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Miniaturized Dual Electromagnetic Oscillatory Actuator

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Abstract. In this research we propose a miniaturized dual electromagnetic oscillatory actuator. The proposed actuator is a moving magnet type voice coil actuator with two rotating parts. The structure of the actuator is simple, which includes two magnets, a coil, and a yoke. We provide a linear model for the actuator. We then determine torque and restoring constants using finite element simulation. We also present the dynamic characteristics of the actuator.

Keywords: Electromagnetic actuator, micro mobile robot, voice coil motor.

1 Introduction

Due to their scalability and short response time, electromagnetic voice coil actuators are widely used in hard-disk drive actuators [1], auto focus actuators for digital cameras [2], and optical micro mirrors actuators [3]. Recently, many biologically inspired insect-like robots have been designed applying micro actuators. The piezo actuators [4] provide faster responses and larger forces compared to their size. However, they require higher voltage inputs and produce limited movement. They also need additional mechanisms to convert linear motion to rotational motion. More recently, polymer actuators are introduced [5], which includes Ionic Polymer Metal Composite (IPMC) actuators. Applying lower voltage inputs, these actuators provide larger deflection in aqueous solution whereas they do smaller deflection and lower force in air. Electromagnetic actuators also provide short response time and proper force. These actuators can be produced massively and inexpensively. DC motors are used in some micro mobile robots [6]. However, it is generally difficult to apply DC motors to micro robots since they require additional gear reducers to provide desired force and speed. Further, an electromagnetic oscillatory actuator for micro mobile robot is developed with a simple structure [7, 8]. This actuator produces oscillatory motion, which is suitable for various micro mobile robots such as tadpole, 2-legged, and 4-legged robots [7].

We propose a novel miniaturized dual electromagnetic oscillatory actuator in this paper, which can be applied to miniature optical devices and micro mobile robots. In general, a rotary mirror in a barcode scanner is driven at 50~60 Hz and responses of insects lie within 100 Hz. Thus, our actuator is designed to be sufficiently small and

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provide faster responses for these applications. We can also change system responses by adjusting an air-gap between a magnet and a coil.

2 Actuator Design and Parameter Analysis

Fig. 1 illustrates the design of our moving magnet type voice coil actuator with two rotating parts. This actuator consists of magnets, a coil, and a yoke similar to a micro mirror system in a barcode scanner. As shown in Fig. 2, magnetic field direction is perpendicular to the direction of coil windings. The direction of electromagnetic forces acting on rotating parts depends on the direction of current.

We model a dual oscillatory electromagnetic actuator based on a typical DC motor model. We propose two types of the actuator, which features the same or opposite magnetic field directions from two magnets as illustrated in Fig. 2. If magnetic field directions of magnets are opposite, Fig. 2 (a), force directions are same such that resulting orientation directions of rotating parts are same. In contrast, considering Fig. 2 (b) where magnetic field directions of magnets are same, forces directions are opposite such that resulting orientation directions of rotating parts are opposite.

We now consider two different forces in our actuator. The magnetic force between the magnet and yoke generates a restoring torque, which pushes the rotating part into

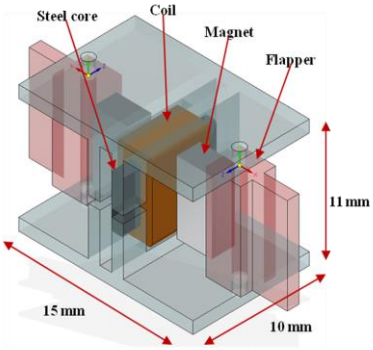
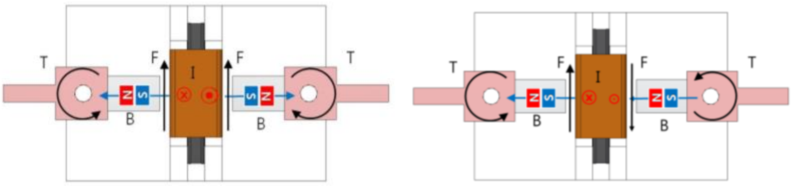


Fig. 1. Design of the moving magnet type voice coil actuator.



(a) Opposite magnet direction (b) Same magnet direction

Fig. 2. Actuator types and resulting Lorentz Forces.

the center position as shown in Fig. 2 similar to a spring force. When current flows, electromagnetic force rotates the rotating part in the clockwise or counterclockwise direction depending on current direction. Denoting the moment of inertia in the actuator by J and the angular acceleration by $\ddot{\theta}$, actuator dynamics can be written by,

$$J\ddot{\theta} + T_{magnetic} = T_{elecromagnetic} . \tag{1}$$

Further, assuming small rotational displacements and linearizing torques, the restoring torque and electromagnetic torque in (1) may be simplified by,

$$T_{magnetic} = K_m \theta \quad \text{and} \quad T_{elecromagnetic} = K_t I , \tag{2}$$

where K_t is the torque constant, K_m is the restoring constant, θ is the orientation angle of the rotating part, and I is the magnitude of coil current. Neglecting coil inductance, the circuit equation is,

$$V = RI + K_e \dot{\theta} , \tag{3}$$

where V is the input voltage, R is the coil resistance, and $\dot{\theta}$ is the angular velocity of the rotating part, and K_e is the back electromotive force (emf) constant. Note $K_e = K_t$ in SI units. Using Laplace transforms of (1)-(3), we can derive actuator model,

$$\frac{\Theta}{V} = \frac{K_t}{JRs^2 + K_t K_e s + K_m R} . \tag{4}$$

Further, we measure J =3.3x10^{-9} kg/m^2 and R= 58Ω from our prototype actuator. We then obtain the magnetic and electromagnetic forces conducting Finite Element Analysis (FEA). As a result, we can easily find the restoring and torque constants using torques (2), which is summarized in Table 1. Applying actuator parameters to the model (4), we can characterize actuator dynamics as shown in Fig. 3.

3 Conclusion

In this research we propose a novel miniaturized dual electromagnetic oscillatory actuator. The actuator is a moving magnet type voice coil actuator with two rotating parts. We introduce the working principle and linear model for the actuator. We obtain actuator parameters using FEA simulation results. We then present the frequency response of the actuator.

Table 1. Toque and restoring constants

Magnet direction	Toque constant (K_t)	Restoring constant (K_m)
Same	4.04 mNm/A	0.92 mNm/rad
Opposite	4.03 mNm/A	0.02 mNm/rad

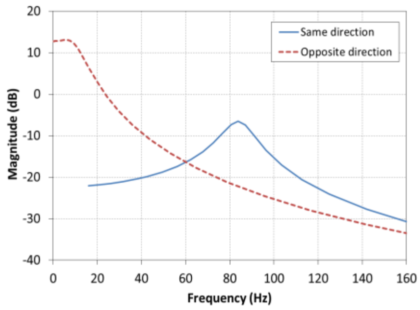


Fig. 3. Actuator dynamic response based on the linear model.

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