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THE PERMANENT MAGNETS MAGNETIC CHARACTERISTICS CHANGE UNDER EFFECT OF 10 MEV ELECTRON BEAM

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Abstract

Nd-Fe-B and Sm-Co magnets were irradiated by electron beam with the energy of 10 MeV and bremsstrahlung. The absorbed dose was 16 and 160 Grad. It was found that whereas magnetic flux of Nd-Fe-B magnets decrease with the irradiation, Sm-Co magnets keep magnetic performance.

INTRODUCTIONS

Rare-earth permanent magnets are key components of modern electron accelerators. High-performance Nd-Fe-B and Sm-Co magnets allow designing quite compact magnetic devices such as dipole magnets, quadrupoles, solenoids and undulators. These devices do not need a power supply and complicated control systems. This approach is especially important for the industrial and technological accelerators.

One of the main issues in the design of accelerators with the permanent magnet is the right choice of magnetic material. The magnetic material should possess high magnetic properties at elevated temperature and withstand electron and photon irradiation.

Recently, the behaviour of Nd-Fe-B and SmCo magnets under 8-10 GeV electron and gamma beams was studied [1-15]. Although such data may provide a useful information about high energy treatment of rare-earth magnets, the mid energy range of energy loads still requires particular investigations.

The aim of the present work is to study the influence of 10 MeV electron beam and bremsstrahlung on the magnetic properties of Nd-Fe-B and Sm-Co magnets.

EXPERIMENT CONDITIONS

Nd-Fe-B and Sm-Co magnets were manufactured by powder metallurgy technology. Magnets were magnetized to the technical saturation in the pulsed magnetic field of 3.5 T. The size of the rectangular samples was 30×24×12 mm. Nd-Fe-B magnets were covered with Ni coating to avoid oxidation. The thickness of the Ni coating was 0.02 mm. Magnetic properties of Nd-Fe-B and Sm-Co magnets are shown in Table 1.

Table 1: Magnetic Properties of Nd-Fe-B and Sm-Co magnets

Magnet	Coercitivity Hcj, kA/m	Remanence Br, T
Nd-Fe-B	955	1.25
Sm-Co	1430	1.05

Magnets were irradiated by the electron beam of KUT-1 accelerator [16]. The energy of electron beam was 10 MeV. The accelerator's axis had a vertical arrangement. The electron beam was travelled from top to bottom. Electron beam adjusting by the magnetic field passed to the air through the titanium foil. In the experiment, the South pole of Nd-Fe-B magnets (30×24 mm side) underwent electron irradiation. The deviation of electron beam density was about 10 % above the sample's surface. During the electron irradiation, magnets were cooled by the water. The temperature of the coolant water was not less than 40 ºC.

Four Nd-Fe-B and four Sm-Co magnets were used in experiments. The following designation was used for both types of magnets. Samples 1 and 2 were irradiated continuously for 20 hours. Electron beam went directly to the surface of sample 1. The absorbed dose for the sample 1 was 16 GRad (the total electron flux was of about 1.4×10^{17} electrons/cm^2). Sample 2 was irradiated simultaneously with the sample 1, but sample 2 was set far from the electron beam at the distance of 40 mm. Sample 3 was irradiated for 20 hours with 24 intervals. The total absorbed dose for the sample 3 was 160 GRad. Sample 4 was not irradiated and it was used as the reference simple for the measurements.

The activity of magnets after irradiation was measured by CANBERRA GC1818 spectrometer with semiconducting pure germanium sensor.

The measurements of the normal component of magnetic flux were performed using Hall probe line (HPL). The distance between Hall probes on the HPL was about 6 mm. The sample was passed transversely to the HPL. The initial position of the sample within HLP was fixed by stoppers. Magnets passed over the HPL with the step from 3 to 5 mm. The distance between magnets and HPL was 3.05 mm. The precision is of magnet's position is about 1 micron [15].

The measurements of the normal component of magnetic flux were carried out from both sides (poles) of the samples within longest axis. The relative error of magnetic flux is about 0.01%.

