A Study on Design of IPMSM for Reliability of Demagnetization Characteristics-based Rotor

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Background

- ❖ The IPMSM used in this study is a traction motor for railway vehicles, and it is located at a low part of a railway vehicle and has a totally enclosed type structure to block the inflow of dust and foreign substances during operation.
- ❖ Since the traction motor for railway vehicles desperately should have high power density, the rare earth neodymium permanent magnet with high residual magnetic flux density was used to increase power density

Objectives

- ❖ The totally enclosed type structure of the IPMSM is vulnerable to temperature because heat does not circulate within it, and the neodymium permanent magnet has a property of being demagnetized at high temperature
- ❖ If a power converter breaks down, high current may flow. This high current creates a large reverse magnetic field, and this reverse magnetic field also may generate demagnetization.
- ❖ Therefore, this paper proposes a anaysis method of demagnetization characteristics that considers the recoil line based on FEM.
- ❖ Development of next-generation railway vehicles recently aims at energy saving and weight lightening so that a rare-earth permanent magnet with high energy density is applied to a synchronous motor, and a considerable number of interior permanent magnet synchronous motors which have power density than those of an induction motor, have been developed.

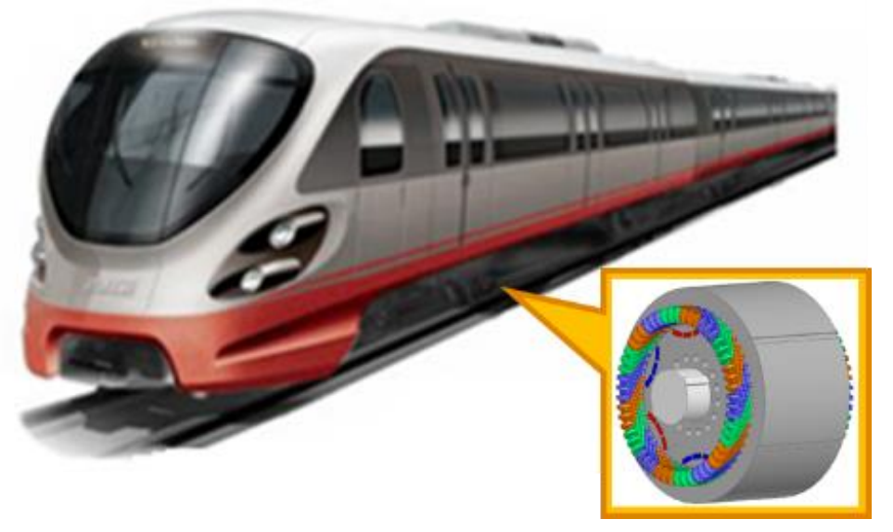
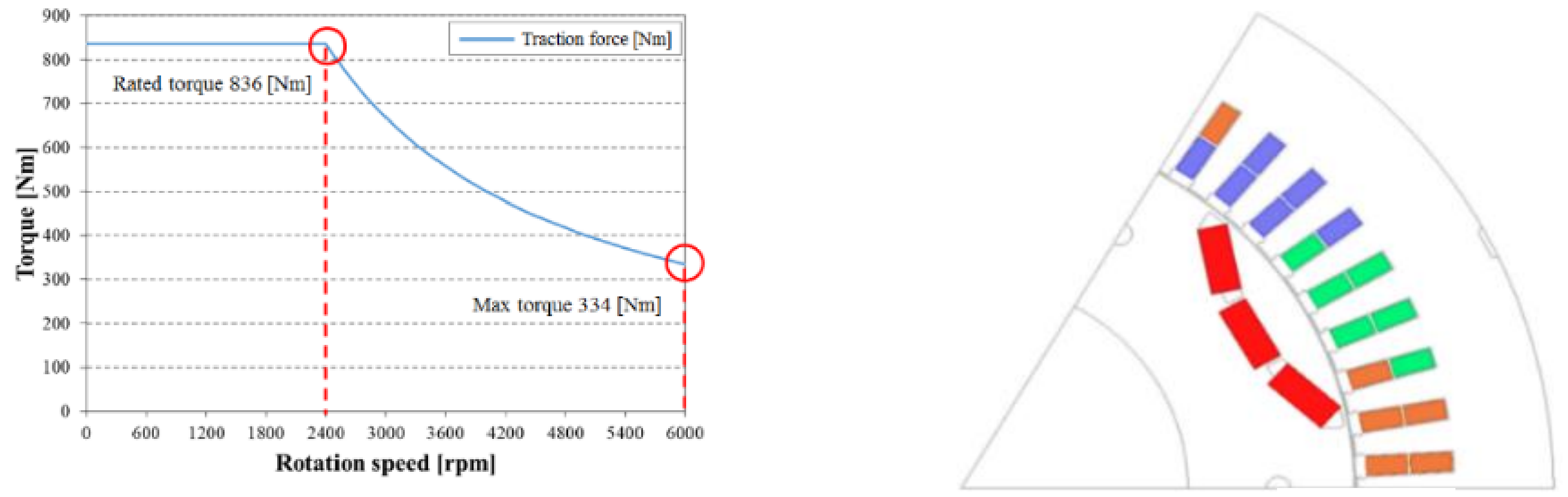


