A Study on Robust Design of Irreversible Demagnetization of IPMSM Rotor Core Using Dy-Free Permanent Magnet

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Abstract

The rapid growth of the hybrid auto (HEV) and electric vehicle (EV) industries is expected to increase demand for small/high-efficiency/high-power drive motors. High-temperature, high-temperature permanent magnet is necessary to realize the high performance of the driving motor. The supply shortage is deepening as China, which accounts for more than 80 percent of the world's rare earth production, has implemented a policy to limit the upper limit of annual rare earth mining. In this paper, the shape of the rotor that maximized the Coercive force so that it can be operated at the actual motor operating temperature (140°C) while completely excluding the rare earth content is studied.

1. Introduction

As the core sector of the 4th industry, the rapid growth of the hybrid vehicle (HEV) and electric vehicle (EV) industries, which are already deployed or are expected to be commercialized, is expected to increase the demand for small / high efficiency / high power drive motors. In order to realize the high performance of the motor, a high heat-resistant permanent magnet is required. In fact, about 0.25kg for one HEV and about 0.6kg for an EV, Nd-based bulk magnets are used, and production demand is growing at an annual average of 15% for the past five years. In addition, China, which accounts for more than 80% of the world's rare earth production, uses trade cards that restrict heavy rare earth, so the supply of heavy rare earth elements is unstable.

For this reason, in this paper, we developed a rotor technology to compensate for the lack of coercive force of electric motors made of Permanent magnet material. Through the research on the design, control and evaluation technology of the permanent magnet synchronous motor rotor, Irreversible demagnetization robust design of the rare earth fully-removed permanent magnet motor required in the future power-based automobile electric drive motor industry was studied.

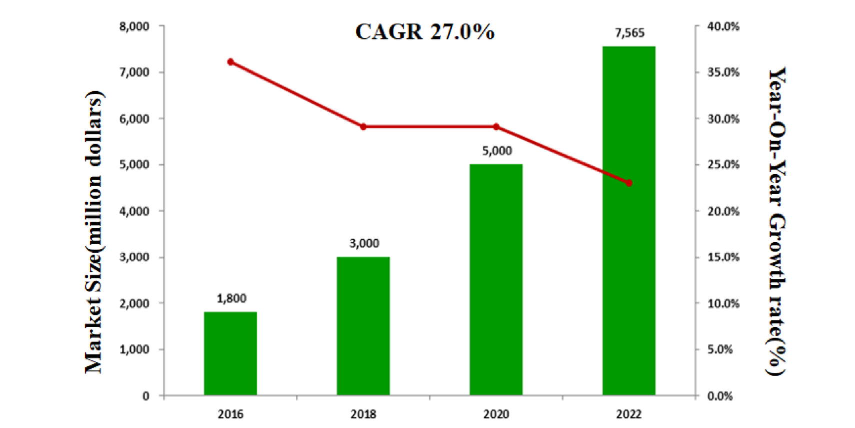


Fig. 1 Global Environmentally Friendly Car Market Status

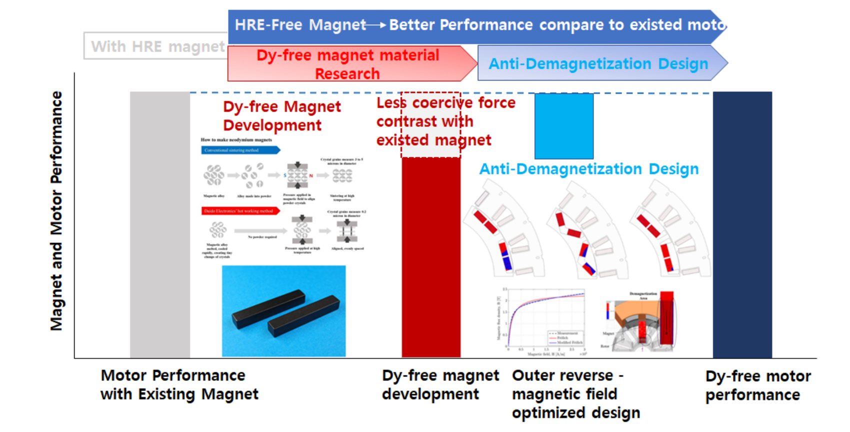


Fig. 2 Heavy rare earth goal and concept map of completely exclusion permanent magnet and motor

