28th – 31st July　REPM 2025

29th July 11:05~

Design Studies on IPMSM with Radially Oriented Arc-Shaped Metal Magnet for Automotive Traction Drives

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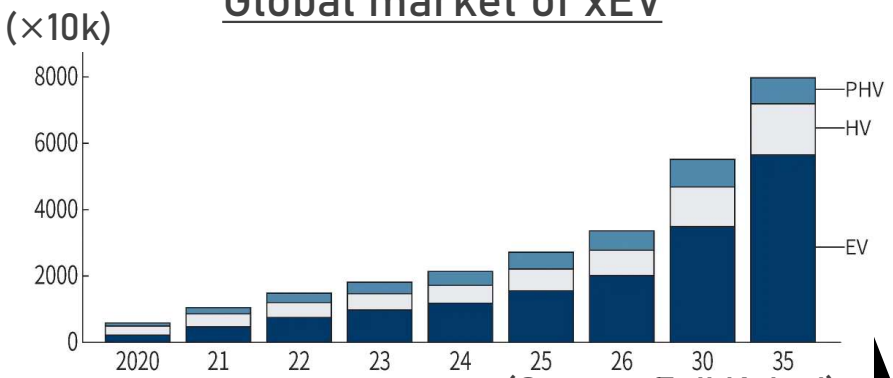
1. Demand for permanent magnets in IPMSM

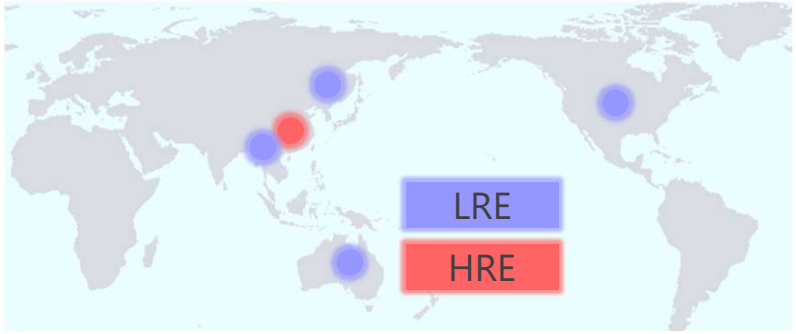
✓ The increasing demand of xEV presents resource risks of RE elements.
✓ Daido has been developing HREE-free hot-deformed magnets for IPMSM.

Global market of xEV

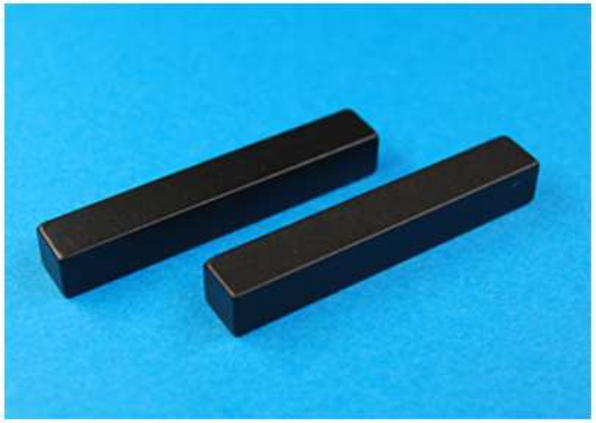


(Source: Fuji Keizai)

Distribution of RE production sites



HREE-free hot-deformed magnet



Motor designing for hot-deformed magnet

Today's presentation
(IPMSM with arc-shaped magnet)

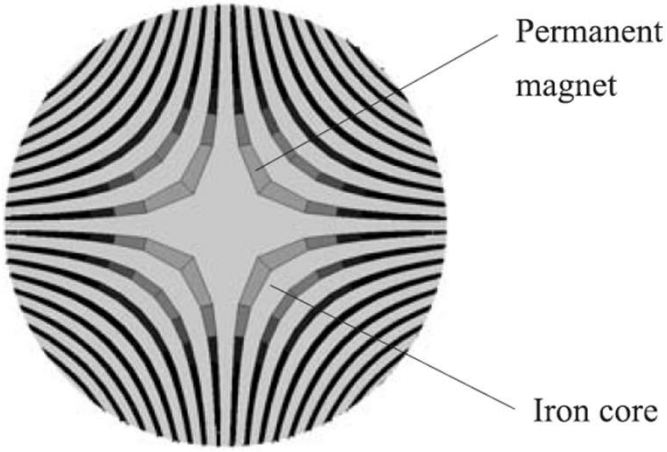
Source: https://global.honda/en/newsroom/news/2016/4160712eng.html

2. IPMSM with radially oriented arc-shaped magnet

✓ An arc-shaped multilayer flux barrier enhances reluctance torque, while embedded permanent magnets in the barrier region provide additional magnet torque.

