A Study on the Simulation and Experiment of Flat Coil Actuator with Shorted Turn for Fast Initial Response

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Abstract — This paper presents a new design and analysis of the flat coil actuator. A shorted turn and a center pole are placed into the flat coil actuator in order to reduce the inductance of the coil and improve the initial response when it is driven by voltage. Dynamic finite element analysis using the commercial electromagnetic solver "MAXWELL" is performed to demonstrate the improvement of dynamic characteristics, especially the fast initial response. Therefore, this paper compares the results derived from the finite element analysis and the actual experiment.

I. Introduction

A flat coil actuator is suitable for a subminiature machine due to thin plate shape of moving coil. In addition, it provides linear motion of high accuracy and fast response using simpler mechanism than rotary motor and has no drawback such as friction, noise and vibration. The flat coil actuator is activated by the magnetic force called the Lorentz force that can be explained by formula (1).

$$F = n \cdot B_g i l_{eff} \qquad (1)$$

Where $\boldsymbol{n}$ is the number of turns of the wire, $\boldsymbol{B_g}$ is the flux density within the air gap, $\boldsymbol{i}$ is the applied electrical current, $\boldsymbol{l_{eff}}$ is the effective length of the wire in the magnetic field for each turn.

The conventional flat coil actuator, however, has the delayed initial response when it is driven by voltage control due to the inductance, which is a typical characteristic of an electromagnetic coil. Kim, therefore, introduced the flat coil shorted turn to improve the initial fast response [1].

This paper proposes a new design and analysis of a flat-coil actuator using shorted turn. The dynamic performance of the new design is verified by finite-element analysis and the experiment.

II. Design of Proposed Actuator

To reduce the inductance, a center steel pole is inserted between the yokes and then wrapped by a thin copper plate, as shown in Figure 1 This thin copper plate is called shorted turn, which promotes the fast increase of the coil current by reducing the inductance under applied voltage [2].

The center pole may reduce the translation limit of the coil because it is placed in the way of the moving coil. However, the translation limit between the center pole and the coil is 1.5mm which is enough for nano or micro scale positioning.

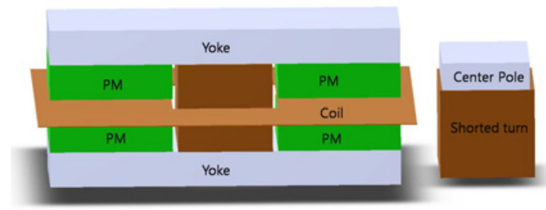

Fig. 1 Schematic diagram of proposed flat coil actuator.

III. Simulation

For precise verification of the dynamic characteristics of the proposed design, including magnetic characteristics such as the eddy current effects and back electromotive force, dynamic finite element analysis was performed using the FEM solver MAXWELL.

For comparison of the dynamic performances of the conventional and the proposed actuator, we created a finite element model for each actuator for the condition in which the coil is in motion under an applied voltage. Accordingly, the actuator system consists of three subsystems: the magnetic, the mechanical and electric subsystems. The commercial magnetic field FE solver "MAXWELL" was used to solve this coupled system.

The magnetic property of the neodymium (NdFe35) was used as the magnetic property of the permanent magnet whose physical properties are given in Table1. Table 2 shows the moving mass and the spring stiffness of the mechanical subsystem. And the flat coil actuator used flexure mechanism of the leaf spring for linear guide as in Figure 2.

A 2-D finite element model which consists of 130,000 triangle elements was created to assist in modeling these coupled systems. The dynamic motion of the coil from the initial position to the right is simulated by 4 µs over a period of 2ms.

Figure 3 and Figure 4 show the coil current versus time and position of coil versus time of the conventional flat coil actuator and the proposed flat coil actuator respectively. The current of the flat coil actuator with shorted turn rises faster than that of the conventional actuator. The flat coil actuator with shorted turn improves the displacement by 10.38% for 2ms.

