Development of auto-tuning system using Bayesian optimization for ion optics in primary beam line with 26 electric nA Kr beam

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We started the project to introduce the auto-tuning system of the accelerator facility to RIBF as reported last year.[1)] As a first step in this project, we adopt an auto-tuning program using sequential learning based on Bayesian optimization[2)] to the beam line optics from the SRC to BigRIPS first production target F0, so-called T-Course.

A test experiment for the project was conducted in May 2022 with Kr^{36+} beam to develop a new method to measure beam intensity and beam spot simultaneously for high-intensity beams. In the method, the phase ellipse and intensity of the primary beam are measured using BigRIPS nominal detectors. Because the direct measurement with these detectors limits the intensity of the primary beam, the charge-converted particles created by the 1 mm-thick Be target at F0 are measured by downstream detectors. This method enables to measure, for example, approximately 10 kcps Kr^{34+} beam at F3 as an indicator of a primary 30 electric nA Kr^{36+} beam.

In the experiment, Kr^{34+} was selected by the F1 slit and measured by PPACs and a scintillator at F3. The beam intensity was set to approximately 0.001 electric nA for the 5 different optical conditions to compare with the nominal method, and spot images were acquired with the viewer target at F0. As a result, they showed good agreement and we confirmed the measured values by F3 detectors were good indicators for the primary beam. Next step, we adjusted the optics of the T-course using the developed indicators. In the optical system tuning, it was necessary to finish the measurement and evaluation in a few tens of seconds for each parameter sets. We converted PPAC data into trajectories and beam widths within a few seconds using the newly developed BYACO[3)] system and passed the data to the optimization program via EPICS. Finally, we optimized the currents of doublet quadrupole magnets QDT11a-b and QDT12a-b with 26 electric nA Kr^{36+} primary beam to maximize the scintillator count rate and minimize the beam widths at F3. Left panel of Fig. 1 shows beam spot measured by F3 PPACs before (left top) and after (left bottom) optimization. As shown in the figures, the horizontal beam widths are reduced from 1.5 to 1.1 mm (rms) at F3. The transmission efficiency was also measured for each optics with the Faraday cup at G01 and beam dump inside the D1 magnet, and it confirmed that both values agree within the errors. Graphs in the right panel of Fig. 1 show measured and calculated beam widths at the location of profile monitors in

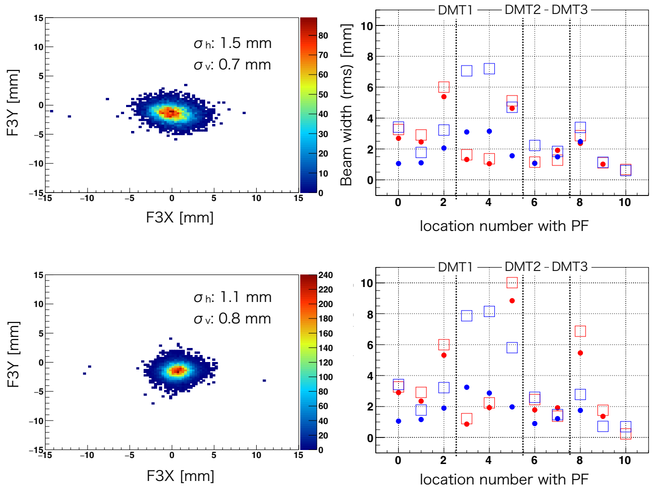

Fig. 1. (Top) Before optimization. (Bottom) After optimization. (Left) beam spot of Kr^{34+} measured by F3 PPACs. (Right) Beam widths at the location of profile monitors. Red (blue) marks correspond to horizontal (vertical) beam widths, and circle (square) marks correspond to the data measured by profile monitors (calculated by the simulation).

T-Course. The location 10 indicates F0. The calculation is based on the measured beam phase ellipse at F3. As shown in the figures, the measured and calculated values are in good agreement, except the vertical beam widths between DMT1 and DMT2. These calculations also show the optimized ion optics realized the smaller beam spot at F0.

In conclusion, we developed a new method to measure beam spot and intensity simultaneously with high-intensity primary beam. With the method we optimized ion optics in T-Course and reduce beam spot size at F0, keeping beam transmission efficiency. This new method using BYACO opens the possibility of optimizing the parameters of the beam lines using not only the beam spot, but also the signal of any downstream detector (*e.g.*, the signal-to-noise ratio of secondary particles) as an indicator. We are developing a new algorithm with safe regions to apply this method for the higher intense primary beam.

References

1) T. Nishi *et al.*, RIKEN Accel. Prog. Rep. **55**, 66 (2021).
2) E. Iwai *et al.*, Proc. PASJ2021, WEOB02 (2021).
3) T. Sumikama *et al.*, RIKEN Accel. Prog. Rep. **54**, 82 (2020).

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