Tokyo Tech

18th International Symposium on Magnetic Bearings

LaMCoS UMR 5259 INSA LYON cnrs

18 – 21 July 2023 Lyon France

Proposal of a One-DOF Actively Controlled Bearingless Motor Using Zero-Sequence Current

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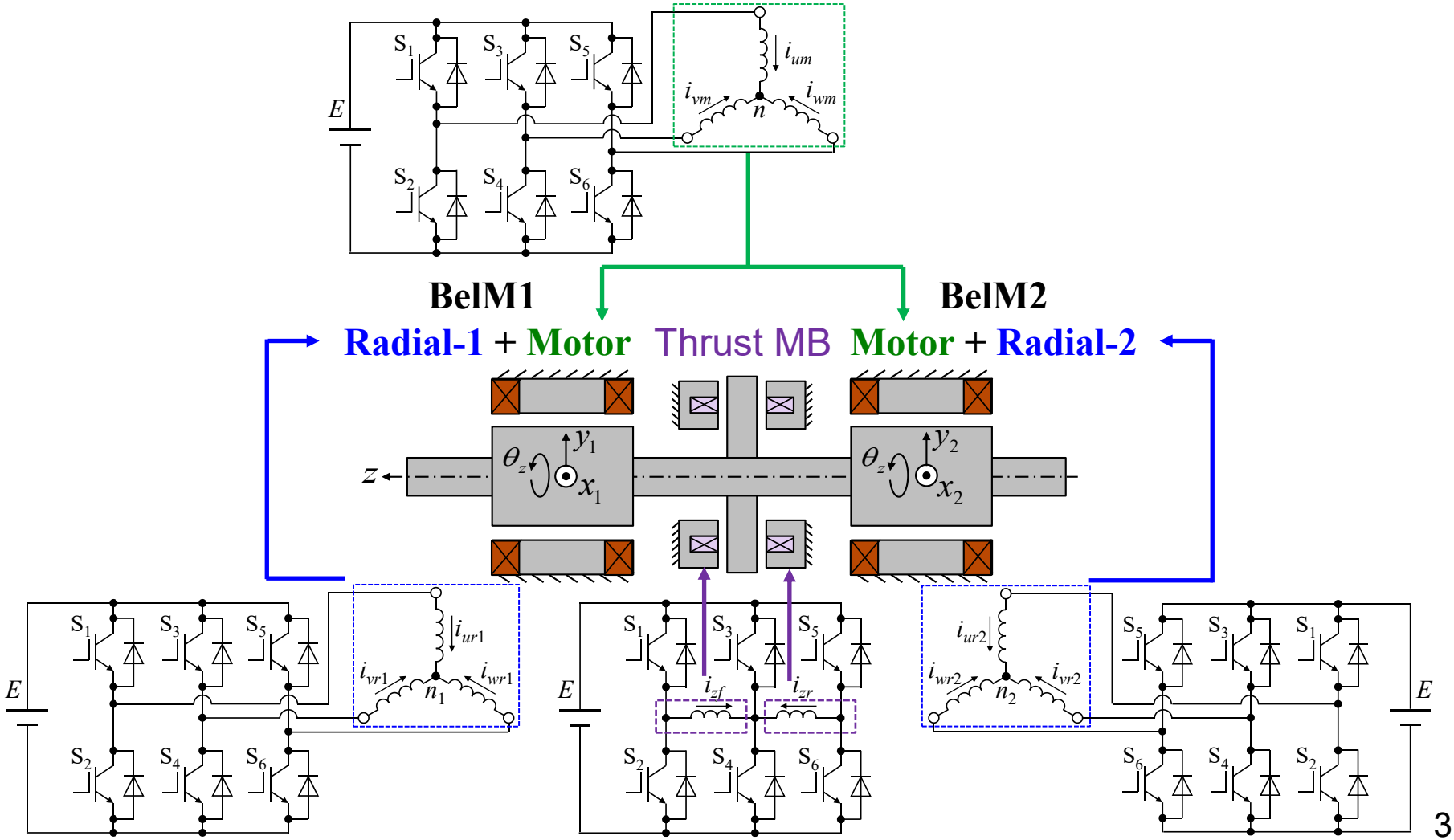
Outline

1. **Introduction**
2. Proposed System
3. Proposed Machine
4. FEA Results
5. Fabricated Machine (only picture. . .)
6. Conclusion

1. Introduction

5-DOF Controlled Bearingless Motor

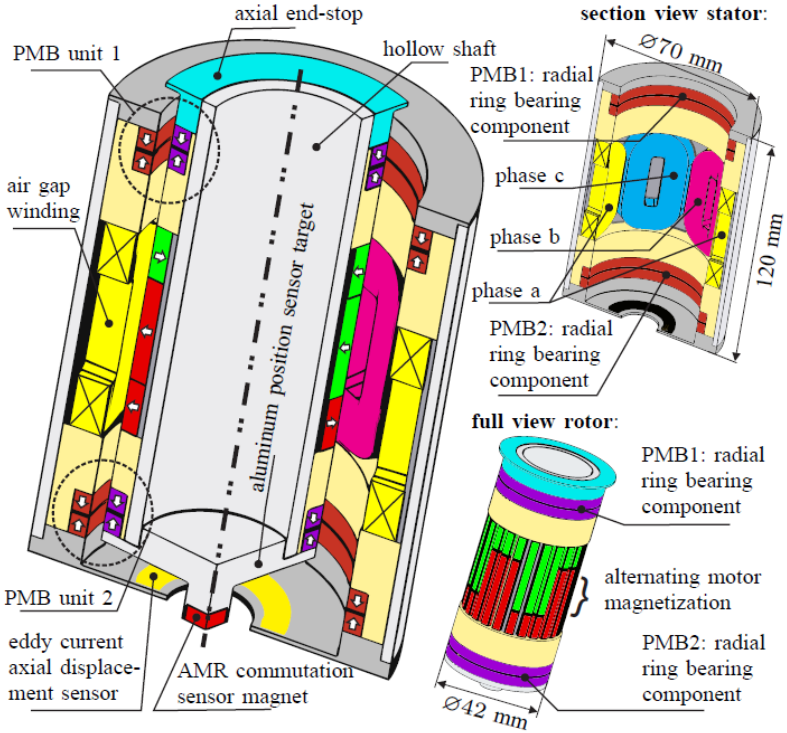
- This system requires at least four three-phase inverters

