Hybrid passive levitation mechanism utilizing thrust force and magnetic force for a pump application

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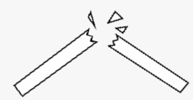
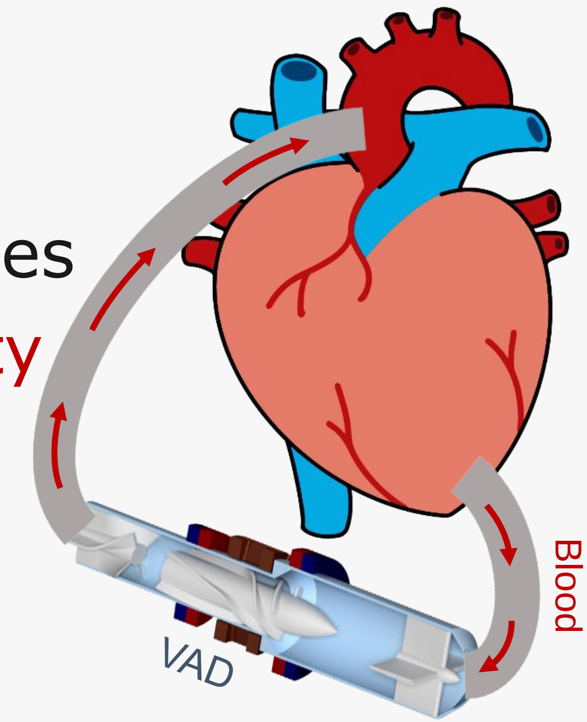
Background

Treatment for heart failure patient:
Ventricular assist device (VAD)

Friction due to contact bearing causes
Blood cell distraction + low durability



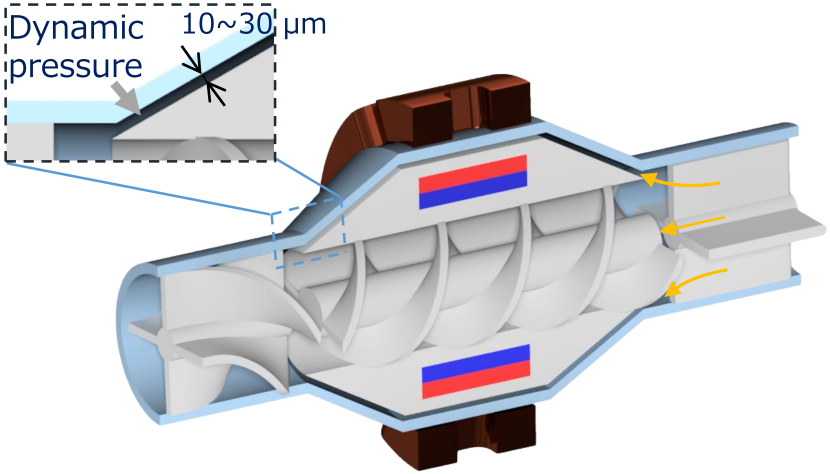
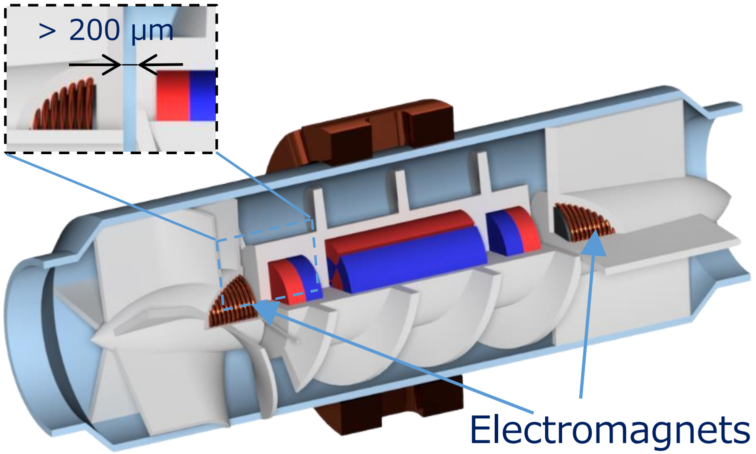


Contactless support for impeller

Current technologies for impeller levitation

Two types available, but advantages and disadvantages

Current impeller levitation technologies

	Hydrodynamic bearing	Active magnetic bearing
		
Disadvantage	Risk of **blood cell distraction**	Risk of **malfunction**
Advantage	**Passive levitation**	**Large gap**

Research motivation

Passive & large gap levitation mechanism

Levitation principle

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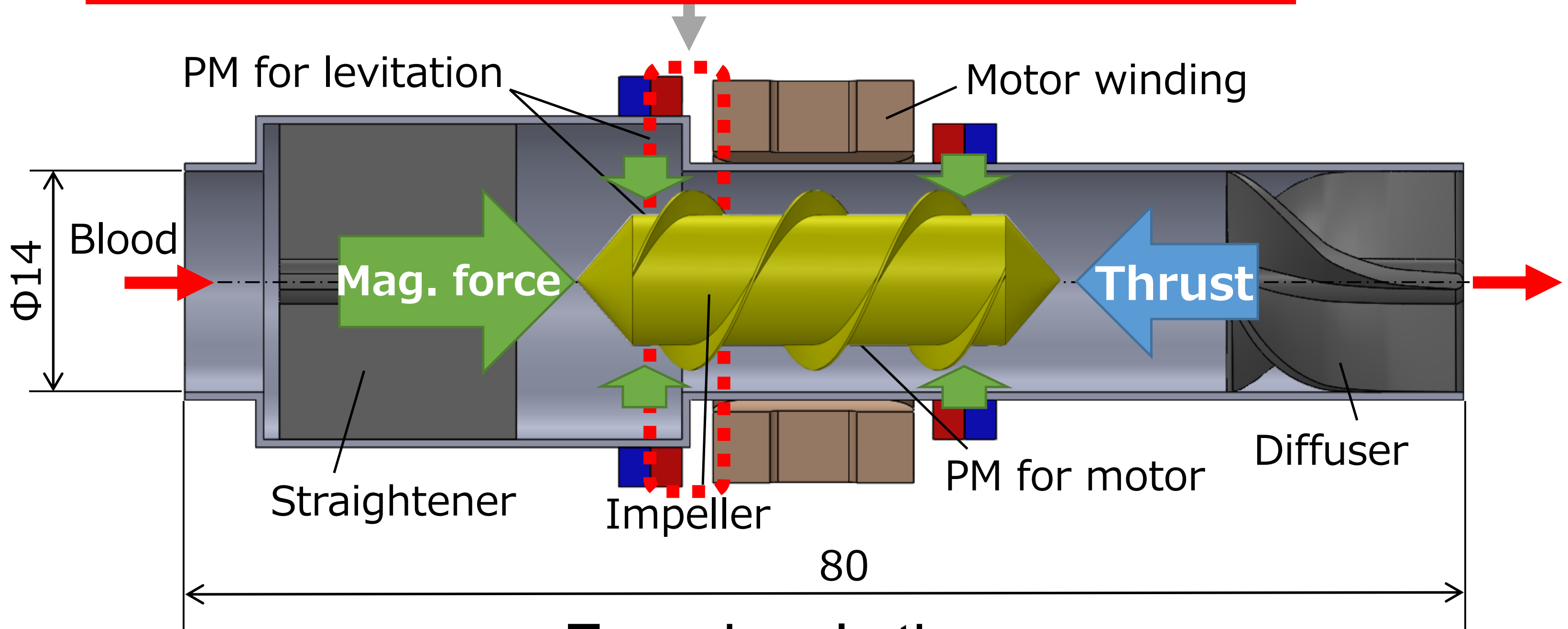
Hybrid passive levitation mechanism utilizing **thrust** and **magnetic force**

Change in diameter ⇒ Change in thrust



Earnshaw's theorem

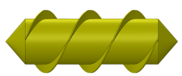
Radial & tilt directions :
→Levitation by mag. force

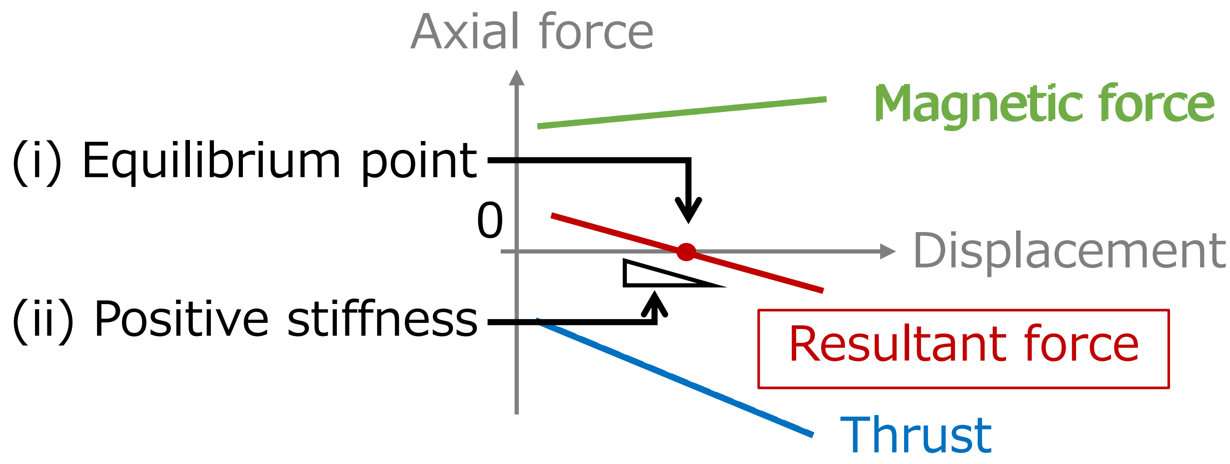
Axial direction :
→ Levitation by thrust & mag. force

