# VUV AND SOFT X-RAY LIGHT SOURCE "NEW SUBARU"

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*Abstract*

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. The first beam commissioning from the SPring-8 LINAC is scheduled at the end of March, 1998. The aim of new SUBARU is to promote industrial activities in the local area (Hyogo prefecture) and to develop experimental investigations for new light sources.

## 1 INTRODUCTION

An 1.5 GeV electron storage ring for the light source in the region of VUV and soft X-ray is under construction at the SPring-8 site using the LINAC as an injector. The project team for new SUBARU between HIT and SPring-8 has been organized to establish the SR research complex in SPring-8. The storage ring has two very long straight sections (LSS,14 m each) comparing its small circumference (∼119 m). Two LSS's are initially used for a 11-m long undulator (L-U) and an optical klystron(FEL), and two short straight sections (4m each) for an 2.3-m undulator (S-U) and an 8-T super conducting wiggler (SC-W). The natural emittance @ 1.5 GeV is 67 nm because the total number of main dipole magnets is 12. The maximum brilliance is expected as $10^{18} (photons/sec/mm^2/mrad^2/0.1\%bw)$. Considering complemenarity to the most brilliant light source in the world, SPring-8, new SUBARU aims to produce a short pulse of radiation. New ideas using such as laser-electron interaction or for beam cooling will be also tested in this ring. The main purpose of the 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 enery 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 project 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 totally covered.

## 2 STORAGE RING

The main parameters of the ring are summarized in Table 1. The characteristics are (1) quasi-isochronous and/or variable momentum compaction facter $\alpha_p$ between ±0.001, and (2) 14-m-LSS's. The ring has a hexagon shape and the unit structure is a double bend achromat cell with two 34-deg. bending magnet(BM) and one invert BM at the middle. The typical envelope functions are shown in Fig.2. The excitation strength of quadrupoles for various $\alpha_p$ is shown in Fig.3. The HOM damped cavity with SiC duct developed and used at INS-SOR and PF[2] is installed.

Table 1: Main parameters of new SUBARU storage ring.

| Fundamentals | | |
|---|---|---|
| Injection energy | 1 | GeV |
| Operation energy | 1.5 | GeV |
| Stored current | $<$ 500 | mA |
| Circumference $L$ | 118.716 | m |
| Revolution period | 0.396 | $\mu$ sec |
| Revolution freq. | 2.525 | MHz |
| Harmonic No. | 198 | |
| RF frequency | 500 | MHz |
| Betatron Tunes | 6.21/2.17 | |
| Chromaticity ($\xi$) | -19/-7.5 | |
| $\alpha_p$ | 0.001 | |
| Straight sections | 4m | ×4 |
| | 14m | ×2 |
| **Operation parameters** | **1. 5** | **GeV** |
| Natural emittance ($1\sigma$) | 67 | nm |
| Coupling | 10 | % |
| Bending field | 1.55 | T |
| Critical photon | 0.53 | nm |
| | 2.33 | keV |
| Radiation loss/ Turn | 176 | keV |
| Damping time | | |
| Longitudinal | 3.42 | msec |
| X/Y | 6.56/6.73 | msec |
| Energy spread | 0.072 | % |
| RF voltage | $>$ 250 | kV |
| Bucket height | $>$ 0.83 | % |
| Synchrotron tune | 0.0021 | |
| Bunch length ($1\sigma_t$) | 26 | psec |
| Touschek life | $>$ 10 | hrs |

### 2.1 Bunch Length

The natural energy spread is calculated as $\sigma_\delta \simeq 4.8 \times 10^{-4} E$ where E is energy of electron beam measured in GeV and the bunch length is given by $\sigma_t \simeq 2.3 \times$