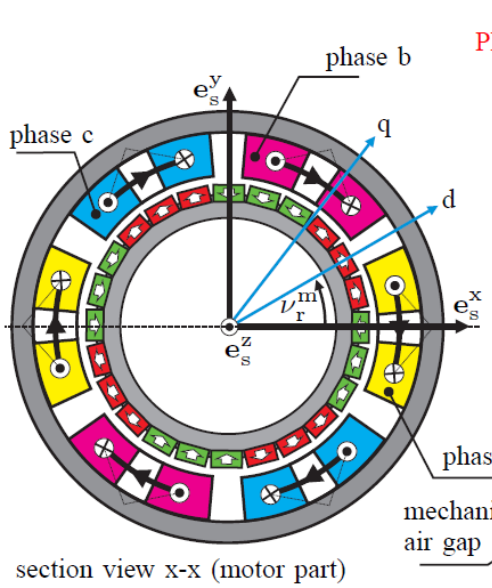


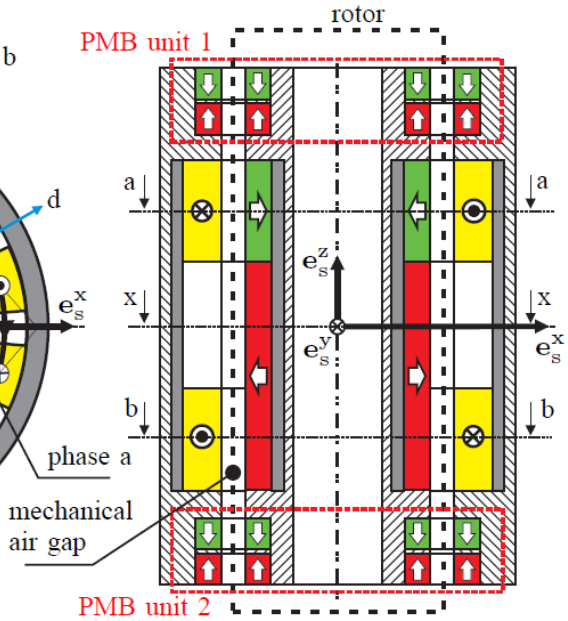
1. Introduction

① JKU, 2014 : One-DOF Controlled Belm

- Motor and thrust windings (core-less coil) are combined
- This system needs 12 power switching devices.





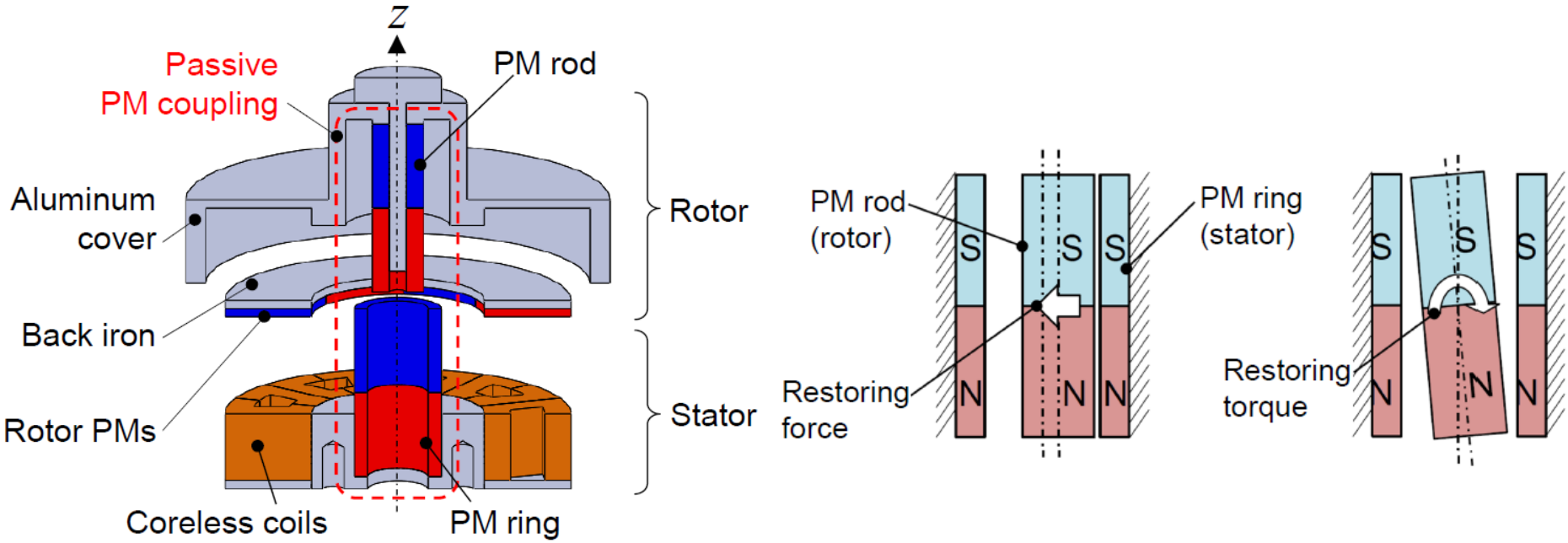


Wolfgang Amrhein, “Experimental Characterization of a Bearingless Rotating Field Axial-Force/Torque Motor”, 2014）

1. Introduction

② Prof. Asama, 2021 : One-DOF Controlled Belm

- Motor and thrust windings (core-less coil) are combined
- d-axis current : active thrust magnetic suspension
- q-axis current: torque
  → needs only three-phase inverter, called “Single-Drive Belm”



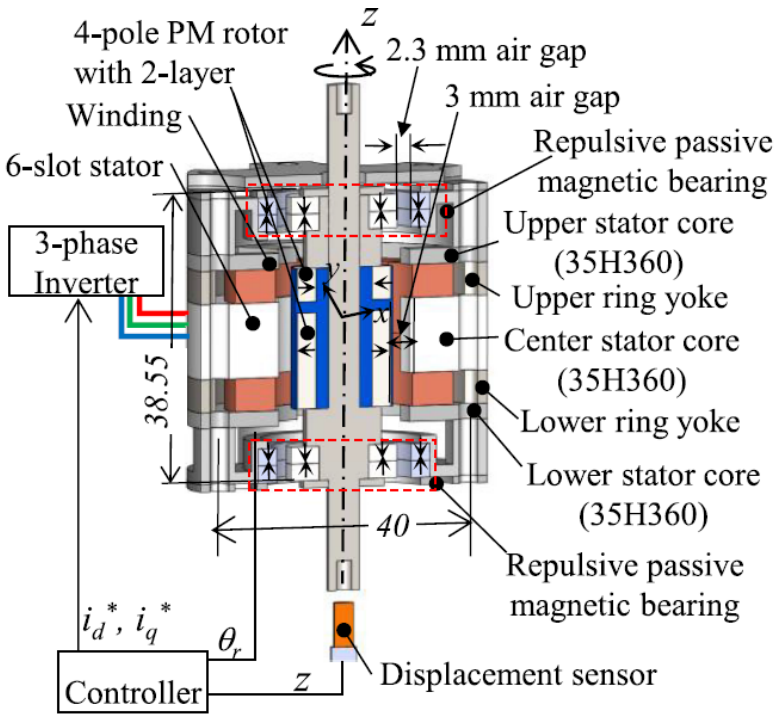
J. Asama, “Development of Axial-Flux Single-Drive Bearingless Motor With One-Axis Active Positioning”, 2021）

