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Present Status of Synchrotron Radiation Facility "NewSUBARU"

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The synchrotron radiation facility NewSUBARU has been constructed in SPring-8 site and user experiments have been started since February 2000. The 1.5 GeV electron storage ring with circumference of 119m produces soft X-ray synchrotron radiation. The present status of the storage ring and the facility is presented.

Key words: NewSUBARU, synchrotron radiation, soft X-ray, facility reports

1. INTRODUCTION

The synchrotron radiation (SR) facility NewSUBARU is a light source designed to generate bright light in the soft X-ray region. It is located in the SPring-8 site as shown in Figure 1 and consists of 1.5 GeV electron storage ring, insertion devices and several beamlines.

In 1994 the Laboratory of Advanced Science and Technology for Industry (LASTI) was founded to initiate the NewSUBARU project [1] at Himeji Institute of Technology. Hyogo prefecture supports the financial costs of both construction and operation of the facility, where research for industrial application of SR and support to company users who is not familiar with experiments using SR are important tasks in addition to basic research.

The construction of the facility began in December 1996 and was completed in August 1998. The beam commissioning started in September 1998 and the first SR was observed in the end of 1998. At the beginning of the beam commissioning, the dynamic gas load due to the SR-induced desorption was so large that the rapid beam loss due to the gas scattering made it difficult to end the commissioning in a reasonable period of time. During the summer shutdown of 1999 the vacuum system of insertion devices was upgraded to overcome this problem. As a result we succeeded in the maximum stored current of 100 mA and the beam lifetime was drastically improved [2]. Since February 2000 the user experiments using SR from bending magnets have been started and some excellent results have been obtained in research such as EUVL [3]. A brief history of the facility is shown in Table I.

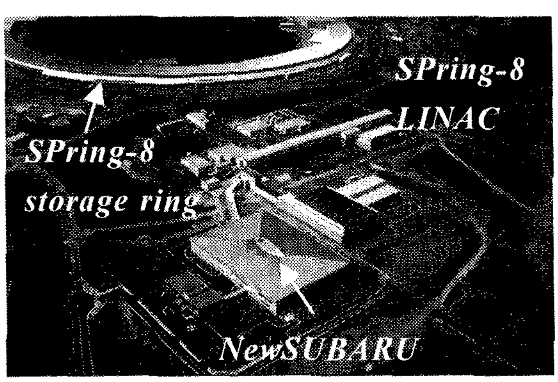

Figure 1. Bird's view of NewSUBARU and SPring-8

Table I A brief history of the NewSUBARU facility

Construction started	Dec. 1996
Building Completed	Jan. 1998
Beam commissioning started	Sep. 1998
First SR observed	Nov. 1998
Upgrade of vacuum system	Aug. 1999
User experiments started	Feb. 2000

2. OPERATION OF THE STORAGE RING

The 1.5 GeV electron storage ring of the NewSUBARU is racetrack-type with the circumference of 119 m and has two 14-m and four 4-m straight sections [4]. Two 4-m straight sections are allocated for a RF cavity and a septum magnet for beam injection. Total of four straight sections can be used for insertion devices. The long straight sections are one of unique features of this ring. The arrangement of the ring and beamlines are shown in Figure 2.

In addition to 12 normal bending magnets the ring adopts 6 inverse bending magnets in order to adjust momentum compaction factor between −0.001 to +0.001. Small value of this factor makes it possible to shorten electron beam length and pulse duration of SR.

The stable operation of the SPring-8 linac and our enormous effort made it possible to achieve injection efficiency of over 90 % from the linac to the storage ring. The maximum stored current of 100 mA is limited by regulation on radiation safety, although the designed value is 500 mA.

The electron beam lifetime is determined by the scattering of electrons with residual gas molecules.

