ESTIMATIONS FOR DEMAGNETIZATION OF ID PERMANENT MAGNETS DUE TO INSTALLATION OF OTR

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Abstract

Demagnetization due to installation of OTR to check the electron beam performance during the operation has been estimated for the permanent magnets of insertion device of XFEL/SPring-8. The estimation of the demagnetization has been performed quantitatively as functions of the electron energy, the gap width of the ID, and the dependence on material of the OTR.

INTRODUCTION

Demagnetization due to high energy electron irradiation is well known for permanent magnets of insertion device (ID) [1]. The demagnetization is one of the most important issues for stable operation of X-ray free electron laser (XFEL) and Synchrotron radiation (SR) facilities, and many experiments were performed [2]. In-vacuum type undulators have been employed to obtain a strong magnetic field. However, the permanent magnets of in-vacuum-type undulators are difficult to replace so that uncontrolled demagnetization must be avoid. The XFEL facility at SPring-8 (SACLA) adopts “compact” as its slogan and employed in-vacuum type undulators so that the demagnetization of ID magnets is crucial issues. Especially, during the commissioning, electron beam is scattered and then hits permanent magnets of insertion devices due to the installation of some instrumentations such as OTR (Optical Transition Radiation) for beam diagnosis. The estimation of demagnetization therefore is very important to perform the commissioning smoothly. Fortunately, star density was found to be the index of demagnetization of thermal stabilized $Nd_2Fe_{14}B$ permanent magnets due to high energy electron irradiation. High energy electrons produce electromagnetic showers and neutrons by photo-nuclear reactions with a thick target block such as the magnets. Star density produced by high energy neutrons reproduces experimental results of demagnetization [3]. By using the index, the demagnetization of the SACLA undulators due to the installation of OTR has been estimated for various cases such as electron energy in ranging from 2 GeV to 8 GeV and the gap width of the permanent magnet from 2mm to 40mm. And we also estimate the allowable time to be able to insert the OTR.

STAR DENSITY WITHIN THE MAGNET

Simulation Model

Star densities within the permanent magnets of the ID were simulated by using the FLUKA Monte Carlo code [4]. In FLUKA, a star was defined by a hadronic inelastic interaction (spallation reaction) at energy higher than the threshold and excludes the spallation due to annihilating particles. 100MeV and neutron were employed for the threshold and the hadron of the simulation, respectively. The geometry of the simulation is shown in Fig.1. The ID including the thermal stabilized neodymium borate ($Nd_2Fe_{14}B$) permanent magnets is 14535 mm long. 0.1mm in thickness is assumed for the equivalent OTR and the electrons hit the centre of the OTR. The gap between upper and lower side of the magnets is variable from 2 mm to 40 mm, which mean the minimum and maximum mechanical gaps of the SACLA undulators, respectively. The magnets are hold by the fixtures made of copper. The distance from the OTR to the ID is set to 46.5 cm that means the minimum distance of SACLA between the OTR and the ID.

Star Density Distribution

Star density distributions due to photoneutrons with the energy of over 100MeV within the magnets are shown in Fig.2 depending on the gap between the up and down ID magnets ranging from 2 mm to 40 mm gap width. In this case, 8GeV electrons are scattered by OTR made of iron with 0.1mm in thickness, and origin of the horizontal axis shows the position of the OTR. The results indicate as follows, (1) the maximum star densities for each gap width decreases with increasing the gap width, (2) the position of the peak density for each gap width moves longer distance to the downstream of the ID with increasing the gap width, (3) the sharpness of the star density distribution decreases with increasing the gap width, and (4) maximum peak star densities are $6.7\times10^{-7} \pm 3.0\times10^{-8}$ and $5.0\times10^{-9} \pm 1.0\times10^{-9}$ for the gap width of 2 mm and 40mm, respectively.

The energy dependence of the star density distributions are shown in Fig.3 with the gap width of 2 mm in ranging from 2 GeV to 8 GeV electrons. In these cases, the position of the peak of the star density distribution moves from the distance of 2.6 m to 8.7 m to the downstream with increasing electron energy. The maximum peak star densities increase slightly with increasing electron energy. Table 1 indicates the comparison of the distance from OTR to the peak position and the star density for the 2 mm and 4 mm ID gap width. Almost half of the distances of 4mm case and twice of the densities are recognized for the case of 2 mm ID gap width in both 2 and 8 GeV electron irradiation cases.