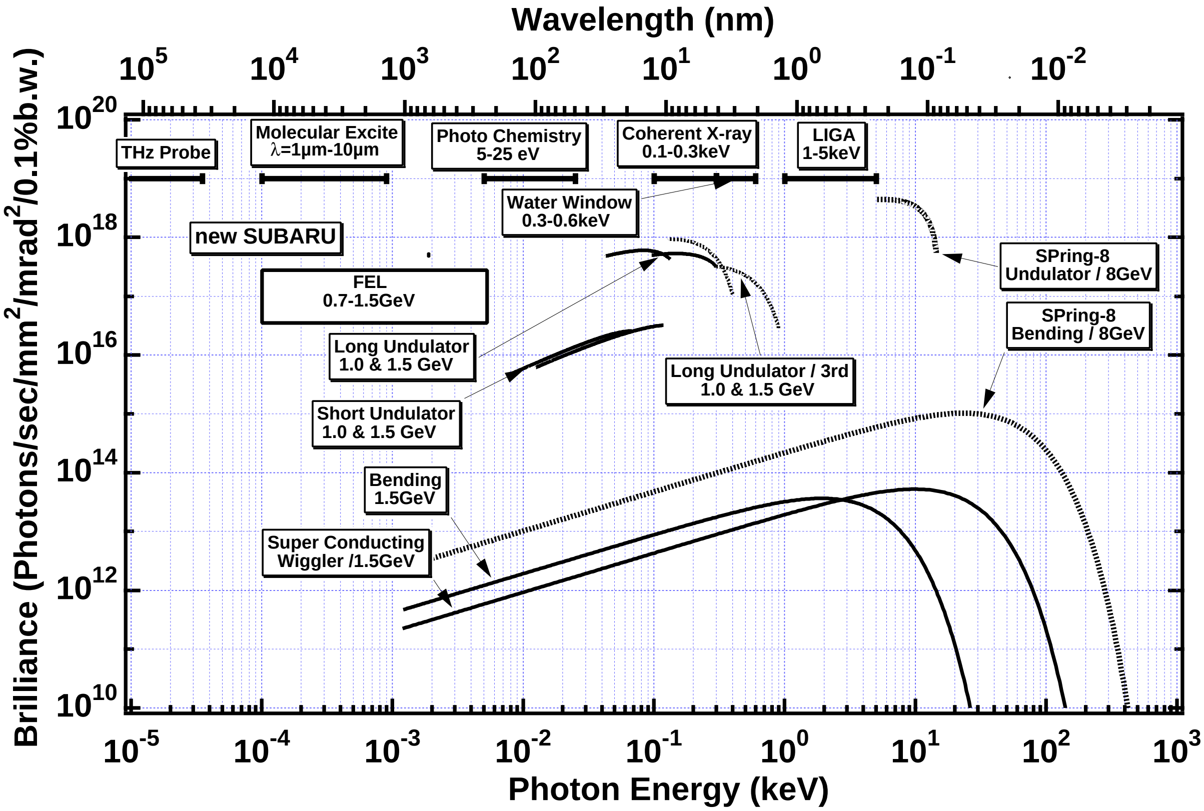


Figure 1: Expected brilliance of new SUBARU project compared with SPring-8.

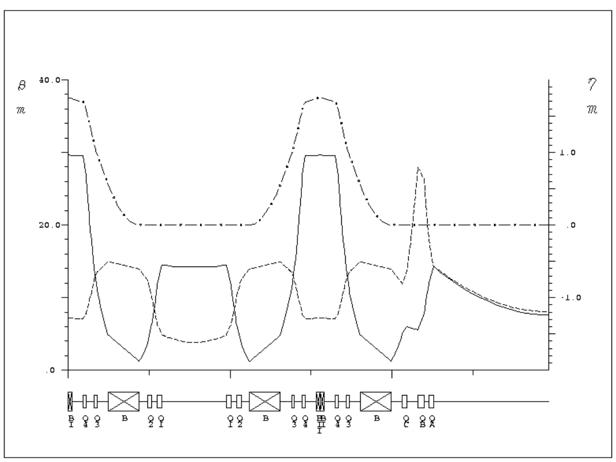

Figure 2: Twiss parameters of the quadrant for $\alpha_p \simeq -0.001$. Real line: $\beta_x$, broken:$\beta_y$, dotted:dispersion($\eta$).

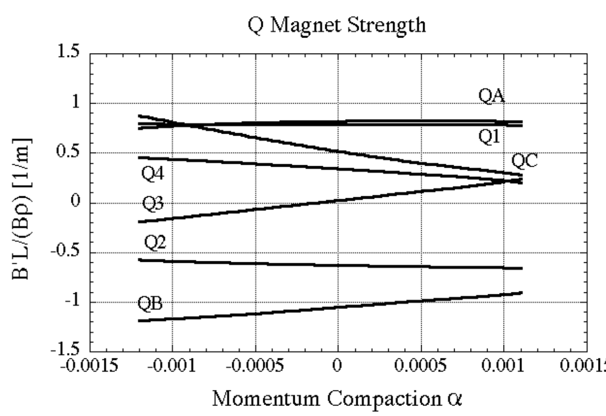


Figure 3: Strength of quadrupoles (QM) for various $\alpha_p$. (Q1,Q2 : main QM, Q3, Q4 : adjusting QM for $\eta$, QA, QB, QC : matching QM for LSS).