Conditions for impeller levitation

Axial direction

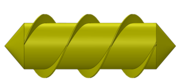
Thrust +
Magnetic force

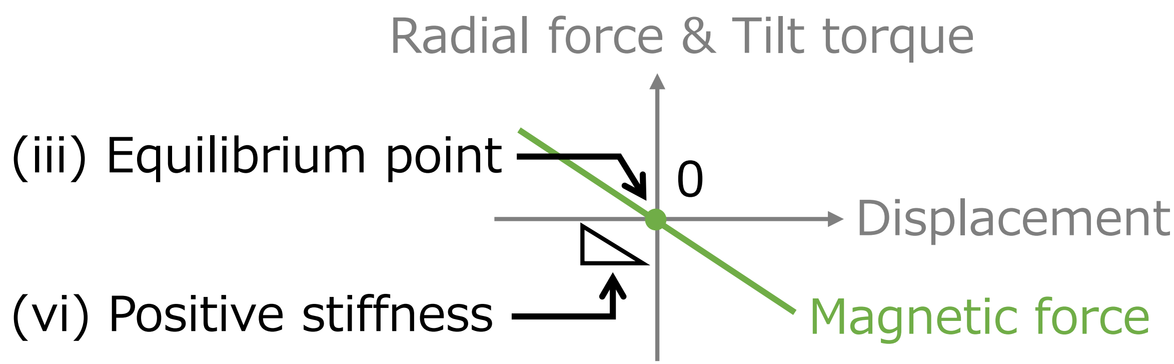




Radial & Tilt directions

Magnetic force





Computational Fluid Dynamic Analysis
→ **Thrust**

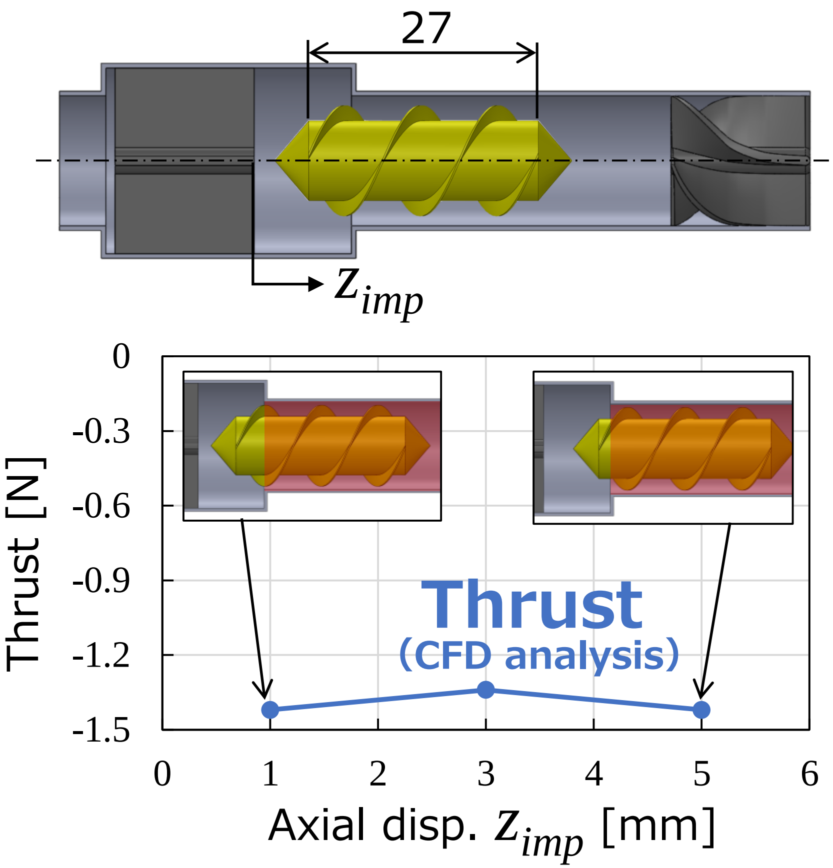
+

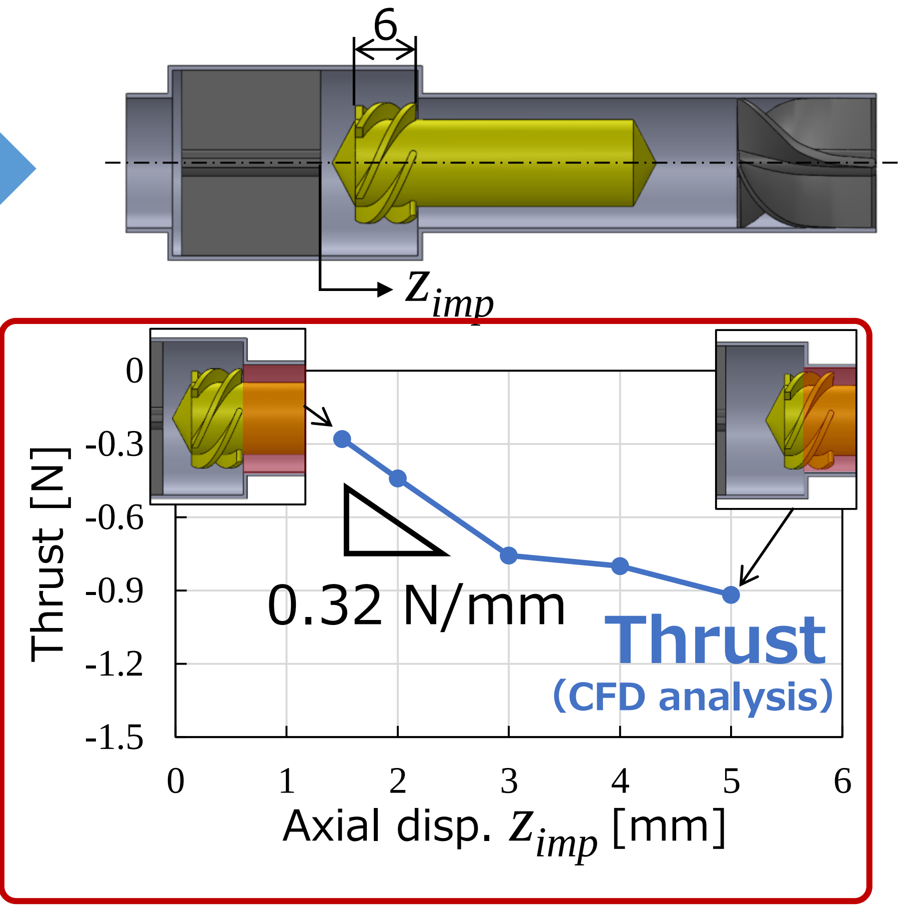
Magnetic Field FEM Analysis
→ **Magnetic force**

Design of thrust by CFD analysis

Design goal: Thrust has positive stiffness

Analysis conditions : 1.5 L/min 10000 rpm



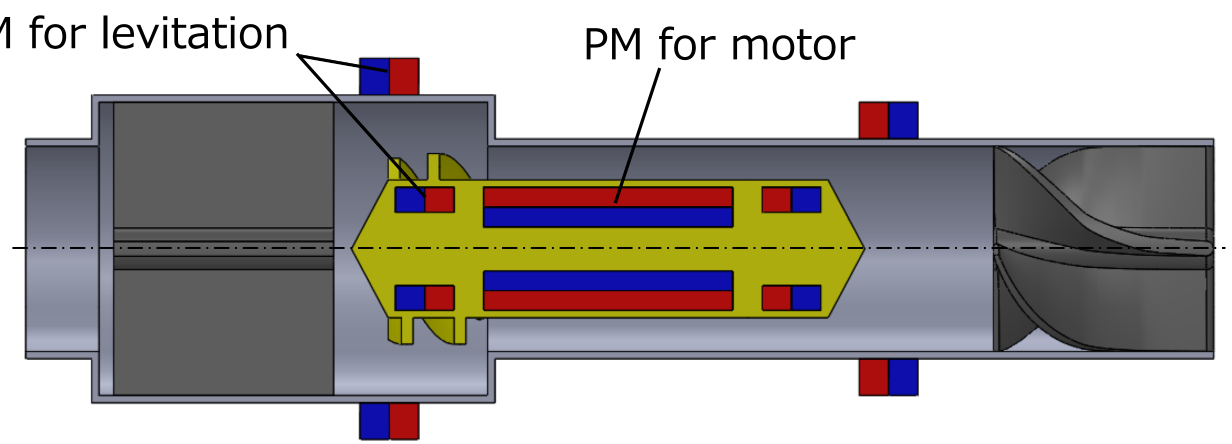


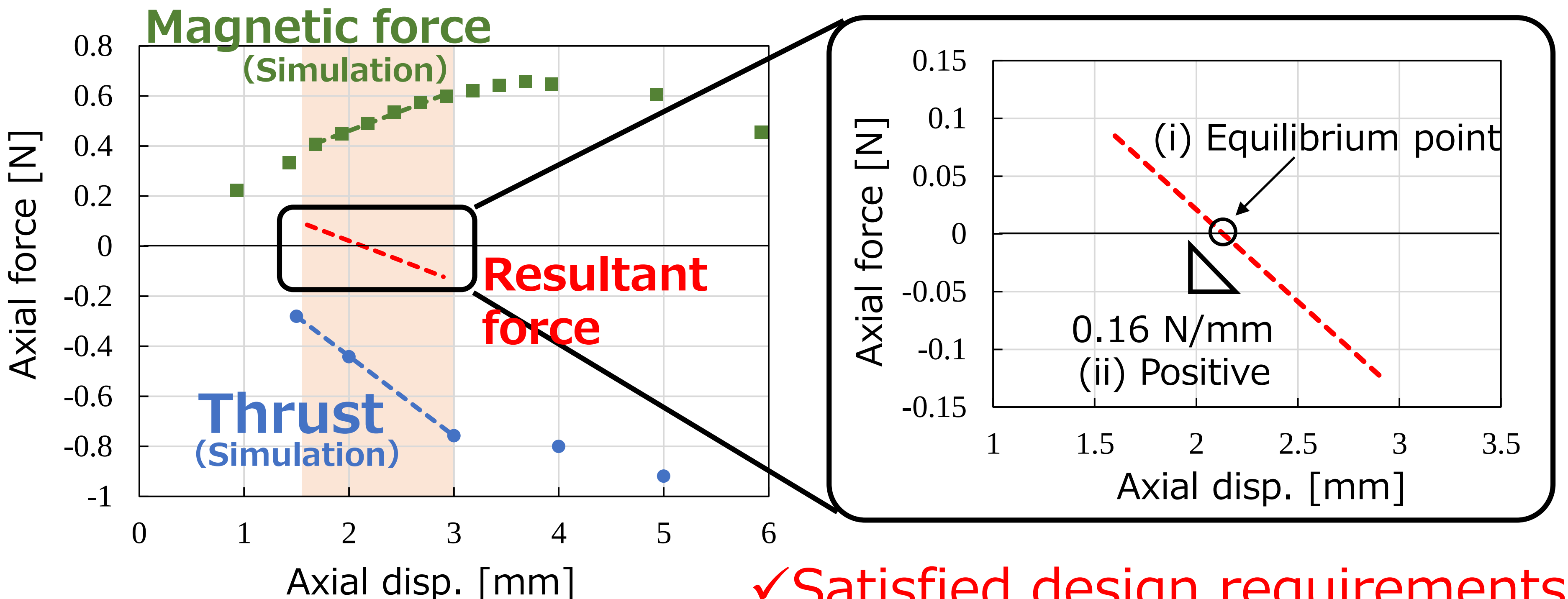
× Zero stiffness

↰ Impeller total length >> Disp.

