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EMITTANCE MEASUREMENT WITH WIRE SCANNERS AT CADS MEBT1*

H. Geng#, S. Pei, H. Wang, Y. Zhao, F. Yan, C. Meng, B. Sun, P. Cheng, B. Xu, Institute of High Energy Physics, Beijing 100049, China

Abstract

The C-ADS project has started beam commissioning. The ion source and LEBT has been commissioned successfully, while the RFQ is under conditioning. The Medium Energy Beam Transport line-1 (MEBT$$) is the place where extensive beam parameter measurement will be carried out. Beam emittance is one of the most critical parameters which have to characterized. In the C-ADS injector-I, the MEBT-1 has installed three wire scanners to measure the beam sizes. The transverse emittance measurement method using the wire scanners will be discussed in detail in this paper.

INTRODUCTION

The injector-I for the C-ADS is making great progress. The ion source has been commissioned successfully. The RFQ is now under conditioning. The hardwares of MEBT-1 has been manufactured and will be installed after the RFQ. Extensive beam parameter measurement will be carried out at MEBT-1 to characterize the beam quality from the RFQ. The MEBT-1 has installed three wire scanners to measure the beam sizes. These three wire scanners enables different schemes for beam emittance measurement.

The most commonly used methods for measuring the beam emittance are the quad-scan method and the multi-wire scanners method [1,2]. As the commissioning will start at low beam current and gradually increase to high beam current, namely from 1mA to 10mA,we will discuss the two methods for beam emittance measurement at different current and compare the vilidity.

PRINCIPLE OF EMITTANCE MEASUREMENT

When transporting from position s_0 to s, the twiss parameters can be described by [3]

$$\begin{pmatrix} \beta \\ \alpha \\ \gamma \end{pmatrix} = M \cdot \begin{pmatrix} \beta_0 \\ \alpha_0 \\ \gamma_0 \end{pmatrix}, \tag{1}$$

where M is a function of the transfer matrix elements from position s_0 to s on the ith row and jth column (m_{ij}), and can explicitly expressed as

$$M = \begin{pmatrix} m_{11}^2 & -m_{11}m_{12} & m_{12}^2 \\ -m_{11}m_{12} & 2m_{12}m_{21}+1 & -m_{12}m_{22} \\ m_{21}^2 & -2m_{21}m_{22} & m_{22}^2 \end{pmatrix}.$$

At the dispersion free place, beam size σ can be expressed as the square root of beam emittance ε and twiss parameter β, e.g.

$$\sigma = \sqrt{\varepsilon\beta}\,. \tag{2}$$

As the beam emittance keeps unchanged (regardless of space charge effect) when passing through a transport line which is composed of a set of quadrupoles and drifts, equations can be obtained by adjusting the strength of quadrupole (or qudrupoles) and measuring the beam sizes one downstream location s, i.e.,

$$\begin{aligned}\sigma_i^{\,2} &= m_{11}^2(K_i)\cdot(\varepsilon\beta_0) - 2m_{11}(K_i)m_{12}(K_i)\cdot(\varepsilon\alpha_0) \\ &\quad + m_{12}^2(K_i)\cdot(\varepsilon\gamma_0)\end{aligned}, \tag{3}$$

where σ_i is the measured rms beam size at the position, $m_{jk}(K_i)$ are the corresponding element of transfer matrix from s_0 to s at the i-th quadupoles setting. There are three unknown variables in Eq. 3, i.e., $\varepsilon\beta_0$, $\varepsilon\alpha_0$ and $\varepsilon\gamma_0$. In principle, the unkown variables can be solved with at least three equations which can be formed by varying the quadrupole strength three times. Normally, more data will be obtained to decrease the error. Making use of the equation that $\beta_0\gamma_0 - \alpha_0^2 = 1$, the beam emittance then can be calculated by

$$\varepsilon = \sqrt{\varepsilon\beta_0 \cdot \varepsilon\gamma_0 - (\varepsilon\alpha_0)^2}\,. \tag{4}$$

This method is normally called the quad-scan method.

