DESIGN OF DOUBLE STORAGE RINGS AT MUSES

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Abstract

Double storage rings (DSR) will play a role to perform various experiments of collision or merging of radio-isotope beams with ions, electron beams and X-rays produced from an undulator. The experiments will be performed at two crossing points. One is for collision of RI beam with electron with crossing angle 20 mrad. Another is for merging for ion beams with angle of 170 mrad. To perform these experiments with high luminosity, electron beam has two different operation modes. The emittance of 10^{-6} m*rad is prepared for the collision with RI and that of 10^{-8} m*rad is done for production of high brilliant X-ray. Dynamic aperture of beam with emittance 10^{-8} m*rad is 16 mm x 3 mm after chromaticity correction.

1 INTRODUCTION

The DSR is an experimental colliding rings planned in Radio Isotope Beam Factory at RIKEN [1]. In the DSR a variety of unique experiments are envisaged through collision of RI beam with X-ray produced from undulator, the collisions of RI beam with electron beam, and merging of RI (ion) beams.

To perform these experiments with high luminosity electron beam is required to have two different operation modes. One is a mode to have emittance of 10^{-8} π m*rad (small emittance mode, S.E.M) at 2.5 GeV to produce high brilliant X-ray from the undulator. Another is to have emittance of the 10^{-6} π m*rad (large emittance mode, L.E.M) at energy of 1 GeV. This mode is used for collision with RI beam.

Ion beam is injected after cooling and accumulation in the Accumulator Cooler Ring [2] and acceleration in the Booster Synchrotron [3]. Maximum magnetic rigidity (Bρ) of injected beam is 14.6 Tm (800 MeV/u for A/Z=3), emittance is 1 π mm*mrad and momentum spread is 0.1 %. Since max. Bρ is 2 times larger than that of electron beam, ion beam is operated by third mode (ion mode, I.M).

In this paper we will report lattice of the DSR for each mode and dynamic aperture of S.E.M.

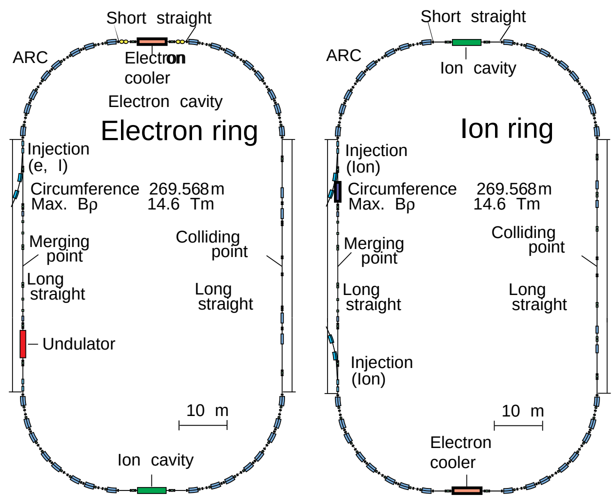

Fig. 1 Two rings in the DSR. 1a is an electron ring and 1b is an ion ring.

2 OVERVIEW OF DSR

The DSR is composed of an electron ring and an ion ring shown in Fig. 1a and b. The electron ring stores not only electron beam but also ion beam for the merging experiment. The ion ring stores only ion beam. The circumference of each ring is 269.568 m which is 8 times larger than that of injector superconducting ring cyclotron [4]. Each ring has four arcs, two long straight sections and two short straight sections.

In each long straight section, two rings cross vertically. One crossing point is used for the collision of RI beam with electron beam (colliding section). Another is used for merging (merging section).

Figure 2 shows a configuration of the magnet in this section. The crossing angle and β values of each ring are chosen as small as possible to get large luminosity. Considering interference of magnets between two rings, crossing angle is determined at 20 mrad (1.145°). Values of β for electron beam are determined at 0.02 m with both horizontal and vertical directions and these for ion beam are

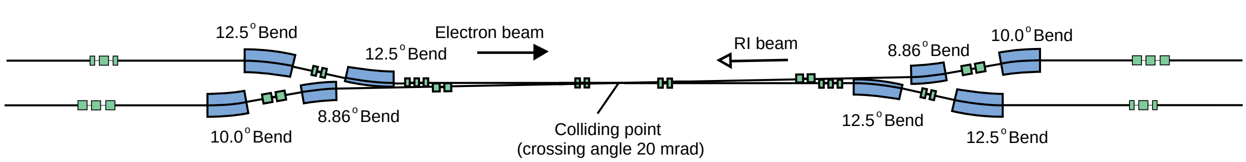

Fig. 2 Side view of the colliding section.

0.1 m. These values are achieved by focusing of a quadrupole doublet (QD1), which is located at a distance of 1.5 m from the colliding point. For ion beam, an additional quadrupole doublet (QDI2) is located at rather long distance (7.5 m) from the crossing point because focusing power of the doublet is small for the ion beam. To obtain small β values, values of β around focusing magnets are very large. The maximum β values of the electron beam are 113 m for horizontal direction and 750 m for vertical and these of the ion are 1223 m (35 mm in beam size) for horizontal and 970 m for vertical.

