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LATTICE DESIGN OF THE UVSOR-IV STORAGE RING

E. Salehi†, Y. Taira, UVSOR, Institute for Molecular Science, Okazaki, Japan
M. Fujimoto[1], L. Guo, NUSR, Nagoya University, Nagoya, Japan
M. Katoh[1], HSRC, Hiroshima University, Higashi-Hiroshima, Japan
[1]also at UVSOR, Institute for Molecular Science, Okazaki, Japan

Abstract

We are designing a storage ring lattice for the future plan of UVSOR. As a candidate, we have designed a storage ring of 1 GeV electron energy, which is higher than the present value, 750 MeV. The magnetic lattice is based on a compact double bend achromat cell, which consists of two bending magnets and four focusing magnets, all of which are of combined function. The circumference is 82.5 m. The emittance is 4 nm in the achromatic condition, which becomes lower in the non-achromatic condition. The lattice has moderately large dynamic aperture with four sextupole families. The lattice of 6-fold symmetry has six straight sections of 4 m long and six of 1.5 m long. Undulators can radiate nearly diffraction-limited light in VUV. If we install high field multipole wigglers at the short straight sections, they can provide high flux tender X-rays. We are expecting usage of a laser-based accelerator as the injector, which might be developed in the next decade. As an alternative plan, we have designed a traditional injector, which consists of a linear accelerator and a booster synchrotron that can be constructed inside of the storage ring.

INTRODUCTION

UVSOR is a low energy synchrotron light source, which had been operated since 1983. After two major upgrades [1-4], now it is called UVSOR-III. The circumference of the storage ring is 53 m and the electron beam energy 750 MeV. It has 8 straight sections and six of them are occupied with undulators of various kinds. One straight section is used for beam injection and another for RF acceleration. It has a moderately small emittance of about 17 nm and provides vacuum ultraviolet light of high brightness.

Nowadays, to meet the demand of diffraction limited light beam in the vacuum ultraviolet and x-ray range from scientific community, several synchrotron light sources, which have exceedingly small emittance less than 1nm, are under consideration, construction, or in operation [5-7]. In such a situation, we have started considering a future plan for UVSOR with an emittance smaller than at least a few nm to provide diffraction-limited light in the vacuum ultraviolet range. As the first step of the investigation, we have analyzed the present magnetic lattice of UVSOR based on tie diagram to explore the possibility to get a lower emittance with some minor changes in the configuration of magnets. We have found a few optics which has significantly (but not drastically) smaller emittance around 10 nm than the present value, 17 nm which may be useful for some special experiments [8]. To reach the low emittance around a few nm, we have started designing a totally new storage ring. The storage ring has a higher electron energy, 1 GeV and a larger circumference, 82.5m. The lattice consists of twelve double bend cells. Among twelve straight sections, two sections will be used for the injection and RF cavity, and ten sections will be used for insertion devices.

In this paper, we will describe the design of the new lattice for UVSOR-IV and the related beam dynamics studies.

LATTICE DESIGN

The lattice has been designed based on a compact double bend achromat cell (DBA), which consists of two bending magnets and four focusing magnets, all of which are combined function magnets. Two sextupole families are located in between two combined dipoles for the chromaticity correction and two harmonic sextupole families are also employed to correct the high order geometric aberrations. This lattice has twelve DBA cells with six long straight sections about 4 m and six short straight sections around 1.5 m long. These lengths are same as those of UVSOR-III. This may enable us to use the undulators at UVSOR_III in the new ring.

The lengths of the straight sections can be longer if the larger circumference is allowed.

It is noted that this lattice has a flexibility on the dispersion function at the straight sections, which enables to realize various operation modes such as of achromatic, lower emittance, or isochronous.

A tune survey was performed to find the linear optics with a low emittance and appropriate optical functions. ELEGANT [9] was used for the calculations. The emittance is around 4 nm in the achromatic condition, which becomes lower in the non-achromatic condition. Figure 1 shows the lattice functions in the achromatic condition. The major parameters are listed in Table 1 and are compared with those of UVSOR-III.

