PRESENT STATUS OF SUPERCONDUCTING COMPACT SR RING NIJI-III

Y.Tsutsui , K.Emura , F.Miura , H.Takada
Electromagnetic Application Systems R&D Department
Sumitomo Electric Industries Ltd.
1-1-3,Shimaya,Konohana-ku,Osaka 554,Japan
T.Yamazaki
Electrotechnical Laboratory
1-1-4,Umezono,Tsukuba,Ibaraki 305,Japan
T.Tomimasu
Free Electron Laser Engineering Corporation
2-7-4,Kyomatibori,Nishi-ku,Osaka 550,Japan

ABSTRACT

The superconducting compact synchrotron radiation(SR) ring NIJI-III has been developed. The beam performance required for x-ray lithography was achieved, in particular the expansion of the SR exposed area wider than 50mmx50mm was obtained by the electron beam wobbling (electron undulating)[1]. Present status of NIJI-III is reported in this paper.

INTRODUCTION

Sumitomo Electric Industries Ltd. (SEI) has been developing the superconducting compact SR ring NIJI-III since 1986[2)3)4)5)]. This project was entrusted by the Research and Development Corporation of Japan, and its purpose was to realize a practical x-ray lithography light source which enables wide area exposure of SR by the electron beam wobbling. Before superconducting magnets were installed, NIJI-III had already been put into operation with iron dipole magnets in 1989 to study beam optics and optimum injection parameters. The replacement with the superconducting bending magnets were completed in August 1990, and the first beam storage was achieved on August 10, 1990. As the result of commissioning a stored beam current of 200mA was successfully accelerated to a final energy of 600MeV in 1991. The exposed area wider than 50mmx50mm was also obtained by the electron beam wobbling. These operating performances were recognized to meet the target specification by the Research and Development Corporation of Japan.

GENERAL DESCRIPTION

The main parameters of NIJI-III are shown in Table 1. Fig. 1 is a photograph of NIJI-III. Since the magnet lattice of NIJI-III consists of four superconducting bending magnets and eight quadrupole magnets, a flexible lattice performance and a low emittance can be obtained.

Table 1.
Main parameters of NIJI-III.

Stored Energy[MeV]	600
Bending Magnetic Field[T]	4
Bending Radius[m]	0.5
Circumference[m]	15.5
Radiation Loss[keV/turn]	23
Harmonic Number	8
Critical Wavelength[Å]	13
Betatron Tune (horizontal) ν_x	2.25
(vertical) ν_y	1.25
Natural Emittance[m·rad]	2.6×10^{-7}

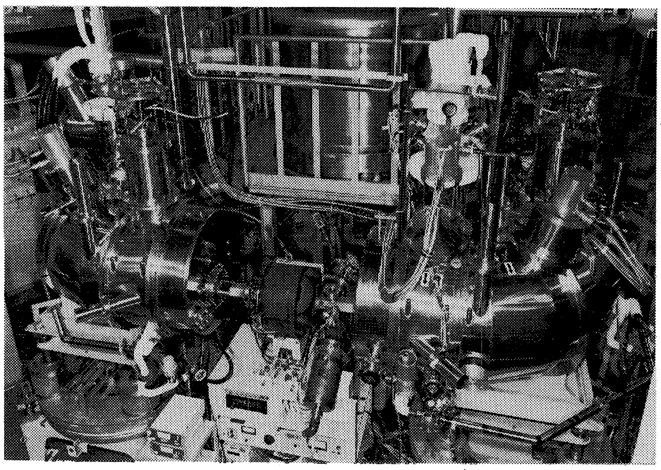

Fig. 1 Photograph of NIJI-III

The cross section of superconducting magnet is shown in Fig. 2[6)7)]. This magnet consists of a curved dipole coil and a quadrupole coil, and air core type is adopted to avoid the magnetic saturation problem. The weight of a magnet is 1.8 metric tonnes, which is much lighter than an iron dipole magnet. The coil configuration was designed on the basis of cos θ type current distribution in order to obtain a wide good field region. The beam duct in this magnet is cooled down at 4.2K and it acts as a cryosorption pump. The estimated pumping speed per magnet reached about 5000l/s for nitrogen gas[8)]. An SR absorber cooled by liquid nitrogen is installed inside a beam duct and shields a duct wall from the SR.

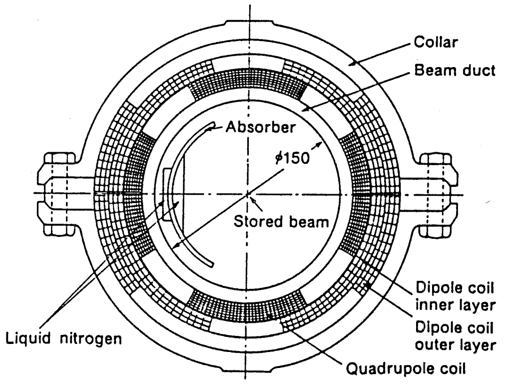

Fig. 2 Cross section of a superconducting magnet.

