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LATTICE DESIGN FOR A FUTURE PLAN OF UVSOR SYNCHROTRON

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Abstract

UVSOR is a 750 MeV synchrotron light source with a moderately small emittance of about 17 nm. We surveyed the periodic solutions as drawing a tie diagram and mapped the emittance and the dynamic aperture on the tune diagram. The aim of this work is to search a possible low emittance solution without a major change of the lattice. Although, we could not find a solution which has a drastically small emittance, we have found a few solutions which has a significantly smaller emittance than present value. 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, 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.

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 1 nm, 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 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. 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. In this report, we present results from simulation studies using Elegant code [1].

OVERVIEW OF UVSOR FACILITY

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. This value was typical as a second-generation synchrotron light source. After 20-year operation, a new magnetic lattice was designed [2, 3]. The new lattice had a small emittance of 27 nm and new four short straight sections in adding to the original four straight sections (Fig. 1, middle). In this upgrade, all the quadrupole magnets are replaced with multipole magnets which can produce 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, which are capable of producing dipole field, quadrupole field and sextupole field. A new optics was designed, which has a smaller emittance, 17 nm [4] (Fig. 1, bottom). Now the ring is called UVSOR-III.

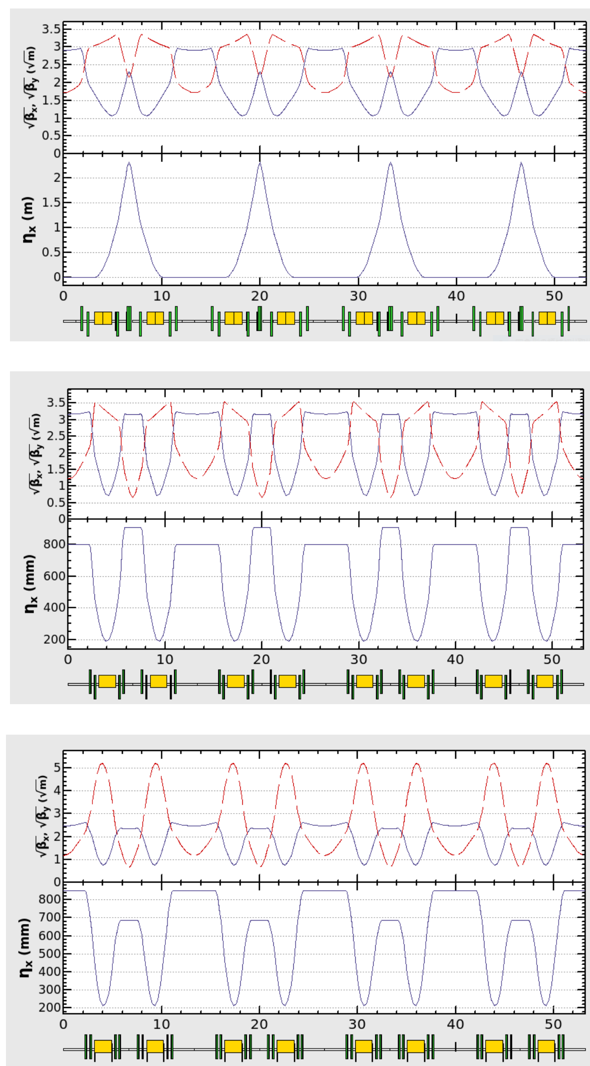

Figure 1: From top to bottom; Optics of UVSOR, UVSOR-II and UVSOR-III. The emittance is 165 nm, 27 nm and 17 nm, respectively.

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LATTICE DESIGN

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 the bending magnets. 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 colors 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 dotted 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.

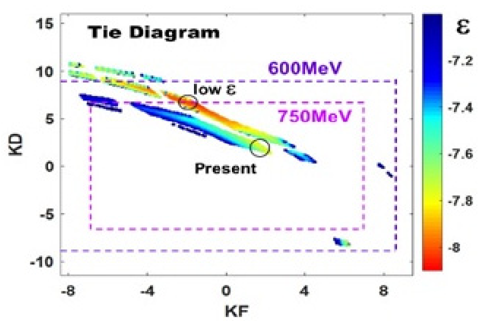

Figure 2: Tie diagram of UVSOR-III magnetic lattice. KF and KD are quadrupole strengths, $B'/B\rho$. The hardware limitations of the quadrupole magnets are indicated by dashed lines for two operating energy, 750 MeV and 600 MeV. The emittance is indicated by the colour in the logarithmic scale. The operating 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 is the maximum betatron amplitude that electrons remain bounded. It should be large enough for the beam injection and storage.

