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Isochronous storage ring of the New SUBARU project

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The aims of the New SUBARU project are to promote industrial applications in the VUV and soft X-ray region and to develop research and development towards new light sources. The main facility of the New SUBARU project is the 1.5 GeV electron storage ring which is under construction at the SPring-8 site in Harima Science Garden City, Japan. The storage ring is quasi-isochronous and has variable momentum dispersion for the deep study of beam dynamics in very short bunches.

Keywords: isochronous; storage rings; light sources; variable dispersion.

1. Introduction

A 1.5 GeV electron storage ring for a light source in the VUV and soft X-ray region is under construction at the SPring-8 (JAERI-RIKEN SPring-8 Project Team, 1991) site using the linac as an injector. The project team for the New SUBARU, from Himeji Institute of Technology and SPring-8, has been organized to establish the synchrotron radiation research complex in SPring-8.

The storage ring has two very long straight sections (14 m each) compared with its small circumference (~119 m). Two long straight sections are initially used for a 11 m long undulator (LU) and an optical klystron (FEL), and two short straight sections (4 m each) for a 2.3 m undulator (SU) and an 8 T superconducting wiggler (SCW). The natural emittance is 67 nm at 1.5 GeV because the total number of main dipole magnets is 12. The maximum brilliance is expected to be 10^{18} photons s^{-1} mm^{-2} $mrad^{-2}$ (0.1% bandwidth)$^{-1}$.

The New SUBARU project is complementary to SPring-8 and aims to produce short pulses of radiation. New ideas such as using laser–electron interactions or beam cooling will also be tested in this ring. The main purposes of the project are as follows: first, research and development towards new light sources such as (*a*) a small and low-cost source in the VUV to soft X-ray region, (*b*) a strong ring-FEL and coherent soft X-ray source, (*c*) very short light pulses, and (*d*) beam cooling to obtain very small emittance and energy spread in a small ring; second, applications for industry and biomedical research such as (*a*) micromachining, (*b*) investigations of new materials and (*c*) X-ray microscopy. The project also has a 15 MeV linac for FEL (named LEENA) (Mochizuki *et al.*, 1996). The expected brilliance and energy region is shown in Fig. 1. The energy region from ~0.1 to ~50 keV will be covered.

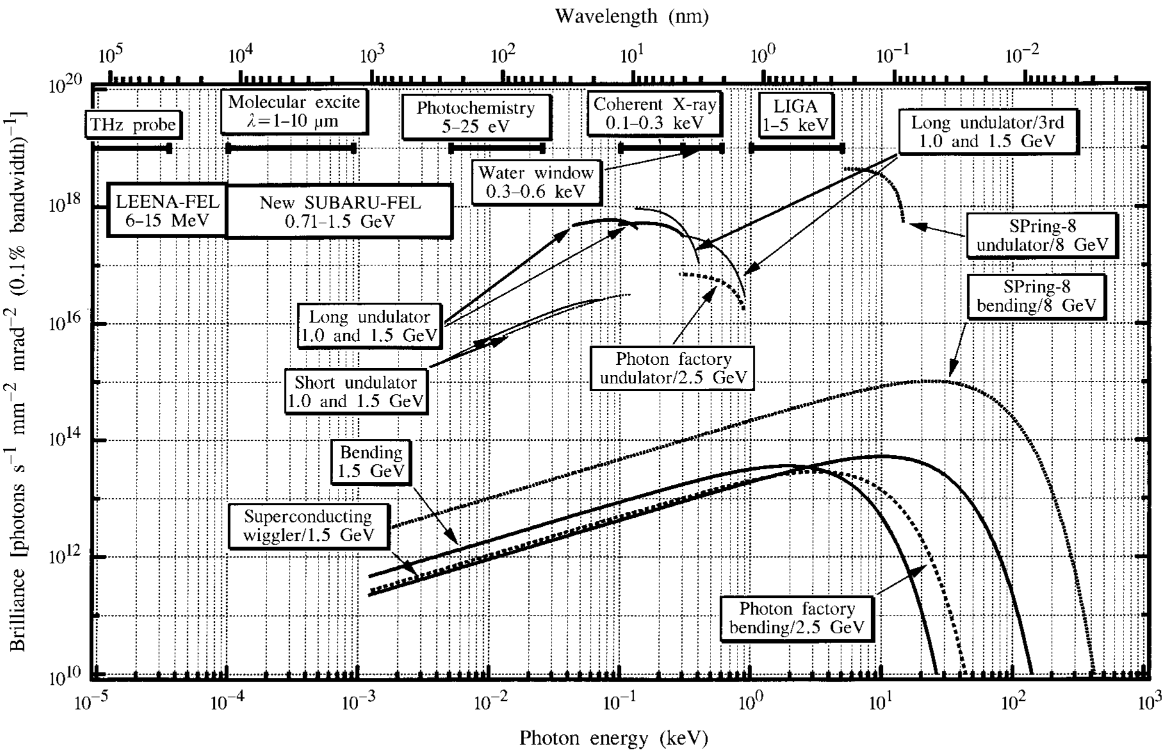

Figure 1
Expected brilliance of the New SUBARU compared with SPring-8 and KEK-PF.

