Gamma Irradiation Effects on the Magnetic Properties of Hard Ferrites

F. Abbas Pour Khotbehsara, B. Salehpour, A. Kianvash

***Abstract*—**Many industrial materials like magnets need to be tested for the radiation environment expected at linear colliders (LC) where the accelerator and detectors will be subjected to large influences of beta, neutron and gamma's over their life Gamma irradiation of the permanent sample magnets using a ^{60}Co source was investigated up to an absorbed dose of 700Mrad shows a negligible effect on some magnetic properties of Nd-Fe-B. In this work it has been tried to investigate the change of some important properties of Barium hexa ferrite. Results showed little decreases of magnetic properties at doses rang of 0.5 to 2.5 Mrad. But at the gamma irradiation dose up to 10 Mrad it is showed a few increase of properties. Also study of gamma irradiation of Nd-Fe-B showed considerably increase of magnetic properties.

***Keywords*—**Gamma ray irradiation, Hard Ferrite, Magnetic coefficient, Radiation dose.

I. Introduction

PERMANENT magnetic materials, such as ferrites which combining insulating ferromagnetic properties, and very resistant to environment factors, have long usage in advanced scientific and technological investigations. However, a limited amount of work has been done to elucidate the effects of gamma irradiation on the physical properties, such as magnetic properties of ferrites. So, these materials need to be tested for the radiation environment expected at linear colliders (LC) where the accelerator, detectors and nuclear power reactors will be subjected to large fluencies of ionizing radiation such as gamma, beta rays, and some other high energetic particles as neutrons, over their life and physical properties, such as magnetic properties. The change of physical properties of magnetic materials caused by irradiation with energetic particles such neutrons, gammas, beta rays, with different energy and doses have been the subject of several investigations. The results, generally, show the negligible effects of irradiation on magnetic properties of these materials at very high doses [1]-[5]. In this work, the effects of gamma ray irradiation on several important magnetic properties of hexagonal barium ferrite ($BaFe_{12}O_{19}$) and Nd-Fe-B magnets have been studied.

A decrease was observed in main magnetic properties, of $BaFe_{12}O_{19}$ along the low doses 0.5 – 2.5 Mrad, but a partial increment of magnetic coefficients was emerged at doses above 10Mrad. The results of gamma irradiation effects on Nd-Fe-B magnets show partly, a considerable increment in important magnetic properties at low doses.

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II. Experimental Procedure

The $BaFe_{12}O_{19}$Samples were prepared from high purity oxides by using the double sintering ceramic technique. The composition was ground to very fine powders, Fe_2O_3 at 10µm and $BaCo_3$ at 15 µm size using an agate mortar in a rotational cylinder. Then they were presintered at 1200^0Cfor calcination. The mixture prepare with the ratio of Fe_2O_3 / BaCo=6 for a certain while. After that, again the composition was ground within mixing with water. In this stage grain's size was almost 1 µm. the liquid mixture after a stage drying was pressed in the form of tablets which have 17 mm diameter and 3 to 4 mm thickness. During the pressing process, samples were concurrently made as codirected species. These tablets finally sintered almost at 1210^0C. It is considerable that cooling process took place slowly to the room temperature. At last sintered samples under a powerful magnetic field were became permanent magnets. Nd-Fe-B samples were provided with 5 and 12 mm, respectively inner and outer, diameters.

Remanence (Br), maximum energy product ($(BH)_{max}$) and some other magnetic properties of $BaFe_{12}O_{19}$ and Nd-Fe-B samples were measured using a Permeametr. Then they were irradiated by means of an energetic gamma- radiation device, ^{60}Co gamma cell, and model: GC-2200 with average photon energy of 1.22Mev, α =2120.75Ci, D^0=0.47 Gy/s and D=0.40Gy.The maximum exposure time of samples was 65 hours and temperature was constant, 22 ^{0}C, during the irradiation process. By means of changing the irradiation period, we provided different doses for our purpose. For accounting the absorbed dose of each sample, we used the common nuclear experimental methods to compute the linear absorb coefficient of any sample. Based on the common nuclear method, irradiated intensity of gamma rayon the surface of sample, I(x), was registered per 60 S. The primary intensity, I_0, also was registered during this period. Absorption coefficient, μ, was calculated with (1):

$$\mu = \frac{Ln(I_0 / I(x))}{x} \tag{1}$$

where x is thickness of the sample. I(x) is relates it to I_0 via:

$$I = I_0 \exp(-\mu x) \tag{2}$$

where μ and x expectedly are absorption coefficient and thickness of the selected sample.

