Design Studies on Beam Transport System of RIKEN RI Beam Factory

Nobuhisa FUKUNISHI, Kensuke KUSAKA, Hiroyoshi SAKURAI, Toshiyuki KUBO, Teruyasu NAGAFUCHI, Hiroki OKUNO, Toshinori MITSUMOTO, Shiro FUJISHIMA, Masayuki KASE, Akira GOTO and Yasushige YANO
RIKEN (The Institute of Physical and Chemical Research)
2-1, Hirosawa, Wako-shi, Saitama 351-01, Japan

Abstract

The beam transport system of the RIKEN RI Beam Factory consists of four parts. The first is a beam line from the injector cyclotron RRC to the intermediate-stage cyclotron IRC. The second is from the IRC to the main accelerator SRC. The third is beam lines from the SRC to experimental halls. The last is a beam line from the IRC to the existing facility. We report here the present status of design studies on the first two beam lines.

1 Introduction

The RIKEN RI Beam Factory (RIBF) aims to produce the world's most intense RI beams at energies of several hundreds of MeV/nucleon over the whole range of atomic masses [1]. To this end, it is necessary to accelerate all the ions from hydrogen to uranium up to more than 100 MeV/nucleon with the beam intensity of 1 pμA.

The acceleration scheme in the RIBF is mainly four steps. The beams accelerated by the existing heavy-ion linac (RILAC) will be injected into the RIKEN Ring Cyclotron (RRC). It is a K540-MeV ring cyclotron. The second-step acceleration will be done by the RRC. Accelerated beams are transferred to the K930-MeV Intermediate-stage Ring Cyclotron (IRC). A part of the beams accelerated by the IRC will be returned to the present facility, the RIKEN Accelerator Research Facility (RARF). The remaining part will be transferred to the K2500-MeV Superconducting Ring Cyclotron (SRC) and the final acceleration will be performed here. The accelerated beams will be guided to the new projectile-fragment separator Big-RIPS, where the production and the separation of RI beams will be done. RI beams will be transferred to experimental halls.

The beam transport system in the RIBF thus consists of four parts. The one is a beam line from the RRC to the IRC. The maximum magnetic regidity (Bρ) required for the beam line is 2.94 Tm which corresponds to a 24.5-MeV/nucleon $^{238}U^{58+}$ beam. The second is a beam line from the IRC to the SRC. The maximum Bρ is 4.57 Tm corresponding to a 58.0-MeV/nucleon $^{238}U^{58+}$ beam. The third is beam lines from the SRC to experimental halls through the Big-RIPS. The last one is a beam line which returns the beams accelerated by the IRC to the RARF. We started to design the beam transport system in the RIBF. We will explain in this report the present status of design studies on the beam line from the RRC to the IRC and that from the IRC to the SRC. The layout of the beam lines is illustrated in Fig.1.

2 Beam Line from RRC to IRC

2.1 Overview of Beam Line

The beam line from the RRC to the IRC mainly consists of five bending magnets, eight quadrupole triplets, two quadrupole doublets and seven quadruple singlets. In addition, there is another Q-doublet in the injection system of the IRC (QDI3). The functions required for the beam line are the dispersion matching, the matching of phase-space ellipses in the transverse direction (beam shaping) and the RF-phase matching.

For the dispersion matching, the bending magnet (BM1) in the injection system of the IRC is designed to produce the desired dispersion. The actual condition required for the beam line is hence to make a doubly achromatic beam just before the BM1. The spatial dispersion of the RRC beam is roughly 2.5 m at the Electric Deflection Channel (EDC). The angular dispersion is zero at the EDC. The 90-degrees bending magnet (BM90) in the E1 experimental hall makes a doubly achromatic beam as shown in Fig. 1. In addition, the section from the EDC to the QTE13 is totally a doubly telescopic system. This enables us to perform an emittance measurement of a beam at the P1 point in the beam line. The momentum analysis will be also performed with the bending magnet BM90.

The beam shaping will be done with four Q-singlets (QSI2-QSI5). To this end, the beam line is designed to be horizontal waist at the QSI2 and the QSI4, and to be vertical waist at the QSI3 and the QSI5. The section from the BM24-1 to the BM24-2 is doubly achromatic and matches the beam direction to the injection system of the IRC. The section from the BM30-1 to the BM30-2 is also doubly achromatic and lowers the beam line by three meters. This vertically achromatic feature causes to defocus a beam in the horizontal direction. To avoid the divergence of the beam, the Q-double QDI1 focuses the beam before this section.

We show results of an ion-optical calculation in Fig.2. The calculation was performed using the TRANSPORT code [2]. The emittance of the beam is 5π mm•mrad and the momentum spread is ±0.05 % in the present calculation. The assumed value of the emittance is based on the observation but depends on the actual beam tuning. For the momentum spread, we use here the double of the observed half-width. The maximum value of the quadrupole-filling factor is designed to be 50 %.