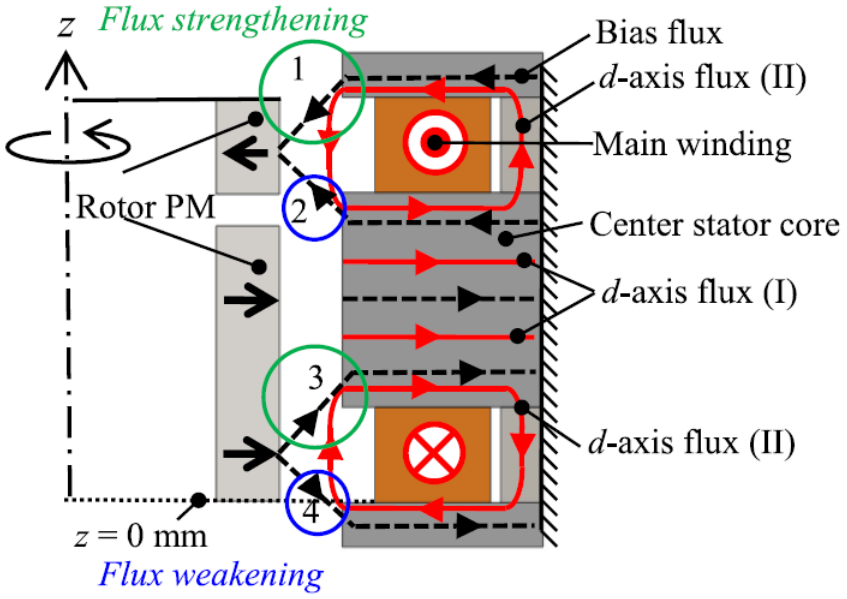
1. Introduction

③ Prof. Sugimoto, 2021 : One-DOF Controlled Belm

- Motor and thrust windings (with core) are combined
- d-axis current : active thrust magnetic suspension
- q-axis current: torque

  → needs only three-phase inverter





H. Sugimoto, "Design, Development, and Experimental Results of a 30 000-R/Min One-Axis Actively Positioned Single-Drive Bearingless Motor", 2021）

1. Introduction

Comparison of Specification

- Power rating is less than 150 W.
- Torque is less than 0.15 Nm.

} applied to only small fan

Research Group	Power device	Motor control	Coil	Output Torque
① JKU, 2014	12	○ dq—axis current	Combined Core-less	122 W @7900rpm 147 mNm
② Prof, Asama, 2021	6	△ Only q-axis current	Combined Core-less	0.3 W @5000rpm 0.58 mNm
③ Prof, Sugimoto,2021	6	△ Only q-axis current	Combined With core	18.4 W @30000rpm 5.9 mNm

Proposes one-dof controlled belm with more than 1 kW

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2. Proposed System

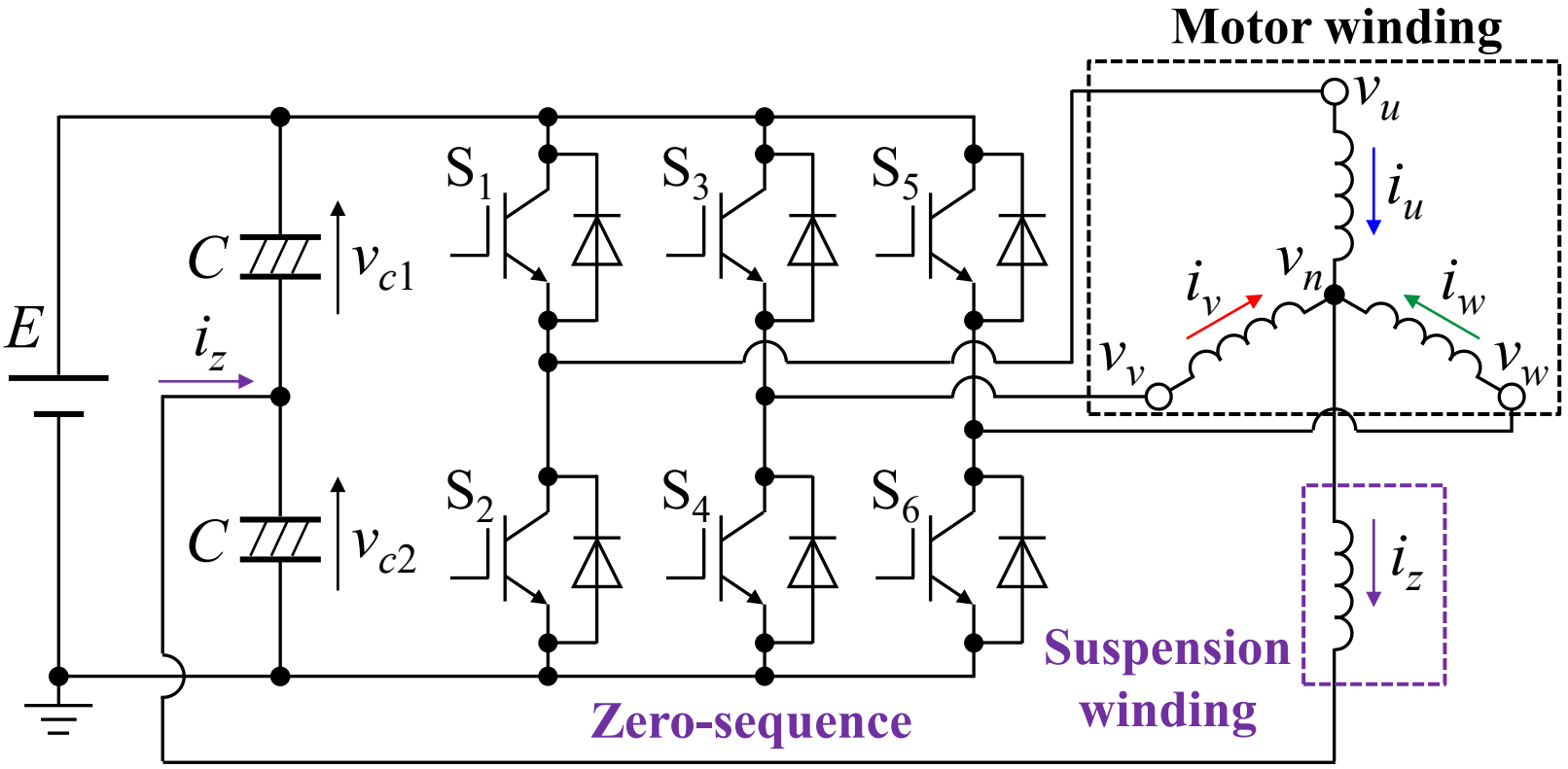
Three-Phase Four-Wire Inverter

- Zero-sequence current, iz is used for active thrust suspension.