It is noticeable that if we occupy three of short straight sections with 2T multipole wigglers in symmetry, the energy loss due to the radiation in the wigglers enhances the damping effect and the emittance reduces to 3.7 *nm*. These wigglers can provides tender X-ray, which are hardly accessible at the present UVSOR-III.

† elham@ims.ac.jp

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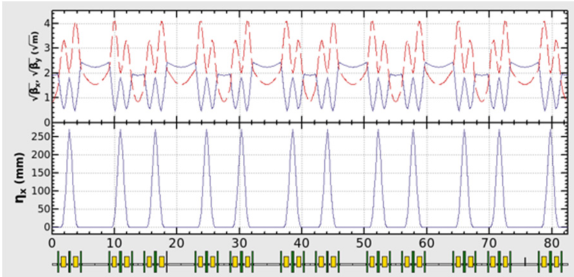

Figure 1: Lattice function of 1 GeV storage ring for UVSOR-IV. The blue and red lines show the horizontal and vertical betatron tune, respectively.

Table 1: Lattice Parameters

	UVSOR-III	UVSOR-IV
Electron energy	750 MeV	1 GeV
Stored current	300 mA	300 mA
Circumference	53.2 m	82.5 m
RF frequency	90.1 MHz	89.4 MHz
Harmonic num.	16	26
RF voltage	120 kV	100 kV
Coupling ratio	0.01	0.01
Energy spread	0.000526	0.000576
Emittance	16.9 nm	4.3 nm
Betatron tunes	(3.75, 3.20)	(8.63, 3.19)

Dynamic Aperture

In a low emittance lattice, strong quadrupoles are generally employed which result into a large negative chromaticity. For chromaticity correction, strong sextupoles are needed. Due to their nonlinear effects, the dynamic aperture, which corresponds to the maximum betatron amplitude where electrons remain bounded, decreases. It should be, anyway, large enough for the beam injection and storage. We use ELEGANT [9] to optimize the dynamic aperture without considering multipole errors and misalignment errors. The strengths of the harmonic sextupoles are selected for maximizing the dynamic aperture. Figure 2 shows the dynamic aperture for on- and off energy (+/- 1,2%) particles at the straight section, which is calculated by tracking 1024 turns. In this optics, the horizontal aperture for the on-momentum electron is sufficiently large, about -23 to 15 mm and vertical aperture is about 6 mm. Further study is ongoing to realize a larger dynamic aperture for off- momentum particles and also with various machine errors.

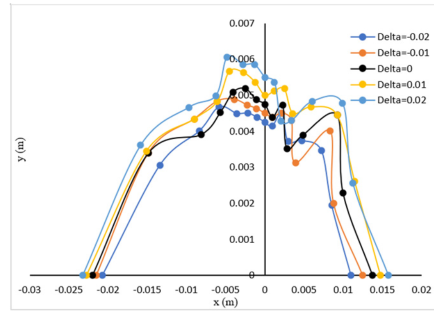

Figure 2: Dynamic aperture of optic for different energy deviation. The particle tracking has been run for 1024 turns passing through the storage ring.

TOUSCHEK LIFETIME AND INTRA-BEAM SCATTERING EFFECTS

The electron beam lifetime had been one of the most important parameters for a synchrotron light source. In recent years, the so called top-up injection is widely employed and the beam lifetime is less important than before. However, to reduce the beam intensity fluctuation and to keep the radiation level sufficiently low for the safety regulation, the lifetime is still an important parameter. Touschek scattering, in which the electrons in a same bunch scatter each other, get large longitudinal momentum, come out of the momentum aperture and get lost, dominates the lifetime in low emittance storage rings, particularly of low energy. Figure 3 shows Touschek lifetime vs. RF voltage. The calculation of Touschek lifetime is based on the momentum acceptance (MA). The relevant MA is the minimum of the RF MA (RF bucket height) and the lattice MA. The RF MA is given by the RF voltage and it is independent of the location in the lattice. The local lattice MA which depends on where the scattering event occurred and varies along the lattice, is obtained with tracking by ELEGANT. It can be seen from Fig. 3 that the lifetime increases with the RF voltage and then saturates as electrons are lost due to exceeding the lattice MA during their post-scattering trajectories.

