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Characteristics Comparison of Magnetic Gears According to Permanent Magnet Material

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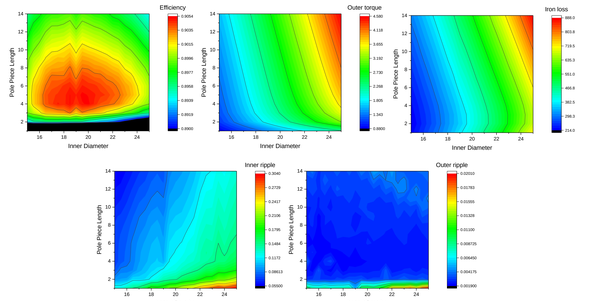
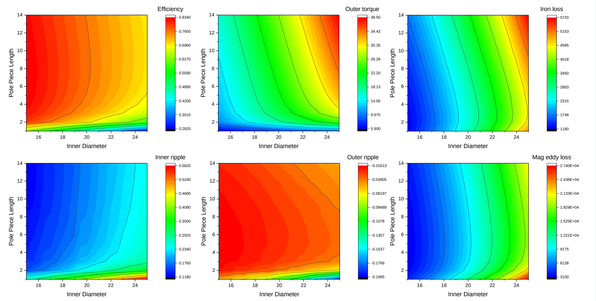
Abstract—The biggest cause of permanent magnet eddy current loss is electrical conductivity of rare earth magnets. In this paper, we applied the ferrite permanent magnet and the NdFeB permanent magnet to the magnetic gears in order to compare the characteristics of the magnetic gear according to the electric conductivity of the permanent magnet. Ferrite and NdFeB were used to design magnetic gears that exhibited the same torque, and then the characteristics of each magnetic gear at the same drive speed were compared. Since the ferrite is not electrically conductive, the ferrite-applied magnetic gear does not exhibit permanent magnet eddy current loss. However, we observed mechanical and electric problems due to its size. Also, the efficiency of the two magnetic gears was reversed on a specific speed.

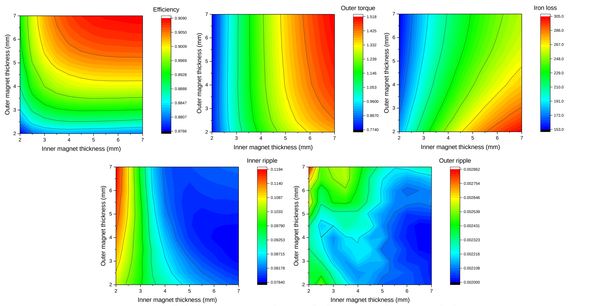
FEA design



< Size Design of the Ferrite Model >

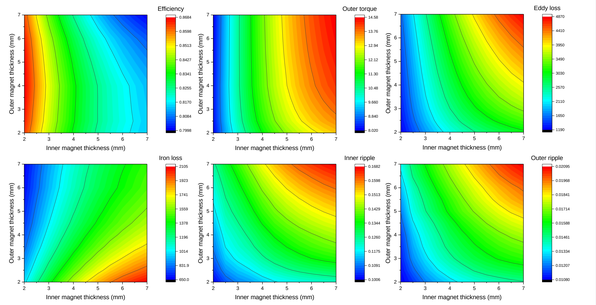


<Size Design of the NdFeB Model>



< Magnet Thickness Design of the Ferrite Model >

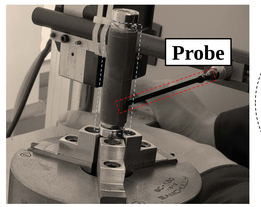
Final model
@ 140krpm, 1.7Nm, 87.2%
@ 4,000rpm, 1.7Nm, 95.7.%

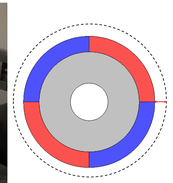


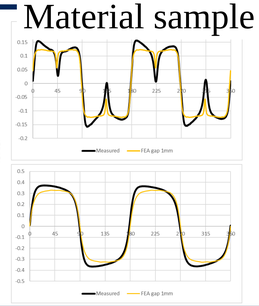
< Magnet Thickness Design of the NdFeB Model >