2. Motor Design Target Specification


Fig. 3 Personal Mobility

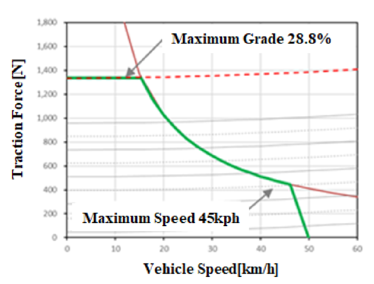


Fig. 4 Traction force and gradeability by vehicle speed

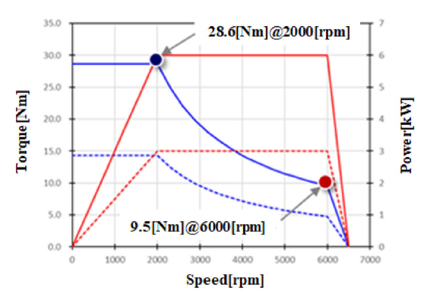


Fig. 5 Drive Motor Target Specification

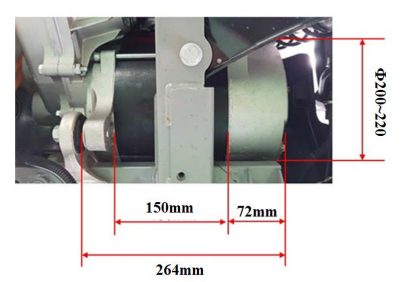


Fig. 6 Conventional Inductor Model Size

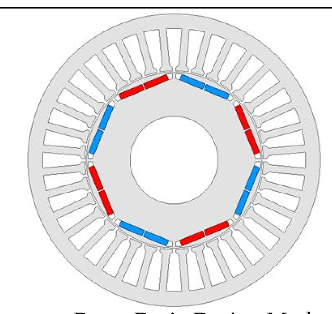


Fig. 7 Rotor Basic Design Mode

	Parameter	Value	Unit
Size	Rotor Diameter	120	mm
	Stator Diameter	200	mm
	Shaft Diameter	60	mm
	Back Yoke	10	mm
	Stack Length	200	mm
	Teeth Thickness	5	mm
	Air-Gap	1	mm
	Slot Opening	2	mm
	Magnet Thickness	6	mm
	Magnet Length	16	mm
Material	Core	35PN230 (S08)	
	Magnet	Freed Magnet	
	Coil	Copper	
Spec.	Base Speed	2,000	rpm
	Max.Speed	6,000	rpm
	Peak Torque @ Base Speed	28.6	Nm
	Peak Torque @ Max. Speed	9.5	Nm
	V_{dc}	58	V
	Peak Current (2min)	275	A_{rms}
	Cont. Current (60min)	110	A_{rms}
	Boost Current (10sec)	330	A_{rms}

Fig. 8 Basic design model specification

3. Magnet Specification and Irreversible Demagnetization Analysis Technique

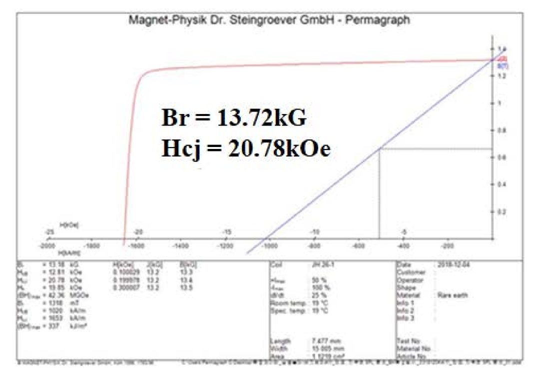


Fig. 9 Magnet B-H Curve 20°C

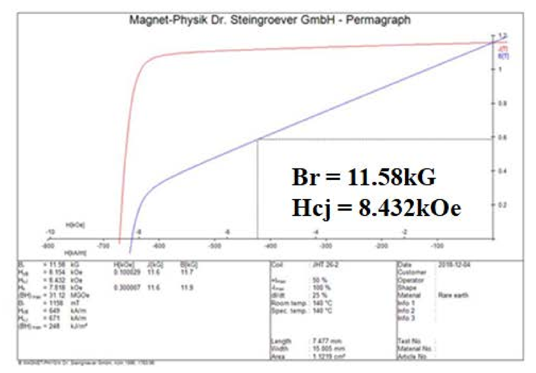


Fig. 10 B-H Curve 140°C

Magnet Spec.			
	20°C	140°C	Unit
Br	13.18	11.58	kG
Hcj	20.78	8.43	kOe
BH_{max}	42.36	31.12	MGOe
Size	135.5		mm^2
Fillet	0.5		mm

