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DEVELOPMENT OF AN AUTOMATIC CALIBRATION SYSTEM FOR BPM

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Abstract

Beam Position Monitor (BPM) is used to measure the horizontal and vertical positions of the beam in the vacuum pip of the accelerator facility. Before online installation, it usually needs to be calibration. High Intensity Heavy-ion Accelerator Facility (HIAF) and China initiative Accelerator Driven System (CiADS) will need a large number of BPM, so it is a great challenge for BPM calibration work. In order to complete this work efficiently and accurately, this research designs and develops an automatic BPM calibration system. This paper mainly described the control and processing programs in this system. The control software was designed by C language to realize automatic calibration functions based on EPICS. A high-order fitting algorithm programmed by Python used to solve the problem of smaller linear range of the capacitive BPM. It significantly improves the accuracy of position measurement after calibration.

INTRODUCTION

HIAF and CiADS will be a next-generation, internationally leading heavy-ion accelerator facility after being established. The precise measurement by the BPM is essential for the desired goal.

Beam position is a key parameter of the accelerator, and it is the judgment basis for beam experiments. In order to maintain the measurement accuracy, it is not only need to improve the technology level of detector design, processing and assembly and reasonable processing technology of signal acquisition, but also required to realize the accurate calibration of the detector [1].

The automatic BPM calibration system designed in this paper can complete the calibration work efficiently, and save lots of time for calibration user. It greatly simplifies the calibration mission of large amount of BPM.

HARDWARE ARCHITECTURE

The hardware architecture of the whole system is shown in Fig. 1. It consists of four major sections, including simulate beam current equipment, calibration platform and motion device, BPM signal processing electronics and industrial computer.

The automatic calibration system is usually performed using the metal wire stretch method. A straightened metal wire is passed through the BPM, and an RF signal is fed to the wire to simulate beam current. An RF signal generator feeds an RF signal by the SMA connector. The signal processing electronics connected the BPM detector via an RF coaxial line. It is used to process and analyse the output signal of the BPM, and acquire the position information of the metal wire relative to the measured BPM detector electrical center. After that it send these data to the industrial computer after calibration ending.

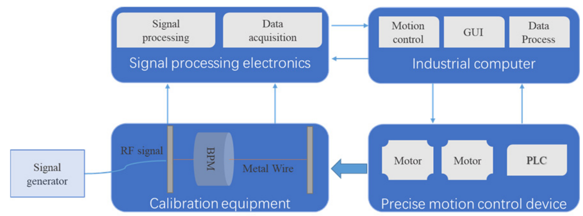

Figure 1: Hardware structure of calibration system.

Calibration Platform and Motion Device

The capacitive BPM is mounted on a two-degree-of-freedom motion platform, which is fixed on a test bench. The motion platform and test bench are shown in Fig 2. The motion platform is produced by Zolix Company in Beijing. Its repeat positioning accuracy is 1 μm, and the measurement precision is 0.1 mm. The motion range in both degrees of freedom is ±150 mm, which guarantees the precision and accuracy of the calibration result and the comprehensive scanning range.

The motion device is mainly combined by the product range of Beckhoff Automation Programmable Logic Controller (PLC) CX2020. It is a modern Industrial PCs (IPC) being produced since 2014 and running Microsoft Windows 7 Embedded operating systems. Equipped with powerful hardware. The CX2020 is capable of supervising and controlling multiple sections of a production process at the same time.

Figure 2: Motion platform and test bench.

BPM Signal Processing Electronics

The BPM system is one of the most important measurement systems for accelerator beam diagnostics and has a large amount of BPM detectors among the beam diagnostic equipment. A typical BPM system is a chain of an in-

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vacuum electromagnetic sensor, front-end analogue RF circuit, high-speed digitizer, FPGA and back-end software. The electronics firstly condition the analog signal, compute the difference over sum signals after Analog to Digital Convert (ADC) [2], and then extract the corresponding according to different frequencies.

The diagram of the electronics is illustrated in Fig. 3.

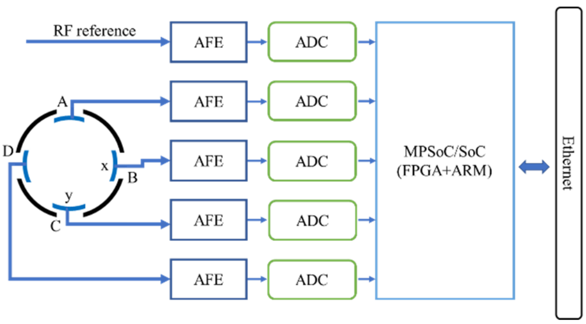

Figure 3: The diagram of the BPM signal processing electronics.