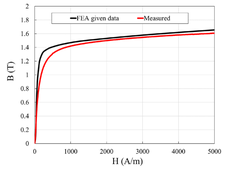
Final model
@ 140krpm, 1.7Nm, 85.7%
@ 4,000rpm, 1.7Nm, 95.4%

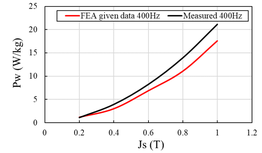
Material sample data



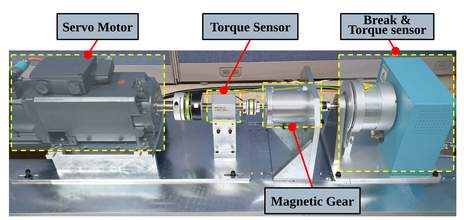








Experiment Setup and Prototype



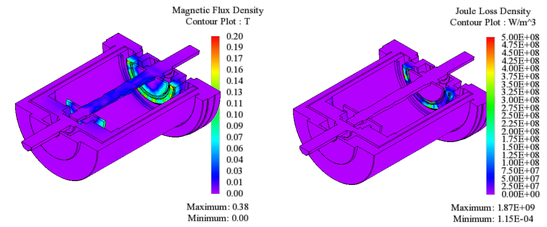
< Ferrite Model >
@ 4,000rpm, 1.7Nm, 86.1%

< NdFeB Model >
@ 4,000rpm, 1.7Nm, 93.2%

Mechanical Losses

- Windage loss $P_{air} = c_f \pi \rho_{air} \omega^3 R^4 L,$
  $= 0.04\text{W} @ 4{,}000\text{rpm} : \text{Negligible}$
  Friction coefficient, Air density, Rotation speed, Rotor diameter, Stack length, respectively
- Bearing loss $M = 0.672 \times 10^{-3} D_{pw}^{0.7} F_a^{1.2} + 3.47 \times 10^{-10} D_{pw}^{3} n_i^{1.4} Z_B^a Q^b$
  Diameter, Load, Speed, Oil viscosity, Oil flow rate, affect the oil viscosity, flow rate factor respectively
- Since the bearing of the output rotor appears as a load, only the bearing of the input rotor is calculated for the actual bearing loss.
  - Ferrite: 2.8*2 = 5.6W @ 4,000rpm
  - NdFeB: 0.35*2 = 0.7W @ 4,000rpm

Housing & Supporter Losses



- the magnetic gear has a large effective air gap, causing a large housing loss due to leakage flux.
  - Ferrite: 3.0W @ 4,000rpm
  - NdFeB: 0.78W @ 4,000rpm

FEA and Experiment Losses

No-load		Magnet material		Rate
		Ferrite	NdFeB	
FEA	Housing loss	3.0 W	0.78 W	**3.8**
	Iron loss	1.5 W	1.3 W	1.2
Experiment	Input power	13.33 W	7.36 W	-
	Output power	0.63 W	0.73 W	-
	Input - Output	12.7 W	6.6 W	1.9
Calculation	Windage loss	0.04 W	0.04 W	1.0
	Bearing loss	5.6 W	0.7 W	**8.0**
	Total loss	10.14 W	2.82 W	3.6
	Difference	2.56 W	3.78 W	0.7

- Total loss : Housing + Iron + Windage + Bearing losses

An interesting fact is that the bearing losses of Ferrite and NdFeB are eight times different. When designed with the same output, the Ferrite's outer diameter is 72mm, about twice that of NdFeB's 37mm. It is the difference in bearing loss as the size of the bearing increases to fit the large outer diameter.
This paper analyzes the design and driving characteristics of the permanent gear material of magnetic gear. NdFeB permanent magnet is used for high output of magnetic gear, but eddy current loss occurs in permanent magnet because of the conductivity of permanent magnet. It is negligible at low speeds but is not suitable for high speed applications because it increases exponentially with high speeds. Therefore, the model applying Ferrite permanent magnet that does not generate eddy current loss was reviewed. However, on the same output, the Ferrite model has a diameter twice that of the NdFeB model. In addition, an increase in housing loss due to a large size also poses a big problem. Therefore, the use of Ferrite permanent magnets for the purpose of reducing the permanent magnet eddy current loss can lead to other problems.