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A BEAM BASED METHOD TO OPTIMIZE THE SBPM SYSTEM*

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Abstract

For the electron accelerator, it is hoped that the trajectory of the beam can pass through the magnetic center of the quadrupole to minimize the orbital motion caused by the instability of the power supply. The relative deviation between the magnetic center of quadrupole and the electric center of adjacent BPM is measured by electron beam usually in various accelerator facilities. But for the stripline BPM (SBPM) system, in order to achieve the best performance, the beam trajectory should also need to pass through the electrical center of the SBPM system. In this paper, a beam based method to optimize the SBPM system was proposed, the intensity of the magnet power was scanned to change the beam position in two-dimension and combine the change trend of the sum signal of adjacent SBPM to find out the relative deviation of BPM electric center and mechanical center. Relevant beam experiment work on the Shanghai Soft X-ray free electron laser (SXFEL) and the benefit of this method will be addressed as well.

INTRODUCTION

The free-electron laser (FEL), based on the linear accelerator, is a fourth-generation light source, which has characteristics such as high brightness, short wavelength, full coherence, and ultra-fast time resolution. Thus, it has become an extremely important research apparatus to meet the demands of biological, chemical, and material science research[1].

For the FEL facility, in order to realize the X-ray radiation of corresponding wavelength, it is necessary to have strict requirements on the parameters such as energy, emittance and the beam position of electron beam. In order to realize the measurement of beam position and correct the beam trajectory using the method of beam based alignment (BBA), various beam position monitors (BPMs) are used in accelerator system.

In the linear accelerator section, the resolution of the beam position is required to be in the micro-meter level. Therefore, the SBPM with the advantages like mature technology, low cost, multi-parameters measurement and simple system structure has become the preferred option for most FEL facilities. The structure of SBPM system generally includes two parts: stripline BPM probe and digital signal processor.

SBPM system also has a lot of other applications, such as relative beam charge measurement and beam length measurement.

But the traditional application is to use BBA to measure the relative deviation between the magnetic center of quadrupole and the electric center of adjacent BPM so as to measure the magnetic center of quadrupole, and use this as a reference point for the beam trajectory and carry out orbit correction, so that the beam can pass through the magnetic center of the quadrupole to minimize the orbital motion caused by the instability of the power supply[2-3].

But for the SBPM system, it is meaningful to measure the deviation between the mechanical center and the electrical center of the system, and then make the beam can also pass through the electrical center by correcting the mechanical installation so as to improve the linearity of beam position measurement and the accuracy of relative charge measurement. The system setup, beam test results and data analysis will be discussed in the following paragraphs.

MEASUREMENT PRINCIPLE

Charged particles that move near the speed of light generate electromagnetic fields around it, including the near field and far field. The near field is related to the amount of charge carried by the particles, so most beam currents and beam position are measured in the near field[4]. A displaced beam produces non-equal current distributions on stripline electrodes. The amount of the induced charge is closely related to the distance from the beam to the surface of the stripline electrode. Comparing these non-equal signals allows to detect the bunch position transverse to the beam direction. The sum signal of four-electrodes also reflects the amount of relative charge. It has the advantages of high-resolution and can perform bunch-by-bunch charge measurement. The 3D model and section structure of common SBPM are shown in Fig. 1.

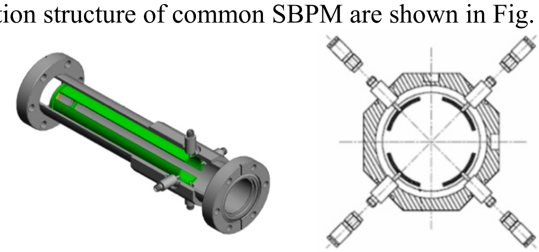

Figure 1: 3D model and section structure of SBPM.

In the digital signal processing, the integral value of each electrode signal waveform is calculated as the amount of induced charge so as to remove the effect of beam elongation. The Δ/Σ method and Logarithmic ratio algorithm are often used to calculate the beam position.

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SYSTEM SETUP

In order to measure the deviation between the mechanical center and the electric center of the system which caused by the inconsistency between the four channels. Then the SBPM can be adjusted accordingly so that the system can work in the beast performance area.

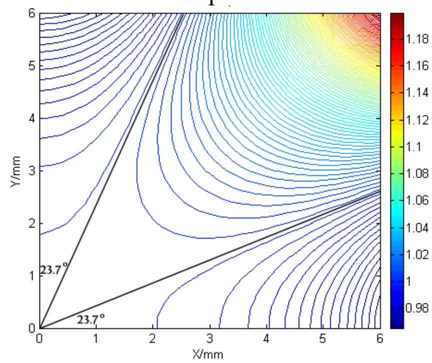

Figure 2: Simulation results of the ideal SBPM probe.

The simulation results of the relationship between the sum signal of ideal SBPM probe and the beam position are shown in Fig. 2. And corresponding system setup and experiments have been conducted in the SXFEL facility. A total of 35 SBPMs are installed along the injector and main accelerator. Fig. 3 show the picture of SBPM and DBPM installed in the SXFEL.