SOFTWARE DESIGN

The software of this system includes motion control program, data acquisition program, and off-line data analysis program. Among them, the data acquisition program runs on a BPM signal processing electronics as an embedded Linux system, the motion control program is developed using the windows-based EPICS architecture. EPICS is a distributed control software framework based on the C/S mode. The off-line data analysis program is written in Python language and using a high-order fitting algorithm program to meet the calibration needs.

Motion Control Program

The main function of the motion control program is to control the motion platform, complete the interaction function with the BPM signal processing electronics to get the position data.

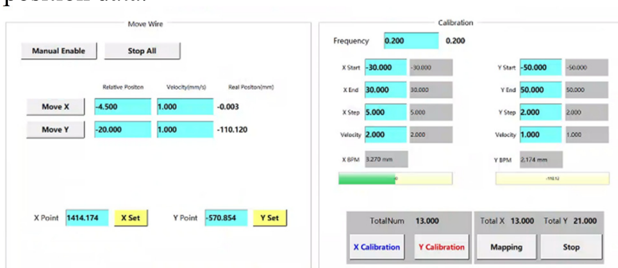

Figure 4: The GUI of the control program.

Its GUI interface is shown in Fig. 4. It shows many information about the motion control, includes home point initialization, getting and setting some essential motion parameters about the motor, such as motion frequency, start and end coordinates, step length, and motion speed. It can also depict the real-time signal and position, and show the total number of points and steps. It not only can realize the calibration functions by making the X or Y single direction movement, but also can satisfy the X and Y double direction movement requires. Press the stop reset button, the corresponding process will be pause and clear immediately. When press the start button again, the new process will be executed at the same time.

The PLC process writes the actual position and other information into the corresponding data structure, and meanwhile sends a trigger signal to the BPM signal processing electronics. They work and save the corresponding position information synchronously. When they have collected enough points required for this calibration, they will stop collecting and meanwhile send the corresponding data to the motion control program. This data will be written to a .txt file which is named after the calibration stop time.

Data Acquisition Program

The embedded digital beam position measurement system been developed can run independently and also can be used in the bus mode. It uses the channel access interface of EPICS to realize data acquisition. EPICS IOC is a distributed real-time database resident in the memory of the controlled device, which runs in the embedded system of the electronics and collects the data of the electronics.

Figure 5 is the GUI of the data acquisition program. Its left shows many Digital Signal Processing (DSP) setting information, ant its right displays the x and y position waveform and average value highlighted by green rectangle.

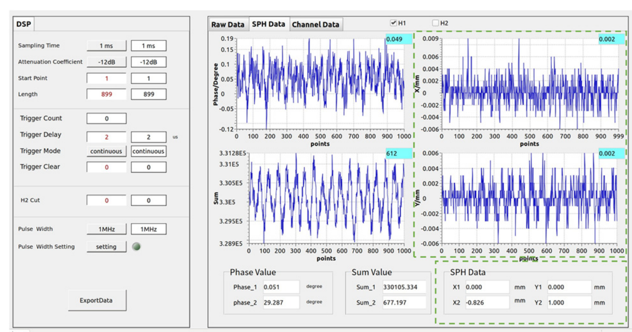

Figure 5: The GUI of the data acquisition program.

It has satisfied higher demand for fast machine protection of high current and power linear accelerator. Besides, it has achieved self-detect false diagnosis intelligently, and on-line calibration function. Its higher measuring accuracy is more suitable for the actual situation of the accelerator system.

Off-line Data Analysis Program

When the beam position is close to the BPM center, x and y are linear function of Δ/Σ respectively, these regions is called linear regions. But in the nonlinear regions, the Δ/Σ response of the BPM is not linear, and a position calculated using a linear scaling factor is acceptable only in a limited region around the BPM center. When the beam position is expected to be in regions where the position cannot be computed linearly, a polynomial approach based on the Maclaurin expansion can be used. With $x = (\Delta/\Sigma)_x$ and $y = (\Delta/\Sigma)_y$ the two ratios, the position X using the Maclaurin expansion is shown as Eq. (1).

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$$X = k_{x0} + k_{x1}x + k_{x2}x^2 + k_{x3}x^3 + k_{x4}x^4 + k_{x5}y + k_{x6}y^2 + k_{x7}y^3 + k_{x8}y^4 + k_{x9}xy + k_{x10}x^2y + k_{x11}xy^2$$
$$Y = k_{y0} + k_{y1}y + k_{y2}y^2 + k_{y3}y^3 + k_{y4}y^4 + k_{y5}x + k_{y6}x^2 + k_{y7}x^3 + k_{y8}x^4 + k_{y9}yx + k_{y10}y^2x + k_{y11}yx^2 \quad (1)$$

The polynomial coefficients for the Maclaurin expansion are calculated truncating the series at the 4th power for the direct terms, and at the 3rd power for the cross-correlated terms. Using least square algorithm implemented in Python, it can solve the problem of smaller linear range of the capacitive BPM.