→ ◎Simplicity

→ ◎dq-motor control

$$
\begin{aligned}
i_u &= I_m \sin(\omega t) + i_z/3 \\
i_v &= I_m \sin(\omega t - 2\pi/3) + i_z/3 \\
i_w &= I_m \sin(\omega t - 4\pi/3) + i_z/3
\end{aligned}
$$



2. Proposed System

What is compromised in the proposed circuit ?

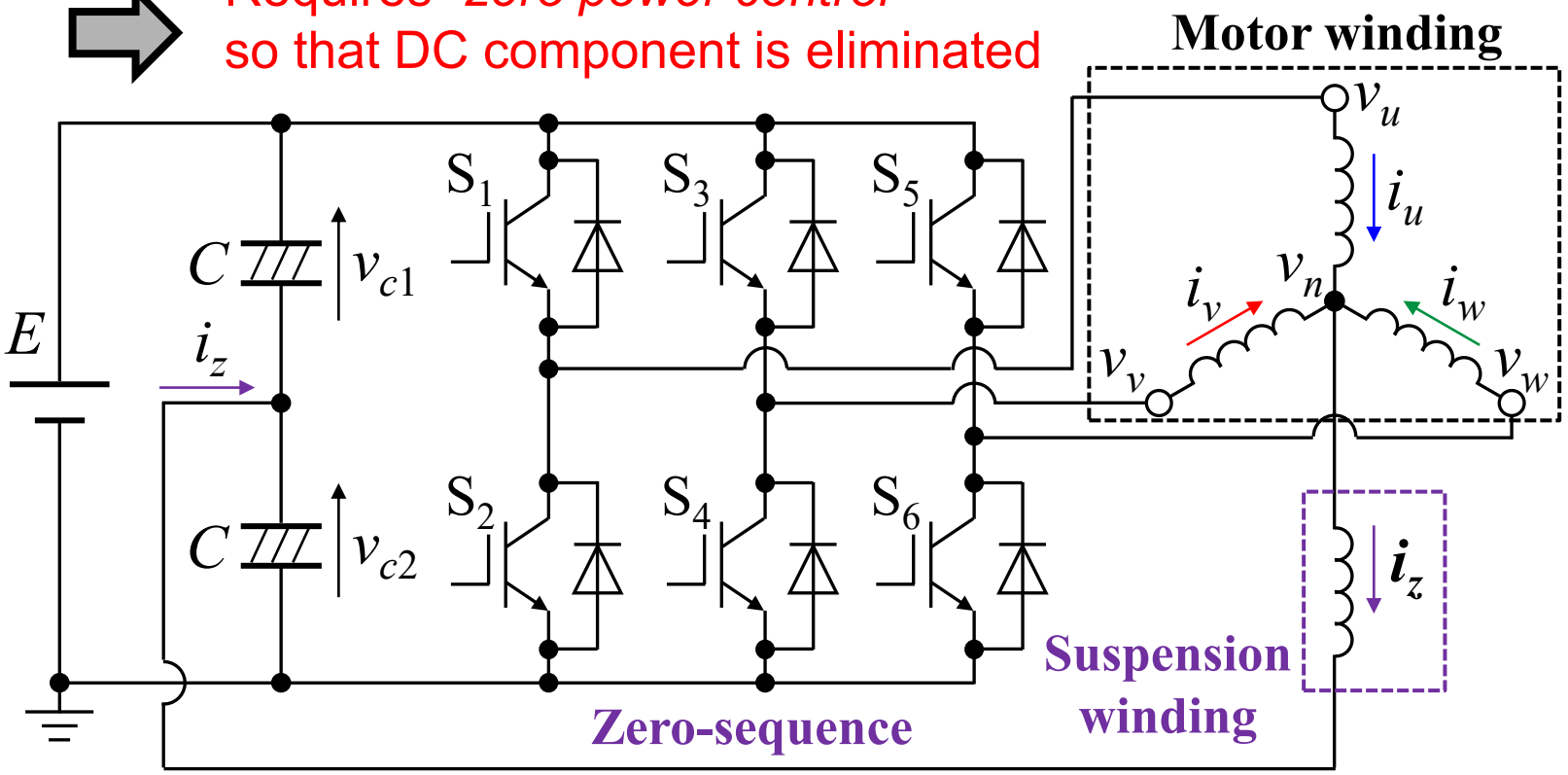
- Zero-sequence current, iz must not have any DC component.

$$i_z(t) = I_{dc} + i_{ac}(t) \qquad V_{c2}(t) = \frac{1}{2C}\int i_z(t)dt = \frac{I_{dc}}{2C}t + \frac{1}{2C}\int i_{ac}(t)dt$$

