NEW SUBARU AND OTHER LIGHT SOURCE PROJECTS IN JAPAN

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Abstract

The New SUBARU is a facility of the VUV and soft x-ray light source and under construction in the SPring-8 site using the existing 1-GeV linac. The main aims of this facility are to develop the *R & D* towards new light sources and to promote fundamental studies for industrial and medical applications. Also considering the complementarity of the existing SPring-8 facility (the world brightest and most brilliant source), the storage ring is designed, apart from the main stream to higher brilliance or to the 3-rd/4-th generation, to try short and/or coherent radiation. There are other projects of brilliant VUV and X-ray sources at the Institute of Solid State Physics (ISSP), Univ. of Tokyo and Tohoku Univ. Designed emittances are a few to 7 nm at 1.5∼2 GeV. Ring circumferences are now about 400 and 200 m each. These have relatively long straight sections (∼15m long) to obtain more coherent and brilliant radiation by long undulators.

1 INTRODUCTION

In JAPAN there are many proposals of synchrotorn radiation sources for VUV and soft X-ray. Among them the New SUBARU facility is almost completed and a beam commissioning is scheduled at this autumn. The others are still in design phase. In this report New SUBARU is descrived in detail, and two public projects of University of Tokyo and Tohoku University are briefly introduced.

2 NEW SUBARU

The main purposes of the New SUBARU(NS) project are as follows. (1) Research and development towards new light sources such as (a) a small and low cost source in the region from VUV to soft X-ray, (b) strong ring-FEL and coherent soft X-ray, (c) very short light pulses and (d) beam cooling to obtain very small emittance and energy spread in a small ring. (2) Application for industry and biomedical such as (i) micromachining, (ii) investigation for new material and (iii) X-ray microscopy. The main facility of the New SUBARU project is the 1.5-GeV electron storage ring which is quasi-isochronous and has variable momentum dispersion for the deep study of beam dynamics in very short bunches. The project team for New SUBARU between HIT(Himeji Institute of Technology) and SPring-8 has been organized to establish the SR research complex in SPring-8. The facility has also a 15-MeV linac for FEL (named as LEENA)[1]. The expected brilliance and enery region is shown in Fig.1. The energy region of ∼0.1eV to ∼50 keV will be covered.

2.1 Storage Ring

The storage ring has two very long straight sections (LSS,14 m each), compared with its small circumference (∼119 m). Two LSS's are initially used for an 11-m long undulator (L-U) and an optical klystron(FEL), and two short straight sections (4m each) for a 2.3-m undulator (S-U) and an 8-T superconducting wiggler (SC-W). 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 $10^{18}(photons/sec/mm^2/mrad^2/0.1\%b.w.)$.

Table 1: Main parameters of New SUBARU storage ring.

Fundamentals		
Injection energy	1	GeV
Operation energy	(0.5∼)1.5	GeV
Stored current	$<$ 500	mA
Circumference L	118.731	m
Revolution period	0.396	μ sec
Revolution frequency	2.525	MHz
Harmonic number	198	
RF frequency	500	MHz
Betatron tunes	6.21/2.17	ν_x/ν_y
Chromaticity (ξ)	-19/-7.5	
α_p	$\pm$ 0.001	
Straight sections	4m	$\times$4
	14m	$\times$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	176(∼230)	keV
Damping time		
Longitudinal	3.42	msec
Horizontal/Vertical	6.56/6.73	msec
Energy spread	0.072	%
RF voltage	$\leq$ 250	kV
Bucket height	$\leq$ 0.83	%
Synchrotron tune	0.0021	
Bunch length ($1\sigma_t$)	26	psec
Touschek life time	$>$ 10	hrs

Considering complementarity to SPring-8 : the most brilliant light source in the world, New SUBARU aims to produce short pulses of radiation. New ideas such as us-

