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Beam Phase Space Characterization via a Slit Emittance Meter and Quad Scan Method

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1. Introduction

We designed and fabricated a slit emittance meter which consists of two pairs of slits with a slit drive control system. It is installed in the BTS (Beam Test Stand) at KOMAC (Korea Multipurpose Accelerator Complex) to characterize the beam phase space distribution. The beam phase space distribution is measured via the slit emittance meter successfully. Quad scan method was performed in the BTS straight beamline where the slit emittance meter was installed. The quad scan experiment is one of the most common experiments to measure the emittance and twiss parameters of the accelerated beam. In this paper, we have compared the results of the slit emittance meter with results from quad scan experiments. This comparison can determine the reliability and limitation of the slit emittance meter as a beam diagnostics tool.

2. Methods and Results

In this section, we first introduce the slit emittance meter at KOMAC. Then result of x-x' and y-y' beam phase space distribution via the slit emittance meter is shown. This result is compared with the result from the quad scan experiment.

2.1 Slit Emittance Meter

Slit emittance meter uses two pairs of slits installed at a distance L = 0.5 m. Fig. 1 shows the cross-sectional view of the chamber with a pair of vertical and horizontal slits. These slits are driven by a set of linear motion manipulator and a stepper motor each. The beam is directed to its first slit pair (slit 1 and 2 for x1 and y1) and chopped into flat beamlets. This beamlet is spread with initial angular spreads in x and y, and then passes through the second slit pair (slit 3 and 4 for x2 and y2). After passing through all the slits, the final beamlet is measured as the beam current at the collector. By repeating these measurements at various combinations of slit positions, the entire phase space f(x, x', y, y') can be measured and the beam emittance and twiss parameters can be obtained. x' and y' are directly measured as x' = (x2-x1)/L and y' = (y2-y1)/L.

The slit emittance meter is installed in the straight beamline of the BTS. BTS consists of a microwave ion source, a LEBT (low energy beam transport) system, a RFQ (Radio Frequency Quadrupole) accelerator, quadrupole magnets and beam diagnostics tools such as current transformer, faraday cups and wire scanners as shown in Fig. 2.

Fig. 1. Cross-section of the chamber where a pair of slits is installed.

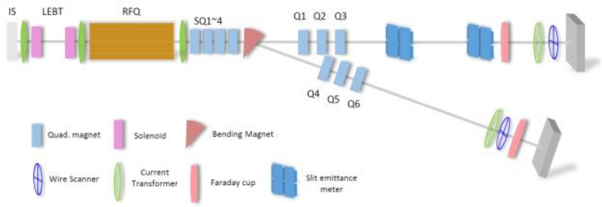


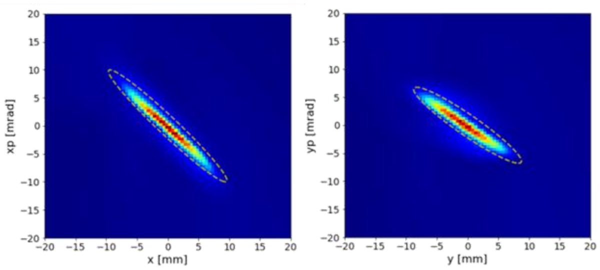
Fig. 2. Slit emittance meter system is installed in one of beamlines in BTS.

The slit emittance meter is installed as seen in Fig. 3

Fig. 3. Picture of the slit emittance meter installed in the BTS.

2.2 Phase Space Measurement via Slit Emittance Meter

x-x' beam phase space distribution is measured using the x1 and x2 slit pair with the moving step of 0.5 mm. Similarly, y-y' beam phase space distribution is measured using y1 and y2 slit pair with the same moving step. From the distributions, we obtained the emittance and twiss parameters in x and y which are given as norm. rms emittance = 0.201 π mm mrad, alpha = 4.304 and beta = 4.258 mm/π mrad for x, and norm. rms emittance = 0.181 π mm mrad, alpha = 2.860 and beta = 3.917 mm/π mrad for y. Ellipses corresponding the above values are drawn in yellow dotted lines in Fig. 4.



(a) (b)

Fig. 4. (a) x-x' and (b) y-y' beam phase space distribution measured using the slit emittance meter : yellow dotted ellipses are drawn with the emittance and twiss parameters obtained from the slit emittance meter.

2.3 Phase Space Measurement via Quad Scan Result

The quad scan experiment consists of one or more quadrupole magnets and beam diagnostics equipment that can measure the beam size. In the BTS beamline, a quadrupole magnet rotates the beam in phase space and the beam projection is measured as the beam size with a WS (wire scanner). Beam emittance and twiss parameters are obtained based on the relationship between the strength of the quadrupole magnet and the beam size. Quad scan method was performed in the BTS straight beamline where a slit emittance meter was installed as shown in below figure, Fig. 5.

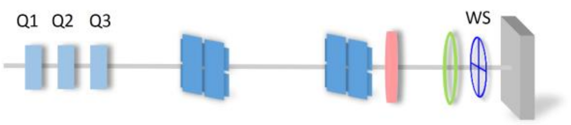


Fig. 5. Quad scan performed with Q3 quadrupole magnet and WS, wire scanner in the straight beamline of BTS.

Square of x and y rms beam sizes are plotted as functions of field gradients of the quadrupole magnet, Q3 in Fig. 6. From this, we obtained the beam emittances and twiss parameters in x and y phase space. These values obtained from the slit emittance meter and quad scan experiments are compared in the next section.

