

EMITTANCE MEASUREMENT WITH MULTI-WIRE SCANNERS FOR BEPC-II LINAC

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Abstract

During the BEPC-II (Beijing Electron and Positron Collider-II) linac upgrade in the summer of 2012, five wire scanners have been installed in the common transport line which connects the linac and the beam transport lines for electrons and positrons. Up to now, four of the five wire scanners could be routinely used for beam size measurement, which makes a fast emittance measurement possible. In this paper, we will show the primary results of BEPC-II linac emittance measurement using the multiple wire scanner method. The least squares method will be used for data analysis.

INTRODUCTION

In the BEPC-II[1][2], which is the upgrade project of Beijing Electron Positron Collider (BEPC), electrons and positrons are accelerated in the linac up to 2.1 GeV and 1.89 GeV. The beams will then be transported through the common transport line to the electron or positron transport line, and finally be injected to the ring. The beam emittance measurement at the common transport line has long been served as a useful tool to characterize the quality of the injected beam. The quad-scan method has long been used to carry out the measurement with fluorescent beam profile monitor[3] and wire scanner [4]. The wire scanner has been proved to be easy to use and has good accuracy [5].

To enhance the linac capability and provide a full energy injection for positron beam of up to 2.3 GeV and electron beam of up to 2.5 GeV, BEPC-II has experienced an energy upgrade in the summer of 2012. During the upgrade, five wire scanners were installed in the common transport line aiming to carry out online emittance measurement and beam tuning for both electron and positron beams and hence increase injection rate.

At beam transport lines, three wire scanners are essential to determine beam emittance and twiss parameters. Up to now, four of the five installed wire scanners could be routinely used for beam size measurement, which makes a fast emittance measurement possible and also provides redundancy. The online measurement and beam tuning program have been developed based on the machine tuning program SAD and is currently under testing. In this paper, we will show the primary beam emittance measurement results which have been analyzed off-line.

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EMITTANCE MEASUREMENT PRINCIPLE

When transporting from position s_0 to s , twiss parameters can be described by:

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

where

$$M = \begin{pmatrix} R_{11}^2 & -2R_{11}R_{12} & R_{12}^2 \\ -R_{11}R_{21} & R_{11}R_{22} + R_{12}R_{21} & -R_{12}R_{22} \\ R_{21}^2 & -2R_{21}R_{22} & R_{22}^2 \end{pmatrix},$$

with R_{ij} the element of the transfer matrix from s_0 to s on the i th row and j th column. 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.

$$\sigma = \sqrt{\epsilon \cdot \beta}. \quad (2)$$

As the beam emittance keeps unchanged when passing through a transport line which is composed of a set of quadrupoles and drifts, equation can be obtained by measuring the beam size at different location s_k , i.e.,

$$\sigma_k^2 = R_{11k}^2 \cdot (\epsilon\beta_0) - 2m_{11k}m_{12k}(\epsilon\alpha_0) + m_{12k}^2(\epsilon\gamma_0), \quad (3)$$

where σ_k is the rms beam size at the position s_k , R_{ijk} the corresponding element of transfer matrix from s_0 to s_k . There are three unknown variables in Eq. 3, i.e., $\epsilon\beta_0$, $\epsilon\alpha_0$ and $\epsilon\gamma_0$. In principle, the variables can 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 by:

$$\epsilon = \sqrt{(\epsilon\beta_0) \cdot (\epsilon\gamma_0) - (\epsilon\alpha_0)^2}. \quad (4)$$

At the BEPC-II linac end, the location of wire scanners relative to the second emittance measurement magnet (EM2) is shown in the Figure 1. The first wire scanner is located 0.579 m after EM2, the other four wire scanners are installed 1.65 m, 0.93 m, 1.65 m and 1.60 m downstream TCQ2 (the second quadrupole in the common transport line), TCQ3, TCQ4, and TCQ6. Up to now, the first four wire scanners have been tested and can be routinely used for beam size measurement. We will use these four wire scanners in our study to measure the beam emittance. The variables shown in Eq. 3 will be solved by the least squares method.

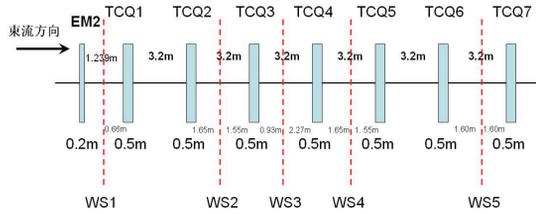


Figure 1: Wire scanners at the common transport line of BEPC-II.

