Characteristics Analysis of a 2-D Differentially Coupled Magnetic Actuator Employing 3-D FEM

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In multi-degree-of-freedom systems, a number of motors are used to achieve a multi-DOF motion. However, these systems have problems such as heavy weight, large size and no back drivability due to-large number of motors. In order to solve the problems, there have been many works to achieve multi-DOF motions using 1 actuator. In this paper, a novel 2-DOF differentially coupled magnetic actuator is proposed and its structure and operating principle are described. Finally, the static force and torque characteristics are computed by employing 3-D FEM.

Index Terms—Differentially coupled, finite element method, multi-degrees-of-freedom, electromagnetic actuator

I. Introduction

MULTI-DEGREE-OF-FREEDOM (multi-DOF) systems are often used in humanoid robots and factory automations. In these systems, a lot of motors are equipped to achieve multi-DOF motions like human arms and also caused problems such as heavy weight, large size and no back drivability. In order to solve the problems, there have been many outstanding works to achieve multi-DOF motions using 1 actuator. Wang *et al.* proposed a 3-DOF electromagnetic actuator with 4 coils [1]. The operating principle is based on that of a 1-DOF permanent magnet synchronous motor. The rotor is housed in the stator and can be fixed at arbitrary positions if the coils are excited appropriately. Kumagai *et al.* also have proposed a multi-DOF actuator which used the principle of an induction motor [2]-[3]. The rotor is completely sphere shaped and made of copper. Around the rotor, 4 armatures which generate time-varying magnetic fields are located. Due to the magnetic fields, induced current is generated on the rotor surface and the rotor rotates by the interaction between the induced current in the rotor and magnetic fields in the stator. Other than this, there are many multi-DOF actuators which have potentials to solve the multi-DOF problems. However those actuators have a lot of coils to generate complex magnetic fields. Therefore special control equipment and methods are needed to operate them.

A differential drive mechanism is adopted in *iCub* which is a child-like humanoid robot [4]-[5]. This device uses two motors, cables and a differential gear and can achieve a two-DOF motion. The control method is a simple like a motor control. In this paper a novel magnetic actuator which also uses a differential mechanism is proposed. The operating principle is based on the differential drive mechanism and the control method is also simple. The basic structure and operating principle is shown and static torque analyses are conducted employing 3-D FEM.

II. Structure and Operating Principle

The whole view of the proposed actuator is shown in Fig. 1. The actuator has two DOFs and the mover can move along Y-axis and can rotate around Z-axis. The actuator is mainly composed of one cylindrical mover and two stators. The rotor has permanent magnets and the magnetic poles alternate every 12 degree. The stators have iron poles with 3-phase windings. By exciting 3-phase currents to coils, the rotor moves or rotates. As shown in Fig. 2, the directions of forces generated by two stators are the same, and the rotor receives translation forces and moves along Y-axis.

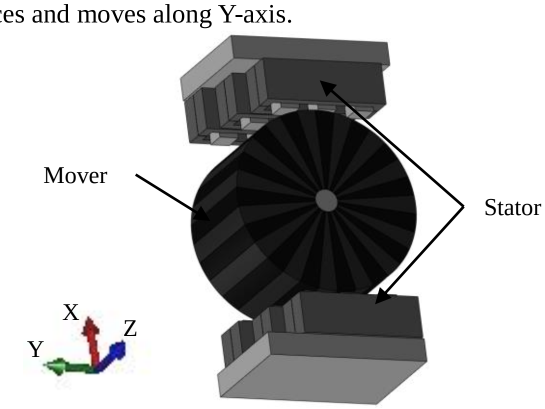

Fig.1. Whole view of the proposed actuator

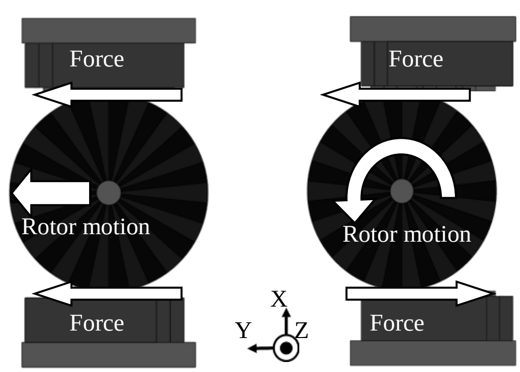

Fig.2. Operating principle (Translation and rotation)

If the directions of the forces are different from each other, torques are generated so that the rotor rotates around Z-axis. By regulating the directions and amplitudes of two forces appropriately, the rotor can move and rotate.

