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PRELIMINARY RESULTS ON TRANSVERSE PHASE SPACE TOMOGRAPHY AT KOMAC

S. Lee*, H.-S. Kim, D.-H. Kim, S.-P. Yoon, H.-J. Kwon, Korea Multipurpose Accelerator Complex, Korea Atomic Energy Research Institute, Gyeongju, Korea
J.-J. Dang, Korea Institute of Energy Technology, Naju, Korea

Abstract

Beam loss is a critical issue to be avoid in the high power proton accelerators due to machine protection from radiation. Nonlinear processes add higher order moments and cause halo and tail structures to the beam. It eventually causes 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. Tomography method reconstructs a multi-dimensional phase space distribution from its lower-dimensional projections. At the Korea Multipurpose Accelerator Complex (KOMAC), we used this method to tomographically reconstruct the transverse (x-x′) and (y-y′) phase space distributions of the beam from the 100 MeV proton linac by utilizing a wire scanner for x and y beam profiles. In this paper, we describe the tomography measurement system and present the preliminary results of phase space reconstruction obtained from the 100 MeV proton linac.

INTRODUCTION

Beam diagnostics research for measuring high power beam distribution becomes more important and is studied in several laboratories [1–4]. Tomographic techniques has been considered to be a useful technique for measuring high power beam distribution. We have a 100 MeV proton linac which is planned to be upgraded for higher energy. For the stable operation and machine protection from radiation in the high power proton linac, we developed Computational Tomography (CT) method to characterize beams. A set of one-dimensional beam profile data (x or y) obtained under various strengths of a quadrupole magnet placed in front of the wire-scanner are converted to two-dimensional phase space distribution (x-x′ or y-y′) using the CT method. In this paper, we describe the experimental setup, CT method and the tomography measurement system developed at KOMAC, and present the preliminary results of phase space reconstruction obtained from the dump beamline in the 100 MeV proton linac.

EXPERIMENTAL SETUP

Current 100 MeV proton linac operating at 350 MHz consists of a microwave ion source (IS) for 20 mA beam current, a low energy beam transport (LEBT), a radiofrequency quadrupole (RFQ), a 20 MeV drift tube linac (DTL I), a medium beam transport (MEBT) and a 100 MeV drift tube linac (DTL II). The described schematics is shown in Fig. 1. After the DTL II, we have a straight beamline to a dump, called dump beamline. Dump beamline is used for the reconstruction of the beam phase space distribution using the CT method. We used first four quadrupole magnet (QM1-QM4) and a wire scanner (WS-1) in the beamline for the experiment shown in Fig. 1. The QM1, QM2, QM3 and QM4 are operated at the current of 60 A, 50 A, -110 A-110 A, and 0 A - 80 A respectively to change the phase advance angle of the beam. The wire scanner (WS-1) measures the beam profile in x and y for every setting of QM1-QM4 during the measurement.

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) phase spaces were reconstructed in this study [5, 6]. Beam profiles in x and y are obtained for all the QM1-QM4 settings and are used for the reconstruction of the transverse beam distribution. 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 such as QM1-QM4 and a detector, i.e. WS-1, keeps its position. The beam right before the QM1 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 QM1 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 and expressed in Eq. (1).

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

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

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

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

* shl@kaeri.re.kr

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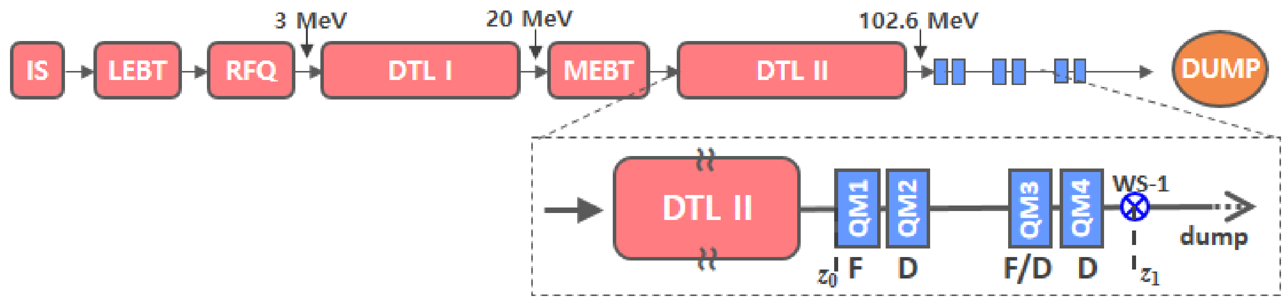

Figure 1: Layout of the 200 MeV proton linac at KOMAC shows the 100 MeV proton linac and the dump beamline. In the dotted line box, quadrupole magnets participating in the CT measurement are shown as QM1-QM4. Beam profiles are measured using a wire scanner WS-1.

