Residual Magnetic Flux Density Distribution Calculation with Consideration of Aligning Field for Anisotropic Bonded NdFeB Magnets

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This paper presents a residual magnetic flux density (B_r) distribution analysis method for an anisotropic bonded NdFeB permanent magnet (PM) taking into account aligning field during the forming process. To manufacture the anisotropic bonded NdFeB magnet, the magnet powders need to be aligned with proper aligning field before magnetizing. Therefore, it is necessary to analyze B_r distribution with the results of aligning field analysis. In order to estimate the B_r distribution, an analysis method by combining the electric circuit equation coupled with the transient finite element method (FEM) and the scalar Jiles-Atherton (J-A) hysteresis model is proposed.

***Index Terms*— Aligning magnetic field, manufacturing processes, permanent magnet, residual magnetic flux density.**

I. Introduction

THE NdFeB magnet can be classified into sintered and bonded types, according to the manufacturing process, and according to the characteristics of magnet powders, it can be classified into isotropic and anisotropic ones. Among the different types of PMs, the anisotropic bonded NdFeB magnets are more attractive to the low power applications. The main reason is that they have lower cost and higher structure flexibility than the sintered ones. Furthermore, they have relatively higher B_r and maximum magnetic energy product than the conventional isotropic bonded NdFeB magnets [1], [2].

The manufacture of the anisotropic bonded NdFeB magnet requires a proper and enough strong magnetic fields to align the anisotropic magnet powders, and this field is named as aligning field. The aligning field can be either a radial or polar pattern [3], [4]. Following the forming process, the magnet powder, which is uniformly distributed and fixed with resin in the PM, is aligned with the aligning field. Although the magnetic property of the anisotropic bonded NdFeB magnets such as B_r, mainly depends on the orientation ratio of particles decided by the alignment field, there does not exist any general guidance for analysis the anisotropic bonded NdFeB magnet.

In the forgoing researches, there are some contributions that investigate the effect of aligning field for the anisotropic bonded NdFeB magnet. However, in [5], [6], and [7], the authors only explained the effect of aligning field on the magnet itself, the effect on the B_r distribution was not mentioned.

In this paper, a numerical method which combines the FEM is proposed to predict the B_r distribution of the anisotropic bonded NdFeB magnet. Before the magnetizing analysis, the aligning field analysis is carried out and the local magnetic property of PM determined by the aligning field is calculated.

II. Forming Process Analysis of Anisotropic Bonded NdFeB PM with Aligning Field

The improvement of the magnetic properties of the anisotropic bonded NdFeB magnet such as B_r and intrinsic coercive force ($_iH_c$) are strongly dependent on the direction and magnitude of aligning field. Therefore, before the magnetizing process analysis, the aligning field based on magneto-static FEM is analyzed firstly. In this analysis, the PM region is taken as air and the permeability of the region is μ_0.

After the analysis, the B vector in the cavity of the molding tool is determined and based on vectors of aligning field and magnetizing field at the specific element, the effective magnetic flux density component is determined as shown in Fig. 1. The component of B can be calculated as follows:

$$B_{comp} = \vec{B}_{mag} \cdot \vec{d}_{align} \qquad (1)$$

where the B_{comp} and B_{mag} are magnitude of effective component of B and magnetizing field, respectively, and d_{align} is the direction vector of aligning field.

Not only the direction but also the magnitude of aligning field has effect on the magnetic performance of the magnet. Therefore, it is necessary to distinguish the magnetic properties based on the magnitude of aligning field. In this article, 4 different cases are considered, as shown in Fig. 2. For example, for case I, there is the largest aligning field around 2.5 T, so the corresponding measured initial magnetization curve and demagnetization curves are selected and applied. For case IV, in the transition region of PM, the aligning magnetic field is

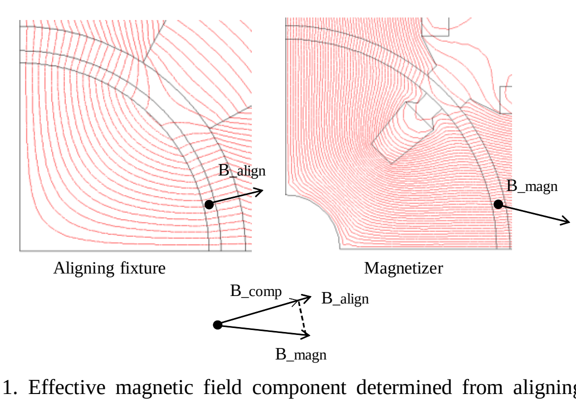

Fig. 1. Effective magnetic field component determined from aligning field and magnetizing field.