IPMSM to enhance reluctance torque

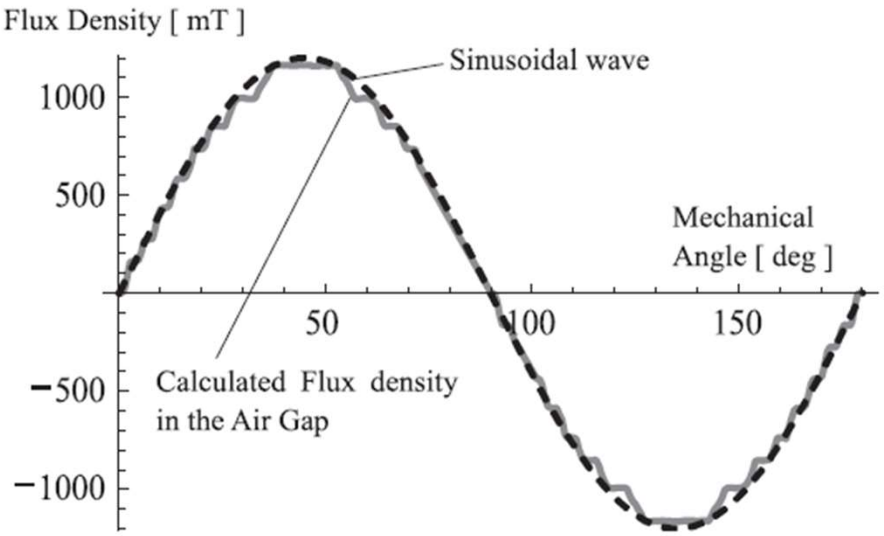
[1]Multi-layers of flux barriers



Embedded block magnets

[2]Arc-shaped magnets

Calculated air gap flux density distribution

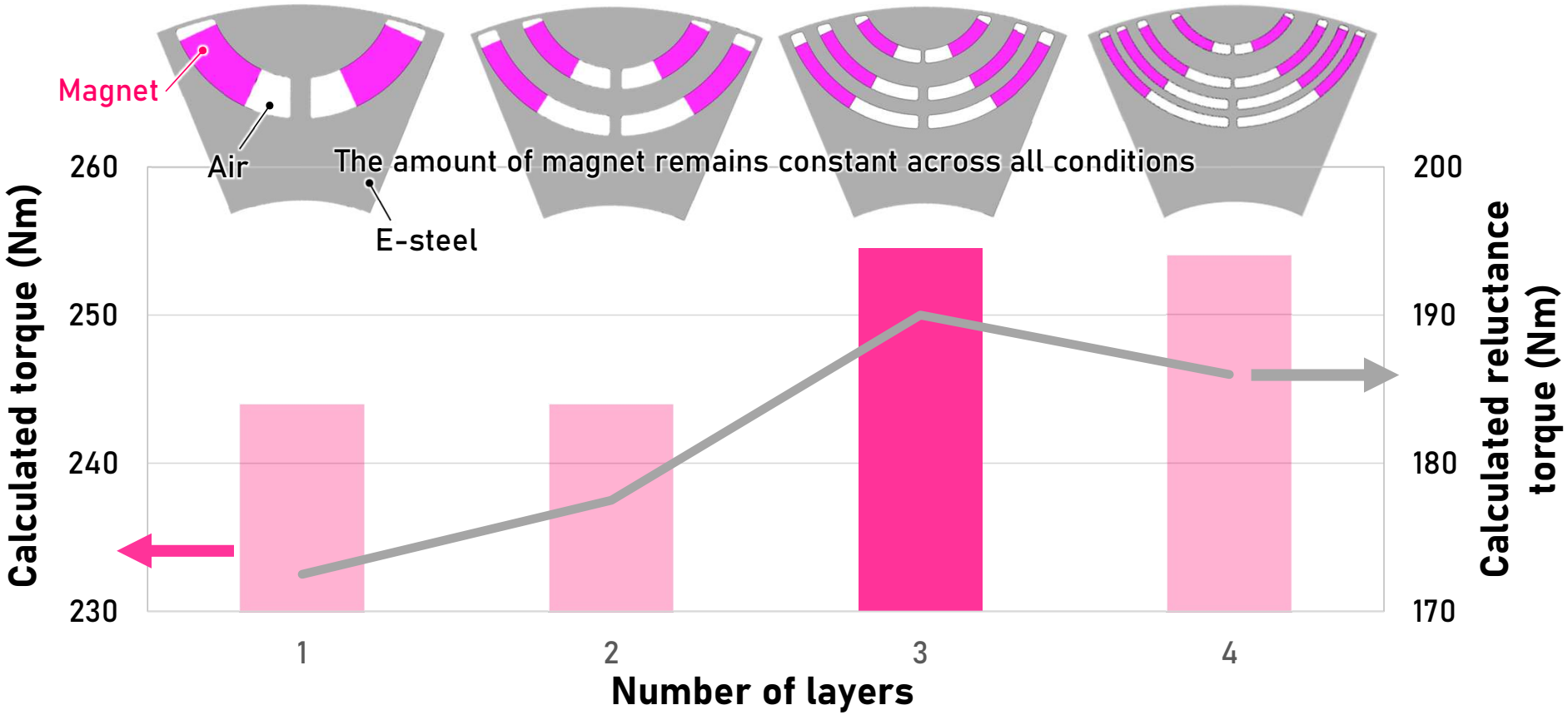


Sinusoidal wave of flux density distribution

