Development of 200,000rpm SPM small motor using Rare Earth Anisotropic Bonded Magnets

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1. Background

1.1 Market and Challenges

Small motors 6 billion units

The Markets for Small Motors shown in Fig. 1 is expanding rapidly. In the Automotive and Home Appliance Markets, inexpensive Brush motors are popular. However, they have a low efficiency, heavy, and poor controllability.

In the Robot Market, the current motors (Fig.2) have the largest share in the global market for small and lightweight motors. However, they are very Expensive.

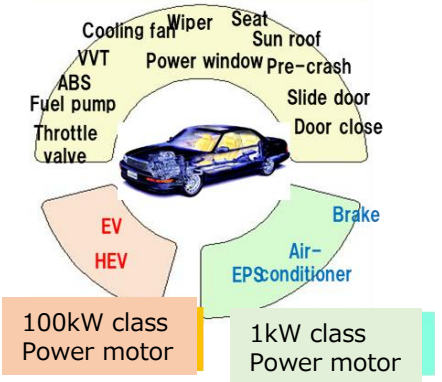


Fig.1 small motors market

1.2 Current Technologies and Issue

- Brush motors: **B** company succeeded in reducing weight by 75%.
- Brushless motors: **M** company realized downsizing by using sintered Nd magnets and increasing rotation speed up to 60,000 rpm.

Fig.2 The current motor in the robot market. (Swiss M company)

Further downsizing and cost reduction

Develop a Motor that is 50% smaller, lighter, and much cheaper than current motors.

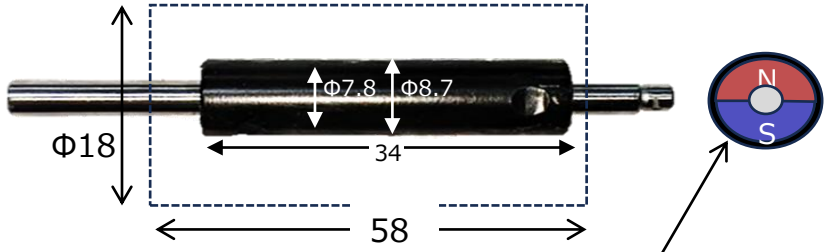
2. Design Concept

2.1. Challenging 50% down size for 120W small motor(Table 1)

(1) 2 Poles Nd-Fe-B Sintered Magnets (current motor) change to the 4 poles **Anisotropic Bonded Nd Magnets** (Magnet and rotor integrated Injection Molding)

(2) Higher Output by **Increasing Rotation Speed (60,000→200,000 rpm).**

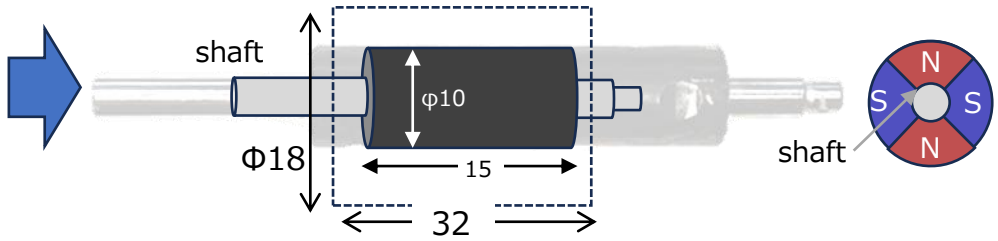
Current Rotor Magnet



Nd sintered magnet size:Φ7.8×L34
weigh:9.0g

with protective sleeves

Development Rotor Magnet



Nd Anisotropic bonded magnet size:φ10×L15
weight:5.9g

without protective sleeves

Injection molded and magnetized at the same time as the rotor

Table 1. Motor Specification Comparison

		Current motor	Development motor
Magnet		Nd Sintered Magnet	Nd Anisotropic Bonded Magnet
Rotor structure		Cylindrical Magnet + Shaft Adhesion	Integral Injection Molding
High Torque	(BH)max	～425kJ/m³*	115～125kJ/m³**
	Pole number	2 poles	4-poles
	Air gap	0.85㎜（including sleeves 0.5㎜）	0.3～0.5㎜
High speed rotation	Electric resistivity	$1.30\times10^{-4}\Omega$cm*	0.017Ωcm**
	Rotation speed	Limited to 60,000 rpm (Eddy Current Heating)	200,000rpm
Lower loss	Flux distribution	Easy in 2 poles	Halbach Anisotropy

