A Dual-Servo Type VCM for a Nano-Level Measurement System

Yong-Min Yoo* and Byung-Il Kwon†

Abstract - In this paper, a dual-servo type VCM (Voice Coil Motor) for the measuring of nano-level displacement and small thrust is proposed and developed. The shape of VCM for improving the resolution of displacement and ensuring a large displacement are presented. The FEM (finite element method) is utilized to analyze the characteristics of VCM that produces linear driving thrust and satisfies the thrust that the measurement system requires. The Prototype is fabricated and an experiment is performed in order to measure displacement. As a result of simulation and testing, the proposed VCM shows the applicable possibility for a nano-level measurement system.

Keywords: Dual-servo, Finite element analysis, Measurement system, Voice coil motor

1. Introduction

Recently, the requirement for a nano-level measurement system has increased due to the development of the semiconductor industry, high precision manufacturing appliance and MEMS technology. Measurement methods of nano-level force and displacement use the piezoelectric effect, electrostatic and electromagnetic phenomenon, and primarily incorporate the piezoelectric device [1-3]. The piezoelectric device makes it easy to control the nano scale position, but a complicated circuit system is required. The VCM has the profitable advantages of a simple circuit system, a fast response and a linear movement for a relatively long operation distance. Despite the fact that the VCM has these advantages, its applications are limited as are the hard disk, pickup actuator and linear oscillating actuator [4, 5].

This paper proposes a dual-servo type VCM shape as a nano-level measurement system and performs the analysis of the VCM characteristics using the FEM. We design the VCM that produces a linearly driving thrust in a wide range of currents (0[A]~1[A]) through a design process and a FEM analysis. We finally manufacture a prototype and compare experiment results with simulation results.

2. Design and Experiment

2.1 Dual-servo type VCM

The VCM utilizes permanent magnets and coil windings to produce thrust (Lorentz's Force). The VCM has the advantage of being easy to control, because a thrust proportional to the current is applied to coil windings. Fig. 1 shows the proposed model of a dual-servo type VCM. The stator part has yokes and permanent magnets, and the moving part has a bobbin and wounded coil windings. Two coils are located in the path of the magnetic field to produce thrust. Coil 2 produces relatively large thrust because the turns of coil 1 are greater than that of coil 1.

The purposes of the proposed model are to improve the resolution of displacement and ensure a large driving range simultaneously. Coil 2 of the lower air gap ensures a large displacement by producing large force relatively and coil 1 of the upper air gap improves resolution of the displacement by producing small force. Because the current of the two coils are controlled at the same time, the VCM is called a dual-servo type VCM. A proper control algorithm is applied to control the current, and the displacement of a dual-servo type VCM is fractioned for inducing each current in coil 1 and coil 2.

The produced thrust of the proposed VCM is calculated as follows;

$$F = N_1 B_1 i_1 l + N_2 B_2 i_2 l \quad [N] \tag{1}$$

Where, N_1, N_2 are turns, B_1, B_2 are flux density in the air gap and i_1, i_2 are the input current of coil 1 and coil 2, respectively. l is the effective length of coil. When input current is applied, the direction of thrust is along the x-axis in Fig. 1.

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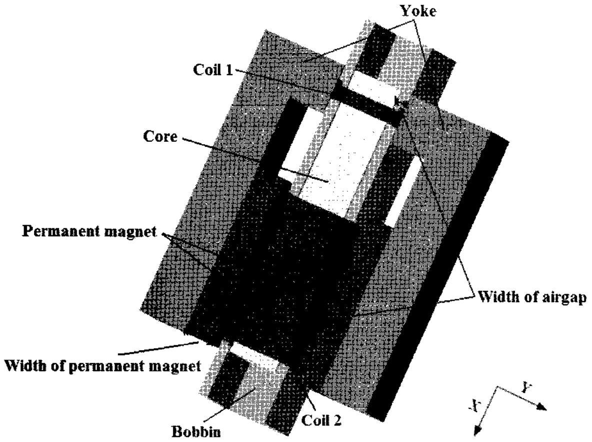


