RADIATION INDUCED DEMAGNETIZATION OF PERMANENT MAGNETS UNDER 10 MeV ELECTRON BEAM

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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 magnetic flux of Nd-Fe-B magnets decrease with irradiation, whereas Sm-Co magnets keeps magnetic performance.

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INTRODUCTION

Rare-earth permanent magnets make up the core of modern miniature electron accelerators for industrial and medical applications. High-performance permanent magnets give the unique advantages of compact devices such as dipole and quadruple magnetic systems, solenoids and undulators. Such small foot-print electron accelerators are free of power and/or complex power supply systems for magnetic field generation. However, continuous exposition of permanent magnets to electron and photon radiation requires both theoretical and experimental approach for the optimal magnetic material choice.

Although there is an extensive literature on the radiation-induced magnetic flux losses of Nd-Fe-B and Sm-Co magnets under electron irradiation form 10 MeV to 8 GeV and γ-photons [1 - 15], every magnetic system is made on the ad-hoc base due to the diverse parameters and specific configurations. In this paper, we present experimental study of radiation-induced magnetic flux losses of Nd-Fe-B and Sm-Co magnets under 10 MeV electron irradiation and Bramsturlung.

1. EXPERIMENTAL SETUP

Nd-Fe-B and Sm-Co magnets were produced by powder metallurgy method [16]. The typical size of the magnetic samples was 30×24×12 mm. Nd-Fe-B magnets were Ni-coated to avoid accelerated corrosion. All permanent magnets were magnetized to the technical saturation at the field of 3.5 T. The specific Nd-Fe-B and Sm-Co composition of the permanent magnets used in this experiments had following magnetic properties of H_{cj}=1150 kA/m, Br=1.2 T and H_{cb}=750 kA/m and Br=1.05 T correspondingly.

Permanent magnets underwent electron treatment with the energy of 10 MeV at the KUT-1 technological accelerator [17]. The KUT-1 accelerator has a vertical axis with the top to down beam out-channel. The magnetic field-altered electron beam was extracted through Ti-foil to the air. The blocks of magnets were located to provide direct electron treatment of 30×24 mm plane, which is the south pole of the magnets. The electron beam had energy electron density spread of 10%.

Magnets were cooled to the temperature of T=40°C under irradiation. A total of eight samples (four Nd-Fe-B magnets and four Sm-Co magnets) were used for the measurement of magnetic flux loss. Samples 1-2 were continuously electron treated for 20 hours. The direct electron beam bombarded the surface of sample 1. The absorbed dose and the total electron flux per 1 cm^2 of the sample 1 was 16 grad and $1.4 \cdot 10^{17}$ correspondingly. Sample 2 was located out the direct electron beam within 40 mm from sample 1. Sample 3 was subjected to electron irradiation lasting 20 hours with breaks of 24 hours. Total absorbed dose of this sample was 160 grad. Sample 4 was chosen as reference sample without radiation treatment.

2. MAGNET RADIOACTIVITY

The gamma-ray spectra of the permanent magnets were measured twenty four hours after the irradiation experiment. CANBERRA GC1818 spectrometer, which equipped with high purity germanium semi conducting detector, was used. It should be noted, that activity of exposed magnets changed insignificantly providing safe manipulation with such magnetic devices.

Gamma-ray spectra of Nd-Fe-B magnets revealed the small quantity of unstable 147Nd isotope (T1/2=10.98 days) after the irradation. 174Nd isotope is the result of 148Nd(γ,n)147Nd reaction with threshold of 7.3 MeV.

