DESIGN OF DOUBLE STORAGE RINGS AT MUSES

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1 INTRODUCTION

At RIKEN, Radio Isotope Beam Factory is proposed, which aim to produce a high flux RI beams for the nuclear science and multi-discipline applications [1]. The Double Storage Rings (DSR) is an experimental colliding rings planned for this project. Figure 1 shows a schematic drawing of the DSR. At DSR a variety of unique experiments are envisaged ; 1) collision of RI beam with electron beam, 2) collision of RI beam with X-ray produced from an undulator and 3) merging of RI

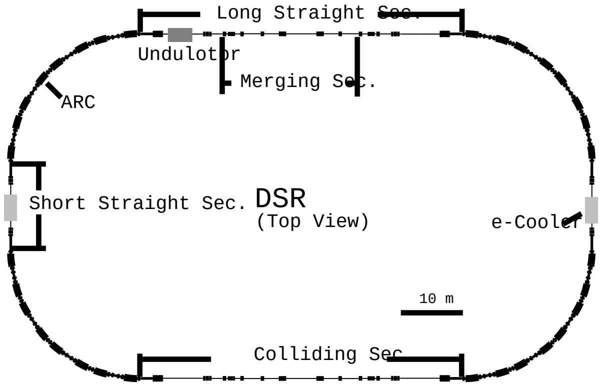

Fig. 1. Top view of the DSR.

(ion) beams. To perform these experiments with high luminosity, the DSR should satisfy several optical requirements. Firstly the one ring of the DSR has to store the electron beam (300 ~2500 MeV) of high current (~ 500 mA) with the emittance 10^{-6} m*rad (large emittance mode) for the experiment 1). For the experiment 2), the emittance of electron beam should be as low as 10^{-8} m*rad [2] (low emittance mode) to produce a high brilliant X-ray from the undulator. The low emittance mode can be achieved with Double Bend Achromatic (DBA) structure of arc section while the large emittance mode is realized by the modification of DBA. Ion beam is required to have a large maximum energy of 14.6 Tm (800 MeV/u for A/Z=3) and is operated by another mode (ion mode).

Two colliding long straight sections are prepared, one is for the collision of RI beam with electron beam with a collision angle 20 mrad (colliding section), and the other is for the merging of ion beams with merging angle 170 mrad (merging section). The RF cavities and beam injection devices should be located at the long straight sections. Two short straight sections will be used for electron coolers to suppress the beam instabilities and to make a short bunch ion beams.

The circumference of the DSR is 258.732 m, which is 46/6 times larger than radius of the injector superconducting ring cyclotron. In the following sections, details of arc section and colliding sections will be described.

2 DESIGN OF EACH SECTION

2.1 Arc section

Figure 2 shows composition of the arc in the DSR for both small and large emittance mode. For the small emittance mode the arc consists of four unit cells with

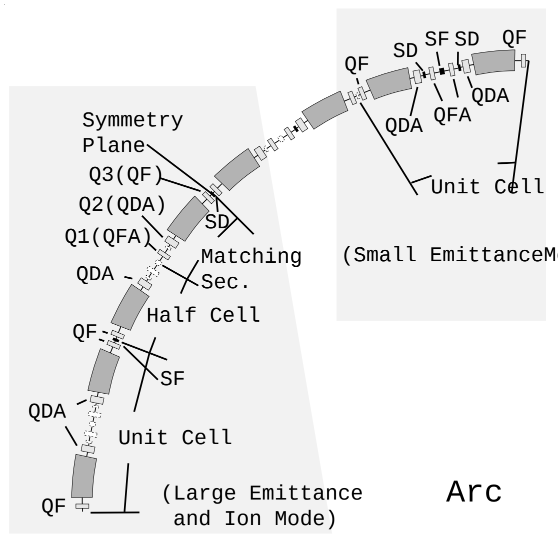

Fig. 2 Composition of the arc for the small and large emittance mode.

DBA structure. The DBA structure is achieved by the quadrupole magnets for focus (QFA) and those for defocus (QDA). In principle the DBA structure can be achieved only by QFA's. However, due to small dispersion between two dipole magnets it is difficult to correct natural chromaticity. The QDA's are used to enlarge dispersion between two dipole magnets and the natural chromaticity is corrected easily. The other quadrupole magnets (QF) are used to fulfill a periodic condition of the cell. Fig. 3 shows β and dispersion functions of the cell. The β functions fulfill the periodic condition. From the result that dispersion is 0 outside the dipole magnets, one can see that DBA structure is achieved in the cell. The horizontal emittance is almost decided by the cell because there are no horizontal bending magnet except for arcs. The obtained value is 8.54 n m*rad. The value is enough small for the small emittance mode.