Fig. 1. Proposed model of a dual-servo type VCM

Fig. 2 shows the structure of the nano-level measurement system having a dual–servo type VCM. The VCM is tightly fastened to the system mechanically. The thrust of the VCM is transmitted by a cantilever through leaf springs and the direction of linear movement of that is the x-axis in Fig. 2. If a cantilever contacts a measurement sample by the movement of the VCM, the load and the indentation depth of that can be measured. In addition, a capacitive sensor is located in lower part of the measurement system to measure the displacement of the VCM.

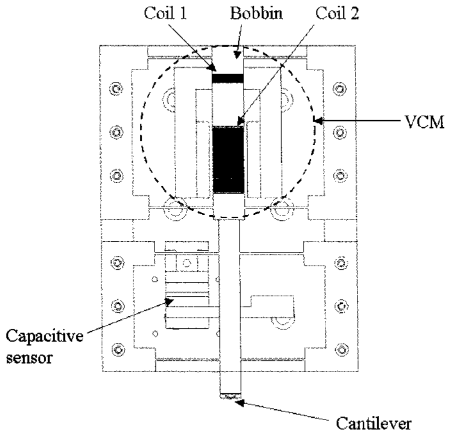


Fig. 2. Structure of the nano-level measurement system

Thrust of the VCM is directly proportional to the displacement and stiffness of the system, as shown in (2).

$$F = x \cdot k_e \quad [N] \qquad (2)$$

Where, x is displacement and k_e is the stiffness of the system.

Table 1 shows the target specification of the nano-level measurement system. The goal of the maximum displacement and the resolution of displacement of the system are 30[㎛] and 2[nm], respectively. Also, the range of induced current is 0[A]~1[A] and resolution of that is 1[mA]. As mentioned above, the purpose of coil 1 and coil 2 is to improve resolution and to guarantee large displacement of the measurement system, respectively. Therefore, the required maximum thrust of coil 1 is 0.38[N] and coil 2 is 5.76[N], because the stiffness of that system is 192[kN/m].

Table 1. The target specification of the nano-level measurement

Specifications		
Resolution of displacement [nm]	2	I=1 [mA] (by coil 1)
Maximum displacement [㎛]	30	I=1 [A] (by coil 2)
Stiffness [kN/m]	192	-
Maximum thrust [N]	Coil 1: 0.38	I=1[A]
	Coil 2: 5.76	

2.2 Design process

Fig. 3 presents the design process. First of all, we determine the dimensions and the magnetic circuit of the proposed model in Fig. 1 by considering the size of the nano-level measurement system as shown in Fig. 2.

