Transactions of the Korean Nuclear Society Fall Meeting
Gyeongju, Korea, October 26-27, 2023

Preliminary Measurement on Transverse Phase Space Tomography in the Dump Beamline at KOMAC

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1. Introduction

Beam loss is a critical issue to be avoid for the stable operation and machine protection from radiation in the high power proton accelerators. Nonlinear processes add higher order moments and cause halo and tail structures to the beam, leading to beam losses. Hence it becomes more important to characterize beams for the high power accelerators. Conventional beam diagnostic methods can measure only approximate elliptical features of the beam and are not suitable for high power beams. Computational Tomography (CT) method reconstructs a multi-dimensional distribution from its lower-dimensional projections. We used this method to tomographically reconstruct the transverse (x, x', y, y') phase space distribution of the beam from the accelerator at KOMAC by utilizing a 2D (x, y) wire scanner. A set of one-dimensional beam profile data obtained under various strengths of a quadrupole magnet placed in front of the wire-scanner are converted to two-dimensional phase space distribution using the CT method. We show the implementation of the tomography measurement techniques to the 100 MeV proton linac at KOMAC. In this paper, we describe the tomography measurement system and present the preliminary results of phase space reconstruction obtained from the dump beam in the 100 MeV proton linac.

2. Methods and Results

In this section, we will describe our experimental setup and CT method for beam phase space reconstruction implemented at KOMAC. Transverse phase space of the beam is reconstructed and shown as a result of the CT method.

2.1 Experimental setup

Dump beamline is used for the reconstruction of the beam phase space distribution using the CT method and is located after the DTL107 in the linac. The beam from the DTL107 is a 102.6 MeV proton beam. We used first three quadrupole magnet (QM1~3) and a wire scanner (WS-1) in the beamline for the experiment shown in Fig. 1. The QM1 and QM2 are operated at the current of 45, 55 and 65 A. The QM3 is operated from -110 A to 110 A as it is installed with a bipolar DC power supply which gives more flexibility in changing phase advance of the beam. The wire scanner (WS-1) measures the beam profile in x and y for every setting of QM1~3 during the measurement [1].

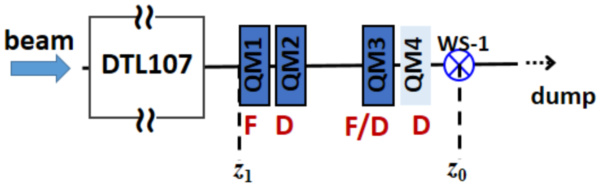

Fig. 1. Schematics of CT experimental setup in the dump beamline.

2.2 Computational Tomography Method for Beam Phase Space Reconstruction

The beam distributions in x-x’ (i.e. horizontal direction) and y-y’ (i.e. vertical direction) trace spaces were reconstructed in this study. Beam profiles in x and y are obtained with a QM1~3 setting and are used for the reconstruction of the transverse beam distribution. We take several sets of x-y beam profiles while changing of the QM1~3 current settings.

In CT method, a filtered back projection algorithm is introduced to reconstruct the beam distribution in the phase space. This algorithm is widely used in medical imaging technique. In the CT imaging system, a detector rotates around the object of interest. However, in this study, the object, i.e. a beam rotates by some beam optics (QM1~3) and a detector, i.e. WS-1, keeps its position.

The beam right before the QM-1 has a beam distribution at z_0 in Fig. 1 is assumed as an ellipse. Then, the beam ellipse at z_1 is determined by the beam matrix at z_0 and a transfer matrix from QM-1 to WS-1. Two points, (x_{p0}, 0) and (0, x'_{q0}), at z_0 rotates to (x_{p1}, x'_{p1}) and (x_{q1}, x'_{q1}) at z_1 through the transfer matrix, ***M*** shown in Fig. 2.