✓ **Positive stiffness**

Design of mag. force in the axial direction

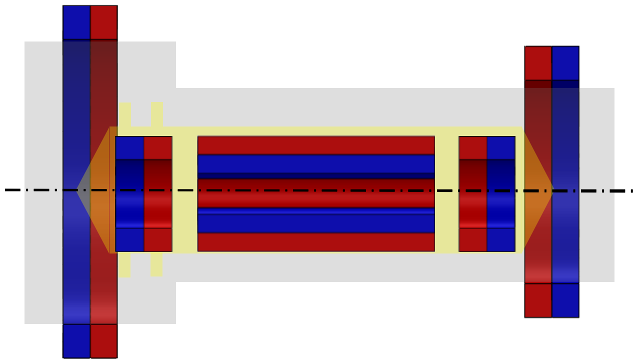


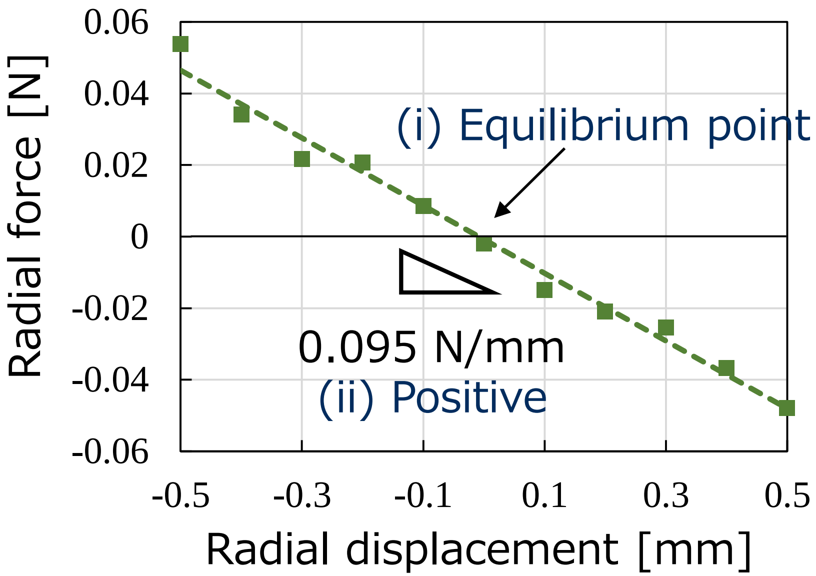


✓Satisfied design requirements

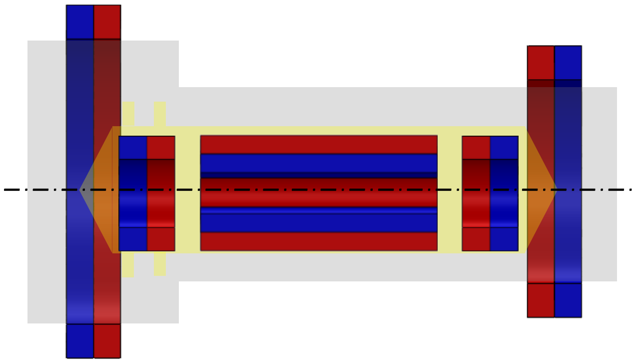
Design of mag. force in the radial and tilt directions

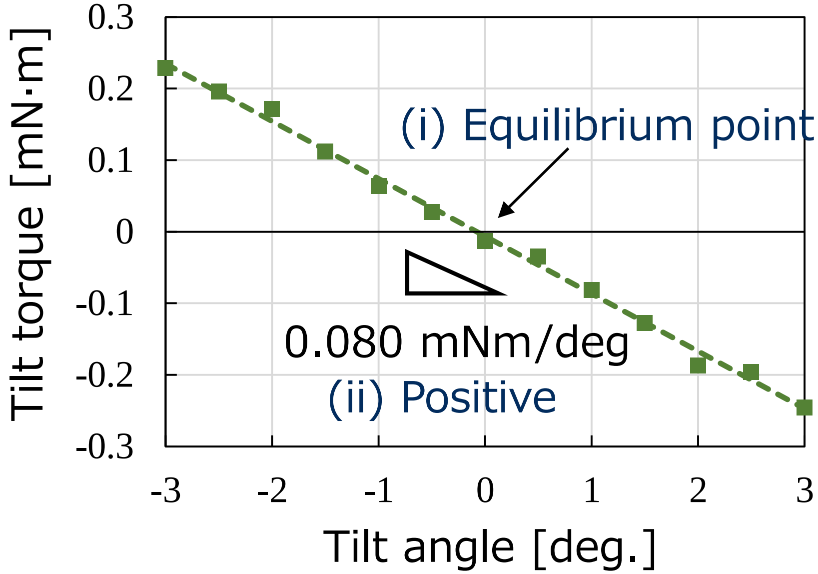
Radial direction





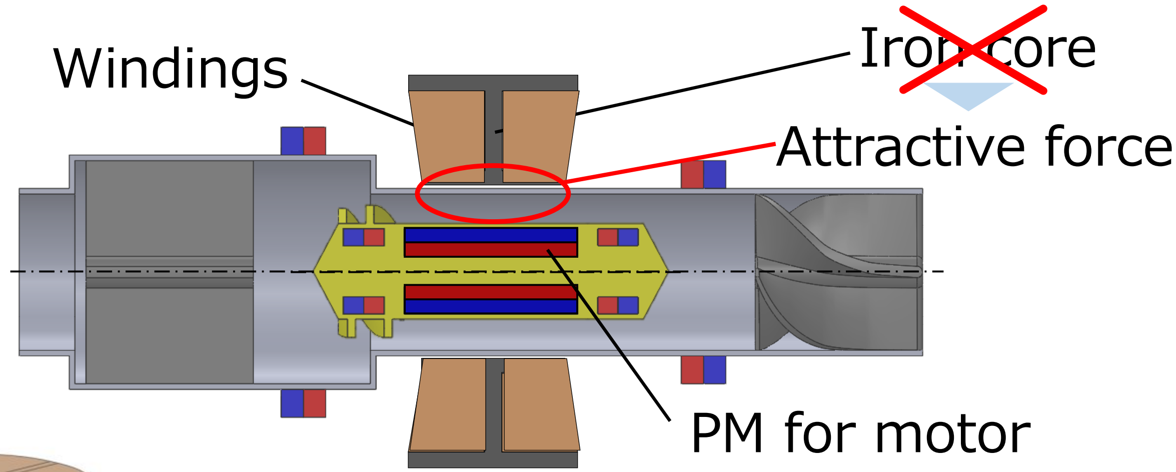
Tilt direction

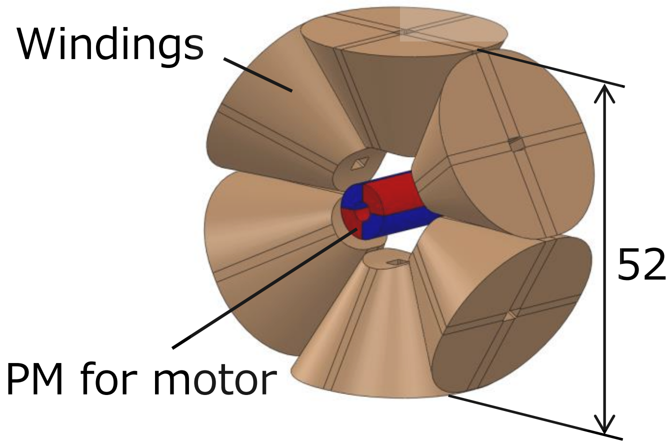




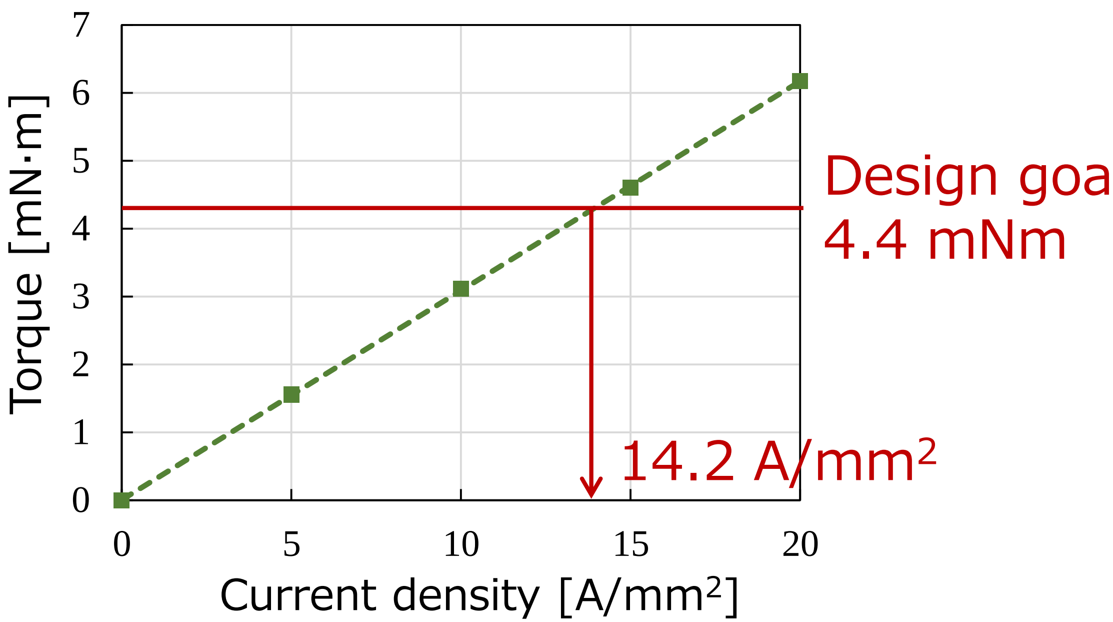
✓Satisfied design requirements in all directions