ACTIVITY MEASUREMENTS

In 24 hour after electron irradiation, the spectrums of the sample's gamma radiation were measured. It was revealed that Nd-Fe-B magnets had a small amount of 147Nd unstable isotope. It is the result of 148Nd(γ,n)147Nd reaction with the energy threshold of 7.3 MeV and half lifetime of 10.98 days. The radiation spectrum of SmCo magnets was characterised by the

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153Sm isotope produced by 154Sm(γ,n)153Sm reaction under gamma radiation of electron bremsstrahlung. The isotope half lifetime is 46.284 hours. Thus, the activity of the magnets after the irradiation was within normal range. The latter allows normal operation of the devices with Nd-Fe-B and Sm-Co magnets in accelerators with the energy of 10 MeV.

MAGNETIC MEASUREMENTS ND-FE-B MAGNETS

Figure 1 shows the HPL experimental data for Nd-Fe-B magnet (sample 1) before treatment.

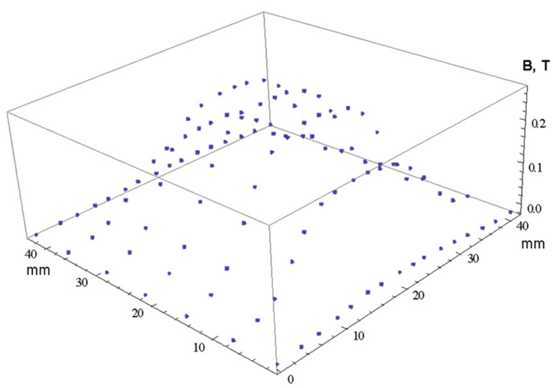

Figure 1: Magnetic field distribution of the Nd-Fe-B magnet (sample 1) before electron irradiation.

3D quadratic interpolation can be used to estimate approximation of magnetic field gradients along the plane of a magnet. It was done using the measured HPL data. The interpolation area was set by the distance between outermost probes of HPL and x-y scanning area. The scanning area was precisely determined by the sample coordinate system. Figure 2 shows the interpolation results for the HPL collected data for sample 1 (Fig. 1).

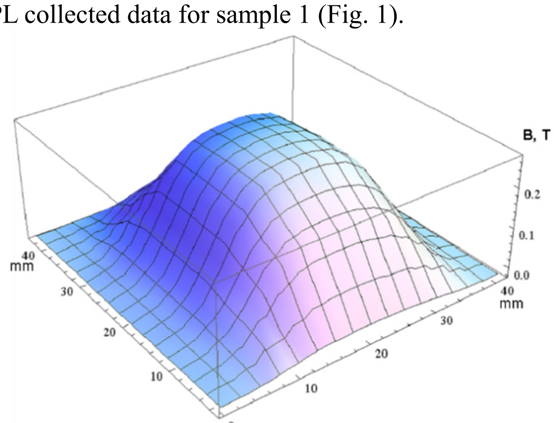

Figure 2: Interpolation of the experimental data for the Nd-Fe-B magnet (sample 1) before irradiation.

In order to estimate the changes in magnetic flux, the integral of the 3D interpolation normal component of magnetic flux was used. Calculated S parameter measured in arbitrary units was chosen as integrated z-component of magnetic flux. The S parameter is calculated within the x-y plane of the magnet. The relative error for S parameter is about 0.5 % within HPL boundaries. The S parameters of Nd-Fe-B magnets before and after the electron irradiation are shown in the Table. 2. S parameter for both poles (South and North) coincided within the experiment accuracy.

Table 2: Magnetic Properties of Nd-Fe-B and Sm-Co Magnets

Nd-Fe-B magnet	Calculated S before electron irradiation	Parameter, a.u. after electron irradiation
Sample 1	175.763 (N)	0.75 in (19 mm)
Sample 2	179.556 (N)	0.75 in (19 mm)
Sample 3	176.357 (N)	0.79 in (20 mm)
Sample 4	175.452 (N)	1.02 in (26 mm)

The interpolation of magnetic field distribution of the sample 1 (North Pole) after electron irradiation is depicted in Fig. 3. One can see that S1 value was decreased to 162.356.

