PERMANENT MAGNET GENERATING HIGH AND VARIABLE SEPTUM MAGNETIC FIELD AND ITS DETERIORATION BY RADIATION

T. Kawakubo, E. Nakamura, M. Numajiri, KEK, Ibaraki, Japan
M. Aoki, T. Hisamura, E. Sugiyama, NEOMAX Co. Ltd., Mishima-gun, Osaka, Japan

Abstract

Conventional high field septum magnet is fed by DC current or pulse current. In the case of DC, the problem of coil support is not very important, but the cooling of the coil is a serious problem. While, in the case of pulse, the problem of support is more important than that of cooling. However, if the septum magnet is made of permanent magnet, these problems are dissolved. And the cost for electricity and cooling water becomes zero. Recently, $Nd_2Fe_{14}B$ sintered magnet which can generate high magnetic field has been developed. Therefore, by using this material, we made a permanent septum magnet which has 1/4 scale of the real size and generates 1 [T] with the variable range of +/- 10%. The magnetic field distribution by changing the representative field in the gap is reported. If this permanent magnet is set in an accelerator, the deterioration of the permanent magnet by radiation will be a serious problem. We also report the dependence of the magnetic field generated by permanent magnet samples on accumulated radiation from various types of radiation source.

CONSTRUCTION OF MAGNET

This magnet is composed of three elements; iron, non-magnetic steel and permanent magnet as shown schematically in Fig. 1. NEOMAX-32EH is used for the permanent magnet because of its high radiation resistance as shown in the following section, and set with various direction of magnetic pole as shown by arrows in Fig. 1. The flatness of the magnetic field in the gap can be obtained by shimming an iron block near the gap, and the strength can be decreased to 80% by removing the outer structure as shown in Fig. 2. The pictures when the outer structure covers the inner structure (septum magnet) fully and removes from it are shown in Fig.3.

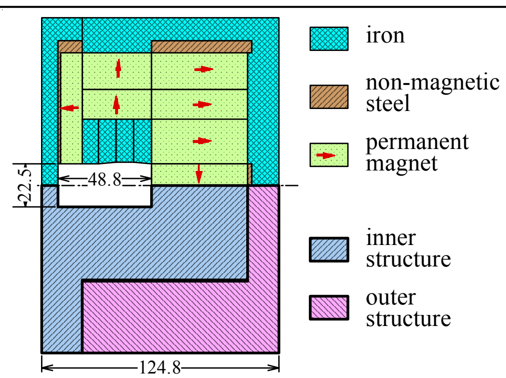

Figure 1: Schematic cross section of permanent septum magnet covered fully by outer structure (unit: mm)

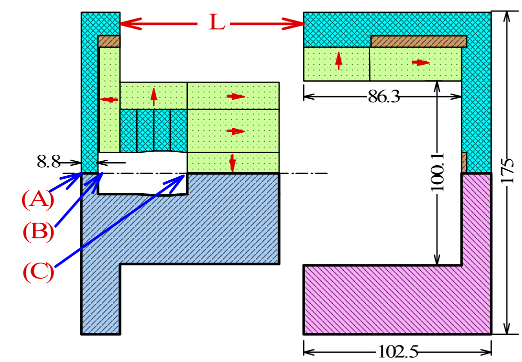

Figure 2: Schematic cross section of permanent septum magnet in the case that outer structure fully removes from the inner structure (unit: mm)

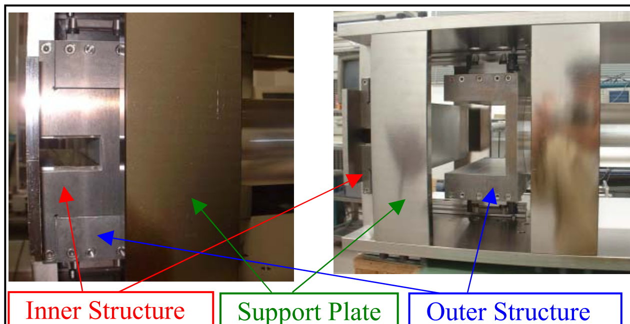

Figure 3: Pictures of permanent septum magnet
Left: Outer structure fully covers inner structure (Fig.1)
Right: Outer structure fully removes from inner structure (Fig.2)

MAGNETIC FIELD

Magnetic field has been obtained not only by measurement but also by calculation by removing the outer structure with three steps. It can be said that the calculations are in good agreement with the measurements. X, Y and Z-axis are defined as horizontal, vertical and longitudinal plane, respectively.

