Preliminary Characterization of Dispersed Beams at KOMAC

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1. Introduction

The beam has been considered to be monochromatic. However, actual beams have a finite momentum spread. Without installing new diagnostics system, we intend to measure momentum spread in the 100 MeV beamlines at KOMAC.

The beam parameters such as Twiss parameters, emittance and momentum spread can be measured via Quad scan method. For the momentum spread, we used two experimental beamlines which are separated by a bending magnet, *i.e.* dump and BL105 beamlines. The beam envelopes in the beamlines are beams without and with dispersion effect by the bending magnet. The increase of the beam size by the dispersion is obtained and then converted into the momentum spread of the beam. In this paper, we present preliminary characterization of dispersed beams and momentum spread measurement at KOMAC.

2. Methods and Results

In this section, we show theoretical expressions related to a dispersed beam through a bending magnet. Based on this theoretical understanding of dispersed beams, we built our strategy to measure momentum spread. Experimental implementation in the beamlines of the 100 MeV linac at KOMAC is explained.

2.1 Dispersed Beam through a bending magnet

Single particle equation in horizontal and longitudinal direction is expressed as

$$\begin{bmatrix} x \\ x' \\ z \\ \frac{\Delta p}{p} \end{bmatrix}_2 = R \begin{bmatrix} x \\ x' \\ z \\ \frac{\Delta p}{p} \end{bmatrix}_1 \qquad (1)$$

where R is a transfer matrix made up of multiplication of transfer matrix of elements from position 1 to 2. For a particle passing through a bending magnet, the transfer matrix, R is given below,

$$R = \begin{bmatrix} R_{xx} & R_{xz} \\ R_{zx} & R_{zz} \end{bmatrix} = R_{edge} \times R_{bend} \times R_{edge}$$

Eq 2 is obtained by substituting the above R in the Eq 1 and is shown below,

$$\begin{bmatrix} x \\ x' \\ z \\ \frac{\Delta p}{p} \end{bmatrix}_2 = \begin{bmatrix} R_{xx} & R_{xz} \\ R_{zx} & R_{zz} \end{bmatrix} \begin{bmatrix} x \\ x' \\ z \\ \frac{\Delta p}{p} \end{bmatrix}_1 \qquad (2)$$

where each element in R is

$$R_{xx} = \begin{bmatrix} \frac{\cos(\varphi-\delta)}{\cos\delta} & \rho\sin\varphi \\ -\frac{1}{\rho}\frac{\sin(\varphi-2\delta)}{\cos^2\delta} & \frac{\cos(\varphi-\delta)}{\cos\delta} \end{bmatrix}$$

$$R_{xz} = \begin{bmatrix} 0 & \rho(1-\cos\varphi) \\ 0 & \frac{\sin(\varphi-\delta)+\sin\delta}{\cos\delta} \end{bmatrix} = \begin{bmatrix} 0 & D \\ 0 & D' \end{bmatrix}$$

$$R_{zx} = \begin{bmatrix} -\frac{\sin(\varphi-\delta)+\sin\delta}{\cos\delta} & -\rho(1-\cos\varphi) \\ 0 & 0 \end{bmatrix} = \begin{bmatrix} -D & -D' \\ 0 & 0 \end{bmatrix}$$

$$R_{zz} = \begin{bmatrix} 1 & \frac{l}{\gamma^2} - (l-\rho\sin\varphi) \\ 0 & 1 \end{bmatrix}$$

ρ and δ are bending and edge angles of a bending magnet. D and D' are dispersion and its derivative.

If a transfer matrix between position 1 and 2 is and a beam sigma matrix σ_1 at 1 is known, then a beam sigma matrix σ_2 at 2 is calculated by the following equation

$$\sigma_2 = R\sigma_1 R^T \qquad (3)$$

where $\sigma_1 = \begin{bmatrix} \sigma_{x1} & 0 \\ 0 & \sigma_{z1} \end{bmatrix}$ and $\sigma_2 = \begin{bmatrix} \sigma_{x2} & 0 \\ 0 & \sigma_{z2} \end{bmatrix}$

Only σ_{x2} term is taken out separately from the above equation Eq 3 as

$$\sigma_{x2} = R_{xx}\sigma_{x1}R_{xx}^T + R_{xz}\sigma_{z1}R_{xz}^T$$

and it corresponds to the equation below,

$$\begin{bmatrix} \varepsilon_2\beta_2 \\ \varepsilon_2\alpha_2 \\ \varepsilon_2\gamma_2 \end{bmatrix}_x = \begin{bmatrix} R_{11}^2 & -2R_{11}R_{12} & R_{12}^2 \\ -R_{11}R_{21} & 1+2R_{12}R_{21} & -R_{12}R_{22} \\ R_{21}^2 & -2R_{21}R_{22} & R_{22}^2 \end{bmatrix}_{xx} \begin{bmatrix} \varepsilon_1\beta_1 \\ \varepsilon_1\alpha_1 \\ \varepsilon_1\gamma_1 \end{bmatrix}_x + \begin{bmatrix} 0 & 0 & D^2 \\ 0 & 1 & -DD' \\ R_{21}^2 & -2R_{21}R_{22} & D'^2 \end{bmatrix}_{xz} \begin{bmatrix} \varepsilon_1\beta_1 \\ \varepsilon_1\alpha_1 \\ \varepsilon_1\gamma_1 \end{bmatrix}_z \qquad (4)$$