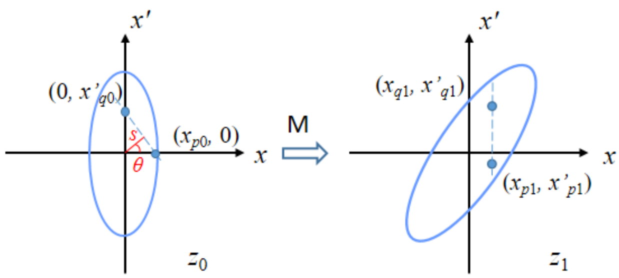

Figure 2: Rotation and elongation of ellipse in phase space

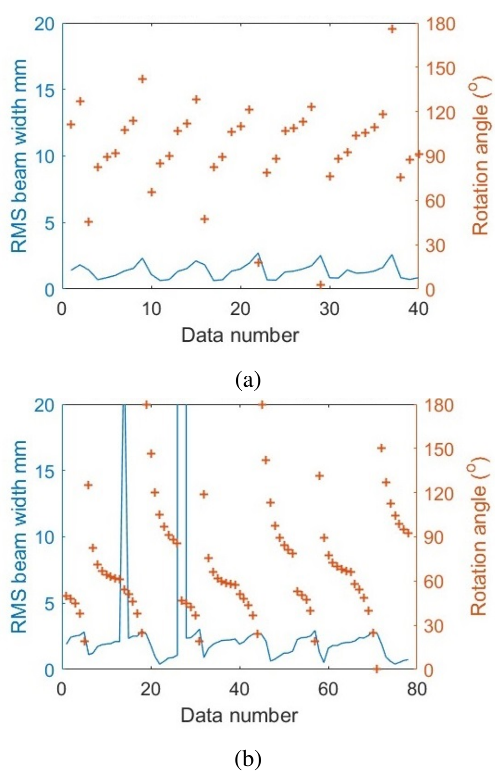

Figure 3: Given the combination of QM1-QM4 settings as Data number in the graph, RMS beam width and rotation angle for the horizontal, x (a) and vertical, y (b) direction are calculated for the beam parameters at z_0.

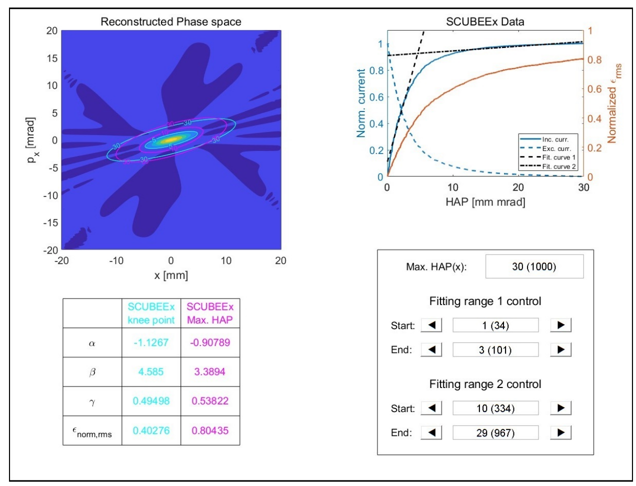

Figure 4: Evaluation program of phase space reconstruction and beam emittance based on SCUBEEx has been developed.

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 expressed in Eq. (2) and (3). The beam profiles are modified by the elongation factors and the rotation angles set by the currents applied to the QM1-QM4. 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.

Before the CT measurement, we performed the quad scan measurement to get the beam parameter at z_0. To obtain the required quadrupole magnet settings (QM1-QM4) for the CT measurement, we estimate the RMS beam width and rotation angle for x and y direction using the beam parameters at z_0, shown in Fig 3. With the estimated magnet settings of QM1-QM4 we set in the CT experiment, the beams are rotated by about 180° both in x and y.

RESULTS

We have developed a MATLAB based post-processing program (Fig. 4) which evaluates a phase space reconstruction and a beam emittance using the Self-Consistent Un-

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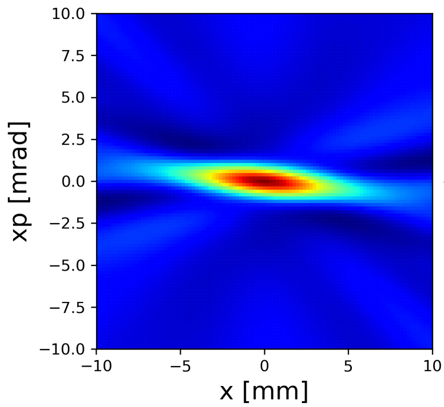
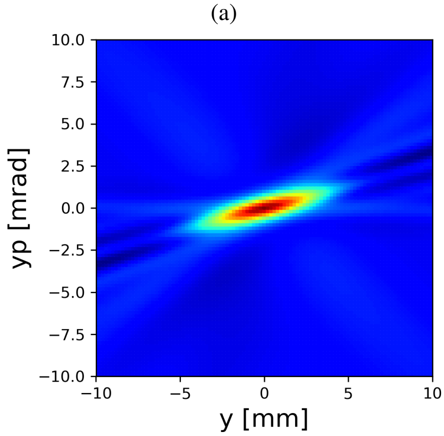


(a)



(b)

Figure 5: Beam envelop calculation of the BL1 (a) and BL2 (b) are plotted as x (blue) and y (red).

Biased Exclusion analysis (SCUBEEx) [7] which reduces the effect of artifacts and negative current. The x-x′ and y-y′ beam phase space distributions are reconstructed as shown in Fig. 5 (a) and (b). The normalized rms emittance and twiss parameters (α, β) in x and y evaluated by the CT method are norm. $\epsilon_{x\ rms}$ = 0.57 π mm mrad, α_x = 0.17, β_x = 3.19 mm/mrad, $\epsilon_{y\ rms}$ = 0.80 π mm mrad, α_y = -0.91 and β_y = 3.39 mm/mrad.

CONCLUSION

The diagnostic method for the reconstruction of the beam phase space distribution in the (x-x′) and (y-y′) coordinates is developed using the CT technique at KOMAC. 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-QM4). The horizontal and vertical emittances of 100 MeV proton beam are evaluated from reconstructed beam distribution in phase space using the SCUBEEx method.

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