The Superconducting Compact Storage Ring NIJI-III

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Abstract

NIJI-III is a compact electron storage ring using superconducting dipole magnets. It has been in operation since August 1990. The peak wavelength of synchrotron radiation spectrum is about 5Å, which is set for x-ray lithography. As the result of commissioning stored beam currents of 400mA at the injection energy and of 50mA at 600MeV were obtained. The lattice performance, including the electron beam wobbling (electron undulating)[1], has been investigated and the design specification is nearly achieved.

I. INTRODUCTION

In recent years compact synchrotron radiation(SR) sources have been developed for industrial application, especially for x-ray lithography. Sumitomo Electric Industries Ltd. (SEI) has been developing a superconducting compact storage ring NIJI-III since 1986. Since this ring is designed for x-ray lithography, a peak wavelength of SR is set about 5Å. The electron beam wobbling is adopted to expand the vertical exposure area. 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 of the superconducting bending magnets were completed in August 1990, and the first beam storage was achieved on August 10, 1990. The ring characteristics and the results of beam operations are reported as follows.

II. GENERAL DESCRIPTION OF NIJI-III

The main parameters of NIJI-III are shown in table 1 and the schematic configuration is shown in figure 1. Since the magnet lattice of NIJI-III consists of four superconducting bending magnets and eight quadrupole magnets, the lattice structure is flexible and in particular a dispersion free condition can be obtained in the straight section. The lattice function at the designed operating point is typically shown in figure 2.

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}

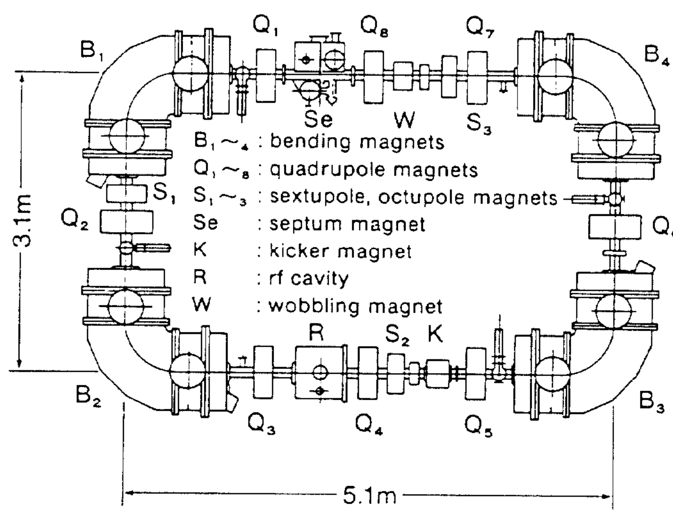

Figure 1. Schematic configuration of NIJI-III.

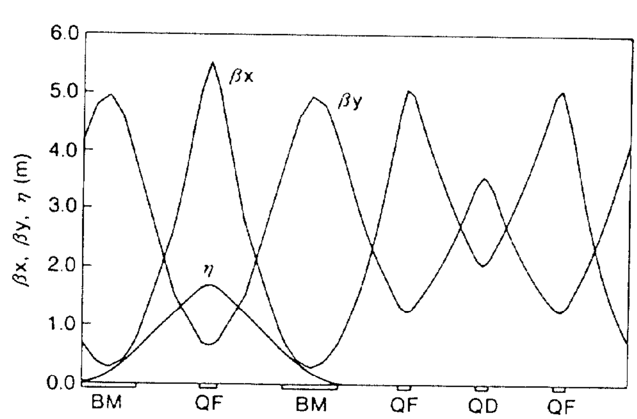

Figure 2. Structure of lattice functions.

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The beam size is one of the most important factors which has great influence on patterning resolution of lithography. Therefore, the magnet lattice was designed in order to obtain a beam size(σ) smaller than 1mm, which is considered to be a requirement for resolving smaller than 0.25μm patterns. The calculated beam sizes are shown in figure 3. Both horizontal and vertical beam sizes are smaller than 0.5mm in the bending section. Although the designed beam size was sufficiently small, it is anticipated that the actual beam size is enlarged more than the calculated value due to some instabilities. This issue is discussed in chapter IV.

