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Implementation of an Efficient Quadrupole Scan Method for the Transverse Beam Characteristics at KOMAC

Seunghyun Lee*, Hyeok-Jung Kwon, Han-Sung Kim, Sang-Pil Yun, Dong-Hwan Kim
Korea Multipurpose Accelerator Complex, Korea Atomic Energy Research Institute, Gyeongju 38180
**Corresponding author: shl@kaeri.re.kr*

1. Introduction

The characterization of the transverse phase space of beams is a basic requirement for particle accelerators. The quadrupole scan technique is a simple and useful method for the transverse beam characterization. To observe beam profiles and perform quadrupole scan measurement, we have installed several wire scanner and measured beam profiles at the KOMAC (KOrea Multipurpose Accelerator Complex) beamlines [1]. In order to monitor the transverse emittance and twiss parameters regularly, it is important to shorten the measurement time of a quadrupole scan experiment yet obtaining reliable results. We tested the operation range in which the wire scanners can measure properly, and examined the quad scan method in which the results are reliable with less measurements. In this paper, we shall describe the implementation of an efficient quad scan method for the transverse beam characteristics at KOMAC.

2. Methods and Results

In this section, we will focus on examining wire scanner operation and experimental method of quadrupole scan using data taken from the KOMAC dump beamline. From this result, transverse phase space of the beam is constructed with beam center measurement.

2.1 Wire Scanner Operation

8 wire scanners [2] are installed in beamlines. The wire scanner can sweep from -75 mm to 75 mm. However due to the beam pipe size of dia. 100 mm, it can measure the beam size form -50 mm to 50 mm as shown in the Fig. 1.

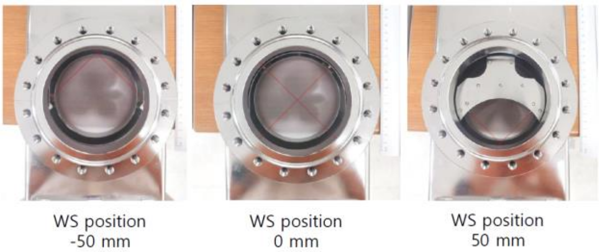


Fig. 1. Wire scanner (WS) is kept at -50, 0 and 50 mm position and red lines are marked for better visibility of the wires.

In the wire scanner, wires are fixed on the fork. The fork is rather big that at 50 mm position, it starts to block the beam pipe center as shown in the last picture of Fig. 1. Therefore, it is best to operate the wire scanners from -50 mm to 35 mm if the beam is not too much bigger than rms radius = 5 mm. Fig. 2. shows the wire scanner at 35 mm position and a blue circle of rms radius = 35 mm is drawn as for the reference.

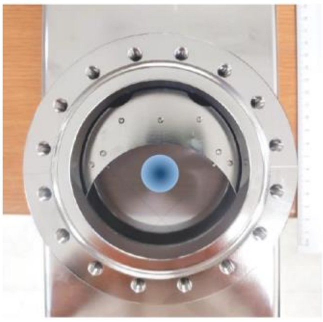


Fig. 2. Wire scanner is kept at 35 mm position and a blue circle of rms radius 5 mm is drawn as for the reference.

Sweeping step size of the wire scanner can be controlled. To choose a suitable step size, we vary the step size while measuring and Gaussian-fitting the beam profile of rms radius ≈ 0.6 mm. Till step size = 1.6 mm, the Gaussian fitting can give consistent beam size shown in Fig. 3. To cover various size of beams, we decide the wire scanner step size as 1 mm. And it is recommended to avoid measuring very small beams (< radius 0.5), because the beam size can vary more than 30% with 1 % quadrupole magnet field error.

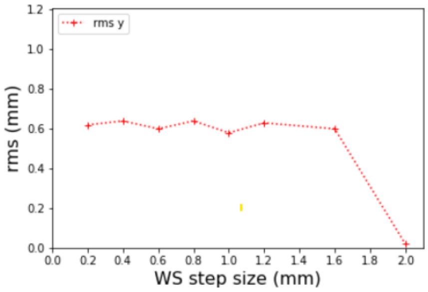
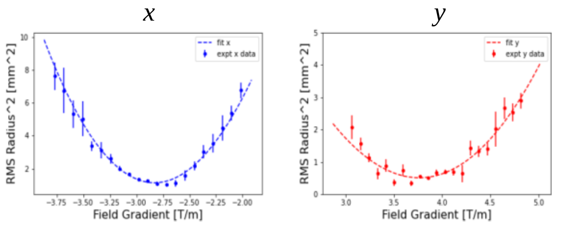


Fig. 3. rms radius are measured by the wire scanner as a function of the wire scanner sweeping step size.

2.2 Experimental Method of Quadrupole Scan

Typical quadrupole scan measurement is plotted in Fig. 4. We apply the error-weighted fitting of parabolic equations [3] from the transfer matrix elements to get emittance and twiss parameters. From data in Fig. 4, norm. rms emittance in x and y are measured to be 1.77 and 0.60 π mm mrad in the dump beamline. We extract parts of measurement data shown in Fig. 4 such as data points in every 2 (A), 3 (B) and 4 (C) listed in Fig. 5.



(a) (b)

Fig. 4. Typical quadrupole scan measurement is plotted as x (a) and y (b) rms radius square as a function of quadrupole magnet field gradient.

From A to C, number of data points are decreased. The data in A, B and C are again fitted in the same way as before to determine how sparsely one can take measurements to get reliable results. After fitting the data of A, B and C, each emittance and twiss parameter is summarized and compared in Table 1.