Design of motor



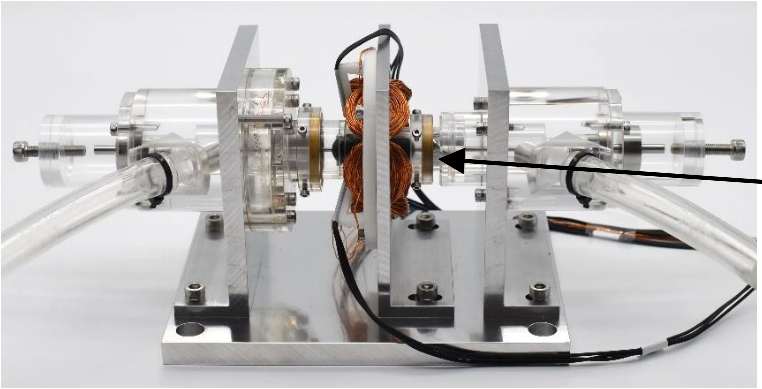


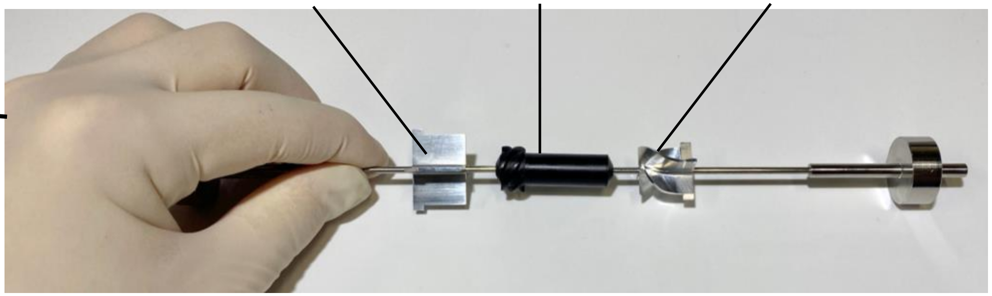
Brushless coreless DC motor (3 phese 6 slots)



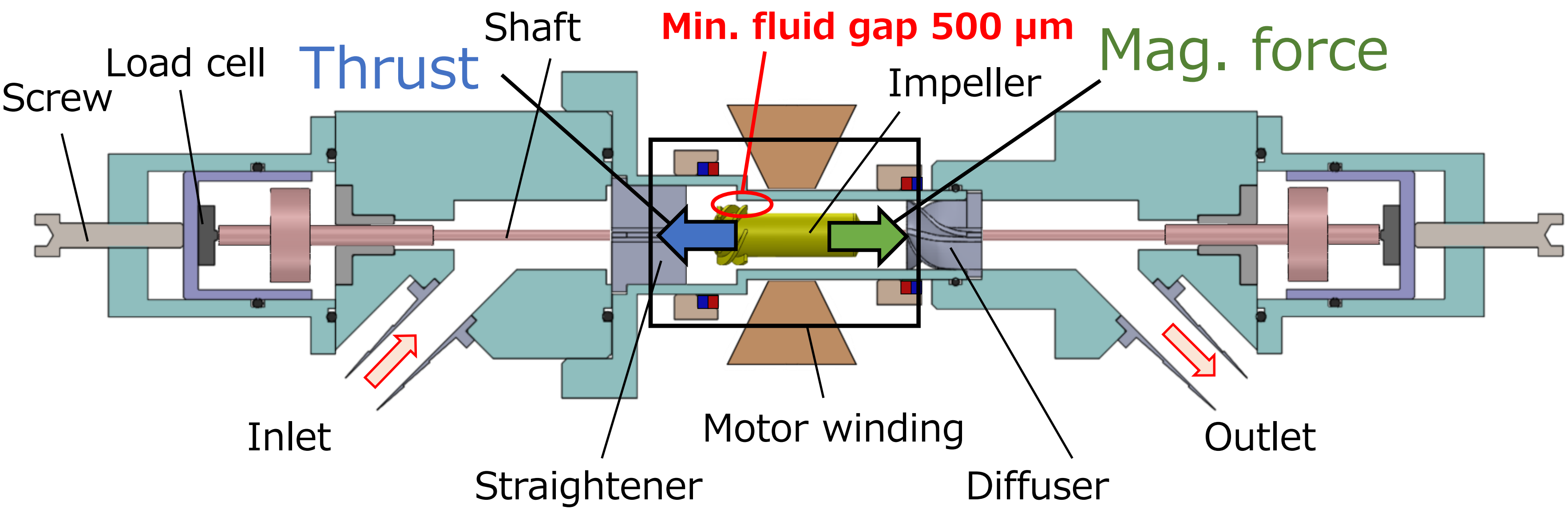
Target torque was achieved

Design and fabrication of prototype

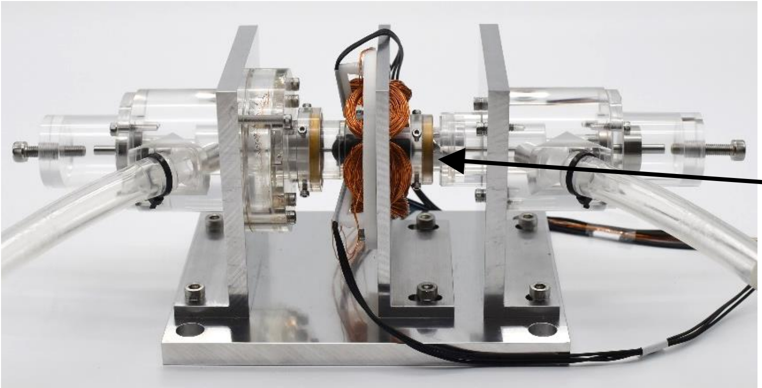


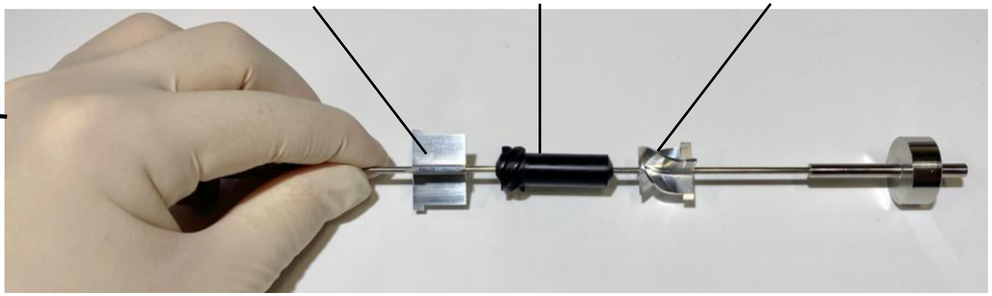


10~15 times larger than hydrodynamic bearing
2 times larger than magnetic bearing