Horizontal distribution (X plane)

- Inside the core gap (at the centre of Y and Z plane) is shown in Fig. 4.
- Leakage field out of the core gap (at the centre of Y and Z plane) is shown in Fig. 5.

The horizontal width having the flat-top within 1% is about 30mm, while the effective thickness of the septum is 30mm. The leakage field is about 0.1% of the gap field.

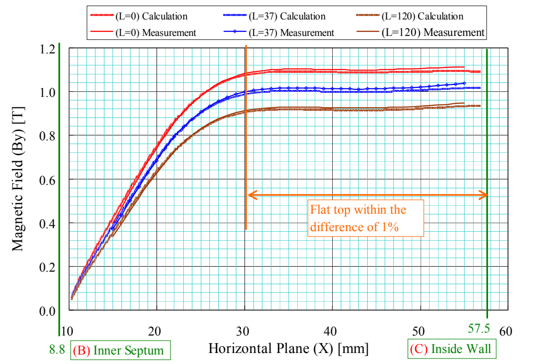

Figure 4: Horizontal magnetic field distribution in the gap (note: (B) and (C) are shown in Fig. 2)

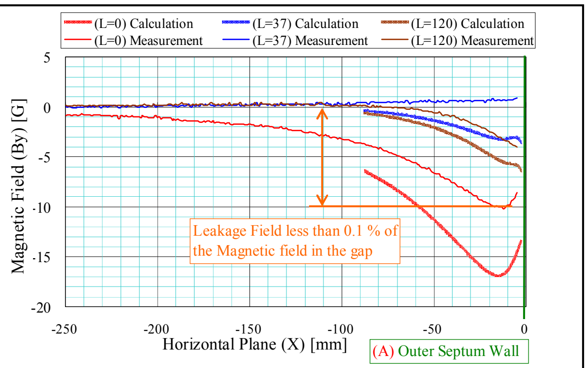

Figure 5: Horizontal leakage field distribution out of septum (note: (A) is shown in Fig. 2)

Longitudinal distribution (Z plane)

Magnetic fields inside the gap along the longitudinal plane (at the centre of X and Y plane) are shown in Fig. 6 by changing L (see Fig. 2). The effective length of the magnet is almost same as the length of the permanent magnet core.

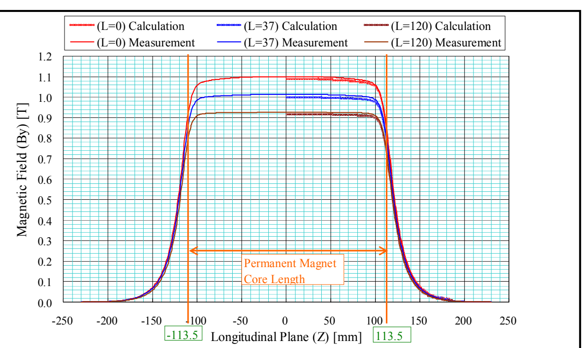

Figure 6: Longitudinal magnetic field distribution in the core gap

DETERIORATON BY RADIATION

Demagnetization

The $Nd_2Fe_{14}B$ sintered magnet can generate high magnetic field, however, there are many reports on its demagnetization by radiation [1]. In order to choose the material which is least affected by radiation, test samples (see Fig. 7) of various types of permanent magnet (see Fig. 8) were irradiated by various radiation sources, and the magnetic field were observed by inserting Hall prove into the gap space.