Table 1
Main parameters of the New SUBARU storage ring.

Fundamentals	
Injection energy	1 GeV
Stored current	<500 mA
Circumference, L	118.716 m
Harmonic number	198
RF frequency	500 MHz
Betatron tunes (ν)	6.21/2.17
Chromaticity (ξ)	−19/−7.5
α_p	0.001
Straight sections	4 m × 4, 14 m × 2
Operation parameters at 1.5 GeV	
Natural emittance (1σ)	67 nm
Coupling	10%
Bending field	1.55 T
Critical photon	0.53 nm, 2.33 keV
Radiation loss turn^{-1}	176 keV
Damping time	
Longitudinal/horizontal/vertical	3.42/6.56/6.73 ms
Energy spread	0.072%
RF voltage	>250 kV
Bucket height	>0.83%
Synchrotron tune	0.0021
Bunch length ($1\sigma_t$)	26 ps
Touschek lifetime	>10 h

Table 2
Structure of the quarter-ring.

Lattice	BIH† (B1)$^{-1}$	(B1) BI	B (B1)	(B0) B	(B0)$^{-1}$ (B2)	B
(B0)	D.5	Q2	D*	S1	D*	Q1
	D.1	S2	D2.			
(B1)	D.7	Q4	D.1	SF	D.3	Q3
	D.1	SD	D.4			
(B2)	D.4*	S1	D.1*	QC	D.6	QB
	D.3	QA	D7.			
Quadrupole						
Name	Q1	Q2	Q3	Q4	QA	QB
l (m)	0.28	0.28	0.18	0.18	0.28	0.38
Name	QC					
l (m)	0.28					
Drift						
Name	D8	D.1*	D.1	D.3	D.4	D.4*
l (m)	0.117	0.118	0.12	0.28	0.48	0.482
Name	D.5	D.6	D.7	D2.	D7.	
l (m)	0.506	0.68	0.69	1.78	7.124	
Rectangular dipole						
Name	B	BI				
Length (m)	1.91	0.45				
Angle (°)	34.0	−8.0				
Sextupole						
Name	SF	SD	S1	S2	SBI‡	
l (m)	0.1	0.1	0.1	0.1	0.45	

† BIH is half of BI. ‡ Pole face windings of BI gives 'SBI'.

2. Storage ring

The main parameters of the ring are summarized in Table 1 and the lattice structure of the quarter-ring is given in Table 2. The characteristics are (i) a quasi-isochronous and/or variable momentum compaction factor, α_p, between ±0.001, and (ii) 14 m long straight sections. The ring has a hexagonal shape and the unit structure is a double-bend achromat cell with two 34° bending magnets (BM) and one inverted bending magnet in the middle. The typical envelope functions are shown in Fig. 2. The higher-order-mode damped cavity with SiC duct developed and used at the ISSP-SRL and the Photon Factory (Izawa *et al.*, 1995) has been installed.

2.1. *Bunch length*

The natural energy spread is calculated as $\sigma_\delta \simeq 4.8 \times 10^{-4}E$, where E is the energy of the electron beam measured in GeV. The bunch length is given by $\sigma_t \simeq 2.3 \times 10^{-8}(AE)^{1/2}\sigma_\delta$ (s), where $\alpha_p = 0.001A$ for the RF voltage can always be higher than 250 kV. On the other hand, the energy spread would become larger due to microwave instability. Supposing that the Keil–Schnell criterion is applicable, σ_δ and σ_t become twice the natural values at ~4 mA bunch^{-1} for $A = E = 1$ and $|Z/n| = 0.1$ (Ω), which is almost the same result as the numerical calculation program *ZAP* (Zisman *et al.*, 1986). Reaching ~3 ps of σ_t is one of the goals of the accelerator research and development.

2.2. *Sextupole correction*

The control of higher-order terms in α_p is very important for a very small α_p or quasi-isochronous ring. As the second-order islands in synchrotron oscillation appear at (Ando & Takayama, 1983)

$$\delta_\pm = [-\alpha_2 \pm (\alpha_2^2 - 4\alpha_1\alpha_3)^{1/2}]/2\alpha_3,$$

where the revolution period is expanded as

$$\Delta T/T = \alpha_p\delta = \textstyle\sum_k \alpha_k\delta^k,$$

the guideline for the free oscillation from these islands in the region of $|\delta| \leq 1\%$ would be $\delta_\pm > 0.1$, which gives (i) $\alpha_2{}^2 - 4\alpha_1\alpha_3 < 0$, or (ii) $|\alpha_3/\alpha_2| < 0.1$ ($\alpha_1 \simeq 0$), or $|\alpha_2/\alpha_1| < 0.1$ ($\alpha_3 \simeq 0$). (In this paper α_p and the momentum slipping factor are treated as the same value.) Then the equations for correction of chromaticity and α_2 are