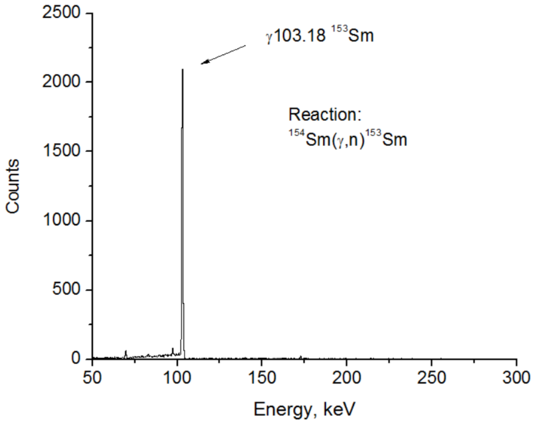

Fig. 1. Typical spectrum of induced radioactivity of Sm-Co magnet 1 after the electron irradiation

Similar measurements were carried out for Sm-Co magnets. Fig. 1 shows gamma-ray spectrum of Sm-Co sample 1 measured for 15 minutes after the electron irradiation. This gamma-ray spectrum is corresponded to the 153Sm isotope (T1/2=46.284 hours) due to 154Sm(γ,n)153Sm reaction. The latter is explained by the exposure to bremsstrahlung. Similar gamma-ray spectra were found for the Sm-Co samples 2-3. It appears that induced radioactivity of exposed Sm-Co sample 2 was five times lower than for irradiated Sm-Co sample 1. Radioactivity of all exposed magnets remained within permissible dose.

3. MAGNETIC MEASUREMENTS

Magnetic flux distribution for magnets was measured by liner with seven Hall probes. The Hall probes were mounted into the copper matrix of the liner to compensate temperature deviation [15]. The distance between Hall probes was about 6 mm. The normal component of magnetic flux was scanned with accuracy about 0.01%. Magnets were moved over and parallel to the liner. The gap between magnetic samples and copper matrix with seven mounted Hall probes was 3.05 mm. The distance between scans point was varied from 3 to 5 mm. The accuracy of scans point was about 1 micron. The initial starting point for all samples was fixed with special stop-bar. Magnets were scanned from both north and south poles.

Figs. 2 and 3 show typical 3-D scan (north pole) and its interpolation for initial Nd-Fe-B magnet 1 before electron treatment.

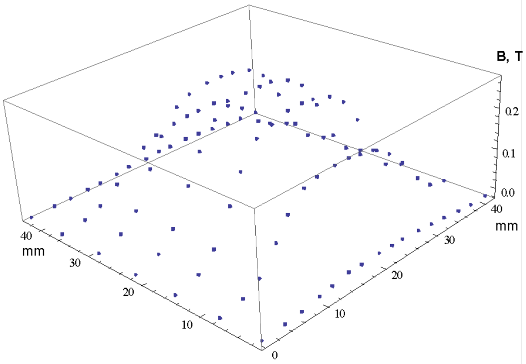

Fig. 2. Typical 3-D scan data of the initial Nd-Fe-B magnet 1 before electron treatment

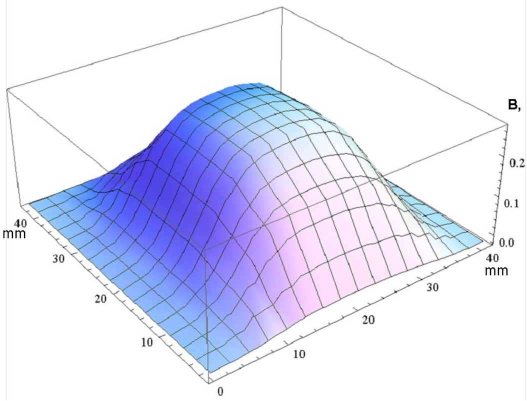

Fig. 3. Interpolation of 3-D scan of initial Nd-Fe-B magnet 1 before electron treatment (hereafter magnetic field distribution)

The area of interpolation was limited by out-to-out distance of Hall probes liner and scanning points along the samples' surface accurately fixed by coordinate system.

Integral of normal component of magnetic flux by scanned area $S=\int B_{norm}ds$ was calculated to estimate magnetic field of the samples in arbitrary units. Repetitive scans and calculated S-parameter for each magnetic sample showed little variation with infinitesimal error of 0.5%.

S-parameters (north pole) for initial non-radiated magnets were as follows: S_1 = 175.763, S_2 = 179.556, S_3 = 176.357 and S_4 = 175.452.

S-parameters for south pole scans were in full agreement with north pole scans within accuracy limits.

