Injection-beam-orbit analysis of AVF cyclotron using 4-dimensional emittance

Y. Kotaka, [*1] Y. Ohshiro, [*1] H. Yamaguchi, [*1] N. Imai, [*1] Y. Sakemi, [*1] T. Nagatomo, [*2] M. Kase, [*2] J. Ohnishi, [*2] A. Goto, [*2] K. Hatanaka, [*3] H. Muto, [*4] and S. Shimoura [*1]

For the purpose of increasing the beam intensity of the AVF cyclotron, the improvement of the injection beam intensity is essential because 80% of the beam intensity produced by ECRIS is lost in this injection line. In order to determine the reason for this loss and to optimize the injection beam orbit, the injection beam orbit is analyzed in view of the space charge effect.

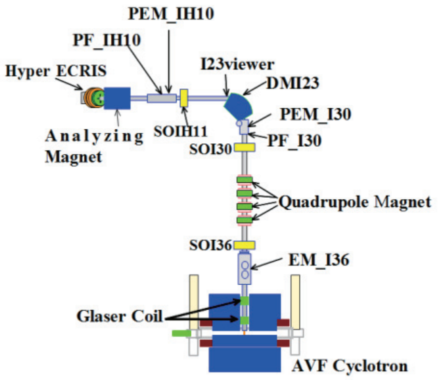

Fig. 1 Beam injection line of the AVF cyclotron.

Figure 1 shows the beam injection line of the AVF cyclotron. We measured the 4-dimensional emittance by the pepper-pot emittance monitor[1)] (PEM_IH10) and calculated the injection beam orbit using the 4-dimensional emittance as the initial value. We adopted two types of calculation models for electromagnets. For the calculation in solenoid coils and quadrupole magnets, we adopted the calculated magnetic field. On the other hand, we adopted the hard-edge model for a dipole magnet (DMI_23). For the edge focus of DMI23, we used the correction indicated by TRANSPORT.[2)] These calculation models were tested by a 25.4-keV $^{4}He^{2+}$ ion beam of 5 eμA. The calculated beam orbit was mostly consistent with the measurement results of the beam viewer (I23viewer), profile monitor (PF_I30) and 2-dimensional emittance monitor (EM_I36).[3)]

To evaluate the performance of these models for the high-intensity beam, we tested them by a 15.4-keV $^{4}He^{2+}$ ion beam of 240 eμA. The calculated beam orbit was not consistent. The result was thought to be caused by the space charge effect.

There are some models for the space charge effect. In the model we adopted first, the beam cross section was circular, and the transverse and longitudinal beam densities were uniform.[3)] Next, we adopted an ellipse instead of a circle because the beam cross section was not always circular.

*1 Center for Nuclear Study, University of Tokyo
*2 RIKEN Nishina Center
*3 RCNP, Osaka University
*4 Center of General Education, Tokyo University of Science, Suwa

The equation of the space charge effect is as follows:[4)]

$$\frac{d^2x}{ds^2} = \frac{4\lambda r_p}{\beta^2\gamma^3 a(a+b)}x, \quad \frac{d^2y}{ds^2} = \frac{4\lambda r_p}{\beta^2\gamma^3 b(a+b)}y \quad \left(r_p = \frac{q^2}{4\pi\epsilon_0 mc^2}\right) \quad (1),$$

where s is the beam axis, (x, y) is the transverse phase-space coordinate, λ is the number of particles per unit length, β and γ are Lorentz factors, a and b are the ellipse axes of the beam, and r_p is the classical radius of the particle.

We solved the equation of the injection beam orbit including equation (1) and compared the 2-dimensional emittance measured by EM_I36. The coordinates (u, w) of EM_I36 are rotated by 45 degree against the coordinates (x, y). The comparisons of (u, u') and (w, w') are shown in Fig. 2 and Fig. 3, respectively. The shapes of the calculated 2-dimensional emittances are close to those of the 2-dimensional emittances measured by EM_I36. The model of the space charge effect is thought to be effective.

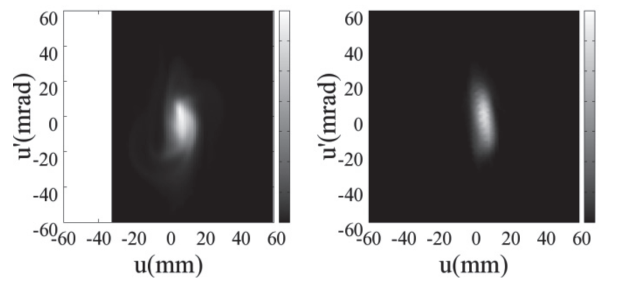

Fig. 2 (left) Image of (u, u') emittance measured by EM_I36. (right) Image of the (u, u') emittance calculated from the measured 4-dimensional emittance.

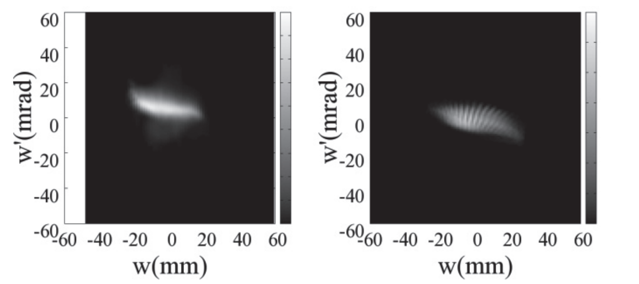

Fig. 3 (left) Image of (w, w') emittance measured by EM_I36. (right) Image of the (w, w') emittance calculated from the measured 4-dimensional emittance.

References
1) T. Hoffmann et al., Proc. 9th BIW, Cambridge, USA (2000), p. 432-439.
2) D. C. Carey et al., FERMILAB-Pub-98/310
3) Y. Kotaka et al., Proc. 13th Annual Meeting of PASJ, Chiba (2016).
4) S. Y. Lee: Accelerator Physics 1st ed. (Singapore, World Scientific, 1999).