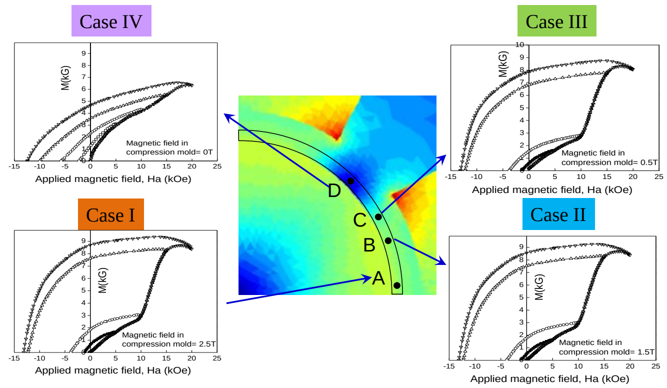

Fig. 2. Selection of initial and hysteresis properties with aligning field.

almost zero, so the initial magnetization curve and demagnetization curves which is measured according to this case, is selected. Apart from case I and IV, the magnetic properties named case II with aligning magnetic field of 0.5 T and case III with aligning field of 1.5 T are also applied. In order to combine the analysis of aligning field and magnetizing analysis, the post process of aligning field analysis is applied.

III. B_r Distribution Calculation Taking into Account Forming Process

After forming process, the prepared magnet is required to be fully magnetized by a considerably strong magnetizing field generated by a magnetizer. The field governing equation and electric circuit equation in the FEM is described in [5].

In order to simplify the analysis process, after achieving the maximum B for each element, the magnetization in the PM is assumed to increase or decrease monotonically. The overall algorithm can be summarized as two steps:

Step 1. Analyze magnetization during the ascent stage of magnetic field according to initial magnetization curves;

Step 2. After achieving maximum B in Step 1, the magnetization is calculated from the hysteresis loops modeled by the J-A hysteresis model.

The magnetizing process is analyzed step by step until the discharge current decreasing to zero, then the magnetization of PM is recorded and treated as residual magnetization of PM (M_r). The M_r saved in each element of PM can be used to the following numerical analysis.

In order to analyze the magnetizing process of the magnet, the magnetization needs to be estimated for each time step.

At the beginning, the magnetization is determined by initial magnetization curves based on magnitude of aligning field. According to the level of aligning field in the specific element, the magnetization is calculated by linear interpolation or extrapolation of measured curves.

After achieving the maximum value of B for each element in PM, the magnetization is determined from hysteresis loops which are modeled by J-A hysteresis model.

Due to the effect of aligning field during the molding process, the hysteresis characteristics need to be modeled according to the different values.

IV. Numerical Results

In order to validate the analyzed B_r value, experimental equipment, which consists of magnetized ring magnet and a magnetic back yoke with thickness of 1.5 mm is built. The normal component of the magnetic flux density (B_{nor}) along inner surface of the magnet is measured by Gauss meter. After the magnetizing analysis by using the proposed algorithm, the B_r value in each element of PM is determined and the data is inputted into the analyzed model of experimental equipment.

By applying the FEA for this model the flux line distribution is obtained as shown in Fig. 3. In order to verify the effect of aligning field, the following four analyses are carried out: magnetizing analysis with considering the magnetic properties only when the aligning fields are 0 T, 0.5 T, 1.5 T, and 2.5 T, respectively. Among the four analyses, the influence of aligning field direction is ignored. Fig. 4 shows the distribution of normal component of surface magnetic flux density of PM comparisons between different cases. It is obvious that, the improved algorithm can give better result than other cases.

V. References

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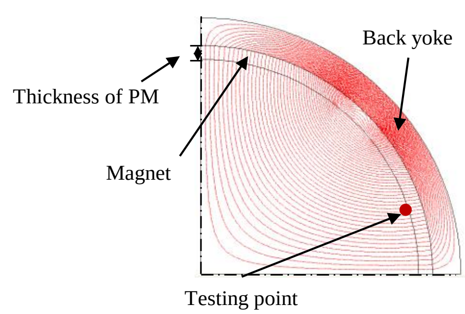

Fig. 3. The flux line distribution of the experimental equipment.

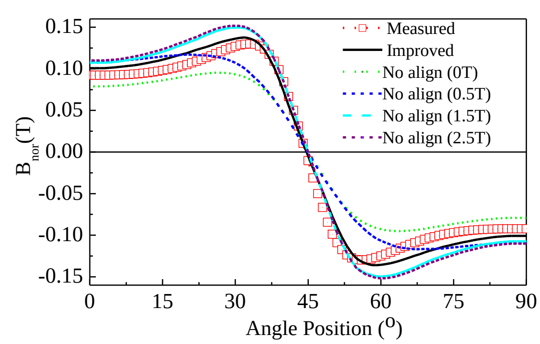

Fig. 4. Normal component of B at the inner surface of magnet with aligning condition of the PM.