Beam emittance analysis of primary beams using profile monitors in the beam transport line from SRC to BigRIPS

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A high-intensity primary beam extracted from the SRC is transported through the T-course to the BigRIPS F0 target, with the unreacted beam stopped at the beam dump. The accurate estimation of the beam emittance is essential for safe beam transport and proper heat-load estimation for the target and beam dump operation.

This report presents an emittance analyisis based on ion-optical calculations, using beam profile measurements from profile monitors[1] (PF monitors) installed in the T-course. The emittance is evaluated by fitting the beam matrix (σ-matrix) to the measured beam profile widths. Specifically, the matrix at the object point $\sigma^{(0)}$ is related to the matrix at the PF monitor position, i, denoted as $\sigma^{(i)}$, by the ion-optical transfer matrix $\mathbf{R}$, such that $\sigma^{(i)} = \mathbf{R}\sigma^{(0)}\mathbf{R}^{\top}$. For systems in which horizontal and vertical directions are decoupled, the vertical matrix element $\sigma^{(i)}_{33}$ is given by $\sigma^{(i)}_{33} = R^2_{33}\sigma^{(0)}_{33} + 2R_{33}R_{34}\sigma^{(0)}_{34} + R^2_{34}\sigma^{(0)}_{44}$. For N PF monitors, $\sigma^{(0)}$ is determined by minimizing the error function $F = \sum_{i=1}^{N}\left(\sigma^{(i)}_{33,\mathrm{obs}} - \sigma^{(i)}_{33}\right)^2$, where $\sigma^{(i)}_{33,\mathrm{obs}} = (\Delta y^{(i)})^2$ is the measured vertical beam width squared at position i. The vertical emittance is then calculated as $\epsilon_{\mathrm{V}} = \sqrt{\det\sigma_{\mathrm{V}}}$, where σ_{V} is the vertical beam matrix consisting of σ_{33}, σ_{34}, and σ_{44}. For the horizontal direction, owing to coupling with the longitudinal direction via bending magnets, a six-parameter matrix $\sigma^{(i)}_{\mathrm{H}}$ is used. While the projected horizontal emittance $\epsilon_{\mathrm{H}}^{\mathrm{proj}} = \sqrt{\sigma_{11}\sigma_{22} - \sigma_{12}^2}$ is conserved only in systems without bending magnets, the horizontal emittance at an achromatic point, $\epsilon_{\mathrm{H}}^{\mathrm{achro}} = \sqrt{\det\sigma_{\mathrm{H}}/\sigma_{66}}$, is conserved in systems without acceleration.

We report results from the analysis of a 345-MeV/nucleon ^{238}U beam delivered in December 2024. The T-course layout and locations of ten PF monitors are shown in Fig. 1, with an example beam profile at the T11a position. Figure 2 shows the measured beam widths and fitting results for both vertical and horizontal directions. The analysis used the exit of the EBM as the object point, as it is the start of the T-course, with first-order transfer matrices $\mathbf{R}$ calculated from the beamline configuration and applied magnet currents. The emittance values obtained are $\epsilon_{\mathrm{V}} = (0.322 \pm 0.033)\pi$ mm·mrad and $\epsilon_{\mathrm{H}}^{\mathrm{achro}} = (0.484 \pm 0.037)\pi$ mm·mrad. Uncertainties were estimated with $\pm 2.5\%$ errors in PF measurements and $\pm 2.0\%$ errors in quadrupole field gradients. Fu-

Fig. 1. Layout of the T-course beam transport line showing the locations of ten PF monitors (labeled 'PF-' in blue text) from the SRC extraction point to the BigRIPS target position. An example beam profile of the 345-MeV/nucleon ^{238}U beam, measured with the PF monitor at T11a, is shown in the inset, demonstrating the typical Gaussian-like beam profile.
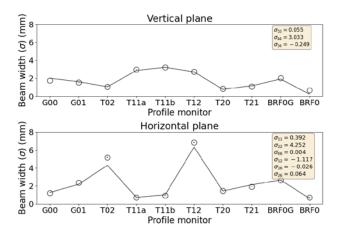

Fig. 2. Measured beam widths (open circles with error bars from Gaussian fitting) and emittance analysis (solid lines) in both vertical and horizontal directions. The resulting beam matrix elements at the PF-BRF0 positions are also shown in the figure.

ture research will include emittance measurements using PPAC position detectors in the BigRIPS beamline to improve the precision of emittance determination through a comparison with the present analysis method.

Reference

1) T. Watanabe et al., Proc. 19th Int. Conf. on Cyclotrons and their Applications, Lanzhou, China, 2010-09 (2010), p. 351.

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