The relation between the points defined on different planes is mathematically expressed as follows:

$$\begin{pmatrix} x_{p1} & x_{q1} \\ x'_{p1} & x'_{q1} \end{pmatrix} = \boldsymbol{M} \begin{pmatrix} x_{p0} & 0 \\ 0 & x'_{q0} \end{pmatrix} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} \begin{pmatrix} x_{p0} & 0 \\ 0 & x'_{q0} \end{pmatrix} = \begin{pmatrix} M_{11}x_{p0} & M_{12}x'_{q0} \\ M_{21}x_{p0} & M_{22}x'_{q0} \end{pmatrix} \quad (1)$$

$$\tan\theta = \frac{x_{p0}}{x'_{q0}} = \frac{R_{12}}{R_{11}} \quad (2)$$

$$a = \frac{x_{p1}}{s} = \frac{R_{11}x_{p0}}{s} = \frac{R_{11}}{\cos\theta} \quad (3)$$

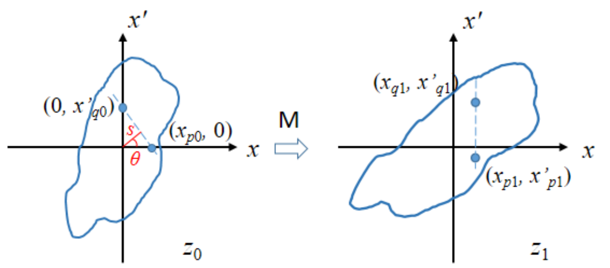

Fig. 2. Rotation and elongation of ellipse in phase space

Therefore, the beam profile measured at z_1 is equivalent to the elongated projection of the ellipse at z_0 rotated by the angle, θ with the elongation factor, a. The beam profiles are modified by the elongation factors and the rotation angles set by the currents of the QM1~3. These beam profiles are called as a sinogram in the CT technique. The beam distribution is reconstructed by the filtered back projection algorithm and the sinogram.

Table I: Emittance and Twiss Parameters obtained in x by quad scan and CT method

	Quad Scan	CT
$\varepsilon_{x\ norm.,\ rms}$ [π mm mrad]	1.42	1.58
α_x	1.00	0.35
β_x [mm/mrad]	3.40	2.32

Table II: Emittance and Twiss Parameters obtained in y by quad scan and CT method

	Quad Scan	CT
$E_{y\ norm.,\ rms}$ [π mm mrad]	0.75	0.93
α_y	-1.09	-0.95
β_y [mm/mrad]	1.36	1.31

2.3 Results

With the QM1~3 operation currents we set in the experiment, the beams are rotated by about 90° and 180° in x and y respectively. The reconstructed x beam distribution is limited by its rotation angle, however it will be improved in future experiment. We have developed a MATALB based post-processing program which evaluates a beam emittance using the Self-Consistent UnBiased Exclusion analysis (SCUBEEx) [2], to reduce effect of artifacts and negative current. The x-p_x and y-p_y beam phase space distributions are reconstructed and obtained, as shown in Fig. 3. The normalized rms emittance and twiss parameters evaluated by the quadrupole scan method and the CT are compared in Table I and II.

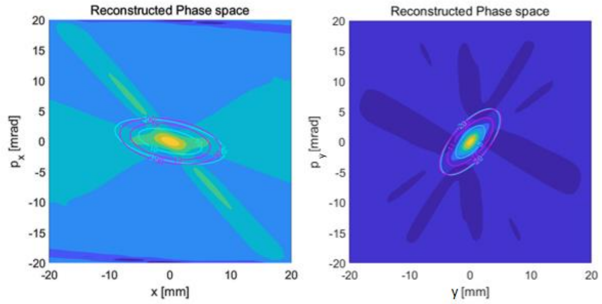

Fig. 3. Reconstructed beam phase space in x-px and y-py

3. Conclusions

The diagnostic method for the reconstruction of the beam phase space distribution in the (x-x') and (y-y') coordinates using the CT technique. The beam profiles in x and y are measured in the dump beamline of the 100 MeV proton linac at KOMAC. The beam distribution in the phase space is reconstructed by the filtered back projection algorithm and the set of the beam profiles measured at various rotation angles set by the quadrupole magnets (QM1~3). The horizontal and vertical emittances of 100 MeV proton beam are evaluated from reconstructed beam distribution in phase space using the SCUBEEx method. The vertical emittance and twiss parameters are closed to those obtained from the quadrupole scan method. For the horizontal emittance and twiss parameters, the results from the CT and quadrupole scan method do not match well due to lack of rotation to secure enough number of sinograms. It will be improved by measuring more beam profiles at rotation angles covering full 180° in future experiments.

ACKNOWLEDGEMENT

This work was supported through KOMAC operation fund of KAERI by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (KAERI-524320-23).

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