Equation can also be obtained by measuring the beam size at different location s_k, i.e.,

$$\sigma_k^{\,2} = m_{11k}^2\cdot(\varepsilon\beta_0) - 2m_{11k}m_{12k}\cdot(\varepsilon\alpha_0) + m_{12k}^2\cdot(\varepsilon\gamma_0), \tag{5}$$

where σ_k is the rms beam size at the measurement position s_k, m_{ijk} is the corresponding element of transfer

*Work supported by the C-ADS project
#genghp@ihep.ac.cn

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matrix from s_0 to s_k. There are also three unknown variables in Eq. (5), i.e., $\varepsilon\beta_0$, $\varepsilon\alpha_0$ and $\varepsilon\gamma_0$. So in principle, In principle, these variables can also be solved with at least three equations which can be formed by measuring beam sizes at three different positions.

The beam emittance then can be calculated similarly with Eq. (4). This is called the multi-wire scanner method.

It is worth pointing out that in the multi-wire scanner method, the quadrupoles strengths can be kept invariant during the emittance measurement, thus it does not disturb the machine running.

EMITTANCE MEASUREMENT WITH MULTI-WIRE SCANNER METHOD

At the C-ADS MEBT1, the location of wire scanners relative to adjacent beam line element is shown in the Fig. 1. The first wire scanner is located 92mm upstream of Q3, the second wire scanner is located 92mm downstream of Q4, while the third wire scanner is located 85mm downstream of Q6.

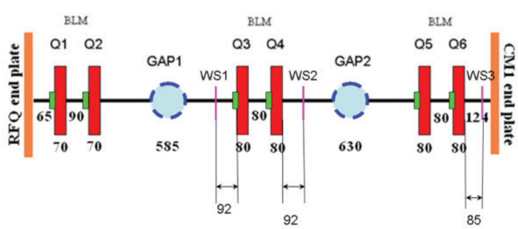

Figure 1: The location of wire scanners at the MEBT1 of C-ADS injector-I.

At the nominal MEBT1 setting and beam current (10mA), the beam spot at the wire scanners simulated with the particle distribution at the RFQ exit are shown in Fig. 2. Assuming the step size of the wire scanners is 0.1mm [4], we can generate the signals which should be obtained from the wire scanners in all three positions.

The obtained signal and the fitted results are shown in Fig.3. The data is shown in black dot. We tried two ways to fit the beam sizes from the data. One is to fit all the data points with the nominal gaussian fit, the fitted result is shown in red curve. The other is to fit only the beam core, namely the data points from -1mm to +1mm, the fitted result is shown in blue curve. The purpose of fitting only the beam is to eliminate the space charge effect on the beam sizes, which may enlarge the beam sizes, especially on the halo part.

From the fitting result we can see that the rms beam size of the whole beam is slightly smaller than the one of the beam core, which is quite different from the space charge effect which we would expect. We think this is because the beam from the RFQ is such a distribution that the beam core rms size is bigger. And this structure could be coming from the waterbag input beam at the RFQ entrance.

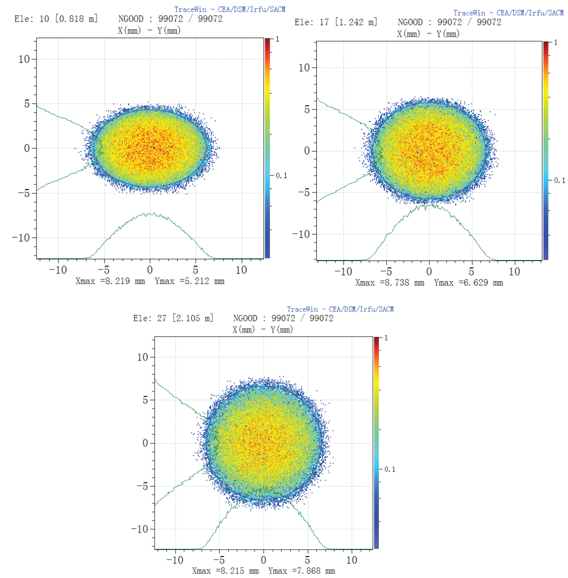

Figure 2: The beam distritutions at the three wire scanners in real space at the MEBT1 of C-ADS injector-I.

