Proposal of 3-Degree-of-Freedom Spherical Actuator with Auxiliary Poles
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Introduction

- **Multi-Degree-of-Freedom (Multi-DOF) actuating system**

  - 1-DOF actuator
  - Multi-DOF actuator

  ![Multi-DOF system](Image)

  - Reducing the Number of coils
  - Stator of a spherical actuator

**Purpose**

A 3-DOF spherical actuator using 5 current phases with auxiliary poles is proposed.

Basic structure and Torque equation

- **Basic structure**

  - Rotor magnet
  - Permanent magnet
  - Spacer
  - Stator

- **Torque equation**

  \[ T = K_s(p_1) + K_s(p_2) + K_s(p_3) + T_{cog}(p_1) + T_{cog}(p_2) + T_{cog}(p_3) \]

Torque constant

Coggging torque

Each coil pair generates a torque and the total torque is obtained by adding up them.

Proposed structure and Basic torque characteristics

- **Conventional and proposed pole structure**

  - Conventional structure
    - Yoke
    - Coil
    - Core
    - Magnetic flux
  - Proposed structure
    - Non-magnetic material
    - Coils
    - Auxiliary pole

  A loop between the main poles and rotor back yoke via the center stator core

- **Basic torque characteristics**

  - **Condition ①**: Longitudinal direction
    - \( \theta = 11.25 \text{ deg} \)
    - Current torque \([\text{Nm}]\)
    - Average of minimum output torque distribution

  - **Condition ②**: Lateral direction
    - \( \theta = 0 \text{ deg} \)
    - Current torque \([\text{Nm}]\)
    - Average of minimum output torque distribution

Optimization Pole Arrangement and Torque Characteristics

- **Condition of optimization**

  - Minimum angle of pole arrangement
    - 45 deg
    - The angle between the magnetic poles - 46 deg or more
    - Latitude: ~70 deg to 70 deg
  - Minimum angle of pole arrangement
    - the magnetic poles are arranged at the center-symmetrical positions
    - Longitude: 0 deg to 180 deg

- **Optimization result**

  - Torque \([\text{Nm}]\)
    - Latitude (deg)
    - Longitude (deg)
    - Pole arrangement using conventional pole
    - Pole arrangement using proposed pole

  - Average of minimum output torque distribution
    - Conventional model: 0.28
      - Increase 86%
    - Proposed model: 0.52

Conclusion

A pole structure using auxiliary poles for 3-DOF spherical actuators was proposed. The 5-phases actuators using the conventional and proposed pole structure were compared. The average torque of the proposed model was higher than that of the conventional model, and the torque area of the proposed model less than 0.01 Nm was smaller than that of the conventional model.