ANALYSIS OF UVSOR-III STORAGE RING LATTICE

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Abstract

In this study, we investigate the present magnetic lattice of the UVSOR electron storage ring to explore the possibility to get a lower emittance with the present configuration of the magnetic lattices. For this purpose, we surveyed the periodic solutions as drawing a tune diagram to map the emittance and the dynamic aperture. Even though, we could not find a solution which has a drastically small emittance, which means that the present optics is fairly optimized for low emittance and also for other requirements, we have found a few solutions which has a small emittance around 10 nm, which is significantly smaller than the present value, 17 nm. They may be useful for some special low emittance operation modes dedicated to developments on new light sources technologies and their applications.

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 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 provide vacuum ultraviolet light of high brightness from the undulators and synchrotron radiation of wide range from the bending magnets.

Nowadays, the generation of nearly diffraction limited light beam in the vacuum ultraviolet and X-ray ranges attracts interests. Aiming to this, several synchrotron light sources, which have exceedingly small emittance less than 1nm, are under consideration, construction, or in operation. In such a situation, we have started considering a future plan for UVSOR with an emittance smaller than 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 with the present configuration of the magnetic lattice. Generally, low emittance lattice will be faced with reduction of dynamic aperture. We surveyed the betatron tunes as seeking a solution which have smaller emittance and sufficiently large dynamic aperture for beam injection. Moreover, we have studied Touschek scattering which limits the beam lifetime and intra-beam scattering (IBS) which tends to increase the beam emittance. We present results from simulation studies using Elegant code [4].

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HISTORY OF MAGNETIC LATTICE OF UVSOR

The original lattice of UVSOR (Fig. 1, top) consisted of four double bend achromat cells which have been widely used in the second and third generation synchrotron light sources. It had four straight sections and moderately large emittance, 160 nm. After 20-year operation, a new magnetic lattice was designed to have a small emittance of

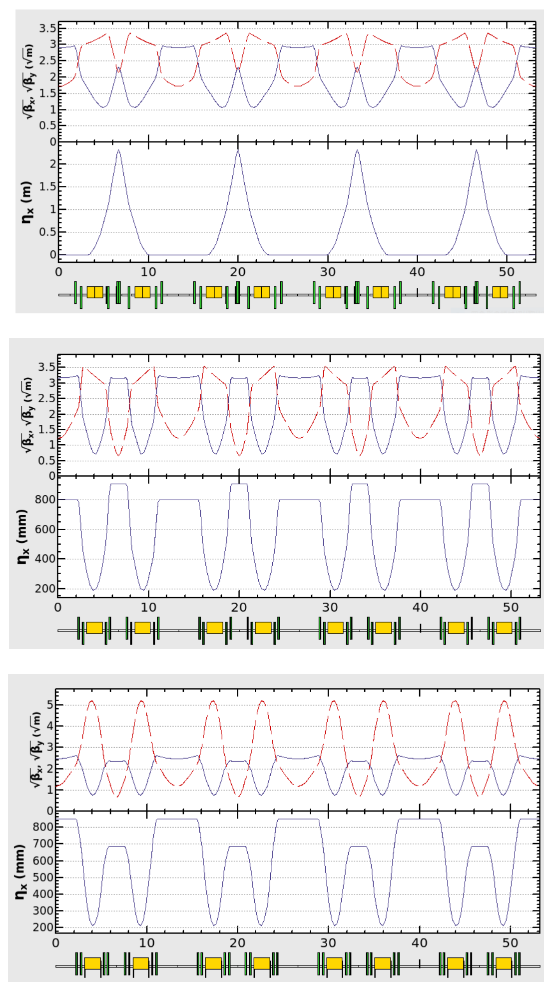

Figure 1: From top to bottom; Optics of UVSOR, UVSOR-II and UVSOR-III. The emittance is 165 nm, 27 nm and 17 nm, respectively.

27 nm [1, 2] and new four short straight sections were created (Fig. 1, middle). In this upgrade, all the quadrupole magnets are replaced with multipole magnets producing both quadrupole and sextupole fields. After this upgrade, the ring was called UVSOR-II.

About ten years after, the bending magnets were replaced with those of combined function type producing dipole, quadrupole and sextupole fields and a smaller emittance of, 17nm was achieved [3, 4] (Fig. 1, bottom). Now the ring is called UVSOR-III.