For the large emittance mode, emittance is made very large by abandoning DBA structure and making dispersion in the dipole magnets large for the configuration given by the small emittance mode. As shown in Fig. 2 the center

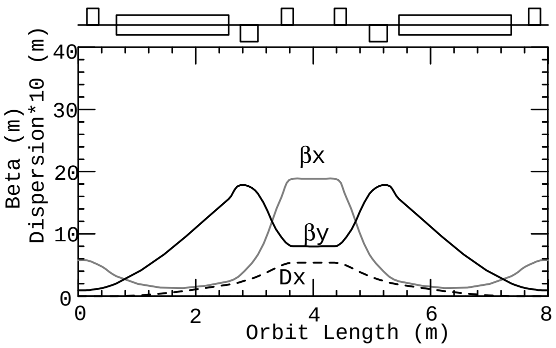

Fig. 3. Beta and dispersion functions in the unit cell for the small emittance mode.

of the arc is 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 to enlarge dispersion in the dipole magnets. In the matching section three quadrupole magnets (Q1, Q2 and Q3) are adjusted to make the symmetry plane at the center of the arc. Figure 4 shows β and dispersion functions of the arc for this mode. The both functions have symmetry plane at the center and a region out of the arc is dispersion free. The obtained

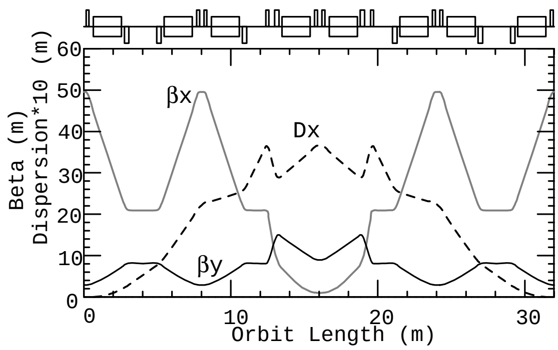

Fig. 4. Beta and dispersion functions in the arc for the large emittance mode.

emittance is 1.08 mmm*rad, which value fulfills the required one.

For the ion mode the composition of the arc is the same as that of the large emittance mode. However the focusing powers of some quadrupole magnets are adjusted to be weaker than those of the large emittance mode. The tendency of the β and dispersion functions are similar. The region out of the arc is also dispersion free in the mode.

2.2 Colliding Section

Figure 5 shows a configuration of the magnet in this section. The crossing angle is chosen small as possible to get large luminosity. In the Fig. 5 pass of the electron beam is shown by black arrows and that of the ion beam is shown by white arrows. The electron beam goes to the crossing point with parallel to horizontal plane after bending down with 15^{o} and bending up with the same angle. The ion beam goes to the point with angle of 20 mrad (1.145^{o}) after bending down with 10^{o} and bending up with 8.855^{o}. Each beam goes to the lower ring passing through similar pass to come to the crossing point.

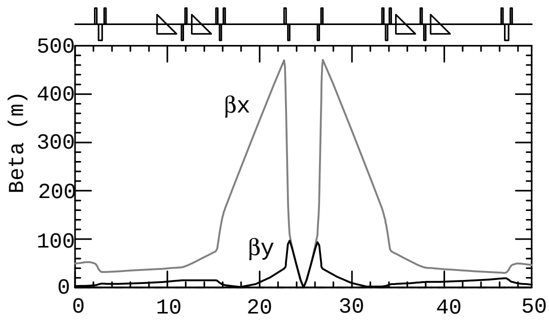

Fig. 6. Beta functions of the electron beam for the colliding section.

The small β values of the both beams at crossing point are also chosen in order to get large luminosity. The β values of the electron beam for both horizontal and vertical direction are 0.02 m and those of the ion beam are 0.1 m.[3] To get small β values a quadrupole doublet (QD1) is located at distance of 1.5 m from the crossing point. The ion beam also passes through the doublet. Since focusing power of the doublet is small for the ion beam additional quadrupole doublet (QDI2) is located at rather long distance from the crossing point. The long distance (7.5 m) is to keep clearance from the beam-line of the electron. The other quadrupole magnets are used to match the emittance of each beam.

The calculated β functions of electron and ion beams are shown in Fig. 6 and 7 respectively. In the calculation the central orbit of the ion beam in the quadrupole doublet is assumed to lie in the center of the QD1 and QD1'. The maximum β values of the electron beam are 470 m for horizontal direction and 100 m for vertical. The all field gradients are less than 30 T/m. For the ion beam the maximum β values are 1200 m (35 mm in beam size) for horizontal and 460 m for vertical. The all field gradient are less than 33 T/m. The large β for the ion mode is due to long distance between the QDI2 and the crossing point.

