A Magnetically Levitated Lead Screw for Complete Non-Contact Power Transmission

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Outline

- Introduction
- Magnetically levitated lead screw
- Characteristics analysis
- Conclusion
Introduction

High cleanliness required conveyance devices

- Panels conveyance device (IHI Corp.)
- Freeze drying machine (Azbil Corp.)

- Suppressing dust generated when driving
- Easiness of sterility

Low dust emission and simple transmission mechanism is critical
Magnetic lead screw (MLS)

- Transmits forces using magnetic force

**Advantage**
- Reduction of particle emission / Low noise
- Sterilization is easy by covering non-magnetic material
Previous research

Spiral surface permanent MLS

Interior permanent MLS

Consequent-pole MLS

Operating principle

Spiral surface permanent MLS

Interior permanent MLS

Consequent-pole MLS

Matsuoka et al., Proposal of a Magnetic Lead Screw Actuator without Helical Permanent Magnets, 2017

Heya et al., Analysis of a Consequent-Pole Magnetic Lead Screw, 2018
MLS: Operating characteristics

- Linear actuator using the MLS

Rotary motor and encoder  Screw  Nut

Linear encoder

Operating verification

Step out

Force sensor-less control

Problem

- Supported by mechanical contact

MLS developed by Berg et al.
- Screw
- Nut
- Linear position transducer
- Force transducer
- Servo drive

MLS developed by Pakdelian et al.
- Nut
- Screw
- Rotary bearing
- Rotor magnets
- Shaft encoder
- Linear guide: linear encoder, rail, torque transducer, rotary machine

MLS developed by our group
- Nut
- Screw
- Crankshaft
- Load motor
- Linear guide
Magnetic levitation

- Levitate a shaft using magnetic force

Integration of MLS and MB for Non-contact power transmission

Hybrid type magnetic bearing (MB)  
Okada et al., 2011
Purpose

➢ Non-contact driving system using a MLS

System configuration

MLLS: Magnetically Levitated Lead Screw

Proposal of a magnetically levitated lead screw
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Structure

- **Basic structure**
  - **Mover**: Screw (magnetic material)
  - **Stator**: Coils, PMs, Magnetic poles, Back yoke

![Diagram of motor structure]

- Back yoke
- PM
- Coil-Y1
- Coil-X1
- Screw (Double-threaded)
- Coil-Y2
- Coil-X2
Structure

- Magnetic poles are faced to screw thread
  Bias magnetic flux: Generated by PMs

Structure except for coils
Levitation mechanism

- Magnetic attraction force
  Generated by unbalance of the magnetic flux distribution

- Magnetization
- Force
- Bias magnetic flux
- Control magnetic flux

Diagram:
- PM
- Coil-X1
- Coil-X2
- Coil-Y1
- Coil-Y2
- Back yoke
Levitation mechanism

- Magnetic attraction force
  Generated by unbalance of the magnetic flux distribution

- Magnetization
- Force
- Bias magnetic flux
- Control magnetic flux

- PM
- Coils X1, Y1, X2, Y2
- Back yoke

Diagram showing the levitation mechanism with magnetic components and flux directions.
Levitation mechanism

- Magnetic attraction force
  Generated by unbalance of the magnetic flux distribution
  - Magnetization
  - Force
  - Bias magnetic flux
  - Control magnetic flux

- Diagram showing the levitation mechanism with coils labeled X1, X2, Y1, Y2 and a back yoke.
Increase of bias magnetic flux

- Thrust is improved by exciting coils

- Magnetization
- Force
- Bias magnetic flux
- Control magnetic flux

Coil-X1, Coil-X2, Coil-Y1, Coil-Y2, Back yoke, PM
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Characteristics analysis

Force characteristics when the screw is moved and rotated

• Investigate the effective suspension force

\[ F_c = F_o - F_d \]

Control force \( F_c \) = output force \( F_o \) – detent force \( F_d \)

Suspension force \( F_S = -F_c \)

Effective suspension force \( F_{ns} = F_S - F_d - F_{mg} \)

Thrust and torque characteristics when the screw is rotated

• Clarify the maximum thrust and torque
Analysis model

3-D mesh model

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<td>Number of nodes</td>
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Analysis condition: suspension force

- Moved in Y-axis: 0 - 0.4 mm
- Rotated in Z-axis: 0 - 90 deg.
- Current density: 12 A/mm$^2$

Exciting condition to generate suspension force
Suspension force characteristics

Suspension forces are bigger than the detent force
Effective suspension force

- All effective suspension forces are positive value.

Proposed MLLS can levitate the screw.
Analysis condition: thrust & torque

- Rotated in Z-axis: 0 - 90 deg.
- Current density: 12 A/mm²

Exciting condition
for increasing the bias magnetic flux
Thrust and torque characteristics

- Works as rotary-linear motion conversion

Max thrust: 19.4 N $\Rightarrow$ 35.9 N

Max torque: 19.4 mNm $\Rightarrow$ 34.5 mNm

Stiffness can be increased by excitation
Conclusion

Proposed MLLS can levitate the screw

Works as non-contact rotary-linear motion conversion mechanism

Future works

- Dynamic characteristics when driving and levitating under control
- Proposal of a motor integrated magnetically levitated lead screw
Thank you for your attention!