WIRE SCANNER EMITTANCE MEASUREMENT AND SOFTWARE DESIGN AT BEPCII

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Abstract

Wire scanners are diagnostic devices to measure beam profiles. Resent years, BEPCII adopts wire scanner measurement system for accurate beam size and emittance measurements. Beam emittance measurements can be performed with no adverse impact on beam and no interruption to normal machine operation. The BEPCII wire scanner system includes sets of wire scanners in linac by which the linac output emittance is determined. In order to make the measurement procedure automated and easily accessible to all operators, wire scanner measurement software is developed. The software can obtain real-time signal data from the Experimental Physics and Industrial Control System(EPICS), calculate emittance, display phase ellipse and optics envelope. In this paper we describe the construction, performance and uses of BEPCII wire scanners measurement system and software.

INTRODUCTION

For BEPCII, linac beam emittance is an important parameter which reflects the linac commissioning status and affects the injection efficiency of BEPCII storage ring. The BEPCII linac has strict limitation on beam emittance of both the positron and electron[1]. So it is very important to be able to measure the beam emittance accurately and rapidly.

The BEPCII linac once adopted fluorescent target measurement method to measure beam profile and emittance. Fluorescent target method can obtain the beam profile image and calculate beam emittance by changing the current of quadrupole[2]. However, fluorescent target measurement method has some obvious disadvantages: camera is used in radiation environment so that the image resolution is affected; beam will be blocked by fluorescent target; changing the current of quadrupole will affect the use of beam; real-time data processing can not be achieved.

Recent years, BEPCII began to adopt the wire scanner system in beam profile and emittance measurement. BEPCII wire scanner measurement system includes a set of four wire scanners at the downstream of the linac by which the linac exit emittance can be measured. Wire scanner measurement method can effectively avoid some problems which exist in fluorescent measurement. It can be performed without adverse impact on beam and real-time data processing almost.

Based on the procedure of BEPCII wire scanner measurement, a beam emittance calculation software is developed in JAVA. The software can obtain real-time signal data from EPICS and calculate emittance, display phase ellipse and optics envelope. It increases the speed of emittance measurement and calculation, also make the measurement procedure automated and easily accessible to all operators.

BEPCII WIRE SCANNER EMITTANCE MEASUREMENT

Wire Scanner

The core component of wire scanner measurement system is wire scanner whichhas three gold-plated tungsten wires (referred to as U, V, H) driven by a running mechanism (shown in Fig.1). The three tungsten wires are separated from each other to ensure that two wires would not be in particle beam at the same time. Therefore, the scanner can carry wires of three different orientations across beam and scans in x, y and 45 degree directions.

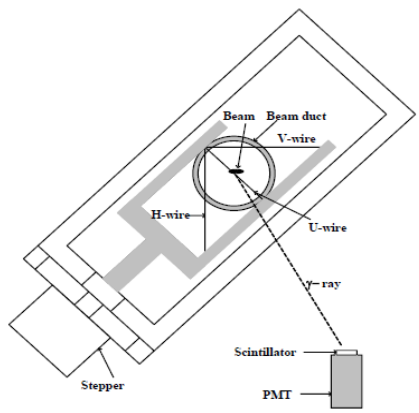

Figure 1: Structure of wire scanner [3].

At the downstream of the scanner, a photomultiplier detector (PMT) is arranged. When the wire scanner is crossing the beam, the signal produced by the interaction of beam particle and the wire will be detected by PMT. The signal is proportional to the beam density. For example, the signal is stronger when the wire is at the beam center than at the edge of beam. According to the position of the wire and the signal variation, the beam density distribution can be got. Normally the beam density distribution is close to Gaussian distribution at the exit of BEPCII linac.

Beam Profile Calculation

The wire scanner signal strength is is proportional to beam density. A chart of signal measured in experiment is shown in Fig. 2.

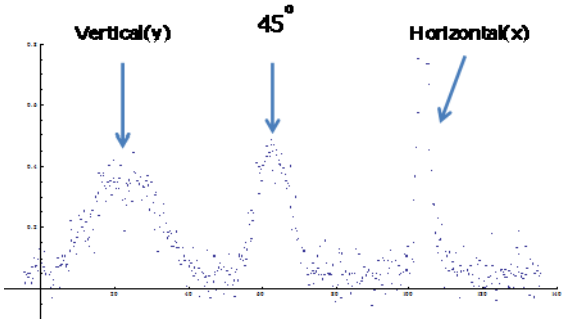

Figure 2: The signal strength vs. wire scanner wire position.

