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Magnetizing technique for permanent magnets by intense static fields generated by HTS bulk magnets: Numerical Analysis

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Abstract

A demagnetized Nd-Fe-B permanent magnet was scanned in the strong magnetic field space just above the magnetic pole containing a HTS bulk magnet which generates the magnetic field 3.4 T. The magnet sample was subsequently found to be fully magnetized in the open space of the static magnetic fields. The finite element method was carried out for the static field magnetization of a permanent magnet using a HTS bulk magnet. Previously, our research group experimentally demonstrated the possibility of full magnetization of rare earth permanent magnets with high-performance magnetic properties with use of the static field of HTS bulk magnets. In the present study, however, we succeeded for the first time in visualizing the behavior of the magnetizing field of the bulk magnet during the magnetization process and the shape of the magnetic field inside the body being magnetized. By applying this kind of numerical analysis to the magnetization for planned motor rotors which incorporate rare-earth permanent magnets, we hope to study the fully magnetized regions for the new magnetizing method using bulk magnets and to give motor designing a high degree of freedom.

Keywords: Bulk magnet; HTS; Permanent magnet; Magnetization; Numerical analysis

1. Introduction

In the past, the pulsed magnetization techniques by electromagnets have been mainly used to magnetize the permanent magnets. Heat generation by continuous magnetic pulse applications results in low production efficiency and safe operations as well as restricting the free designing for electromagnetic devices such as motors or generators. As we know, since it is difficult to generate the magnetic field more than 2 T by means of iron pole pieces coupled with normal pulse coils, we would expect to introduce a novel method to magnetize the rare earth permanent magnets like Nd-Fe-B. As we know, the melt-processed REBa\textsubscript{2}Cu\textsubscript{3}O\textsubscript{y} (RE=Y, Sm, Gd, Dy, Eu; abbreviated as RE123) bulk materials containing RE\textsubscript{2}BaCuO\textsubscript{5} (RE211) fine particles act as quasi permanent magnets when they trap the applied magnetic field \cite{1, 2}. The performances of trapped fields of the superconducting bulk magnets have been greatly improved by fabricating large and homogeneous material, which exhibit what we call single domain distributions in the magnetic field mapping \cite{3}. The developments on the production processes have led stable supply of bulk materials in the commercial market.

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In the former experiments, it has been reported that the permanent magnet composed of Nd-Fe-B was uniformly and fully magnetized when the magnetic pole scanned just above the magnet sample to give its intense field more than 3 T.[4, 5] An example of former magnetization experiments is shown in Fig. 1. As the attempt was conducted as preliminary tests, they have found that the permanent magnets are fully magnetized by the static field of HTS bulk magnets when the iterative pitch of scanning was adjusted to be 10 mm, as shown in Fig. 1(b). It is also important to note that the distribution is fairly smooth without any signature due to the 10 mm pitch scanning of the Nd-Fe-B plate along the direction perpendicular to the y-axis.

In this study, the finite element method was carried out for the static field magnetization of a permanent magnet using a HTS bulk magnet. We succeeded for the first time in visualizing the behavior of the magnetizing field of the bulk magnet during the magnetization process and the shape of the magnetic field inside the body magnetized.

2. Experimental procedure and conditions

2.1. Superconducting bulk magnet and magnetic field distribution

A Gd123 bulk magnet (Nippon Steel Co.) with a diameter of 60 mm and a thickness of 15 mm was used in the magnetization experiment. The bulk magnet was reinforced by fitting a stainless steel ring around it in order to withstand heating/cooling and the stress resulting from magnetic field trapping, and it was fixed in the freezing section of a compact Gifford-McMahon (GM) cryocooler (AISIN SEIKI Co., GR101). The distance between the bulk magnet surface and the magnetic pole surface is designed to be 3 mm. Although the magnetic poles are settled face-to-face with a pair of magnetic poles, we deal with the N pole in this experiment. The appearance is shown in Fig. 2(a), and the magnetic field distribution at the surface of the magnetic pole is shown in Fig. 2(b). Helium gas is intermittently supplied from the compressor to the cryocooler and the magnetic pole on the frame of the cooler. The temperature is adjusted by the temperature controller shown in the right-hand side at the bottom of the photograph.