DC component

unbalance

Requires "*zero power control*"
so that DC component is eliminated



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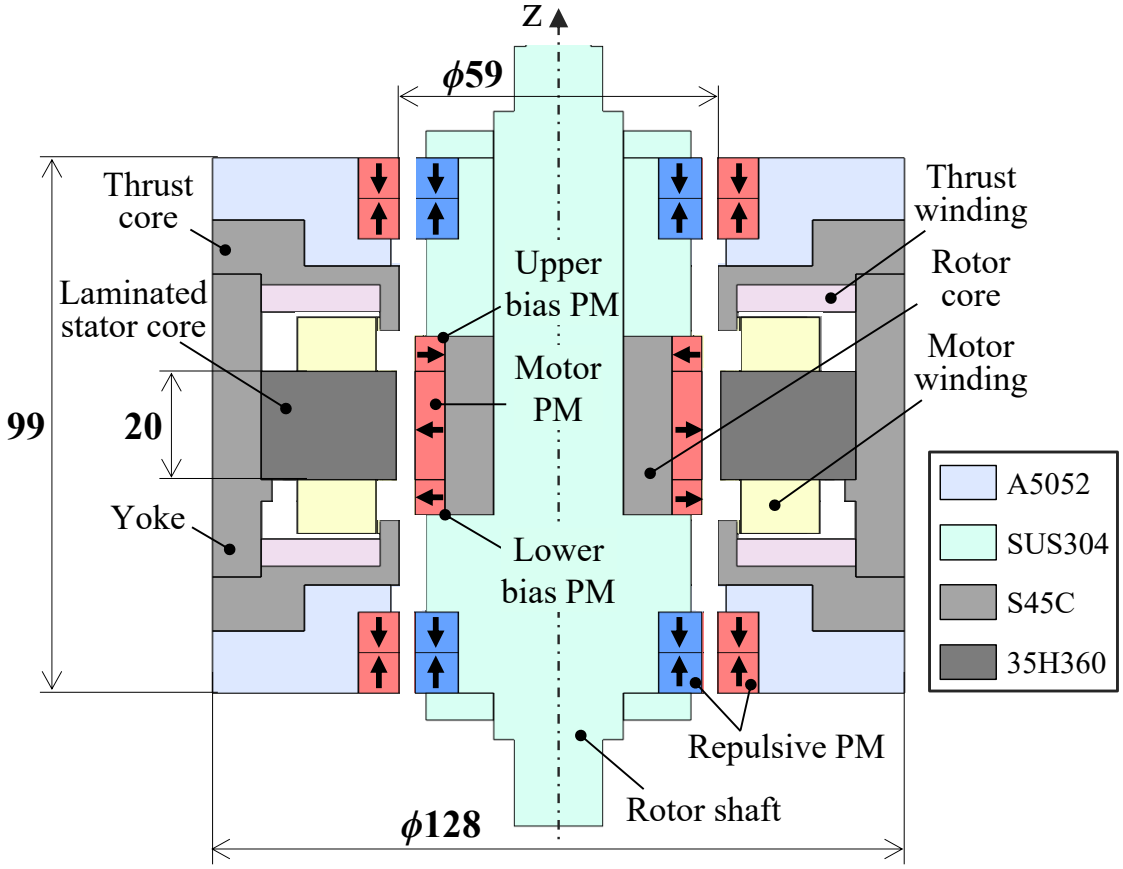
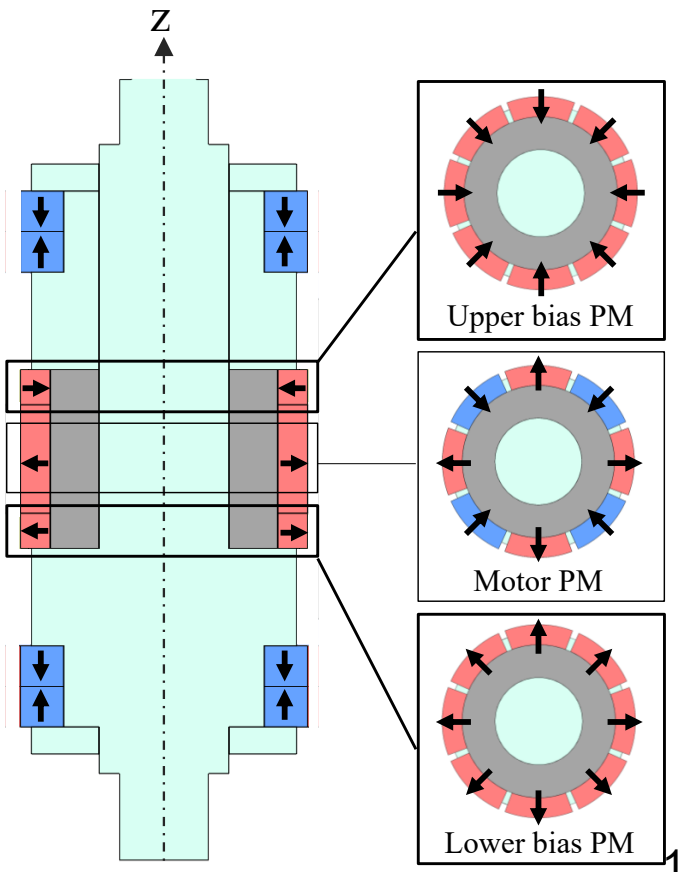
3. Proposed Machine

Structure

- Consists of repulsive passive MBs, thrust suspension, motor
- To avoid the touchdown, wide gap is adopted.
  → RPMBs and motor air-gaps are 3.0 mm and 3.5 mm