1st element of the matrix in Eq 4 is expressed as below,

$$\varepsilon_{x2}\beta_{x2} = [(R_{11}^2)_{xx}\,\varepsilon_{x1}\beta_{x1} - (2R_{11}R_{12})_{xx}\,\varepsilon_{x1}\alpha_{x1} + (R_{12}^2)_{xx}\,\varepsilon_{x1}\gamma_{x1}] + D^2\varepsilon_{z1}\gamma_{z1}$$

Total beam size $\sqrt{\varepsilon_{x2}\beta_{x2}}$ is shown as

$$\sqrt{\varepsilon_{x2}\beta_{x2}} = \sqrt{[(R_{11}^2)_{xx}\,\varepsilon_{x1}\beta_{x1} - (2R_{11}R_{12})_{xx}\,\varepsilon_{x1}\alpha_{x1} + (R_{12}^2)_{xx}\,\varepsilon_{x1}\gamma_{x1}] + D^2\varepsilon_{z}}$$

$$\therefore \text{ Total beam size } = \sqrt{\text{beam size}_{\Delta p/p=0} + D^2\frac{\Delta p}{p}^2} \qquad (5)$$

Eq 5 shows that dispersion affects the beam size, and momentum spread can be measured by comparing beam sizes with and without dispersion.

2.2 Experimental Methods

Our strategy is to simulate beams with and without dispersion effect using a bending magnet in the beamline. We measured beam emittances and Twiss parameters at two locations (green and blue dots) in the dump and BL105 beamlines which are separated by a bending magnet. With the help of an envelope simulation code, we bring these two beams right after the bending magnet (yellow dot) as shown in Fig. 1.

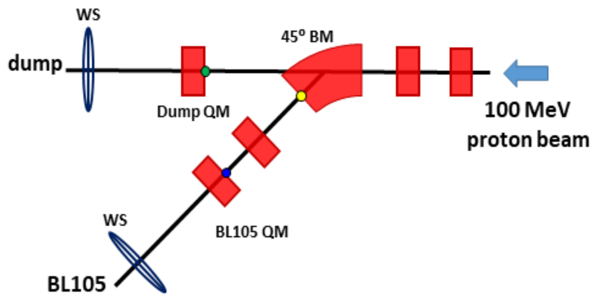
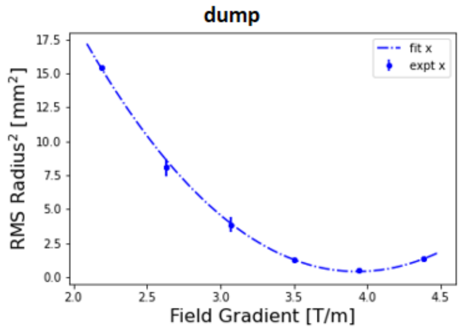


Fig. 1. Wire scanner (WS) is kept at -50, 0 and 50 mm position and red lines are marked for better visibility of the wires.

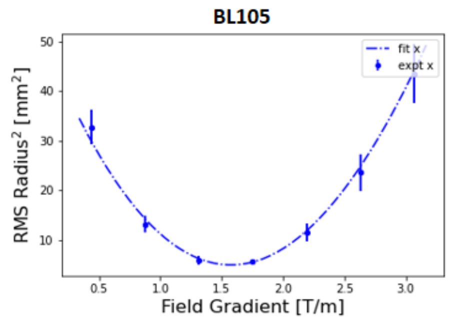
The beam from dump beamline (green dot) does not have any dispersion effect so second term of right hand side in the Eq 5 =0. The beam from BL105 (blue dot) is dispersed beam due to the bending magnet and the beam size would be larger. Beam emittances and Twiss parameters in the dump and BL105 beamlines are measured via Quad scan method.

2.3 Momentum Spread Measurement

Quad scan results in dump and BL105 beamlines are shown in Fig. 4and Table I.



(a)



(b)

Fig. 2. Quad scan measurements are plotted as x rms radius square as a function of quadrupole magnet field gradient in (a) dump and (b) BL105 beamlines

Table I summarized beam emittances and Twiss parameters at green and blue dots in dump and BL105 beamlines respectively.

Table I: Emittance and Twiss Parameters measured at DUMP and BL105

Parameter in	DUMP	BL105
X norm. rms emit. [π mm mrad]	1.01	1.85
alpha X	-5.12	-0.65
beta X [mm/ π mrad]	12.51	7.46

Using the envelope simulation code, we brought the two beams to the yellow dot location shown in Fig. 1 and the beam emittances and Twiss parameters are summarized in Table II.

Table II: Emittance and Twiss Parameters measured at DUMP and BL105

Parameter at yellow dot location	From DUMP	From BL105
X norm. rms emit. [π mm mrad]	1.01	1.85

alpha X	-3.90	-1.81
beta X [mm/ π mrad]	7.46	4.10

Using values in Table II and Eq 5, $\frac{\Delta p}{p}$ is estimated as below,

$$\frac{\Delta p}{p} = \frac{1}{D}\sqrt{\beta_{from\ BL105}\varepsilon_{from\ BL105} - \beta_{from\ DUMP}\varepsilon_{from\ DUMP}}$$

$$= 13.039 \times 10^{-4}\ (0.13\ \%)$$

whereas simulated $\frac{\Delta p}{p} = 0.469$ %. Estimated value is smaller than simulated momentum spread value. However, this is our first momentum spread measurement and this measurement can be improved to obtain momentum spread value closed to the simulated one.

3. Conclusions

The beam parameters such as Twiss parameters, emittance and momentum spread are measured via Quad scan method. Using the envelope simulation code, we brought these two beams to the location where we can compare beam sizes with and without momentum spread. In this paper, we express theoretical equations related to dispersed beams and present estimated preliminary measurement of momentum spread at KOMAC.

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