EMITTANCE MEASUREMENT WITH WIRE SCANNERS AT C-ADS INJECTOR-I

H. Geng*, F. Yan, Y. Zhao, C. Meng, Y. Sui, L. Yu
Institute of High Energy Physics, Beijing 100049, China

Abstract

The transverse emittance at C-ADS injector-I has been measured by the wire scanners at the Medium Energy Beam Transport-I (MEBT1). We have studied the effects of different fitting methods on the beam sizes and the emittance results. The The effects of whether or not the quad-scan beam sizes have crossed the waist on fitted emittance will also been shown.

INTRODUCTION

One of the two front end injectors—injector-I of CADS has be designed and constructed by the Institute of High Energy of Physics(IHEP) [1]. The Medium Energy Beam Transport Line-1 of injector-I plays an important role in transporting and matching the beam from the RFQ exit to the entrance of the super-conducting Spoke-012 cavities.

To quantify the beam quality and validate the design for the cryo-modules, the beam transverse emittances have been measured using a wire scanner and the quad-scan method [2]. To analyse the wire scanner data and obtain the beam sizes, we have tried a few different methods, e.g., simple Gaussian fitting, Gaussian fitting the beam core, direct calculation with statistical formula with all data and beam core.

In this paper, we will show the effects of different fitting methods on beam sizes and thus on emittances. The The effects of whether or not the quad-scan beam sizes have crossed the waist on fitted emittance will also been shown.

MEBT-1 LAYOUT

The layout of MEBT-1 [3] is shown in Fig. 1. MEBT-1 line is composed of three doublets (Q1 to Q6) and two bunchers (GAP1 and GAP2). Three wire scanners have been installed to measure the transverse beam sizes. A more detailed description of the design of MEBT-1 can be found in ref-1.

In our measurements, we use the second wire scanner, which is located at the downstream of Q4 to measure the beam sizes. To reduce the errors, the two bunchers were both turned off during the measurements. According to our study, quad scan data with beam sizes cross the waist could give a much smaller calculation error, thus, the strengths of Q1 and Q2 were tuned independently to obtain the valid data for emittances calculations at horizontal and vertical plane.

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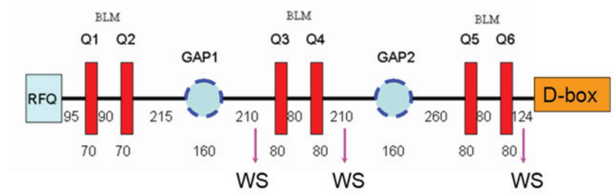

Figure 1: The layout of MEBT-1 for CADS injector-I.

DIFFERENT BEAM SIZES FITTING METHODS

Here, we consider four different types of fitting methods to calculate the beam sizes. First, the Gaussian with offset method. In this method, we use the function shown in Eq. 1 to fit the wire scanner data, and obtain the beam sizes.

$$I = B + A * \exp \frac{-(x - x_0)^2}{2\sigma_x^2} \tag{1}$$

In Eq. 1, I is the wire scanner intensity, B is the background offset, A is the maximum intensity of the Gaussian function, x_0 is the center of the Gaussian function, normally can be set to the position where the signal has a maximum intensity, and σ_x is the fitted beam size. Second, the Gaussian without offset fitting at beam core method. Here, we fit the wire scanner data within $\pm(2 \sim 3)\sigma_x$ region only, and the data is fitted use the function shown in Eq. 1 by taking the background offset $B \equiv 0$.

The third method is direct calculation method. We use the wire scanner data to direct calculate the root mean square beam size. The formula is shown in Eq. 2.

$$\sigma_x = \sqrt{< x^2 >} = \sqrt{\frac{\sum I_i (x_i - x_0)^2}{\sum I_i}} \tag{2}$$

In Eq. 2, I_i is the signal intensity at position x_i. The fourth method is also a direct calculation method, but with only beam core data. This method can suppress the contribution of the tail signal to the beam sizes.

