POSSIBILITY OF GENERATING 7.5KEV SYNCHROTRON RADIATION AT NEWSUBARU

Satoshi Hashimoto#, Mititaka Terasawa, NewSUBARU, LASTI, Univ. of Hyogo
Ainosuke Ando, KEK/JPARC

Abstract

There is an attractive possibility that the critical energy of synchrotron radiation of the NewSUBARU can be increased by introducing superconducting (SC) magnets in the storage ring. There are two possibilities of introducing the SC magnets: one is by replacing the inverse bending magnet with a SC magnet and the other is by installing a SC wiggler. In this paper, the effect of 5 T SC magnets on lattice functions of the ring is discussed and a hard X-ray beam line for material science research is proposed.

INTRODUCTION

The NewSUBARU synchrotron light source was designed to generate vacuum ultra violet (VUV) and soft X-ray, and active research and development has been going on. The electron storage ring is operated at a beam energy of 1.0 or 1.5 GeV. The critical energy of the synchrotron radiation from the bending magnet is 2.3 keV and the energy of the X-rays emitted from an undulator is approximately 1 keV. Thus, the X-rays with a higher energy of about 10 keV have much lower intensity.

In the measurement of photoelectrons, near-edge X-ray absorption fine structure (NEXAFS) and fluorescence, soft X-rays are a powerful tool for spectroscopic studies of materials such as boron, carbon, nitrogen, oxygen, fluorine. On the other hand, X-ray diffraction and fluorescence measurements using hard X-rays are also important and useful for a wide variety of materials. Recently, there have been increasing demands for the development and the precise characterization of advanced new materials, and synchrotron light is providing the most precise and sensitive method for such studies.

Considering this trend, we propose to set up a superconducting (SC) magnet in place of one of the inverse bending magnets in the NewSUBARU storage ring, with the aim of producing higher-energy X-rays and contributing to material research and development more extensively. In this paper, we report on the facility upgrade design.

UPGRADE PLAN

There are two possible methods for introducing superconducting dipole magnets in the NewSUBARU storage ring. One is by replacing an inverse bending magnet with a SC magnet and the other is by installing a SC wiggler. With the SC dipole magnet, one can obtain much higher energy X-rays. For example, the critical energy of 7.5 keV can be obtained assuming that we use a 5 T SC magnet at 1.5 GeV operation, as shown in Fig. 1.

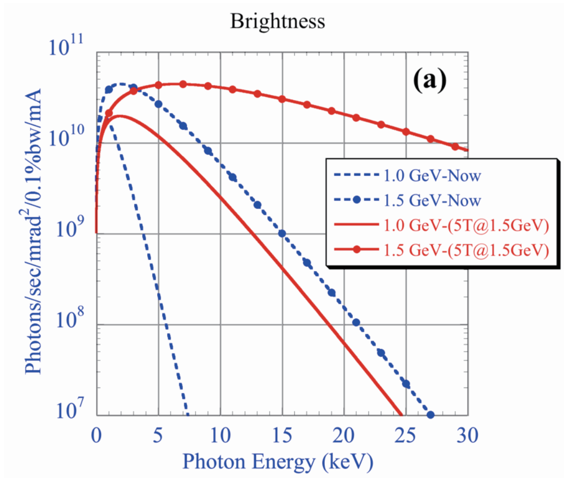

Fig. 1. Expected photon spectrum (brightness) for an electron beam current of 1 mA.

Figure 2 shows a line drawing of the NewSUBARU with its present beam lines. The NewSUBARU is a racetrack-type storage ring with a circumference of 120 m and has six double-bend achromatic cells. One cell consists of two 34° bending magnets (BM) and one inverted bending magnet (IBM) between them [1]. The SC magnets can be installed at the locations A and/or B in the ring. The superconducting IBM (SC-IBM) replaces the original IBM at A, and the SC wiggler is installed at B, a dispersion-free straight section.

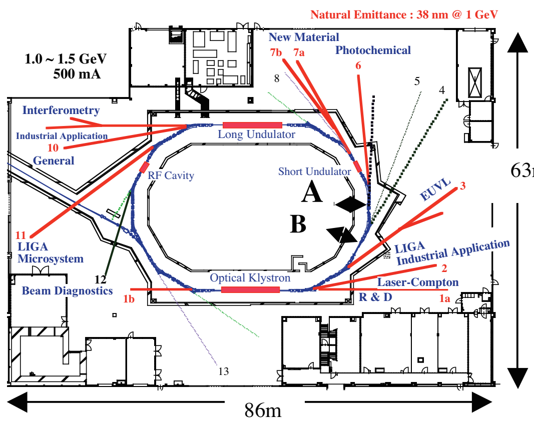

Fig. 2. Line drawing of NewSUBARU facility. A is the proposed position for superconducting IBM, and B is that for the superconducting wiggler.

#hashi@lasti.u-hyogo.ac.jp

ELECTRON BEAM OPTICS

To install the SC magnets, it is necessary to consider the modification of the lattice functions, which may cause serious degradations of brightness, fill time, beam lifetime, and beam orbit stability. Here, the effects of these magnets on electron beam optics are discussed.