$10^{-8}(AE)^{1/2}\sigma_\delta(sec)$ where $|\alpha_p| = A\times0.001$, because the RF voltage can be always higher than 250 kV. On the other hand the energy spread would become more large due to microwave instability. Supposing the Keil-Schnell criterion is applicable, $\sigma_\delta$ and $\sigma_t$ become twice of 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 $\sigma_t$ is one of the goals of the accelerator R&D.

### 2.2 Sextupole Correction

The control of higher order terms in momentum compaction facter is very important in a very small $\alpha_p$ or isochronous ring. As the second order islands in synchrotron oscillation appear at[3],

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

where revolution period is expanded as,

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

the guide line for the free oscillation from these islands in the region of $|\delta| \leq 1\%$ becomes, $(1)|\delta_{\pm}| > 0.1,\ or\ (2)\alpha_2^2 - 4\alpha_1\alpha_3 < 0,\ or\ (3)|\alpha_3/\alpha_2| < 0.1(\alpha_1 \simeq 0),\ |\alpha_2/\alpha_1| < 0.1(\alpha_3 \simeq 0)$. (In this paper $\alpha_p$ and $\eta$(momentum slipping facter) are treated as the same value.) Then the equations for correction are,

$$d\xi_x/dg_j = (\beta_x D)_j/(4\pi),$$

$$d\xi_y/dg_j = -(\beta_y D)_j/(4\pi),$$

$$d\alpha_2/dg_j = -D_j^3/(2L),$$

$$dA_{n,p}/dg_j = (2^{1/2}8\pi n)^{-1}[\beta_x^{3/2} g \cdot exp\{i(p\theta + nQ_x)\}]_j,$$

$$dB_{1,q}/dg_j = (2^{1/2}4\pi)^{-1}[\beta_x^{1/2}\beta_y g \cdot exp\{i(q\theta + Q_x)\}]_j,$$

$$dB_{\pm,r}/dg_j = (2^{1/2}8\pi)^{-1}[\beta_x^{1/2}\beta_y g \cdot exp\{i(r\theta + Q_{\pm})\}]_j,$$

where $\xi = \Delta\nu/\delta,\ \nu$ is a tune of betatron oscillation, $\beta$ and $D$ are the envelope function and momentum dispersion, $L$ is the circumference of a ring, $g = l(\partial^2 B_y/\partial x^2)/B\rho$ and the suffix $j$ means the $j$-th sextupole. $p,\ q$ and $r$ are integers which satisfy $n\nu_x = p\ (n = 1$ or $3),\ \nu_x = q$, and $\nu_x \pm 2\nu_y = r,\ \theta$ is the azimuthal angle of the ring, $Q_a = \psi_a - \nu_a\theta, (a = x$ or $y),\ \psi_a$ is the phase advance of betatron oscillation and $Q_{\pm} = Q_x \pm 2Q_y$. Instead of the last three equations for resonance driving terms, so-called Collins' distortin function[4] should be carefully controlled. In new SUBARU, these are $A_{1,}, B_{1,6}$ and $B_{-,2}$ and 5 families of 50 sextupoles seem enough for the correction.

## 3 INSERTION DEVICE AND BEAM LINE

Table 2 summarizes the ID's where $\lambda_u$, 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 wave length and B is the brilliance ($photons/sec/mm^2/mrad^2/0.1\%bw$). S-U, L-U and SC-W mean the short undulator, long undulator and superconducting wiggler, repectively. Comments on this table are a) critical photon energy and b) 0.5∼0.7 GeV operation of electron beam. 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).

### *3.1 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 $\mu$m region. The storage ring will be operated mainly at 0.5 ∼ 0.7 GeV, because the 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 one period is selected by changing current connection. The phase slipping number is optimized at each wave length between 7 and 71. The distance between the mirrors, of which radius is ∼13 m, is one fourth of the ring circumference.

Table 2: 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 ×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 | 5.2×2 |
| W(nm) | 8.1∼ 149 | 1.4∼ 29 | 0.1∼ 0.23$^{a)}$ | 200∼ 12000$^{b)}$ |
| B | $4 \times 10^{16}$ | $10^{18}$ | $7 \times 10^{13}$ | |

### *3.2 Beam Line*

There are 4 beam lines (BL) from ID'S and 9 BL's from BM at the bending point of 10 degrees. Table 3 shows the present category in discussion.

Table 3: Beam lines in discussion.

| 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 |

In this year two BL's are constructed for EUVL (extreme ultra-violet lithography) and LIGA.

## 4 REFERENCES


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