Fig. 4 shows the magnetic field distribution of exposed Nd-Fe-B magnet 1. As can be seen, electron irradiation resulted in change of magnetic field distribution of Nd-Fe-B sample 1 and decrease of its S-parameter to 162.356 (north pole).

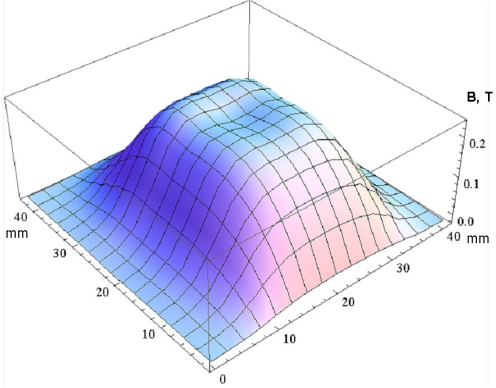

Fig. 4. Magnetic field distribution for Nd-Fe-B sample 1 (north pole) after electron irradiation. Absorbed doze 16 Grad

Magnetic field distribution of south pole of Nd-Fe-B magnet 1 after irradiation is shown in Fig. 5. It can be seen that magnetic field distribution and S parameter for south and north poles (about 160.2) have the similar patterns and value.

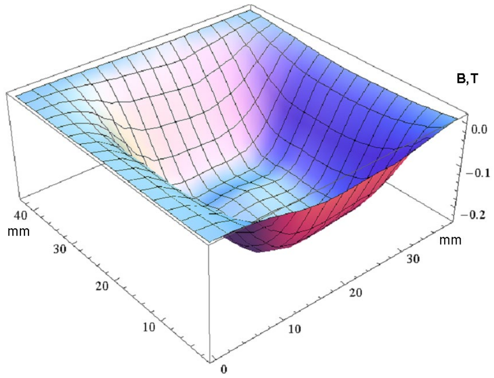

Fig. 5. Magnetic field distribution of Nd-Fe-B sample 1 (south pole) after electron irradiation

Magnetic field distribution of Nd-Fe-B sample 2 (north pole), which was exposed to Bremsstrahlung, is plotted in Fig. 6. It is evident from the Fig. 6 that there was no marked change in both pattern and S_2=178.526.

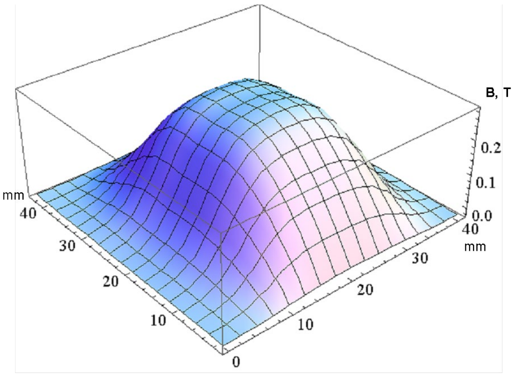

Fig. 6. Magnetic field distribution of Nd-Fe-B sample 2 (north pole) after irradiation (Bremsstrahlung)

Contrary, a considerable drop in S_3 total integral of normal component of magnetic flux up to 126.556 and transformation of the magnetic field shape of Nd-Fe-B sample 3 took place.

Equivalent magnetic measurements after electron irradiation were performed with four Sm-Co magnets. The initial *S* parameters (south pole) of 151.94, 149.007, 152.326 and 152.519 were for Sm-Co magnets 1-4 correspondingly. The values of the magnetic field integral (*S*) from the north pole for all of these samples before irradiation, within the limits of measurement accuracy, coincided with those given above for the south pole. Fig. 7 depicts the magnetic field distribution of initial Sm-Co magnet 1 (south pole).