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.

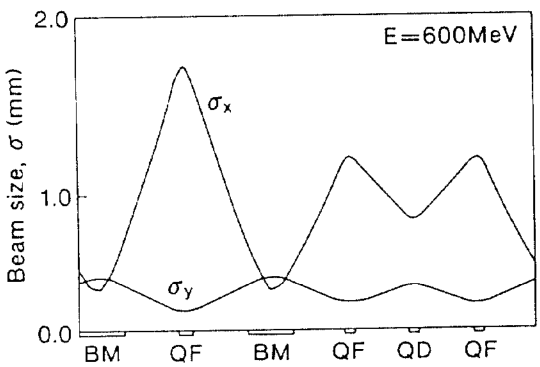

Figure 3. Calculated beam sizes assuming that a coupling constant is 0.1.

III. SUPERCONDUCTING BENDING MAGNET[2]

The superconducting magnet consists of a curved dipole coil and a quadrupole coil. Its cross section is shown in figure 4. By choosing a $\cos\theta$ winding type the magnetic field homogeneity of less than 5×10^{-4} is obtained within ±30mm in the horizontal direction, which is in good agreement with the values calculated by 3 dimensional magnetic field analysis. No magnetic materials are used in this magnet to avoid a magnetic saturation problem, and its weight is about 1.8ton, which is much lighter than an iron dipole magnet. The magnetic field produced by a dipole coil is nominally 4T at 600MeV and the field index can be varied from 0 to 0.5 by a quadrupole coil excitation. The beam duct in this magnet is cooled down at 4.2K and it acts as a cryosorption pump. The estimated pumping speed per one magnet reached about 5000l/s for nitrogen gas[3]. An SR absorber cooled by liquid nitrogen is installed inside a beam duct and shields a duct wall from the SR.

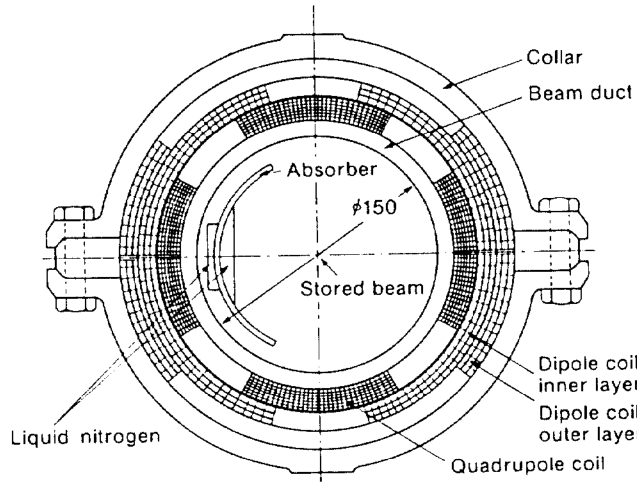

Figure 4. Cross section of a superconducting bending magnet.

IV. STATUS OF NIJI-III

A. Operating Results

After the first beam storage with four superconducting bending magnets in August 1990 a major effort has been devoted to increasing a stored beam current. As the result of commissioning a stored beam current above 400mA was obtained at the injection energy in January 1991. The beam acceleration tests also have been carried out, and a stored beam current of about 50mA was successfully accelerated up to 600MeV. 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 are approximately design values. Dispersion functions were also estimated by measuring changes of closed orbit distortion(COD) against rf frequency. Achromatic conditions are nearly attained in the long straight sections at this operating point, as shown in figure 5. These operating performances suggest that there is no serious problem on the magnetic field quality of the superconducting bending magnets.