Replacement of an inverse bend

The typical optical functions with the normal and SC IBMs are shown in Fig. 3. The parameters of the magnets are shown in Table I.

There are significant changes in the vertical betatron function β_y, and the vertical tune shift $\Delta\nu_y$ is 0.025. The vertical tune shift can be easily corrected by adjusting two quadrupole magnets located in the short straight section. The corrected betatron functions and dispersion function are almost the same as those of a normal IBM. Thus, it is found that there are no practical problems with the beam optics. The operation at 1.5 GeV is suitable for producing a sufficient number of photons with an energy of as high as 7.5 keV.

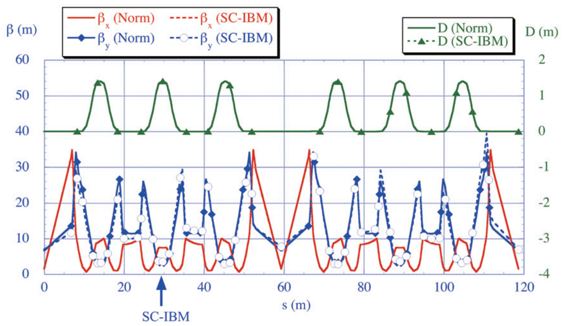

Fig. 3. Twiss parameters along the storage ring. Solid and broken lines indicate optics with the normal and the superconducting inverse bend, respectively.

Table 1: Parameters of normal conducting (NC) and superconducting (SC) IBMs for 1.5 GeV.

	NS magnet	SC magnet
Bending angle (deg.)	8	8
Length (m)	0.4469	0.14
Maximum field (T)	1.56	5.0
Magnet type	rectangular	rectangular

SC wiggler

Now we consider installing a three-pole SC wiggler in a short straight section. The wiggler configuration is shown in Fig. 4. The bending angles of the central pole θ are 0.3 rad at 1.0 GeV, and 0.2 rad at 1.5 GeV for a field strength of 5 T. Without any additional correcting quadrupole magnets, the maximum β_y can reach ~ 500 m. Thus, we have to install the three additional quadrupole magnets in the short straight section where the SC wiggler is located, as shown in Fig. 5. Q0 quadrupole magnets with a length of 0.1 m are located at both ends of the wiggler. Q10 and Q20 quadrupole magnets should be excited differently. For $\theta \leq 0.2$ rad, the optics can be corrected to the same level as that shown in Fig. 3. However, for $\theta = 0.3$ rad, the optics could not be completely corrected, as shown in Fig. 6.

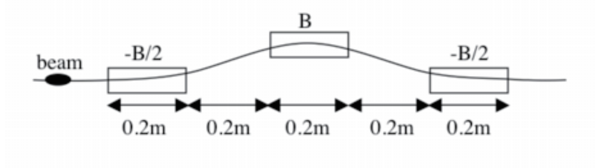

Fig.4. SC wiggler composed of three superconducting magnets. Peak field strength is B for the central pole and –B/2 for the compensating poles.

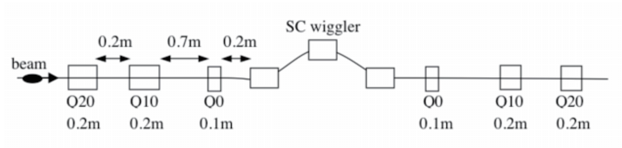

Fig. 5. Configuration of the SC Wiggler section.

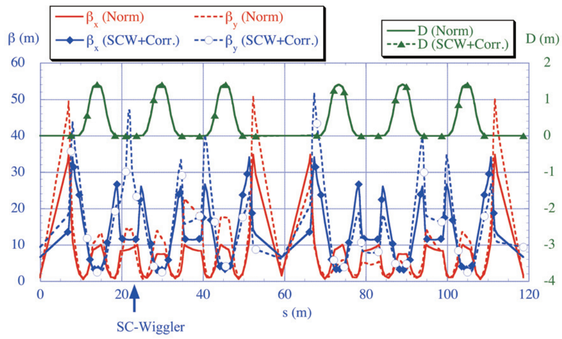

Fig. 6. Optics without/with SC wiggler (θ is 0.3 rad). The latter is corrected by additional quadrupole magnets.

From these results, we can conclude the following concerning the SC wiggler. (1) Three quadrupole families are required for the correction of lattice functions. (2) There are no serious problems with the SC wiggler of $\theta \leq 0.2$ rad. (3) The maximum value of β is ~ 50 m for a wiggler of $\theta > 0.2$ rad even when the β functions in both horizontal and vertical planes are corrected. This would introduce some difficulties in beam injection and degradation of beam lifetime. However, this problem is limited to a 5 T SC wiggler at 1.0 GeV operation and may be easily overcome by the top-up operation.

SUPERCONDUCTING DIPOLE MAGNET

The SC IBM with a field of 5 T has to provide a total bending angle of 8°. We consider equipping a duplicate of the "Superbends", which was the SC magnet developed for ALS in LBNL [2]. The SC magnet is C-shaped so that it can be inserted into or removed from the storage ring without disassembling the vacuum chamber.

