Charge stripper ring for RIKEN RI beam factory†

H. Imao*1

The use of charge strippers is almost inevitable for the efficient acceleration of particularly heavy ions such as uranium in heavy-ion accelerator complexes. At the RIKEN RI Beam Factory (RIBF), the total charge stripping efficiency of two strippers, He gas[1,2] and rotating graphite sheet disk strippers,[3] used for uranium acceleration is less than 5%, which creates a serious bottleneck for potential intensity upgrades in the near future. We have proposed the use of charge stripper rings (CSRs)[4,5] as a cost-effective method to achieve a 10-fold increase in the intensity of the ^{238}U beams at RIBF.

Figure 1 shows a design view of the CSR for the first stripper (CSR1), which is a compact isometric ring with the same design circumferences of 37.1953 m (15 times the distance interval of the beam bunches from the RIKEN Ring Cyclotron (RRC) at a frequency of 18.25 MHz) for all circulating uranium beams with eight different charge states from 59+ to 66+. CSR1 consists of gas strippers (He and nitrogen strippers), eight main bending magnets (BM1-8), two acceleration cavities, a re-buncher, four charge-dependent quadrupole stations, injection magnets (IBM and injector quadrupole triplets), extractor bending magnets (EBM1 and EBM2), steerers for closed-orbit distortion corrections, and diagnostic boxes involving beam diagnostics and vacuum pumps. In the CSR1, beams other than the selected U^{64+} beams reenter the stripper with a ring after recovering the energy lost in the stripper. The U^{35+} beams are injected simultaneously into the charge stripper ring using the charge exchange injection method. The recycling cycles are repeated, and only the U^{64+} beams are continuously extracted, using a magnetic deflection channel. The isometric ring is used to hold the bunch structure of beams to match the acceptance of the latter-stage cyclotrons.

The CSR1 lattice is a mirror-symmetric reversed lattice with the symmetry plane at the center of the stripper section. The high-density quadrupole stations equipped with a quadrupole doublet or triplet for all charge states will be used to control the optics for all charge states. The design of a compact quadrupole magnet is a key issue. We have already finished the calculations and are preparing to manufacture "hourglass-like" quadrupole magnets[6] as shown in Fig. 1.

We conducted some calculations for the key design issues of CSR1. A realistic lattice for 8 charge states circulating in CSR1 was derived. Possible sources of emittance growth with a new multi-stage stripper scheme were also investigated. We also performed calculations for the beam transport of U^{35+} from RRC to CSR1 and then those of U^{64+} from CSR1 to fRC. The effective charge stripping efficiency of CSR1 in the present calculation was approximately 60%, and further detailed calculations and optimizations were conducted.

References
1) H. Okuno *et al.*, Phys. Rev. ST Accel. Beams **14**, 033503 (2011).
2) H. Imao *et al.*, Phys. Rev. ST Accel. Beams **15**, 123501 (2012).
3) H. Hasebe *et al.*, EPJ Web Conf. **229**, 01004 (2020).
4) H. Imao *et al.*, Proc. CYC2016, Zurich, Switzerland, 2016, pp. 155–159.
5) H. Imao *et al.*, Proc. IPAC2018, Vancouver, Canada, 2018, pp. 41–46.
6) Patent application filed by RIKEN and HITACHI Engineering Co., Ltd. with the application number JP2020-056540 in Japan.

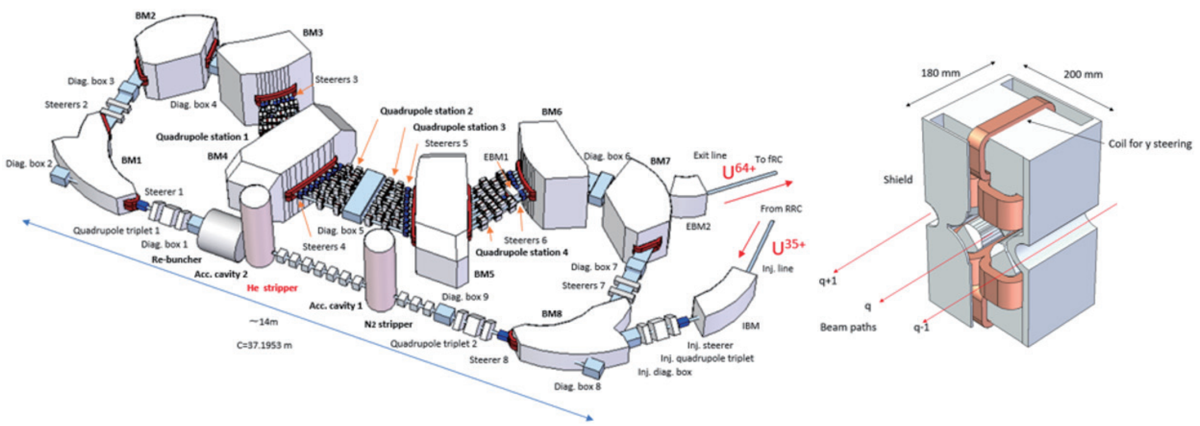

Fig. 1. Design view of the CSR1 (left) and "hourglass-like" quadrupole magnet (right).

† Condensed from the article in J. Instrm. **15**, P12036 (2020)
*1 RIKEN Nishina Center