Evaluation of beam orbit calculation method for the injection line of AVF cyclotron and performance evaluation of pepper-pot emittance monitor

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We finished developing a calculation method for the beam orbit from the Hyper ECR ion source to the center of the AVF cyclotron using the 4D emittance measured with a pepper-pot emittance monitor[1] (PEM_IH10).[2,3] We attempted to numerically evaluate our calculations of 15 types of beams by comparing other diagnostics.

To evaluate our beam orbit, we compared it to the 2D emittance measured by the 2D emittance monitor[4] (EM_I36) installed 6.2 m away from PEM_IH10 using χ^2 test. However, it should be noted that the 1D distribution projected from the 2D distribution was used for the comparison. χ^2 is defined as the sum of squared differences of each position or each angle between the measurement and the calculation divided by an assumed dispersion. However, this value itself is not significant because this experiment was conducted to observe the relative variations in the results. This value was estimated so that χ^2/DOF becomes approximately 1 when the calculation may conform to the measurement by visual judgement.

4D emittance was measured using a standard (x, y) coordinate system perpendicular to the beam direction, where x and y denote the horizontal and vertical directions, respectively. The coordinate system of EM_I36 (u, w) was rotated by 45 degree against the (x, y) coordinate system, and u' and w' were the angles of u-axis and w-axis, respectively. The left part of Fig. 1 indicates the scatter plot of χ^2/DOFs of u and u'. The χ^2/DOFs of w and w' is indicated in the right part of Fig. 1. The displacements in the position or angle between the measurement and calculation were determined but they were canceled to determine the distribution conformity in this comparison. All values of χ^2/DOF were is found to be scattered up to 6. The reasons of this variation are being

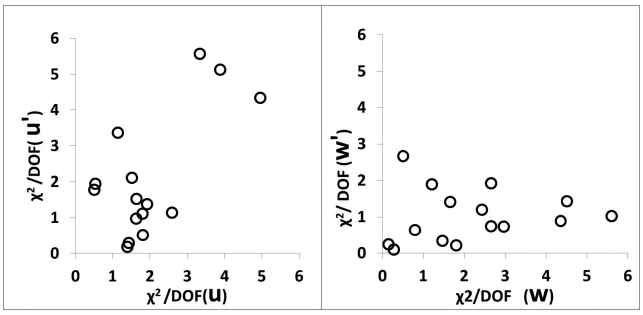

Fig. 1. (left) Scatter plot shows χ^2/DOFs of u and u'. (right) Scatter plot shows χ^2/DOFs of w and w'. Fifteen beams (H^+, D^+, $^4He^{2+}$, $^7Li^{2+}$, $^{11}B^{4+}$, and $^{18}O^{6+}$) are tested.

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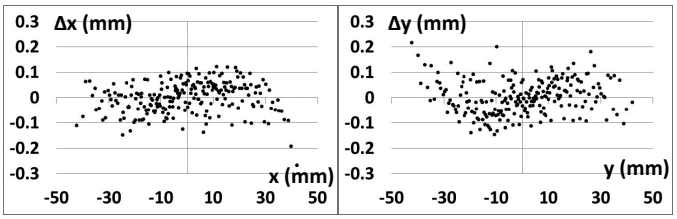

Fig. 2. Differences in distribution between fiducial points and measured position on pixel coordinate: x-axis (left) and y-axis (right).

examined singly.

The above-mentioned displacements for positions and angles were approximately 10 mm and 10 mrad, respectively. One of the considerable reasons is the magnetic hysteresis of the vertical deflection dipole magnet (DMI23). We measured the magnetic hysteresis and found the magnetic difference to be 1.7% when the commonly-used excitation current varied from 10 to 20 A. For example, 1.0% magnetic field difference is estimated to cause 10 mm difference at 300 mm from DMI23 when the excitation current is 25 A. Because we used a setting excited current for the beam orbit calculation without knowing this, these displacements in positions and angles occurred. Therefore, the magnetic field of DMI23 needs to be measured.

After the beam orbit calculation, we started the performance evaluation of PEM_IH10 for improvement and focused on the position error of the fluorescent plate. As its view was recorded by the digital camera, it transformed to real space by the relationship between the fiducial points on the fluorescent plate and their measured positions on the pixel coordinate. The position error was estimated from the differences between the fiducial points and their transformed positons. Previously, there were 15 fiducial points with a diameter of 1 or 2 mm. The standard deviations (SD) of the differences of x direction and y direction were 0.12 and 0.19 mm, respectively. For improvement, we used a graph paper pasted on the fluorescent plate and selected 225 fiducial points at 5 mm interval in the area of 70 mm square. The differences in the distributions of x and y are shown in the left and the right parts of Fig. 2, respectively. The SD of differences of x and y were improved to 0.06 and 0.07 mm, respectively. Other performance evaluation will be conducted.

References

1) T. Hoffmann *et al.*, AIP Conf. Proc. **546**, 432 (2000).
2) Y. Kotaka *et al.*, Proc. 14th Annual Meeting of PASJ, (2017), pp. 1118–1122.
3) Y. Kotaka *et al.*, RIKEN Accel. Prog. Rep. **51**, 138 (2018).
4) Y. Kotaka *et al.*, RIKEN Accel. Prog. Rep. **41**, 96 (2008).