LATTICE DESIGN FOR A FUTURE PLAN OF UVSOR

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Abstract

As the first step of the design study for a future plan of UVSOR synchrotron, we analyze the magnetic lattice of the present UVSOR (UVSOR-III). We draw a "tie diagram" and seek a possible lower emittance optics. Although we could not find an optics which has a drastically small emittance, we have found a few optics which has a significantly smaller emittance than present value and may be considered for a future upgrade.

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.

Now, several synchrotron light sources, which have very small emittance less than 1nm, are under consideration, construction or operation, aiming to generate nearly diffraction limited light beam in the vacuum ultraviolet and X-ray ranges. In such a situation, we have started considering a future plan for UVSOR. One direction is to achieve a small emittance to provide diffraction-limited light in the vacuum ultraviolet range. For this purpose, the emittance smaller than at least a few nm is required. As the first step of the investigation, we have analyzed the present magnetic lattice of UVSOR to explore the possibility to get a low emittance with some minor changes. In this report, some preliminary results will be presented.

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 has four straight sections and moderately large emittance, 160 nm. This value was typical as a second generation synchrotron light source. However, after 20 year operation, the ring was losing competitiveness among new light sources of third generation. Therefore, a new magnetic lattice was designed and it was realized in 2003 [1, 2]. 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 are capable of 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, which are capable of producing dipole field, quadrupole field and sextupole field. A new optics was designed, which has a smaller emittance, 17 nm [3] (Fig. 1, bottom). In parallel, the top-up operation scheme was introduced [4]. By moving the injection point from a long straight section to a neighboring short straight section, the long straight section was opened for installing an undulator. Now the ring is

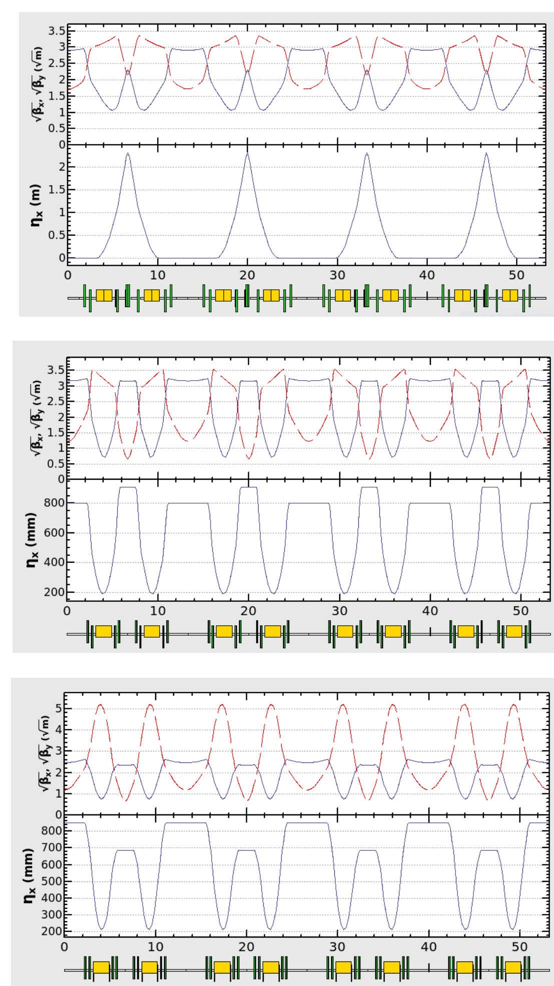


Figure 1: From top to bottom; Optics of UVSOR, UVSOR-II and UVSOR-III. The emittance is 165 nm, 27 nm and 17 nm, respectively.

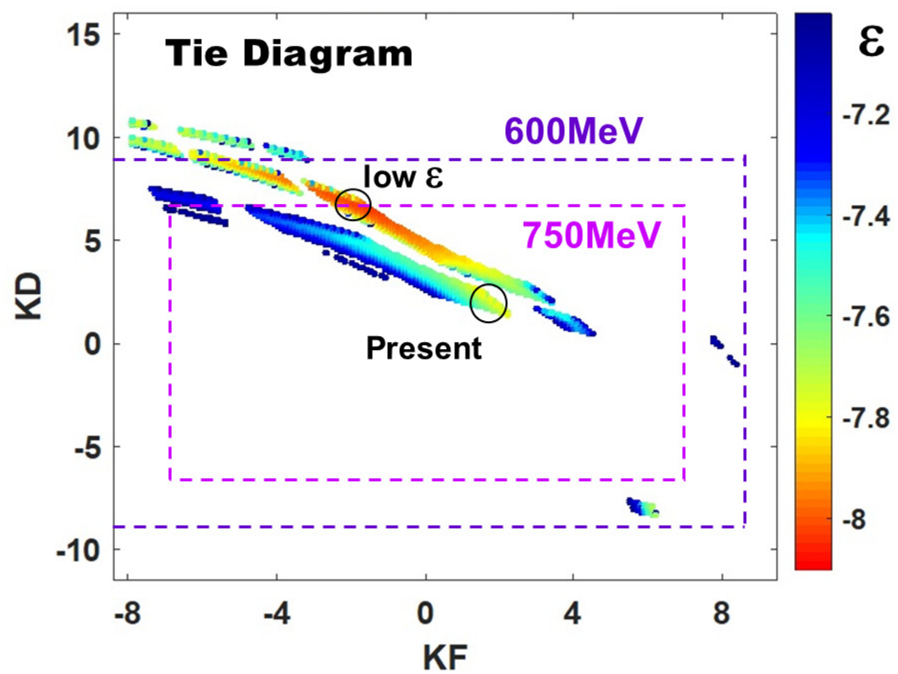
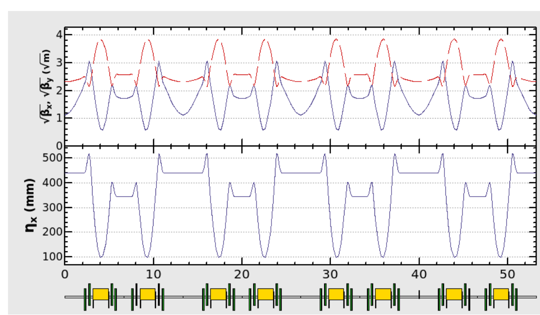