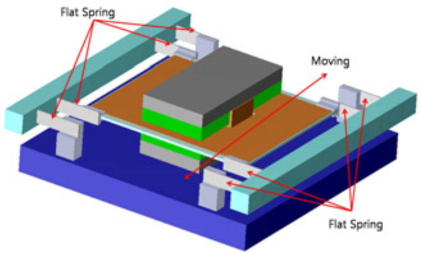

Fig. 2 Schematic diagram of compound leaf spring of flat coil actuator.

TABLE I
Magnetic property of NdFe35

Residual Induction	1.23(T)
Coercivity	11184.1(Oe)
Relative permeability	1.0997

TABLE 2
Specification of mechanical subsystem

Mass	0.33(Kg)
Spring siffness	0.25(MN/m)

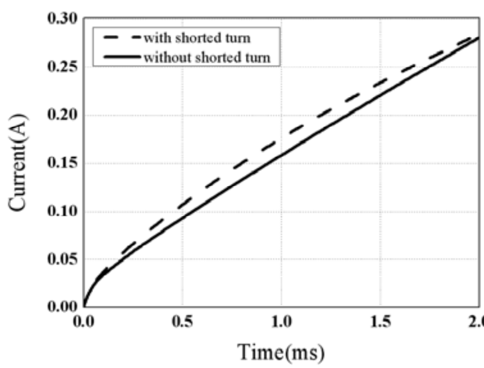

Fig. 3 Comparison of current of coil versus time between models with and without shorted turn.

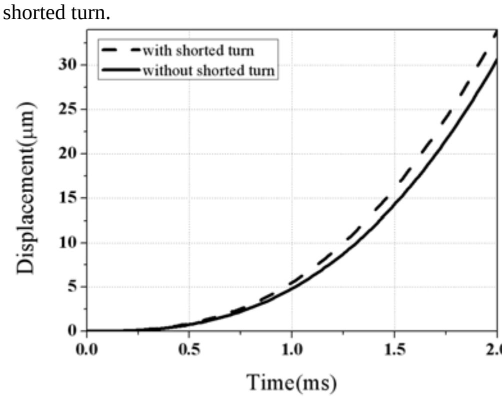

Fig. 4 Comparison of position versus time between models with and without shorted turn.

IV. Experiment

Flat coil actuator was fabricated by the derived parameter using simulation and the actuator was tested to measure the dynamic performance.

Figure 5 shows flat coil actuator using shorted turn and double compound linear guide for the test. The actuator to prevent the noise that caused by external vibration was installed on the air vibration isolation table.

Figure 6 shows schematic diagram of experimental system. Laser interferometer measures the displacement of moving coil when voltage is applied to the flat coil actuator by DC power supply.

The laser interferometer is the most widely used to measure the position. It measures the positioning from the displacement of a moving reflector in terms of the wavelength. [3]

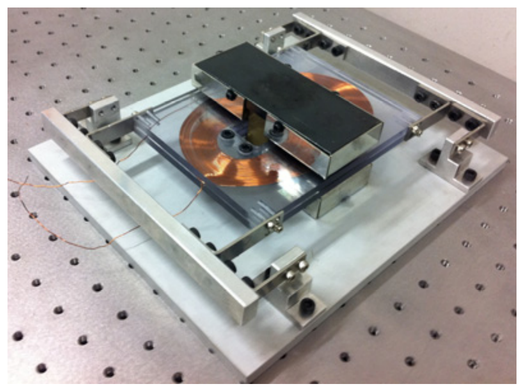

Fig. 5 Flat coil actuator using shorted turn and double compound linear guide.

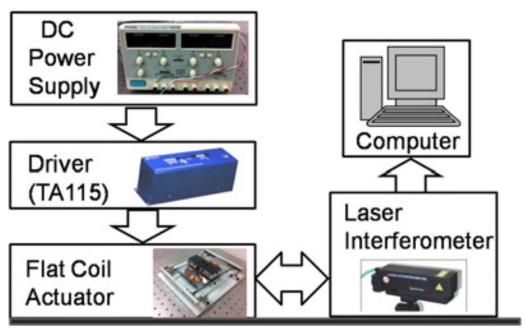

Fig. 6 Schematic diagram of experimental system.

V. References

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[2] Hi Dong Chai, "Electromechanical Motion deviece", pp201~206

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