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MEASURING ENERGY SPREAD USING BEAM SCREEN MONITOR AND FOUR STRIP-LINE ELECTRODES FOR HLS II INJECTOR*

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Abstract

In order to nondestructively measure the beam energy spread with a beam energy of 0.8GeV in the injector at the upgrade project of Hefei Light Source (HLS II) in real time, a beam energy spread monitor (BESM) using beam position monitor (BPM) with four stripline electrodes has been developed. And a screen monitor (SM) near the BESM is used to measure beam energy spread destructively. This paper introduces in brief the beam position measurement system and beam transverse profile measurement system. The relationship between the transverse size at the BESM and at the SM (Flag3) is discussed in detail in this report. The result shows that energy spread measuring result of BESM and SM is 0.19% and 0.18% respectively. So we can draw a conclusion that the BESM is capable of nondestructively measuring the beam energy spread.

INTRODUCTION

With the upgrade project of Hefei Light Source (HLS II), the beam diagnostics system, main power system, transverse and longitudinal multi-bunch feedback system, beam control system and manipulation system have been upgraded [1]. HLS II injector is composed of electron linac with 0.8-GeV and beam transfer line. The electron gun emits a bunch every second. The beam charge is 1 nC/bunch, with a repetition rate between 1Hz and 10 Hz. The new BPM system is consist of 19 stripline BPMs and 19 Libera Brilliance Single Pass modules with each BPM [2]. The BPM system is usually used to measure beam position, beam emittance. The beam transverse profile measurement system is composed by 5 Flags.

The advantage of destructive measuring method is quick and precise. And the most meaningful advantage of nondestructive measuring method is that there is no effect on other diagnostic experiment.

Original work that design and calibrate of BPMs have completed by J. Fang and J. Y. Zou etc. There are 2 energy spread measurement system installed in HLS II injector. They analyzed the multi-moment of the electromagnetic field and measured formula of position and quadrupole component. According to the study achievement of T. Suwada etc, the beam energy spread can obtain through derive beam position from quadrupole moment [3]. We can obtain the energy spread through formula below:

$$\sigma_x^2 - \sigma_y^2 \approx \beta_x \varepsilon_x + (\eta_x \, {}^{\Delta E}\!/\!_{E})^2 - \beta_y \varepsilon_y + g \,. \quad (1)$$

Where g is a parameter caused by machining errors and gain imbalance; ε_x, ε_y are transverse horizontal emittance and vertical emittance.

In the past plan, we will install a beam energy spread monitor (BESM) with eight stripline electrodes to measure beam energy spread. Because we have installed an energy gap between bend magnet (named BM1) and TL-ST4 (As shown in Fig. 1) to limit the beam energy spread. Therefore synchrotron radiation emitted from bend magnet will be obstructed by the energy gap. So we can use four stripline electrodes BPM (TL-ST4) instead of eight stripline electrodes BPM as BESM.

As shown in Fig. 1, a nondestructive beam energy-spread monitor (BESM) consisted of TL-ST4 and SM is used to measure the energy spread in HLS II injector.

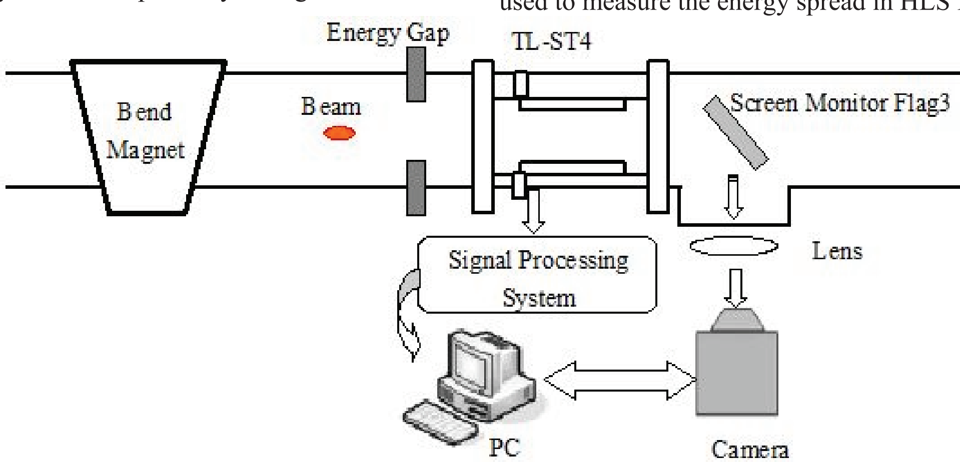

Figure 1: Sketch of energy spread measurement system.

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The SM is used to measure the beam transverse width and beam energy spread destructively. And we can compare their measuring result.