EXPERIMENTAL RESULTS FOR ELECTRON BEAM

In order not to interrupt normal operation and better characterize the instantaneous beam quality, the emittance measurement was carried out at the nominal BEPC-II linac setup, with a beam energy of $E_0 = 2.13$ GeV. The beam size measurement results from the four wire scanners are shown in Fig. 2, where the abscissa axis is the distance moved by the wire and the vertical axis is the intensity of the signal. We can clearly see three peaks corresponding to three wires crossing the beam. As the beam distribution at the exit of BEPC-II linac can be considered as Gaussian distribution approximately, the signal can be fitted by three gaussian functions. The fitting results are also shown in Fig. 2. The beam size at vertical and horizontal direction can be obtained from the first and third peak by dividing $\sqrt{2}$.

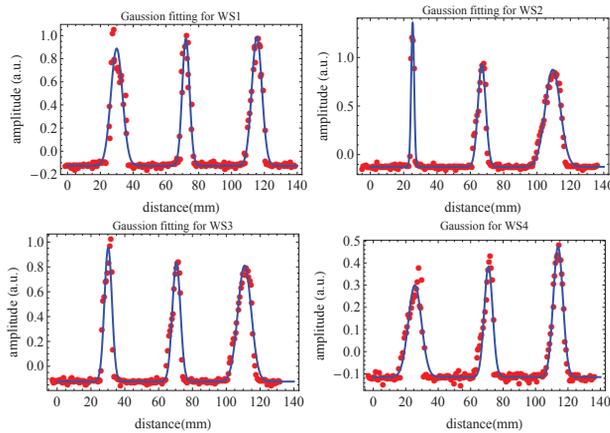


Figure 2: The collected signal at different wire scanners(dotted) and the Gaussian fitting result(line) for electron beam.

After measuring beam sizes at the four wire scanners, $\epsilon\beta_0$, $\epsilon\alpha_0$ and $\epsilon\gamma_0$ can be solved with the least square method for both x and y plane. Here we choose s_0 as the exit of EM2. Then the transfer matrix can be obtained and the parameters at the exit of EM2 can be calculated. The results are:

$$\epsilon_x\beta_{x0} = 4.6 \text{ mm}^2; \epsilon_x\alpha_{x0} = 0.017 \text{ mm} \cdot \text{mrad};$$

$$\epsilon_x\gamma_{x0} = 0.0094 \text{ mrad}^2.$$

The beam emittance can be easily obtained using equation 4 as:

$$\epsilon_x = 0.21 \text{ mm} \cdot \text{mrad}$$

The corresponding twiss parameters at the exit of EM2 are:

$$\beta_{x0} = 22 \text{ m}; \alpha_{x0} = 0.083.$$

Similarly, the emittance and twiss parameters can be obtained for y plane of electron beam:

$$\epsilon_y = 0.21 \text{ mm} \cdot \text{mrad}$$

$$\beta_{y0} = 30 \text{ m}; \alpha_{y0} = -0.34.$$

The self consistency of the measurement can be characterized by the comparison of the reconstructed beam sizes using the calculated emittance and twiss parameters with the measured ones. The result is shown in figure 3, where the reconstructed beam sizes are shown as stars and the measured data are plotted as dots. It is clearly shown that the measured data are well agree with the measured ones, which means our measurements and calculations are in good consistency.

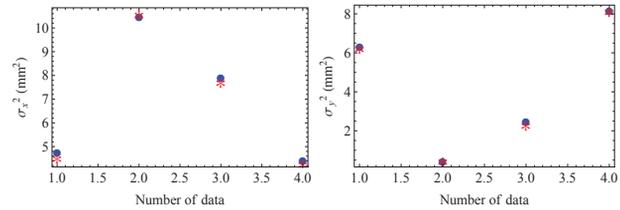


Figure 3: The comparison of the reconstructed beam sizes(stars) using the calculated emittance and twiss parameters with the measured ones (dots).

EXPERIMENTAL RESULTS FOR POSITRON BEAM

Again, the emittance measurement for positron beam was carried out at the at the nominal BEPC-II injection setup, with a beam energy of $E_0 = 2.13$ GeV. The beam size measurement results from the four wire scanners are shown in Fig. 4, where the abscissa axis is the distance moved by the wire and the vertical axis is the intensity of the signal. The measured signal is again fitted with three gaussian functions and the fitting results are shown in Fig. 4. The beam size at vertical and horizontal direction can be obtained from the first and third peak by dividing $\sqrt{2}$.