Source of images: Kondo, IEEJ Transactions on Industry Applications vol.131 No.11 pp.1269-1275

2. IPMSM with radially oriented arc-shaped magnet

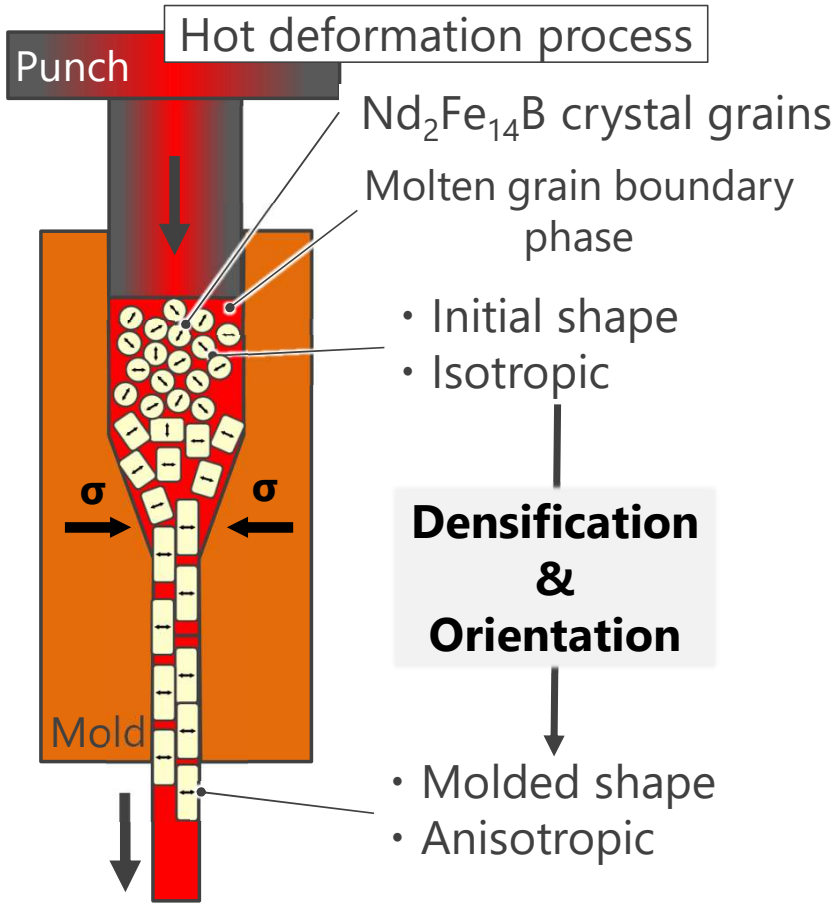
✓ 3-layer stacking arc-shaped magnets can maximize total & reluctance torque.
✓ 4-layer stacking induces magnetic saturation on e-steel area between magnets.