Fig. 11 Magnet specification

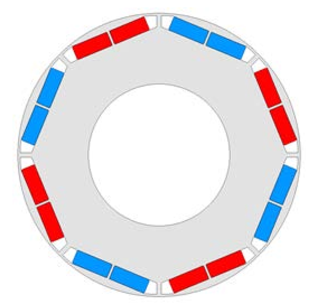


Fig. 12 Bar Type

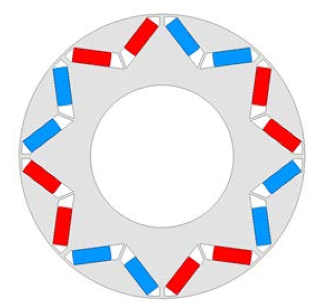


Fig. 13 V Type

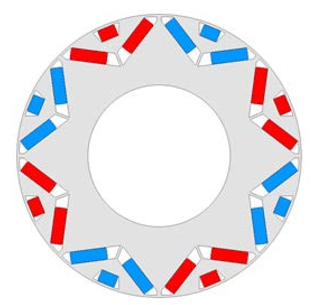


Fig. 14 Double Type

In order to analyze the irreversible demagnetization according to the shape of the rotor, the research was conducted on three shapes: Bar Type, V Type, and Double Type.

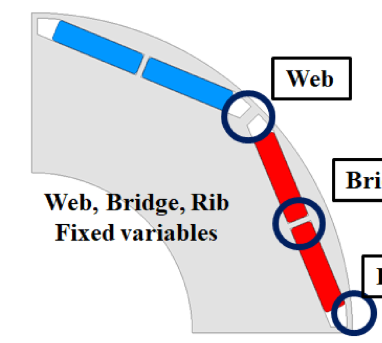


Fig. 15 Fixed Variables

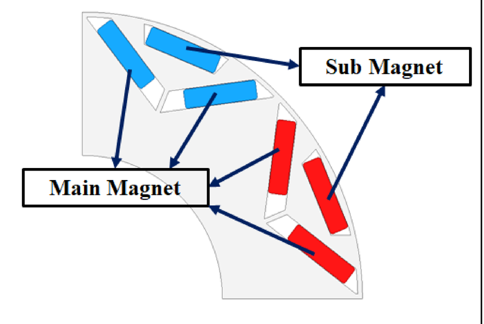


Fig. 16 Double Type Magnet

All three types had the same magnet usage. The web, bridge and ribs were fixed at 2mm, 1mm and 1mm respectively.

In case of double type, bar type magnet close to airgap is defined as sub magnet and V type magnet close to shaft as main magnet.