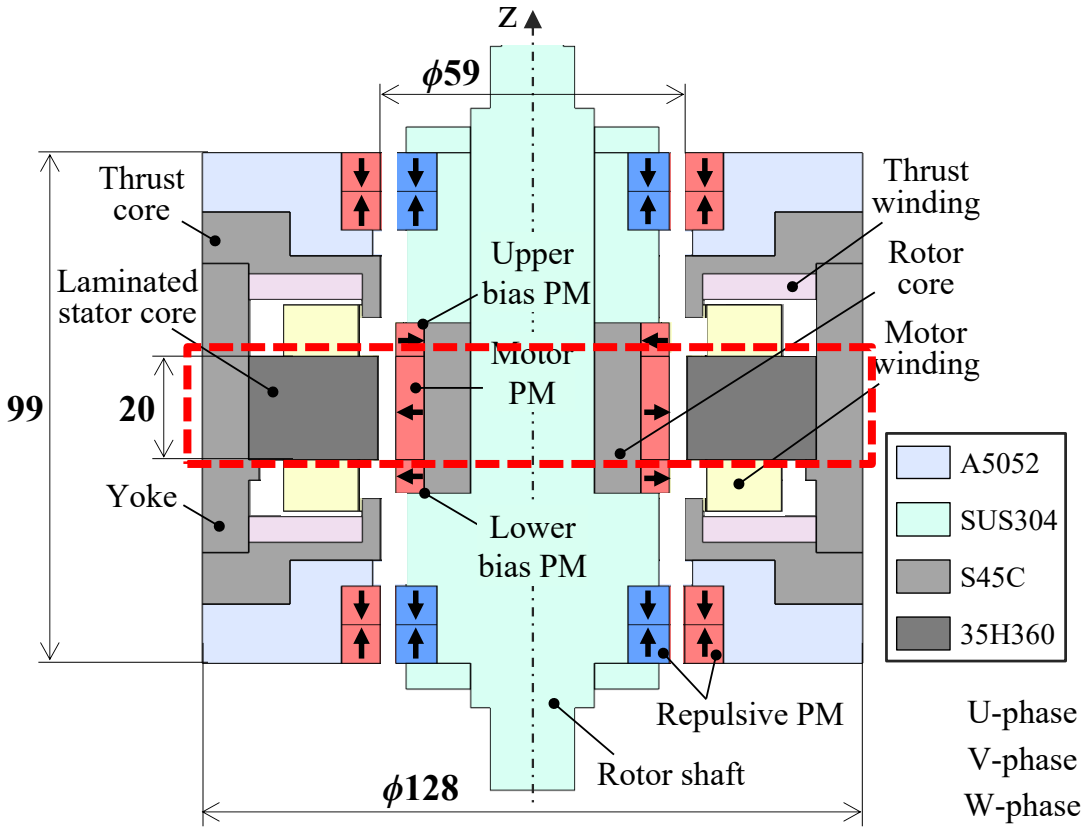


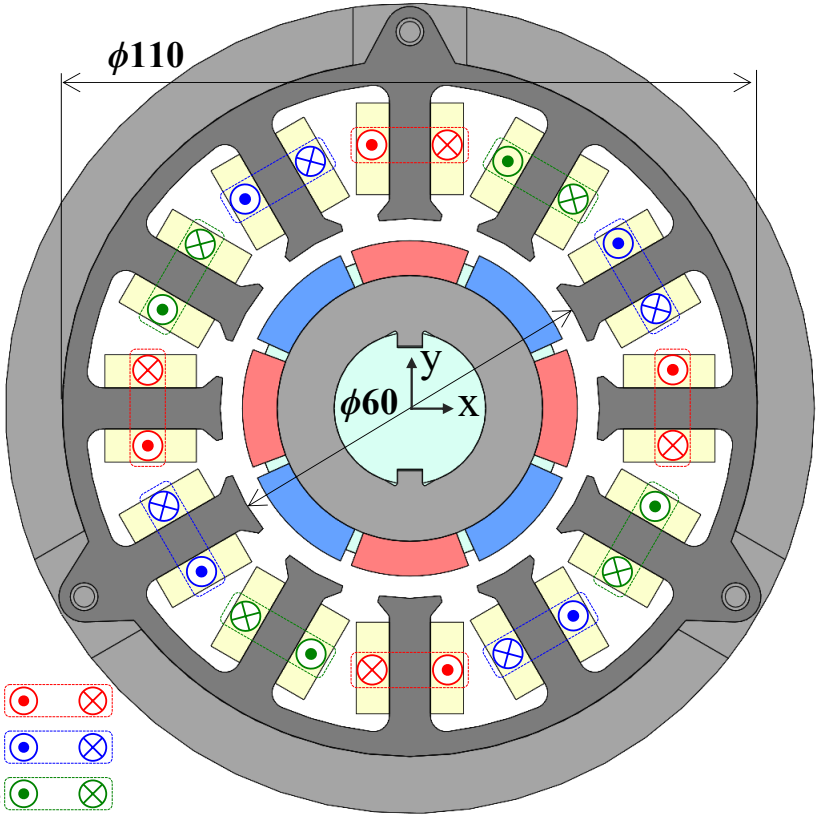


3. Proposed Machine

Motor Structure

- 8-pole 12-slots with three-phase concentrated winding

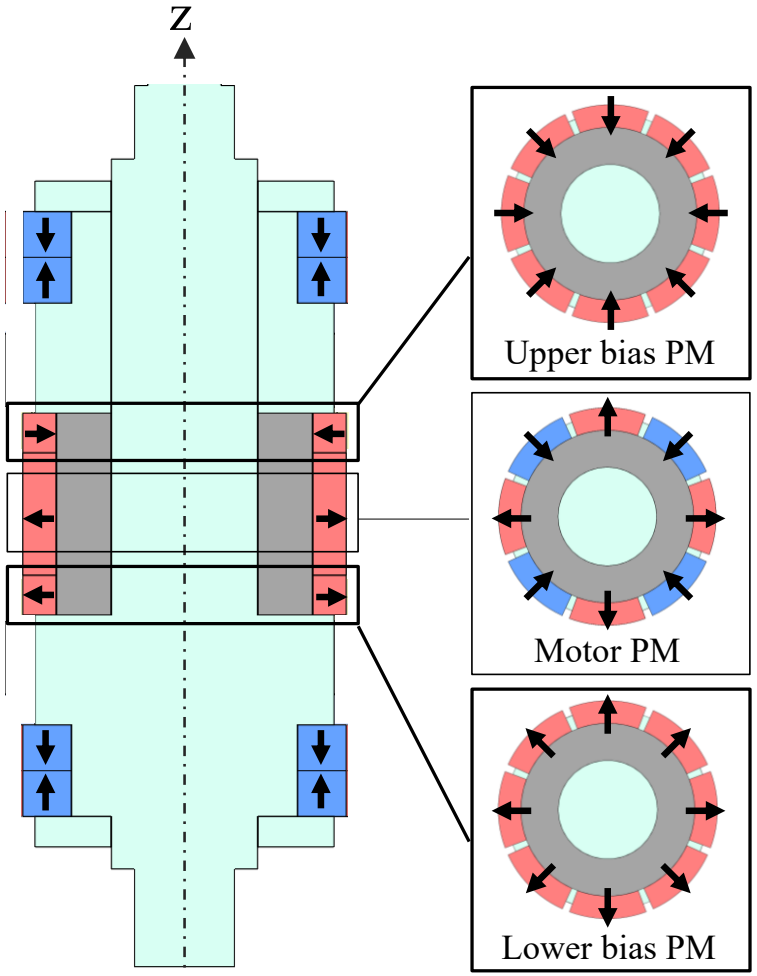


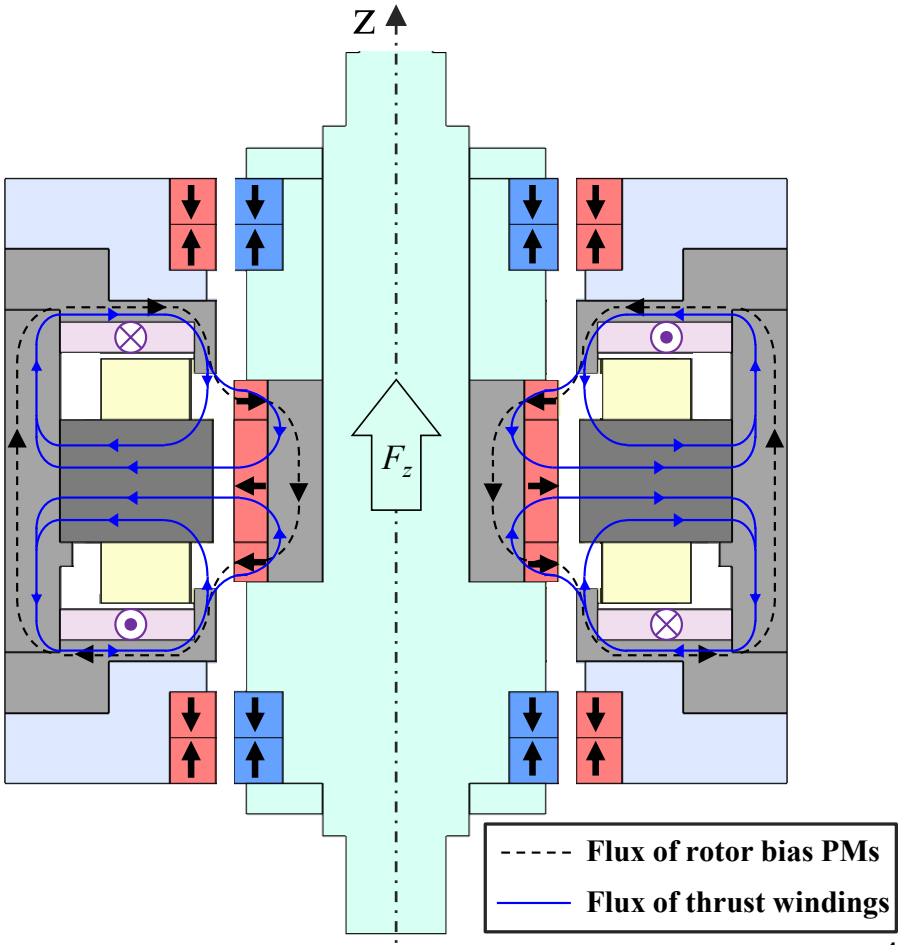


3. Proposed Machine

Principle of Active Thrust Suspension

- Thrust force is generated by zero-sequence current flowing in thrust suspension winding.