Source: Kano, Industrial Applications Forum Lecture in 2022

2. IPMSM with radially oriented arc-shaped magnet

✓ Hot-deformation process can provide various shape magnets.
✓ Arc-shaped and radially oriented magnets can be producible.



- Initial shape
- Isotropic

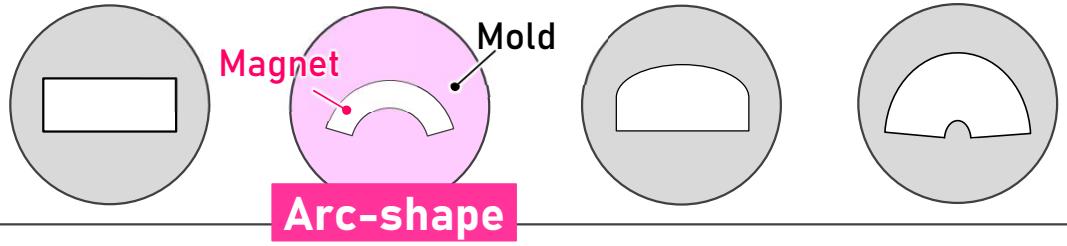
Densification & Orientation

- Molded shape
- Anisotropic

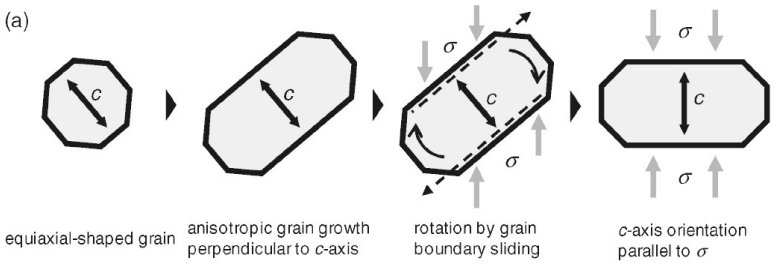
■ Shape

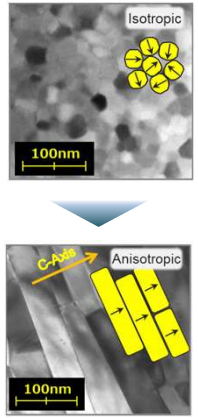
- Magnet shape is defined by the mold shape.

Various mold shapes



■ Orientation





- *c*-axis is oriented parallel to σ.
- σ direction can be changed by the mold design.

3. Fabrication & Demonstration

✓ The prototype and reference devices underwent performance evaluation tests under identical test bench and power conditions.

	Reference (Prius 3rd)	Prototype
Magnet	Sintered magnet (HREE-contained) B_r = 1.30T @R. T. H_{cJ} = 2,070kA/m@R. T.	Hot-deformed magnet (HREE-free) B_r = 1.30T @R. T. H_{cJ} = 1,640kA/m@R. T.
Rotor		