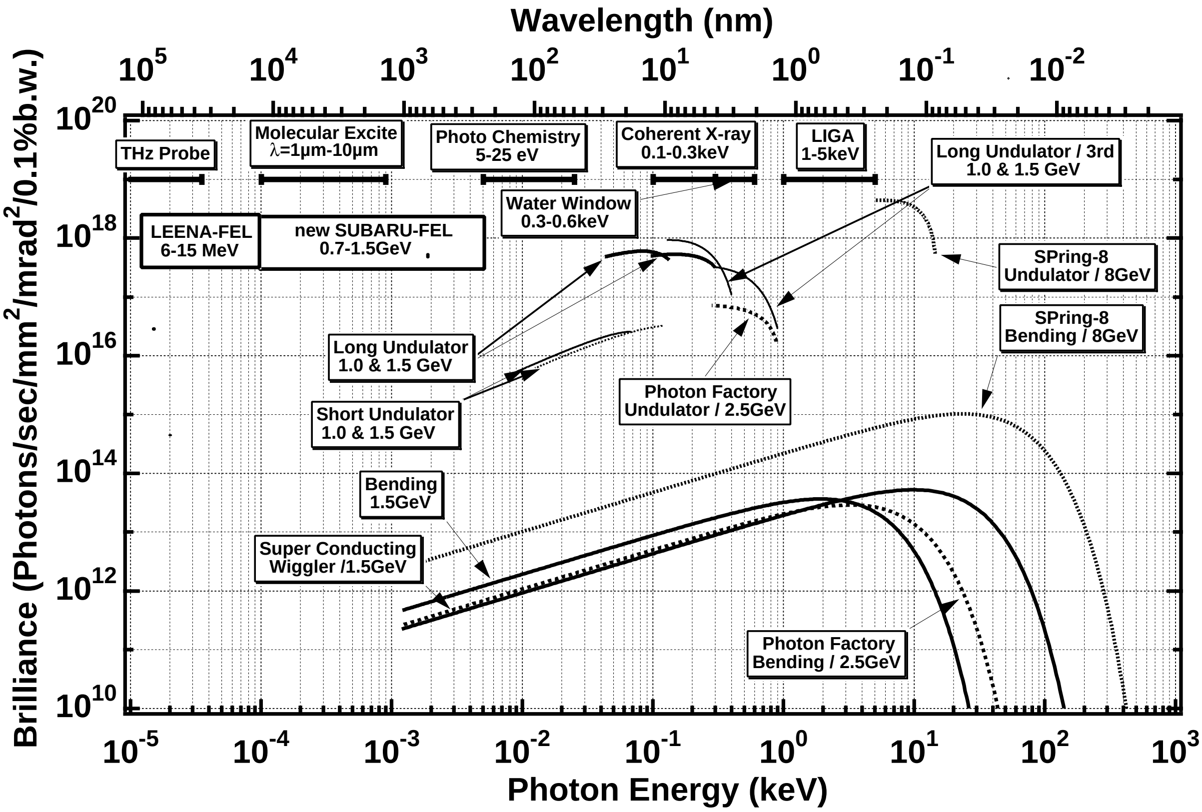

Figure 1: Expected brilliance of New SUBARU compared with SPring-8 and KEK-PF

ing laser-electron interaction or for beam cooling will be also tested in this ring. The main parameters of the ring are summarized in Table 1, and the lattice structure of the 1/4-ring is given in Table 2. The characteristics are (1) quasi-isochronous and/or variable momentum compaction factor α_p between $\pm$0.001, (2) 14-m LSS's, and (3)ready for short pulse radiation by such as backward Compton scattering by laser. The ring has a hexagon shape and the unit structure is a modified double bend achromat (DBA) cell with two 34-deg. bending magnet(BM) and one inverted BM(BI) at the middle. The typical envelope functions are shown in Fig.2. The HOM damped cavity with SiC duct developed and used at ISSP-SRL and KEK-PF[2] is installed.

2.2 Bunch Length and Sextupole Correction

The natural energy spread is calculated as $\sigma_\delta \simeq 4.8 \times 10^{-4}E$ where E is the energy of electron beam measured in GeV. The bunch length is given by $\sigma_t(sec) \simeq 2.3 \times 10^{-8}(AE)^{1/2}\sigma_\delta$ where $|\alpha_p| = A \times 0.001$. On the other hand, the energy spread would become more large due to microwave instability. Supposing the Keil-Schnell criterion is applicable, σ_δ and σ_t become twice the natural values at $\simeq 4$ mA/bunch for $A = E =$1 and $|Z/n| = 0.1(\Omega)$, which is almost the same result by ZAP. To reach ~3 psec of σ_t in disregard of beam intensity is one of the goals of the accelerator R&D. The control of higher order terms in α_p is very important for very small α_p or in a quasi-isochronous ring

