Shape Optimal Design of a Powder-Aligning-Fixture of Four-pole Anisotropic Bonded NdFeB Ring Magnet

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***Abstract*—This paper presents a shape optimal design method of molding tool for powder aligning anisotropic bonded NdFeB magnet during molding process of a 4-pole ring type magnet. The residual magnetic flux density of the anisotropic magnet is not only determined by the magnetizing field but also the aligning field. In order to maximize the B_r of PM, the geometry of the mold tool needs to be optimized. During the optimal design process, the B_r can be determined by the transient FEM combined with the J-A hysteresis model with consideration of aligning field.**

***Index Terms*—Anisotropic bonded NdFeB ring magnet, powder alignment fixture, shape optimal design.**

I. Introduction

These days, extensive efforts are contributed to the anisotropic bonded NdFeB magnet. Very recently, new *anisotropic bonded* NdFeB magnets have been developed by using anisotropic NdFeB powders [1].

Nowadays, the commercialized anisotropic NdFeB magnet powder enables to produce residual magnetic flux density to ~1.32T and maximum magnetic energy product of ~304kJ/m^3 [2]. In order to fully utilize the magnetic properties of the magnet powders, however, it is necessary to ensure that the anisotropic powders are fully aligned with the proper orientation during molding process [3]-[5].

Although filling density of the powder, resin compound and temperature of molding tool have influence on magnetic properties of the magnet, the geometry of molding tool has significant affect on the properties because of orientation difference of magnet powder, and magnetizing field depends on geometry of molding tool.

In this paper, we present a systematical optimal algorithm to design a 4-pole powder aligning mold tool by using transient FEM combined with J-A hysteresis model with consideration of alignment field, which is analyzed by various geometry of mold tool. Because of huge computation time of magnetizing analysis (usually ~2hours) the adaptive response surface method with Latin hypercube sampling strategy and Particle swarm optimization algorithm is applied to search global optimal solution.

II. Problem Description

Fig. 1 shows a designed powder aligning fixture, which is composed of a mold tool and a 4-pole electromagnet. The cavity of mold tool consists of an outer nonmagnetic hard alloy ring and inner back yoke made of low carbon steel.

In order to manufacture the 4-pole *anisotropic bonded* NdFeB magnet, firstly, the magnet powder and resin compound are injected into the mold tool cavity. Subsequently, it is compressed into a nearly net shape at 100-150°C under the pressure of 0.4 GPa with radial pattern aligning field generated from the 4-pole electromagnet. Finally, the mold tool and PM are cooled until reaching the room temperature. The magnet powders are uniformly distributed in the permanent magnet with specific orientation.

The magnetic properties of the PM strongly depend on the aligning field due to degree of alignment. In order to demonstrate this phenomenon, some measurement results are shown to confirm. Fig. 2 shows the influence of magnitude of aligning field on magnetic properties of anisotropic magnet. With increasing aligning field, the residual magnetic flux density and maximum magnetic energy product are enhanced, especially at the region of low aligning field. Even though the intrinsic coercive force of the magnet is slightly reduced, it can be said that the increasing aligning field can improve the magnetic properties. Actually, not only the magnitude of aligning field has influence on the magnetic properties but also the angle difference between aligning field and

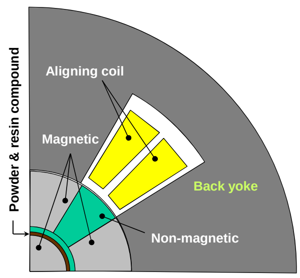

Fig. 1. Powder alignment fixture topology.

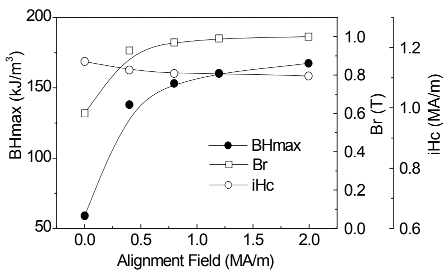

Fig. 2. Magnetic properties of PM with different alignment field.

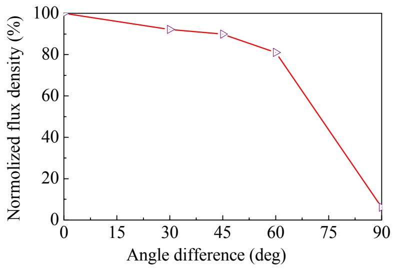

Fig. 3. Normalized magnetization with different magnetization angle against preferred orientation at magnetizing field of 5T.

magnetizing field, as shown in Fig. 3. With the same magnetizing field of ~5T, the residual magnetic flux density decreased with larger angle difference between aligning field and magnetizing field, especially at big angle difference. Fig. 4 shows the structure of the magnetizing fixture to magnetize the prepared magnet. Due to the structure difference of the aligning fixture and the magnetizing fixture, the magnetic field directions during alignment process and magnetizing process are different in region of PM.