In the merging section configurations of magnets of both rings are same. Merging angle of the section is 10 ^{o} and values of β at merging point is 0.6 m for both horizontal and vertical directions. The maximum β value in this section is not so large (102 m for horizontal and 58 m for vertical) because β at merging point is not so large. In this section an undulator to produce high brilliant X-ray and beam injection are also located. The beam of the undulator is required to be small (2 m) and parallel for the electron beam of S.E.M. Electron beam is injected into the electron ring with multi-turn injection method for horizontal direction. Horizontal emittance of an injected electron beam is just after multi-turn injection 15 π mm*mrad. Ion beam is inserted into both rings with one turn.

Short straight sections are used for an electron cooler and RF cavities. The electron cooler is prepared for ion beam to suppress beam instabilities and beam-beam effect and to make a short bunch of ion beam. For efficient electron cooling the ion beam should be parallel and have small size. In the section four quadrupole magnets are inserted and make the required beam. The obtained β value is about 7 m over all the section.

The arc section is designed to adjust emittance of electron beam. Figure 3 shows configuration of the arc in the DSR for both S.E.M and L.E.M.

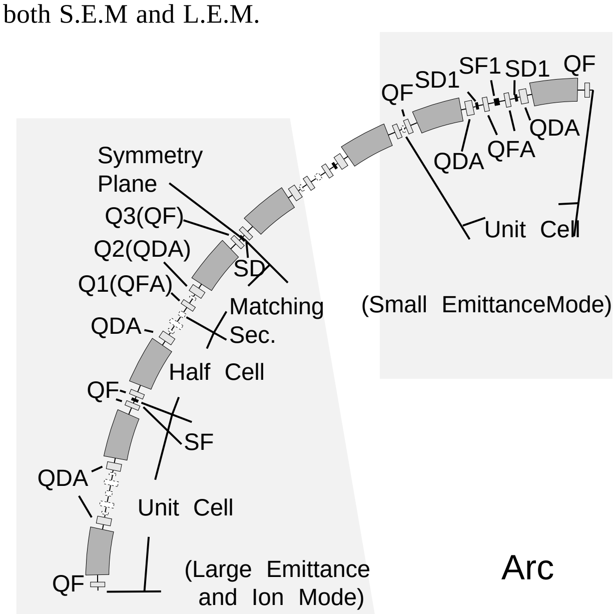

Fig. 3 Compositon of the arc section.

For the S.E.M the arc consists of four unit cells with Double Bend Achromat (DBA) structure. The DBA structure is achieved by the quadrupole magnets for focus (QFA) and those for defocus (QDA). The other quadrupole magnets (QF) are used to fulfill a periodic condition of the cell. Fig. 4 shows β and dispersion functions of the cell. Beta functions fulfill the periodic condition. The horizontal emittance is almost decided by the cell because there are no horizontal bending magnet except for arcs. The obtained value of horizontal emittance is 13.9 π nm*rad at 2.5 GeV.

For the L.E.M, emittance is made large by abandoning DBA structure. As shown in Fig. 3 the center of the arc is a symmetry plane of β and dispersion functions. The half arc consists of an unit cell, a half cell and a matching section. In the unit and half cell the QFA's are not used. In the matching section three quadrupole magnets (Q1, Q2 and Q3) are adjusted to make the symmetry plane at the center of the arc. The region out of the arc is dispersion free in the mode. The obtained value of emittance is 0.76 π μm*rad.

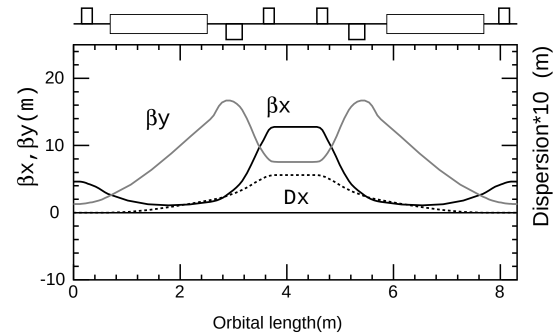

Fig. 4 β and dispersion functions in the unit cell for S.E.M.

For the I.M the composition of the arc is the same as that of the L.E.M. However, since magnetic rigidity of ion beam is much larger than that of L.E.M, focusing powers of quadrupole magnets are adjusted to be weaker than those of the L.E.M. The region out of the arc is also dispersion free in the mode.

3 RING PARAMETERS

After the design of each section we calculated the ring parameters for each operation mode. For I.M, two cases are calculated. One is for collision with electron beam (I.M-C). Another is for merging (I.M-M).

The obtained parameters of the four modes are summarized in Table 1. Large chromaticity for S.E.M is due to DBA structure of the arc. Those of L.E.M and I.M-C are originated from large β values and strong filed gradients of quadrupole magnets in the colliding section.