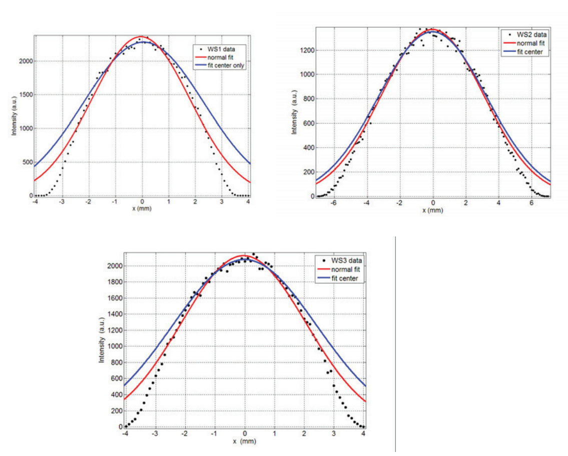

Figure 3: The fitted beam sizes at the three wire scanners in MEBT1.

From Eq. 4 and Eq. 5 we can calculate the beam emittance. In comparison, we have also simulated the beam sizes at 0mA current, and calculated the beam emittance. The results are summarized in Table 1. Here all emittance has been converted to normalized one for comparison.

EMITTANCE MEASUREMENT WITH QUAD-SCAN METHOD

For the study of the quad-scan method, there can be many different combinations of quadrupoles and wire scanners. For simplicity and to characterize space charge effect, we picked one quadrupole and the first downstream wire scanner with the longest distance in

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between, namely Q2 and wire scanner-1 in our case. To avoid the complicity from RF cavities, we turned off the first buncher at MEBT1. The measurement system is then simplified to Q2 and a long drift to wire scanner-1. The signal data is also animated by tracking particles through MEBT1. At the nominal beam current (10mA), the tracking data and the theoretical results are compared in Fig. 4.

Table 1: Comparison of Measured Emittance at 0 mA and 10 mA at MEBT1

Parameter	Theoretical value	Fit at 0mA	Fit at 10mA
ε_x (mm. mrad)	0.20	0.21	0.45
β_x (mm/mrad)	0.12	0.12	0.17
α_x	-1.31	-1.43	-2.10
ε_y (mm. mrad)	0.20	0.20	0.30
β_y (mm/mrad)	0.13	0.13	0.19
α_y	1.46	1.47	1.72

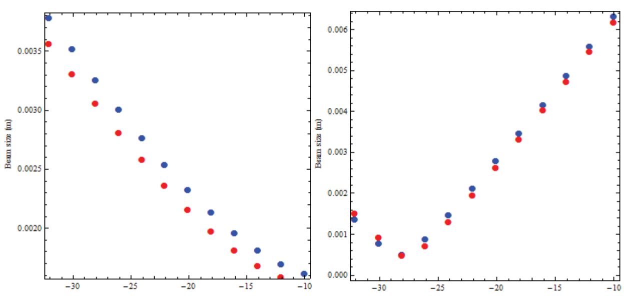

Figure 4: The tracking (red dots) and theoretical (blue dots) beam sizes at the first wire scanner in MEBT1. Beam size in x and y planes are on the left and right respectively.

From Eq. 3 and Eq. 4, the beam emittance can be calculated. The results are summarized in Table 2.

Table 2: Comparison of Measured Emittance at 10 mA with Quad-Scan Method

Parameter	Theoretical value	Fit at 10mA
ε_x (mm. mrad)	0.20	0.21
β_x (mm/mrad)	0.38	0.37
α_x	1.49	1.38
ε_y (mm. mrad)	0.20	0.22
β_y (mm/mrad)	2.13	1.91
α_y	-12.8	-11.8

SUMMARY

Two different methods for emittance measurement at C-ADS MEBT1 have been studied. It has been shown that the multi-wire scanner method could only work at low beam current, where the space charge effect is negligible. At the nominal beam current (10mA), the beam emittance measured by multi-wire scanner method has a deviation as big as 100%. Meanwhile, the quad scan method works quite well even at high current (10mA). The error of the emittance measurement is only 5%. It is worth pointing out that, in our study, the systematic error from the wire scanner has not been taking into account.

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