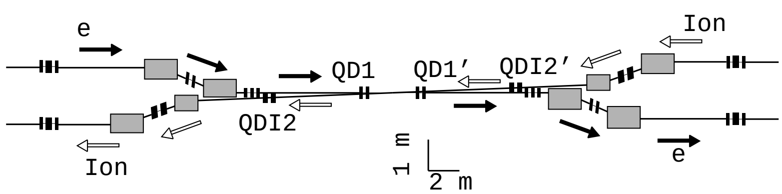

Fig. 5. Side view of the colliding section.

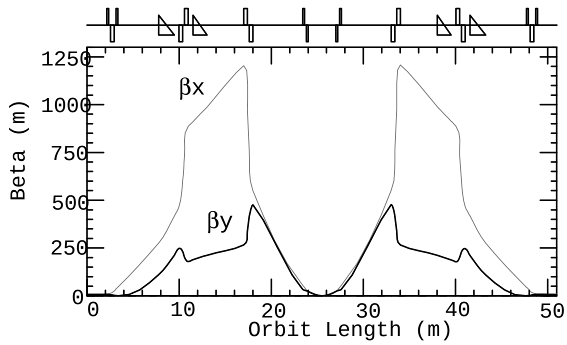

Fig. 7. Beta functions of the ion beam for the colliding section.

2.3 Merging Section

Figure 8 shows a configuration of the magnets for the merging section. The passes of the ion beams are shown by white and black arrows in fig. 8. The crossing angle, 10^{o} is chosen by the requirement from experiments.

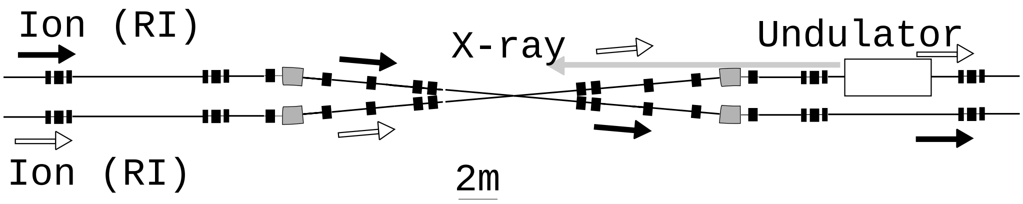

Fig. 8. Side view of the merging section

The small values are also chosen in the mode to get large luminosity. The values are 0.6 m for both direction. To get small β value quadrupole doublet is inserted at distance of 3.5 m from the crossing point. To match the emittance several quadrupoles are inserted the section. The configurations of the quadrupole magnets of two beam lines are all the same. The maximum β value in this section is less than 74 m for horizontal and 53 m for vertical. Field gradients of all magnets are less than 35 T/m. The small β value compared to the that of the colliding section is due to large β value at the crossing point

The β function of the undulator is required to be small and similar value for the electron beam with small emittance. The requirement is fulfilled by inserting a quadrupole triplet between the arc and the undulotor. The obtained β is about 5 m over all the section.

2.4 Short Straight Section

The short straight section is used for the electron cooling of the ion beam. For efficient electron cooling the ion beam should be parallel and small size. In the section a quadrupole triplet is inserted and make the required beam. The obtained β is almost the same and the value of the β is about 6 m over all the section.

3 RING PARAMETERS OF EACH OPERATION MODE

After the design of the each section we calculated the ring parameters for each operation mode. In this paper we mention about large emittance mode and ion mode for collision of electron and ion.

The obtained parameters of the both modes are summarized in Table 1. Natural chromaticity is corrected using sextupoles as shown in Fig. 2. The obtained strengths of the large emittance mode are 11.3 m^{-3} for SF and -26,1 m^{-3} for SD and those of the ion mode are 73.0 m^{-3} for SF and -96.3 m^{-3} for SD. These very large values of sextupoles are due to large chromaticities, which are almost originated from large β values and strong filed gradients of quadrupole magnets in the colliding section. For reason the chromaticity correction will be needed in the section locally

	Large emi. mode	Ion mode
Tune νx	4.7931	6.6677
νy	7.6866	5.6609
Chromaticity		
ξx	-74.41	-72.69
ξy	-27.40	-32.26
Transition γ	4.819	5.230
Momentum compaction	0.043	0.037
Max. b (m) βx	470	1173
βy	101	458
b at colliding section (m) βx*	0.02	0.1
βy*	0.02	0.1

Table. 1. Ring parameters of DSR for the large emittance and ion mod

REFERENCES

[1] Y. Yano et al., these proceedings.
[2] M.Wakasugi et al., these proceedings.
[3] K. Yoshida et al, these proceedings.