STUDY ON RADIATION RESISTANCE OF PERMANENT NDFEB-BASE MAGNETS UNDER CONTINUOUS RADIATION CONDITIONS

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The development of present-day technologies and materials for creating permanent magnets (in particular, at NSC KIPT), and increasing demands for devices in which these materials are used for physics and technology of intense (10 to 40 MeV) electron beam forming have motivated the comprehensive study on characteristics of these materials under extreme conditions of their use.

The decisive advantages of permanent-magnet (PM) systems are their small dimensions, the absence of electric power supply, the simplicity of design, the possibility of creating periodic structures directly in the vacuum chamber of the basic facility (e.g., undulators and wigglers in free electron lasers). On the other hand, with the magnetic structure brought closer to a high-power electron beam there arises a danger of radiation action on the magnet material causing changes in its characteristics and even failure. So, concurrent with planned programs performed at newly created and operating today nearly continuously the facilities of the R & D "Accelerator" Complex, experiments are conducted to investigate magnet specimens based on the NdFeB alloy.

The alloys for rare-earth PMs were produced by combined induction smelting of metal components in a crucible and subsequent molding. The 34% Nd-1.1% B-4.9% Fe ingots were manufactured in the induction vacuum furnace with an alundum crucible using the powder mixture Nd-NM3, ferroboron FB20, Fe - EhP335. The pouring was made in such a way as to ensure quick cooling of the melt in order to minimize its oxidation.

After that, the alloy was processed by the conventional powder metallurgy technique; i.e., first it underwent grinding to particles, 400 ... 600 μm in size, and, then, wet milling in alcohol down to < 10 μm particles with the use of a vibratory ball mill. The aim of milling is to produce the particles that can be considered as tiny single crystals which comprise no grain boundaries. In this case, each particle has one axis of easy magnetization and this provides nearly a total particle orientation. On the other hand, the sintering requires that the particle surface be sufficiently large in order to ensure a high rate of the reaction during sintering. The milling is finished after the optimum granulometric composition is attained.

The anisotropic properties of the material produced are formed in the oriented magnetic field following which the powder is compacted in the mold. The direction of pressing is coincident in this case with the direction of magnetization. The press capacity should be sufficient enough for the billet to keep its strength in subsequent operations, but at the same time it should not be too great lest the disorientation of C-axes of powder particles take place. At the end of the compaction cycle, for demagnetization purposes, the field equal in magnitude and opposite in direction as compared to the initial field is applied to the billet.

The compacted material is sintered in vacuum resistance furnaces at a temperature between 1050 and 1100°C. After cooling down, the specimens were selectively examined for their magnetic properties, mass and geometrical shape; then the specimens were subjected to mechanical treatment (abrasion) and were checked for their magnetic properties again. The subsequent two-step heat treatment is carried out at a temperature between 250 and 300°C for 1.5 hour.

The process is completed by grinding the products to obtain the required shapes and dimensions, and also by final magnetization in the ORIENTIR facility (NSC KIPT design), the field intensity being ≥ 3000 kA at $\tau \geq 5$ ms.

The radiation tests of magnet specimens were carried out in the field of bremstrahlung from one of accelerators of the Technological Complex [1]. The upper boundary of energy spectrum from bremsstrahlung photons (E_m) was estimated to be 11 MeV.

The value of dose absorbed in the process of specimen irradiation was measured with the process dosimeter DRD-4/40 detectors mounted directly on the object under irradiation. The specimens were irradiated over certain time periods Δt which correspond to the operation interval of the absorbed dose of the detector (15 ... 35kGy). The dose value in the specimen was calculated by

$$dD/dt = \frac{\mu_M \cdot \rho_d}{\mu_d \cdot \rho_M} \cdot \frac{D_d}{\Delta t},$$

where μ_m, μ_d are the linear energy attenuation coefficients of photons in the specimen material under study and in the detector, respectively, at an effective photon energy $E_{eff} = E_m/2$; ρ_m and ρ_d are the densities of the specimen and the detector; D_d is the dose measured by the detector.

Simultaneously, the electron beam charge ΔQ corresponding to the irradiation time Δt was measured. The ΔQ value was calculated by the method of computer integration of beam current pulse train. As a result, the dose received by specimens during the irradiation run was calculated by

$$D = \frac{\mu_M \cdot \rho_d}{\mu_d \cdot \rho_M} \cdot \frac{D_d}{\Delta Q} \cdot Q \ ,$$

where Q is the beam charge in one irradiation run.

Six rectangular (6×8×16 mm^3) plate-type magnet specimens prepared by the above-described technique were taken for tests in the radiation field. The specimens were numbered 1, 2, ...6, and their opposite planes were arbitrarily called as "top" and "bottom"(see the tables) that corresponded to the magnetic poles N - S. The

direction of the magnetization vector was easily determined with the Hall detector (type Sh1-8 device); the same device was used to measure the magnetization value.

Table 1 characterizes the initial stage of experiments. The upper line gives the initial magnetization values (zero dose); the following three lines correspond to the irradiation doses given on the right.

Table 1

	Specimen number						Dose
	1	2	3	4	5	6	
T	2585	2605	2650	2800	2640	2370	D = 0 (initial magnetization values, Oe)
B	2925	2920	2950	2850	2510	2485	
T	2620	2420	2600	2820	2630	2290	D_1 = 350 Mrad
B	2990	2890	2950	2770	2560	1860	
T	2570	2230	2620	2820	2610	2080	D_2 = 450 Mrad
B	2810	2840	2910	2770	2570	1880	
T	2550	2425	2360	2810	2600	1940	D_3 = 450 Mrad
B	2700	2840	2840	2760	2580	1820	

A cursory analysis of the data has shown that the extreme specimens, i.e., the 1st and the 6th, exhibit most noticeable changes in magnetization. It was assumed that all six specimens “stuck” together into a single packet might screen each other in the radiation field and only the extreme specimens remained unprotected. Besides, this package may display the “effect of contact with a ferromagnetic body” which reduces the PM flux [2].

To minimize the mentioned phenomena in the next series of irradiation runs, the specimens were placed into an aluminum specimen holder, providing their spatial separation and excluding direct contacts.

Table 2.

	Specimen number						Dose
	1	2	3	4	5	6	
T	2420	2400	2480	2750	2510	1630	D_4 = 700 Mrad
B	2640	2835	2820	2720	2580	1740	
T	2560	2470	2550	2870	2550	1450	D_5 = 500 Mrad
B	2210	2880	2900	2750	2610	1720	
T	2545	2160	2485	2790	2500	1310	D_6 = 700 Mrad
B	1930	2830	2880	2690	2540	1660	
T	2210	2310	2420	2720	2370	1280	D_7 = 700 Mrad
B	1850	2740	2810	2620	2390	1425	

The results of the first tests of NdFeB-base PM specimens, the manufacturing process of which has been mastered at NSC KIPT, suggest the following conclusions and recommendations

The initial residual magnetization can reach 3 kOε

Irradiation in the gamma-radiation field to doses of 350 to 700 Mrad at intervals of 2 to 4 weeks leads to a gradual reduction in magnetization with an obvious anisotropy along the technological package of specimens

At a total dose D ≅ 4 Grad the reduction in magnetization can reach about 3% in the middle of the assembly and nearly 45% at its edges.

Improvement and refinement of geometry and technique of irradiation experiment are required

On developing particular PM-based devices, it is recommended that the scale model device should be tested at real radiation conditions in order to predict the final parameters.

REFERENCES

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