Fig. 1 Railway Vehicle for Application of High Power-Density IPMSM

Conclusion

- ❖ This paper describes a study on an analysis method of demagnetization characteristics of a permanent magnet synchronous motor based on the FEM (finite element method).
- ❖ The totally enclosed type structure of the IPMSM is vulnerable to temperature, and if a power converter breaks down, high current may flow so that it is definitely necessary to consider analysis of the demagnetization characteristic in the design and analysis stage.
- ❖ This paper proposed an analysis method of demagnetization characteristics by considering the recoil line based on FEM.
- ❖ This proposed method quantitatively predicted effects of the demagnetization through the Back electromotive force and magnetic flux distribution, and its reliability was improved by reanalysis after changing material.
- ❖ Validity of the analysis method proposed by the temperature saturation test and the performance test of the prototype was proven, and in conclusion, an analysis method process of the FEM-based demagnetization characteristics was also established.

IPMSM for Traction of Railway Vehicles



(a) (b)

Fig. 2 Torque-speed curve and IPMSM model (a) Required traction force curve per railway vehicle motor (b) IPMSM model for traction of railway vehicles

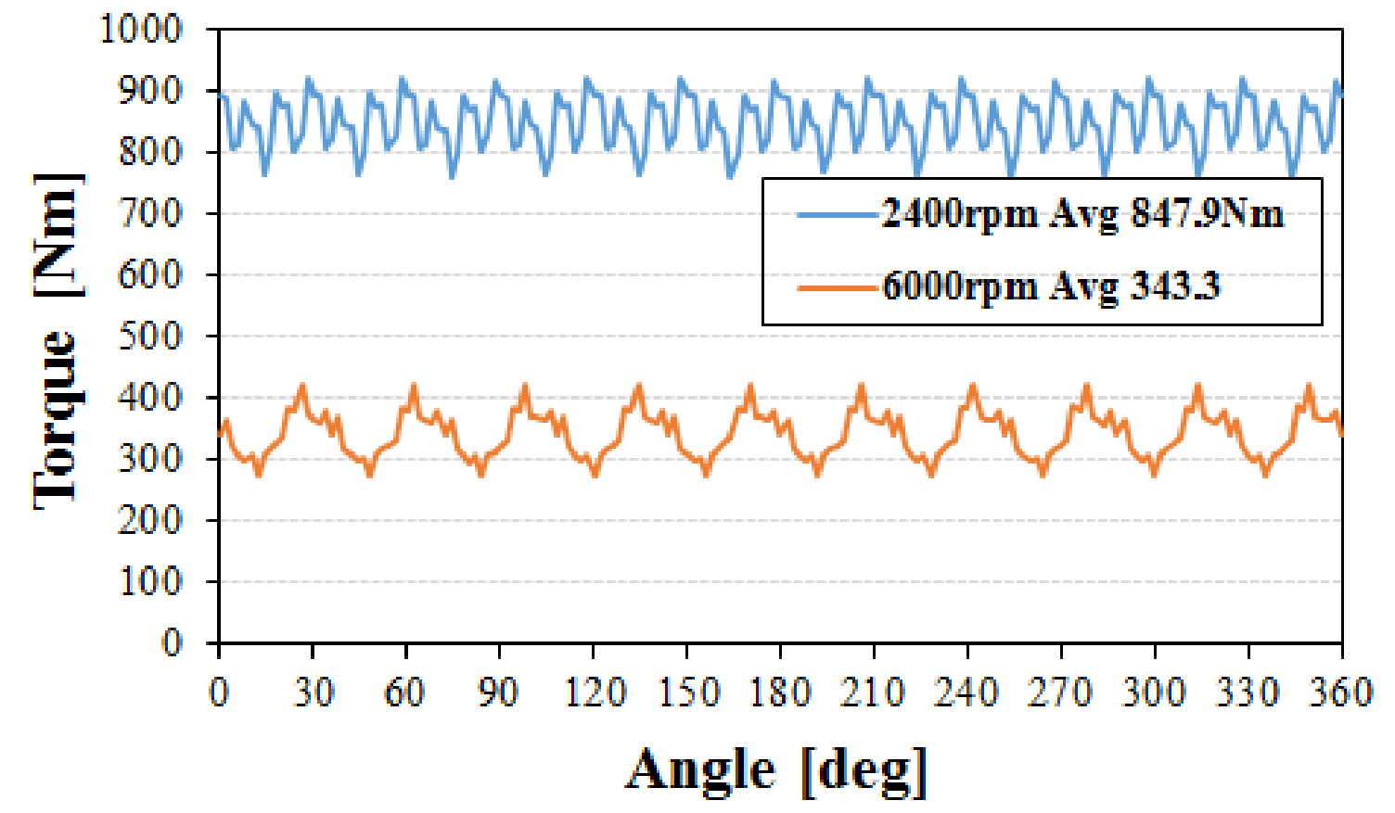


Fig. 3 IPMSM torque waveform for traction of railway vehicles

TABLE Ⅰ Main Characteristics of IPMSM

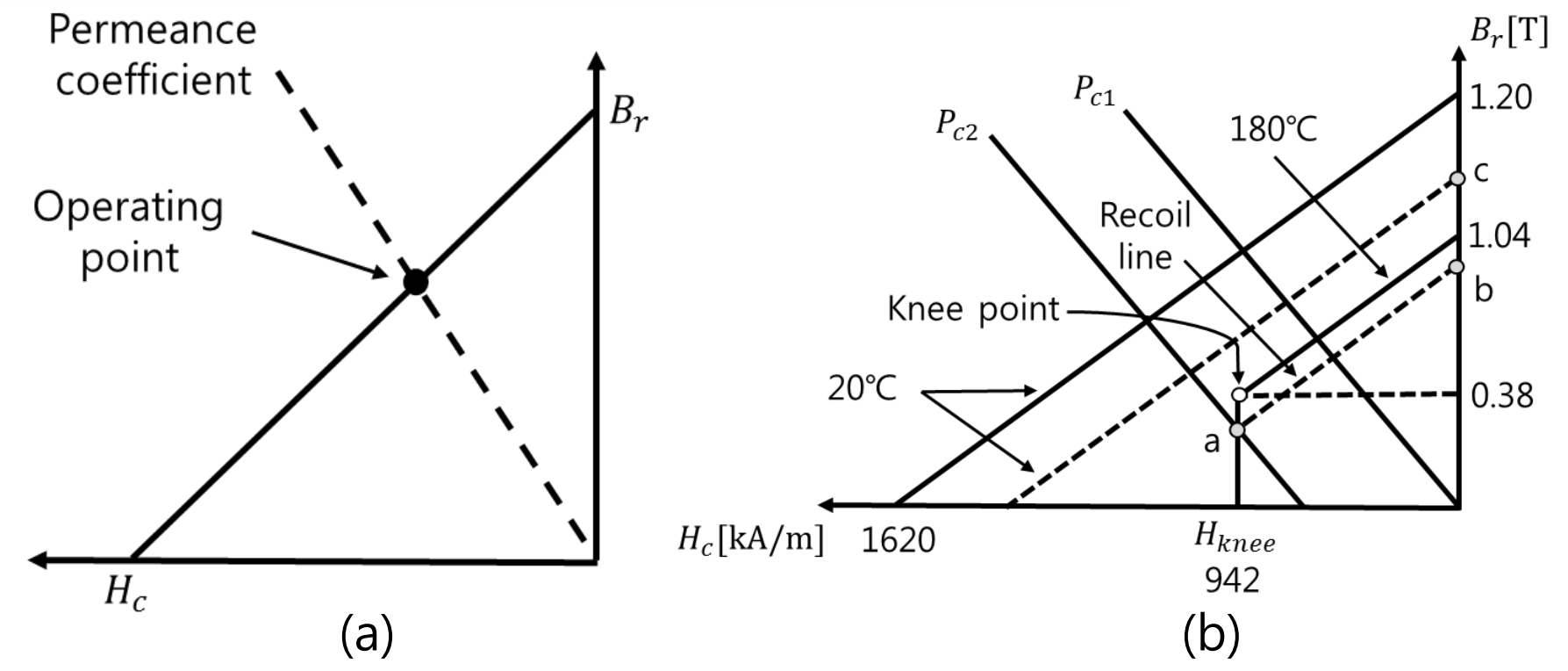
Contents	2400rpm	6000rpm	Unit
Average torque	847.9	343.3	Nm
Torque ripple	85.3	152.8	Nm
Core loss	1603.4	5543.1	W
P.M eddy current loss	73.9	87.7	W
Copper loss	2715.2		W
Output/Weight	0.915(2400rpm)		kW/kg
Efficiency	98	96	%