The off-line data analysis program is designed in Python language using pyepics [3]. Figure 6 shows a very simple GUI, which contains many important information. It allows the operators to import the measure data files, set the calculate range of the calibration BPM and press the calculate button on the corresponding area. Finally, the calibration coefficients are computed and shown in the GUI and saved in a .csv file.

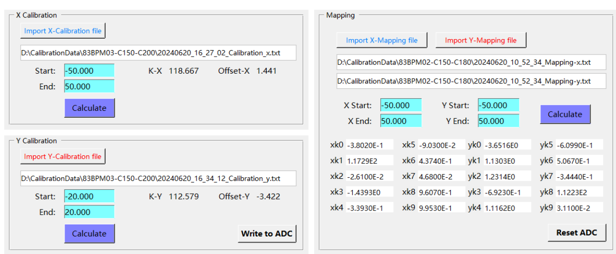

Figure 6: The GUI of the off-line data analysis program.

CALIBRATION EXPERIMENT

The capacity BPM with inner 25 mm-diameter was selected, aimed to verify whether the calibration system can realize the expected functions [4]. Before computing the probe calibration coefficient vector k_x and k_y, it is necessary to collect the position data k_{x0}, k_{y0}, $(\Delta/\Sigma)_x$ and $(\Delta/\Sigma)_y$. Considering the signal line diameter and collimation error, a circle with 12 mm radius around the BPM center is selected as the data acquisition area. Set the distance between each point to 1 mm, then start the automatic calibration program.

Figure 7 shows the mapping chart of the collected raw coordinate data before calibration. In the chart, blue points represent the actual position of the metal wire, orange points are the fitting data after using the high-order fitting algorithm, and the green points are the raw coordinate data collected by BPM signal processing electronics before calibration. While Fig. 8 shows the raw coordinate data after calibration. In that, green points depict the post-calibration coordinate value collected by BPM signal processing electronics, it verified that this high-order fitting algorithm can significantly improve the linear range of the BPM.

CONCLUSION

This paper designed an automatic calibration system for BPM probe and carried out a BPM probe calibration experiments. A high-order fitting algorithm programmed by python used to solve the problem of smaller linear range of the capacitive BPM. It significantly improves the accuracy of position measurement after calibration.

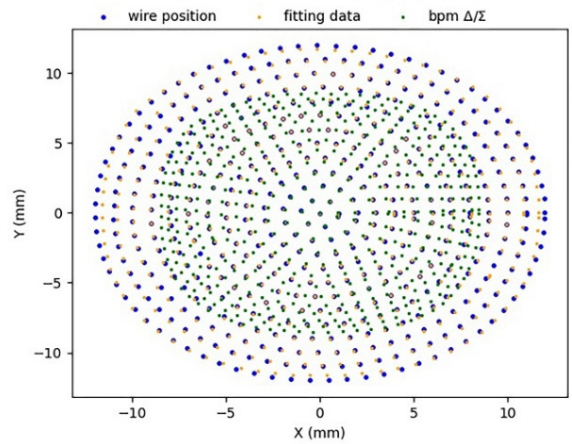

Figure 7: Theoretical and computational coordinates in a 12 mm-radius circle of pre-calibration.

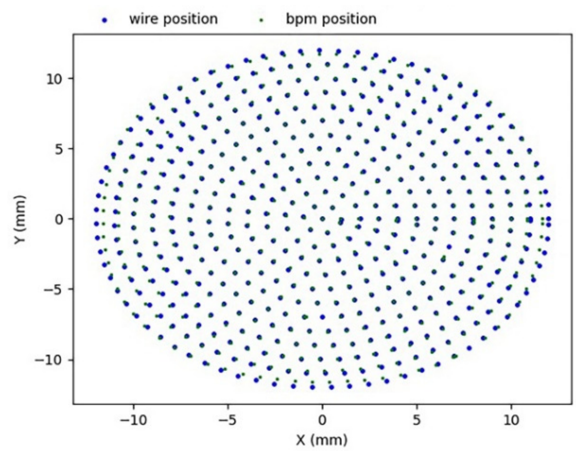

Figure 8: Theoretical and actual measurement coordinates in a 12 mm-radius circle of post-calibration.

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