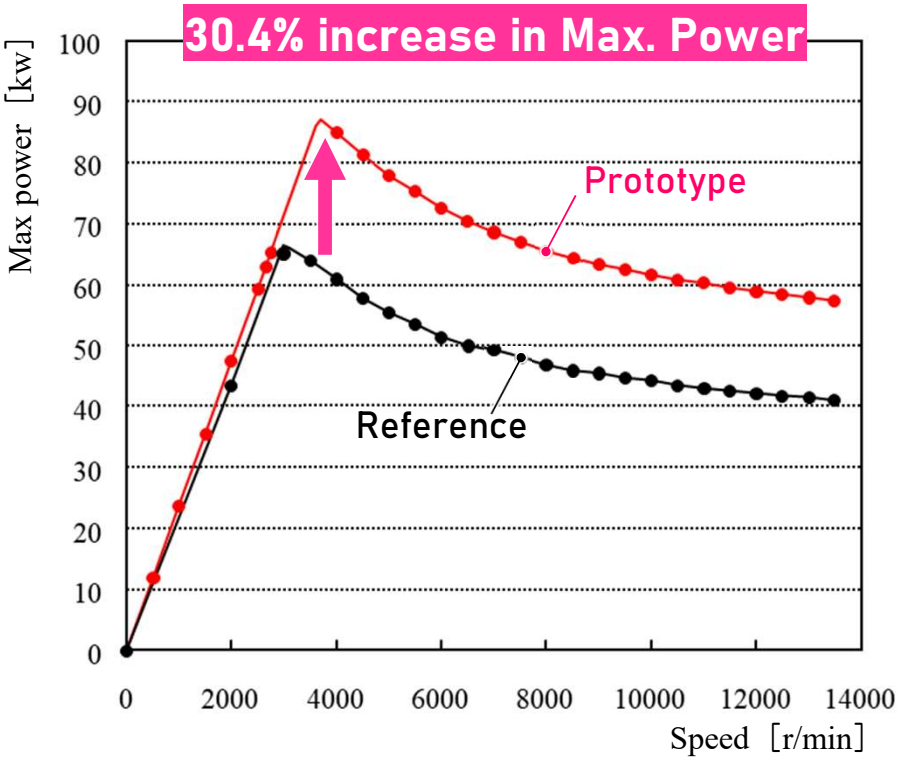
Installed magnets with each rotor have the same B_r and total weight

Condition	Value
Stator outer diameter	264 mm
Stack length	50 mm
Air gap length	0.8 mm
Number of stator slots	48
Number of rotor poles	8
Max. terminal voltage	398 V_{rms}
Withstand voltage of switching device	1200 V_{0-p}
Max. inverter current	170 A_{rms}
Max. current density of armature coil	26 A_{rms}/mm^2
Coil space factor	0.46
Max. torque in Ref. motor	244 Nm
Max. power(sinusoidal PWM) in Ref. motor	65.0 kW
Max. speed in Ref. motor	13,500 rpm

