CALIBRATION OF BEAM POSITION MONITORS IN THE INJECTOR OF HLS II*

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Abstract

A beam position monitor(BPM) system is being installed to improve the beam position measurement of the injector at the upgrade project of Hefei Light Source (HLS II). The new BPM system is consists of 19 stripline BPMs and 19 Libera Brilliance Single Pass modules. Before installation, the response of the BPMs must be mapped to improve the accuracy of measurement. The theoretical equations of both position and quadrupole component of the BPM are calculated first, using both formula and matlab simulation. A laboratory calibration system is built. The inconsistency of Libera Brilliance Single Pass channels is measured to improve the accuracy of calibration. The calibrating results show the position sensitivity is less than 5% difference compare to the theoretical value, while the quadrupole component sensitivity is less than 10% difference.

INTRODUCTION

The HLS (Hefei Light Sourse) facility is an 800 *MeV* electron storage ring, with a 200 *MeV* Linac injector and a transport line. Starting mid of 2009 the HLS is being upgraded, known as HLS II. The emittance will be reduced while the storage energy will stay at 800 *MeV* .

Figure 1 shows schematically the injector of HLS II facility. An electron gun emits bunches spaced by 1 *s* , with bunch pulse 1 *ns* . The bunch charge is typically between 0.1 and 1 *nC* . There are 8 accelerating modules, with capability of accelerate the beam to 800 *MeV* .

Three types of BPMs are installed in the different sections of the injector. They are also shown in Fig. 1. 17 regular stripline BPMs, typically built inside quadrupoles, are evenly distributed over the entire facility. They mainly measure the position of the beam. A long_stripline BPM is installed at the begin of beam transport section, which has the same parameters of electrode as regular stripline BPM, but a little longer of the vacuum pipe. An eight_stripline BPM with eight electrodes is mounted near the end of injector, to measure not only position of the beam, but also the emittance and energy spread of the beam.

ANALOG CALCULATION

In general, the BPMs in the injector can be divided into two categories, the four electrode stripline BPMs which include the regular BPM and the long_stripline BPM, and the eight electrode stripline BPM. The main parameters of the BPMs are given by the table below [1]:

Table 1: Parameters of BPMs in HLS II Injector

Type of BPM	Total length	Electrode length	Vacuum radius	Electrode radius
Regular stripline	300 *mm*	150 *mm*	17.5 *mm*	13.1 *mm*
Long stripline	500 *mm*	150 *mm*	17.5 *mm*	13.1 *mm*
Eight stripline	300 *mm*	150 *mm*	17.5 *mm*	14.6 *mm*

Type of BPM	Electrode thickness	Angles of electrode
Regular stripline	1.5 *mm*	45°
Long stripline	1.5 *mm*	45°
Eight stripline	1.5 *mm*	60°/15°

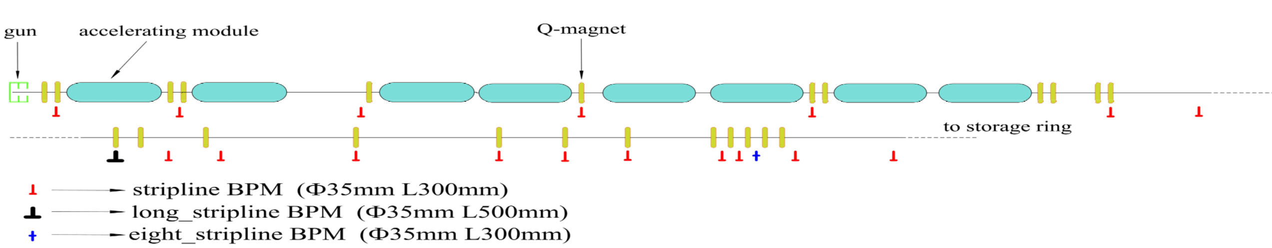

Figure 1: Schematic of the HLS II injector and of the BPM types built in.

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Before calibration, some key parameters, such as position sensitivity and quadrupole component sensitivity of BPM need to be computer simulated first [1].

Position Sensitivity

Position sensitivity of four electrode stripline BPM can be calculated by:

$$S_{\Delta/\Sigma} = 4\frac{\sin(\phi/2)}{\phi}\frac{1}{b} \tag{1}$$

Where ϕ and b are the electrode angle and electrode radius of the BPM. With parameters in Table 1, the result is $0.1488mm^{-1}$.

Also, the position sensitivity of eight electrode stripline BPM is given by:

$$S_{\Delta/\Sigma} = 4\frac{\sin(\phi_1/2) - \sin(\phi_2/2)}{\phi_1 - \phi_2}\frac{1}{b} \tag{2}$$

Where ϕ_1 and ϕ_2 are the total angle of a grouped electrode and the gap angle between the two electrodes of it. And with parameters in Table 1, the result is $0.1288mm^{-1}$.