Usually assuming the beam profile density distribution is Gaussian distribution. Therefore the signal of wire scanner can be thought as superposition of three Gaussian distributions. The three Gaussian peaks from left to right represent the beam density distribution in vertical, 45-degree and horizontal directions individually, as shown in Fig. 2. The signal strength can be expressed as Eq. 1.

$$Y(u) = Y_0 + A_1 e^{\frac{(\mu-\mu_1)^2}{2\sigma_1^2}} + A_2 e^{\frac{(\mu-\mu_2)^2}{2\sigma_2^2}} + A_3 e^{\frac{(\mu-\mu_3)^2}{2\sigma_3^2}} . \quad (1)$$

In Eq. 1, Y_0 is a constant due to background noise; A_1, A_2, A_3 are amplitudes of three Gaussian peaks; μ_1, μ_2, μ_3 are center positions of Gaussian peaks; σ_1, σ_2, σ_3 are beam profile sizes in three directions; μ and $Y(\mu)$ are the position and the signal strength of the wire scanner. Using the detected signal data, an equation related to μ and $Y(\mu)$ could be established, then the vertical and horizontal beam profile sizes will be got by solving the equation with nonlinear least squares method.

BEPCII Wire Scanner Emittance Measurement

In the case of high energy beam, the interaction between the interior particles and between beam and residual air molecules can be ignored. According to Liouville's theorem, in the condition of conservative field, the beam emittance ε stays the same. The transmission equation of Beam envelope σ can be expressed with elements of transfer matrix R_{ij} and initial Twiss parameters(α_0, β_0, γ_0)

$$\sigma^2 = R_{11}^2(\varepsilon\beta_0) - 2R_{11}R_{12}(\varepsilon\alpha_0) + R_{12}^2(\varepsilon\gamma_0). \quad (2)$$

In Eq. 2, the beam envelope σ can be obtained by fitting the beam signal data got from the wire scanner. To determine the emittance, at least three beam profiles need to be measured. More profiles provide better error estimation.

Now there are five wire scanners at the downstream of BEPCII linac. The first wire scanner is located after EM2 (emittance measurement magnet) and the other four wire scanners are installed downstream TCQ2(the second quadrupole in the common transport line), TCQ3, TCQ4 and TCQ6. The layout of wire scanners is shown in Fig 3. Now the first four wire scanners are tested well and can be used in emittance measurement.

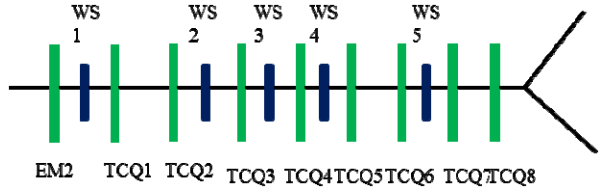

Figure 3: Wire scanners layout at the downstream of BEPCII linac.

Usually BEPCII wire scanner emittance measuring procedure consists of three steps: 1)make four scanners scan beam to get four groups of horizontal and vertical profiles in each position, 2)obtain the horizontal and vertical equations as Eq.3 shows, in which beam envelope σ are functions of transfer matrix

$$\begin{pmatrix} \sigma_1^2 \\ \sigma_2^2 \\ \sigma_3^2 \\ \sigma_4^2 \end{pmatrix} = \begin{pmatrix} R_{111}^2 & -2R_{111}R_{112} & R_{112}^2 \\ R_{211}^2 & -2R_{211}R_{212} & R_{212}^2 \\ R_{311}^2 & -2R_{311}R_{312} & R_{312}^2 \\ R_{411}^2 & -2R_{411}R_{412} & R_{412}^2 \end{pmatrix} \begin{pmatrix} \varepsilon\beta_0 \\ \varepsilon\alpha_0 \\ \varepsilon\gamma_0 \end{pmatrix}. \quad (3)$$

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

3)solving the Eq. 3 and Eq. 4, the beam emittance and the Twiss parameters can be got.