3. Experimental Procedure

3.1 Rotor Shaft Fabrication and Injection Molding of Magnets

(1) Molding flow: Pellet → Injection Molding (Magnet and Shaft integrated) and Magnetization

(2) Experimental conditions

・**Pellet** (Fig.3): RNT-5214(Mate Co., Ltd.)
Magnetic properties : Br:8.2kG, HcJ:14.3kOe, (BH)max:14.8MGOe

・**Shaft** : S45C with Knurling and Shot Blasting

・**Injection mold :**Permanent Magnet Mold (Nd Sintered Magnet (N38EH) under Halbach direction Magnetic Field.

・**Injection Molding Machine** (Fig.4) :Injection Temp. 280℃
Mold Temp. 85°C, Holding Pressure: 29MPa

・Magnetization : simultaneously performed with Injection molding.

Fig.3 pellet(RNI-5214)

3.2 Evaluation

(1)Magnetic Properties
・**Surface Flux**: Gauss Meter
・**Magnet Properties**: VSM

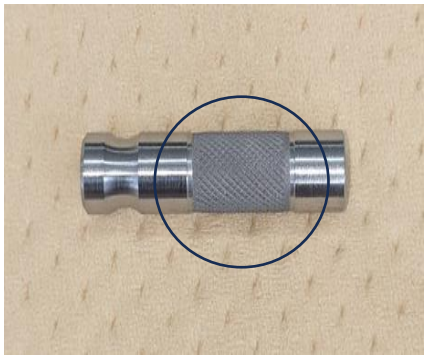
(2) High-Speed Rotation Evaluation
・Air Turbine type Rotating Device(Fig. 5)
(Maruwa Electric Inc.)

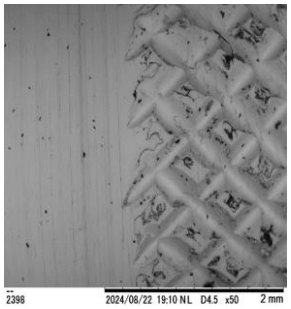
Fig.5 Air turbine type rotating device.

Fig.4 Injection Molding Machine.

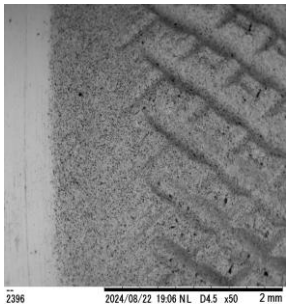
4. Experiment Result

4.1 Shaft Surface Design

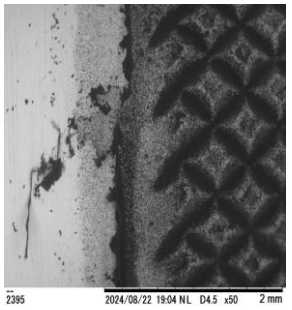




1st. Knurling



2nd. Shot blasting

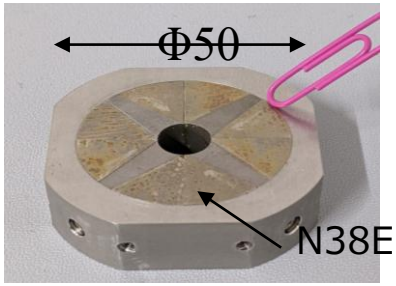


3rd. Adhesive coating

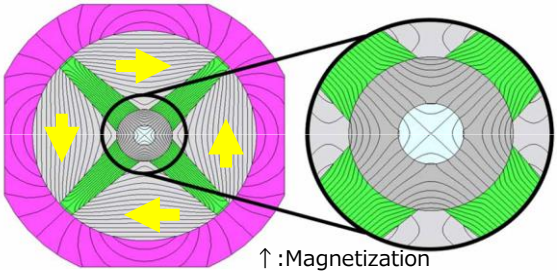
Fig.6 Shaft Surface Treatment.