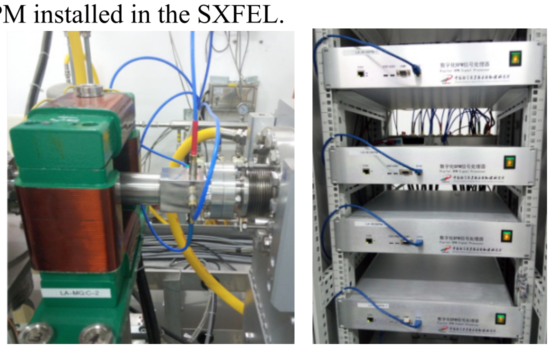

Figure 3: The installed SBPM and DBPM.

The system consists of two parts: SBPM probe and the Digital BPM processor. The work frequency was selected at 500 MHz and the variable attenuators controlled by FPGA to increase the dynamic range and complete the signal conditioning. The signal digitized by the ADC is processed in the FPGA and the results is uploaded via EPICS. The system diagram is shown in Fig. 4.

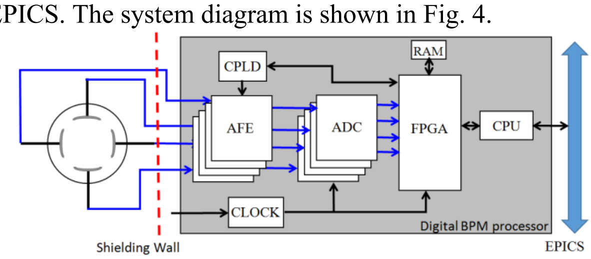

Figure 4: System diagram of the SBPM.

In the experiment, the position of the electron beam is changed in the horizontal and vertical directions by scanning the current of the correction magnet, and in order to eliminate the influence of beam charge jitter, the SBPM in front of the correction magnet was selected to normalize the beam charge, Fig. 5 show the block diagram of the experiment.

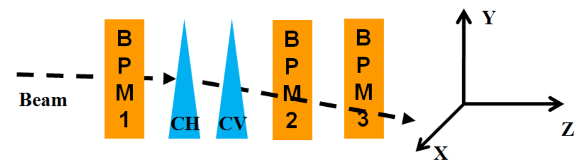

Figure 5: Block diagram of the experiment.

RESULTS FROM THE BEAM TEST

Using python-based script loops to set the strength of correction magnet in the horizontal and vertical direction to implement a two-dimension scan. Meanwhile, the data of beam position and the sum signal of four-electrodes at different step are also collected.

The mechanical center is the position when the signal amplitudes of the opposite channel digitized by the signal processor are the same (Δ/Σ is used to calculated the beam position). But the electric center is the position when the sum signal of the four-electrodes is maximized, which reflects the electrical performance of the system.

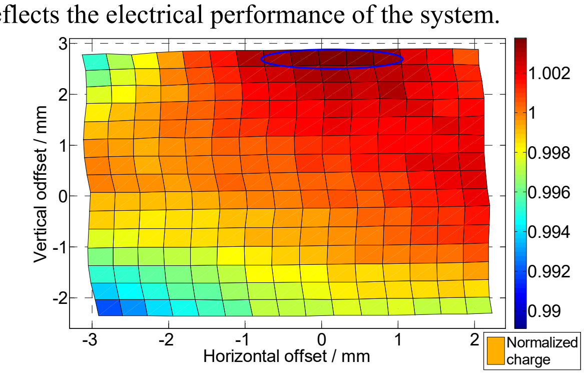

Figure 6: Results of the deviation between the electrical center and the mechanical center of SBPM7.

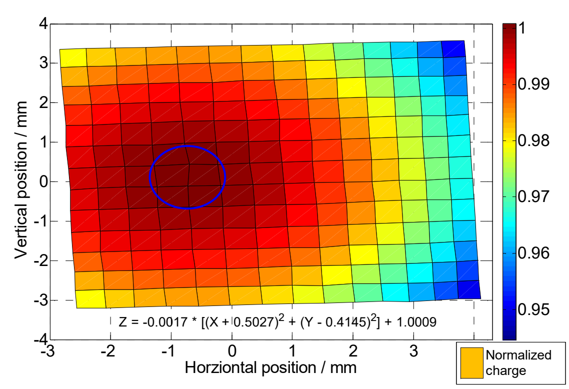

Figure 7: Results of the deviation between the electrical center and the mechanical center of SBPM11.

The different SBPM results after normalized are shown in Fig. 6 and Fig. 7, respectively. From the results of Fig. 6, the electrical center and the mechanical center are widely deviated and the electrical center is located at the edge of the scanning value. This is due to the fact that there is a large difference in one of the channels (in the

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vertical direction) and the result calculated by Δ/Σ is treated as an electric center when BBA is used. Which also indicates the defects of using the Δ/Σ results as the electric center of the SBPM system.