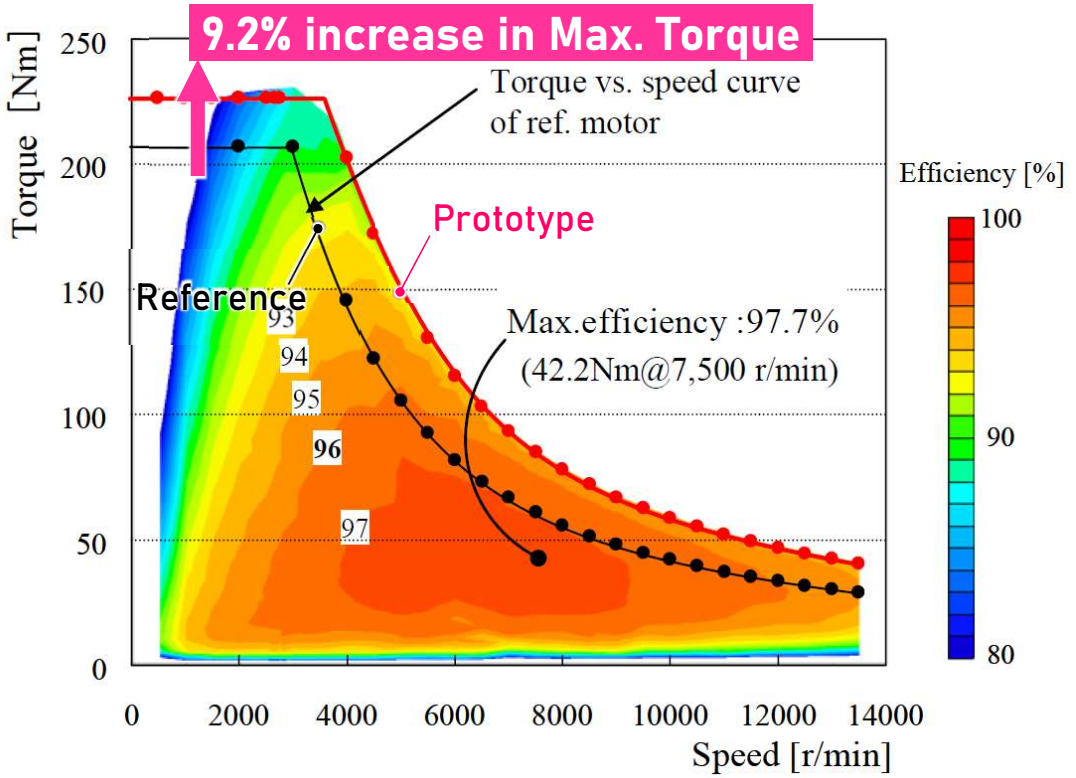
3. Fabrication & Demonstration

✓ Evaluations using motor testing device confirmed a 30.4% increase in maximum power and a 9.2% increase in maximum torque.

Power vs. speed curve



Torque vs. speed curve

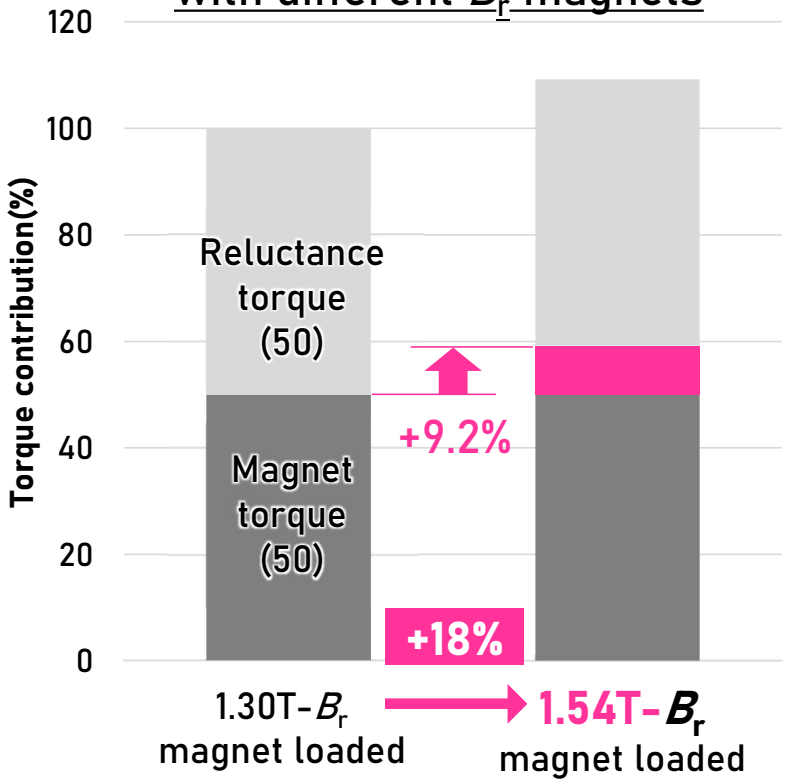


Source of images: Kano, IEEJ Transactions on Industry Applications vol.140 No.4 pp.255-264