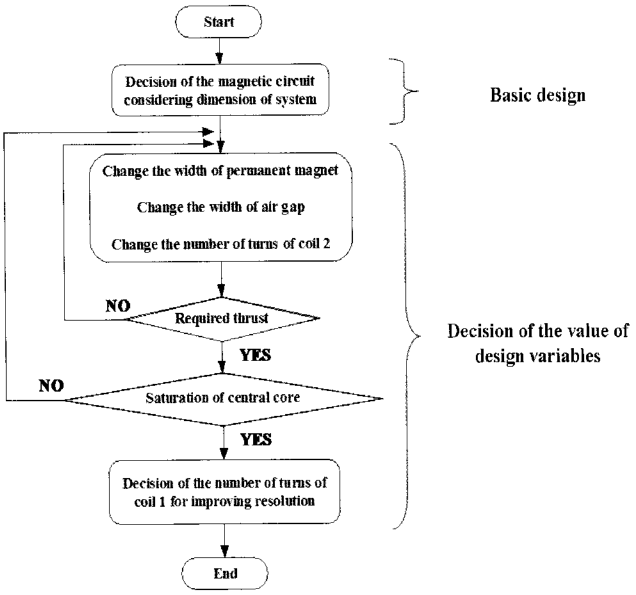


Fig. 3. Design process

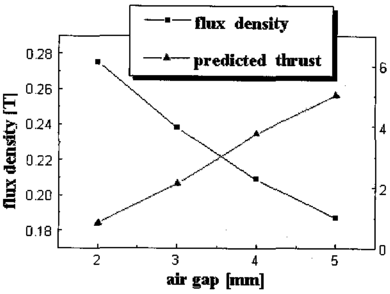
The design variables are the width of permanent magnet, the width of air gap and the number of turns of coil 2. The design variables are changed according to the design process as shown in Fig. 3 until they satisfy the required thrust of the system. For improving control performance, we minimized non-linearity between thrust and current by saturating yoke and core [6, 7]. Finally, the design of the VCM is completed by determining the number of turns of coil 1 for improvement of resolution.

2.2.1 Basic design

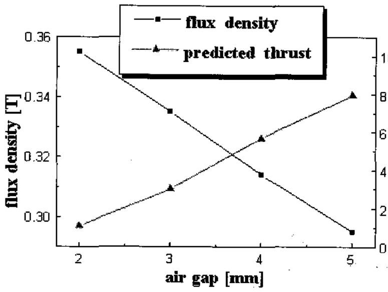
The size of VCM is 50×60×15 (width×length×height, unit: [mm]) considering restriction of the system size. The effective length of two coils of the VCM is 30[mm], which is twice as large as the axis length. The material of core and yoke are S23 for high permeability and reduction of leakage.

2.2.2 Decision of the value of design variable

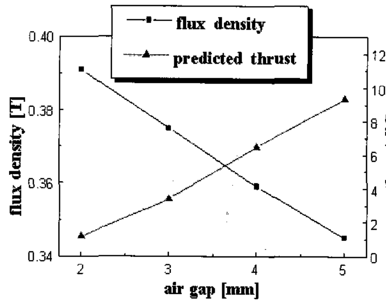
We utilized an Nd-Fe-B type permanent magnet with a residual flux density of 1.2[T]. The length and height of the permanent magnet are determined to be 35[mm] and 15[mm], respectively. The flux density of air gap with variation of the width of permanent magnet and air gap are obtained using the 2D-FEM. Next, we predicted thrust of the VCM by (1). Fig. 4 shows air gap flux density and predicted thrust with variation of width of the permanent magnet and air gap. The number of turns of coil 2 changed according to the width of the air gap, as indicated in Table 2.



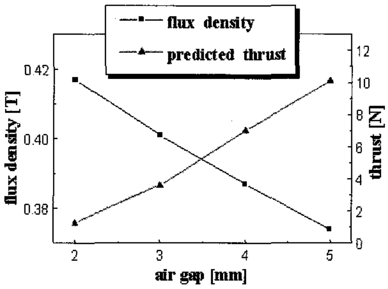
(a) Width of permanent magnet: 2[mm]



(b) Width of permanent magnet: 4[mm]



(c) Width of permanent magnet: 6[mm]



(d) Width of permanent magnet: 8[mm]

Fig. 4. Comparison of air gap flux density and predicted thrust with variation of width of permanent magnet and width of air gap

Table 2. Turns of coil 2 with variation of width of air gap

Width of air gap [mm]	2	3	4	5
Turns of coil [turns]	100	300	600	900

The requested thrust of coil 2 parts is 5.76[N] because required maximum displacement and stiffness of the system are 30[μm] and 192[kN/m] respectively, as shown in Table 1. Therefore, we select three models to satisfy the requested thrust of the system.