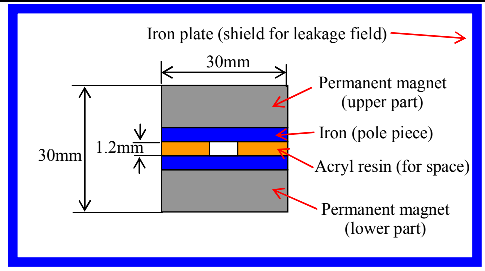

Figure 7: test sample for radiation exposure

Permanent magnet name	Energy product	Residual magnetic flux density	Intrinsic coercive force
	(BH)max.	Br	H_{CJ}
(NEOMAX-)	kJ/m^3	T	MA/m
47	374	1.42	0.88
44H	342	1.33	1.3
39SH	303	1.26	1.7
35EH	279	1.21	2.0
32EH	255	1.15	2.4

Figure 8: Characteristics of permanent magnet

(1) γ-ray source

The test samples were irradiated by γ-ray from ^{60}Co in Japan Atomic Energy Research Institute (JAERI-Takasaki). As shown in Fig. 9, there is no demagnetization in all samples.

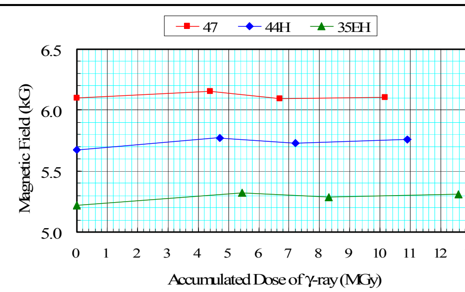

Figure 9: Irradiation by γ-ray source

(2) Pure neutron source

14MeV pure neutrons were used to irradiate the samples in the facility of Fast Neutron Source (FNS) of JAERI-Tokai. The demagnetization of test samples is shown in Fig. 10. The irradiated neutrons were obtained by calculating the solid angle from neutron source.

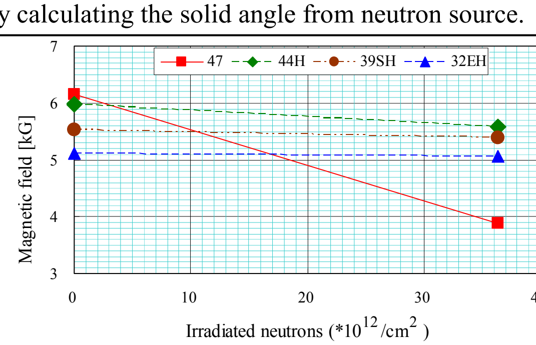

Figure 10: Irradiation by 14 MeV pure neutrons

(3) Radiation caused by beam loss of KEK-PS

Beam loss at the extraction points of KEK-PS 500MeV booster ring and 12GeV main ring mainly generates γ-ray and neutron. Since we know that there is no demagnetization by γ-ray, we only measured the accumulated neutron fluence by using the reaction of $^{27}Al(n, sp)^{22}Na$. In this method, the neutron having the energy less than 20MeV can not be detectable because of small cross section of reaction. Because there is an atmospheric part in the main ring extraction beam line near septum magnet, the beam loss per unit time is about 20 times larger than that of booster extraction. The test samples were set near the extraction place of the booster and main ring, respectively. The demagnetization of both cases is shown in Fig. 11 and Fig. 12, respectively.

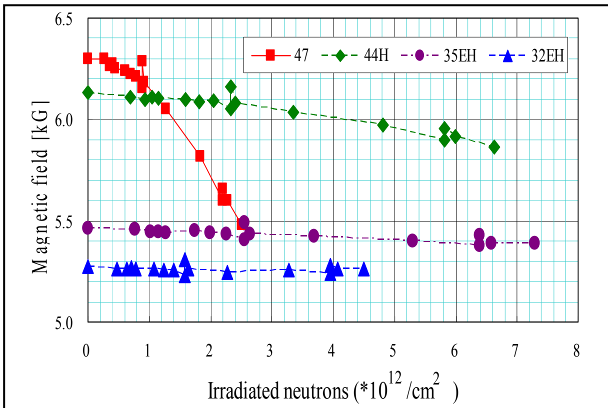

Figure 11: Irradiation by neutrons produced by beam loss at the extraction of KEK-PS-500MeV booster