LATTICE DESIGN OF UVSOR

Tie-diagram

We have analyzed the present magnetic lattice of UVSOR III based on a tie diagram. To draw the tie diagram, four family quadrupoles are grouped into two families (QF and QD) located symmetrically around each bending magnet. The two quadrupole strengths are surveyed, as checking the absolute value of the trace of the transfer matrix for one revolution smaller than 2, both in horizontal and vertical. The result is shown in Fig. 2. The area where the periodic solution exists is indicated with colours which represents the emittance. We found a few areas which give emittance smaller than the present value 17 nm. However, there seems no solution which gives the emittance much smaller than 10 nm. The hardware limitations of the quadrupole field strengths are indicated by dashed lines in the figure. For the operation energy, 750 MeV, a part of the low emittance region is out of the limitation. However, if the machine is operated at 600 MeV, most of the low emittance area is within the limitation. It should be noted that the emittance is proportional to the square of the electron energy, the low energy operation would give even smaller emittance.

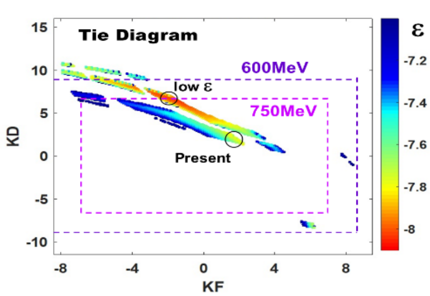

Figure 2: Tie diagram of UVSOR-III magnetic lattice. KF and KD are quadrupole strengths, $B'/B\rho$. The hardware limitations of the quadrupole magnets are indicated by dashed lines for two operating energy, 750 MeV and 600 MeV. The emittance is indicated by the colour in the logarithmic scale. The operating areas of the present optics and the low emittance optics are indicated by black circles.

Tune survey

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 decreases, which should be large enough for the beam injection and storage.

To search low emittance lattice with large dynamic aperture, we surveyed the betatron tunes and mapped the dynamic aperture and the emittance on the tune diagram. Based on the result, we can find a reasonable operating point which gives emittance as small as possible with large dynamic aperture acceptable for the machine operation.

The survey was performed as follows. For a given betatron tunes, the strength of sextupoles is optimized to correct linear chromaticity. In this study, the sextupoles are also grouped into two families as the quadrupoles. Then, the dynamic aperture is evaluated by particle tracking simulation. This procedure is repeated for the operating point where the periodic solution exists. Tune survey results for the dynamic aperture area (up) and the emittance (botton) are shown in Fig. 3.

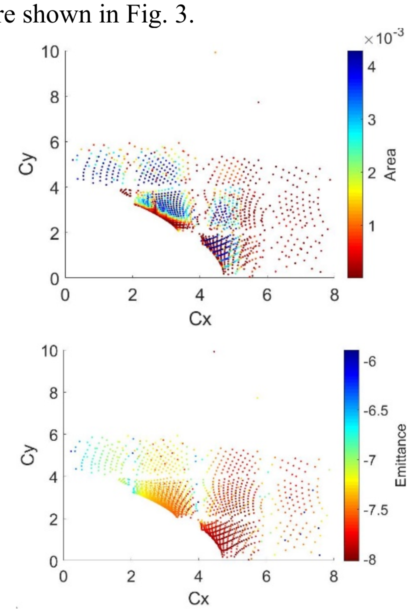

Figure 3: Results of tune survey for emittance (top), dynamic aperture area (bottom).

OPTICS OF NEW LOW EMITTACE LATTICE

We selected two operation tune points on Fig. 3, which give emittance around 10nm and moderately large dynamic aperture. Table 1 presents their major parameters. Their optical functions are presented in Fig. 4. In these optics, the vertical betatron function at the short straight sections are not as small as the present optics. Therefore, these optics may not be compatible with the operation of the narrow gap undulators, which are currently operational. However, in some special studies which requires a small emittance as possible, these optics may be useful.

