DESIGN OF ULTRA-LOW EMITTANCE RING WITH MULTI-BEND LATTICE ON A TORUS-KNOT

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Abstract

We proposed a torus knot type synchrotron radiation ring in that the beam orbit does not close in one turn but closes after multiple turns around the ring. Currently, we are designing a new ring based on the shape of a (11, 3) torus knot for our future plan 'HiSOR-II.' This ring is mid-low energy light source ring with beam energy of 700 MeV.

Recently some light source rings are achieving very low emittance that reaches a diffraction limited light by adopting a multi-bend scheme to the arc section of the ring. It is not difficult for low-mid energy VUV-SX light source ring because the electron beam less than 10 nmrad can provide the diffraction limited light in the energy less than 10eV. However the multi-bend lattice has many families of the magnets, therefore it is not easy to decide the parameters of the lattice. Especially, it is difficult for the torus knot type SR ring because there is a lot of geometric limitation around the cross points of orbits. We present the details of the designing procedure and the specifications of the ultra-low emittance light source ring having innovatively odd shape.

INTRODUCTION

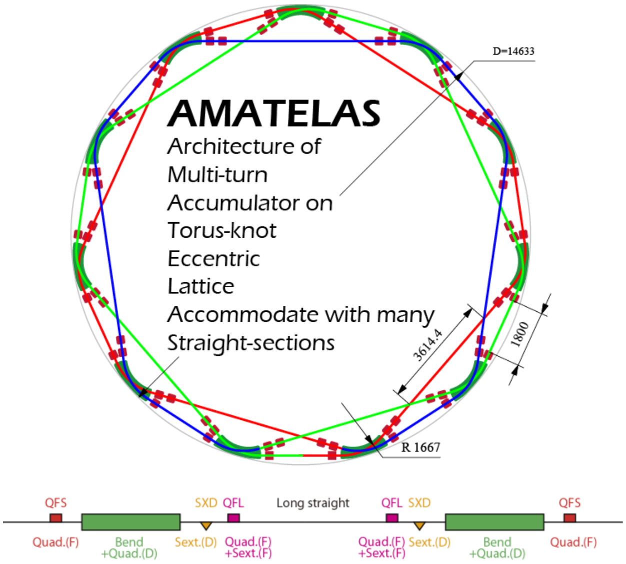

Figure 1: Schematic drawings of (11, 3) AMATELAS designed for HiSOR-II and the lattice of unit cell.

For small light source rings, it is very important to obtain a lot of straight sections in which we can install insertion devices, but it is difficult in reality because they are occupied by various magnets, RF systems or beam monitors. In this context we got a hint from the shape of the torus knot [1], and contrived the ring which had the orbit closed after multiple turns around the ring [2] and named it AMATELAS.

We are planning a new light source ring for our facility [3], therefore we are designing a new ring based on the shape of a (11, 3) torus knot for our future plan 'HiSOR-II' [4]. This ring has 11 long straight sections and we can place insertion devices efficiently by placing the elements such as quadrupole magnets near bending magnet, outside of the orbit crossing section. Furthermore, this ring has about 3 times longer closed orbit in comparison with the conventional ring, the diameter of this ring is as compact as 15 m, but its total orbit length is as long as 130 m. The (11, 3) AMATELAS designed for HiSOR-II storage ring [5] and the lattice of unit cell are shown in Figure 1, and beta or dispersion function of a unit cell is shown in Figure 2.

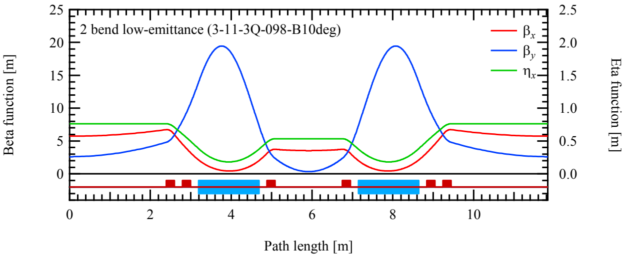

Figure 2: Optical function of (11, 3) AMATELAS for HiSOR-II storage ring.

ULTRA-LOW EMITTANCE RING WITH MULTI-BEND LATTICE

In late years, some compact light source ring achieved ultra-low emittance of several tens of nmrad. For VUV light sources, it means that it obtains the diffraction limited light to achieve such a low emittance beam. Generally, the beam emittance to obtain the diffraction limited light is given as the following.

$$\varepsilon \le \frac{\lambda}{4\pi}$$

If energy of the light from undulator is 10 eV, this equation shows that emittance should be less than about 10 nmrad. We judged emittance of this size to be possible by adopting the multi-bend lattice, and we started the design ultra-low emittance light source ring for HiSOR-II [6].

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Multi-bend Lattice

In the original lattice shown in Figure 1, it has two bending magnets in one unit cell. It is advantageous to lower emittance that the bend is divided into more bends, however, we decided to adopt the multi-bend lattice having 4 bending magnets for reasons of the geometric size of this ring. There are many variations to length of magnets or drift spaces between the magnets in lattices having 4 bends in one cell, but we notice that placement is not so much easy from necessity to place on a torus-knot shape.