In the excitation process, the field cooling method was carried out [6]. The cooled section with the magnetic pole was removed from the frame and the magnetic pole was inserted into the room-temperature bore of a superconducting solenoid magnet (JASTEC) and the cooled to 31.7 K in the magnetic field of 5 T in order to trap the magnetic field. The strength and distribution of the magnetic field were measured by scanning a Hall element (F. W. Bell, BHT920)
in contact with the surface of the magnetic pole. The maximum value of the magnetic field was 3.27 T at the center of the magnetic pole. As is clear in Fig. 2(b), we see the flat distribution of the trapped field near the peak. This shows that the magnetic field distribution at the bulk magnet surface is trapezoidal and that the 5 T magnetic fields applied during magnetization is lower than the magnetic field of trapping ability of the bulk magnet at the temperature.

2.2. Magnetization experiment and measurement procedure

A plate-shaped Nd-Fe-B sample (NEOMAX, HS-47DH) was used as the rare earth magnet material to be magnetized. The shape is 76 × 50 × 5 mm. The preference direction of the magnetocrystalline anisotropy is perpendicular to the magnet surface. Fig. 3 shows a view of the magnetization experiment using the bulk magnet. The permanent magnet material is fixed in a pair of the stainless steel plates shown at the center of the photograph. The plate is scanned in the vertical plane using the upper and lower handles. The magnetic field generated from the surface of the bulk magnet passes through the stainless steel plate and magnetizes the permanent magnet inside. The thickness of the stainless steel plate is 1.25 mm, and the distance between the bulk magnet surface and the permanent magnet surface is 4.25 mm. In this study, the excitation is operated by scanning the magnetic poles in the same plane as the magnetic pole, like a painting walls. The magnetization procedure was carried out once in the central portion (Fig. 4).

The results are shown in Fig. 5.

3. Numerical analysis model

In this study, the commercially-available software J MAG (JSOL) was adopted to conduct a 3-D electromagnetic field analysis of the finite element method. The bulk magnet analysis model (bulk model) used a uniform ring current inside the bulk model to represent the magnetic field trapped by the bulk magnet. This model created a macroscopically equivalent model of the phenomenon in which a magnetic field forms as a result of a superconducting current trapping the penetrating magnetic flux at pinning points in the bulk magnet. Fig. 6 shows a comparison of the
magnetic field distribution perpendicular to the bulk magnet surface and that at the bulk model surface. The values are 3.4 T and 3.6 T, respectively. In both cases, the distribution of magnetic field shows the conical shape, which is a characteristic of the bulk magnets. The magnetic field gradients of the bulk magnet and the bulk model are 0.086 T/mm and 0.096 T/mm, respectively. Next, in the permanent magnet analysis model (magnet model), measured values for the magnetization ratio, The initial magnetization curve, The maximum coercivity, and preferred direction of magnetization of the rare earth magnet (NMX-S49CH, Hitachi Metals) are given as the material characteristics, respectively. Fig. 7 shows the trapped field distributions of the permanent magnet exposed to a magnetic field of 5 T and the analysis model with the magnetization ratio set at 100%. It is possible to confirm that in both cases, a magnetic field that is strong at the edges is formed and that the area near the center is smoothly magnetized.

4. Comparison of experimental and numerical analysis results

Fig. 8 shows a comparison of the magnetic field distribution at the surface of the permanent magnet magnetized by a single central scan and the calculated results given by the numerical analysis. In the fully magnetized region at the center of the scan trajectory, one can see a similar level of magnetic field of 0.12 T which indicates the found and full magnetization. At the edges of the scan trajectory, however, the initial rise is steeper than that of the experimental values. The maximum value is 0.18 T. In the magnet model, the results obtained by the analysis of full magnetization indicated stronger magnetic flux densities at the ends of the magnet compared to the experimental values, what are almost the same as the experimental values at the center. The numerical analysis reproduced the magnetization of the permanent magnet with a fully magnetized region only in the scanned area, which is similar to the experimental results.

5. Conclusions

The finite element method was carried out for the static field magnetization of a permanent magnet using a HTS bulk magnet. Previously, our research group experimentally demonstrated the possibility of full magnetization of rare earth permanent magnets with high-performance magnetic properties with use of the static field of HTS bulk magnets. In the present study, however, we succeeded for the first time in visualizing the behavior of the magnetizing field of the bulk magnet during the magnetization process and the shape of the magnetic field inside the body being magnetized. By applying this kind of numerical analysis to the magnetization for planned motor rotors which incorporate rare-earth permanent magnets, we hope to study the fully magnetized regions for the new magnetizing method using bulk magnets and to give motor designing a high degree of freedom.

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