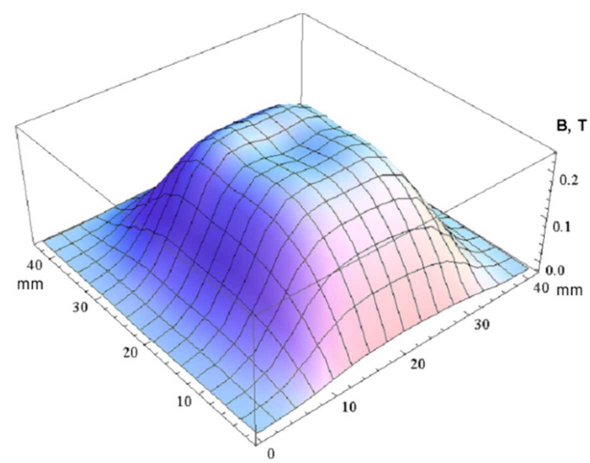

Figure 3: Interpolation of experimental data for Nd-Fe-B (sample 1) after irradiation. The absorbed dose was 16 GRad.

The magnetic field distribution for the sample 2 after bremsstrahlung irradiation is the same as before irradiation and the integral value S2 is 178.526 is practically the same.

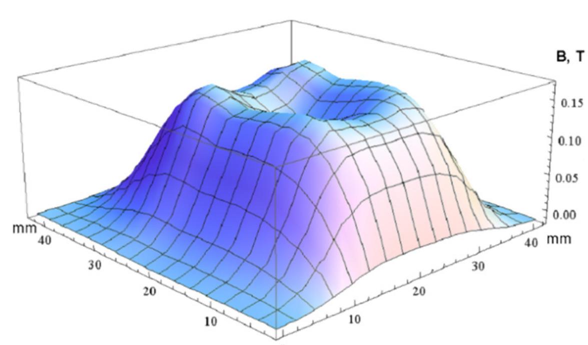

Figure 4: Interpolation of magnetic field distribution after irradiation for the sample 3.

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The essential changes in the magnetic field distribution after irradiation were observed for sample 3 (Fig. 4).The integral value of S3 for the sample 3 was decreased to 126.556. It should be noticed that field integral S decreasing was not proportional to the absorbed dose value.

SM-CO MAGNETS

The similar magnetic measurements were done for SmCo magnets. The S parameters are as following the South Pole for the sample 1 is 151.94, for the sample 2 is 149.007, for the sample 3 is 152.326, for the sample 4 is 152.519. The S parameters of North Pole were the same as for the South Pole within experiment accuracy.

The interpolation of the magnetic field distribution of sample 1 after irradiation is shown in Fig. 5. It was revealed that magnetic field distribution was as before the irradiation.

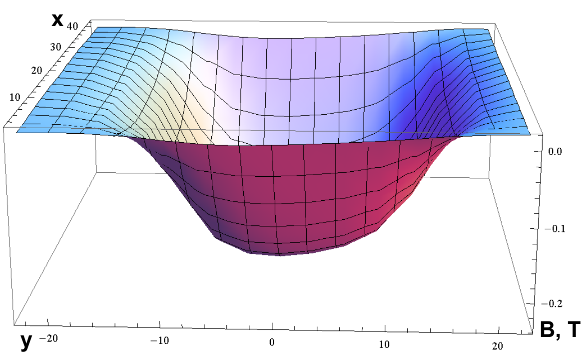

Figure 5: The interpolation of magnetic field distribution for SmCo magnet (sample 1) after irradiation.

The absorbed dose of 160 GRad for the sample 3 did not change the initial magnetic field distribution around the magnet. The S parameter of sample 2 is 148.397 and 149.727, for the sample 3 are 149.714 and 150.065 for the north and south poles respectively.

The magnetic field distributions of reference samples were not changed during experiments.

CONCLUSION

In summary, direct electron irradiation of Nd-Fe-B magnets results in some losses of magnetic flux and change of its distribution. Re-magnetization of Nd-Fe-B magnets after irradiation returns their magnetic properties to the initial values. Bremsstrahlung generated by electron beam does not change the magnetic flux of samples.

