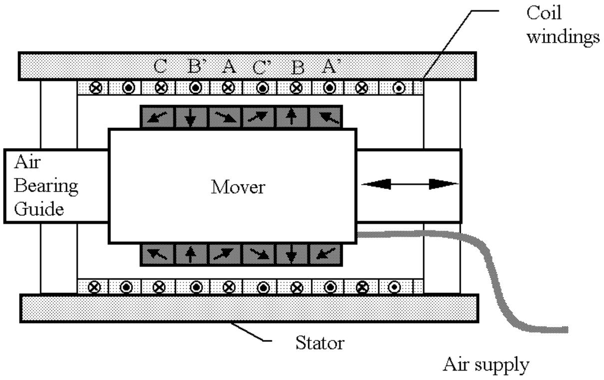


Fig. 2 Linear motor system guided by air bearing

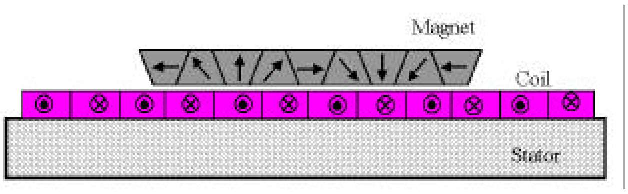


Fig. 4 Concerned model of a multi-segmented trapezoidal (MST) magnet array

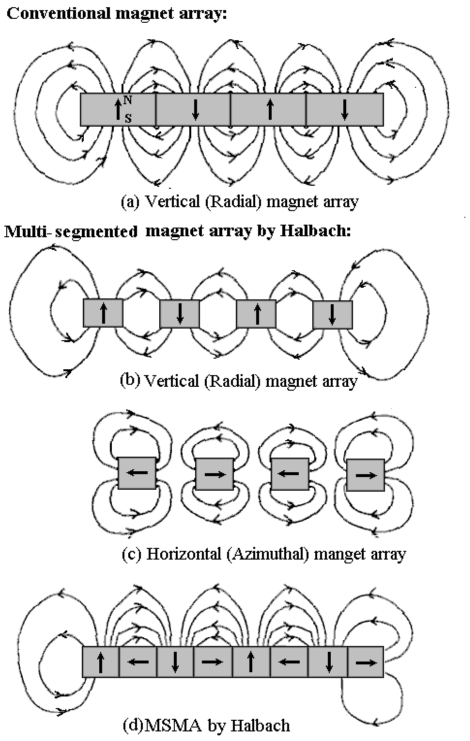


Fig.3 Intuitive illustration of flux distribution in conventional magnets array and MSMA proposed by Halbach.

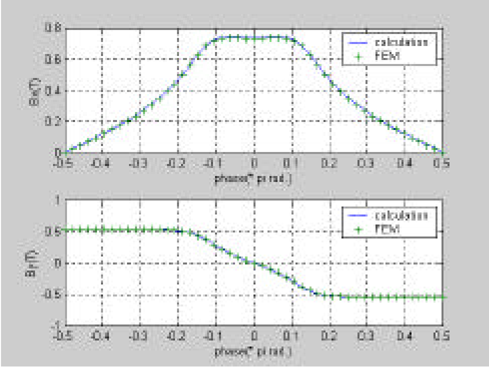


Fig. 5 Verification of the model using FEM: the flux density along coil surface.