On the beam bunching, detailed investigations are necessary. The RF-phase width of the RRC is 10 degrees. On the contrary, the RF-phase acceptance of the IRC is 20 degrees because a flattop resonator will be introduced. The first-order ion-optical calculation with ±0.05 % of the momentum spread predicts that the full width of the beam pulse at the Electric Inflection Channel (EIC) of the IRC is 24 degrees, which nearly corresponds to the RF-phase acceptance. Note that the assumed value of the momentum spread is the double of the observed half-width.

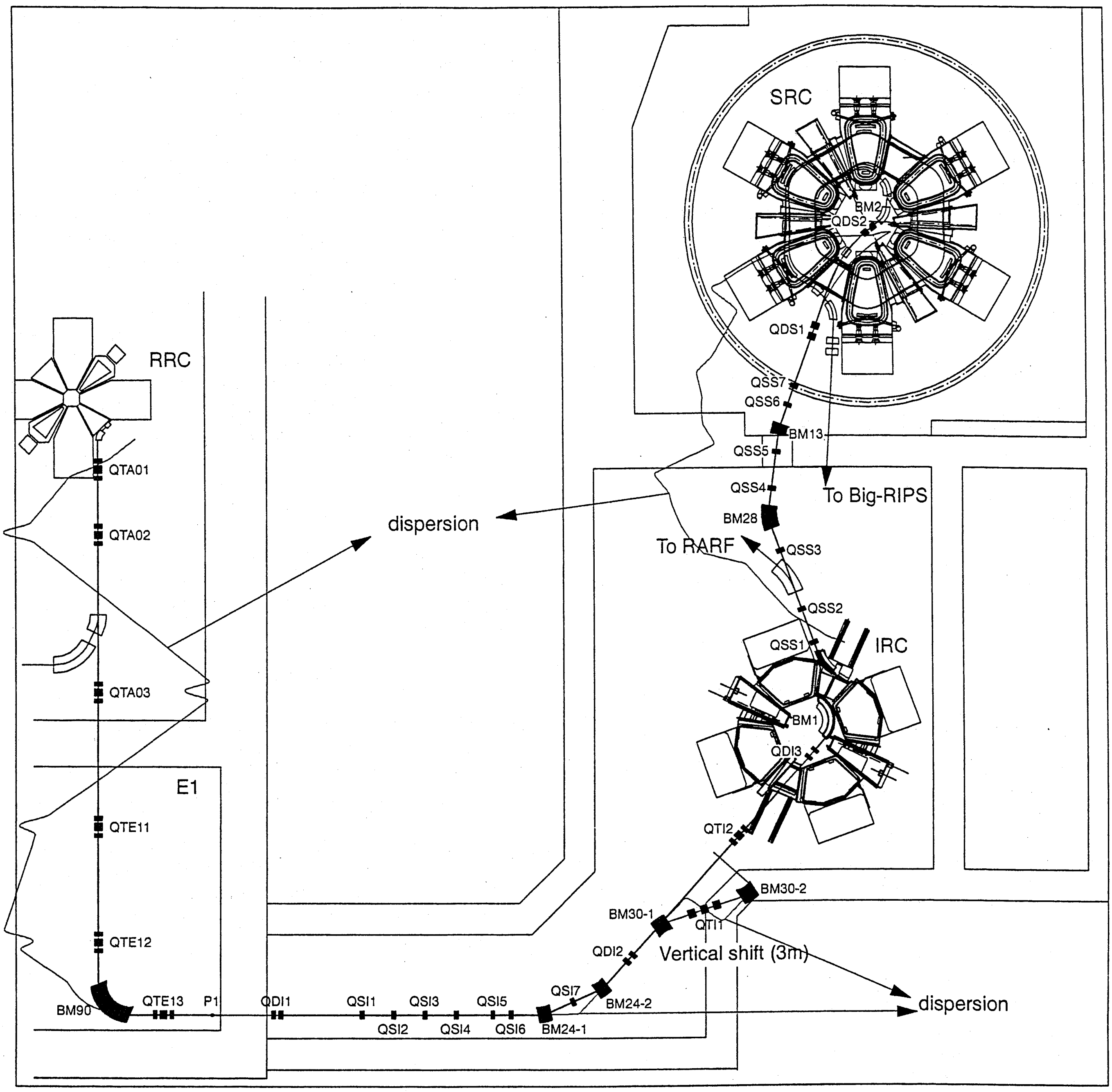

Fig.1 Rayout of the beam transport system in the RI Beam Factory. The scale is 1/400.