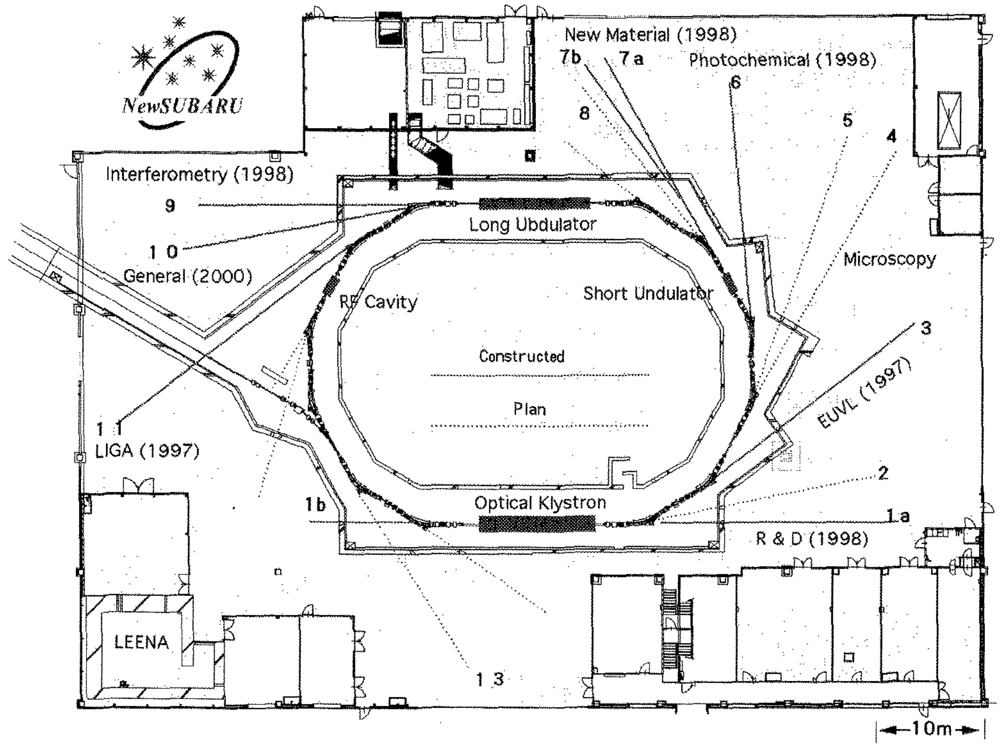

Figure 2. NewSUBARU storage ring and beamlines

The beam dose during one operation cycle (about two weeks) is only a few Ahrs because of the injection charge limit determined by the thin tunnel wall. The beam lifetime is about one hour with a stored current of 60 mA. In order to improve vacuum pressure in the ring NEG pumps were reactivated in summer shutdown of 2000. The main parameters of the ring are summarized in Table II.

Table II Storage ring parameters

Circumference (m)	119
Injection energy (GeV)	1.0
Beam energy (GeV)	1.0
Beam current (mA)	100
Beam lifetime (hour)	1 @60mA
Tunes	6.23 / 2.17
Harmonic number	198
Emittance (nm rad)	40
Energy spread	0.047 %
Momentum compaction factor	+0.001

Electron orbit is measured with 18 beam position monitors (BPMs) in vertical and horizontal planes. Closed orbit distortion (COD) is corrected within 20μm by 18 steering magnets.

The electron beam emittance has been measured by direct observation of visible SR with CCD camera. Measured emittance is in good agreement with designed value. The double sweep streak camera was also installed in order to measure bunch length of electron beam and is under calibration.

We have also observed ion trap instability. In order to avoid the instability, high voltage of 800V is applied to ion clearing electrodes and the ring is operated with the filing pattern in which 50 bunches are sequentially filled. The beam lifetime is also improved by giving perturbation on electron beams in vertical direction with a RF shaker because ionized molecules stayed around an electron orbit are kicked away by the perturbation.

During user time the ring is operated with momentum compaction factor of +0.001. In machine study we demonstrated small momentum compaction factor of +0.0003.

3. INSERTION DEVICES

Three insertion devices have been installed in the ring: 11-m Long Undulator (LU), Optical Klystron Free Electron Laser (OK-FEL) in 14-m long straight sections and Short Undulator (SU) in one of 4-m sections. The parameters of the insertion devices are shown in Table III.

LU has 200 periods and is 10.8-m long. Generally speaking, it is difficult to operate such a long insertion device in a relatively low energy storage ring. We have successfully demonstrated the operation of the storage ring with LU closed gap of 35 mm, although the beam life is reduced to 70 %.

However the measured spectrum width of undulator radiation was broader than calculated one. We suspect that there is horizontal error field in LU and electron orbit is vertically kicked. The fact that measured vertical distribution of total power of radiation was also broader than calculated one agrees with this assumption. Field measurement before installation of LU did not show such a large error. Error field may arise from field measurement error, sunk of concrete floor,

Table III Parameters of insertion devices

	Long Undulator	Short Undulator	Optical klystron
Type	Planar	Planar	Planar
Magnet	Permanent	Permanent	Electromagnet
Period length	54	76	160 / 320
Number of periods	200	30	32.5 / 16.5
Total length (m)	10.8	2.28	10.92
K parameter	0.3 – 2.5	0.3 - 5.3	0.3 – 4.4 / 0.3 - 11
Radiation wavelength	3.1 – 13 nm	4.4 – 66 nm	200nm - 10μm

distortion of girder, shimming and so on. In order to withdraw the full performance of LU re-measurement of magnetic field and re-alignment will be performed after April 2001.

After construction of BL7, commissioning of SU started in September 2000. We are estimating performance of SU: alignment of radiation axis, calibration of spectrometer and measurement of undulator radiation spectrum.