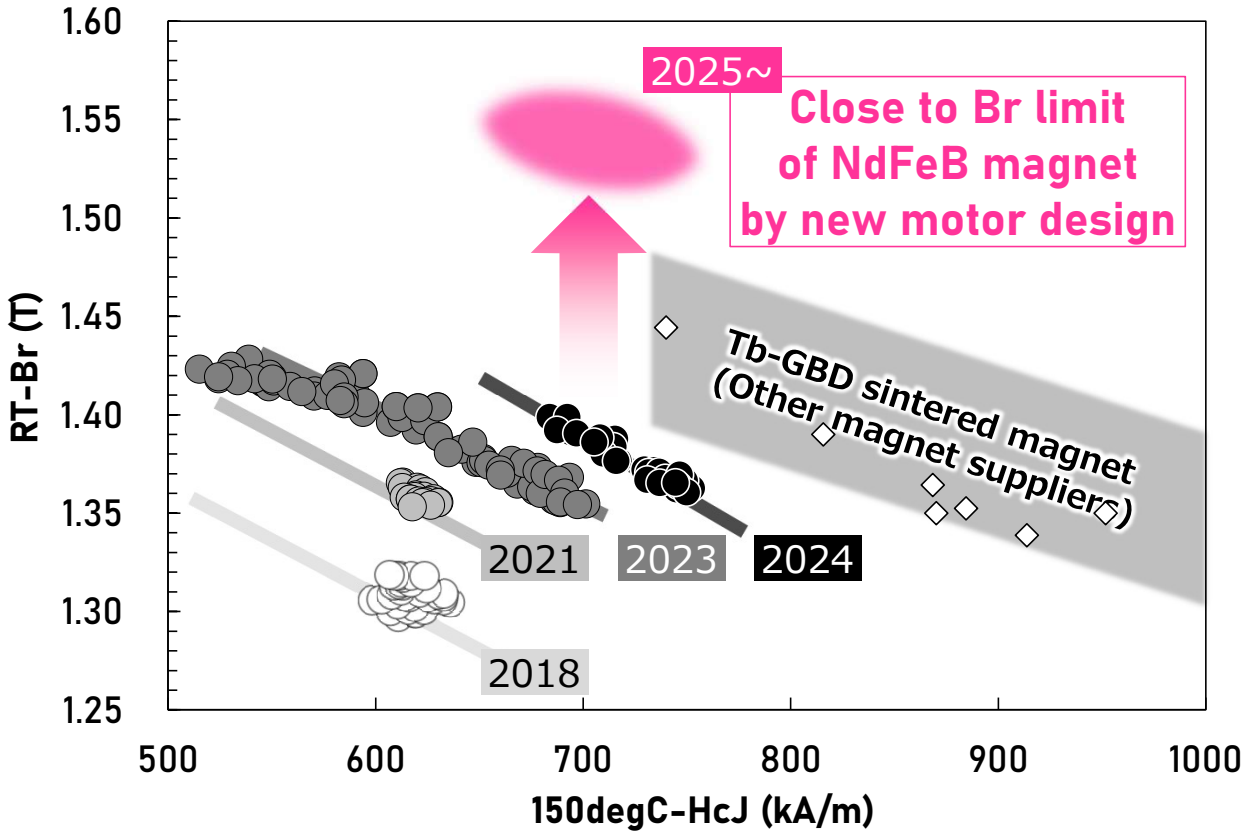
4. Potential for flexible shape and orientation of magnet

✓ A 9.2% increase in torque in 50-50 motors equates to an 18% B_r enhancement, which indicates high potential of arc-shaped magnets in IPMSM.

50-50 motor torque comparison with different B_r magnets

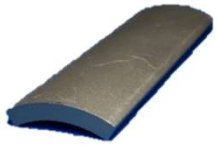
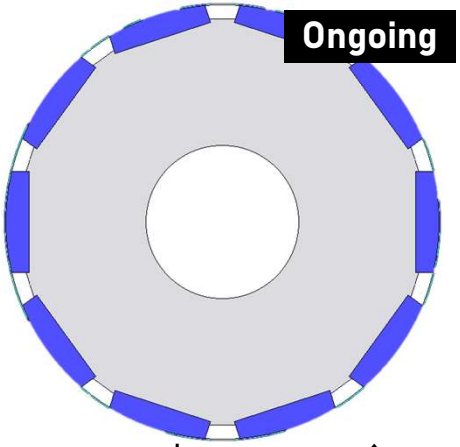


Magnetic properties of Daido's HREE-free magnets



4. Potential for flexible shape and orientation of magnet

✓ Future efforts will focus on proposing motors utilizing hot-deformed magnets, which could further unlock the potential of motor performance.

Orientation *c*-axis: ↑				
Shape	Arc	Lucent	Bread loaf	Fan
Product (Prototype)				
Designed rotor	 Enhancing torque and output	 Enhancing torque and output	 Ongoing Ripple ↓ & Torque ↑	 Improving efficiency and NV

Conclusion

- ✓ The increasing demand for magnets poses a resource risk, necessitating a reduction in usage through the effective utilization of reluctance torque.
- ✓ The implementation of arc-shaped magnets in an IPM has resulted in a significant performance improvement.
  - 9.2% increase in maximum torque
  - 30.4% increase in maximum power
- ✓ Further verification of high-performance motors utilizing hot-deformed magnets will continue, along with proposals to clients, focusing on optimization of shape and orientation.

Thank you for your attention!!