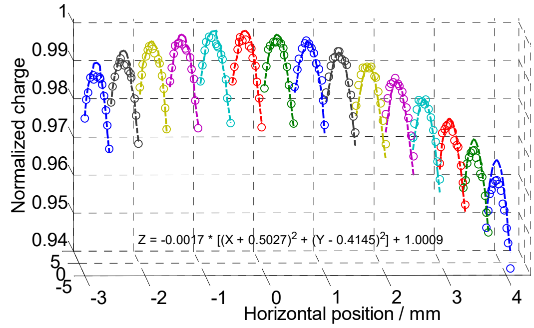

Figure 8: Fitting results in two-dimension.

Fig. 8 shows the results of two-dimension surface fitting. It can be known from the fitting results of experiment data that the mechanical center deviates from the electrical center both in horizontal and vertical direction, more than 400 um.

The information in Fig. 7 and Fig. 8 also shows the relationship between the sum signal and the beam position when it used for the measurement of the beam charge. Therefore, from the analysis of electrical performance, the sun signal of SBPM can be precisely used for bunch-by-bunch charge measurement when the beam position is close to the electrical center. However, the normalized beam charge decreases when the beam has a large offset. It is necessary to correct the results using the calibration factor which have been got in Fig. 8 or to adjust the support structure during the mechanical installation so that the beam can also pass through the electrical center of the SBPM system to ensure the best performance.

Based on this experiment, a total of 35 SBPMs (the other 9 SBPMs are not work in the first phase) are scanned in horizontal direction by an external sine excitation signal with a period of 10 minutes to detect whether the opposite channels of the SBPMs has obvious defects. Due to the presence of the Lorentz force on the electron beam due to the magnetic field of the correction magnet, the beam will be more off-center at the end of the accelerator. The amplitude of the sine excitation signal is controlled in a very small range to ensure that most quadrupole magnets can work in the linear region.

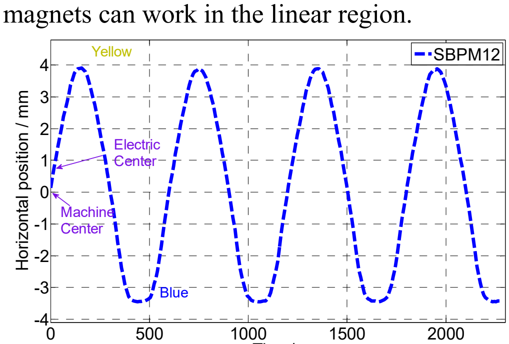

Figure 9: Beam position in SBPM12 throughout the entire time period.

The beam positions in SBPM12 throughout the entire time period are shown in Fig. 9 that the characters are consistent with the excitation signal. And Fig. 10 shows the results of normalized charge changes for all SBPMs collected in one hour.

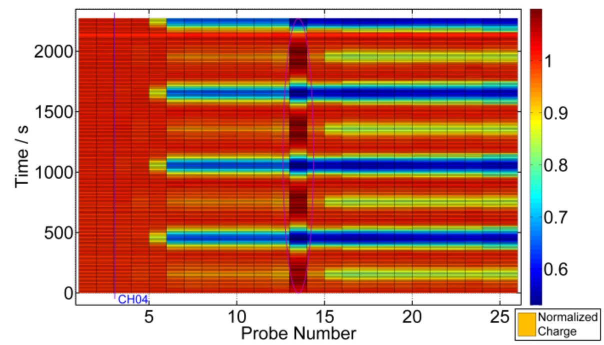

Figure 10: The normalized sum signal changes for all SBPMs collected in one hour.

From the results shown in Fig. 10, obviously it can be seen that there are have four cycles which consistent with the characters of excitation signal and the relationships between the sum signal of the SBPM and the beam position. Looking at the alternating dark and light strips in the longitudinal direction, the asymmetry of the stripes indicates that the excitation signal is not symmetrical about the electrical center of the SBPM.

In addition, at the location of SBPM13, it can be seen that the normalized signal distribution is inconsistent with other SBPMs. Comparing the colorbar and the measured beam position distribution, the result show that the measured signal is always on the side of the electrical center and the deviation between mechanical center and the electric center up to 7 mm which indicates there has obvious defects in the opposite electrodes or channels. Performing a step-by-step investigation to detect this phenomenon is caused by the excessive insertion loss in one of the DBPM channel.

CONCLUSION

The method of scanning the intensity of the magnet power to change the beam position in two-dimension to measure the deviation between the mechanical center and electric center of the SBPM system was proposed in this paper. The intention is to find out the obvious defects of the opposite electrodes or channels and correct the mechanical installation to make the beam can also pass through the electric center of the SBPM system to optimize the performance. The experiments have been done in SXFEL and one of the result indicates that there are deviations in both horizontal and vertical directions, more than 400 um. And explains the defects of traditional method of using the Δ/Σ results as the electric center of the SBPM system based on the example of SBPM7. We will try to correct it during the next mechanical installation to optimize the performance of the system.

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