	S.E.M	L.E.M	I.M-C	I.M-M
Tune νx	15.781	6.754	6.235	5.637
νy	9.569	8.163	5.018	5.732
Chromaticity				
ξx	-30.5	-37.7	-62.7	-11.4
ξy	-35.4	-90.7	-47.6	-10.3
Transition γ	85.20	4.857	5.071	5.071
Momentum				
compaction	0.	0.042	0.039	0.039
Max. β (m) βx	0014	113	1223	102
βy	25.5	750	970	57.8
β at colliding	51.8			
section (m) βx^*		0.02	0.1	4.2
βy^*	8.5	0.02	0.1	4.8
β at merging	10.5			
section (m) βx^*		5.0	10.0	0.6
βy^*	3.9	5.0	10.0	0.6
	23.4			

Table 1 Parameters of the DSR for several modes.

4 CHROMATICITY CORRECTION AND DYNAMIC APERTURE

Natural chromaticity (ξ) causes tune spread ($\Delta\nu$) originated from $\Delta p/p$ ($\Delta\nu=\xi\Delta p/p$). Since $\Delta p/p$'s of injected electron beam and ion beam are 0.1 % $\Delta\nu$'s of these beams are 0.1 ~ 0.9. These large $\Delta\nu$ cause particle loss because tune crosses several resonance line. Cromaticity correction is important to reduce $\Delta\nu$. The correction can be done using sextupoles located at non-zero dispersion. However, since use of sextupole causes third order resonance principally dynamic aperture decreases. In this chapter we will mention about chromaticity correction and dynamic aperture for S.E.M.

Natural chromaticity of S.E.M. is corrected using sextupoles (SF1, SD1) as shown in Fig. 3. Phase advances between entrances of two arcs including the short straight section are adjusted to compensate phase modulation caused by a sextupole. When the phase modulation is small it is written by

$$\Delta a = f_1(\cos 3\Phi_X + 3\cos\Phi_X)\Delta s + f_2(\cos(\Phi_X+2\Phi_y)+\cos(\Phi_X-2\Phi_y)+2\cos\Phi_X)\Delta s$$

$$\Delta b = f_3(\cos(\Phi_X+2\Phi_y)+\cos(\Phi_X-2\Phi_y)+2\cos\Phi_X)\Delta s$$

where Δa and Δb are phase modulations of x and y, Φ_x and Φ_y are phase at sextupole, $f_{1\sim 3}$ are functions of initial amplitude, strength of sextupole and beta functions of x and y and Δs is length of sextupole. Using initial phase (Φ_{x0} or Φ_{y0}) and phase advance (ϕ_x or ϕ_y), Φ_x (Φ_y) is written

$$\Phi_x\,(\Phi_y) = \Phi_{x0}\,(\Phi_{y0}) + \phi_x\,(\phi_y)$$

When strength and beta functions of two sextupole magnets are same, modulation caused by two sextupole magnets are compensated if $m\phi_x + n\phi_y = (2k+1)\pi$, where k is integer and combination of m and n are m=1 or 3, n=0 and m=1 n=2 or -2. In the DSR phase advances between entrances of two arcs including the short straight section are 7π for x and 4π for y to compensate all components of phase modulation. The obtained values of sextupoles to correct chromaticity are 44.06 m^{-3} for SF1 and –65.77 m^{-3} for SD1. We also performed particle tracking using MAD. In the tracking we used the second ordered Lie-algebra method. Fig. 5 shows results of tracking. In this figure initial condition is x = 8 mm, y=1.5 mm, px=py=0 mrad and $\Delta p/p$=0.1 %. Numbers of turn is 1000. Twiss parameters of a view point are 4.6 m and 1.3 m for β_x and β_y and 0 m for α_x and α_y Outside of this region particle is lost. From this result dynamic aperture for S.E.M. is 16 mm x 3 mm. This value is comparable to needed aperture.

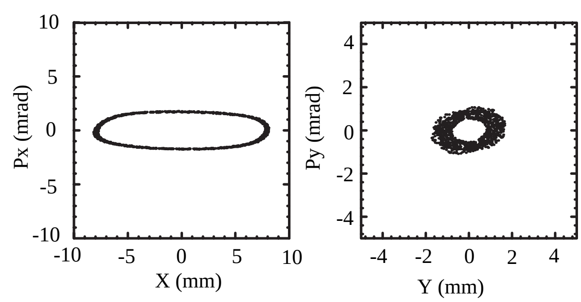

Fig. 5 Particle tracking

5 CONSIDERATION

Obtained dynamic aperture is rather small. It is due to large phase modulation by sextupoles. To increase dynamic aperture additional families of sextupole should be introduced. We are studying properties of sextupole such as strength and configuration.

For other modes we will calculate dynamic aperture. In particular, L.E.M. and I.M.C have large chromaticities originated from the colliding point. In these modes correction may be done locally.

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