EXTRACT OF QUADRUPOLE COMPONENT

The normalized induction signal on stripline electrode is given by table1

Table 1: Normalized Signal on Stripline Electrode

	Right	Left	Top	Bottom
Monopole	1	1	1	1
Dipole	Z_{1x}	$-Z_{1x}$	Z_{1y}	$-Z_{1y}$
Quadrupole	Z_2	Z_2	$-Z_2$	$-Z_2$
Sextupole	Z_{3x}	$-Z_{3x}$	$-Z_{3y}$	Z_{3y}
Octupole	Z_4	Z_4	Z_4	Z_4

Where symbols are given by

$$\begin{cases} Z_{1x} = 2\dfrac{\sin(\phi/2)}{\phi/2}\dfrac{x_0}{b}, Z_{1y} = 2\dfrac{\sin(\phi/2)}{\phi/2}\dfrac{y_0}{b} \\ Z_2 = 2\dfrac{\sin\phi}{\phi}\dfrac{\sigma_x^2-\sigma_y^2+x_0^2-y_0^2}{b^2} \\ Z_{3x} = 2\dfrac{\sin(3\phi/2)}{3\phi/2}\dfrac{3\sigma_x^2-3\sigma_y^2+x_0^2-3y_0^2}{b^2}\dfrac{x_0}{b} \\ Z_{3y} = 2\dfrac{\sin(3\phi/2)}{3\phi/2}\dfrac{3\sigma_x^2-3\sigma_y^2+3x_0^2-y_0^2}{b^2}\dfrac{y_0}{b} \\ Z_4 = \\ \dfrac{\sin(2\phi)}{\phi}\dfrac{3\left(\sigma_x^2-\sigma_y^2+x_0^2-y_0^2\right)^2-2\left(x_0^4+y_0^4\right)}{b^4} \end{cases} . \quad (2)$$

Where ϕ is the opening angle of the electrode (As seen in Fig. 2), b is the duct radius, x_0, y_0 are the beam position in the x and y directions, and σ_x, σ_y are the horizontal and vertical width of the bunch.

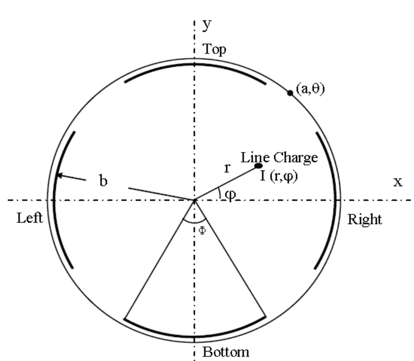

Figure 2: Architecture of four stripline electrodes BPM.

As shown in Fig. 2, the BPM is consisting of four stripline respectively named Top, Right, Bottom and Left.

σ_x^2-σ_y^2 can be derived by the following way:

$$\begin{aligned} Q_{\Delta/\Sigma} &= \frac{V_R+V_L-V_T-V_B}{V_R+V_L+V_T+V_B} \\ &= S_{\Delta/\Sigma-Q}\cdot(\sigma_x^2-\sigma_y^2+x_0^2-y_0^2)+O\left(\frac{1}{b^6}\right) \end{aligned} . \quad (3)$$

Where $Q_{\Delta/\Sigma}$ is the quadrupole component, and $S_{\Delta/\Sigma-Q}$ is the sensitivity of $Q_{\Delta/\Sigma}$:

$$S_{\Delta/\Sigma-Q} = 2\frac{\sin\phi}{\phi}\frac{1}{b^2} . \quad (4)$$

Where x0, y0 are the beam position in the x and y directions. They can be obtained from four stripline signals. By canceling x_0, y_0 from Eq. 3 and then we will obtain σ_x^2-σ_y^2. According to the calibrate result of TL-ST4 [4], then:

$$\begin{aligned} &Q_{\Delta/\Sigma} = -0.0095+0.0058x_0+0.0032y_0+0.0077x_0^2 \\ &+0.0079y_0^2++0.0076\sigma_x^2-0.0076\sigma_y^2 \end{aligned} . \quad (5)$$

And then, σ_x^2-σ_y^2 is described by:

$$\sigma_x^2-\sigma_y^2 = \frac{1}{0.0076}\begin{pmatrix} Q_{\Delta/\Sigma}+0.0095-0.0058x_0-0.0032y_0 \\ -0.0077x_0^2-0.0079y_0^2 \end{pmatrix} . \quad (6)$$

DATA-ACQUISITION SYSTEM

The data-acquisition system consists of a Beam Position Measurement System and a Beam Profile Measurement System. The Beam Position Measurement System consists of a Libera Brilliance Single Pass processor with 500MHz bandwidth, a Linux-based computer, a Libera Clock Splitter and EPICS network, as shown in Fig. 3. The four signals from each strip-line sent directly to the processor with a suitable relay time. The Clock Splitter provides the processor a trigger pulses synchronized with the beam. The processor will digitize the analog signals and calculate the beam position. Simultaneously, the beam position, four digital signals will be sent to EPICS through soft IOC.

