Installation of new central region for energy upgrade at RIKEN AVF cyclotron

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We changed the structure of the central region of the AVF cyclotron to a new one in September 2017. The new structure is the same as the one that was beam-tested in August 2016, except that a part of the inner wall of its RF shield was scraped by hand so that the inflector can be rotated. In the beam test that was conducted in 2016, protons were successfully accelerated to an energy of 30 MeV with harmonic H = 1 acceleration mode. However, the structure was reverted to the previous one because the transmission efficiency of 5-MeV/nucleon $^{56}Fe^{15+}$ beam was 10% and worse than half of the conventional efficiencies.[1)] Although the injection acceptance for the original (S1) and new (S2) structures had been calculated in 2016, more detailed simulations including a buncher located at I36 (2.03 m above the median plane of the cyclotron) were executed again in 2017.

Figure 1 shows the injection acceptance sizes of 12-MeV/nucleon deuterons for S1 and S2. The injection acceptance is defined as the phase-space size of the particles accelerated beyond a radius of 180 mm. The abscissa indicates the relative phase angle to the RF at the starting point of the tracking calculation located just above the buncher. Both the dee voltages were 40 kV. The injection acceptances for S1 and S2 were almost the same. The same applies to the other beams. Considering the results of the beam test that was conducted in 2016, the extraction efficiencies for S2 may be worse than those for S1. The reasons for this are not clear because simulations for the extraction efficiencies were not done sufficiently due to the involvement of many adjustable parameters. On the other hand, in the machine time of 9.1-MeV/nucleon $^{12}B^{4+}$ performed in July 2017, only half of the beam current of 300 particle nA that was requested by the experimenters could be supplied. This was due to large beam losses in the first turn for S1, because this beam needed high acceleration voltages. The new structure S2 can reduce the injection beam losses for beams that need high voltages. Therefore, from these two points, we decided to install S2 again and to use it in the machine time for the experiments.

Figure 2 shows a comparison of the transmission efficiencies before and after the installation of S2. The transmission efficiencies are defined as the ratio of the beam currents of Faraday cups FC-I36 and FC-C01 located at the injection and extraction beam lines of the cyclotron. The transmission efficiency of 9.1-MeV/nucleon $^{12}B^{4+}$ beams increased four times and the extracted beam current reached 800 particle nA. Although the transmission efficiencies depend on the kind of beams and the time for operational adjustment of the cyclotron, it seems that the transmission efficiencies for S2 are as good as those for S1 or much better in some cases. Moreover, in the machine study after the installation of S2, we succeeded in accelerating 14-MeV/nucleon deuterons which could not be accelerated before. However, while their injection efficiency was 40–50% as high as other beams, the extraction efficiencies were poor, approximately 10%, which is too low and can supply only weak beams of 1–2 particle μA. Since the increase in the energy of deuterons are strongly requested by experimenters, we plan to do beam simulations and machine study to increase the extraction efficiencies for 14 MeV/nucleon deuterons.

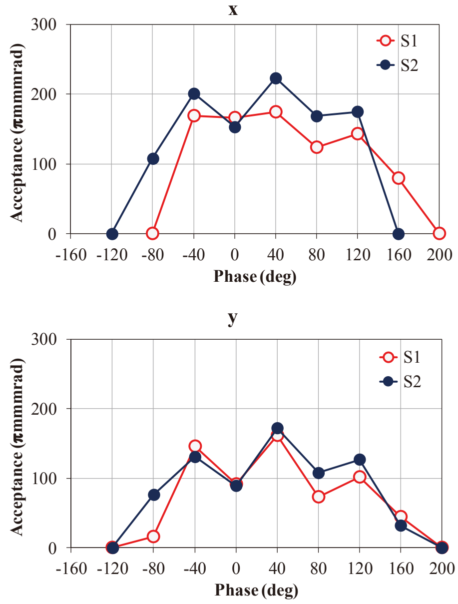

Fig. 1. Injection acceptance sizes for 12-MeV/nucleon deuterons in two orthogonal directions.

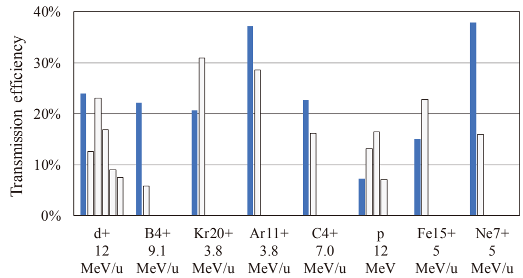

Fig. 2. Transmission efficiencies of the AVF cyclotron after and before the installation of the new structure S2. Filled bars indicate the transmission efficiencies after the installation and empty bars indicate those before the installation.

Reference

1) J. Ohnishi *et al.*, RIKEN Accel. Prog. Rep. **50**, 145 (2017).

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