Proposal of Magnetic Geared Screw Motor

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Graduate Student
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1. Background and Purpose
2. Proposed model and Operational principle
3. Transmission force and torque characteristics
4. Conclusion
Introduction – Feed screw –

<table>
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<tr>
<th>Transmission</th>
<th>Slide screw</th>
<th>Ball screw</th>
<th>Static pressure screw</th>
<th>Magnetic screw</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface contact</td>
<td>Point contact</td>
<td>Mediate a fluid</td>
<td>Non-contact</td>
</tr>
</tbody>
</table>

| Noise/Friction        | Big         | Small      |                        |                |
| Efficiency            | Low         | High       |                        |                |

Advantage of magnetic screw
- Force limiter function when overloaded
- Integrated a linear driving mechanism and elastic component

Introduction – Magnetic Screw Motor –

Increase the force density of the IPM screw motor without helical permanent magnets

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1. Background and Purpose
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Structure

- High Speed Screw Rotor (HSSR) (Only rotary motion)
- Low Speed Screw Mover (LSSM) (Only linear motion)
- Permanent magnet
- HSSR yoke
- Stator
- Salient yoke
- LSSM pole piece
- Coils
- Stator back yoke

Integrated structure of magnetic screw, gear and motor
The operating principle is divided into a magnetic gear part and a motor part.
**Operation principle of magnetic gear part (1/4)**

Modulated wave due to the permeance distribution of the salient poles

It can be regarded as a magnetically skewed permanent magnet.
Operation principle of magnetic gear part (2/4)

Movement of the magnetic flux distribution wave

The HSSR rotates around the Z axis

The magnetic flux distribution wave moves in the Z axis direction.
The axial section is similar to a conventional magnetic gear.
Operation principle of magnetic gear part (4/4)

Step 1. The HSSR is rotated, and the magnetic flux distribution wave is moved.

Step 2. The modulated harmonic flux is generated by LSSM, and coupled with stator flux.

Step 3. The LSSM moves according to the operational principle of a magnetic gear.

Gear ratio: \[ G_r = \pm \frac{N_I}{N_h} \]
The magnetic circuits of the motor part is similar to a conventional 3-phase synchronous motor.

The operating principle is the same as a 3-phase synchronous motor.
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**Analysis model**

**Specifications**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Outer diameter [mm]</td>
<td>70</td>
</tr>
<tr>
<td>Stack length [mm]</td>
<td>60</td>
</tr>
<tr>
<td>Pole-slot combination</td>
<td>10 pole 12 slot</td>
</tr>
<tr>
<td>Gear ratio</td>
<td>3.33</td>
</tr>
<tr>
<td>Number of Salient poles (HSSR, Z direction)</td>
<td>3</td>
</tr>
<tr>
<td>Number of pole pieces (LSSM, Z direction)</td>
<td>10</td>
</tr>
<tr>
<td>Number of stator permanent magnets (Stator, Z direction)</td>
<td>7</td>
</tr>
</tbody>
</table>

- Maximum transmission force as a magnetic gear
- Torque to rotate the HSSR
- Magnetic flux linkage as a motor
Static analysis condition

- Transmission force of the LSSR and HSSR
- Torque of the HSSR
- Flux linkage of the coil

Discretization data and software

<table>
<thead>
<tr>
<th>Number of elements</th>
<th>2,640,696</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of nodes</td>
<td>463,071</td>
</tr>
<tr>
<td>Number of edges</td>
<td>3,116,666</td>
</tr>
<tr>
<td>Number of faces</td>
<td>5,294,292</td>
</tr>
<tr>
<td>Software</td>
<td>MagNet 7</td>
</tr>
<tr>
<td></td>
<td>(by Siemens AG)</td>
</tr>
</tbody>
</table>
The reaction force from the LSSM

If the motor part generates a torque of more than approximately 0.15 Nm, the proposed actuator can output a maximum thrust force.
Flux linkage of the coil

The flux linkage forms a 3-phase alternating flow

The magnetic circuit forms a 3-phase synchronous motor
Characteristics when currents are applied

1. Under over load
   - LSSM: Fixed
   - HSSR: Rotated
   - Stator: Currents are applied (5A/mm²)

2. At maximum transmission force
   - LSSM: Moved
   - HSSR: Rotated
   - Stator: Currents are applied (5A/mm²)

The characteristics when currents are applied under $i_d = 0$ control are investigated.
Characteristics under over load condition

The transmission force waveform of the LSSM
→ when currents are applied = when currents are not applied
→ The motor and magnetic gear parts do not influence on each other
Characteristics at maximum transmission force

The phase angle difference between the HSSR and LSSM fluctuates due to the force and torque ripples of the LSSM and HSSR, respectively.
Comparison of transmission force density of magnetic screw motor

<table>
<thead>
<tr>
<th>Outer diameter [mm]</th>
<th>Helical 94.5</th>
<th>201 × 204</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack length [mm]</td>
<td>25</td>
<td>178</td>
<td>96</td>
</tr>
<tr>
<td>Transmission force [N]</td>
<td>450</td>
<td>2000</td>
<td>23.1</td>
</tr>
<tr>
<td>Permanent magnet</td>
<td>Helical</td>
<td>Plate</td>
<td>Rectangular</td>
</tr>
</tbody>
</table>

Comparison of transmission force density of magnetic screw motor

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.37</td>
<td>2.56</td>
<td>0.28</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Transmittion force densities

The torque density of the proposed motor is about 75% lower than that of a magnetic screw motor using helical permanent magnets.

→ This is caused by the leakage magnetic flux due to an IPM structure.

The transmission force of the proposed motor is approximately 9% higher than that of the conventional IPM type motor.
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Conclusion

• A new magnetic geared screw motor which a magnetic geared screw is integrated with a motor was proposed.
  • The basic structure and operating principle of the proposed motor were shown.
  • The static characteristics of the magnetic geared screw motor were investigated employing 3-D FEM.
  • The proposed motor could realize a linear motion, and the transmission force of the proposed motor was approximately 9% higher than that of the conventional IPM type motor.

• A problem that torque ripple is large remained.
  • In future works, a torque ripple reduction method will be investigated.