4.2 Permanent Magnet type Tooling

Tooling Appearance



Electromagnetic Field Analysis



↑:Magnetization direction

Magnetic flux lines

Enlarged view

Fig.7 Permanent Magnet type Tooling Design

Halbach Alignment in Tooling

4.3 Integral Molded Rotor Shaft

Fig.8 Integral Molded Rotor Shaft

The Anisotropic Bonded Nd Magnets integrally were assembled onto the shaft (Magnetization is simultaneous with Injection molding).

4.4 Test Results of the Designed Rotor Shafts

4.4.1 Magnetic Properties and surface flux distribution of Magnets

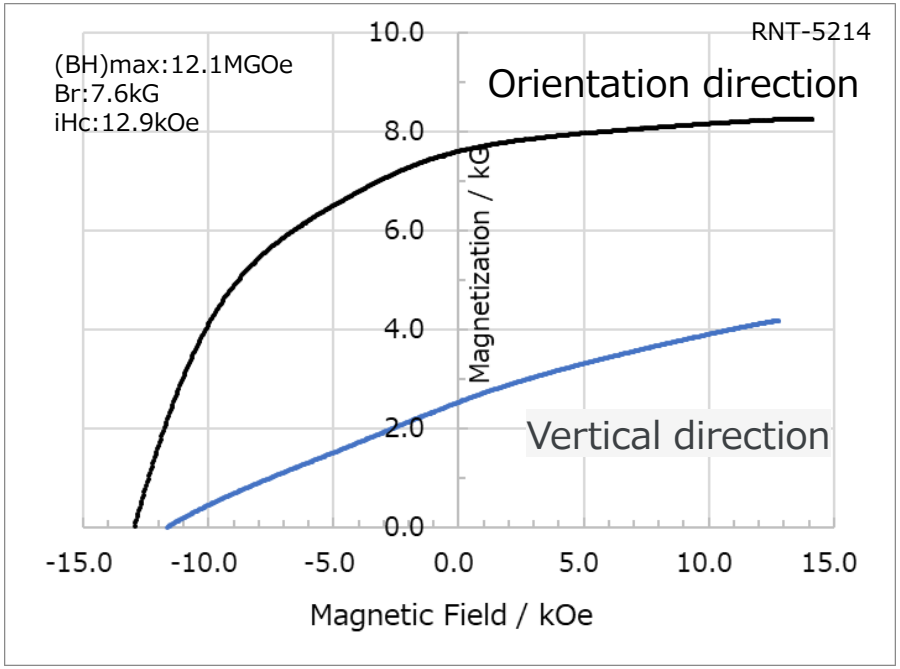


Fig.9 Demagnetization curves of magnets.