Quadrupole Component Sensitivity

With parameters in Table 1, quadrupole component sensitivity of four electrode stripline BPM in the HLS II injector is $0.0105mm^{-2}$ and the quadrupole component sensitivity of eight electrode stripline BPM in the HLS II injector is $0.0073mm^{-2}$ [1].

Mapping Simulation

The mapping results of the calibration are simulated using matlab. BPM electrodes and a beam are established first. By counting the simulated voltages on the electrodes, the calibrate beam position can be simulated. With the simulated beam position changes, the mapping results of the calibration can be carried out and fitted.

With the simulated beam moving by the step of $0.5\,mm$, in a rectangular region from -5 mm to +5 mm, the simulated mapping results of four electrodes BPM and eight electrodes BPM is given by Fig 2.

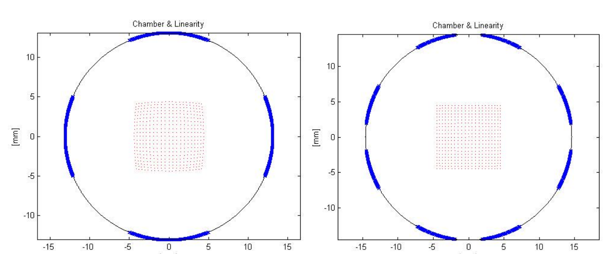

Figure 2: simulated mapping results from -5 mm to +5 mm.

By fitting the mapping results, the simulated BPM calibration formula of position and quadrupole component can be carried out [2]:

$$\begin{cases} x = 6.5240u + 2.8068u^3 + 1.9430uv^2 \\ y = 6.5229v + 1.9480u^2v + 2.8070v^3 \\ Q = 0.0104x_0^2 - 0.0104y_0^2 + 0.0102\sigma_x^2 - 0.0102\sigma_y^2 \end{cases} \tag{5}$$

$$\begin{cases} x = 7.7619u + 2.7821u^3 + 0.4060uv^2 \\ y = 7.7762v + 0.3452u^2v + 2.7828v^3 \\ Q = 0.0071x_0^2 - 0.0071y_0^2 + 0.0070\sigma_x^2 - 0.0069\sigma_y^2 \end{cases} \tag{6}$$

Equation 5 shows the calibration formulas of four electrodes BPM and the Eq. 6 shows the formulas of eight electrodes BPM. x and y are the position of the beam, u and v are counted by the voltages of the electrodes [4]. Q is the quadrupole component when beam at (x_0, y_0) position. σ_x and σ_y are the emittances.

In the fitting function, there are four dominant parameters. Two of them are the reciprocal of the position sensitivities (The first coefficient in the previous two formulas). And remaining two are quadrupole component sensitivities (The first coefficient in the third formula). The higher order terms can also be seen from the function.

Channel Coupling Correction

The coupling coefficient between the electrodes should be considered. Using CST MWS, the BPM can be simulated and the coupling coefficient can be calculated . Table 2 shows the coupling coefficients and the sensitivity changes caused by the coefficients.

Table 2: Sensitivity Changes caused by Channel Coupling

Type of BPM	Sensitivity	Uncoupled	Coupled	Coeff-icient
Four electrodes stripline BPM	$S(mm^{-1})$	0.1488	0.1295	0.87
	$S_Q(mm^{-2})$	0.0105	0.0084	0.80
Eight electrodes stripline BPM	$S(mm^{-1})$	0.1288	0.1224	0.95
	$S_Q(mm^{-2})$	0.0073	0.0067	0.92

CALIBRATION TEST STAND

Figure 3 shows the offline-calibration test stand. A continuous 500 MHz rf signal is sent down an antenna wire to simulate the beam, signals induced on the BPM striplines are measured by Libera Brilliance Single Pass [3], a stepping motor controls the BPM movement. The whole system is placed on a standard optical platform.

Some improvements had been done compared with the previous experiment [4]. The optical platform, signal source and electric displacement platform are replaced by

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more precise instrument. A tungsten wire of a radius of 0.1 *mm* was chosen as the antenna wire, for its thinness and it can be pulled very tight.

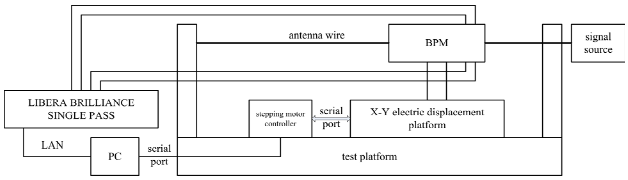

Figure 3: Calibration test stand.