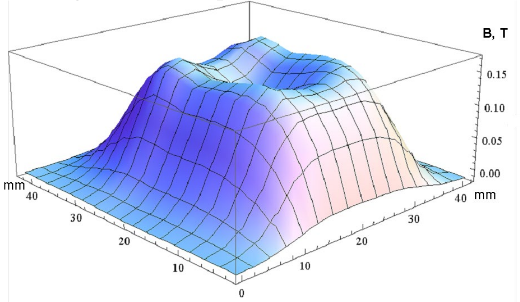

Fig. 7. Magnetic field distribution of Nd-Fe-B sample 3 (north pole) after electron irradiation. Absorbed doze 160 Grad

The magnetic field distribution of other three initial Sm-Co magnets 2-4 was analogous to Fig. 8

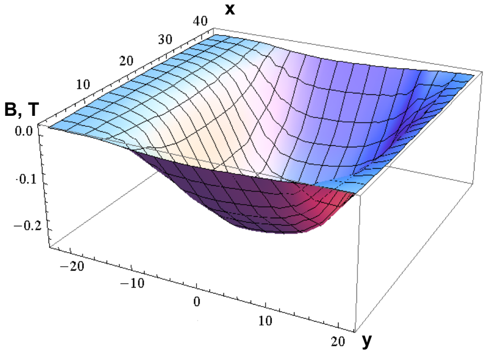

Fig. 8. Magnetic field distribution of initial Sm-Co magnet 1 (south pole)

Results of interpolation of magnetic field distribution of Sm-Co magnet 1 (south pole) after irradiation are shown in Fig. 9.

Calculations revealed S=-150.64 and 153.962 of exposed Sm-Co magnet 1 for south and north poles correspondingly. However, integrals of normal component of magnetic flux of irradiated Sm-Co samples 2-3 (north and south poles) were insignificantly lower S=-148.397, -149.727 and -149.714, -150.065.

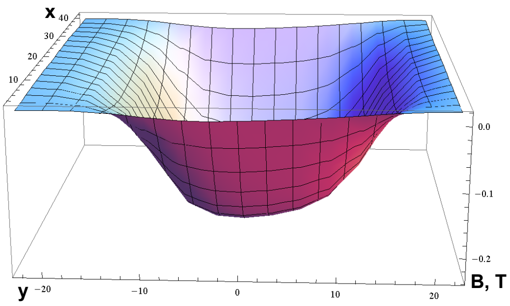

Fig. 9. Magnetic field distribution of Sm-Co magnet 1 (south pole) after irradiation

Magnetic field distribution of Sm-Co sample 3 (south pole) after electron irradiation is depicted in Fig. 10.

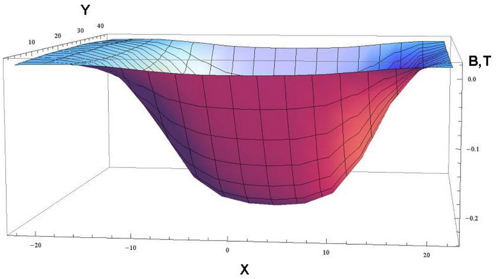

Fig. 10. Magnetic field distribution of Sm-Co sample 3 (south pole) after electron irradiation

It can be seen that radiation dose of 160 Grad did not cause the change of initial magnetic flux. Reference magnetic samples showed full stability of magnetic properties within experimental period.

Magnetic properties of exposed Nd-Fe-B magnets 1 and 3 were totally restored by the remagnetization process. Figs. 11-13 shows the results of magnetic field distribution after the remagnetization.

Magnetic field distribution of exposed Nd-Fe-B magnet 1 (see Fig. 4) was changed after the remagnetization (see Fig. 11) resembling initial non-radiated state (see Fig. 3). Calculated *S* of 175.224 coincided with the original, within the error of the measurement method.