Design and fabrication of prototype

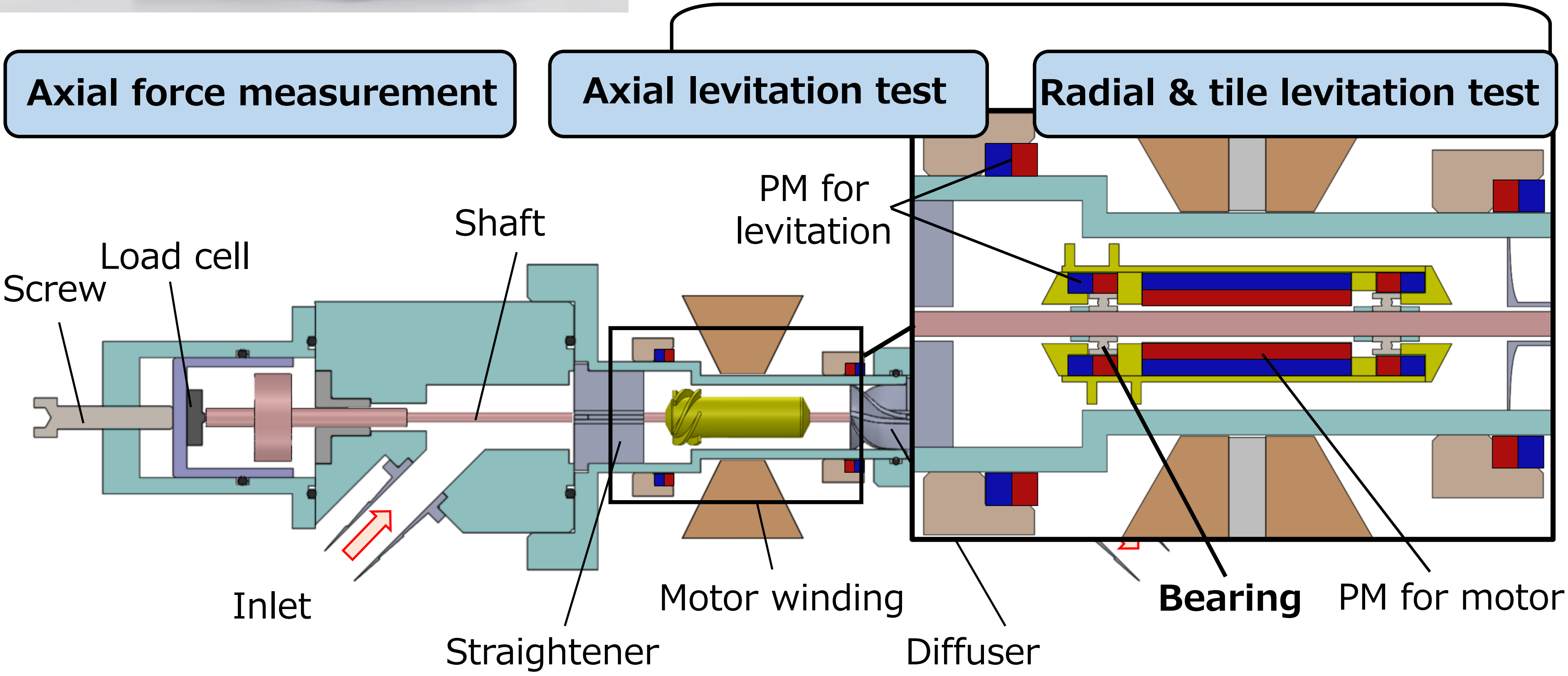




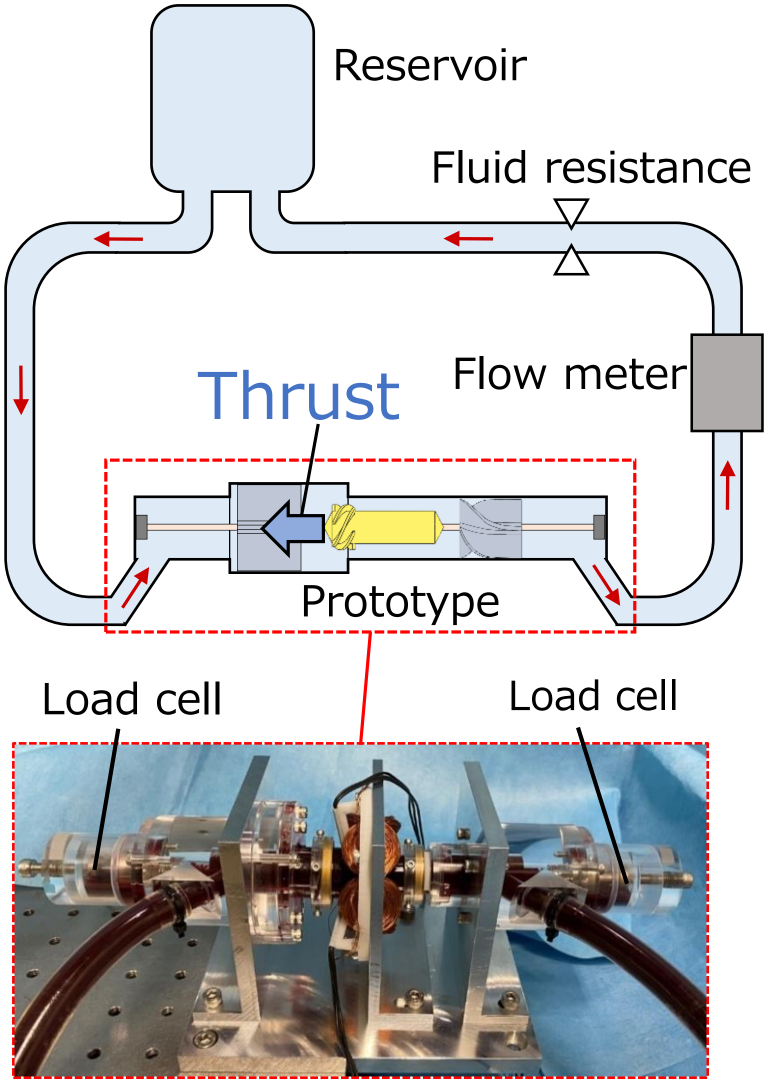
Axial force measurement

Axial levitation test

Radial & tile levitation test

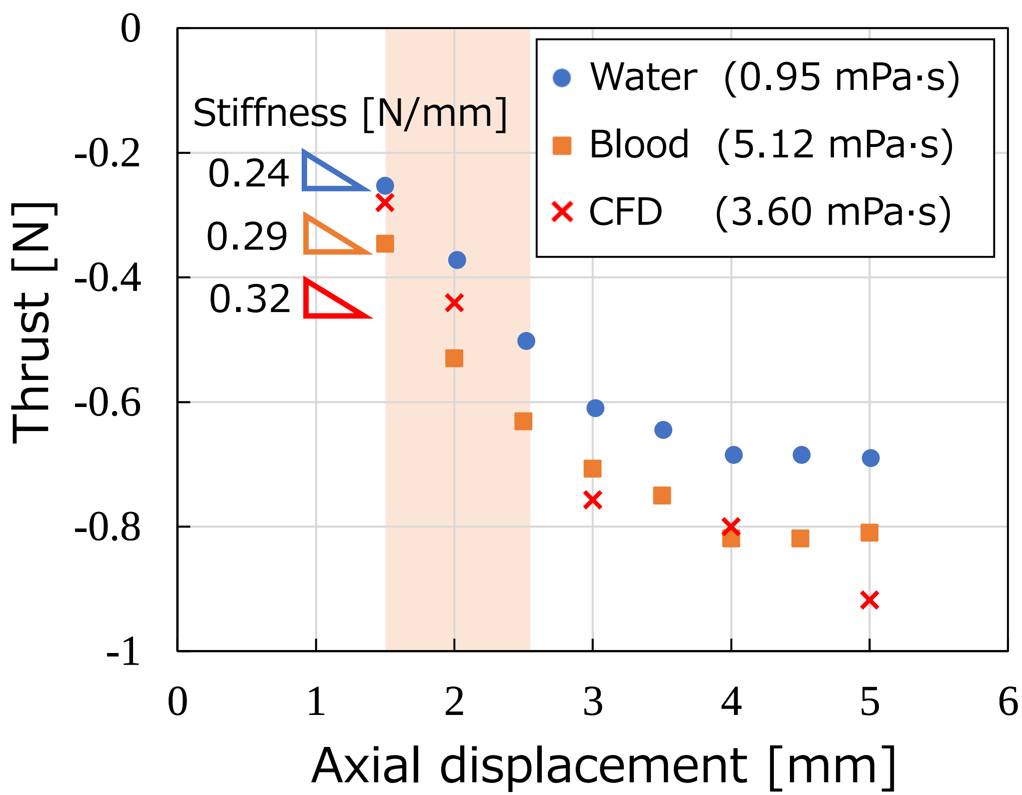


Measurement of axial thrust



10000 rpm   1.5 L/min

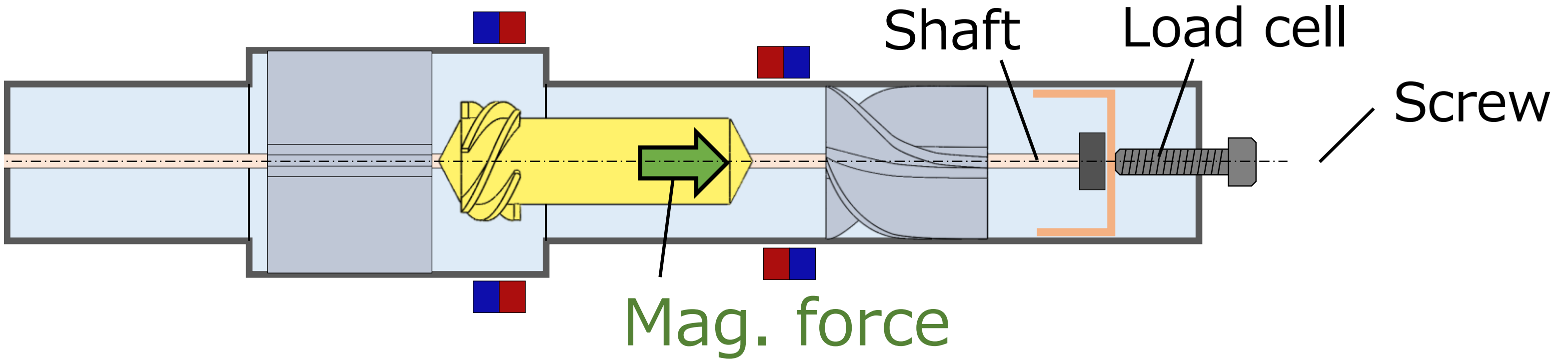
Fluid : Porcine blood, water

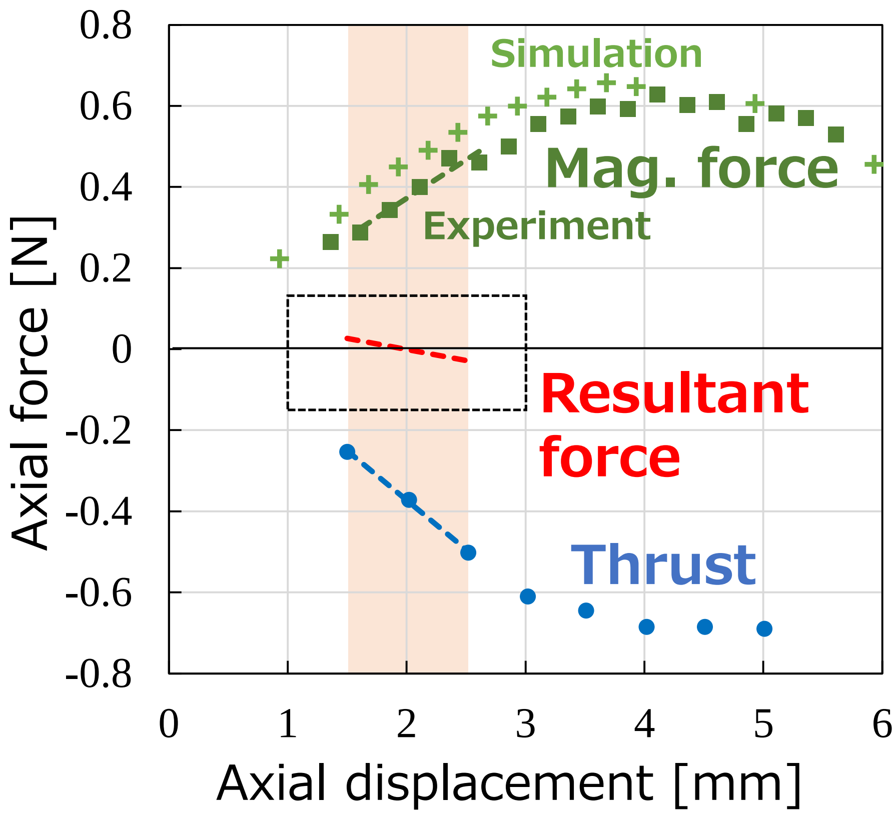


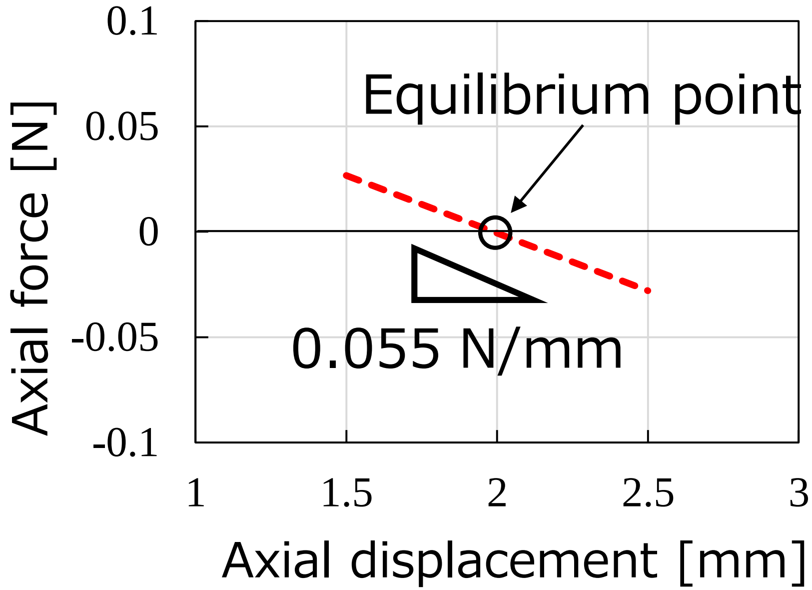