After fitting the beam size, $\epsilon\beta_0$, $\epsilon\alpha_0$ and $\epsilon\gamma_0$ can be solved with the least square method for both x and y plane. By choosing s_0 at the exit of EM2, the following parameters can be calculated,

$$\epsilon_x\beta_{x0} = 34 \text{ mm}^2; \epsilon_x\alpha_{x0} = -1.3 \text{ mm} \cdot \text{mrad};$$

$$\epsilon_x\gamma_{x0} = 0.061 \text{ mrad}^2.$$

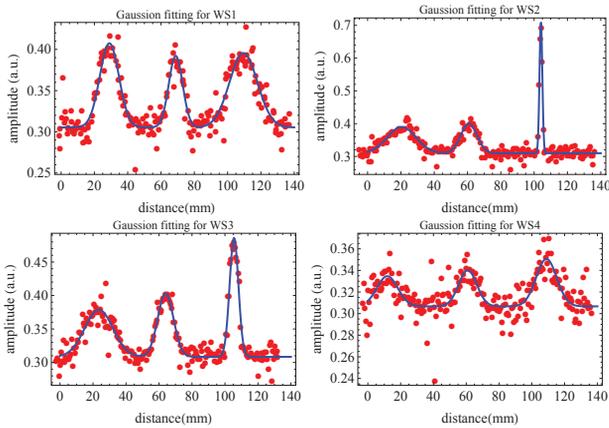


Figure 4: The collected signal at different wire scanners(dotted) and the Gaussian fitting result(line).

The beam emittance thus can be obtained using equation 4 as:

$$\epsilon_x = 0.63 \text{ mm} \cdot \text{mrad}$$

The corresponding twiss parameters are:

$$\beta_{x0} = 54 \text{ m}; \alpha_{x0} = -2.1.$$

Similarly, the emittance can be obtained for y plane of positron beam:

$$\epsilon_y = 1.1 \text{ mm} \cdot \text{mrad}$$

The twiss parameters are:

$$\beta_{y0} = 12 \text{ m}; \alpha_{y0} = -0.25.$$

The comparison of the reconstructed beam sizes using the calculated emittance and twiss parameters with the measured ones are shown in figure 5. We can see that the reconstructed beam sizes are in good agreement with the measured ones for x plane of the positron beam, while a big deviation is observed for y plane. The big deviation in y plane implies that the error for the calculated emittance is big, which also help explain why the emittance in y plane is much bigger than the one in x plane for positron beam. The big error in y plane mainly comes from the low signal to noise ratio (see Figure 4) which causes a big deviation when fitting beam sizes can be clearly seen in Figure 4.

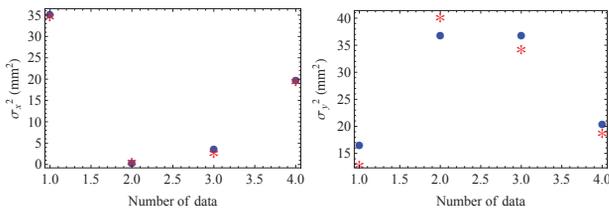


Figure 5: The comparison of the reconstructed beam sizes (stars) with the calculated emittance and twiss parameters with the measured ones (dots) for positron beam.

DISCUSSION

The designed beam parameters at BEPC-II linac end are $\epsilon_x = \epsilon_y = 0.1 \text{ mm} \cdot \text{mrad}$ for electron beam and $\epsilon_x = \epsilon_y = 0.4 \text{ mm} \cdot \text{mrad}$ for positron beam at 1.89 GeV beam energy. The measurement is carried out at a beam current of 2 A at the gun exit for electron beam, which correspond to about 2 times of the designed beam current. The increase of beam current is considered to be the reason of the big measured emittance compared to the designed value. For the positron beam, the measured emittance can be scaled to 0.71 mm at 1.89 GeV and is considerable larger than the designed value.

The emittance measurement for both electron and positron beam have been carried out at the common transport line of BEPC-II with multiple wire scanner method. Each wire takes about 40 second to finish the measurement. The whole emittance measurement process takes less than 3 minutes, which enables a relatively quick on-line beam tuning possible for each injection. The present results are obtained at nominal machine status, no fine tuning involved. It can be seen that the signal to noise ratio is good for electron beam, but relatively poor for positron beam, especially for the signal from WS4. The signal to noise ratio are expected to be improved by tuning the upstream quadrupoles and correctors.

ACKNOWLEDGEMENT

The authors are grateful for the help and cooperation from the operators of BEPC-II linac.

This work is supported by National Natural Sciences Foundation of China (Grant No. 11175195) and XIE Jialin Foundation of Institute of High Energy Physics (No. 542013IHEPZZBS202).

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