In sum, the mold tool needs to be designed to obtain maximum magnitude of aligning field with limited ampere turns of aligning fixture and keep the angle difference between aligning field and magnetizing field at specific position as small as possible.

III. Shape Optimization For Powder Alignment Fixture

Fig. 5 shows mold tool of ring type anisotropic magnet. There are three sector pieces made by magnetic and non magnetic materials to focus the magnetic flux and prevent magnetic flux short circuit. In the figure, there are six dimensions to describe the mold tool. Among them, r_1 and r_2 are fixed because of constant shape of the magnet, and r_4 is also fixed because of fixed dimension of electromagnet. Only r_3, α, and β are selected as design variables, as shown in Table I. In order to verify the effect of r_3 on anisotropic angle, three cases of r3-r2 are selected, as shown in Fig. 6. Moreover, the influence of angle β of mold tool on magnitude and direction of alignment field is also taken into account, as shown in Fig. 7. In order to maximize the B_r in PM, a proper fitness function needs to be defined. The residual flux density vector for each element of magnet can be calculated by previously developed transient FEM combined with the J-A model with consideration of aligning field, in fact, only the radial component of the B_r vector is effective flux. Therefore, the fitness function can be defined as follows:

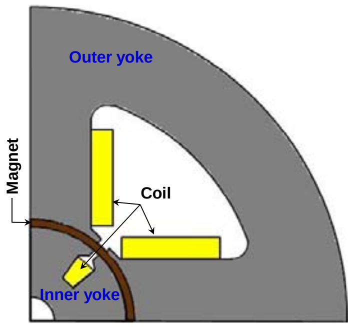

Fig. 4. Magnetizing fixture topology.

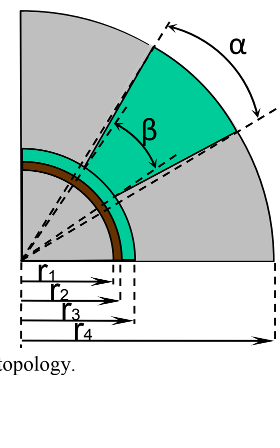

Fig. 5. Molding tool topology.

TABLE I
Design Variables For Molding Tool

Item	r_1 [mm]	r_2 [mm]	r_3 [mm]	r_4 [mm]	α [°]	β [°]
Min	—	—	16	—	25	5
Max	—	—	19	—	35	30
Fixed	14	15	—	55	—	—

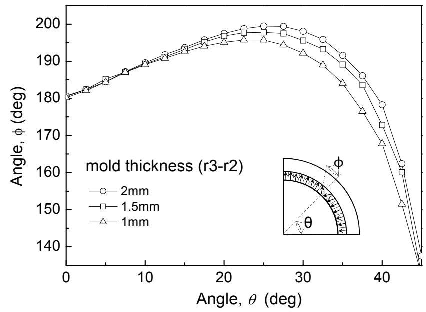

Fig. 6. The influence of mold wall thickness (r3-r2) on alignment direction.

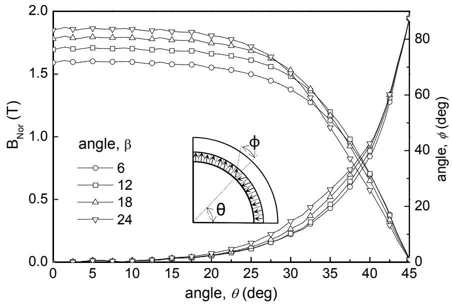

Fig. 7. The influence of angle β of mold tool on magnitude and direction of alignment field.

$$f(\alpha,\beta,r_3)=\frac{1}{N_{ele}}\sum_{i=1}^{N_{ele}}\left|\vec{B}_r^{\,i}\cdot\vec{d}^{\,i}\right| \tag{1}$$

where N_{ele} is the number of the element, which belongs to PM, $\boldsymbol{B_r^i}$, and $\boldsymbol{d^i}$ are residual magnetic flux density vector and normal vector for the *ith* element, respectively.

In the version of full paper, the optimization procedure will be explained in more detail, and the optimized design of mold tool will be applied to obtain maximum B_r.

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