Analysis Method for FEM-based Demagnetization Characteristics

A. Analysis Method for FEM-based Demagnetization Characteristics

$$P_c = \mu_o \frac{S_g}{S_m} \frac{l_m}{l_g} \quad (1)$$

l_g is the length of the air gap
S_g is the area of the air gap
l_m is the length of the permanent magnet
S_m is the area of the permanent magnet



(a) (b)

Fig. 4 B-H characteristics curve (a) Permeance coefficient and operating point (b) Demagnetization characteristic curves of the neodymium permanent magnet (N38UH), caused by the high temperature and by the reverse magnetic field.

- ☞ As the temperature of the neodymium permanent magnet rises, the residual magnetic flux density B_r and the coercive force H_c drop, and an inflection point called "knee point" is created in the second quadrant that is higher than the characteristic temperature.
- ☞ As the permeance coefficient P_{c1} becomes P_{c2} during load, and the permanent magnet temperature starts to rise from room temperature 20°C to 180°C, demagnetization occurs at a coercive force of 942 kA/m and a magnetic flux density of 0.38T.
- ☞ At this time, as a new recoil line is created from point a to point b, and the residual magnetic flux density is lowered to point c, not to 1.2T even if it returns to the room temperature of 20°C.

B. Permeance Coefficient and B-H demagnetization characteristics

- ☞ The demagnetization analysis is definitely necessary, and the analysis result shows that the phenomenon of being permanently demagnetized by the new recoil line occurs. Therefore, this paper proposes an analysis method of demagnetization characterization that considers the recoil line.
- ☞ The analysis of demagnetization characterization that considers the recoil line shows that as the temperature rises during operation of the motor in Fig. 4, the B-H curve changes and the permeance coefficient changes by the reverse magnetic field during the load.
- ☞ We have constructed the scenario in this paper that the motor is actually operated, and have studied the analysis method of the demagnetization characteristics by considering the recoil line.
- ☞ Scenario: **T1** is the driving section under the **no-load condition**
  T2 is the driving section under the **100% and 200% load condition**
  T3 is the **section that the demagnetized counter** electromotive force is identified after driving **(reverse magnetic field)** under load

