LATTICE DESIGN OF THE NIRS SMALL RING FOR HEAVY IONS

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Abstract

A small ring has been proposed at NIRS and its design study has been carried out. The NIRS small ring will deliver heavy-ion beams with energies from 1 to 50 MeV/u, bunch lengths of 10 to 1,000 ns, and a small emittance, while a circumference of the ring is as small as 25 m. To realize a small ring with an electron cooler, a double bend achromatic lattice with a superperiodicity of 1 was chosen as a basic structure. An outline of the design and calculated results of the lattice are described in the paper.

1 INTRODUCTION

The HIMAC injector can provide heavy-ion beams from p to Xe with an energy of 6 MeV/u [1,2]. A small ring which accepts beams from the injector was newly proposed[3]. The purpose of the new ring is to supply beams, which have different characteristics from those of existing synchrotron rings as follows: (1) short bunched beams of less than 10 ns, (2) variable beam energy ranging from 1 MeV/u to 50 MeV/u for q/A=1/2 ions, (3) high intensity and small emittance both in transverse and longitudinal directions. A beam deceleration is needed to obtain a beam in a low energy region.

Beams from the small ring will be used by experimental users including radiation chemistry, biology, nuclear physics, and nuclear engineering. Short bunched beams of less than 10 ns with enough intensity will give unique tools for studying time evolution of chemical or nuclear reaction processes. Being combined with the HIMAC synchrotron, beams with a large variety of LET or residual ranges can be provided at HIMAC.

The small ring is also expected to work as a booster ring for the HIMAC synchrotron in the future. Heavy ion beams heavier than Ar are injected to the synchrotron rings after stored in the small ring to increase an intensity.

The new ring should be very compact because of a limited space available. The circumference is expected to be 25 m or less.

2 BASIC FEATURES OF THE SMALL RING

An electron cooler (EC) will be installed in the ring to obtain high quality and high intensity beams. Applying a bunch rotation method to the high quality beams, short bunched beams will be obtained.

A dispersion-free section is required for an electron cooler. A twofold symmetric double bend achromatic structure is chosen to realize the small size of the ring. Two pairs of quadrupole magnets will be installed to compensate tune shifts caused by the space charge effect including the effects with the mixed electron beams, and by a solenoid field of an EC.

For the injection and the extraction, large horizontal beta-function values are required at these points. Small beta-functions, on the other hand, are necessary in a cooling solenoid to obtain a high cooling efficiency. To meet these two requirements in one small ring, a super-periodicity of 1 is chosen. A new compact RF cavity may be required to cope with the limited space.

3 DESIGN OF THE LATTICE

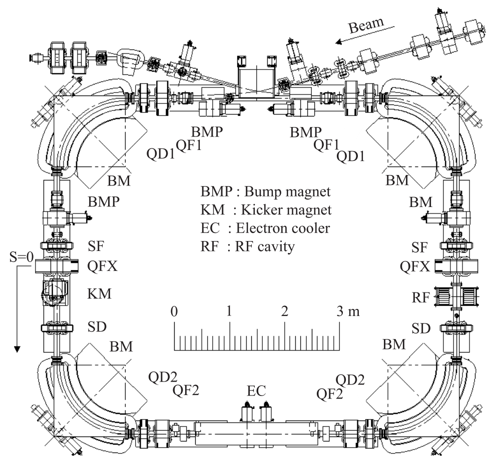
Design parameters of the small ring are listed in Table 1, and a layout is shown in Fig. 1.

Table 1: Design parameters of the small ring

Injection energy [MeV/u]	6
Extraction energy for q/A=1/2 [MeV/u]	1-50
Acceptable charge to mass ratio	1-1/4
Circumferences [m]	24.654
Magnetic rigidity [T.m]	0.3-2.1
Bending radius [m]	1.25
Bending angle [deg]	90
Number of quadrupoles	10
Length of EC solenoid [m]	0.5
Nominal tune (Hori. / Vert.)	2.23/0.82
Natural chromaticity (Hori. / Vert.)	-2.25/-6.85
Momentum compaction factor	0.116
Bunch length [ns]	10 - 1000
Expected beam intensity [pps]	$> 5\times10^9$
Momentum spread [%]	< 0.01

The ring has four 90-degree laminated bending magnets. A bending radius of the magnet is 1.25 m and the maximum field strength is 1.68 T. The edge angle is 22.5 degrees for obtaining a reasonable defocusing force. Two pairs of the straight sections, 4.8 m and 3.6 m, are required in the ring. One of the long straight sections is used for the beam injection and extraction, and the other is for the electron cooler. A typical repetition rate of the ring is designed to be 1 Hz.