Table 2: Structure of 1/4-ring of NS

Lattice	BIH $(B1)^{-1}$	(B1) BI	B (B1)	(B0) B	$(B0)^{-1}$ (B2)	B
(B0)=	D.5 D.1	Q2 S2	D* D2.	S1	D*	Q1
(B1)=	D.7 D.1	Q4 SD	D.1 D.4	SF	D.3	Q3
(B2)=	D.4* D.3	S1 QA	D.1* D7.	QC	D.6	QB
Quad.						
Name	Q1	Q2	Q3	Q4	QA	QB
l (m)	.28	.28	.18	.18	.28	.38
Name	QC					
l (m)	0.28					
Drift						
Name	D*	D.1*	D.1	D.3	D.4	D.4*
l (m)	.117	.118	.12	.28	.48	.482
Name	D.5	D.6	D.7	D2.	D7.	
l (m)	.506	.68	.69	1.78	7.124	
Rect. dipole						
Name		B	BI	BIH is a half of BI.		
Radius(m)		3.221	3.221	Pole face windings of BI		
Angle(deg.)		34.0	-8.0	gives sextupole,"SBI".		
Sext.						
Name	SF	SD	S1	S2	SBI	
l (m)	.1	.1	.1	.1	.9	

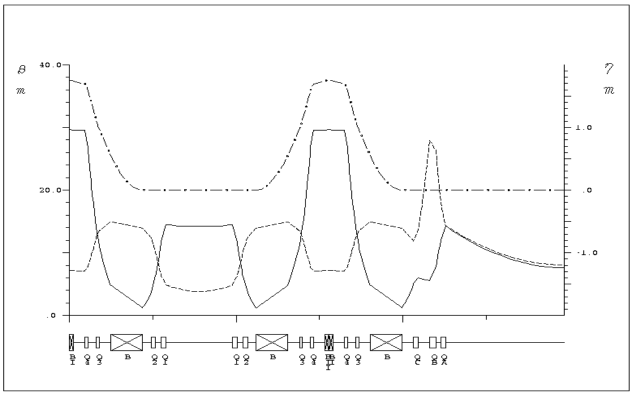

Figure 2: Twiss parameters of the quardrant for $\alpha_p \simeq -0.001$. Solid line: β_x, broken:β_y, dotted:dispersion(η)

Table 3: Main parameters of New SUBARU ID's.

Type	S-U	L-U	SC-W	FEL
$\lambda_u(mm)$	76	54	350	160 /320
N	30	200	1	32.5/16.5 $\times$2
g(mm)	25~ 58	25~ 44.5	30	40
K	1.3~ 5.3	0.8~ 2.5	262	1.7~ 12
L_u(m)	2.3	10.8	0.7	5.2$\times$2
W(nm)	8.1~ 149	1.4~ 29	0.1~ 0.23$^{a)}$	200~ 12000$^{b)}$
B	4 $\times 10^{16}$	10^{18}	7 $\times 10^{13}$	

a)critical photon energy, b)0.5~0.7 GeV operation

to keep free oscillation from higher order islands[3]. Five families of 50 sextupoles seem enough for these correction and dynamic aperture[4].

2.3 Insertion Device and Beam Line

Table 3 summarizes the insertion devices(ID's) where λ_u and N are the length and the number of period, g and L_u are the gap height and the total length. W is the covered region of photon wavelength and B is the brilliance ($photons/sec/mm^2/mrad^2/0.1\%b.w.$). As seen in the table, the K values of undulators are almost higher than 1 and the harmonics will be positively used (see Fig.1). There are four beam lines (BL) from ID and nine BL's from BM as shown in Table 4. Two BL's for EUVL(extreme ultraviolet lithography) and LIGA are under construction.

2.4 FEL / Optical Klystron

The main aims of the hardware development in FEL are to obtain lasing in the wave region less than 200 nm and high average power in μm region. The storage ring will be

Table 4: NS beam lines

Purpose	Source	Energy(keV)
EUVL	BM	0.08~0.3
LIGA	BM	3
Holography & coherence	L-U	0.08~0.3
Materials creation	BM	< 1
Photo-active materials	BM	< 1
Light source R&D	FEL	0.006
X-ray microscope	L-U/S-U	0.3~0.6
Topography	SC-W	> 2
Optical elements R&D	BM	0.05~1

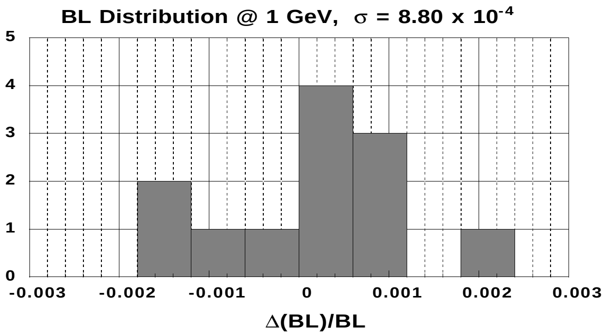

Figure 3: $\Delta(BL)/(BL)$ distribution of NS-BM

operated mainly at 0.5 $\sim$ 0.7 GeV because a simple calculation gives gains more than a few tens 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 which radius is ~13 m, is one fourth of the ring circumference.