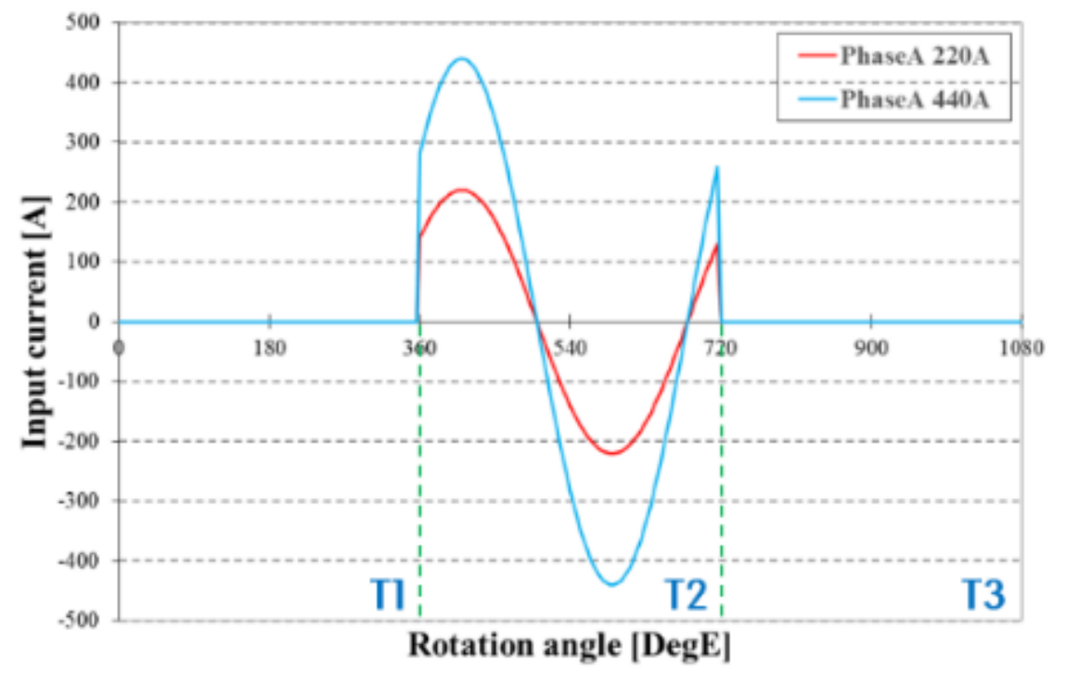


Fig. 5 Current waveform of A-phase

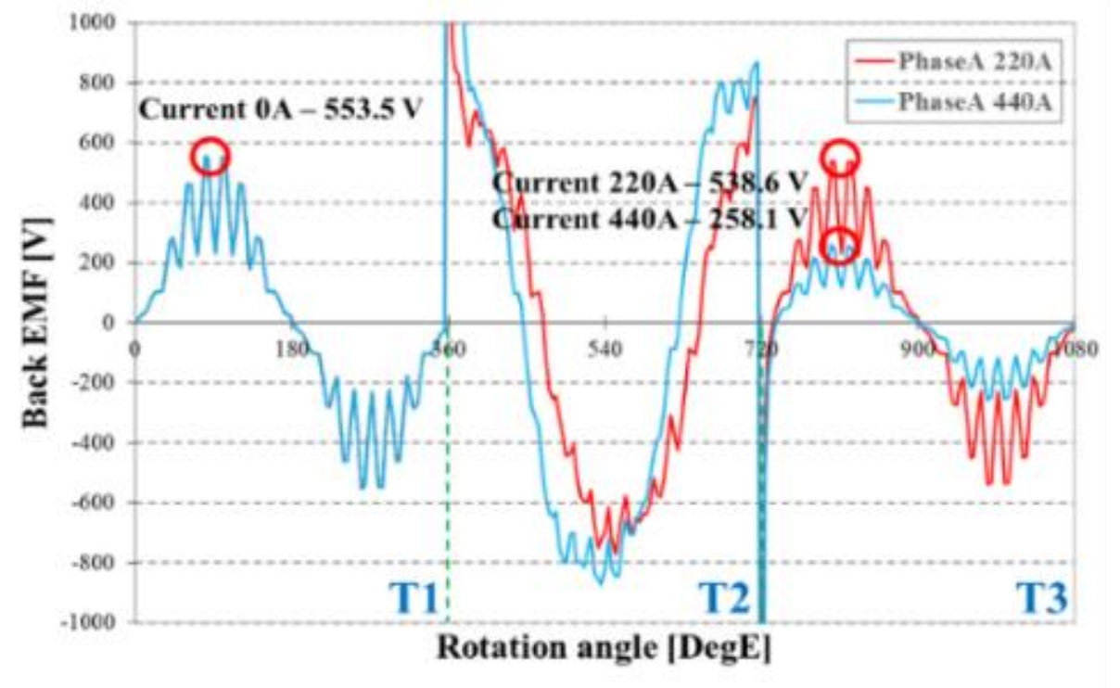


Fig. 6 Demagnetization analysis results of the N38UH (220A, 440A, 180 ℃)