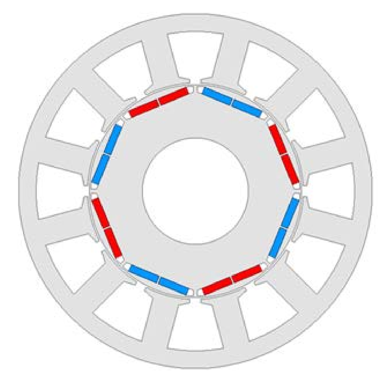


Fig. 17 8Pole 12Slot Concentration Winding

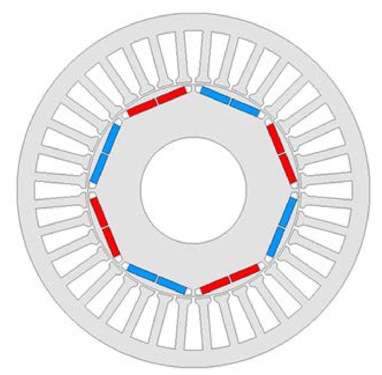


Fig. 18 8Pole 36Slot Distribution Winding

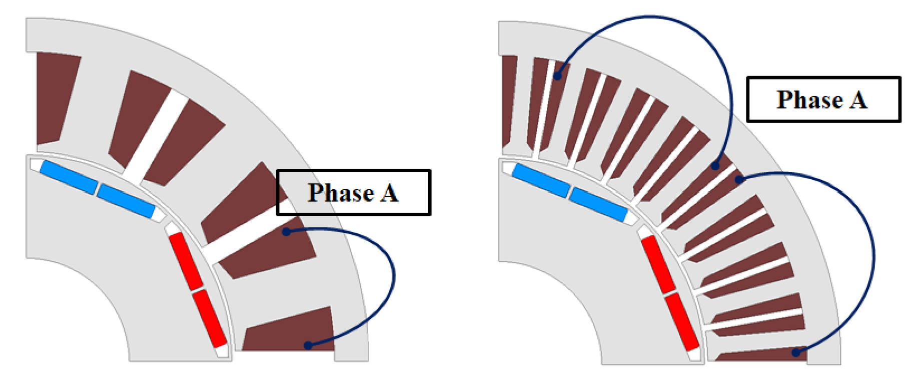


Fig. 19 Winding Layout

4. Characteristic analysis by motor type

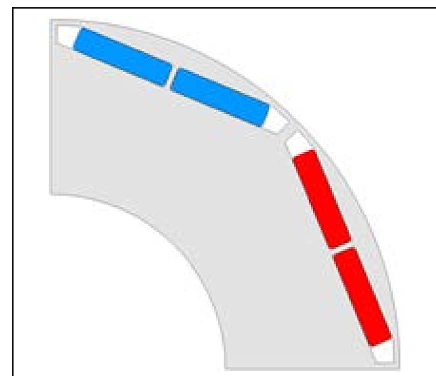


Fig. 20 Magnet Depth : 0mm

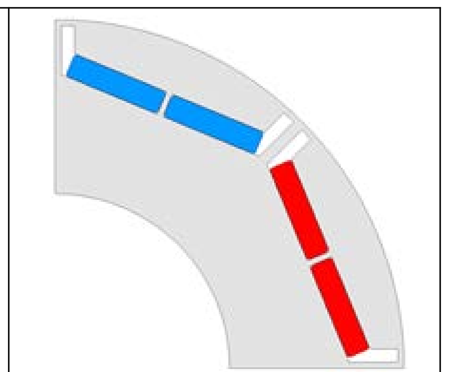


Fig. 20 Magnet Depth : 5mm

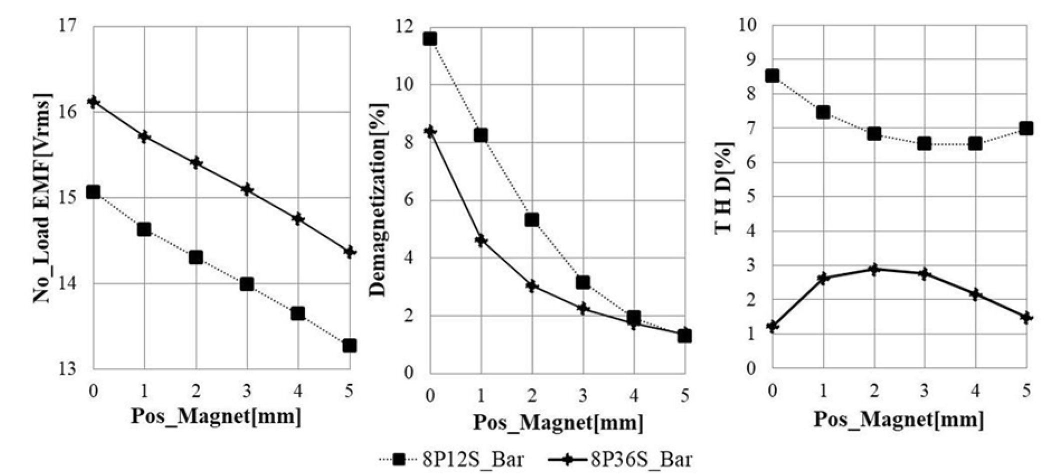


Fig. 21 Bar Type Data

All three types had the same magnet usage. The web, bridge and ribs were fixed at 2mm, 1mm and 1mm respectively.

In case of double type, bar type magnet close to airgap is defined as sub magnet and V type magnet close to shaft as main magnet.