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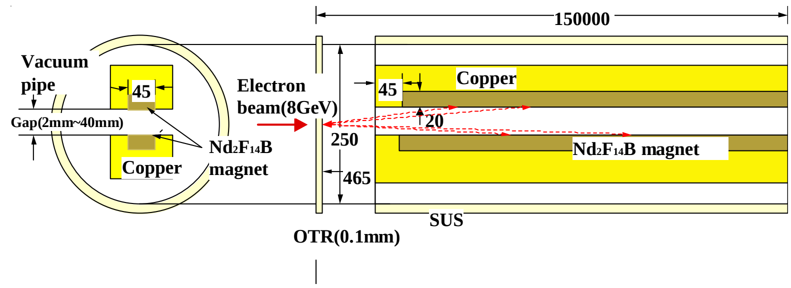

Figure 1: Geometry of simulations. (unit: mm).

Stainless steel, aluminium, and YAG ($Y_3Al_5O_{12}$: density 4.6 g・cm^{-3}) are usually use for the material of OTR. Figure 4 shows the results of the star density distributions for each OTR materials with 0.1 mm thick. The OTR made of aluminium produce the lowest star density in the same thickness of 0.1 mm. In the case of aluminium OTR with 1 mm thick, the peak position of the star density moves to almost 7.2 m distance from the OTR and the density increases from about 2.4 x 10^{-7} to about 7.8x10^{-7} star・cm^{-3}・electron^{-1} so that the thickness of the OTR is also important to reduce the star density.

Table 1 Comparison of maximum star density and peak position between the 2 mm and 4 mm ID gap width.

ID gap width	Electron 8 GeV		Electron 2 GeV	
	Distance	Density*	Distance	Density*
2 mm	8.7 m	6.7x10^{-7}	2.6 m	5.5x10^{-7}
4 mm	16.7 m	2.8x10^{-7}	4.2 m	2.2x10^{-7}

(*Density unit: star・cm^{-3}・electron^{-1})

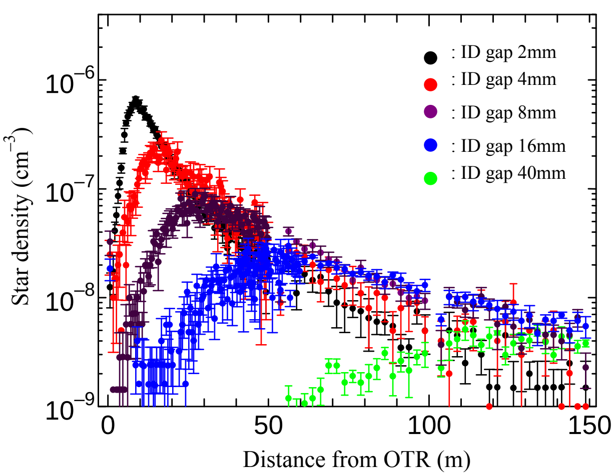

Figure 2: Star density dependence within the magnets on the gap width of ID due to 8GeV electrons injected into OTR. (Black: gap width 2mm, Red;4mm, Purple; 8mm, Blue; 16mm, Green; 40mm).

ESTIMATION OF DEMAGNETIZATION

Demagnetization of thermal stabilized magnets

Permanent magnets are well known to be demagnetized by thermal fluctuation or high energy electron irradiation. To reduce the effect of the thermal fluctuation of the magnetic field and demagnetization due to electron irradiation, thermal stabilized treatments of permanent magnets are usually performed and the treated magnets use to ID. The demagnetization of thermal stabilized neodymium borate ($Nd_2Fe_{14}B$) magnets is known to be much less than that of without thermal treatment magnets and in proportion to the number of the electrons depending on the energy of the electron [5]. The index of the demagnetization of neodymium borate magnets after thermal stabilized treatments due to high

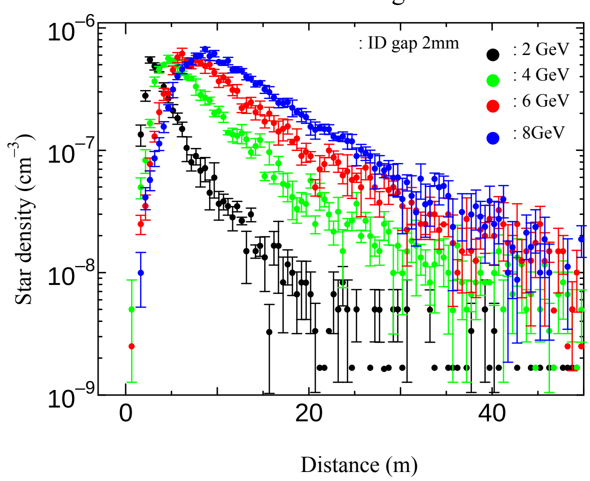

Figure 3: Star density distributions depending on electron energy within the magnet of ID. (Black; electron energy 2GeV, Green; 4GeV, Red; 6GeV, Blue; 8GeV).