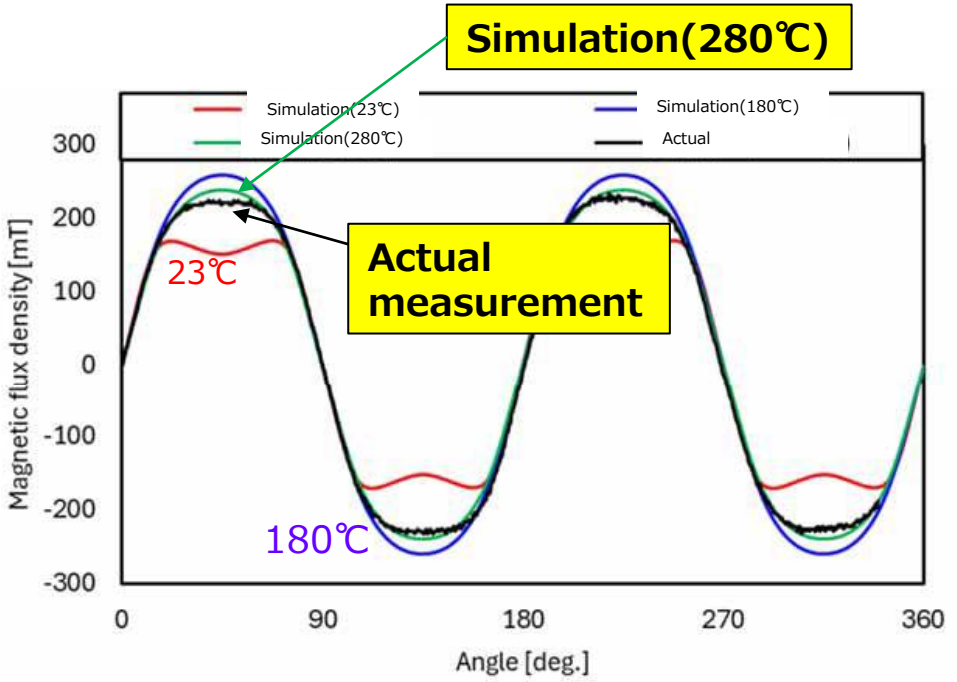


Fig.10 surface flux distribution.

・Br at Orientation direction is **92.7%** of the catalog value.

・Actual measurements corresponded to simulation results.
・**Sine wave** was obtained.

Anisotropic Bonded Magnets with 4-Poles of Aligned Magnetic Powder were obtained by Integral Injection Molding.