Five kinds of the quadrupole magnets, called QFX, QF1,QD1,QF2,QD2, are used in the ring. The QFX's are placed in the center of the short straight sections to obtain the dispersion-free sections for the electron cooler and the beam injection and extraction section. Other magnets are installed in the long straight sections for the fine tunings. A large value of a field gradient, 24T/m, is required for



the QF2 and QD2. One of the criterion on designing the quadrupole magnet is that the magnetic field strength should be 0.75 T or less on pole tips.

Fig. 1 : A layout of the ring.

Difference of the fractional part between horizontal and vertical tunes should be as large as possible to avoid the coupling resonance in the EC solenoid. A few candidates of the working points are searched. However, many of them result in the undesirable behavior in the beta-functions, such as in-phase oscillation in horizontal and vertical direction or small values of beta-functions. Finally, the working point of (2.23,0.82) was chosen.

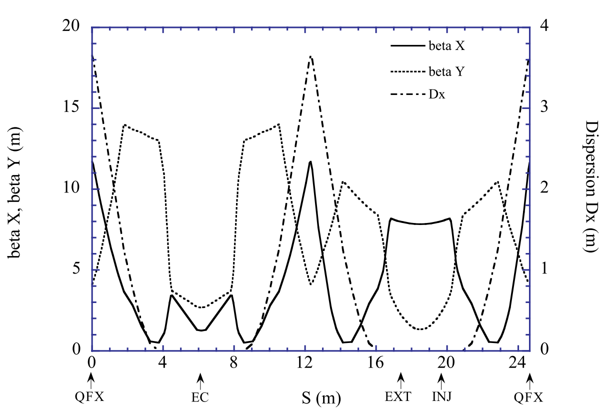
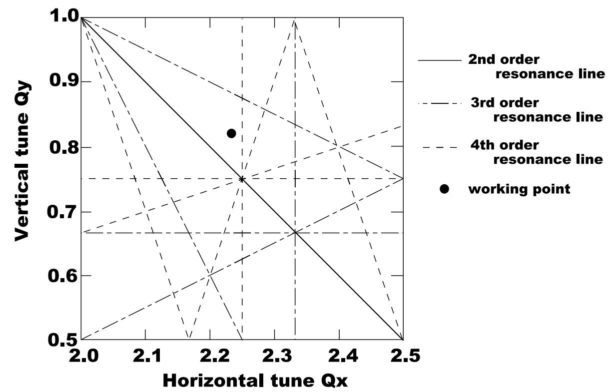


Fig. 2: Lattice functions of the small ring. A distance parameter s is measured from the center of the QFX. A solid line shows βx, a dashed line shows βy, and a dot-dashed line is a horizontal dispersion function Dx. EC, EXT, and INJ are the positions of EC solenoid, extraction, and injection respectively.

Figure 2 shows calculated values of lattice functions with MAD. The maximum values of the beta-functions are 11.5m at the QFX in the horizontal direction and 14 m at the bending magnets in the vertical direction. The



maximum value of the dispersion is 3.7 m at QFX. A tune diagram of the ring is shown in Fig. 3.

Fig. 3: Tune diagram of the small ring. Resonance lines up to 4th order are shown. A closed circle indicates a working point.

4 INJECTION AND EXTRACTION

The multiturn injection method will be applied to the ring. A measured value of emittance for the injector beam is 7 π.mm.mrad (90 % unnormalized), both in horizontal and vertical directions. The corresponding acceptance of the ring is expected to be 200 π.mm.mrad and 10 π.mm.mrad, respectively. To obtain high intensity beams, an optimization of a partial acceptance was carried out [4], and we found that 87.1 % of the horizontal phase space can be filled with injected beams. In the calculation, a constant collapsing rate of the bump field is assumed, and septum thickness of the electrostatic inflector was assumed to be 0.3 mm. A turn number during the injection period will be 68 or more, and a number of the carbon ions after the injection is estimated to be more than 2.4×10^{9} ppp for a typical injector beam intensity. To obtain more intense beams, a stacking with an electron cooler will be tried. In this case, a number of circulating particles is limited by a space charge tune shift in a vertical direction. For ions with q/A=1/2, the space charge limited intensity is estimated to be 1×10^{10} ppp to keep the tune shift within 0.1.