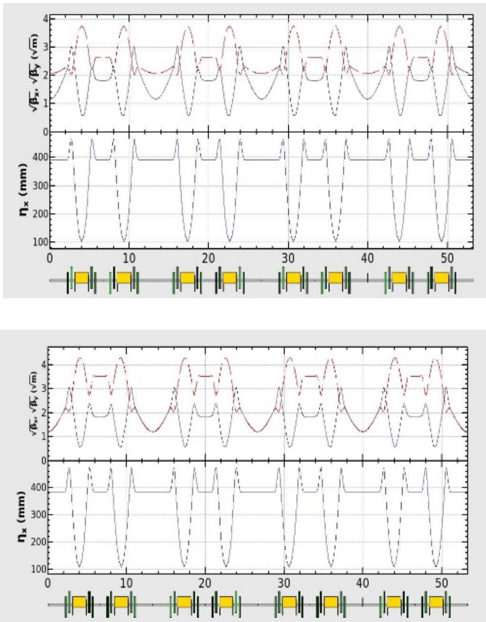

Figure 4: Examples of new low emittance optics. Upper; optics which gives a small emittance of 9.6 nm at 750 MeV. Lower; optics which gives a moderately small emittance of 10 nm.

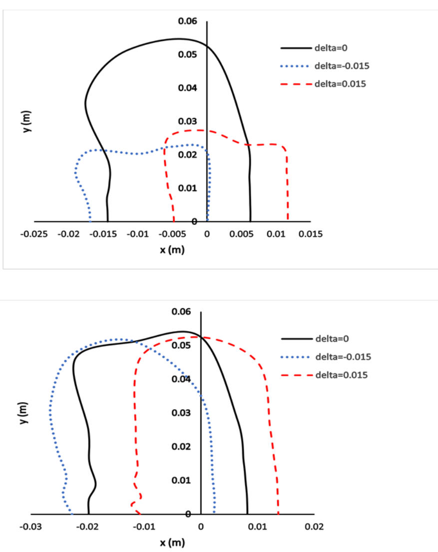

Figure 5: Dynamic aperture of optics A (top) and optic B (bottom) for different particle momentum spread, δP/P=0, -0.01, and 0.01.

Table 1: Parameters of New Optics

	UVSOR-III	Optics A	Optics-B
Electron Energy	750 MeV	750 MeV	750 MeV
Emittance	16.9nm	9.6 nm	9.9 nm
Betatron tunes (H, V)	(3.75, 3.20)	(5.25, 1.39)	(5.20, 1.84)

Figure 5 shows the dynamic aperture of optics A (top) and optic B (bottom) for different particle momentum spread, δP/P=0, -0.01, and 0.01. The machine errors are not included. The dynamic aperture is calculated by tracking 1024 turns in the simulation. In optics A, the horizontal aperture for the on-momentum electron is about -10 to 5 mm and vertical aperture is about 50 mm. In Optics B, the horizontal aperture for the on-momentum electron is about -20 to 10 mm and vertical aperture is about 50 mm.

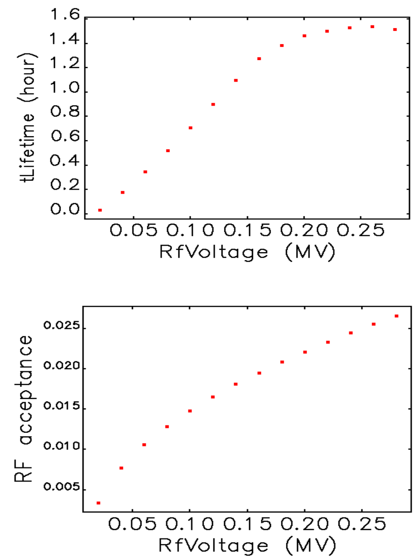

Figure 6: Touschek lifetime vs RF voltage (top) RF acceptance vs RF voltage (bottom).

TOUSCHEK LIFETIME AND INTRA-BEAM SCATTERING EFFECT

The electron beam lifetime had been one of the most important parameters for a synchrotron light source. In these years, so called top-up injection is widely employed, 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 radiation safety regulation, the lifetime is still an important parameter. Touschek scattering, in which the electrons in a same bunch scatters each other, get large longitudinal moment, come out of the momentum aperture and are lost, dominates the lifetime at low emittance storage rings, particularly of low energy. Figure 6 (top) represents Touschek lifetime vs. RF voltage. The calculation of Touschek lifetime is resulted from 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 independent of the location in the lattice as shown in Fig. 6 (bottom). The local lattice MA which depends on where the scattering event occurred and varies along the lattice, derived from tracking by Elegant. It can be seen from Fig 6 (top), the lifetime increases as the RF voltage and then saturates as electrons are lost due to exceeding the lattice MA during their post-scattering trajectories.