2.5 Field Measurement of Magnet

Field measurement has been done at the manufacuring company. The typical results of 12 dipoles (iron block) is shown in Fig.3. The deviations of $\Delta(BL)/(BL)$ are 8.80×10^{-4} and 1.37×10^{-3} at the 1.0 and 1.5 GeV excitation level, respectively.The main source is the deviation of magnet gaps, 6.43×10^{-4}, and the remainings would be those of magnetization. These values are rather larger than those of laminated magnets and the maximum excursion of closed orbit is estimated as about 2 mm.

2.6 Magnet Alignment

The precise alignment of magnets has been put in practice. The network consists of the ring center, 6 central points of BI and 24 entrance & exit points of BM because of the large bending angle. Figure 4 shows the estimated errors of radial positions where the crosses are at the initial installation and the brack points are after the first adjustment. These errors should be reduced at the level of 0.05~0.1 mm in rms.

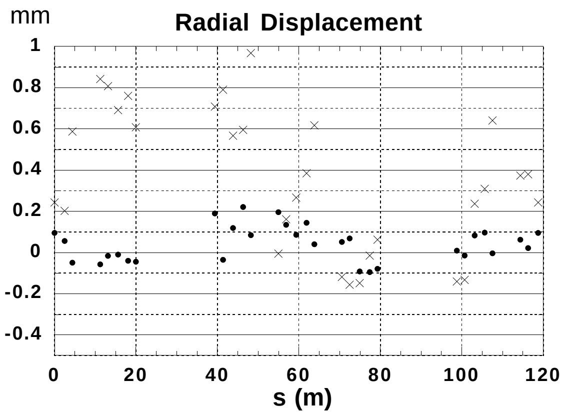

Figure 4: Radial displacement of BM & BI in NS. cross:initial installation, point:after the first adjustment

Table 5: Storage ring parameters of VSX and TOHOKU

	VSX	Tohoku	
Energy	2.0	1.5∼1.8	GeV
Stored current	400	300	mA
Circumference	388.45	194.2	m
Lattice type	DBA	DBA	
Betatron tunes	18.84/9.55	12.2/3.25	ν_x/ν_y
Straight sections	7m ×12	5m ×10	
	14.3m ×4	15m ×2	
Natural emittance (1σ)	5.1	7.4	nm
N0. of dipoles	32	24	
RF frequency	500.1	500.1	MHz
RF voltage	1.4	1.0	MV
Energy spread	0.067	0.066	%
α_p	0.000687	0.0014	
Bunch length (1σ)	4.04		mm

3 VSX PROJECT

The VSX project[5] is proposed by ISSP(Institute for Solid State Physics), University of Tokyo. The facility is an accelerator complex consists of a 250∼300-MeV linac, an energy booster synchrotron and a 2-GeV storage ring, and will be used for fundamental science by nationwide users. The maximum brilliance of ID and BM are 10^{20} and $10^{15} photons/s/mm^2/mrad^2/0.1\%bw$, respectively. The fundamental parameters of the storage ring are shown in Table 5. Now the project is in the drastic review and a rather small storage ring given in Table 6 is proposed at the first step. This ring, which consists of a kind of multi-bend achromatic (MBA) lattice, matching cells and LSS's, is limitted by diffraction and Touschek life, and very charanging for accelerator scientist. But it should be discussed enough wethere such a ring is practical and easy for users. The relative dimensions of these facilities are shown in Fig.5.

Table 6: Example of diffraction limitted ring

Energy	∼1.0	GeV
Circumference	∼200	m
Lattice type	MBA	
Straight sections	∼30m	×2
Natural emittance (1σ)	∼0.5	nm
Stored current	200	mA
α_p	0.0004	

4 TOHOKU SR RING

Laboratory for Nuclear Study, Tohoku University, has a 300-MeV linac and a 1.2-GeV booster-strcher ring with the circumference of ∼50m. The parameters of the proposed storage ring are shown in Table 5. Electron beam is injected at 1.2 GeV and accelerated up to 1.8 GeV, then storaged. To obtain lower emittance of about 4 nm, there is an operation mode breaking double achromaticity in short straight sections. Also lowering the storage energy, diffraction limitted radiation will be tried. The main aims of the project are almost same as those of VSX, but there are large activities at Tohoku University.