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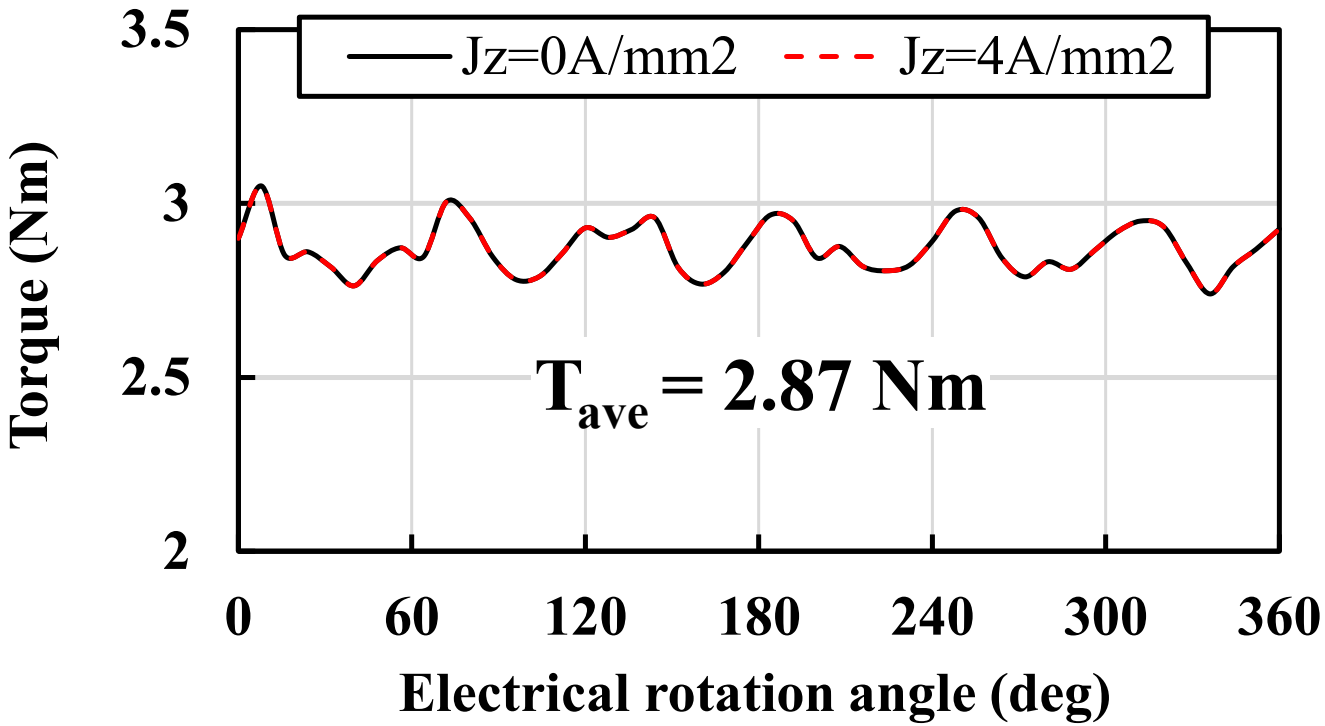
4. FEA Results

Torque: motor current density 8 A/mm^2

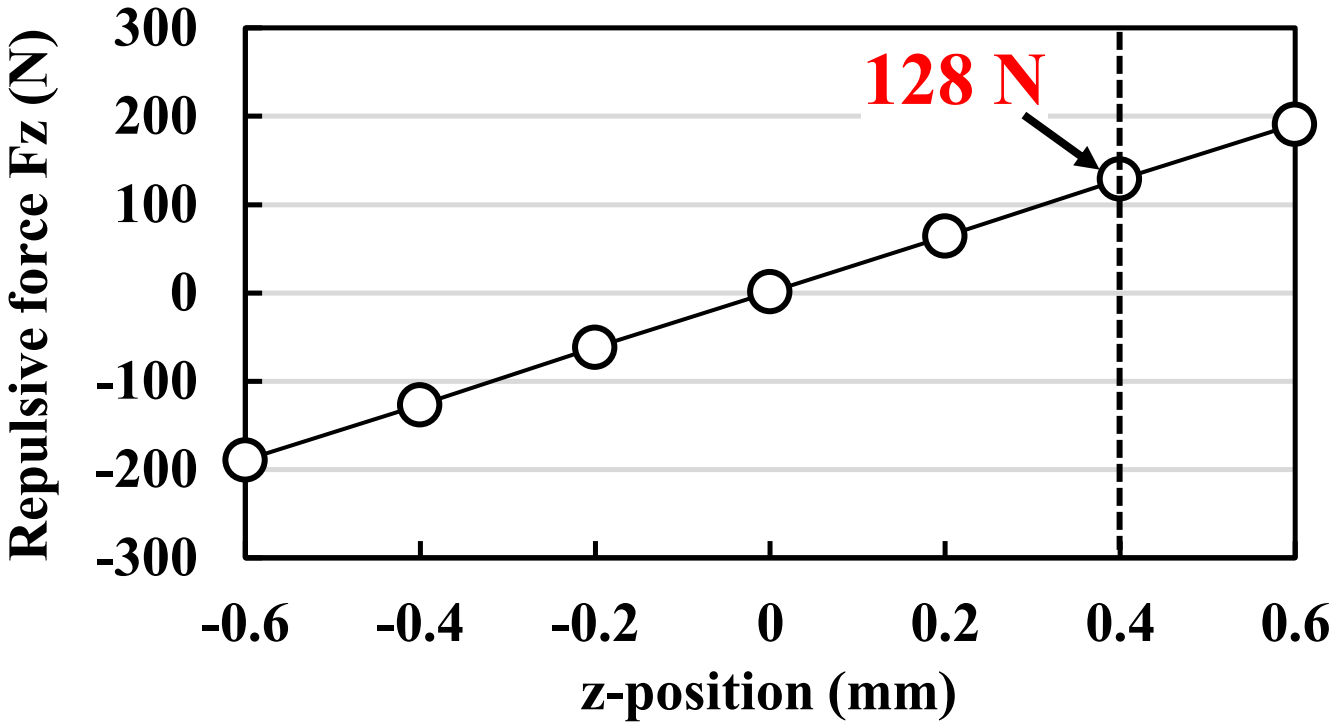
- The zero-sequence current has no influence on torque.
- The average torque is 2.87 Nm.
  → achieve 1 kW under the rated current at 3328 rpm



