PA02

NIJI-III Superconducting Compact Light Source Facility

Katsuji Emura, Tsuyoshi Haga, Tsuyoshi Shinzato, and Hiroshi Takada

Harima Research Laboratories, Sumitomo Electric Industries, LTD.
1431-12, Harima Science Garden City, Kamigori, Hyogo, 678-12 Japan

ABSTRACT

Sumitomo Electric Industries established a synchrotron radiation (SR) facility named "Harima Research Laboratories" in 1993. The facility is located in Harima Science Garden City where the large SR facility "Spring-8" is being under construction. Main purpose of our laboratory is to develop the advanced technologies on SR application, particularly for micro-fabrication, photo-chemistry and x-ray tomograph. In the facility, a 600MeV superconducting compact SR ring "NIJI-III", a 100MeV compact linac and five beamlines have been installed. Nowadays, NIJI-III usually provides SR light to users for 16 hours in a day.

1. Introduction

Recently, it has been discovered that SR has potential for the industrial applications, thus a compact, easy-to-use SR machine has been awaited in this area. We have continued our R&D efforts to develop compact SR machine. It mainly consists of a linac and an SR ring. Both of them require compact design. We first launched the development of a compact SR ring under the direction of the Electrotechnical Laboratory of the Agency of Industrial Science and Technology. Incorporating many advanced technologies, such as a superconducting bending magnet, the compact SR ring named "NIJI-III" was completed[1,2,3]. NIJI-III was achieved its design goal of 200mA stored current at 600MeV and the demonstration of large area exposure, 50mm×50mm, using the electron-beam wobbling method[4]. Based on these results, at the end of July 1993, NIJI-III was transferred from Tsukuba to our newly opened Harima Research Laboratories in order to accelerate the development of advanced SR application technologies.

For the linac, we had accumulated the basic engineering technologies needed for system design through joint research with ISIR Osaka University, and completed the development of a compact linac by ourselves in 1993. The linac has an accelerating gradient of 22MeV/m, which is the world's highest class for commercial machines[5,6]. We have thus succeeded in downsizing the linac, as well as the SR ring.

2. Facility overview[7]

Figure 1 is a bird's eye view of our facility. Both the linac and SR ring are installed in an accelerator room which is surrounded with 1.4m-thick shielding wall. Of the 3,500 square meter total floor space, 1,500 square meters is occupied by an accelerator room and an experimental hall.

The linac's output beam, typically macropulse current of 100mA at 100MeV, is introduced into the SR ring through the beam transport system approximately 25m long. It injects an electron beam with small beam radius, less than 5mm, and minimum achromatism into the SR ring.

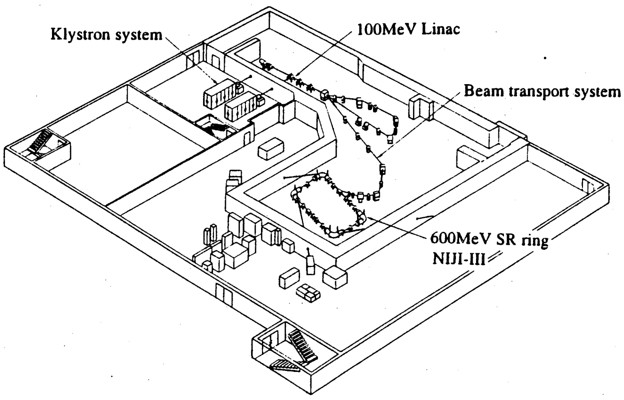

FIG. 1. Bird's eye view of the first floor of Harima Research Laboratories.

3. SR ring "NIJI-III"

A schematic configuration and main parameters of NIJI-III are summarized in Fig.2 and Table I, respectively. NIJI-III is a rectangular-shaped ring with approximate dimensions of 3.5×6.4m. Since its lattice structure is likely Chasmann-Green lattice, a dispersion-free condition can be obtained in the long straight section and dispersion functions are kept small in the bending section. The latter characteristic is the key issue for realizing a small beam size at the light source point. Both horizontal and vertical beam sizes are smaller than 0.5mm in the bending section.

The superconducting bending magnets can generate a maximum magnetic field of 4.0T, which enables us to obtain a peak wavelength of 5Å at beam energy of 600MeV as shown in Fig.3. The most notable feature of NIJI-III is the power leads of the superconducting bending magnets. These are made of high temperature (HTc) practical superconductors fabricated by ourselves. These power leads offers advantages of reductions in Joule loss, suppression of ambient heat transfer and hence improving the economy of the cryogenics.