4.4.2 High-Speed Rotation Test of Shaft

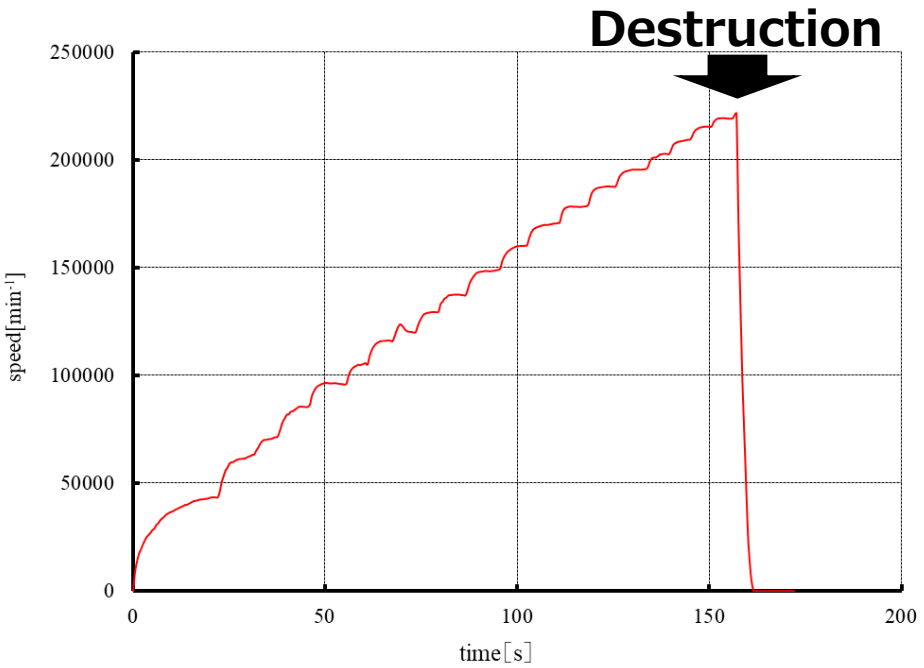


Fig.11 High-speed shaft rotation test

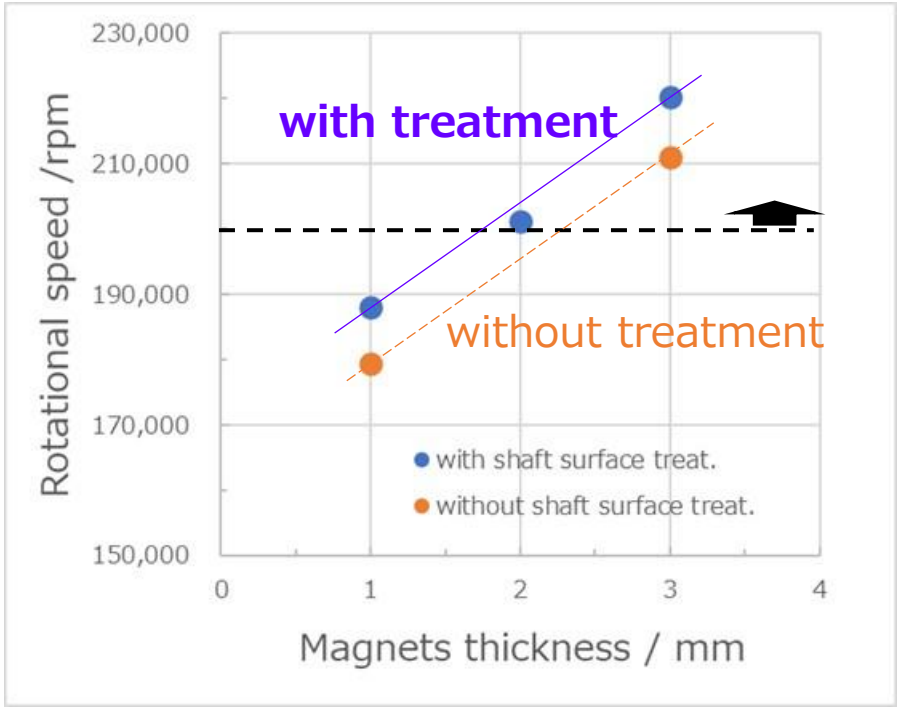


Fig.12 Magnetic thickness and rotation speed

The combined measure of shaft surface treatment and magnets with thickness of 3mm enabled stable operation at high rotation speed of 200,000 rpm **without Protective Sleeves.**

4.5 Motor Simulation and Design

4.5.1 Motor Simulation

Design variables

- Stator Inner Diameter r: 6.5 to 8.5 mm (yoke thickness: 0.5 to 2.5 mm)
- Coil opening angle θ: 5 to 30 deg

Material

- Shaft: S45C
- PM: S5P-12ME

Objective function

- Torque: Maximized
- Copper loss/iron loss: 0.95 to 1.05

Analysis conditions

- Rotation speed: 200krpm
- Current density: 6.0Arms/mm²

Size

- Rotor: Magnetization radius 5.0mm
- Air gap: 0.3mm
- Stacking thickness: 15mm

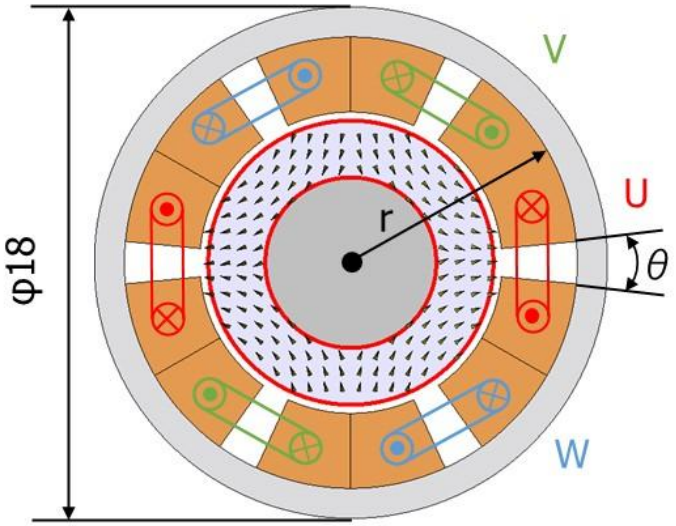


Fig.13 Concentration winding model

4.5 Motor Simulation and Design

4.5.2 Simulation Results (Stator material 10JNRF)

1.Maximum Torque Model

Size
r : 8.43 [mm]
(Back Yoke Thickness :0.57 [mm])
θ : 5.46 [deg]
Slot Area : 10.22 [mm²]