It is difficult to obtain analytically the dynamic aperture in a realistic machine. We employed a simulation method. 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.

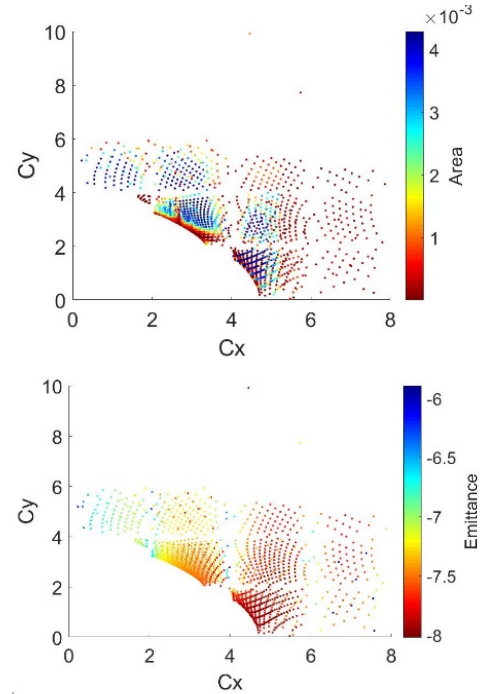

Figure 3: Results of tune survey for emittance (top), dynamic aperture area (bottom).

OPTICS AND DYNAMIC APERTURE FOR NEW LOW EMITTANCE LATTICE

We selected two operation tune points on Fig. 3, which give emittance around 10 nm 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, this optics may not be compatible with the operation of the narrow gap undulators, which are operational. However, in some special studies which requires a small emittance as possible, these optics may be useful.

Table 1: Parameters of New Opyics

	UVSOR-III	Optic A	Optic B
Electron energy	750 MeV	750 MeV	750 MeV
Emittance	16.9 nm	9.6 nm	11.1 nm
Betatron tunes	(3.75, 3.20)	(5.23, 1.39)	(4.71, 1.78)

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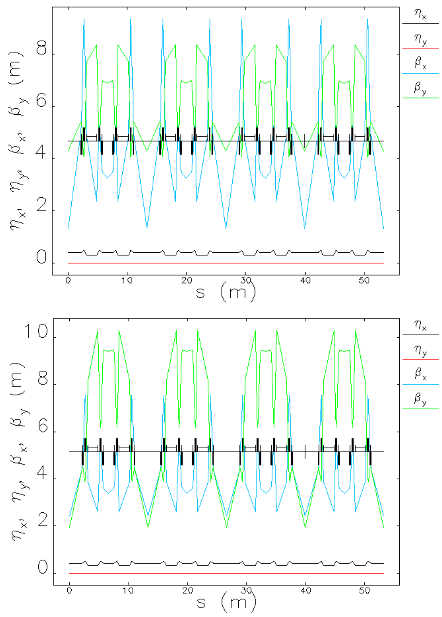

Figure 4: Optics of a low emittance lattice with emittance of 9.6 nm (top) and 10.2 nm (bottom) at 2.5 GeV.

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 -48 to 48 mm and vertical aperture is about 50 mm. There is no significant change on the dynamic aperture by energy deviation.

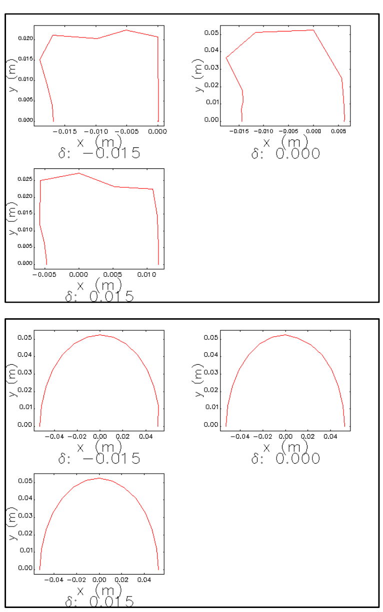

Figure 5: Dynamic aperture of optic A (top) and optic B (bottom) for different energy deviation. The particle tracking has been done for 1024 turns passing through the storage ring.

CONCLUSION

We have analyzed the optics of UVSOR for the present magnetic configuration. We have found a few optics which has significantly (but not drastically) smaller emittance around 10 nm than the present value, 17 nm. We found 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.

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