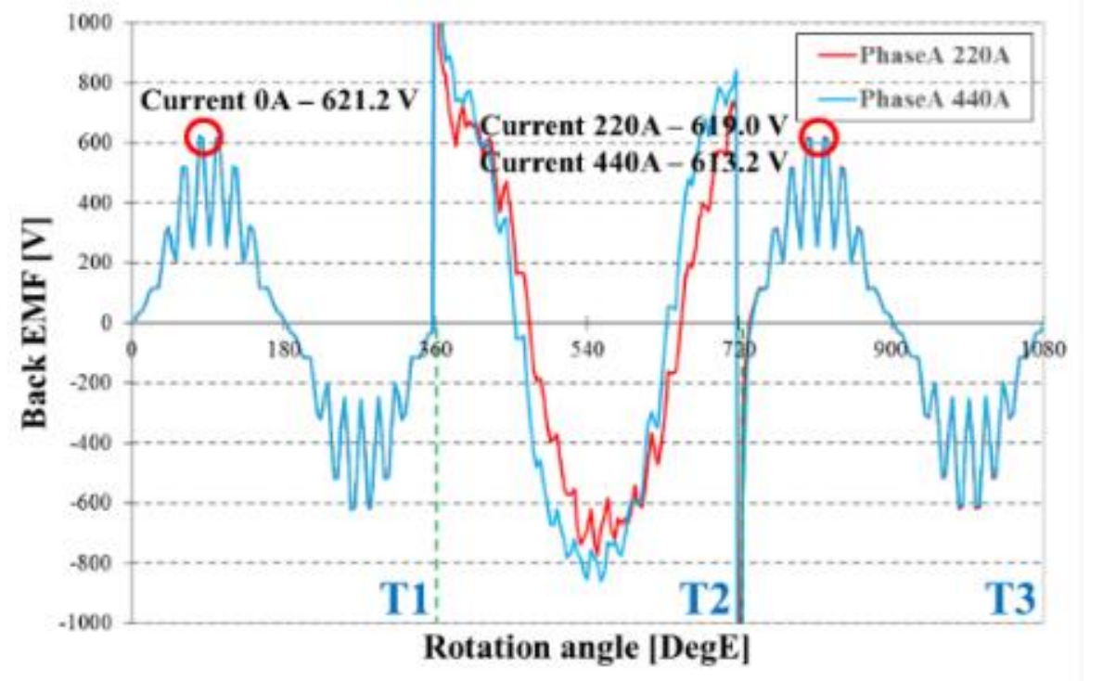
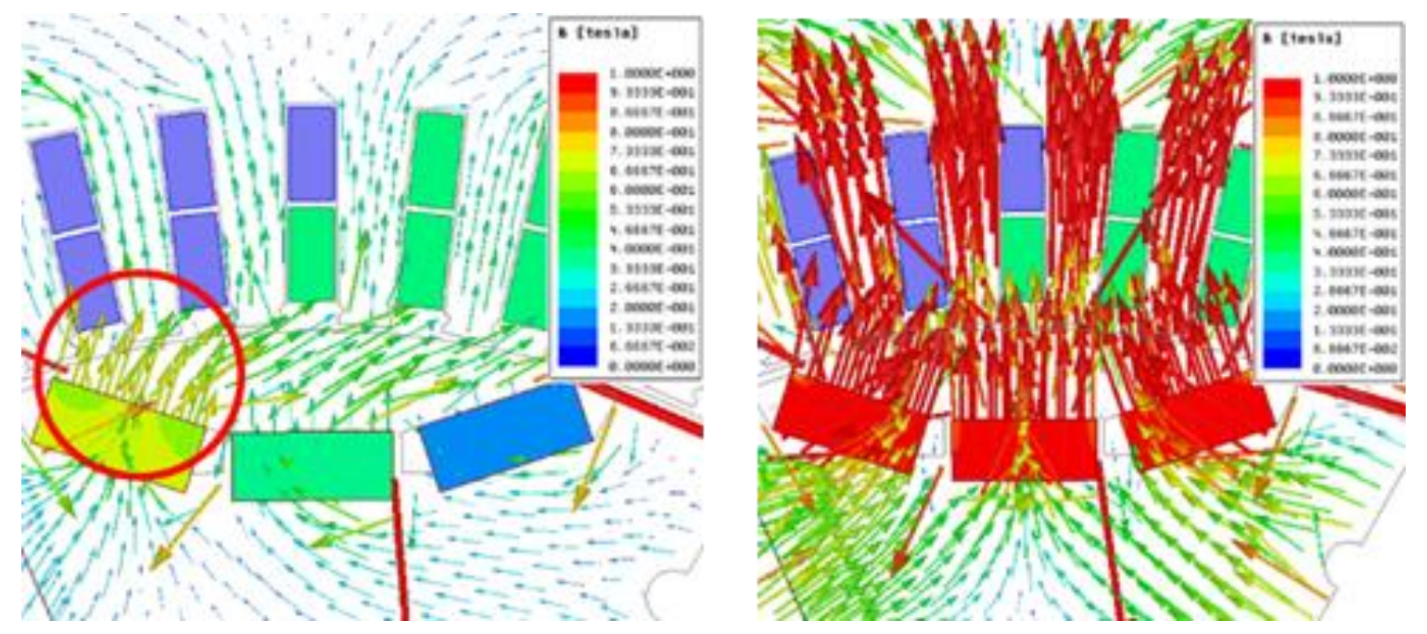