Table 3. Characteristics and dimensions of the VCM models to satisfy required thrust

Model Characteristics	I	II	III
Width of permanent magnet [mm]	4	6	8
Width of air gap [mm]	4	4	4
Flux density of air gap [T]	0.314	0.359	0.387
Predicted thrust [N]	5.652	6.462	6.966
Displacement of system [μm]	29.44	33.66	36.28
Flux density of central core [T]	1.654	1.811	1.887

When the permanent magnet width is larger than 6[mm], as indicated in Table 3, VCM maintains linearity of thrust according to variation of current because the central core is saturated sufficiently. Considering the efficiency of the permanent magnet volume, we finally decide in model II that the permanent magnet and air gap width are 6[mm] and 4[mm], respectively. Flux density in the upper air gap of model II is 0.622[T]. The number of turns of coil 1 is determined to be 10[turns] to satisfy the resolution of displacement (2[nm]) when resolution of the current is 1[mA] by (1) and (2).

2.2.3 Design results and characteristics

Fig. 5 shows the shape and dimensions of the designed VCM. Coil 1 and 2 are fixed in a bobbin.

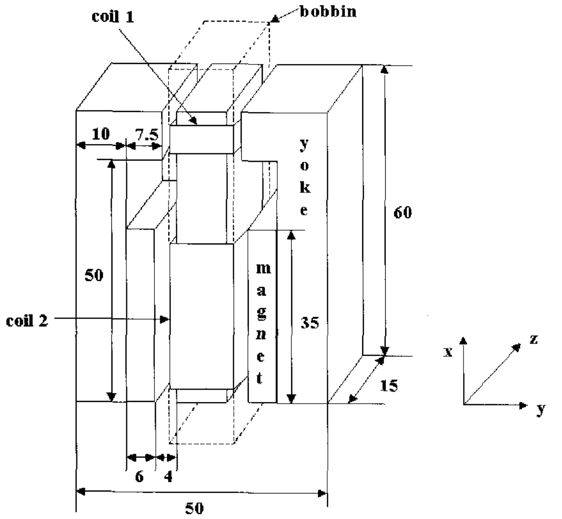
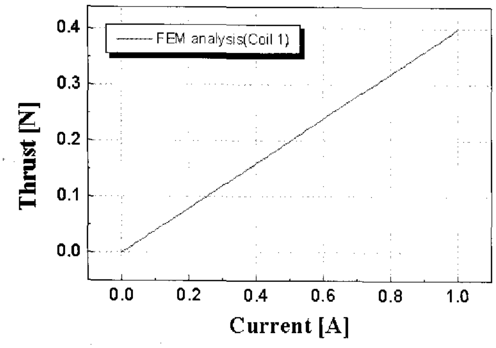
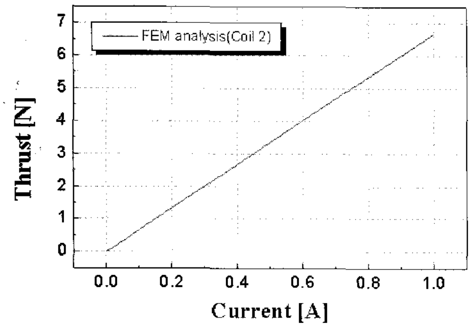


Fig. 5. Dimensions of the designed VCM [unit: mm]



(a) Coil 1



(b) Coil 2

Fig. 6. Thrust characteristics according to the current variation

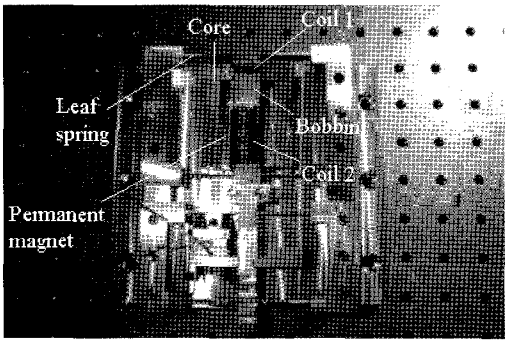
Linear thrust characteristic of the dual-servo type VCM is very important because the nano-level measurement system needs precision position control. To verify linearity of thrust, we perform 2D-FEM analysis that applies value of determined design variables. The thrusts produced by coil 1 and coil 2 increases linearly, as shown in Fig. 6. Table 4 shows characteristics of coil 1 and coil 2. Maximum displacement of each coil is calculated by (2) when input current is 1[A]. The resolution of displacement of each coil is calculated by (2) when input current resolution is 1[mA].