FEL is a tunable light source in which electromagnetic field stored in a resonator is amplified by a relativistic electron beam. OK undulator is made from normal electromagnets with periods of 160 or 320 mm and was designed to oscillate at relatively long wavelength from visible to infrared region. The spontaneous emission from OK-FEL at visible wavelength was measured in October 2000 and FEL oscillation experiments will start in 2001.

The calculated on-axis brilliance is shown in Figure 3.

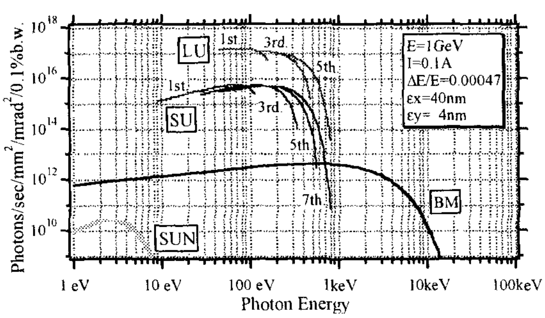

Figure 3
Calculated brilliance at the NewSUBARU light sources. E=1GeV, I=100mA, ΔE/E=0.047%, εx/εy=40/4 nm rad.

4. BEAMLINES AND USER EXPERIMENTS

There are 13 beamports in the ring, 4 for insertion devices and 9 for bending magnets. Seven beamlines are completed in December 2000. The characteristics of these beamlines are shown in Table IV.

BL3 is a beamline for Extreme Ultra Violet Lithography (EUVL). The user group including major Japanese companies succeeded in lithography of a 0.056 μm linewidth [3].

BL11 is used for fabrication of micro machines by use of SR (LIGA)[5, 6].

BL9 is a beamline for precise measurement using coherent soft X-ray from LU.

BL1 is a beamline for R&D of light sources such as Free Electron Laser and γ-ray production by Compton scattering. The preliminary experiments successfully demonstrated the γ–production of 10^3/s with energy of 20 MeV by incidence of Nd:YAG laser.

BL6 was completed in April 2000 and user experiments have already started.

BL7 for SU was completed in September 2000 and calibration of spectrometer started [7].

BL10 was completed in November 2000 and user experiments will start at the beginning of 2001.

A plan of BL4 for bio-medical is now under way.

There are three modes of machine operations: user experiment, machine study and vacuum baking by SR. The ring now operates 24 hours a day and 5 days a week. In principle 9:00-17:00 from Tuesday to Friday is user time for SR experiments and Monday for machine study. In order to keep the stored beam current 40 mA during user time, electron beams are continuously injected from linac to the storage ring every 40 seconds. From 17:00 to 9:00 the ring is operated, even though there is no user

Table IV Characteristics of beamlines at the NewSUBARU light source.

BL	Source	Energy	Purpose
1	Undulator (OK)	0.006 KeV	Light source R&D, Free electron laser, Compton scattering
3	Bending	0.08-0.3 KeV	Extreme Ultra Violet Lithography (EUVL)
4 (plan)	Bending	0.3-0.6 KeV	Development of equipment for medical diagnosis
6	Bending	< 1 KeV	Development of new material
7	Undulator (SU)	< 1 KeV	Structural analysis, Material development
9	Undulator (LU)	0.08-0.3 KeV	High precision measurement
10	Bending	< 1 KeV	Multi-purpose BL
11	Bending	< 6 KeV	Micro system technology (LIGA)

experiment or machine study, in order to gain beam dose. With an increase of beam dose on-beam pressure decreases and beam lifetime is improved. Although the beam lifetime is increasing day by day, lots of beam dose is required in order to realize long lifetime.

From January to November 2000 the total operation time is 2473 hrs of which 776hrs for the user experiments, 297 hrs for the machine study and 1400 hrs for vacuum baking by SR. The machine availability is about 97%. The machine fault of 3 % is due to the troubles of power supplies of the bending magnets and those of klystron.

The operation energy of the ring has been restricted to 1.0 GeV according to the regulation on radiation safety. The beam-energy ramping to 1.5 GeV will be possible in 2001.

There is no photon BPM in beamlines. For stable delivery of radiation to users, installation of photon BPM and feedback systems will be necessary.

The number of facility users reaches 47 in November 2000 and is expected to be rapidly increasing. Researchers who want to perform experiments with SR can use the facility under a joint research with LASTI.

5. SUMMARY

The synchrotron radiation facility NewSUBARU was constructed in 1998 with support from SPring-8. The user experiments have been started since February 2000. Seven beamlines are completed and some excellent experimental results have been obtained. The beam lifetime is only a few hours but is gradually improving with an increase of beam dose.

The authors thank all SPring-8 staff for their cooperation.

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