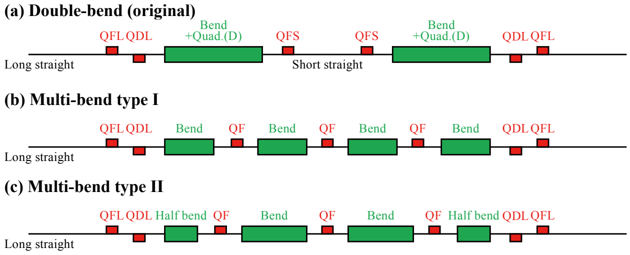

Figure 3: Multi-bend type cells compared with double-bend lattice. (a) is original double-bend lattice. (b) shows multi-bend lattice that all bends has equal length, and (c) is the other type that 2 bends at the end of arc have a half length.

The schematic draws of two types of the multi-bend lattices are shown in Figure 3. In this figure, (a) shows the original double-bend lattice, (b) and (c) are the multi-bend lattices. (b) shows the lattice that all bends has equal length. In another type (c), the length of two bends at the end of arc section is half of the ones in the central section. In (11, 3)-AMATELAS, type (c) is chosen because a certain angle is necessary to cross the orbits.

Geometry

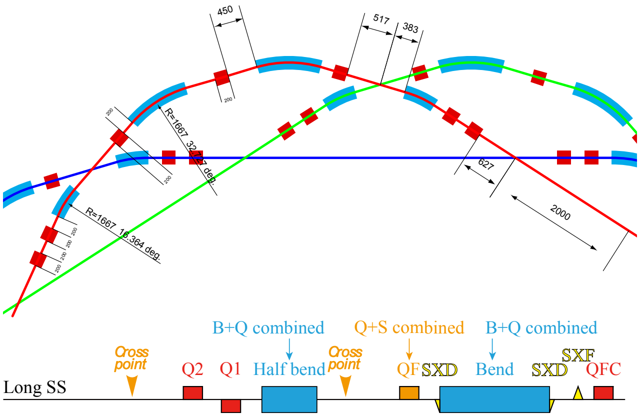

Figure 4: Geometry of unit cell of HiSOR-II and lattice of half of unit cell.

In original double-bend type lattice, beam orbit crosses in the bending magnets, but it is necessary to consider where it should cross in these multi-bend lattices. As for the simplest geometry, all magnets of arc section are placed in the outside of the crossing section, however actually it is impossible to have enough length.

Finally, we decide that it is the most suitable to place a crossing at the drift space between the bending and quadrupole magnet at the end of arc. Figure 4 shows a geometry of unit cell of (11, 3)-AMATELAS with multi-bend lattice for HiSOR-II.

Further, the sextupoles are necessary to correct the chromaticity. Two SXFs are placed between bend and QFC, and QFs are combined function magnets that have quadrupole and sextupole field. Defocus SXDs are combined to the ends of poles of two bending magnets.

Achromatic Lattice

Because AMATELAS has many straight sections for insertion devices, it is necessary to consider influence by the undulators. Therefore we adopt a lattice of Achromat system. A dispersion function is determined by the K-value of bends and quadrupole in an arc section, from half bend to half bend, accordingly its three parameters are almost decided by achromatic condition.

In the case that we choose the K-value of bending magnets, the value of dispersion at the quadrupole QF is fixed. And the focusing forces of quadrupoles are given to minimize the emittance so that the dispersion becomes the minimum at the centre of bending magnets.

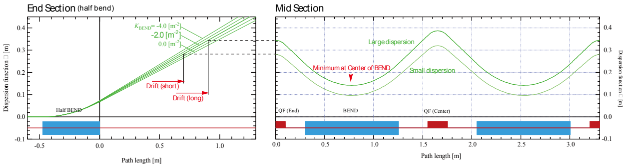

Figure 5: Designing of dispersion function.

K-survey and Operating Point

When achromatic lattice is built by few magnets, the optical function in the arc section is almost fixed. Therefore quadrupole doublets Q1 and Q2 are added the outside of the arc to give the variability of the horizontal and vertical beta functions.

Figure 6 shows the results of K-value survey by the quadrupole doublets which provides two free parameters to choose operating point. Figure (a) shows natural emittance in the K-map of two quadrupoles Q1 and Q2. Figure (c) shows dynamic aperture at the centre of the long straight section in the betatron tune map.

The sextupoles to correct the chromaticity are supposed in the strength that $(\xi_x, \xi_y)=(+1, +1)$. Red and blue dot in each figure show operating point decided by the requirement that $\varepsilon<10$ nmrad and enough aperture.

In this operating point, natural emittance reaches 9 nmrad, but aperture at the centre of long straight section is not enough for injection. Therefore this lattice is modified to supress the sextupole fields and get enough aperture, the horizontal beta function at the centre of cell becomes larger. The modified linear optics in three cells are shown in Figure 7.