The electron beam is injected by the linear accelerator TELL of the Electrotechnical Laboratory(ETL). The injection energy is about 280MeV, at which TELL is routinely operated.

Beam performance

After the first beam storage with four superconducting bending magnets in August 1990, the maximum stored beam current of 450mA was obtained at the injection energy as the result of commissioning. The operating point with a high efficiency for beam storage was at the horizontal and vertical betatron tunes of 2.22 and 1.20, which were approximately design values and did not change with the replacement of iron magnets by the superconducting ones. The beam accumulation rate was not reduced by the magnet replacement either, and it reached about 150mA/min. Dispersion functions were also measured at this operating point, and the achromatic condition was nearly attained in the long straight section as shown in Fig. 3.

At the beginning of the beam energy ramping test, the rapid beam loss due to betatron tune shifts were observed. In order to compensate the tune shifts, the excited current of quadrupole magnets were adjusted by computer control. As a result, a stored beam current of 200mA was successfully accerelated to 600MeV. The beam lifetime was about 3 hours for 200mA at 600MeV and was limited by the increased vacuum pressure of $1x10^{-8}$Torr as against $2x10^{-10}$ Torr without beam. This pressure rise was due to the gas desorption from SR absorbers. The photon dose on the absorber surface has been reducing the outgassing. Therefore the beam lifetime is expected to be lengthened by a decrease in pressure rise.

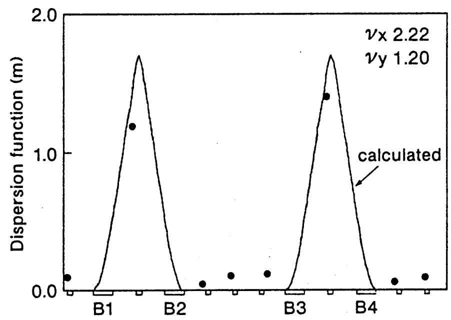

Fig. 3 Dispersion function.

Longitudinal coupled bunch instability

Although the beam size of NIJI-III was designed to be much smaller than 1mm in order to reduce a penumbra blurring in lithography process, a beam size growth and a beam fluctuation were observed. They were considered to be caused by the longitudinal coupled bunch instability, because synchrotron sidebands were clearly observed in the beam signal. The energy dependence of beam sizes was measured by use of CCD camera, as shown in Fig. 4. The beam size growth is remarkable in the low energy region and gradually decreases with an increase in beam energy. For 200mA at 600MeV the beam sizes were smaller than 1mm, and it meets the requirement for quarter-micron resolution lithography. The beam fluctuation ,however, was considered to have an influence on delicate applications of SR. Therefore, suppression of the longitudinal coupled bunch instability was tried by the decoupling method with a sideband cavity. This method was very effective and the synchrotron sidebands were remarkably damped without elaborate adjustment of the sideband cavity[9].

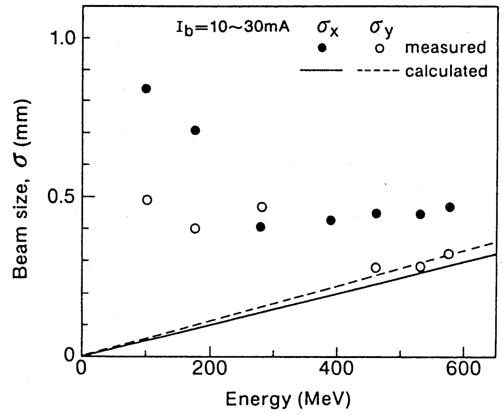

Fig. 4 Energy dependence of beam sizes.

Electron Beam Wobbling

The electron beam wobbling was carried out by a wobbling magnet which was installed in a long straight section. Fig. 5 shows that the center of a exposed area was vertically scanned and the exposed area was expanded wider than 50mm at the distance of 4m from the SR light source point. Fig. 6 is a photograph of the exposed area expanded to 50mmx50mm. The wobbling frequency was 20Hz and the triangle-shaped wave form was adopted at this experiment. Although this wobbling frequency was close to that of the beam fluctuation due to the longitudinal coupled bunch instability, the beam stability was not affected.

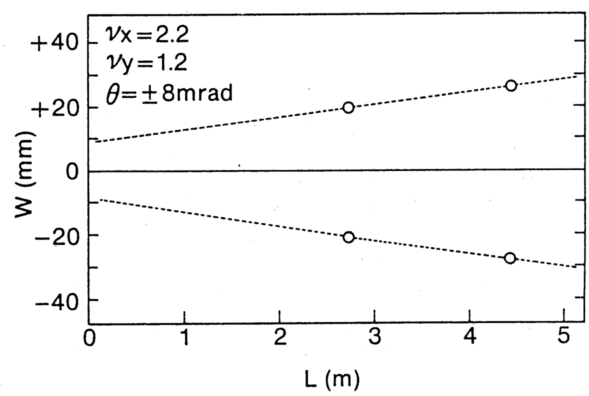

Fig. 5 Vertical displacement of the exposed area center at the distance(L) from SR light source point. Kick angle (θ) of wobbling magnet is ±8mrad.