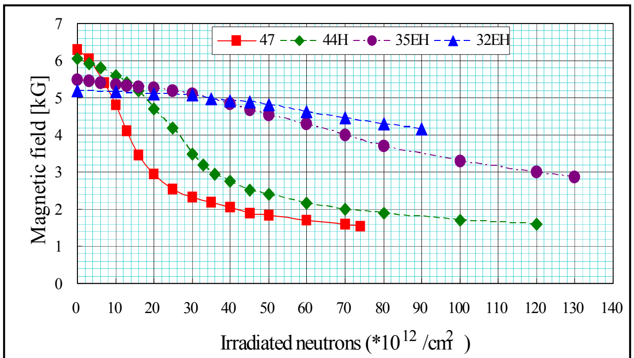

Figure 12: Irradiation by neutrons produced by beam loss at the extraction of KEK-PS-12GeV main ring

(4) Demagnetization vs. intrinsic coercive force

The above measurements show that NEOMAX-32EH has the most radiation hardness. In order combine the date of FNS case and KEK-PS case, the irradiated neutron number measured by $^{27}Al(n, sp)^{22}Na$ reaction should be extended to the neutron number having the energy less than 20MeV. From the neutron spectrum generated by the high energy proton beam loss, the neutron number having the energy larger than 1MeV is estimated to be three times of the number with the energy larger than 20MeV. Therefore, multiplying 3 to the irradiated neutrons in Fig. 11 and 12, demagnetization per ($1*10^{12}$ [neutrons/cm^2]) in Fig. 13 was calculated. As shown in Fig. 13, there is some relationship between demagnetization and intrinsic coercive force.

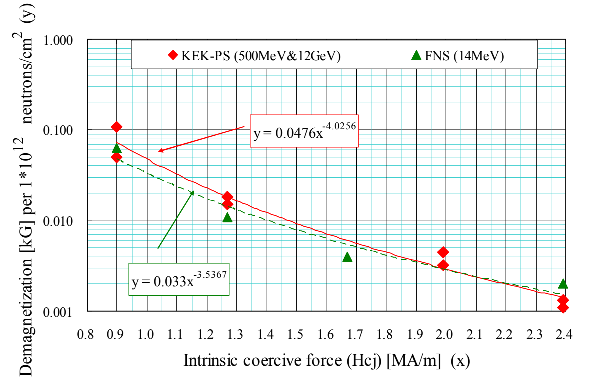

Figure 13: Relationship between demagnetization and intrinsic coercive force

(5) Re-bound of magnetic field

As shown in Fig. 11, some peaks indicate that the re-bound of the magnetic field arises after stopping irradiation in the booster ring, which saturates about two weeks after. This phenomenon also arises in the main ring and FNS. The ratio of re-bound magnetic field (B_{re}) to the field (B_{bef}) just before the re-bound effect seems to be roughly proportional to B_{bef} as shown in Fig. 14. More data should be taken to make this relationship more clear.

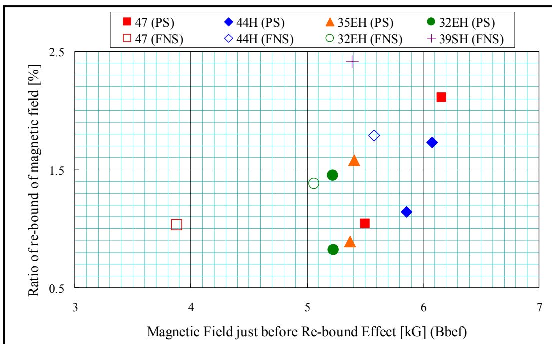

Figure 14: Re-bound of magnetic field of test samples set in the KEK-PS booster and FNS

Residual radiation of permanent magnet

The residual radiation of various kinds of permanent magnet and metal were measured and analyzed [2]. The radiation mainly comes from ^{54}Mn and ^{60}Co, and the residual radiation of NEOMAX magnet is almost the same level as that of stainless steel.

REFERENCES

[1] Since we do not have enough space to introduce the papers, see the references of the following paper:, K. Makita, et. al., Journal of the Magnetics Society of Japan, 28, 326-329 (2004) (in Japanese)

[2] M. Numajiri, et. al., Proc. of the Fifth Workshop on Environmental Radioactivity (2004) (in Japanese)