Good agreement with CFD

✓**Thrust has positive stiffness**

Measurement of axial magnetic force

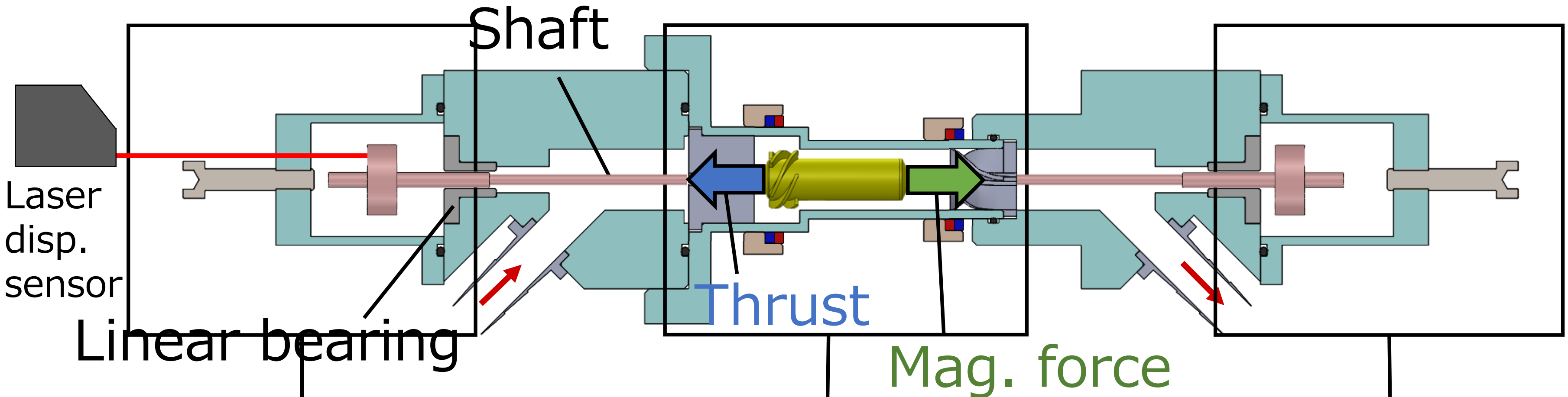




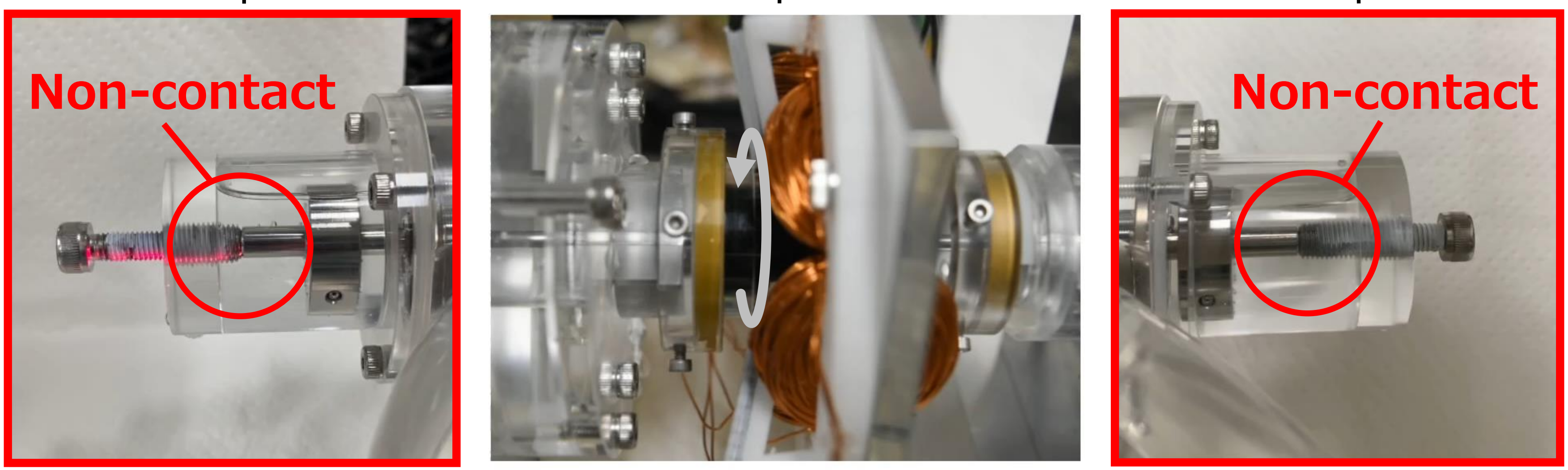


✓ **Levitation conditions satisfied**

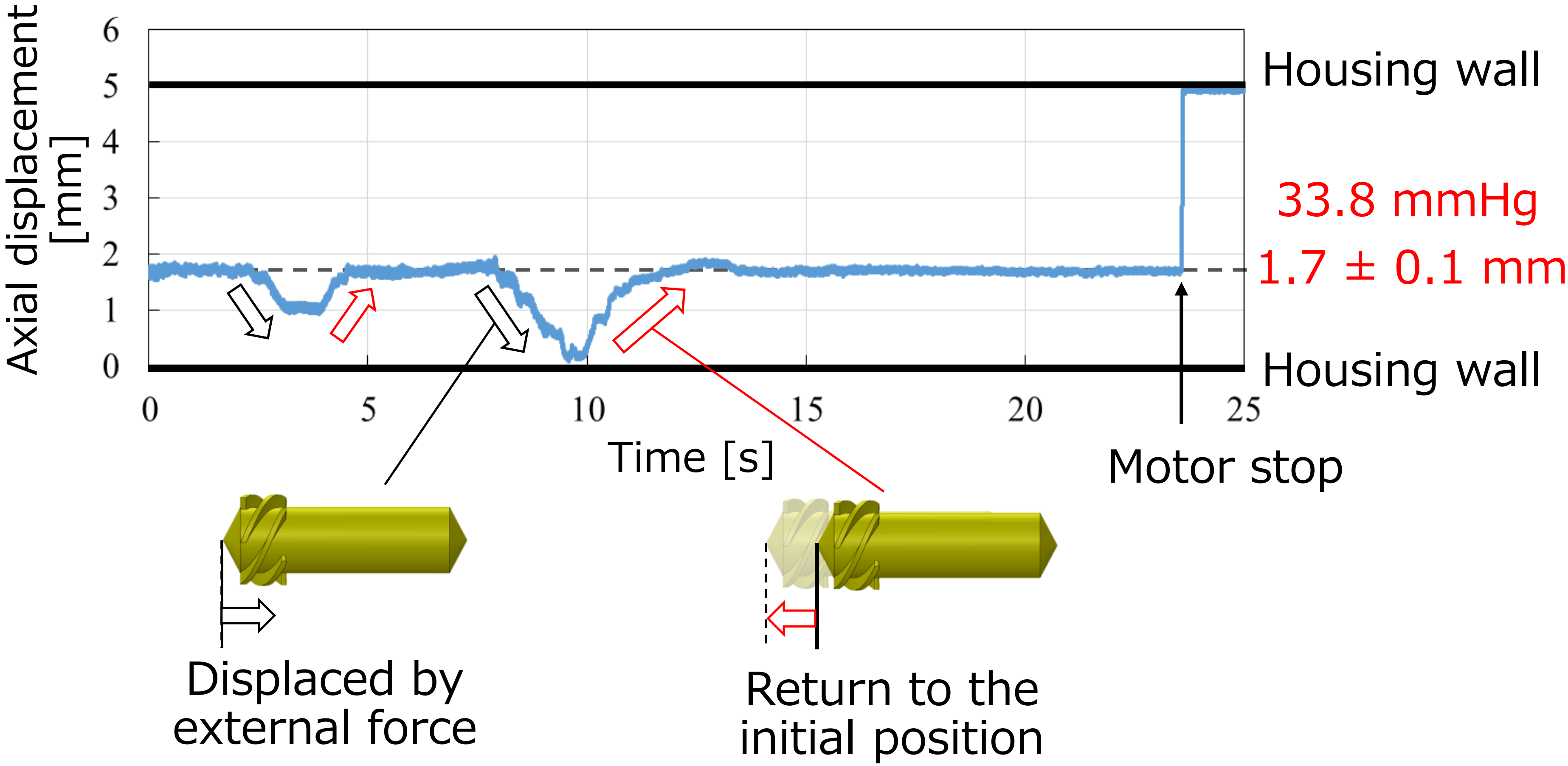
Axial levitation test



10000 rpm 1.5 L/min In water



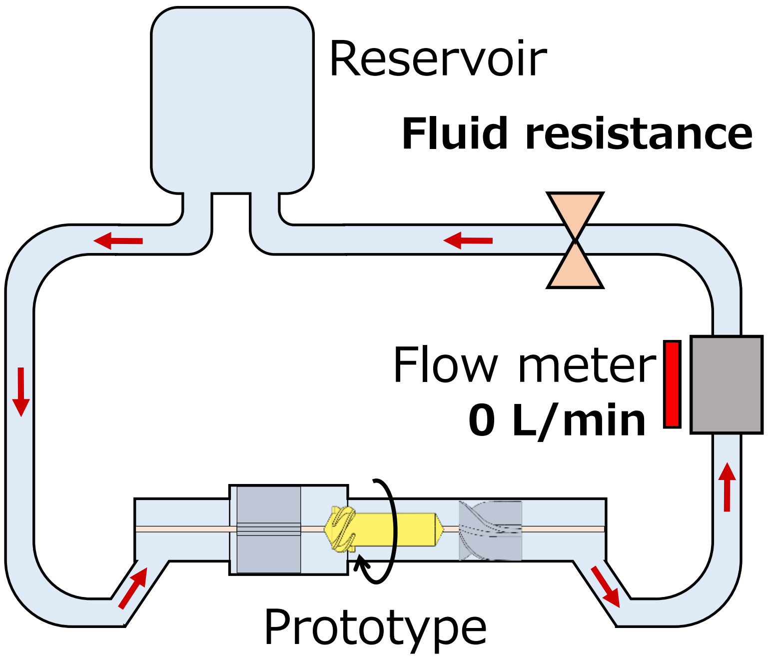
Axial levitation test

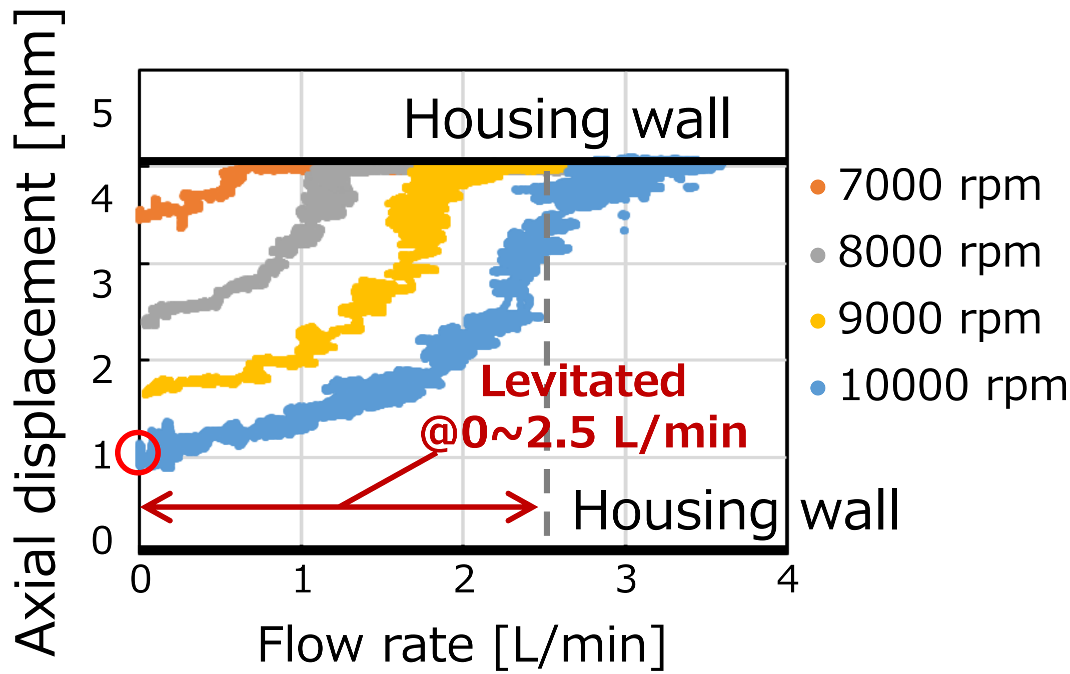