We use three typical wire scanner signals as an example to show the difference of the four fitting methods. The three signals are quasi-Gaussian, narrow-pointed and wide-plump signals. Fig. 2 to Fig. 4 show the different fitting results for these three types of wire scanner signals. For the quasi-Gaussian signal, we can see that the two Gaussian fitting results are roughly the same, so are the two formula calculation results. While the Gaussian fitting results and the formula calculation results has a deviation of about 15%.

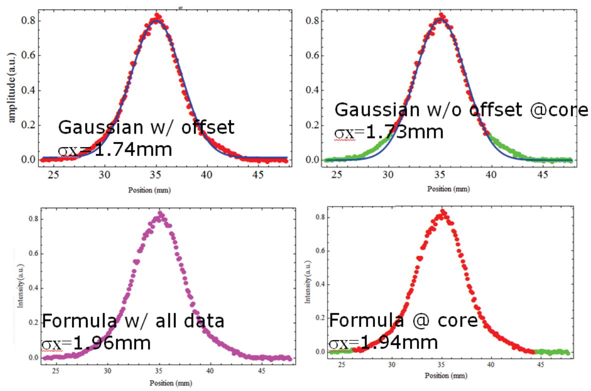

Figure 2: Fitting results for a quasi-gaussian signal with four different fitting methods. The green dots shown in the right plots are excluded in the fitting or calculation of beam sizes.

Similarly for the narrow-pointed signal. But the formula calculation results is almost two times larger than tge Gaussian fitting results. We have to note that in both the two Gaussian fitting methods, the top of the signal is not well fitted. And because of the long tail of the signal, the formula calculated beam size is much larger.

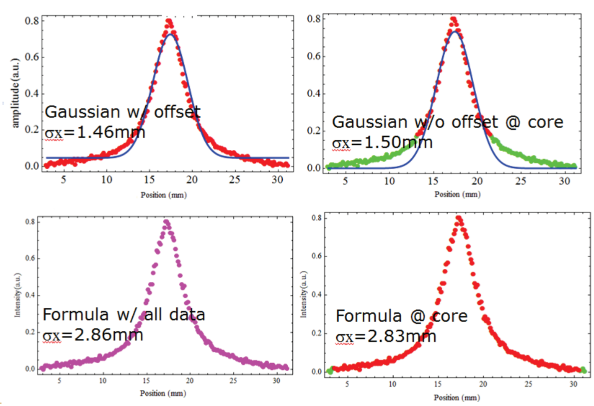

Figure 3: Fitting results for a narrow-pointed signal with four different fitting methods. The green dots shown in the right plots are excluded in the fitting or calculation of beam sizes.

For the wide-plump signal, the results of the two Gaussian fitting methods have a difference of ~ 20%.

From the fitting results of the three typical data signals, we can see that for one set of wire scanner data, the fitted beam sizes can be very different, depending on the shape of the data signal. The more the signal deviate from Gaussian distribution, the bigger the beam sizes difference will be using different fitting methods. And the difference in beam sizes will of course result in different beam emittances, which is again depending on the beam sizes fitting methods.

COMPARISON OF EMITTANCES RESULTS

Fig.5 shows the beam sizes analysed from the wire scanner data with the four different methods. Each beam size set has also been used to calculate the input beam TWISS parameters and the emittance using the transfer matrix method. The lines in Fig. 5 shows the theoretical beam sizes using the calculated beam TWISS parameters and the emittances, which are shown in Table 1.

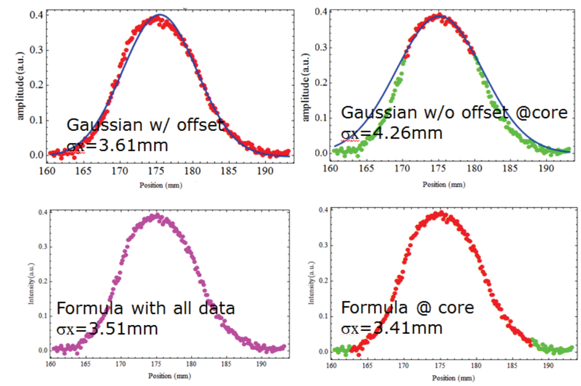

Figure 4: Fitting results for a wide-plump signal with four different fitting methods. The green dots shown in the right plots are excluded in the fitting or calculation of beam sizes.