The outer portion of the SC magnet system is maintained at room temperature. The cold mass assembly, which is composed of superconducting coils with steel poles, a laminated steel yoke, a LHe vessel, a LN_2 vessel, a high temperature superconducting leads, and a cryo cooler among others, is mechanically connected to the outer portion via epoxy fiberglass suspension straps with an intermediate 50 K heat station. A peak field of 5.69 T is obtained at center of the pole with 300 A [2].

X-RAY BEAM LINE AND APPLICATIONS

To promote material science research at the NewSUBARU with a hard X-ray, a new beam line that can accommodate a high-resolution X-ray spectrometer, a strong focusing mirror, and a microbeam system with a precise-positioning equipment must be constructed. X-ray fluorescence analysis, absorption fine structure spectroscopy, and diffraction measurement can be carried out using this experimental station.

Figure 7 shows a line drawing of the beam line for X-rays emitted from the SC-IBM located at A shown in Fig. 2. In the beam line, a high-resolution wavelength dispersion spectrometer with a pair of flat crystals such as Si(111) is placed downstream from the spherical mirror. The spectrometer is set inside the concrete shield tunnel to obtain a well-collimated photon beam with a small radius. Outside the concrete wall, a toroidal mirror is used so that the photon beam can be focused on the specimen in the experimental chamber.

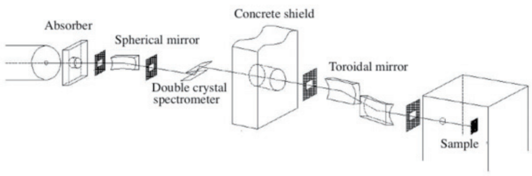

Fig. 7. Line drawing of beam line for radiation from the SC-IBM.

If the energy of emitted photons increases, the facility can be used for research on not only light elements and their alloys but also transition metals such as lanthanoids, and actinoids.

The beam line proposed in Fig. 7 can be utilized for X-ray fluorescence (XRF) analysis [3], highly sensitive trace element analysis [4], and NEXAFS analysis [5]. In combination with Kirkpatrick and Baez focusing optics, X-ray microbeam analysis and surface and intersurface analysis under grazing incidence condition can also be performed [6].

Recently, the stress and strain analyses of materials by an X-ray diffraction technique have become very important in industry [7]. Given that high-energy X-ray is an excellent tool for nondestructive testing, three-dimensional imaging in combination with computerized tomography (CT) systems will be a superior technique in the near future [8].

CONCLUSIONS

There is an attractive possibility that the critical energy of synchrotron radiation can become very high if the NewSUBARU is upgraded by introducing super-conducting magnets in the storage ring.

In this paper, the influence of the SC magnets on lattice functions of the ring has been discussed. If one of the inverse bending magnets is replaced with the SC magnet, there would be negligible effect on the electron optics. The expected vertical tune shift can be easily corrected by adjusting two quadrupole magnets in the short straight sections. With the SC wiggler, additional quadrupole magnets have to be placed at both ends of the wiggler to reduce the deformation of optics. With this arrangement, there will be no serious problems in operation at a beam energy of 1.5 GeV. In the case of 1.0 GeV operation with a 5 T SC wiggler, there may be some difficulties in beam injection and the beam lifetime will be shortened, although the reduction of the stored current may be overcome by the top-up operation.

In conclusion, by setting up the superconducting magnets in the NewSUBARU storage ring, material science research may be highly promoted. XRF analysis, trace element analysis, NEXAFS analysis, and diffraction techniques are expected to be extensively applied to not only metals and other industrial materials, but also biological and medical materials, cultural artifacts and geological samples.

REFERENCES

[1] A. Ando and T. Hattori, J. Biomed. Nanotechnol. **2** (2006) 83.

[2] D. Robin, J. Krupnick, R. Schlueter, C. Steier, et al., Nucl. Instrum. Methods Phys. Res., Sect. A **538** (2005) 65.

[3] H. Saisho and H. Hashimoto: in *Applications of Synchrotron Radiation to Materials Analysis*, ed. H. Saisho and Y. Gohshi (Elsevier, Amsterdam, 1996) 79.

[4] S. Hayakawa and S. Tohno: Spring-8 Research Frontiers 2000/2001, 2001, 68.

[5] S. Hayakawa and Y. Gohshi: in *Applications of Synchrotron Radiation to Materials Analysis*, ed. H. Saisho and Y. Gohshi (Elsevier, Amsterdam, 1996) 171.

[6] S. Hayakawa, X. P. Jia, M. Wakatsuki, Y. Gohshi and T. Hirokawa: J. Cryst. Growth **210** (2000) 388.

[7] A. Yamamoto, S. Nakahigashi, M. Terasawa, T. Mitamura, Y. Akiniwa, T. Yamada, L. Kiu, T. Shoubu, and H. Tsubakino: J. Synchrotron Radiat. **13** (2006) 14.

[8] M. Terasawa, S. Nakahigashi, Y. Onishi, and A. Yamamoto: submitted to J. Nucl. Sci. Technol.