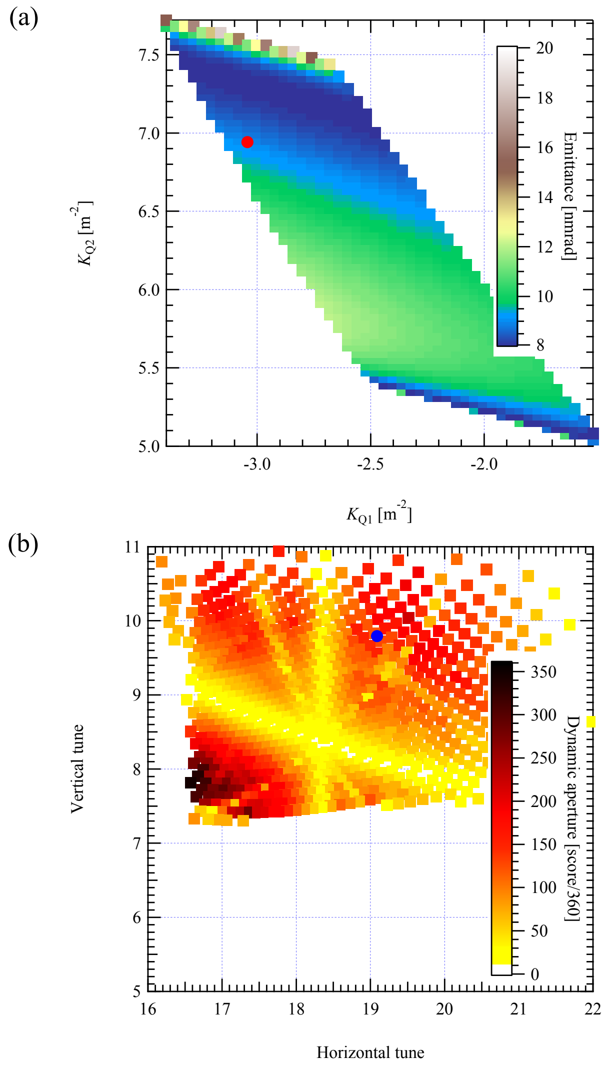

Figure 6: Result of K-survey. (a): natural emittance, (b): dynamic aperture.

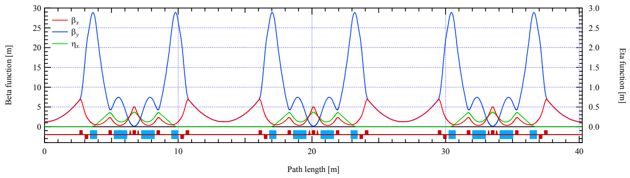

Figure 7: Optical functions in 3 cells.

SUMMARY

We are designing the light source ring based on the torus-knot shape as our future plan HiSOR-II. We can get smaller emittance and may get diffraction limited light in the VUV region adopting a multi-bend lattice to this ring.

As a result of considering in various lattices in the linear dynamics, we are able to make the lattice that reached emittance is 9.08 nmrad as our target. Figure 8 shows the bird eye view of (11, 3) AMATELAS with multi-bend lattice for HiSOR-II, and the main parameters are shown in Table 1.

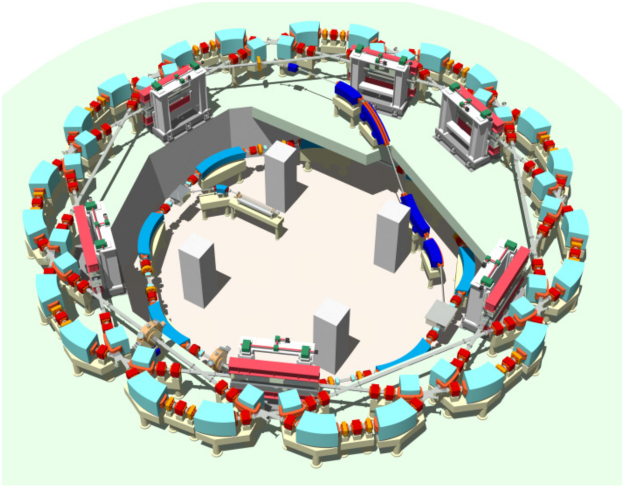

Figure 8: The bird eye view of (11, 3) AMATELAS with multi-bend lattice for HiSOR-II.

Table 1: The Main Parameters of (11, 3) AMATELAS with Multi-Bend Lattice for HiSOR-II Storage Ring

Orbit shape	(11,3) Torus knot
Perimeter	50.868 m
Orbit length	147.517 m
Beam energy	700 MeV
Straight sections	4.000 m ×11
Betatron tune	(19.090, 9.794)
Chromaticity	(+1.0, +1.0)
Natural emittance	9.08 nmrad
Ring current	300 mA
RF voltage	500 kV
Coupling	10.0 %
Harmonic number	50
RF frequency	101.6 MHz
Touschek life time	3.9 hours

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