Improvement of injection beam-orbit analysis of AVF cyclotron

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]

In order to increase the beam intensity of the AVF cyclotron, the injection beam transport system must be improved. As the first step of this improvement, we have developed a calculation method of the beam orbit down to the center of the AVF cyclotron from the ion source by using the 4-dimenssional emittance measured with a pepper-pot emittance monitor[1)] (PEM_IH10), as shown in Fig. 1. One feature of our calculation method was the use of the 3D magnetic field calculated with a calculation code to take into account the fringe fields of electromagnets. The other was to implement a space charge effect.[2–4)]

As reported previously, the beam-orbit calculation with such magnetic-field distributions of solenoid coils and quadrupole magnets was successful.[2)] Therefore, we also renewed the model of the dipole magnet DMI23 shown in Fig. 1 from the hard-edge model of a dipole magnet with a fringing field and pole-face rotations[5)] to 3D magnetic-field distributions. The result did not differ from that of the previous model. However, this has helped us to find a practical beam energy by calculating the beam orbit with the 3D dipole magnetic field including the fringing field.

In order to improve the calculation of the space charge effect, we formulated a multistep-ellipse model instead of a single-ellipse model. In the single-ellipse model, the shape and beam-intensity distribution of the beam cross section are approximated by an ellipse and by a uniform distribution, respectively. However, the real beam-intensity distribution is not uniform.[3)] Therefore, we increased the number of ellipses that keep the center and give each ellipse the amount of beam elements that exist within it.

To construct the equation of motion (EOM),[4)] a standard ellipse must be defined by the combination of the average, standard deviation, and correlation of the beam-intensity distribution. Multistep ellipses are made by evenly dividing the ellipse, the radius of which is 6 times larger than the radius of the standard ellipse, into 30 ellipses.

First, the EOM including the space charge effect for the beam element in the innermost ellipse is constructed. Then, the EOM for the beam element located between the second and first innermost ellipse is constructed from the second ellipse. For the outer ellipses, the EOM is constructed accordingly. The beam elements beyond the outermost ellipse are neglected.

The result of the multistep-ellipse model is shown in Fig. 2. Ion beam measured is $^4He_2{}^+$ at 15.4 keV and 250 eμA. The left of Fig. 2 shows a beam-intensity distribution measured by I23viewer, which is a beam viewer and is shown in Fig. 1. The middle of Fig. 2 shows a beam-intensity distribution calculated using the single-ellipse model. The radius of the single ellipse is 1.8 times larger than the radius of the standard ellipse. The right of Fig. 2 shows a beam-intensity distribution calculated using the multistep-ellipse model. It can be seen that the multistep-ellipse model reproduces the measured distribution better than the single-ellipse model.[6)] The reason for this is thought to be that each beam distribution of the cross section on the beam axis is close to the real distribution.

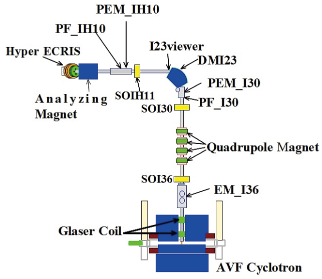

Fig. 1. Injection beam line of the AVF cyclotron.

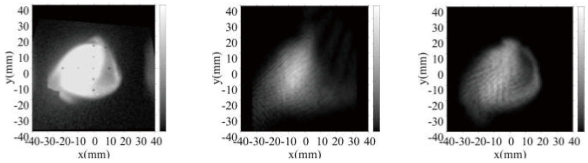

Fig. 2. (Left) Beam-intensity distribution measured with I23viewer. (Middle) Beam-intensity distribution calculated by the single-ellipse model. (Right) Beam-intensity distribution calculated by the multistep-ellipse model. The ion beam is $^4He_2{}^+$ at 15.4 keV and 250 eμA.

By these improvements, the shapes of the beam deduced from the calculated beam orbit have become close to the measured ones. In addition, we plan to find a method to evaluate these differences of shapes quantitatively. However, the calculated central position and beam angle were not always the same as in the measurement. This is a problem to be improved in the future.

References

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*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