Axial levitation with a gap of 500 μm without active control is demonstrated by the thrust and mag. force combination mechanism

Flow rate and speed range levitation possible

Axial levitation is evaluated by changing flow rate and speed





Even if the flow rate and speed are varied Axial levitation can be maintained for a specific range

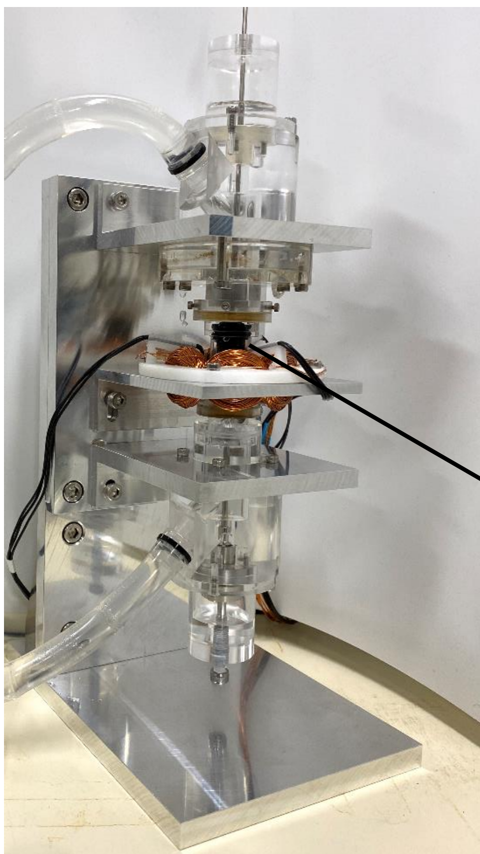
Radial and tilt levitation test

Radial stiffness
0.095 N/mm
(Simulation)