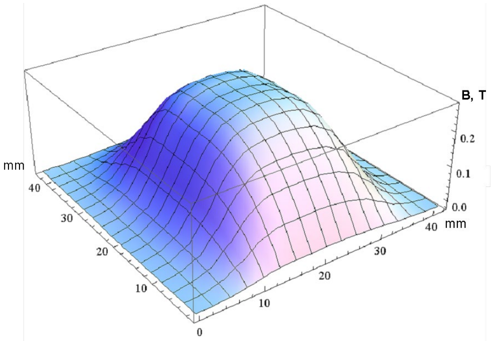

Fig. 11. Magnetic field of exposed Nd-Fe-B magnet 1 after the remagnetization (north pole)

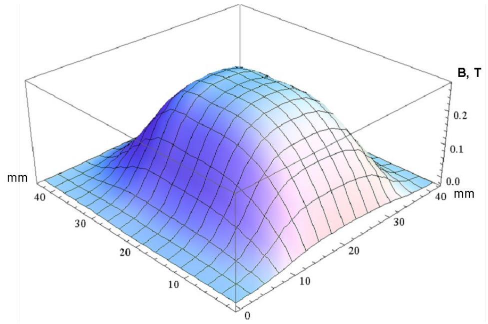

Fig. 12. Magnetic field of exposed Nd-Fe-B magnet 3 after the remagnetization (north pole)

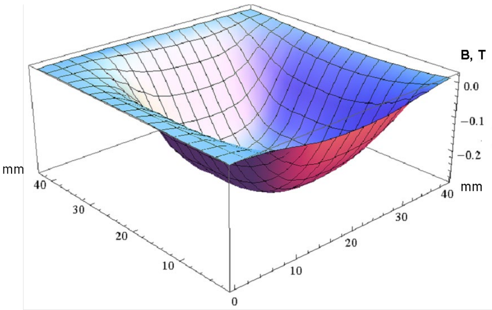

Fig. 13. Magnetic field of exposed Nd-Fe-B magnet 3 after the remagnetization (south pole)

The same effect was observed for the distribution of magnetic field around Nd-Fe-B magnet 3 (see Figs. 12 and 13). The S value for the north pole of the sample was 174.894, and for the south pole –176.78.

CONCLUSIONS

In summary, we examined the effect of 10 MeV electron beam irradiation on Nd-Fe-B magnets. It was found that decrement of magnetic flux of Nd-Fe-B magnets depended on radiation dose. However, magnetic properties of exposed Nd-Fe-B magnets were totally restored by the remagnetization process. It was shown that Bremsstrahlung had a little effect on magnetic performance of Nd-Fe-B magnets.

The results demonstrates that irradiation of Sm-Co magnets with direct 10 MeV electron beam and bremsstrahlung did not change the magnetic field distribution around the samples under absorbed dose of 16 Grad. Furthermore, a 10-fold increase in the absorbed dose did not lead to a noticeable change in the magnetic properties of Sm-Co magnets.

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ИЗМЕНЕНИЕ ХАРАКТЕРИСТИК ПОСТОЯННЫХ МАГНИТОВ ПОД ВОЗДЕЙСТВИЕМ ЭЛЕКТРОННОГО ПУЧКА С ЭНЕРГИЕЙ 10 МэВ

В.А. Бовда, А.М. Бовда, И.С. Гук, А.Н. Довбня, В.Н. Лященко, А.О. Мыцыков, Л.В. Онищенко, С.С. Кандыбей, О.А. Репихов

Проведено исследование изменения магнитных свойств образцов магнитов из Nd-Fe-B- и Sm-Co-сплавов. Образцы облучались электронным пучком ускорителя с энергией 10 МэВ. Приведены результаты исследования величины поля вокруг образцов для величины поглощённой дозы 16 и 160 Град.

ЗМІНА ХАРАКТЕРИСТИК ПОСТІЙНИХ МАГНІТІВ ПІД ВПЛИВОМ ЕЛЕКТРОННОГО ПУЧКА З ЕНЕРГІЄЮ 10 МеВ

В.О. Бовда, О.М. Бовда, І.С. Гук, А.М. Довбня, В.М. Лященко, А.О. Мициков***, Л.В. Оніщенко, С.С. Кандибей, О.О. Репіхов***

Проведено дослідження зміни магнітних властивостей зразків магнітів з Nd-Fe-B- і Sm-Co-сплавів. Зразки опромінювалися електронним пучком прискорювача з енергією 10 МеВ. Приведено результати дослідження величини поля навколо зразків для величини поглиненої дози 16 і 160 Град.