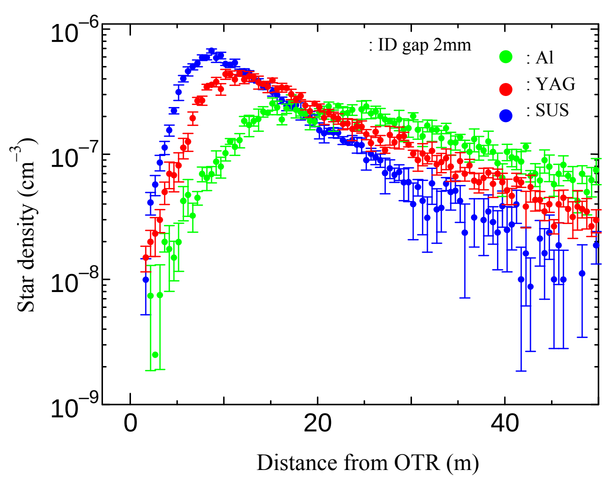

Figure 4: Star density distribution for the dependence on the material of OTR with 0.1mm thick.

energy electron irradiation is presented and formalized as follows by the experiments with the analyses of the FLUKA simulations [3].

$$\Delta \xi (\%)/N=1.9\times10^{-11}*S \qquad (1)$$

Where N is the number of the electrons, and S is the star density (cm^{-3}) with the neutron threshold energy of 100MeV ($E_{th} \geqq 100$MeV).

Demagnetization due to Installation of OTR

Using the data of the star density distributions for each case and the formula (1), the demagnetization can be estimated during the installation of the OTR and time limit of the installation under the assumption of the maximum permissible demagnetization for smooth operation of SACLA. The maximum intensity of accelerated electrons is designed to be 0.5 nC for one pulse (3.125×10^{9} e/pulse) so that the conservative estimation of the demagnetization for the one electron pulse is summarized in Table 2, including the distance from OTR to the position where the maximum demagnetization appears. In these cases of the same thickness, the case of the OTR made of stainless steel with the 2mm gap width will appear the maximum demagnetization, and about two orders higher than that of the case with 40 mm gap width. The demagnetization rate for the case of the OTR made of aluminium with 1 mm thick is almost same as that of the case of the OTR made of stainless steel with 0.1mm in thickness. The gap, therefore, must be opened fully during the OTR installation.

The maximum repetition rate of SACLA and the maximum permissible demagnetization which we

Table 2: Demagnetization rate for various conditions (*Distance from OTR to the position of the maximum demagnetization).

OTR (mm)		Energy (GeV)	Gap width (mm)	Demagnetization. /pulse (%)	Distance (m)*
SUS	0.1	8	2	4.0×10^{-8}	8.7
	0.1	2	2	3.3×10^{-8}	2.6
	0.1	8	4	1.7×10^{-8}	17
	0.1	2	4	1.2×10^{-8}	4.1
	0.1	8	40	3.0×10^{-10}	110
	0.1	2	40	2.6×10^{-10}	30
Al	0.01	8	2	2.3×10^{-9}	78
	0.1	8	2	1.4×10^{-8}	22
	1.0	8	2	4.6×10^{-8}	7.2
YAG	0.1	8	2	2.6×10^{-8}	11
	1.0	8	2	7.1×10^{-8}	4.2

designed are 60 Hz and 1% under 10 years continuous operation, respectively, so that the most conservative estimation for allowable time to install the OTR made of stainless steel with 0.1mm thick is 10.6 minutes for the gap full opened (40 mm), and 4.7 seconds for the mechanical minimum gap width (2mm) for every one hour.

CONCLUSION

Demagnetization due to installation of the OTR to check the electron beam performance during the operation has been estimated quantitatively for the permanent magnet of insertion device of SACLA (XFEL/SPring-8). As the results, we found that there is small possibility to appear the demagnetization of the permanent magnets of IDs due to installation of OTR of stainless steel with 0.1mm in thickness under the full opened gap width. On the other hand, the demagnetization will be appeared with high possibility under the OTR operation with the minimum gap width. Demagnetization rates for the installation of the stainless steel OTR with 0.1 mm thick and the OTR made of aluminium with 1 mm thick are almost same.

In this study, some future problems are pointed out, one of which is to consider the effect of the beam profile, especially halo part of the beam. Another is the effects of the differences for the performance of the magnets such as the dependence on the coercivity.

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