$$\mathrm{d}\xi_x/\mathrm{d}g_j = (\beta_x D)_j/4\pi, \qquad \mathrm{d}\xi_y/\mathrm{d}g_j = -(\beta_y D)_j/4\pi,$$

$$\mathrm{d}\alpha_2/\mathrm{d}g_j = -D_j^3/2L,$$

where $\xi = \Delta\nu/\delta$, β and D are the envelope function and momentum dispersion, respectively, $g = l(\partial^2B_y/\partial x^2)/B\rho$, and the suffix j means the jth sextupole. It is also very important to

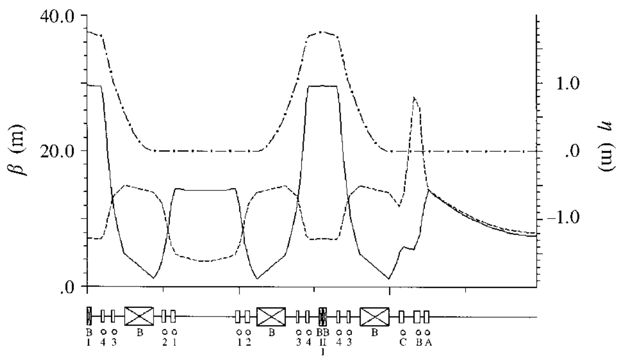

Figure 2
Twiss parameters of the quadrant for $\alpha_p \simeq -0.001$. Solid line: β_x; broken line: β_y; dotted line: dispersion (η).

Table 3
Main parameters of the New SUBARU insertion devices.

Type	SU	LU	SCW	FEL
λ_u (mm)	76	54	350	160/320
N	30	200	1	32.5/16.5 × 2
g (mm)	~25	~25	30	40
	58	44.5		
K	~1.3	~0.8	262	~1.7
	5.3	2.5		12
L_u (m)	2.3	10.8	0.7	5.2 × 2
W (nm)	~8.1	~1.4	~0.1	~200
	149	29	0.23†	12 000‡
B	4×10^{16}	10^{18}	7×10^{13}	

† Critical photon energy. ‡ 0.5–0.7 GeV operation.

control resonance driving terms or so-called Collins' distortion functions (Ando, 1984). In the New SUBARU, five families of 50 sextupoles seem enough for the correction.

3. Insertion device and beamline

Table 3 summarizes the insertion devices, where λ_u and N are the length and number of period, g and L_u are the gap height and total length, W is the covered region of photon wavelength, and B is the brilliance. As seen in the table, the K values of the undulators are ~1 and the harmonics will be positively used (see Fig. 1).

3.1. *FEL/optical klystron*

The main aims of the hardware development in FELs are to obtain lasing in the wavelength region <200 nm and high average power in the micrometre region. The storage ring will be operated mainly at 0.5–0.7 GeV because a simple calculation gives gains greater than a few tens of percent at the peak current of 10 A, including energy widening. Normal conducting magnets are used for the undulators and dispersive section, and the length of the period is selected by changing current connection. The distance between the mirrors, of radius of curvature ~13 m, is one-quarter of the ring circumference.

Table 4
Beamlines under discussion.

Purpose	Source	Energy (keV)
EUVL	BM	0.08–0.3
LIGA	BM	3
Holography and coherence	LU	0.08–0.3
Materials creation	BM	<1
Photoactive materials	BM	<1
Light source R&D	FEL	0.006
X-ray microscope	LU/SU	0.3–0.6
Topography	SCW	>2
Optical elements R&D	BM	0.05–1

3.2. *Beamline*

There are four beamlines from insertion devices and nine beamlines from bending magnets. Table 4 shows the present category under discussion. This year, two beamlines have been constructed, for EUVL (extreme ultraviolet lithography) and LIGA.

References

Ando, A. (1984). *Part. Accel.* **15**, 177–207.

Ando, A. & Takayama, K. (1983). *IEEE Trans. Nucl. Sci.* **30**, 2604–2606.

Izawa, M., Koseki, T., Kamiya, Y. & Toyomasu, T. (1995). *Rev. Sci. Instrum.* **66**, 1910–1912, 1926–1928.

JAERI-RIKEN SPring-8 Project Team (1991). SPring-8 Project Part I Facility Design 1991 (revised). SPring-8, Japan.

Mochizuki, T., Miyamoto, S., Amano, S. & Niibe, M. (1996). *First Lasing of LEENA Free-Electron Laser at LASTI*. Proceedings of the 18th International Free-Electron Laser Conference, Rome, August.

Zisman, M. S., Chattopadhyay, S. & Bisognano, J. J. (1986). Report LBL-21270/EGS-15.