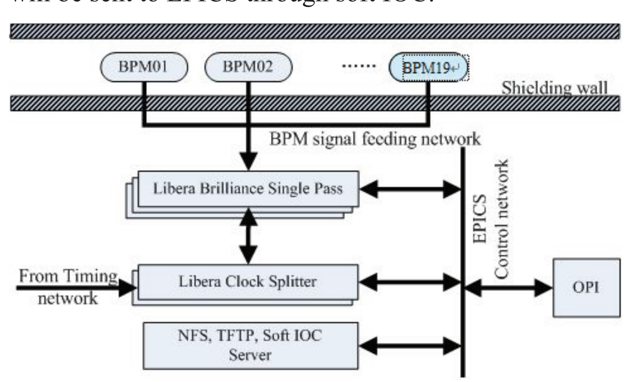

Figure 3: Measurement system architecture of four strip. line BPM.

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The Beam Profile Measurement System consists of a SM, a GE680 Prosilica camera, a Windows-based PC with LabVIEW and gigabit Ethernet. The screen is composed of a fluorescent screen which use Ce:YAG crystals and a OTR screen and their resolution is approximately 50 micron. Once the electron gun emitting a bunch, the camera will receive a trigger signal with a suitable delay time and gather a picture immediately. And then the camera sent this picture to LabVIEW. LabVIEW will process this picture and acquire the beam sizes information and then sent them to EPICS through caLab.

BEAM TEST AND RESULT ANALYSIS

In order to decreasing the affection of beam position to quadrupole moment, we should insure the beam position at BESM near to the center. We can do this by controlling horizontal steering magnets (named HC7) and vertical steering magnet (named VC7). One data point of BESM and SM was obtained by every second.

The horizontal positions are 0.050±1.50 mm and the vertical positions are 0.061±0.030 mm. That is to say the horizontal position jitter is larger than vertical position jitter. It is obvious that the beam is not stable in horizontal coordinate. Table 2 gives the part of optics parameters and emittance at the SM and the BESM.

Table 2: Beam Optics Parameters at SM and BESM

Optic parameter	SM	BESM
β_x/β_y	8.76/11.98	15.03/6.71
η_x/η_y	1.15/0	1.34/0
$\varepsilon_x/\varepsilon_y$	25.56/25.56	25.56/25.56
σ_x/σ_y	2.35/0.48	2.75/0.41

The quantity σ_x^2-σ_y^2 is 6.01±2.86 mm^2. Because σ_x/σ_y is about 44, σ_x^2 is approximately equal to σ_x^2-σ_y^2 (in other words, σ_y is so little that we can ignore it). Moreover, Flag3 is so near that we can use σ_y at Flag3 to replace it at BESM.

Figure 4 shows the measured result of the energy spread by BESM. The result shows that the energy spread are 0.18% and the RMS is 3.3×10^{-4}.

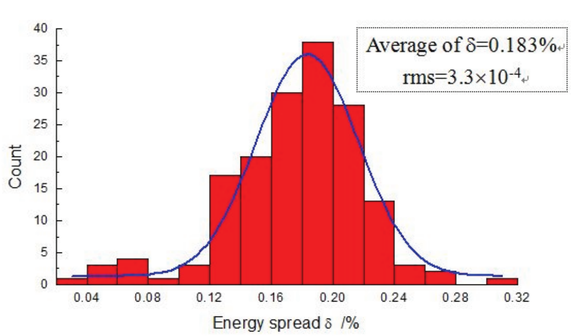

Figure 4: The beam energy spread measured by BESM.

At the same time, we used the SM to measure the beam transverse widths beam energy spread. Fig. 5 gives a picture snapped by camera. The average of beam energy spread measured by SM is 0.185% and the RMS is 1.68×10^{-4}, and σ_y is about 0.33mm. This shows that the result measured by BESM agree very well with it by SM. This shows that the BESM is capable of nondestructively measuring the beam energy spread.

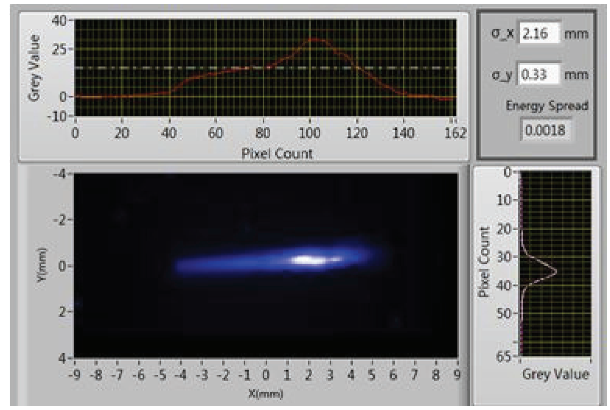

Figure 5: Beam profile at SM (Flag3).

SUMMARY

In this report, we used Libera Brilliance Single Pass processor to acquire beam position and quadrupole moment information, and used GE680 and LabVIEW to obtain beam transverse profile information. And then we calibrated the quadrupole moment to obtain beam energy spread. The result shows that the beam energy spread measured by the BESM and the SM is 0.18% and 0.185% respectively. The BESM may measure the beam energy spread nondestructively on line.

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