Characteristics Analysis of High-Speed Three-Degree-of-Freedom Electromagnetic Actuator for Image Stabilizations

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Recently, image quality deteriorations due to vibrations have become a problem. A lens-unit-swing system is one of the image stabilization technologies that generate an inverse motion against camera shakes, which consists of a lens and an imaging device. This system can correct an image from camera shakes over wide rotation ranges around three axes. On the other hand, this system has some problems such as the increases of the size and power consumption. Therefore, three-degree-of-freedom actuators are expected to become a solution for these problems. In this paper, we propose a novel three-degree-of-freedom electromagnetic actuator for image stabilizations, which can be controlled by a simple control system. The basic structure and operating principle of the actuator are described. Moreover, the static torque characteristics are computed by electromagnetic field analyses using 3-D finite element method, and the effectiveness of the actuator is verified.

***Index Terms*— Actuators, Electromagnetic analysis, Finite element method, Permanent magnet motors.**

I. Introduction

RECENTLY, a high-quality image has been obtained by a digital camera because of its improved imaging performance. However, image quality deteriorations due to vibrations have become a problem. In order to solve this problem, various image stabilization technologies have been developed [1-3]. Rotational and translational vibrations occur when shooting. The translational vibration has a small influence on the image quality deterioration. However, the influence of the rotational vibration on the image deterioration is dominant. A lens-unit-swing system is one of the image stabilization technologies that generate an inverse motion against a camera shake, which consists of a lens and an imaging device. This system can correct the image from camera shakes over wide range rotations around three axes. However, the lens-unit-swing system has some problems such as the increases of the size and power consumption.

On the other hand, recently, various multiple-degree-of-freedom actuators have been developed [4-7]. These actuators have advantages such as the decrease of the device size and power consumption. In this paper, we propose a novel three-degree-of-freedom (3-DOF) electromagnetic actuator for image stabilizations, which can be controlled by a simple control system. The basic structure and operating principle are described. Moreover, the static torque characteristics are computed by electromagnetic field analyses using 3-D finite element method (FEM), and the effectiveness of the actuator is verified.

II. Structure and Operating Principle

The overview of the proposed 3-DOF electromagnetic actuator is shown in Fig. 1. This actuator is mainly composed of an inner mover and an outer stator. The mover consists of six permanent magnets (N_dF_eB, *Br* =1.4T) and an inner yoke. The stator consists of an outer yoke, a rolling yoke and coils. In this paper, the rotation around X, Y and Z axes are defined as panning, tilting and rolling motions, respectively. The movable angle of the panning and tilting motions is ±25 deg., and that of the rolling motion is ±5 deg. The coils for the panning and tilting motions are wound around the outer yoke. In addition, the coil for the rolling motion is wound around the rolling yoke.

The operating principle of the actuator is shown in Fig. 2. The panning torque is due to Lorentz force. The coils carrying

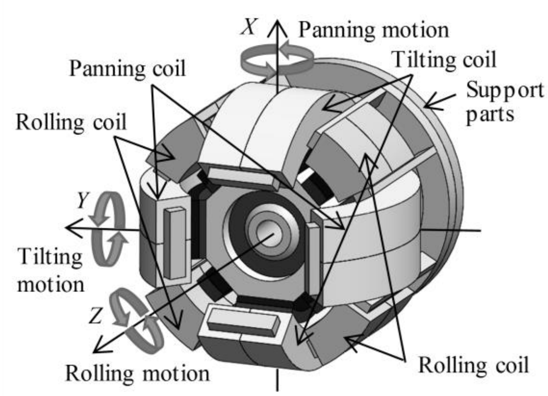

Fig. 1. Overview of the actuator.

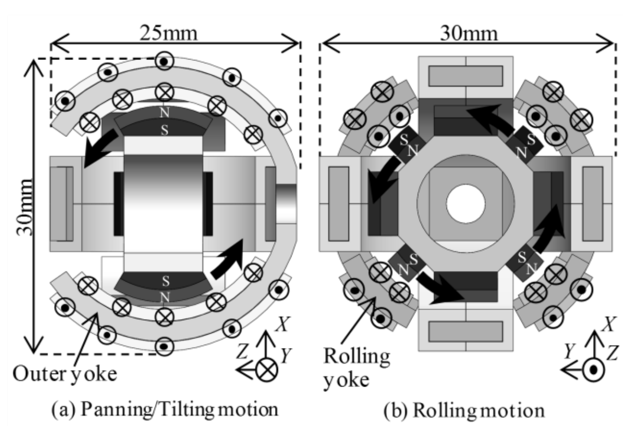

Fig. 2. Operation principle.

currents generate tangential direction forces that cause the panning torque, and the mover makes a panning motion. Similarly, the tilting and rolling torques are generated, and the mover makes tilting and rolling motions, respectively.