Fig. 7 Demagnetization analysis results of the Sm2Co17 (220A, 440A, 180 ℃)



(a) (b)

Fig. 8 Magnetic flux vector diagram (180 °C, 440A)
(a) N38UH (b) Sm2Co17

TABLE Ⅱ Residual magnetic flux density B_r of N38UH and of Sm2Co17

		20°C	130°C	140°C	150°C
N38UH	B_r	1.190	1.123	1.109	1.093
Sm2Co17		1.148	1.116	1.112	1.109

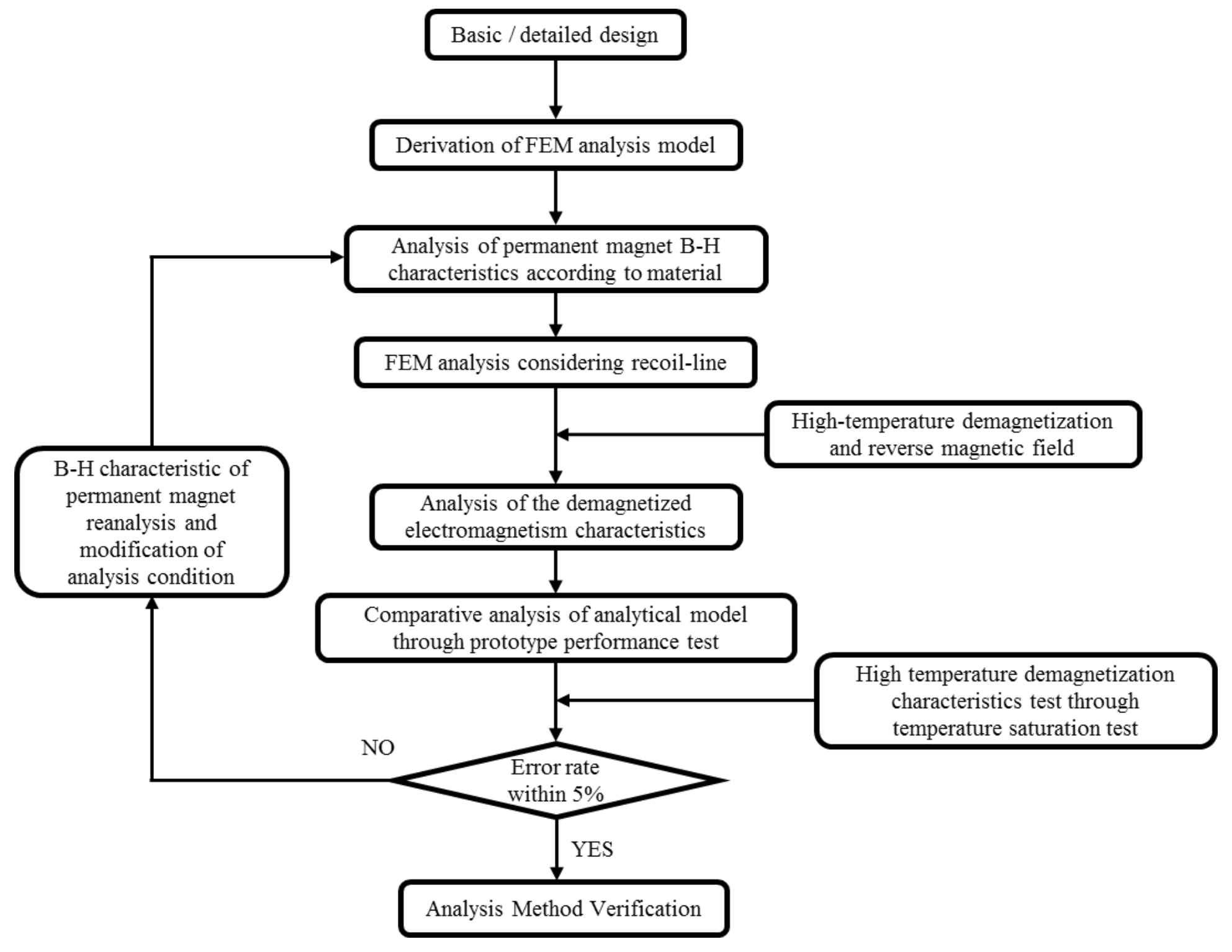