III. Analysis Method and Results

A. Analysis Method

In order to compute the static force and torque of the actuator, the **T**-Ω method is employed [6]. In this study, eddy currents are ignored because the actuator moves slowly.

$$\boldsymbol{J_m} = rot\,\boldsymbol{T_m} \tag{1}$$

$$\boldsymbol{J}_0 = rot\,\boldsymbol{T}_0 \tag{2}$$

$$div\{\mu(\boldsymbol{T_m} + \boldsymbol{T}_0 - grad\,\Omega)\} = 0 \tag{3}$$

where $\boldsymbol{T_m}$ and $\boldsymbol{T}_0$ are the current vector potential of the equivalent magnetizing current density $\boldsymbol{J_m}$ and forced current density $\boldsymbol{J}_0$ respectively, Ω is the magnetic scalar potential, and μ is the permeability.

B. Analysis Results

The force and torque characteristics of the mover from 0 to 24 degree were analyzed. The 3-D FEM model is shown in Fig. 3 and the current waveforms in each step are shown in Fig.4. When the excited translation forces are computed, the same currents are excited to the coils of two stators. The computed forces are shown in Fig. 5. The maximum non-excited force is 10 N and the excited forces are higher than non-excited forces in any angular position. This means the rotor can move along Y-axis. When the excited torques are computed, the current amplitudes of two coils are the same but the current directions are opposite.

Fig. 3. Mesh model of the proposed actuator

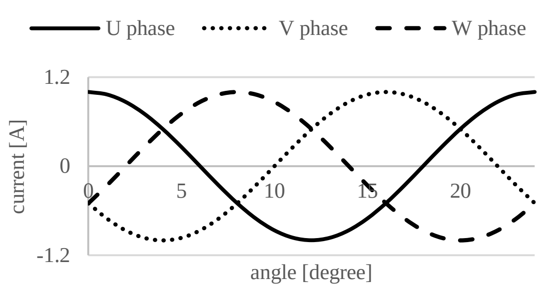

Fig. 4. Current waveforms (translation)

The computed torque are shown in Fig. 6. In any angular position, the excited torque are also higher than non-excited torques. This means the rotor can rotate around Z-axis.

Conclusion

In this paper, a novel differentially coupled magnetic actuator was proposed. By adopting a differential mechanism, the actuator can achieve a 2-DOF motion with simple control equipment and control method. The static torque characteristics were computed by 3-D FEM and the force and torque could be generated by controlling the current phases. In the final paper, dynamic torque characteristics will be analyzed.

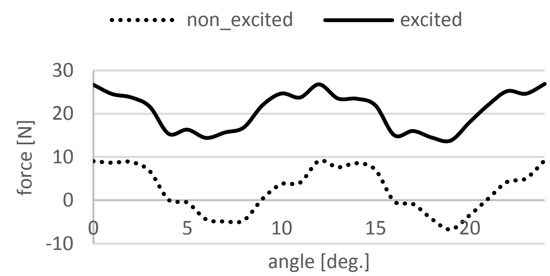

Fig. 5. Computed forces (translation)

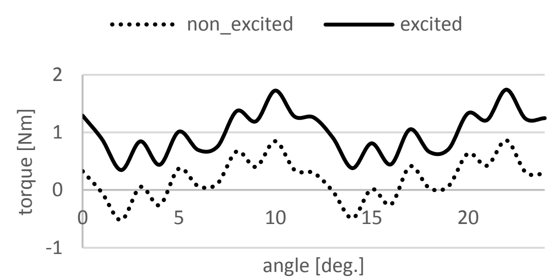

Fig. 6. Computed torques (rotation)

IV. References

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