This actuator has two operating features. First, this actuator can be controlled by only three-phase currents. Therefore, 3-DOF motions can be achieved by a simple control system. Second, the detent torque works as an attractive force to return to the origin. These features contribute to downsize the system.

III. Analysis Method and Results

A. Analysis Method

An electromagnetic field analysis using 3-D FEM is conducted to verify the static torque characteristics of the actuator. In order to compute the characteristics, the *T-Ω* method is employed [8]-[9]:

$$J_m = \mathrm{rot} T_m \tag{1}$$

$$J_0 = \mathrm{rot} T_0 \tag{2}$$

$$\mathrm{div}\{\mu(T_m + T_0 - \mathrm{grad}\,\Omega)\} = 0 \tag{3}$$

where T_m and T_0 are the current vector potentials of the equivalent magnetizing current density J_m and forced current density J_0, respectively, Ω is the magnetic scalar potential, and μ is the permeability.

B. Analysis Results

The detent and excitation torque of the actuator are computed by electromagnetic field analyses using 3-D FEM. The 3-D FEM model is shown in Fig. 3.

The analysis results of the panning and tilting motions are shown in Fig. 4. A current of 1.2 A is applied to the panning and tilting coils. The average excitation torque is 15.4 mNm and the excitation torque are higher than the detent torque in any angular position. Moreover, the analysis result of the rolling motion is shown in Fig. 5. A current of 0.3 A is applied to the rolling coil. The average excitation torque is 11.2 mNm and the excitation torque are higher than the detent torque in any angular position. These results mean the mover of the proposed actuator can be rotated around three axes.

IV. Conclusion

In this paper, we proposed a novel 3-DOF electromagnetic actuator, which can be controlled by a simple control system. The static torque characteristics of the actuator was verified by ~~an~~ electromagnetic field analyses using 3-D FEM. In the final paper, Dynamic characteristics of the actuator will be shown.

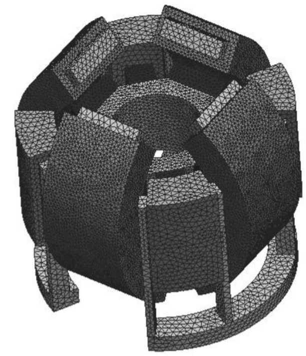

Fig. 3. 3-D mesh model (except the air region).

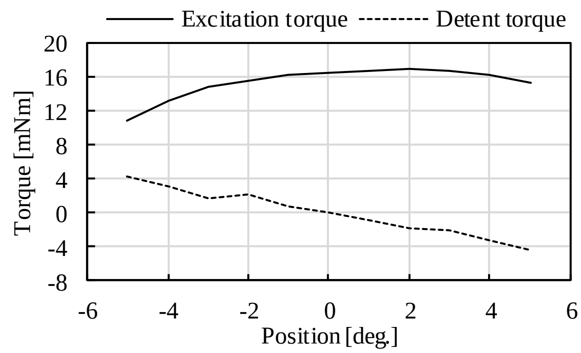

Fig. 4. Excitation and detent torques in panning and tilting motions.

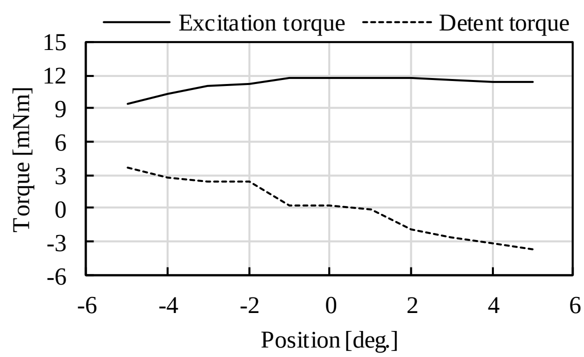

Fig. 5. Excitation and detent torques in a rolling motion.

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