Design variables	Minimum	Maximum	Interval
Magnet_Depth	0mm	5mm	1mm

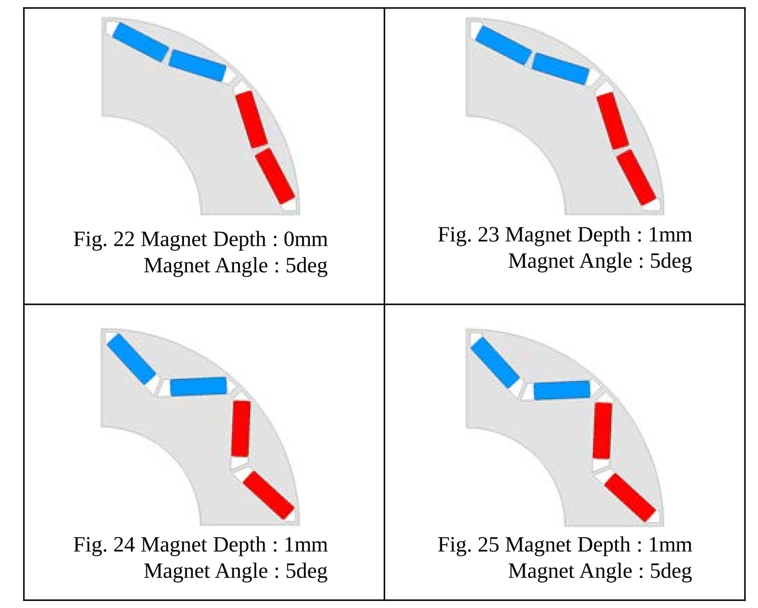


Fig. 22 Magnet Depth : 0mm Magnet Angle : 5deg

Fig. 23 Magnet Depth : 1mm Magnet Angle : 5deg

Fig. 24 Magnet Depth : 1mm Magnet Angle : 5deg

Fig. 25 Magnet Depth : 1mm Magnet Angle : 5deg

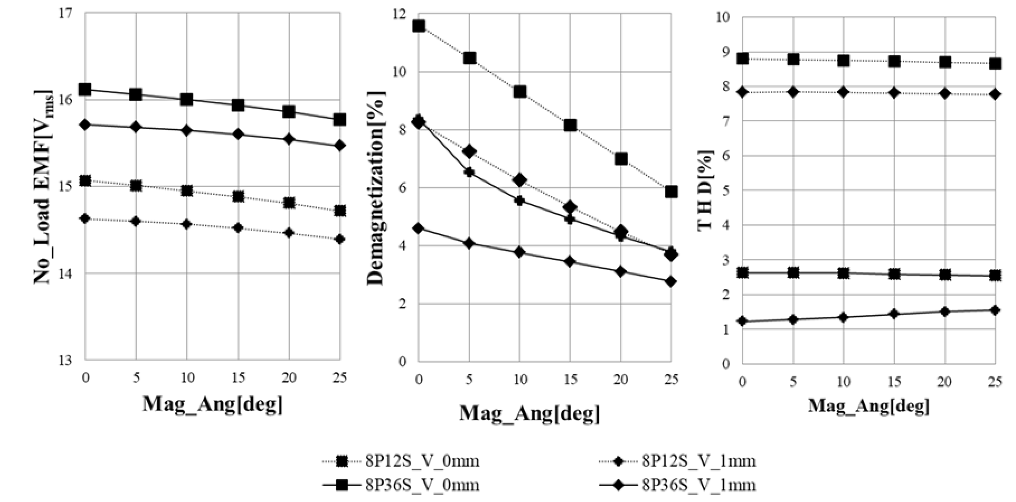
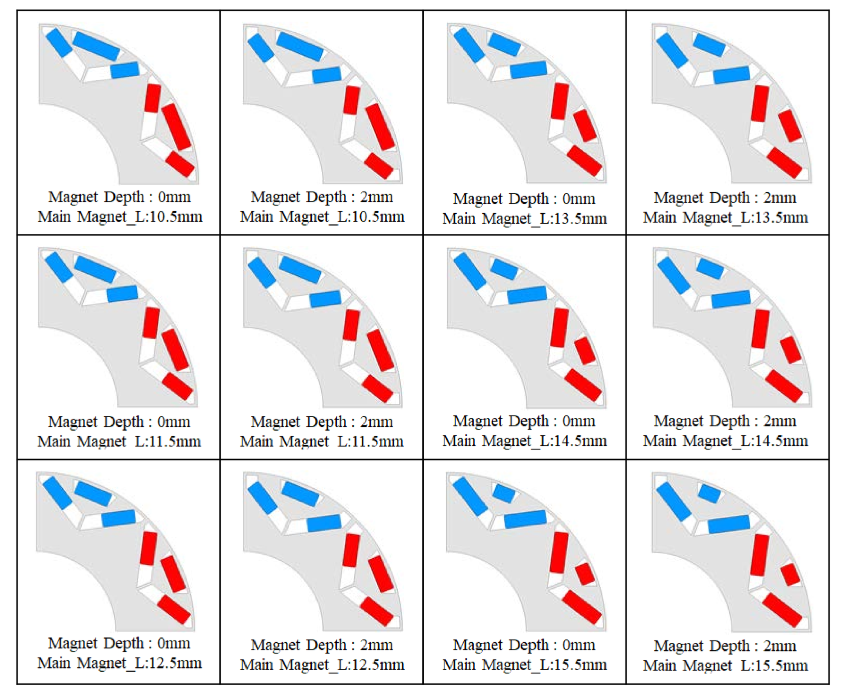
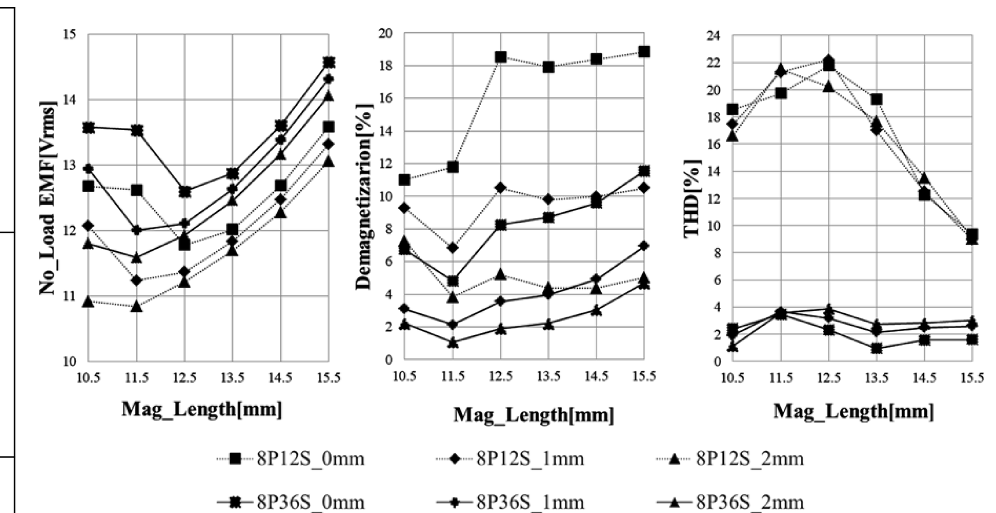