Table 4. Characteristics of each coil

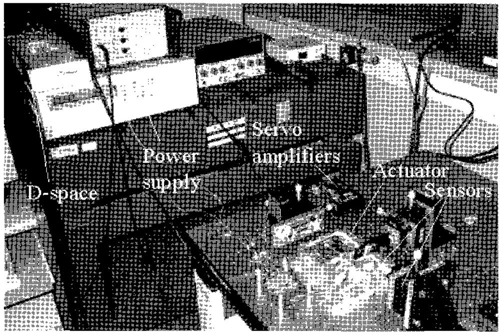
Quantity	Coil 1	Coil 2
Maximum thrust [N]	0.4	6.67
Maximum displacement [μm]	2	34.7
Position resolution [nm]	2	34.7

2.3 Experiment

Fig. 7(a) shows the prototype of dual-servo type VCM, which is designed according to the above design process. An experiment is implemented to measure displacement of the VCM as illustrated in Fig. 7(b). The measurement system is controlled by D-space control equipment. The displacement of the VCM is measured by capacitive sensor.



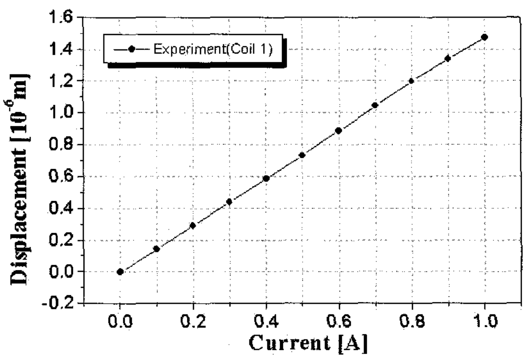
(a) Prototype



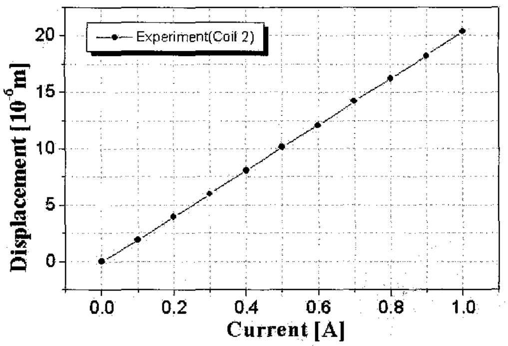
(b) Experiment setup

Fig. 7. Prototype and experiment setup

Fig. 8 shows the experimental results of the VCM. When input current is 1[A], the experimental value of coil 1 and coil 2 is 1.5[μm] and 20.2[μm], respectively. They have slight differences between the 2D-FEM analysis. The differences are the result of leakage flux of the upper and lower parts of air gap, mechanical manufacturing, assembling error and experimental environment. Though experimental results do not satisfy the planned specification of the nano-level measurement system, we improve the resolution of displacement by coil 1 and ensure a large driving range by coil 2. We also get linearly driving thrust in a wide range of currents (0[A]~1[A]).



(a) Coil 1



(b) Coil 2

Fig. 8. Experimental results

3. Conclusion

In this paper, we proposed a shape of dual-servo type VCM for the system that measures nano-level displacement and small thrust. The design of the VCM is performed by the design processes that determine the dimensions, the magnetic circuit of the VCM and the value of design variables that have an effect on the thrust. We could design the VCM in which thrust increases linearly. The design variables were determined using the 2D-FEM. Coil 2 of the lower air gap ensured a large displacement by producing large force relatively and coil 1 of the upper air gap improved resolution of the displacement by producing small force. Hence, we improved the resolution of displacement and ensured a large driving range. We made an experiment using a fabricated prototype. Through the experimental results, we verified that the proposed shape of the VCM is a useful model for the nano-level measurement system.

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