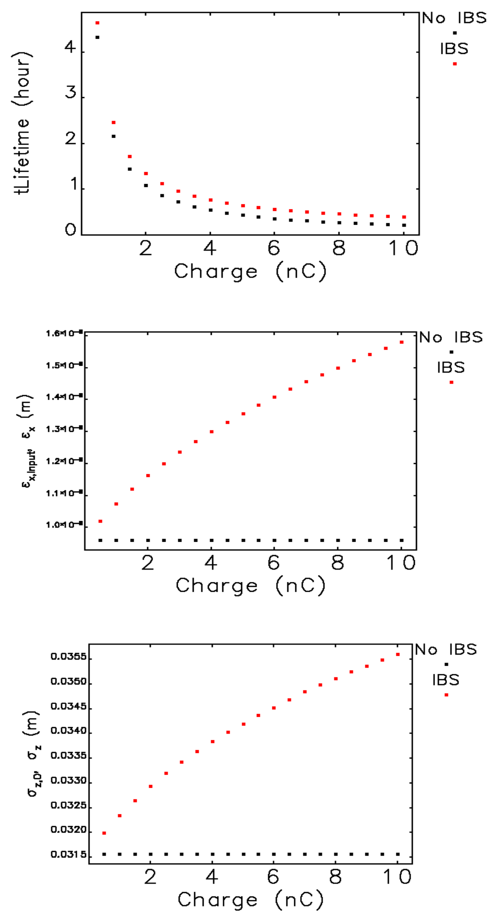

Figure 7: IBS effect on Touschek lifetime (top), longitudinal emittance (middle), and bunch length (bottom) versus bunch charge.

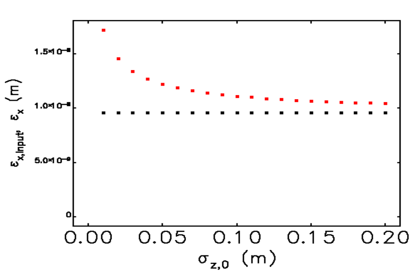

Figure 8: Longitudinal emittance vs bunch length with IBS (red) without IBS (black) at the bunch charge of 4.5nC.

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 [6]. Figure 7 shows the Touschek lifetime (top), the emittance (middle), and the bunch length (bottom) versus bunch charge with IBS effect (red) and without IBS effect (black). From Fig. 7 (top), IBS effect increases Touschek lifetime while the emittance is increases as shown in Fig. 7 (bottom). At the multi-bunch mode of UVSOR, the bunch charge is 4.5 nC, Touschek lifetime by simulation is 0.7 hours. The increasing of the emittance due to IBS effect is around 45% 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 and another technique is the addition of a harmonic cavity to produce a bunch lengthening, which is routinely used at UVSOR-III [5]. To check the possibility of using harmonic cavity, we run the simulation code with different values of bunch length. Figure 8 shows the result of IBS effect on the emittance versus bunch length for bunch charge corresponding to 4.5 nC. The plot shows that the lengthening of bunch due to harmonic cavity up to 5 times the one calculated with the fundamental cavity can decrease the effect of IBS on the emittance by 10%.

CONCLUSION

To analyse the optics of UVSOR for the present magnetic configuration, we surveyed the betatron tunes and mapped the dynamic aperture and the emittance on the tune diagram. We have found a few optics which has significantly (but not drastically) smaller emittance around 10 nm than the present value, 17 nm. We considered two candidates for further study. They have a relatively larger vertical betatron function at the short straight sections where the narrow gap undulators are presently operational. It may be useful for some special experiments which requires small emittance. This optic requires larger quadrupole strengths, which is close to or beyond the hardware limitation at 750 MeV. It may be interesting to realize this at 600 MeV. In this case, the emittance would be further reduced to 6 nm.

We investigated IBS effect in the low-emittance optic of UVSOR. Our simulations shows that IBS effect on the beam emittance is strong. One possible technique to decrease the IBS effect is lengthening bunch due to using harmonic cavity. Simulations presented here shows that a factor 5 increase of the bunch length can reduce IBS effect to 10% of emittance increase at the bunch charge corresponding to 4.5 nC.

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