At the injection energy of 100MeV, a maximum stored current of above 150mA was achieved with an accumulation rate of 30mA/s. No transverse instability is observed at the injection energy. Although sextupole and octapole magnets are installed in NIJI-III, those are no need to excite for electron storage.

Accelerating the stored beam to the final energy of 600MeV is accomplished by ramping all magnets simultaneously. Beam acceleration has been carried out in which currents of more than 100mA can be accumulated at the final energy. A ramping ratio between the exciting currents of superconducting bending magnets and of normalconducting quadrupole magnets is not a constant value through the acceleration, from 100MeV to 600MeV. This is attributed to magnetic saturation on the quadrupole magnets at high energy region and eddy current generated in the vacuum ducts in the bending section.

The beam lifetime was approximately 6 hours for the stored current of 100mA at 600MeV. The lifetime is thought to be limited by the vacuum pressure of 2×10^{-9}Torr. It will be lengthened by a decrease in pressure rise. NIJI-III usually operates day and night when NIJI-III provides SR light to users. Electrons are usually refilled into NIJI-III 4 times per day.

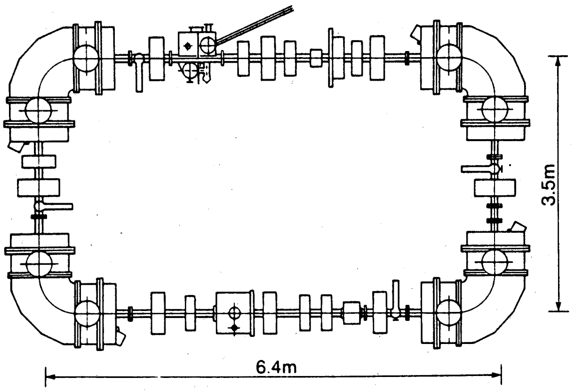

FIG. 2. Schematic configuration of NIJI-III

TABLE I. Main parameters of NIJI-III

Electron energy	600 MeV
Stored beam current	200 mA
Circumference	18.89 m
Bending magnetic field	4.0 T
rf frequency	158.7 MHz
Harmonic number	10
Critical wavelength	13 Å
Horizontal betatron tune	2.37
Vertical betatron tune	1.35
Momentum compaction factor	0.087
Emittance	0.38 mmmrad

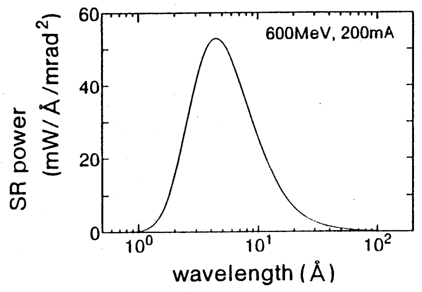

FIG. 3. Output SR spectrum

4. Electron injector

Electrons for injection into NIJI-III are provided by a compact linac. Main parameters of the linac is listed in Table II. The linac normally produces electrons at 100MeV with a pulse width of 1 μs. Our final goal of development of the linac is to realize a compact machine, as well as the SR ring. At the end of 1993, an accelerating gradient of 22MeV/m was achieved, which is the world's highest class for commercial machines. Also, the linac has another notable feature. It can produce a long-pulse beam of 10μs which is suitable for free electron laser (FEL) oscillation[8,9]. Our activities on FELs are summarized in latter section.

TABLE II. Main parameters of the linac

cathode	EIMAC Y646B
rf frequency	2856 MHz
beam energy	100 MeV (short pulse) 76 MeV (long pulse)
macropulse current	100 mA
energy spread	0.5 %
normalized emittance	60π mmmrad
repetition rate	2 pps
accelerating gradient	22 MeV/m
Klystron	TH2146

Electron gun is a thermionic triode gun based on a dispenser cathode assembly (EIMAC model Y646B). A high d.c. voltage of 200kV is applied to anode-cathode gap in order to obtain high beam brightness. A brightness of more than 10^{10}A/m^{2}rad^2 has been achieved in experiments carried out before installation into the linac system.

The bunching system consists of three tubes: subharmonic prebuncher (SHPB), prebuncher (PB), and buncher (B). The phase bunching characteristic of this system is evaluated by a ballistic-model simulation. As a result, for the electrons emitted from the gun, more than 40% are bunched into a 50 degree phase spread at the entrance of the buncher. The SHPB is a standing-wave cavity with a resonance frequency of 476MHz. It was made of stainless-steel. A portion of the inner surface of the cavity was coated by OFHC in order to optimize both a shunt impedance and Q-value of the cavity.