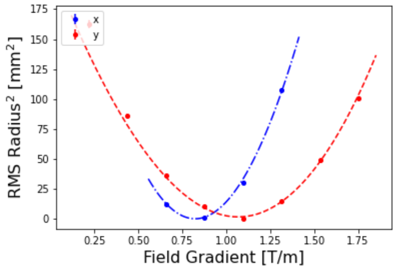
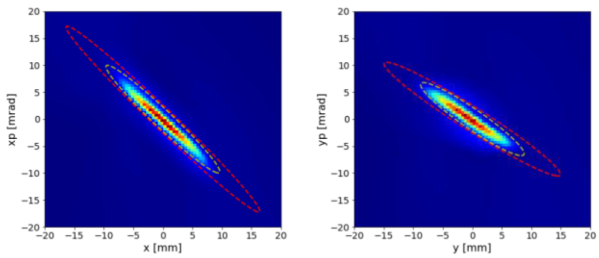


Fig. 6. Quad scan result is plotted as square of rms radius (blue: x, red: y) as a function of field gradient of the quadrupole magnet, Q3.

2.4 Comparison of Results between Slit Emittance Meter and Quad Scan

Results from the slit emittance meter and the quad scan experiment differ. And prominent difference is in the emittance values. Ellipses are drawn in red dotted lines in Fig. 7 with results from the quad scan experiments. Red dotted lines are much larger in size compared with yellow ones, meaning that the slit emittance meter measures smaller beam sizes than the actual.



(a) (b)

Fig. 7. (a) x-x' and (b) y-y' beam phase space distribution measured using the slit emittance meter : dotted ellipses are drawn with the emittance and Twiss parameters obtained from the slit emittance meter (yellow) and quad scan experiment (red).

Table I: Emittance and Twiss parameters obtained via slit emittance meter and quad scan method

	x-x'		y-y'	
	slit	quad	slit	quad
ε [π mm mrad]	0.201	0.399	0.181	0.355
α	4.304	6.462	2.860	3.969
β [mm/π mrad]	4.258	6.216	3.917	5.795

2.5 Comparison of Beam Profiles between Slit Emittance Meter and Quad Scan

In order to understand the reason why the beam emittance from the slit results is measured to be smaller than that from the quad scan results, the beam distributions at x1, y1, x2, y2 slit positions are simulated with the quad scan results using the TraceWin code. We performed a computational simulation that sets the beam distribution particle with the emittance and twiss parameters obtained from the quad scan as beam input parameters in the code. Comparing the two beam sizes, we could see that the beam was measured smaller by the slits of the slit emittance meter, which resulted in smaller emittance values being measured by the slit emittance meter. The quad scan emittance was 1.50 times larger for x and 1.39 times larger for y. Whether this ratio is constant will be known through several repeated experiments, and if so, the slit emittance meter simply needs to be multiplied by the ratio so that the slit emittance meter measurements are consistent with the quad scan measurements. And with this slit emittance meter, both the ellipse characteristics and phase space distribution of the beam can be obtained. We plan to find out the cause of the small beam size through additional experiments in the future.

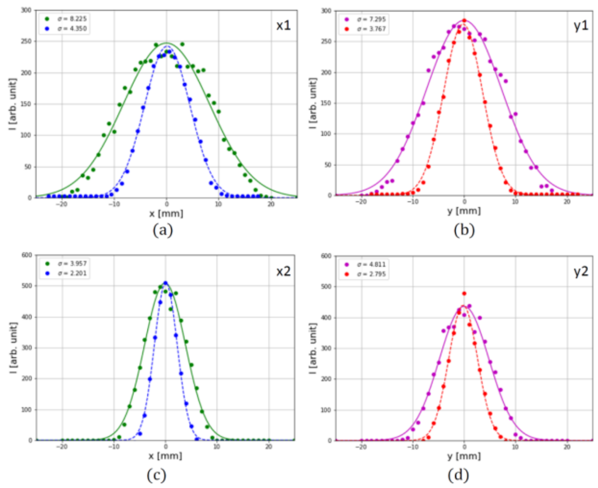


Fig. 8. Comparison of x, y beam distributions: (a) x1 distribution of slit measurement (blue) and computerized simulation of quad scan results (green) (b) y1 distribution of slit measurement (red) and computerized simulation of quad scan results (magenta), (c) x2 distribution of slit measurement (blue) and computerized simulation of quad scan results (green) and (d) y2 distribution of slit measurement (red) and computerized simulation of quad scan results (magenta)

3. Conclusions

We measured the x-x', y-y', x-y', y-x' and x'-y' beam phase space distributions and successfully reconstructed the beam phase space distributions of x, y, x-x', y-y', and x-y' from the x'-y' beam phase space distribution data. By comparing the results of the slit emittance meter with the emittance and Twiss parameters obtained from quad scan experiments, we identified the direction to ensure the consistency between the slit emittance meter and other beam profile measurement equipment and derived a method for this purpose. Applying the precise measurement technique of the 4D beam transverse phase space distribution to a 100 MeV proton accelerator will enable more accurate analysis of the transverse phase space distribution of high-energy proton beams. Based on this, we aim to ensure stable and efficient operation of the 100 MeV proton accelerator and beam services. Furthermore, it is anticipated that future research on beam diagnostic techniques will help in the successful energy upgrade of the accelerator.

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