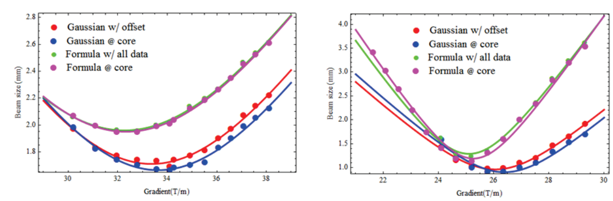

Figure 5: Fitting results of beam emittances at horizontal (left) and vertical (right) planes. The dots are beam sizes obtained with four different fitting methods, and the lines are the beam sizes calculated with the fitted TWISS parameters and emittances using the corresponding beam sizes set.

We can see from both Fig. 5 and Table 1 that the results of the two Gaussian fitting methods agree while the two formula calculation methods agree. The emittance difference between Gaussian fitting and formula calculation methods is ~ 20% in horizontal and ~ 130% in vertical. The differences in emittance at horizontal plane is relatively small, compared to the vertical plane. This is because the wire scanner signals at horizontal plane are mostly quasi-Gaussian distribution, which gives a relatively small difference in beam sizes when using different fitting methods. For the vertical plane, the wire scanner signals are mostly either narrow-pointed or wide-plump distribution, which have a big difference in beam sizes when using different fitting methods as described in the previous section.

From the RFQ design results, the MEBT-1 input beam parameters should be $\alpha_x = -1.31$, $\beta_x = 0.12$ m/rad, $\epsilon_x = 0.20$ mm· mrad, $\alpha_y = 1.46$, $\beta_y = 0.13$ m/rad, $\epsilon_y = 0.20$ mm·mrad. From Table 1, we can see that at horizontal plane, the fitting result with the formula calculation at beam core method agrees the best with the RFQ simulation results. While for the vertical plane, the fitted emittance is either too big or too small compared to the RFQ design results. This disagreement might come from the fitting methods of beam sizes, which may not be proper when

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Table 1: Fitting results of beam emittances at horizontal and vertical planes with four different fitting methods. The unit of $\beta_{x,y}$ is m/rad, and $\epsilon_{x,y}$ is mm· mrad.

	Gaus.	Gaus@core	Formula	Form.@core
α_x	-1.22	-1.25	-1.07	-1.09
β_x	0.113	0.110	0.10	0.120
ϵ_x	0.168	0.164	0.192	0.193
α_y	2.87	3.50	1.83	2.15
β_y	0.301	0.365	0.176	0.194
ϵ_y	0.130	0.123	0.279	0.269

the beam phase space is severely tilted or much deviated from Gaussian distribution. We are also studying the wire scanner data with the Multi-Objective Genetic Algorithm (MOGA), which gives a vertical emittance of $\epsilon_y = 0.206$mm·mrad [4] and is in good agreement with the RFQ design results.

CONCLUSION

We have discussed four different methods for analysing the beam sizes with the wire scanner data. Three typical signal data, quasi-Gaussian, narrow-pointed and wide-plump, were used as example to show the differences of beam sizes. The results show that for quasi-Gaussian signal, the deviation in beam sizes is roughly $\sim 20\%$, but for the signals which are greatly deviate from Gaussian distribution, the fitted beam sizes can be very much different from each other using the four different fitting methods.

We also show the fitted beam emittance with the beam sizes analysed with four different methods. The results show that at the horizontal plane, the emittance calculated with the beam sizes fitted by the formula at beam core is in good agreement with the RFQ simulation result. But at the vertical plane, none of the four fitting methods give a emittance which is in reasonable agreement with the RFQ simulation results. More study based on MOGA has also been carried out, and good agreement has been found at vertical plane.

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