4. FEA Results

Repulsive (unstable) Force in the thrust direction

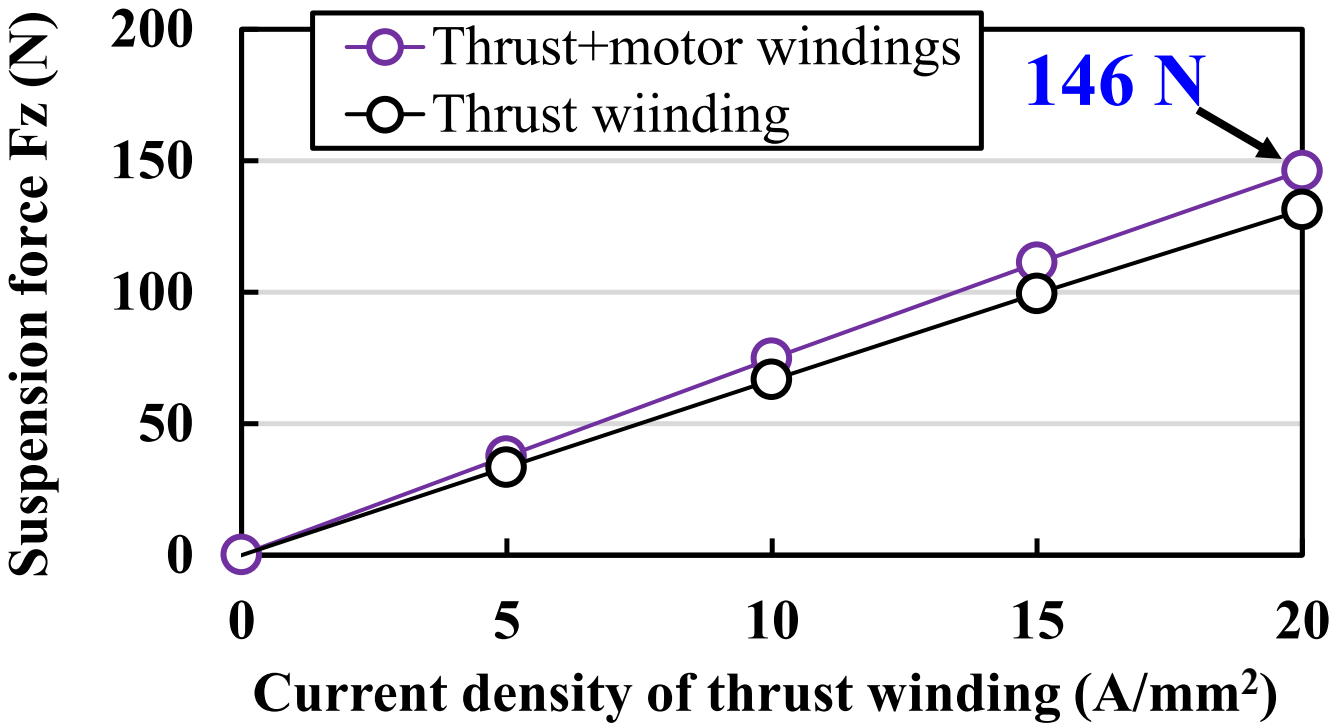
- Repulsive force in the thrust direction is 128 N at the z-position of 0.4 mm in the start-up of the magnetic suspension.



4. FEA Results

Active Thrust Force

- Active Thrust force is also generated by zero-sequence current flowing in motor winding in addition to thrust winding.
- Active thrust force reached 146 N at 20 A/mm^2, which exceeds the repulsive force (128 N) in the z-direction at the start-up



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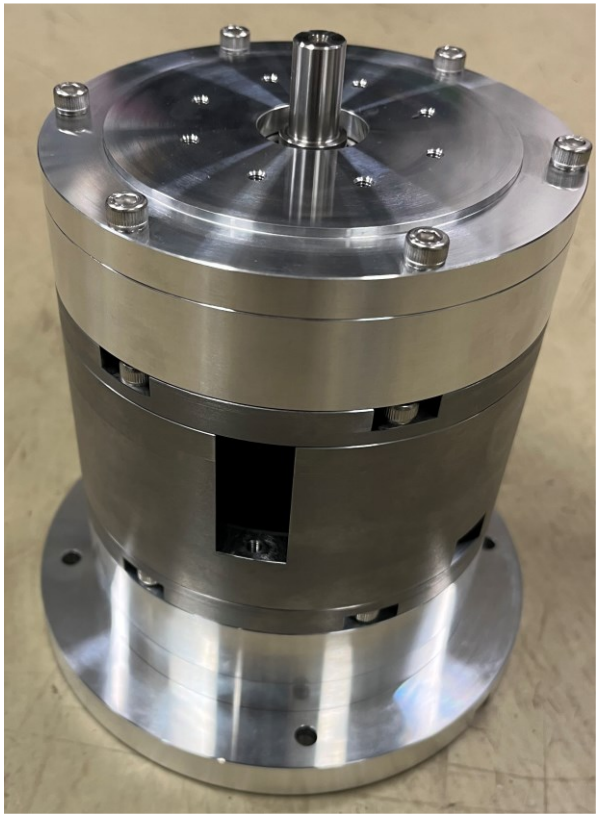
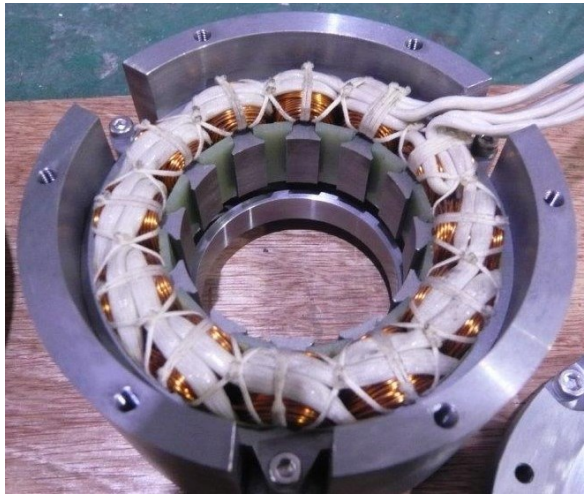
5. Fabricated Machine

Picture of Test Machine

- The proposed machined was fabricated one month ago.
- Experiment will be conducted in the future works.





6. Conclusion

Summary

- One-DOF controlled Belm with more 1 kW was proposed.
- The proposed system needs only one three-phase inverter because zero-sequence is utilized for thrust suspension.
- FEA results demonstrated the effectiveness of the proposed

Future Works

- First, levitation test will be conducted
- Then, the torque and thrust suspension force will be measured.