Channel Inconsistency

Besides the improvements of the equipments, the channel inconsistency of Libera Brilliance Single Pass should be measured and considered in the subsequent fitting. The signal source generate a continuous 500 *MHz* rf signal and fed into the four channels of Libera Brilliance Single Pass. The responses to the same input signal are recorded (see Fig. 4), and the coefficient of the ratio between the different channels is calculated.

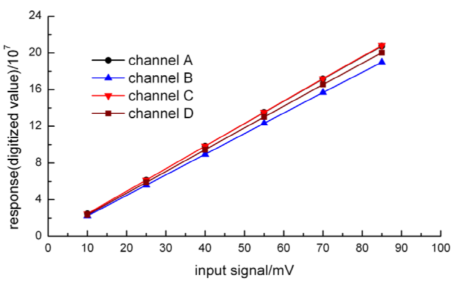

Figure 4: Channel response under different input signal

Setting channel A as a standard, fitting the rest channels we can get the response coefficient between the channels: $V_B = 0.911V_A$, $V_C = 1.002V_A$, $V_D = 0.967V_A$.

Then, these parameters are set into Libera Brilliance Single Pass to eliminate channel inconsistency.

CALIBRATION RESULTS

All 19 BPMs are calibrated at test bench, Fig. 5 shows the mapping result of a four electrodes stripline BPM.

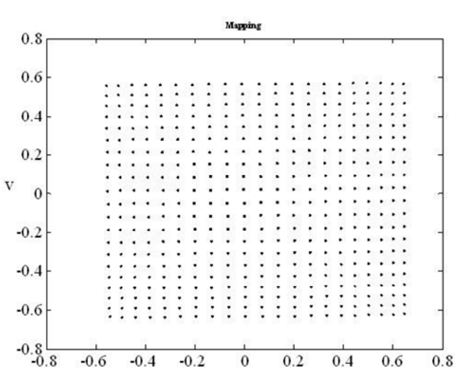

Figure 5: Mapping result of a BPM.

By fitting the mapping results, the calibration formula of position and quadrupole component can be carried out:

$$\begin{cases} x \approx -0.475+7.30u+2.82u^3 \\ y \approx 0.334+7.37v+2.68v^3 \\ Q \approx -0.0073+0.0074x_0+0.0050y_0+0.0077x_0^2 \\ -0.0078y_0^2+0.0077\sigma_x^2-0.0078\sigma_y^2 \end{cases} \quad (7)$$

The result is similar to the simulating formula (Eq. 5). Derived from the result, the position sensitivity is about 0.135mm^{-1} and the quadrupole component sensitivity is about 0.0077mm^{-2}, which are very close to the theoretical value (with channel coupling correction). The offset constants are less than 0.5mm.

Figure 6 shows the difference between measured result and theoretical value of sensitivities, and also shows the offset constants of all 19 BPMs.

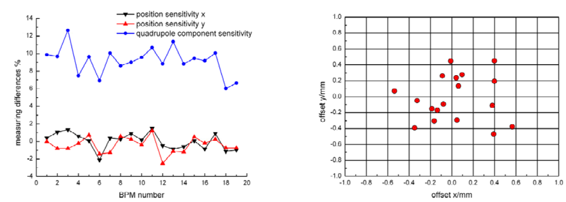

Figure 6: The sensitivities and offset of all 19 BPMs.

From the results the measured position sensitivities are less than 5% difference from the theoretical value, while most of the quadrupole component sensitivity differences are less than 10%, and the offset constants are less than 0.5mm.

SUMMARY

In the injector of HLS II, 19 beam position monitors are allocated. Several theoretical calculations have been done, sensitivities are calculated and mapping results are simulated, the channel coupling is also considered. A calibration test bench is built with several improvements, and the channel inconsistency is measured. All the BPM offline calibration has been done before installation, the results agreed well with the theoretical value.

REFERENCES

[1] FANG Jia, SUN Bao-Gen, LU Ping, et al. "Design and Calculation for Stripline Monitor of HLS Injector," Nuclear Science and Techniques. 2010.9，44(Suppl.):506-511.

[2] S.Sato, T.Tomisawa, et al. "Beam Position Monitor and its Calibration In J-PARC LINAC," PAC'07, p.4072-4074.

[3] J.Y.Zou, J.Fang, B.G.Sun, et al. "Application of Libera Brilliance Single Pass at NSRL LINAC BPM System," IPAC'11, p.1284-1286.

[4] Zou Junying, Fang Jia, Sun Baogen, et al. "Test of Libera Brilliance Single Pass" High Power Laser and Particle Beams, 2012, 24(11):2893-2896.