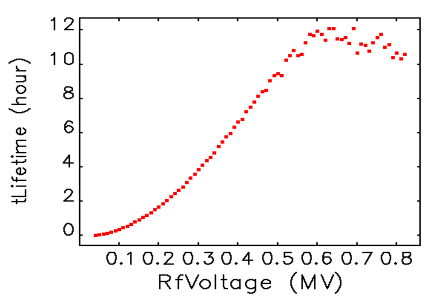

Figure 3: Touschek lifetime vs RF voltage.

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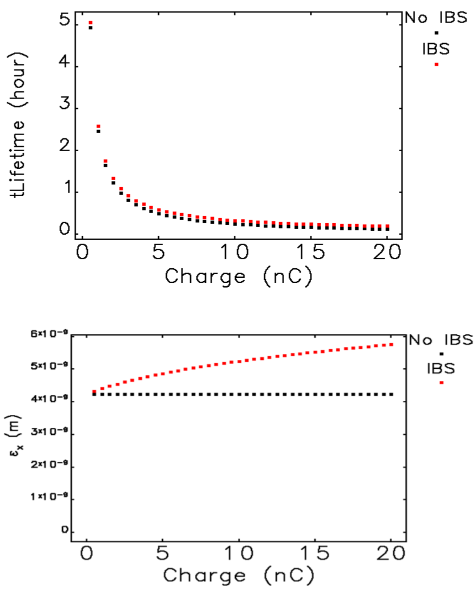

Figure 4: IBS effect on Touschek lifetime (top) and longitudinal emittance (bottom) versus bunch charge.

Intra-beam scattering (IBS), which is the result of the multiple small-angle Coulomb scattering of charged particles in the beam, can increase beam emittance. Figure 4 shows the Touschek lifetime (top) and the emittance (bottom) versus bunch charge with IBS effect (red) and without IBS effect (black). From Fig. 4 (top), we see that IBS effect increases the Touschek lifetime, while the emittance is increased as shown in Fig. 4 (bottom). In single-bunch mode, the new lattice design would have a bunch charge of about 11.6 nC , and the Touschek lifetime would be of about one hour. The increase of the emittance due to IBS effect is around 26% that is far from the target emittance. Fortunately, there are some techniques that can reduce its impact, such as increasing the transverse coupling using some designated skew quadrupoles. Another technique is the addition of a harmonic cavity to produce a bunch lengthening, which is routinely used at UVSOR-III [10]. To check the possibility of using harmonic cavity, we run the simulation code with different values of bunch length. Figure 5 shows the result of IBS effect on the emittance versus bunch length for bunch charge corresponding to 11.6 nC. The plot shows that the lengthening of the bunch due to harmonic cavity up to 80 mm can decrease the effect of IBS on the emittance to an acceptable level with to $\epsilon_0 = 4.3\ nm$.

CONCLUSION

A new 1 GeV storage ring lattice with a circumference of 82.5 m has been proposed to upgrade the UVSOR synchrotron facility. The lattice has been designed based on DBA cell to have a low emittance. Optimising the magnet arrangement and the working point, a small natural emittance 4.2 nm is obtained in the achromatic condition. The lattice has twelve straight sections, ten of them are available for insertion devices. Occupying 3 short straight sections with 2T multipole wigglers can reduce the natural emittance to 3.6 nm-rad. Moreover, these wigglers provide intense tender X-rays.

Dynamic aperture was studied for on- and off-momentum particles without machine errors. Our simulations show that IBS effect on the beam emittance is significant. One possible technique to decrease the IBS effect is lengthening the bunches by using harmonic cavity. Our simulations shows that the increasing of the bunch length by 80 mm can reduce IBS effect on the emittance to an acceptable level.

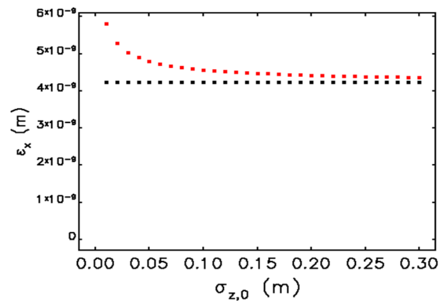

Figure 5: Longitudinal emittance vs bunch length with IBS (red) without IBS (black) at the bunch charge of 10.1nC.

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