By means of (3), mass absorption coefficient was calculated:

$$\mu_m = \frac{\mu}{\rho} \tag{3}$$

where ρ is mass density of the selected sample. Mass thickness of the sample was computed through (4):

$$x_m = \frac{m}{A} \tag{4}$$

where A is the area of the sample.

Absorbed dose taken by each sample directly is proportional to the energy and intensity that has been irradiated to it. Because for each sample, the mass, area, and irradiation time were constant. Based on the relations for definition of intensity, (5), and absorbed dose, (6), average absorbed dose for each sample is calculated by (7):

$$D = \frac{E}{m} \tag{5}$$

where m is mass of the sample and E is the absorbed energy taken by:

$$I = \frac{E}{A.t} \tag{6}$$

where E is absorbed energy and t is irradiation time of the sample. A is its area.

$$\overline{D} = (D_0 / 2)(1 + \exp(-\mu_m x_m)) \tag{7}$$

where D_0 is irradiated dose on the surface of the sample. μ_m and x_m expectedly are mass absorption and mass thickness coefficients.

TABLE I
UNITS FOR MAGNETIC AND RADIATION PROPERTIES

Symbol	Quantity	Conversion from Gaussian and CGS EMU to SI [a]
B	magnetic flux density, magnetic induction	1 G → 10^{-4} T = 10^{-4}Wb/m^2
H	magnetic field strength	1 Oe→ $10^3/(4\pi)$ A/m
M	magnetization	1 erg/(G·cm^3) = 1 emu/cm^3 → 10^3 A/m
α	activity	1Ci → 3.7 × 10^{10} nucleon/s
D^0	Dose rate	rad/s → 10^{-2}Gy/s
ρ	mass density	1 g/cm^3→ 10^3 Kg/m^3
m	mass	g →10^{-3} Kg
x	thickness	10^{-1}cm→10^{-3}m
D_0	absorbed dose	rad→10^{-2}Gy
$\overline{D}$	Average absorbed dose	rad→10^{-2}Gy
μ	Liner absorbed coefficient	1/cm→10^2 1/m
μ_m	Mass absorbed coefficient	Cm^2/g →10^{-1}m^2/Kg
X_m	Mass thickness	g/cm^2→10 Kg/m^2

Selected magnetic properties were measured after irradiation at the same condition of the previous method and results were compared. Tables I-IV include some of symbols, physics properties, and irradiation properties about each sample.

III. RESULTS AND DISCUSSION

Figs. 1 (a) and (b) show two different magnetic properties' changes of $BaFe_{12}O_{19}$, solid line, and Nd-Fe-B, dashed line that have exposed with gamma radiation of ^{60}Co. In these figures percentage changes of Remanence (Br) and maximum energy product ($(BH)_{max}$)of $BaFe_{12}O_{19}$ and Nd-Fe-B have been shown via average taken doses, respectively Figs. 1 (a) and (b). For $BaFe_{12}O_{19}$ the exposition with gamma ray in dose rang of 0.5 to 2.5 Mrad results showed more agitations. By increasing the irradiation dose, a negligible positive increase was appeared. However the existence results of previous studies show uncountable effects for doses up to 700 Mrad, it is noticeable that our research chiefly alludes to doses down the 3 Mrad. The intensive changes of magnetic properties of $BaFe_{12}O_{19}$ need more investigation.

The intensive changes of magnetic properties of $BaFe_{12}O_{19}$ need more investigation. This could be explained on the basis that the irradiation of ionizing gamma radiation with the material generally gives rise to the production of lattice defect and then the displacing of atoms from their equilibrium position.

To explain how the effects of high energetic particles on magnetic properties for different kind of radiation, a summary of other investigators has been given in [6]. The abstract of considerations could be knew at displacing of structural ions in the crystal materials and agitation making in the electron's order layers because of irradiated high energy particles and finally the change of spin vectors of them. At the gamma irradiation experiment, it could be consider that the produced electrons of probable pair production or Kampton diffraction due to the high energy photons of gamma ray act as high energetic electrical charged particles and make the agitations of electron's order layer and even displacing of light ions of target sample.

So depend on electrons or positrons made by pair production, with maximum energy up to 220 Kev, and also because of electrons from Kampton effect, displacing of light ions from their equilibrium lattice position is probable. in addition, because of high energy electrons' collisions to the magnetic domains' walls, movement of them and even changing of their size is possible. Based on the all phenomena mentioned above, the changes appealed in magnetic properties of hard ferrite in this work reasonable [7].