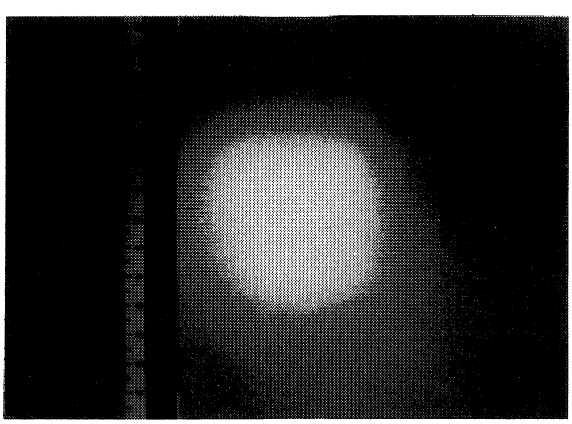

Fig. 6 Exposed area expanded by the electron beam wobbling.

The wobbled beam orbit approximately agreed with the calculation of a linear lattice perturbation as shown in Fig. 7. The effect of electron beam wobbling on the beam lifetime was also examined. Fig. 8 shows the beam lifetime as a function of the kick angle of the wobbling magnet. The shortening of the beam lifetime was not observed within a kick angle of 8.1mrad. The maximum vertical displacement of the beam orbit reaches to 25mm at a kick angle of 8mrad. This wide effective aperture agrees with the result of dynamic aperture analysis by the beam tracking[3]. For an increasing kick angle of greater than 8.1mrad the beam lifetime radically decreases. It is considered to be caused by the orbit displacement close to the physical aperture at straight sections.

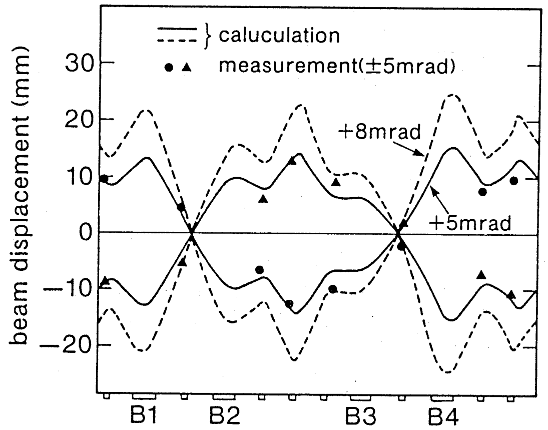

Figure 7. Vertical displacement of the wobbled beam orbit. Solid circles and triangles indicate the measured beam positions at a kick angle of ±5mrad. Solid lines and broken lines indicate the calculated orbit at kick angles of ±5mrad and ±8mrad respectively.

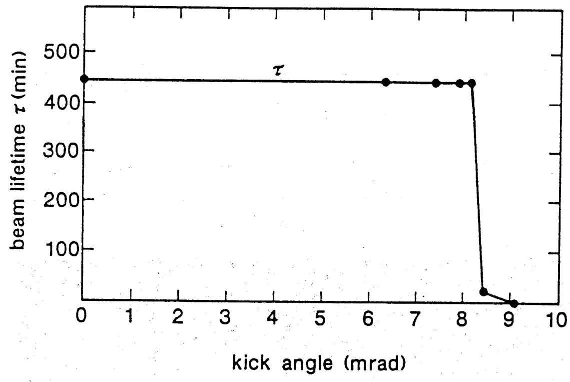

Figure 8. Beam lifetime as a function of the kick angle of the wobbling magnet.

SUMMARY

The superconducting compact SR ring NIJI-III has been successfully developed and the required specification for x-ray lithography light source was achieved. The operating performance suggests that there is no serious problem on the superconducting magnets. By the improvement in the vacuum condition NIJI-III is expected to be a more intense light source.

ACKNOWLEDGMENTS

The authors would like to thank the staff of the High Energy Radiation Section, ETL and the engineers of SEI for their support.

REFERENCES

1) T.Tomimasu, Jpn. J. Appl. Phys., vol.26, (1987) 741.

2) K.Emura et al., Proc. of the 7th Symposium on Accelerator Science and Technology, Osaka, December, 1989, p344.

3) H.Takada et al., Jpn. J. Appl. Phys., vol.30, (1991) 1893.

4) Y.Tsutsui et al., Proc. of the Particle Accelerator Conf., San Francisco, May, 1991, to be published.

5) K.Emura et al., Rev. Sci. Instrm., January, 1992, to be published.

6) T.Okazaki et al., Proc. of the 11th International Conf. on Magnet Technology, Tsukuba, August, 1989, p241.

7) T.Okazaki et al., Proc. of the 12th International Conf. on Magnet Technology, Leningrad, June, 1991, to be published.

8) F.Miura et al., Proc. of the 7th Symposium on Accelerator Science and Technology", Osaka, December, 1989, p130.

9) M.Moriguchi et al., presented at this symposium.