The accelerating tube is a disk-loaded waveguide with a constant gradient structure. There are no rf windows or bellows in the waveguide system between the accelerating tubes and the klystrons, in order to withstand the rf power even if the klystron generates its maximum rf power of 45MW. To stabilize the energy of the output electrons, two approaches are principally effective. Output power of the klystron is designed for stable, since its modulator generates a voltage pulse stabilized within 0.3% owing to parallel pulse forming network (PFN). Also, the resonance frequency of the accelerating tube is stable, since its temperature is controlled within ±0.02 degree by a water-cooling system.

5. Beamlines and SR applications

We have installed five beamlines in NIJI-III. Outline of the beamlines are summarized in Table III. In part of them, the distance from the SR light source point to the irradiation chamber is less than 3m, which enables us to obtain high photon density by no means inferior to GeV-class medium scale SR ring.

In this section, we briefly describe our representative activity on SR applications. Recently, micro-fabrications using a deep-etch x-ray lithography are demanded in several fields such as a precision engineering, advanced communication technology, medical engineering and so on. We have studied on LIGA process, German acronym for Lithographie, Galvanoformung, Abformung, which allows microstructures of any lateral shape to be fabricated with structual heights of several hundred micrometers. We have succeeded in the development of PZT microstructures for micro-ultrasonic transducers[10].

TABLE III. Beamlines

	BL-I	BL-II	BL-IIIa	BL-IIIb	BL-IV
Photon energy (keV)	0.02~0.13	1~10	3~10	0.1~1.5	0.1~10
Mirror	toroidal	none	none	cylindrical toroidal	none
Monochro-mator	toroidal grating	none	double crystal	spherical grating	none
Experiments	photo-chemistry	micro-fabrication	tomograph XAFS	photo-emission	photo excited process

6, Free electron laser (FEL)

Recently, we proceeded with studies on FEL in an infra-red region using our compact linac. Experimental conditions at present are summarized in Table IV. We have succeeded in observing a spontaneous emission ranging from 2 to 10 μm. Main components of the FEL system are briefly described in following section.

The linac's output beam is introduced into an undulator section through the beam transport system (BTS). The BTS for FEL requires very severe spec: double achromatic and quasi-isochronous should be realized in the undulator section. Simulations concerning the beam optics were carried out for lattice design. The BTS consists of two bending magnets and five quadrupole magnets. The bending angle of the two bending magnets is very small, 25.0 degree without edge-focusing, to realize the quasi-isochronism.

TABLE IV. Experimental conditions of FEL

beam energy	50 MeV
peak current	25 A
K parameter	0.84
magnetic field	0.23 T
FEL wavelength	2.8 μm
gain	10 %

Our undulator is the Halbach type using Nd-Fe-B permanent magnets. Total length of the undulator is 2m with periods number of 50. A roundtrip time in the optical resonator is set to be 24th harmonics of the micropulse interval time of 2.1ns. The optical resonator consists of two concaved Au-coated OFHC mirrors.

Gain calculation were carried out in accordance with the reference No.11. Small signal gain on our experimental system are estimated to be 10%. In this calculation, five modified coefficients are necessary to calculate. In our condition, the modified coefficient caused in the energy spread of the electron beam is by far smallest in them. Therefore, we have tried to find out the optimum conditions which enable to obtain the energy spread of less than 0.9%.

7, Conclusion

NIJI-III superconducting compact light source facility was operated at our newly opened Harima Research Laboratories in Harima Science Garden City. Nowadays, NIJI-III routinely operates in 600MeV-100mA and provides SR light to users for 16 hours in a day. We are just accelerating the development of advanced technologies on SR applications. Also, we intend to upgrade quantum radiation equipment such as FEL.

References

1, H.Takada et al., Jpn. J. Appl. Phys. 30, 8 (1991)
2, K.Emura et al., Proc. 7th Symp, Accelerator Science and Technology, RCNP Osaka, 344 (1989)
3, K.Emura et al., Rev. Sci. Instrum. 63, 1 (1992)
4, T.Tomimasu, Jpn. J. Appl. Phys. 26, 741 (1987)
5, K. Emura et al., Sumitomo Tech. Rev. 39 (1995)
6, T.Haga et al., in this proceedings
7, H.Takada et al., "Synchrotron Radiation Facilities in Asia", IONICS, Tokyo (1994)
8, K.Emura et al., Proc 20th Linear Accelerator Meeting in Japan, Osaka (1995)
9, T.Shinzato et al., in this proceedings
10, Y.Hirata et al., Proc. IEEE Micro Electro Mechanical Systems Workshops (1995)
11, P.W.van Amersfoort et al., The FELIX project status report April 1988, Rijnhuizen Report ((-176