5 CONCLUDING COMMENTS

The main trend of storage rings for synchrotron light sources is to obtain higher brilliance and hence smaller emittance. But the theoretical minimum emittance of a ring with double achromatic straight sections is given by $\varepsilon_N(nm) \simeq (2 \sim 3) \times 10^4 E^2(GeV)/N^3$, where E is the beam energy and N is the total number of bending magnets.Therefore to get ∼1 nm emittance at GeV region, ring circumference becomes almost more than 400 m. Although breaking double achromaticity in straight sections(SS's) gives emittance of almost one tenth of the above, Touschek life in such a ring becomes inevitably very small and also there are small numbers of SS's for ID. The optimum usage of a storage ring and the best accelerator configuration to make a breakthrough in brilliance would be basically reconsidered.

6 REFERENCES

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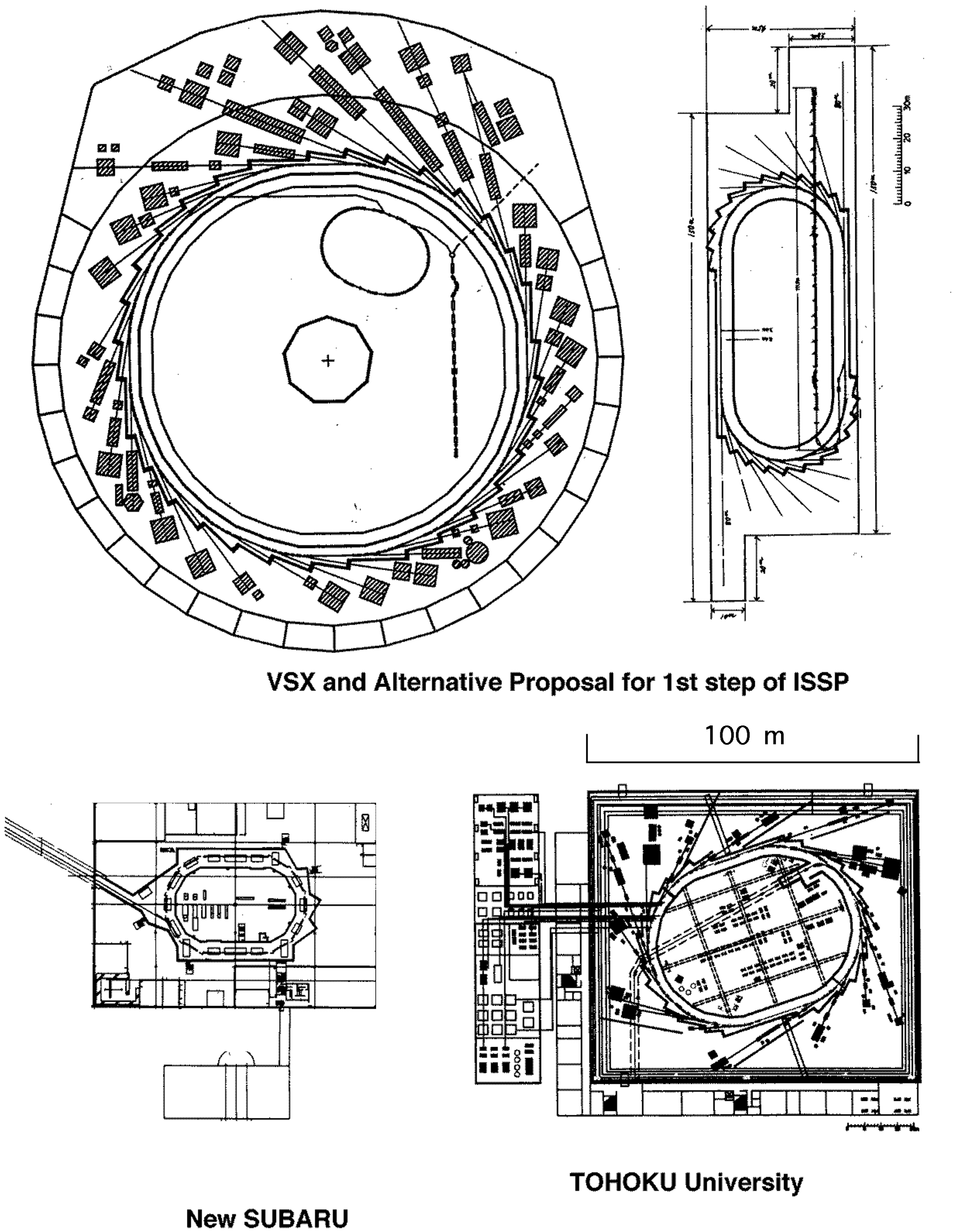

Figure 5: Plane view of each projects