Software Development

In order to make the measurement procedure automated and easily accessible to all operators, wire scanner measurement and calculation software is developed in JAVA. The software can obtain real-time signal data from EPICS, calculate beam emittace and Twiss parameters, draw phase ellipse and display optics envelope diagram.

The program interface is shown from Fig.4 to Fig.7, which could realize the following functions: beam profile size calculation and display, beam emittance calculation and display , display of beam phase ellipses in different positions, display of beam envelope in linac and transport line which connects the linac and the ring.

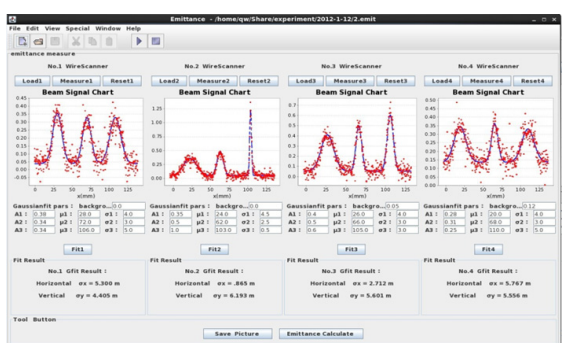

Figure 4: Beam size calculation.

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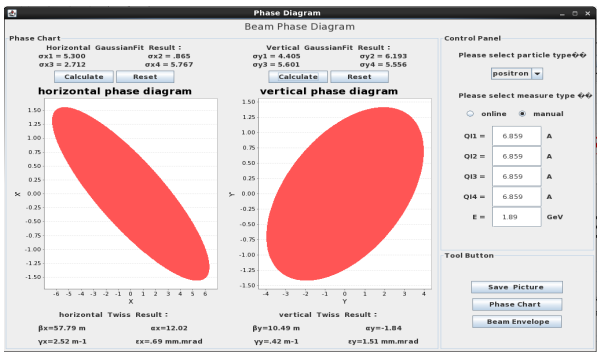

Figure 5: Emittance calculation.

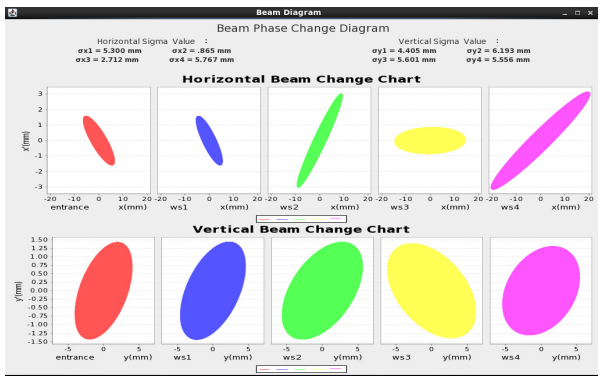

Figure 6: Phase Ellipse.

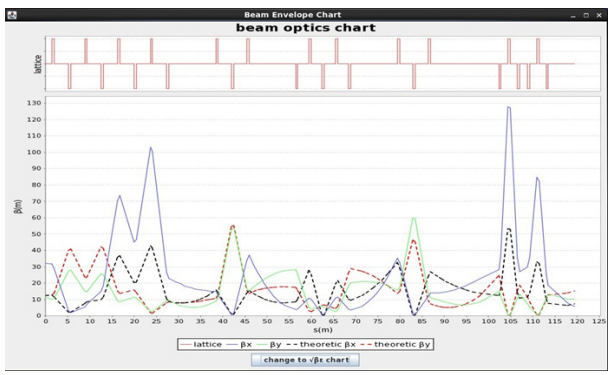

Figure 7: Beam envelope.

Now the software has been put into use in BEPCII emittance measurement experiment. It works well during the experiment. And the results calculated by this software are agree with the result calculated by other method. Therefore it is thought that the software can realize the real-time emittance measurement as designed. It will be released to the BEPCII operators soon.

Conclusion

BEPCII wire scanner measurement system includes sets of wire scanners at the exit of linac for accurate measurements of beam size and emittance. It can be performed with no adverse impact on beam and no interruption to normal machine operation. According to the measuring procedure, a new emittance calculaton software is developed, which offers a fast and easy way to do the emittance measurement. Now the complete version of this project is tested and will be released to the BEPCII operators soon.

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