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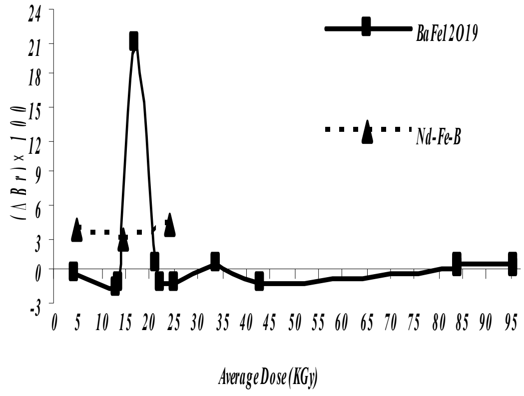
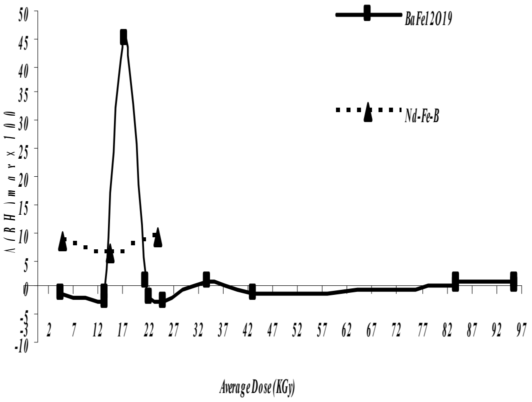


(a)



(b)

Fig. 1 (a) Percentage changes of remanence (Br) (b) percentage changes of maximum energy product ($(BH)_{max}$)

TABLE II
THICKNESS, MASS, DENSITY, AND AREA FOR $BaFe_{12}O_{19}$

Thickness(Cm)	Mass(g)	Density(g/cm^3)	area(cm^2)
0.41	4.39	4.72	2.85
0.44	4.77	4.82	2.41
0.25	2.86	4.85	2.33
0.35	3.73	4.39	2.45
0.43	4.82	4.63	2.43
0.27	2.82	4.86	2.16
0.43	4.53	4.62	2.31
0.44	4.63	4.59	2.28
0.44	4.63	4.59	2.28
0.42	4.39	4.57	2.31
0.43	4.61	4.43	2.41
0.28	2.98	4.85	2.23
0.27	2.88	4.80	2.21

TABLE III
LINER ABSORPTION COEFFICIENT, MASS ABSORPTION COEFFICIENT, AND MASS THICKNESS FOR $BaFe_{12}O_{19}$

Liner absorption coefficient (1/cm)	Mass absorption coefficient(Cm^2/g)	Mass thickness(g/cm^2)	dose
5.44	0.115	1.92	5
5.39	0.111	2.13	15
10.60	0.219	1.23	15
10.70	0.229	1.52	20
8.00	0.173	1.98	25
10.85	0.223	1.30	25
9.38	0.203	1.96	30
8.23	0.179	2.03	40
8.02	0.175	2.03	50
9.40	0.206	1.90	100
8.62	0.194	1.91	100
11.10	0.229	1.34	110
11.30	0.235	1.30	110

APPENDIX

Table IV includes the change of two magnetic properties due to the gamma irradiation exposure mentioned above. Table V includes all information of Nd-Fe-B samples.

TABLE IV
AVERAGE ABSORBED DOSE, PER CENT CHANGE OF REMANENCE, AND PER CENT CHANGE OF MAXIMUM ENERGY PRODUCT FOR $BaFe_{12}O_{19}$

Average absorbed dose (KGy)	per cent change of Remanence	per cent change of maximum energy product
4.5	-0.48	-1.12
13.42	-0.85	-0.94
13.23	-1.45	-2.35
17.06	35	26
21.37	21.21	0
21.85	0.48	1.1
25.1	-1.33	-2.04
33.91	-3.81	-9.34
42.52	0.5	1.22
83.82	0	0
84.50	0.5	1.3
95.50	0.45	1.05
95.54	0	0

TABLE V
THICKNESS, MASS, DENSITY, AREA, ABSORPTION COEFFICIENT, MASS ABSORPTION COEFFICIENT, MASS THICKNESS, DOSE, AVERAGE DOSE, PER CENT CHANGE OF REMANENCE, AND PER CENT CHANGE OF MAXIMUM ENERGY PRODUCT OF ND-FE-B

thickness(Cm)	Mass(g)	Density(g/cm^3)	area(cm^2)
0.13	0.85	7.47	0.87
0.13	0.38	7.47	0.32
0.13	0.85	7.72	0.85
Absorption coefficient(1/cm)	Mass absorption coefficient(cm^2/g)	Mass thickness (g/cm^2)	dose
0.465	0.062	0.97	5
0.775	0.103	1.18	15
0.670	0.086	1.00	25
Average absorbed dose(KGy)	Per cent change of Remanence	Per cent change of Maximum energy product	
4.85	3.78	8.47	
14.13	3.01	5.82	
23.92	3.89	8.77	

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