HISOR-II, COMPACT LIGHT SOURCE WITH A TORUS-KNOT TYPE ACCUMULATOR RING

A. Miyamoto and S. Sasaki
HSRC; Hiroshima Synchrotron Radiation Center, Hiroshima University
2-313 Kagamiyama, Higashi-Hiroshima, Japan

Abstract

We proposed a ring in which a beam orbit is not closed with one turn and return to starting point after multiple turns around the ring. The idea of this new accumulation ring was inspired based on the torus knot theory. This ring has a very long closed orbit in comparison with a conventional ring which has the orbit of one turn. Therefore this ring has long beam orbit before returning to the starting point and has many straight sections which is advantageous to installation of insertion devices.

On the other hand, this ring must achieve low emittance to operate as the 3rd generation light source ring. Therefore we designed lattice of this ring and achieved enough low emittance as 3rd generation light source ring by using bending magnets with combined function.

INTRODUCTION

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.

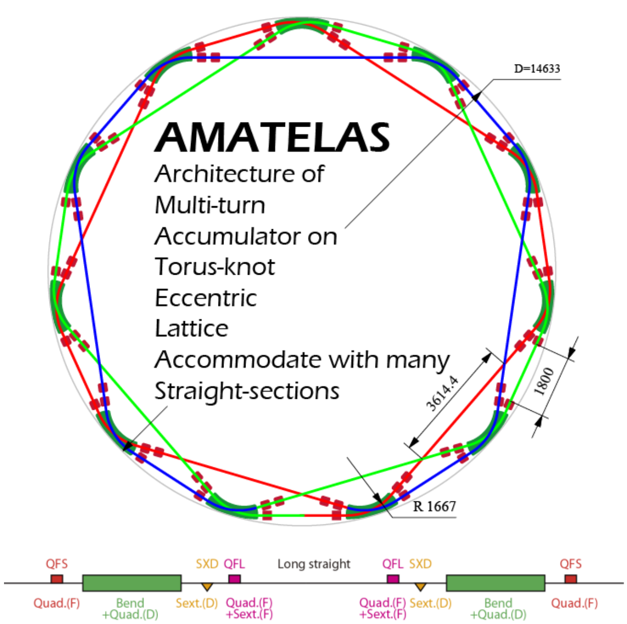

Figure 1: Schematic drawings of (11, 3) AMATELAS designed for HiSOR-II and the lattice of unit cell.

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 AMATELAS ring designed for HiSOR-II and the lattice of unit cell are shown in Figure 1.

LOW EMITTANCE LATTICE

Generally, Double Bend Achromat (DBA) is well known as a low emittance lattice, and it is often used for synchrotron light source rings. In late years, the lattice which introduced dispersion into the straight sections is engaged to achieve low emittance than that of DBA.

The natural emittance is written with radiation integrals as follows [5].

$$\varepsilon_x = C_q \gamma^2 \frac{I_5}{I_2 - I_4}$$

Where C_q is the classical radius of the electrons, and I_2, I_4 and I_5 are

$$I_2 = \oint \frac{1}{\rho^2} ds,\ I_4 = \oint \frac{D}{\rho}\left(\frac{1}{\rho^2} + 2K\right) ds,\ I_5 = \oint \frac{\mathcal{H}}{|\rho|^3} ds.$$

In MAX-III of MAX-lab. [6], they adopt the combined function type bending magnet with QD field and use the lattice that K in I_4 is negative value and achieve ultra low emittance. Therefore we considered the possibility of adoption of the MAX-III type lattice to the AMATELAS ring.

DESIGN OF BENDING MAGNET

Crossed Orbit in Bend with Quadrupole Field

The combined type bending magnet with QD fields are indispensable for MAX-III type lattice. Contrarily in AMATELAS, since the beam orbit crosses in the bending magnet, it is impossible to lay over two bending orbit having field gradient. Therefore we consider one wide magnet which have field gradient along imaginary centre orbit, and two orbits cross in the bending magnet. Figure

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2 shows the bending magnet with gradient field and two crossed beam orbits inside it.