Each Parameter

- **Torque : 2.57 [mNm]**
- ripple rate : 0.79 [%]
- Copper loss : 0.99 [W]
- Iron loss : 1.57 [W]
- Efficiency : 95.01 [%]

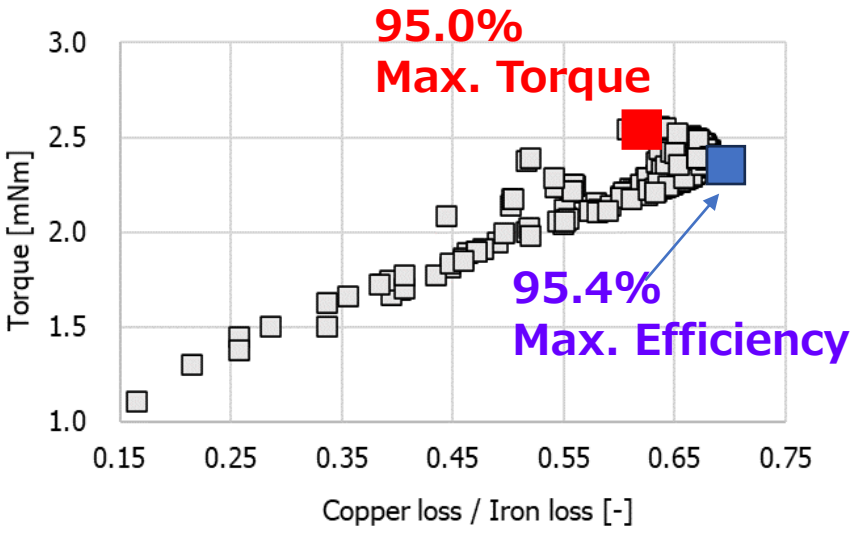


Fig.14 Optimization Result.

2.Maximum Efficiency Model

Size
r : 8.05 [mm]
(Back Yoke Thickness :0.95 [mm])
θ : 5.00 [deg]
Slot Area : 8.82 [mm²]

Each Parameter

- Torque : 2.39 [mNm]
- ripple rate : 1.00 [%]
- Copper loss : 0.97 [W]
- Iron loss : 1.42 [W]
- **Efficiency : 95.42 [%]**