An injection error was mainly produced by a current ripple of injection and transport-line magnets. Assuming an injection error of ±0.15mm at the injection point, the stability of the power supply should be less than $\pm1\times10^{-3}$. It is not difficult to attain this value.

The injection and extraction points are placed in the same long straight section to save the space. A length of the long straight section is limited to be 3.3 m. An inflector and a deflector are located symmetrically in the center of the long straight section, as shown in Fig. 1. A septum magnet is placed at the center of the long straight section and excited both for beam injection and extraction. A septum is 22 mm thick. Four bump magnets are also excited during the periods for beam injection and extraction. They make the bump orbit be parallel to the central orbit between the injection and the extraction points.

Fast extraction scheme is included in the design. A magnetic deflector, with a septum thickness of 4.5 mm, and a fast kicker magnet are prepared for the extraction. The fast kicker magnet is 0.25 m long, and produces a maximum field of 0.025 T with a rise time of 80 ns.

5 CLOSED ORBIT DISTORTION

Closed orbit distortion (COD) was estimated in order to evaluate the necessary gap height of the bending magnets and bore radii of the quadrupole magnets.

Standard deviations of positioning and strength error are assumed to be: (1) 0.1 mrad of rotation around the beam axis for the bending magnets, (2) 0.2 mm of displacement in both horizontal and vertical direction for the quadrupole magnets, and (3) 0.05 % of field error for the bending magnets. COD was evaluated in one hundred virtual small ring with different errors. Standard deviations of the COD are obtained from these results. They are shown in Fig. 4. A realistic value of closed orbit displacement is estimated to be two times of the standard deviation. Geometrical dimensions of magnets are determined with these values.

The COD correction should be taken into account to adjust beam direction and beam position inside the EC solenoid. Eight position monitors and eight correctors will be prepared for COD correction. Two of the eight position monitors are electrostatic monitors for low intensity beams, and others are pick-ups installed inside beam ducts of QFs. Four of the eight correctors will be installed inside bending magnets for a horizontal correction. Two of the remaining four-correctors will be installed near QFXs for a horizontal correction, where a horizontal beta function takes a large value. Others are vertical correctors installed in a long straight section for injection. Besides eight correctors and eight position monitors for COD correction, two pairs of correctors and a pair of beam monitors are prepared for the fine adjustment of the orbit inside the EC solenoid. They are installed in both sides of the electron cooler. With these monitors and correctors, we obtained a COD value of 0.4 mm or less at any point in the ring.

Design study of the NIRS small ring is being continued. The fast kicker and the magnetic septum has been assembled and the measurements will be carried out within a few months.

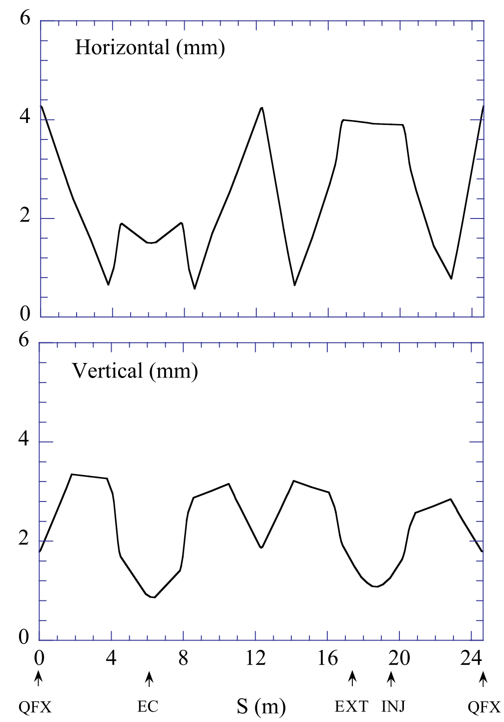


Fig. 4 : A standard deviation of COD along the beam axis estimated with 100 examples. A distance parameter s is measured from the center of the QFX.

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