B. Beam Size

The energy dependence of beam sizes was measured by use of CCD camera, as shown in figure 6. The beam size growth is observed and is remarkable in the low energy region. It was considered to be caused by longitudinal coupled bunch instability, because synchrotron sidebands were clearly observed in the beam signal. It is noteworthy that the beam size growth due to longitudinal coupled bunch instability decreases as the beam energy increases. Consequently the beam sizes are

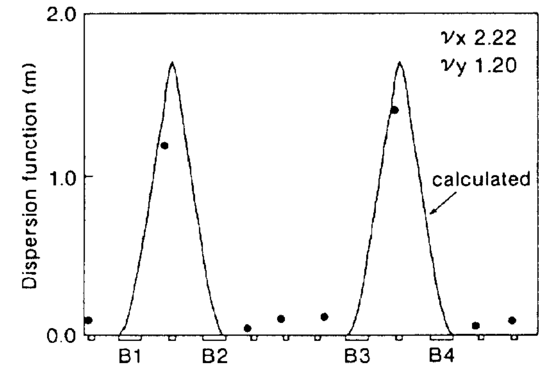

Figure 5. Dispersion function.

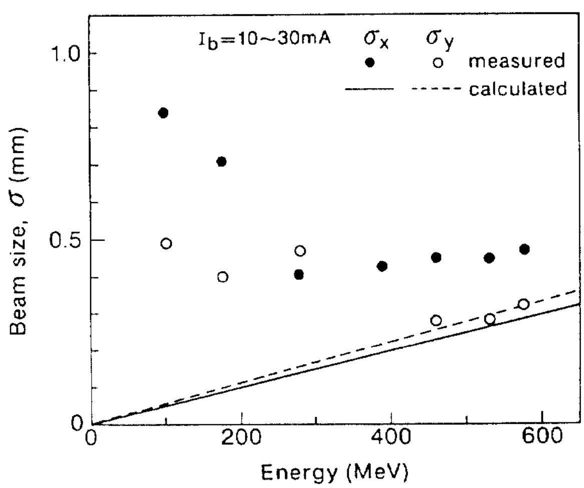

Figure 6. Energy dependence of beam sizes.

smaller than 0.5mm and the beam size growth is not significant at the beam energy of 600MeV.

C. Vacuum and Lifetime

Since SR absorbers could not be sufficiently baked due to their configuration inside the beam duct, the photon induced gas desorption from SR absorbers was remarkable at the early stage of beam operation. For example the average vacuum pressure was about $5x10^{-8}$ Torr for 400mA at 280MeV as against $2x10^{-10}$ Torr without beam. However, the photon dose reduced the outgassing rapidly and the normalized pressure rise decreased from 10^{-10} Torr/mA to 10^{-11}Torr/mA by the operation dose of about 500mA·h at 280MeV. The beam lifetime was about 150 minutes for 50mA at 600 MeV and was almost limited by the vacuum pressure of $1x10^{-8}$Torr. It is expected to be lengthened by a decrease in pressure rise.

D. Electron Beam Wobbling

The electron beam wobbling was carried out by a wobbling magnet shown in figure 1. Figure 7 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 of bending magnet B2. This wobbled beam orbit approximately agreed with the calculation of a linear lattice perturbation.

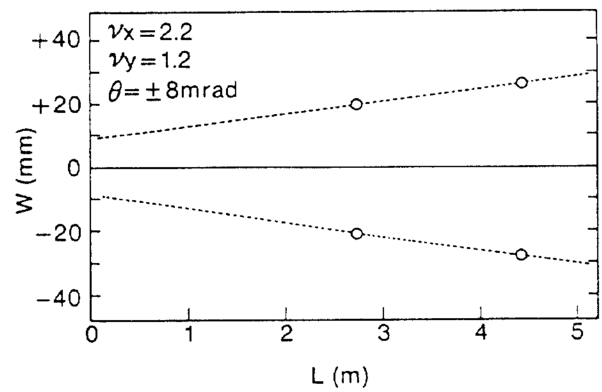

Figure 7. Vertical displacement of the exposed area center at the distance(L) from SR light source point. Kick angle (θ) of wobbling magnet is ±8mrad.

V. SUMMARY

The superconducting compact storage ring NIJI-III was designed as a x-ray source which meets the lithography requirements, and has almost successfully been put into operation. By more improvements in the vacuum and the machine conditioning during the acceleration, a designed stored beam current of 200mA at full energy is expected to be achieved soon.

VI. ACKNOWLEDGMENTS

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