Fig. 9 Process of analysis method of FEM-based demagnetization characteristics

Prototyping and Performance Test

Fig. 10 IPMSM prototype

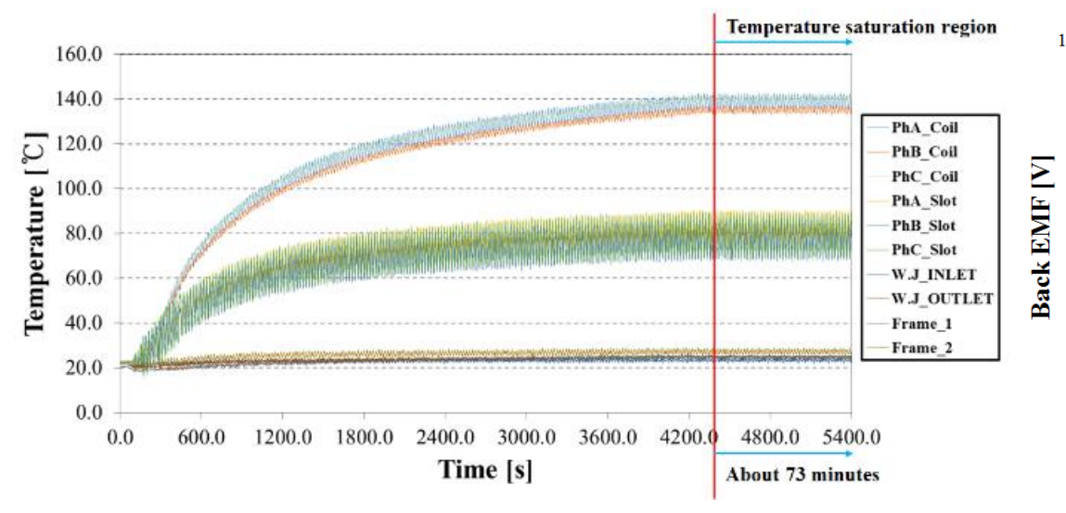


Fig. 11 Temperature saturation curve of IPMSM (@2400rpm)

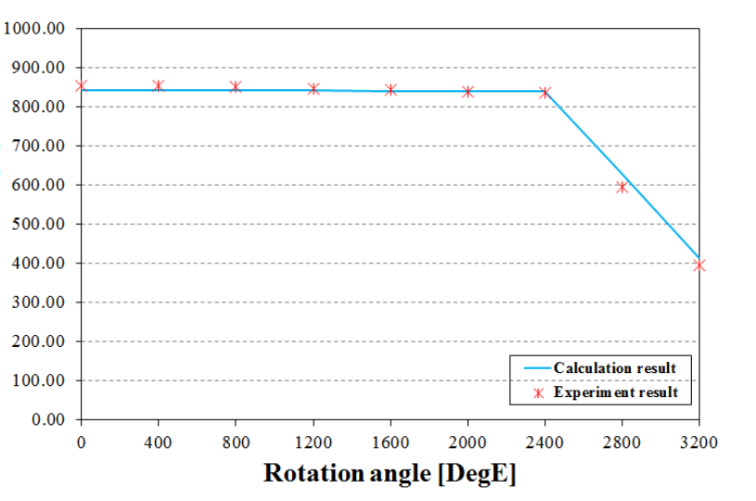


Fig. 12 Torque property comparison of the performance test and analysis results