} Small against weight

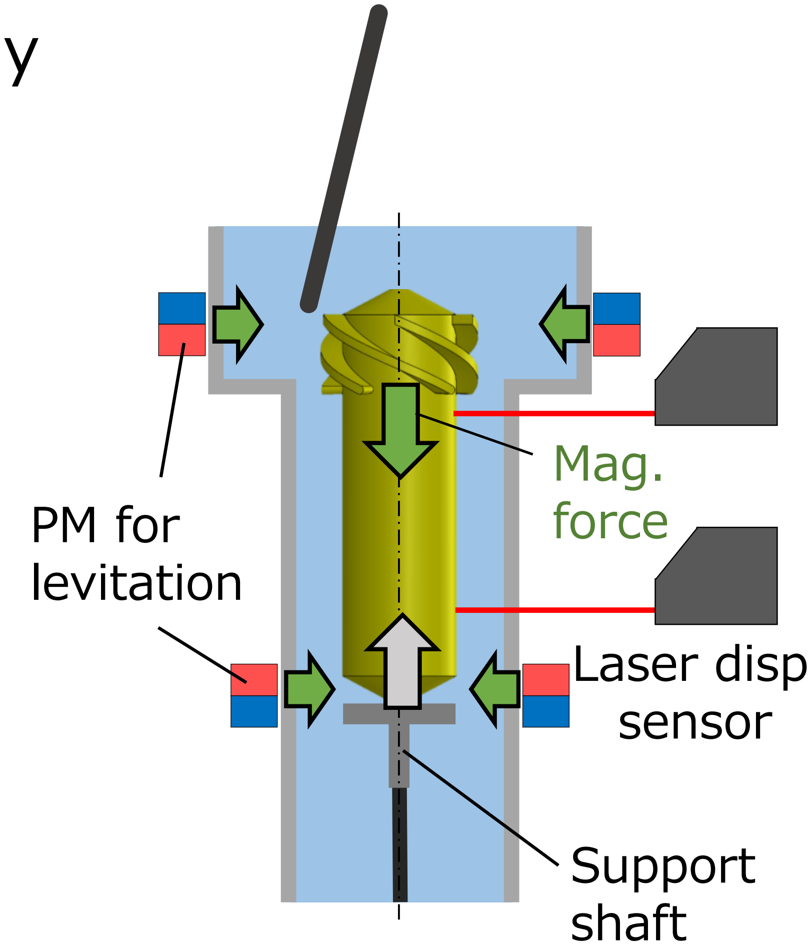
↓

Placed vertically



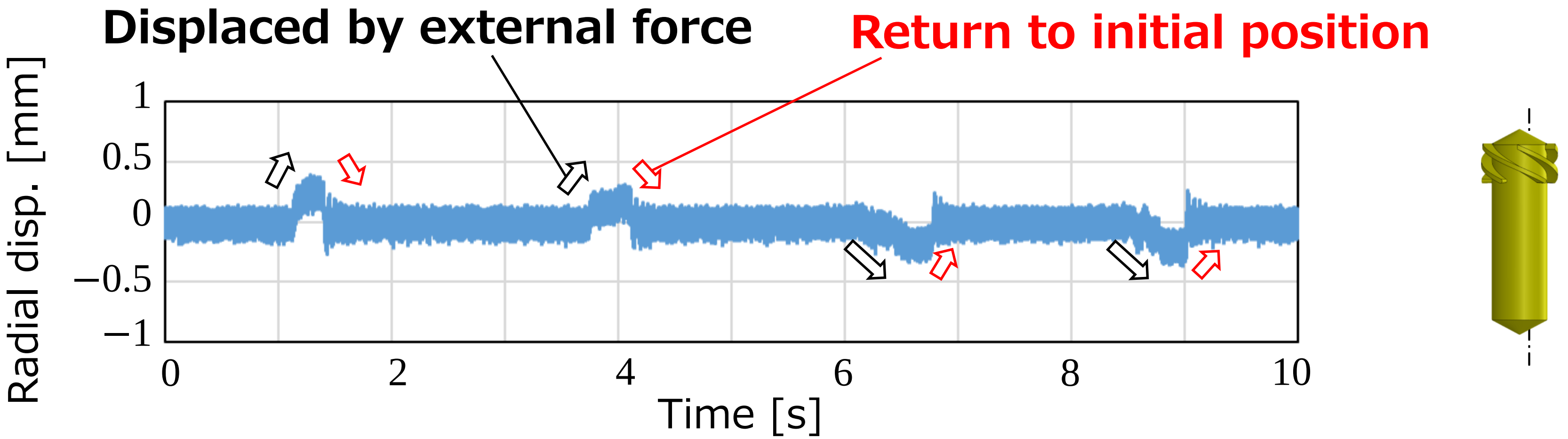
Remove shaft

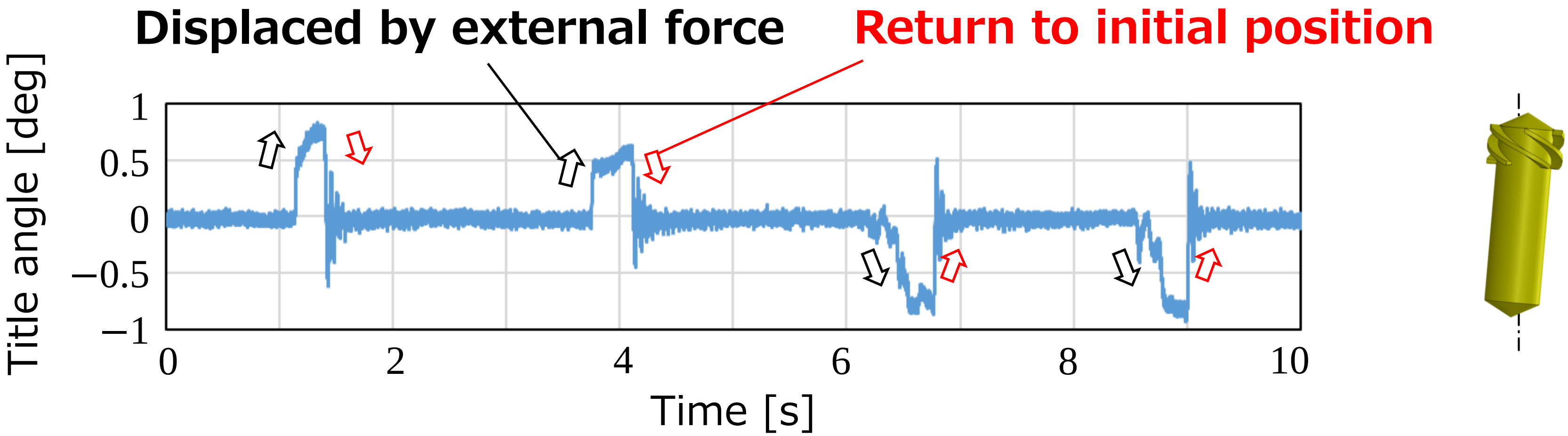
Impeller



0 rpm in water

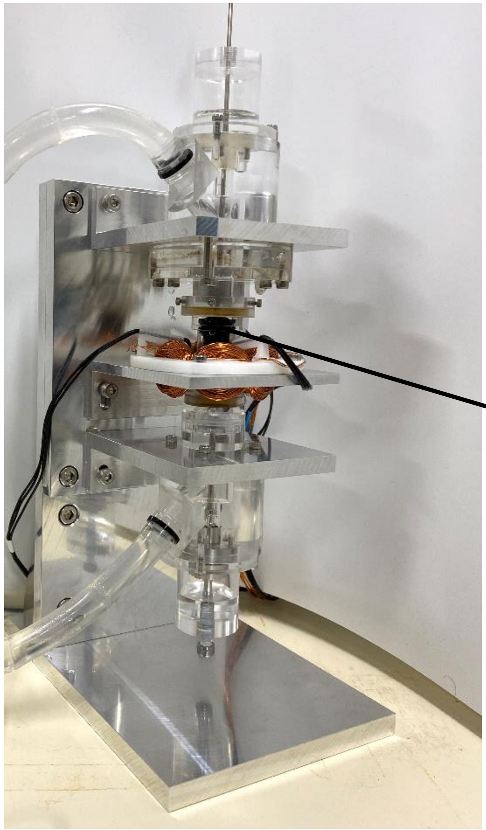
Radial and tilt levitation test





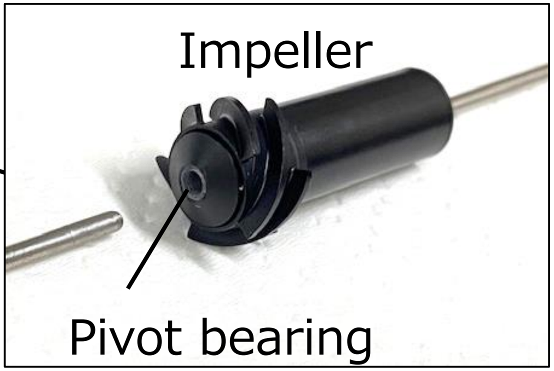
Positive stiffness in radial and tilt directions were confirmed

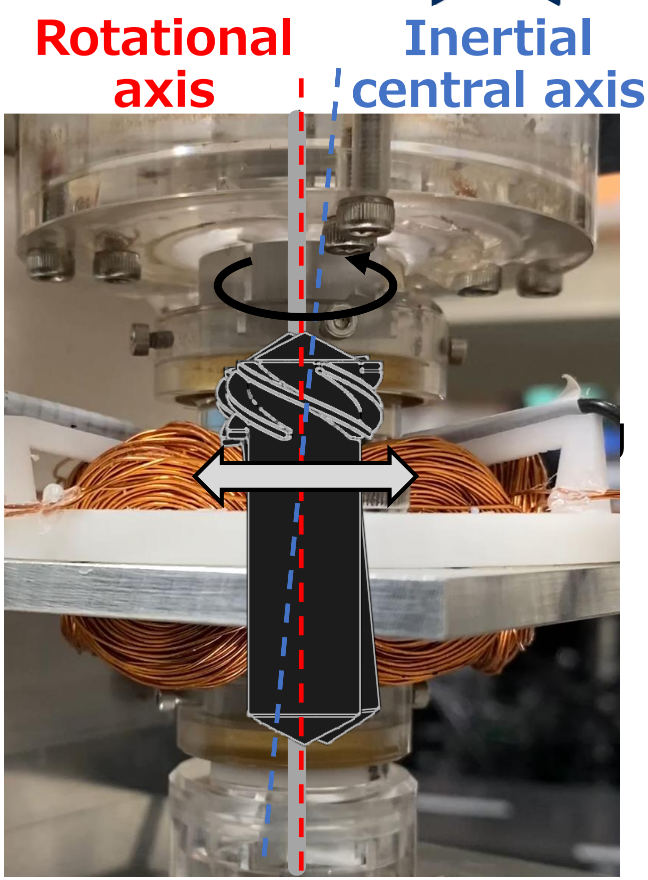
Levitation test in the all direction



Pivot bearing

Shaft detachable





10000 rpm
1.5 L/min in water

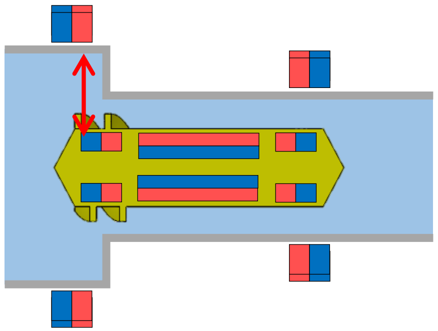
Contact in radial & tilt directions

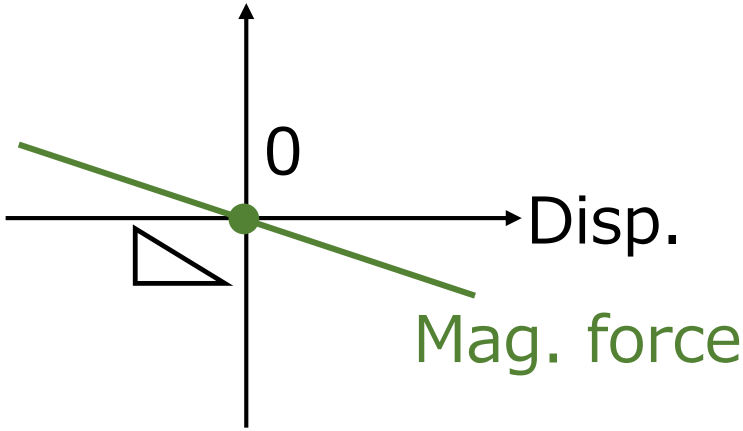
Enhancement of stiffness in these directions necessary

Issues and future work

Mag. force ⤴

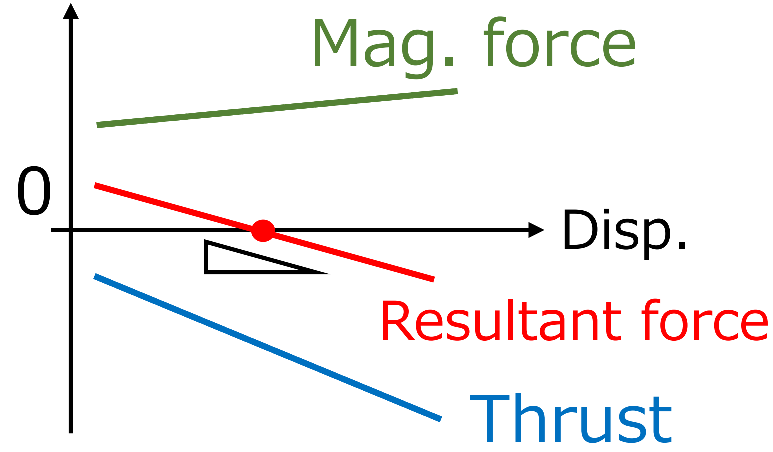
- **Increased size of PM**
- **Magnetic gap reduction**





Thrust ⤴

- **Design optimization of pump structure**



Summary

Hybrid passive levitation mechanism utilizing **thrust** and **magnetic force** has been proposed

- A mechanism with **positive stiffness** in all directions was designed using CFD and magnetic field analysis.
- Axial forces were measured and the resultant force was shown **positive stiffness of 0.055 N/mm**.
- The axial, radial, and tilt directions were independently levitated.

Future work

- Enhancement of stiffness
- Demonstration of levitation in all directions

For more detail, please access our journal paper!

https://ieeexplore.ieee.org/document/10179009

R. Magari and W. Hijikata, IEEE Trans. Mechatronics, 2023