SmCo magnets irradiated with absorbed dose up to 160 GRad do not show changes in the magnetic performance.

REFERENCES

[1] S. Okuda, K. Ohashi, and N. Kobayashi, "Effects of electron-beam and y-ray irradiation on the magnetic flux of Nd-Fe-B and Sm-Co permanent magnets", Nucl. Instr. Method, vol. B94, pp. 227-230, 1994.

[2]. H.B. Luna *et al.*, "Bremsstrahlung radiation effects in rare earth permanent magnets", Nucl. Instr. Method, vol. 285(1), pp. 349-354, 1989.

[3] J. Alderman *et al.*, "Measurement of radiation-induced demagnetization of NdFeB permanent magnets", Nucl. Instr. Method, vol. 481(1-3), pp. 1-3, 2002.

[4]. A. N. Dovbnya *et al.*, "Study on radiation resistance of permanent nd-fe-b-base magnets under continuous radiation conditions", Problems of Atomic Science and Technology. Series "Nuclear Physics Investigations", no. 3(34), pp. 48-49, 1999.

[5] T. Bizen *et al.*, "Demagnetization of undulator magnets irradiated high energy electrons", Nucl. Instr. Method, vol. 467, pp. 185-189, 2001.

[6] T. Bizen *et al.*, "High-energy electron irradiation of NdFeB permanent magnets: Dependence of radiation damage on the electron energy", Nucl. Instr. Method, vol. 574(3), pp. 401-406, 2007.

[7] R. Qiu *et al.*, "Radiation damage of Nd2Fe14B permanent magnets at 2.5 GeV electron accelerator", Nucl. Instr. Method, vol. 594(2), pp. 111-118, 2008.

[8]. R. S. Gao *et al.*, "Study of γ -ray irradiation effect on permanent magnets", J. Appl. Phys., vol. 103, pp. 103-105, 2008.

[9] T. Ikeda and S. Okuda, "Magnetic flux loss of the permanent magnets used for the wigglers of FELs by the irradiation with high-energy electrons or X-rays", Nucl. Instr. Method, vol. 407(1-3), pp. 439-442, 1998.

[10] N. Simos *et al.*, "An experimental study of radiation-induced demagnetization of insertion device permanent magnets', in *11th European Particle Accelerator Conf. (EPAC'08)*, Genoa, Italy, Jun. 2008, pp. 2112-2114.

[11] P. Vagin, O. Bilani, A. Schöps, S. Tripathi, T. Vielitz, and M. Tischer, "Radiation damage of undulators at PETRA III", *in Proc. IPAC'14*, Dresden, Germany, Jun. 2014, pp. 2019-2021.

[12] R. Qiu, H-S. Lee, J. Li, T-Y. Koo, T. Bizen, and Q. Fan, "Demagnetization of Nd-Fe-B permanent magnet at 2.5 GeV electron accelerator", Journal of Nuclear Science and Technology, vol. 45, pp. 46-49, 2008.

[13] T. Bizen, Y. Asano, and X.–M. Maréchal, "SPring-8. Irradiation Experiments and Magnet Protection Plans at SPring-8", IEEE Editorial Style Manual, IEEE Periodicals, Piscataway, NJ, USA, Oct. 2014, pp. 34-52.

[14] T. Bizen, "Brief review of the approaches to elucidate the mechanism of the radiation-induced demagnetization", *in Proc. ERL2011*, Tsukuba, Japan, 2011, pp. 121-126.

[15] V. A. Bovda *et al.*, "Magnetic field losses in Nd-Fe-B magnets under 10 MeV electron irradiation", Problems of Atomic Science and Technology. Series "Nuclear Physics Investigations", no. 3(109), pp. 90-94, 2017.

[16] M. I. Ayzatsky *et al.*, "The NSC KIPT electron linacs - R&D", Problems of atomic science and technology. Series "Nuclear Physics Investigations", no. 2(33), pp. 19-25, 2003.