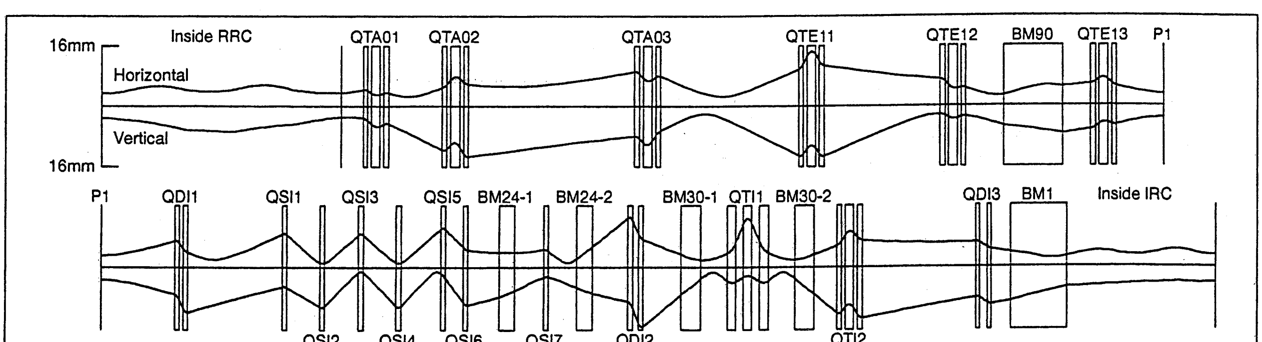

Fig.2 Beam envelope calculated for the beam line from RRC to IRC. A first-order ion-optical calculation was performed. The beam emittance is 5π mm•mrad and the momentum spread is $\pm 0.05\%$ in this calculation.

2.2 Magnets

Specifications of the magnets are summarized in Tables 1 and 2. We fixed the design and started the construction for quadrupole magnets.

Table 1. Parameters of bending magnets in the line from the RRC to the IRC.

Type of magnet	BM90	BM24	BM30
Deflection angle (deg.)	90	24	30
Curvature radius (m)	2.0	2.0	2.0
Pole gap (mm)	60	60	60
Total number of windings	280	280	280
Maximum current (A)	300	300	300
Pole face rotation (deg.)	24/24	12/12	15/15

Table 2. Parameters of the quadruple magnets.

Type	Q220	Q420
Aperture (mm)	70.0	70.0
Maximum gradient (T/m)	15.0	15.0
Maximum current (A)	150	150
Length of pole (mm)	220	420
Effective length (mm)	250	450

3 Beam Line from IRC to SRC

The functions required for the beam line from the IRC to the SRC are the dispersion matching and the beam shaping. The beam bunching is not necessary because the beam transport system is short enough. The beam line consists of two bending magnets, seven Q-singlets and a Q-doublet. In addition, the injection system of the SRC has another Q-doublet. In the beam line, there is no section that is doubly achromatic. Hence, the beam shaping and the dispersion matching couples mutually. The roles of Q-magnets are as follows. The QSS1 changes the beam shape for both horizontal and vertical directions but give little effect on the dispersion. The QSS2 is very sensitive to the beam shaping in the horizontal direction. On the contrary, the QSS3 mainly changes the beam shape in the vertical direction. The QSS4 and the QSS6 are mainly used for the dispersion matching. Moreover, the first magnet of the QSD1 is important for both the beam shaping and the dispersion matching. By adjusting six Q-magnets mentioned above, the beam accelerated by the IRC is matched to the conditions in injecting to the SRC.

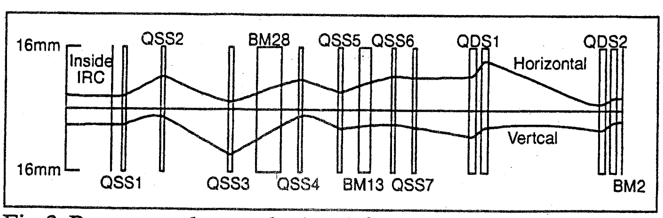

Fig.3 Beam envelope calculated for the beam line from the IRC to the SRC.

We here show the result of an ion-optical calculation in Fig. 3. In this calculation, the matching conditions are given at the entrance of the BM2. From the BM2 to the EIC of the SRC, orbit calculations were performed. The assumed emittance of the beam is 3.3π mm•mrad and the assumed momentum spread is ±0.05 % in this calculation. The quadrupole-filling factor is less than 50 % for this beam line. The dispsersion calculated here is shown in Fig. 1. We want to mention here that the central orbit of the beam dose not coincide with the arrangement of the magnets in Fig. 1. This is because the effect of special steering magnets in the injection system of the SRC is not taken into account precisely. These steering magnets will be used to match the beam trajectory to the injection system under the strong stray field from the sector magnets of the SRC which depends non-linearly on the magnetic regidity of the beam [3]. In this sense, the present calculation should be modified.

We plan to use same types of quadrupole magnets in this beam line. Although the maximum value of the magnetic regidity is much larger than that of the beam line from the RRC to the IRC, intervals between successive quadrupole magnets are long enough for the use of Q220-type magnets.

4 Summary

We made ion-optical studies for two beam lines connecting the three cyclotrons in the RIBF. Beam bunching, monitoring system and vacuum system should be studied hereafter.

References

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[3] S. Fujishima et al., "Analysis of the Injection and Extraction Trajectories in the RIKEN Superconducting Ring Cyclotron", in proceedings of the 15th International Conference on Cyclotron and Their Applications", Caen, 1998.