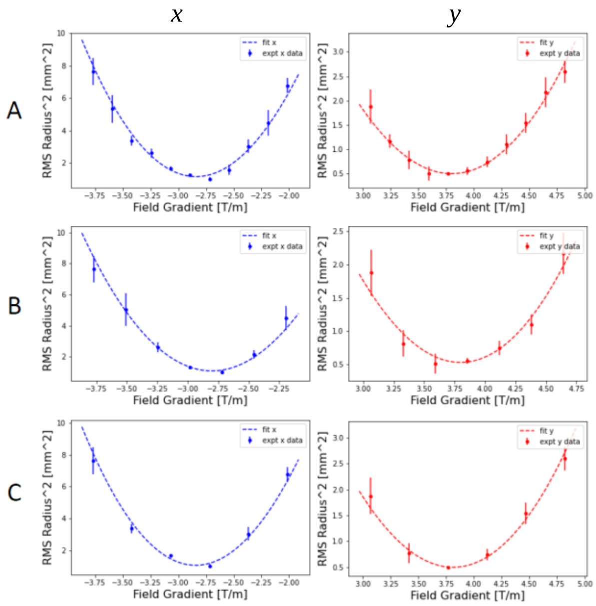


Fig. 5. Data points in every 2 (A), 3 (B) and 4 (C) of Fig. 4. are extracted and plotted together.

Table I: Emittance and Twiss Parameters

	full data	A	B	C
X norm. rms emittance [π mm mrad]	1.77	1.77	1.70	1.72
alpha X	15.69	15.50	15.73	16.63
beta X [mm/mrad]	14.27	14.07	14.37	15.09
Y norm. rms emittance [π mm mrad]	0.60	0.59	0.59	0.59
alpha Y	14.90	14.91	14.08	14.97
beta Y [mm/mrad]	11.75	11.70	11.05	11.73

Compared with the emittance and twiss parameters obtained from the full data, those from A, B and C come within the margin of 7 % difference. It means that not many quadrupole magnet gradient points are needed for the reliable measurement. One can still get consistent and reliable results by taking many measurements at few quadrupole magnet gradient values (at least three) for better statistics.

2.3 Phase Space Construction

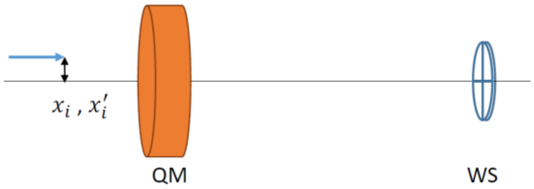


Fig. 6. Schematics of a quadrupole magnet and a wire scanner with an off centered beam is drawn.

A beam with x_i *and* $x_i{}'$ goes through a quadrupole magnet (QM) and a drift space till a wire scanner (WS). The equation for obtaining x_f *and* $x_f{}'$ is given by,

$$\begin{bmatrix} x_f \\ x_f' \end{bmatrix} = M_{drift} \times M_{QM} \times \begin{bmatrix} x_i \\ x_i' \end{bmatrix}.$$

In the experiment, we measure beam center shift in x and it is expressed as

$$x_f = x_i\left(\cos\sqrt{k}l - D\sqrt{k}\sin\sqrt{k}l\right) + x_i'\left(\frac{\sin\sqrt{k}l}{\sqrt{k}} + D\cos\sqrt{k}l\right)$$

for a focusing quadrupole magnet, and

$$x_f = x_i\left(\cosh\sqrt{k}l + D\sqrt{k}\sinh\sqrt{k}l\right) + x_i'\left(\frac{\sinh\sqrt{k}l}{\sqrt{k}} + D\cosh\sqrt{k}l\right)$$

for a defocusing quadrupole magnet,
where *D* = Drift distance between the QM and the WS
l = effective length of the QM

The same equations can be written in terms of y. Using above equations, we fit the *x* and *y* beam center values as a function of quadrupole field gradient as shown in Fig. 7.

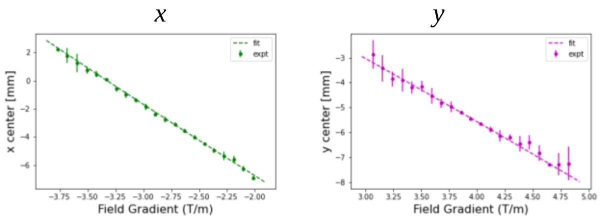


Fig. 7. x and y beam centers are plotted as a function of quadrupole field gradient.

To construct phase spaces for *x* and *y*, other than just emittance and twiss parameters, we need information on

x, x', y and y'. After gathering all the values, the phase spaces of x and y are plotted as below.

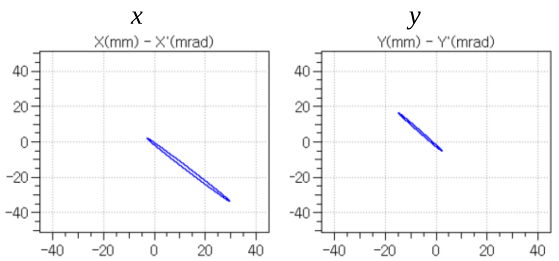


Fig. 8. Phase spaces in x and y are plotted.

3. Conclusions

We tested the suitable operation range (scanning from -50 ~ 35 mm, step size = 1 mm) of the wire scanners installed at KOMAC. Experimental method of quadrupole scan is examined using data taken from the KOMAC dump beamline. For reliable result and better statistics, it is good to take many measurements at just few quadrupole magnet gradient values (at least three). Other than beam size information, one can utilize beam center information to get x, x', y and y'. From this result, transverse phase space of the beam is constructed and can be very useful in beam transport calculations and error analysis.

REFERENCES

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