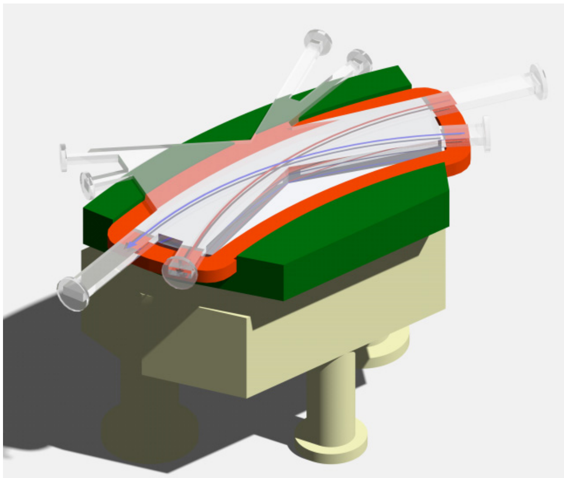

Figure 2: Two crossed orbits and the bending magnet with gradient field.

When we remove bending fields, this orbit is similar to the orbit passing a quadrupole magnet diagonally. However, it is necessary to consider that the bending radius and the focusing force change by the differences of the bending forces and changing the angles against the imaginary centre orbit.

Therefore we calculated practical orbit passing through a bending magnet and the deviation of focusing force along the imaginary centre orbit with concrete parameters. These are shown in Figure 3. The blue dotted line in the figure shows the arc orbit of radius 1800 mm without quadrupole field, and the green solid line shows the practical orbit with defocusing force of -0.98 m^{-2}. And the red line shows the defocusing force in its condition, it is found that the deviation is smaller than 0.5%.

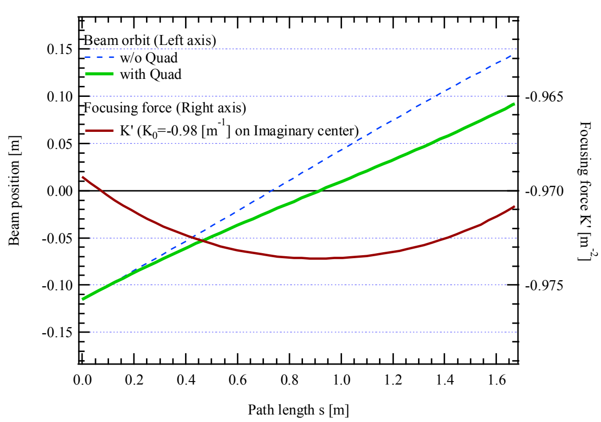

Figure 3: The deviation of quadrupole field along the orbit in the combined bending magnet.

Dividing the Bend for Lattice Design

When we design the lattice, it is very troublesome that the quadrupole field in the bending magnet is not constant. Therefore in designing procedure, we divide the bending magnet into several arcs to be able to use linear matrix. We show dimensions of the orbit divided to 6 arcs when -0.98 m^{-2} quadrupole field was given along the imaginary centre orbit in Figure 4.

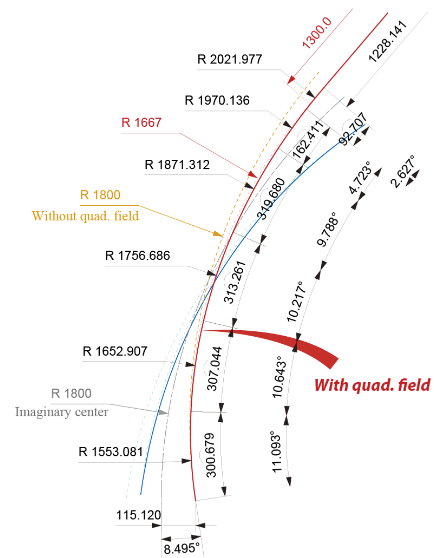

Figure 4: The orbit divided to 6 arcs in the bending magnet with -0.98 m^{-2} defocusing force.

Furthermore, the stepped quadrupole field as Figure 5 is given in each section of a divided arc. The integrated defocusing force KL of each section is equal to the product of stepped K and length of the section L.

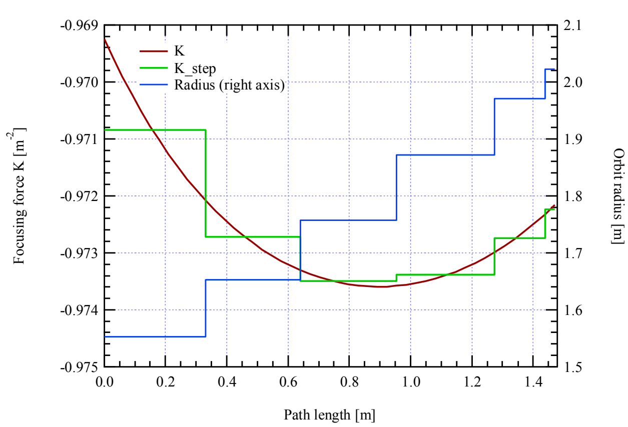

Figure 5: The stepped quadrupole field that we used for a linear lattice design.