Fig. 26 V Type Data

Design variables	Minimum	Maximum	Interval
Magnet_Depth	0mm	1mm	1mm
Magnet_Angle	5deg	25deg	5deg

In the case of the V type, it can be seen that the amount of change in the counter electromotive force decreases as the angle increases. It is considered that the amount of decrease in Noload EMF is small because it is concentrated in the form of collecting magnetic flux by the shape of the magnet. On the other hand, demagnetization decreases with increasing magnet angle. As the angle increases, the reverse magnetic field from the stator does not directly touch the magnet. THD has a slight change in angle and is lower in distribution winding than in concentration winding.





Design variables	Minimum	Maximum	Interval
Magnet_Depth	0mm	2mm	1mm
Main Magnet_L	10.5mm	15.5mm	1mm

In the case of the Double Type, the magnet usage is the same and the length of the Sub magnet is reduced to have the same magnet usage as the length of the Main magnet increases. As the main magnet length increases, the back EMF and demagnetization increases above a certain size. The deeper the magnet insertion depth, the more the leakage magnetic flux was generated and the counter electromotive force was also reduced.

In the double type, the magnetic flux flows from both ends of the main magnet, near the bridges and ribs, and thus is affected by demagnetization. The magnetic field coming into the sub magnet is all-passed to the high-permeability rotor core next to the magnet and is more affected by the main magnet located behind it. Because of this phenomenon, even though demagnetization is in progress in the main magnet, the magnet is not affected by the sub magnet.

6. Conclusion

In this paper, a robust design of an irreversible device was proposed to compensate for the coercive force of a motor manufactured using a magnet that excludes strong rare earths. By dividing the rotor shape of the IPMSM into three types, we assigned design variables to each type and compared the demagnetization and no-load EMFs. In order to know the variation due to the combination of the number of pole slots, it was designed and analyzed by dividing it into distributed windings and concentrated windings. Demagnetization was less than 3% and THD was less than 3% in the V-type distribution winding. It showed the best characteristics among several models.