Development of a new indicator for the auto tuning system with high-intensity primary beams

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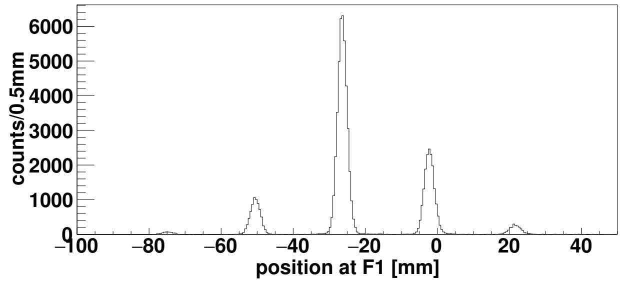
At the RIBF facility, more than 600 parameters, such as quadrupole magnets, steerers, rebunchers, and radio-frequency (RF) voltages/phases, are manually adjusted. After more than 10 years of operation, the local beam loss has been suppressed to a few percentage points. However, in order to control the beam beyond 1 particle μA, we need to optimize the parameters more precisely according to the beam state at the time while keeping the beam loss below 0.1%. Therefore, we decided to conduct research to introduce automatic parameter optimization using machine learning.

In this project, we adopt an auto tuning program using sequential learning based on Gaussian process regression, which is developed and already integrated in the regular operation at SACLA of SPring-8.[1)] We apply the program to RIBF via EPICS. As the first step to introduce the program to RIBF, we attempted to optimize the beam-line optics from the SRC to the first production target of BigRIPS, F0.

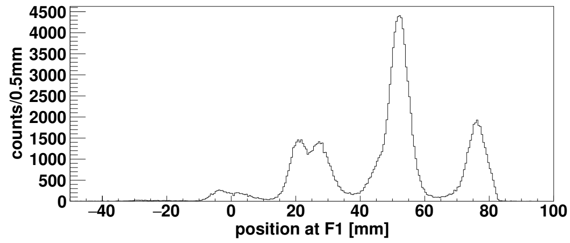
There are two approaches underway in this project: (A) the development of an auto tuning system for low-intensity beams using fluorescent targets and (B) the development of a new indicator for an auto tuning system with high-intensity beams using secondary beams. For (A), we conducted a 12-h experiment in October 2020 using a faint U^{86+} beam of about 0.001 electric nA (enA) and succeeded in increasing the transmission efficiency by 2% and reducing the spot width by 13% at F0 over the manually optimized optics.[2)]

For (B), we devised a method using different charge states as indicators for high-intensity primary beams. A primary U^{86+} beam is injected to a 1-mm-thick Be target at F0 to produce several charged-state particles. The primary beam width and intensity on the target are estimated from the trajectories and count rates of charge-converted particles at downstream focal planes with parallel-plate avalanche counters (PPACs) and a scintillator at the F3 focal plane. Figure 1 shows the distribution of different charged states at the slit position F1. As shown, the production rate of particles varies depending on each charge.[3)] One charge state is selected by adjusting the Bρ of the beam line and the F1 slit condition. The measurements of the beam spot size and intensity are realized for primary beams up to 10 enA by selecting charge states with lower production rates as the primary beam intensity increases.

We conducted an experiment to test this indicator in May 2021 with faint U^{86+} beams. The optimization program developed in approach (A) was utilized with the new indicator. The 1-mm-thick Be target was set behind the fluorescent viewer to compare the new indicator with the spot image obtained by the fluorescent target. We confirmed that the program optimized the 7 magnet currents simultaneously to increase value of the indicator. However, it was revealed that the transmission efficiency with optics "optimized" by our program was 10% worse than that with the manually optimized optics by comparing the beam current with upstream and downstream Faraday cups.



(a) Positions with a 1-mm-thick Be target



(b) Positions with a 1-mm-thick Be and fluorescent target

Fig. 1. Position distribution of U ions for different charge states at slit position F1.

After investigation, we found that this was due to the non-uniformity of the thickness of the fluorescent target, which increased the momentum spread and the beam size at the slit position as shown in Fig. 1(b). The distribution width was not small enough compared with the slit width of 23 mm, and the counts of the downstream scintillator strongly depended on the shape of the distribution at F1, rather than the primary beam intensity at F0. In order to solve the problem, we aim to adopt a 1-mm-thick Be solely to avoid enlarging the beam size at slit position F1.

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References

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