DETERMINATION OF OPERATING POINT

Because there are only four kinds of magnets that have quadrupole field in this ring, we surveyed each focusing magnet and calculated the natural emittance of the ring, determined the operating point that had a suitable optical functions. Firstly, we surveyed quadrupole field of QFS, QFL and Bend in the lattice shown in Figure 1, and picked the operating points with the natural emittance less than 20 nmrad from them. In such a procedure, we decided quadrupole field of -0.98 m^{-2} of the bending magnet. And we divided the bending magnet by the method described previously to prepare for the linear matrix calculation.

Secondarily, we surveyed the natural emittance of the ring and the dynamic aperture at centre of a long straight section in a condition to choose the quadrupole field of SXD that the emittance became lowest when free parameters were given for two quadrupole magnet of QFS and QFL. The calculated emittance by this K-survey method is shown in Figure 6.

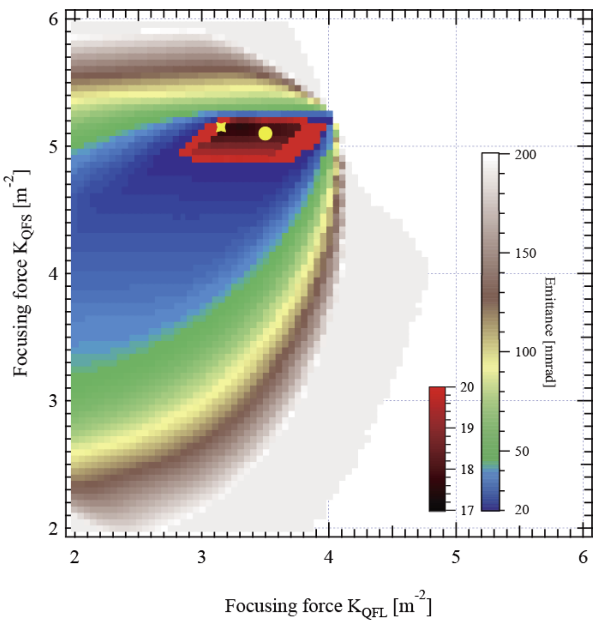

Figure 6: The natural emittance calculated by K-survey.

SUMMERY

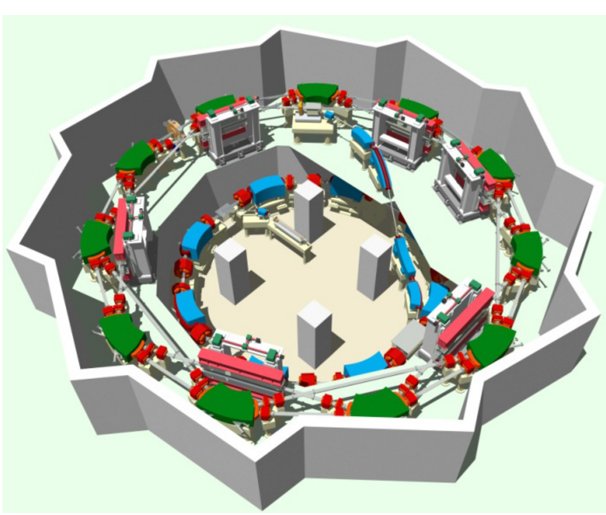

Figure 7: The bird's-eye view of (11, 3) AMATELAS for HiSOR-II complex.

We proposed a new ring based on the torus knot which was suitable for a small accumulation ring. The accumulation ring which has the orbit with several turns before returning to the starting point has many straight sections and it is advantageous in that we can install many insertion devices if it is a SR light source ring. Further, we adopted the MAX-III type lattice in this ring and found the possibility that could realize low emittance.

HiSOR-II will have the injector for the top-up injection, and its details are under consideration. A bird's-eye view of HiSOR-II accelerator complex is shown in Figure 7. And the latest parameters of (11, 3) AMATELAS designed for HiSOR-II storage ring is shown in Table 1.

Table 1: The Final Parameters of (11, 3) AMATELAS for HiSOR-II Storage Ring

Perimeter	45.97 m
Orbit shape	(11,3) Torus knot
Perimeter	45.97 m
Orbit length	130.187 m
Beam energy	700 MeV
Straight sections	3.614 m ×11 1.728 m ×11
Harmonic number	88
RF frequency	202.645 MHz
Betatron tune	(10.362, 7.807)
Natural emittance	17.9 nmrad
Chromaticity	(+1.0, +1.0)

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