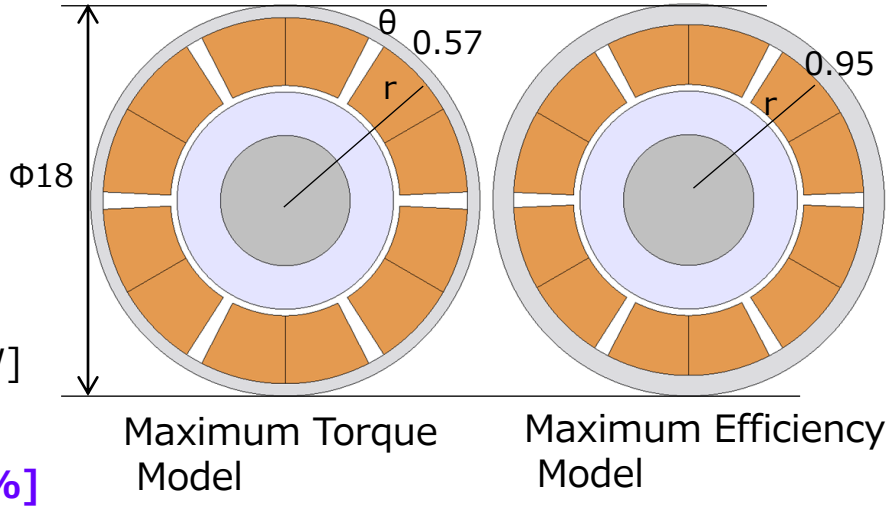
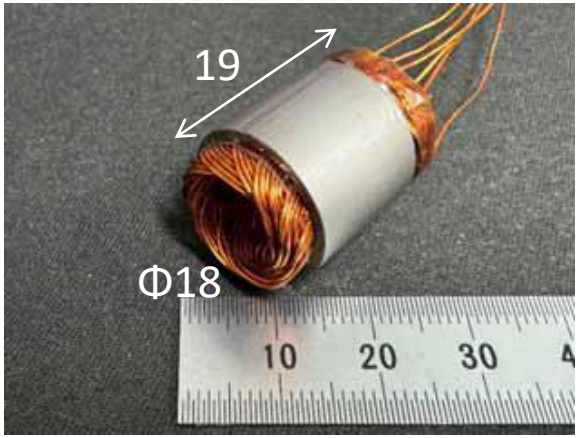
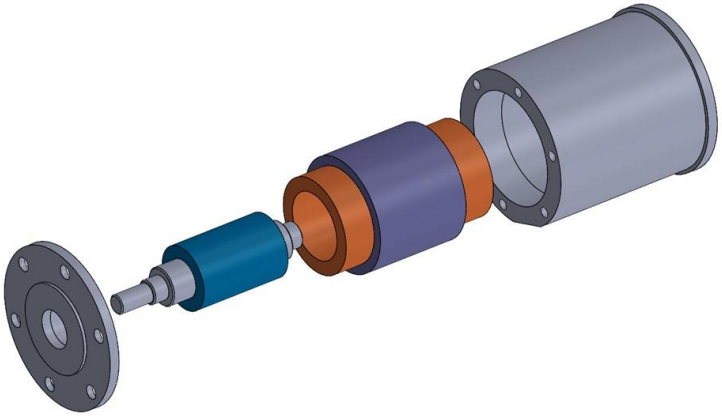
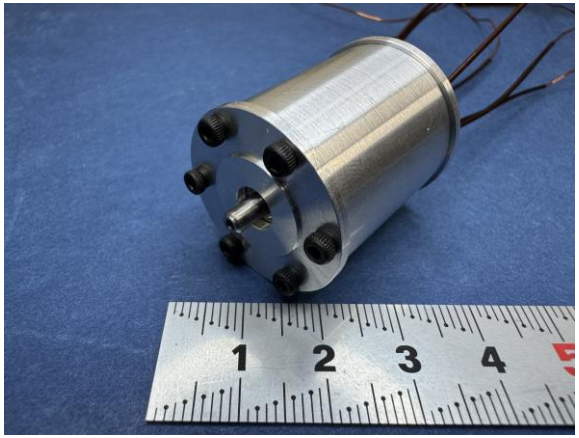


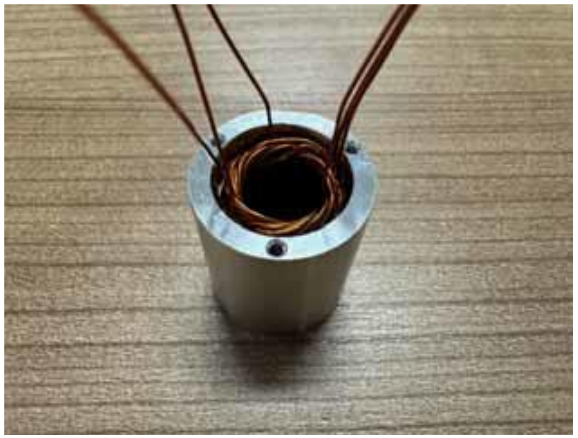
Fig.15 Motor Size

4.6 Appearance of prototype Motor









Rotation Test of Small Motor in Progress

By ARMIS Corp.

5. Summary and Future Plans

Summary

1. We succeeded in using injection molding simultaneously with magnetization to mold an Nd-based Anisotropic Bonded Magnet integrally onto the shaft.

2. Anisotropic Bonded Magnets with 4-Poles of Oriented Magnetic Powder were obtained by Integral Injection Molding.

3. A shaft capable of 200,000 rpm was obtained without **Protective Sleeves**.

4. Small Motor Rotation Test in Progress

Future Plans

1. 40W class Development of a 200,000 rpm Motor for Handpieces (Fig.15)

※ The current handpiece is an air turbine type(200,000 rpm).

2. 50% lighter robot motor

Fig.17 Handpiecs

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