Figure 2: Tie diagram of UVSOR-III magnetic lattice. KF and KD are quadrupole strengths, $B'/B\rho$. The hardware limitations of the quadrupole magnets are indicated by dashed lines for two operating energy, 750 MeV and 600 MeV. The emittance is indicated by the color in the logarithmic scale. The operating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

called UVSOR-III.

TIE-DIAGRAM OF UVSOR LATTICE

To investigate the possibility to reduce the emittance more without a major change of the lattice, we draw so-called "tie diagram", which indicates the quadrupole parameter region where a periodic solution exists. In reality, UVSOR-III has four quadrupole families. However, to draw the tie diagram, they are grouped into two families (QF and QD) located symmetrically around the bending magnets. The code, Elegant, was used and the two quadrupole strengths are surveyed, which give 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 emittance of each parameter set is indicated by the color. There are 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 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.



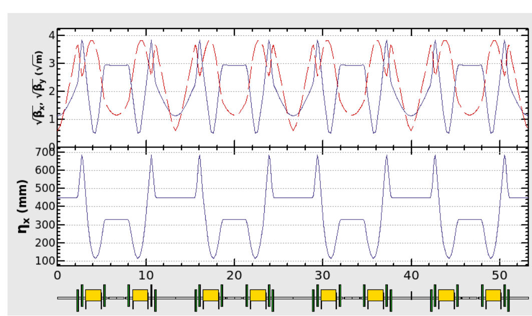


Figure 3: Examples of new low emittance optics. Upper; Optics A which gives a small emittance of 9.4 nm at 750 MeV. Lower; Optics B which gives a moderately small emittance of 13.3 nm with less numbers of quadrupoles (one quadrupole family at the short straight sections are removed).

NEW LOW EMITTANCE OPTICS

On the tie diagram, we can find some areas which gives a smaller emittance than the present value. Making these parameters as the initial values for four quadrupole families, we designed some optics which may be worth to investigate further. The optics (Optics A) presented in Fig. 3 (upper) has an emittance smaller than 10 nm at the electron energy, 750 MeV. In this optics, the vertical betatron functions at the 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. In some special studies which requires a small emittance as possible, this optics may be useful.

Another interesting optics (Optics B) is shown in Fig. 3 (lower), which gives a small emittance, 13 nm, with a few numbers of quadrupoles. In this optics, we can remove one quadrupole family at the short straight sections. This may be beneficial to install new devices for beam handlings, beam monitors or some ports for introducing laser beams into the ring for laser Compton scattering experiments.

Table 1: Parameters of New Optics

	UVSOR-III	Optics A	Optics-B
Electron Energy	750 MeV	750 MeV	750 MeV
Emittance	16.9 nm	9.4 nm	13.3 nm
Betatron tunes (H, V)	(3.75, 3.20)	(5.25, 1.25)	(5.20, 3.25)

SUMMARY AND DISCUSSION

We have analyzed the linear 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.

It may be interesting to compare the results with the theoretical minimum emittance [5]. Under the thin lens (small angle) approximation on the bending magnets, the minimum emittance is given by the following simple formula, which mostly depends on the electron energy and the bending angle of one bending magnet.

$$\varepsilon_{x0}^{\min} = \frac{C_q \gamma^2}{J_x} \frac{1}{12\sqrt{15}} \theta_{BM}^3$$

Here, $C_q = 3.84\times10^{-13}(m\cdot rad)$, J_x, the horizontal damping partition number, γ, Lorentz factor and θ_{BM}, the bending angle per one bending magnet. In case of UVSOR, it is about 5 nm. Normally, the emittance values in the real designs are larger than the theoretical minimum by a factor of 2 or more. Therefore, we think that the emittance around 10 nm is practically the minimum of the present configuration.

The optics A has a relatively larger vertical betatron function at the straight sections than the present optics. Therefore, it may not be compatible with the operation of narrow gap undulators, which are presently operational. However, it may be useful for some special experiments which requires small emittance as possible. This optics 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.

So far, we only treat the linear optics. We will study chromaticity correction, dynamic aperture, collective effects and the beam injection, in the next step.

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