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CALIBRATION OF THE BPM OFFSETS IN CRYOMODULE AT CiADS INJECTOR II

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Abstract

China Initiative Accelerator Driven System (CiADS) project is a strategic plan to solve the nuclear waste problem and the resource problem for nuclear power plants in China. For CiADS driven linac, which has a long superconducting accelerator section, traditional ways to calibrate the Beam Position Monitor (BPM) are not always available. In order to calibrate the BPM offsets in cryomodule so as to adjust the beam orbit effectively and accurately, we have tried to scan the superconducting solenoid's current, read the BPM values, and fit the data to get BPM offsets.

INTRODUCTION

The Injector Scheme II which is being built at IMP is composed of an ion source, a low energy beam transport line (LEBT), a 162.5 MHz radio frequency quadrupole accelerator (RFQ), a medium energy beam transport line (MEBT) and a superconducting Half Wave Resonator (HWR) accelerator section. In superconducting accelerator section, beam loss is particularly deleterious. Large beam orbit excursion is one of the major reasons causing beam loss. In order to align the beam orbit accurately to the centroid of the accelerator components, calibration of the BPM offsets is essential.

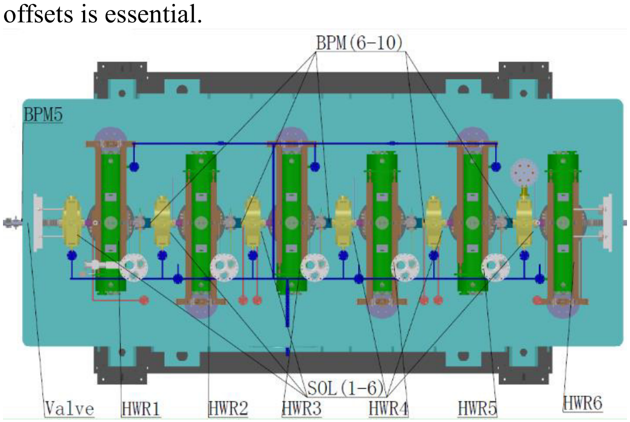

Figure 1: Layout of CM1 of C-ADS Injector II.

Traditional methods of calibrating BPM offsets always need quadrupoles [1]. But in cryomodule, such as CM1 shown in Fig. 1, there is no quadrupole. On this occasion, solenoid may be a substitute. In this report, the formulations of calibration of the BPM offsets with solenoid will be briefly described in the second section. The experiment designs and results are demonstrated in the third section. Finally, the summary of the studies will be given and some ideas for further studies will also be discussed in the last section.

MATHEMATICAL THEORY

Let x, x', y, and y' be coordinates of the particle and the subscript 0 and 1 denote the beginning and ending point of the lattice, we get

$$\begin{pmatrix} x_1 \\ x_1' \\ y_1 \\ y_1' \end{pmatrix} = M \cdot \begin{pmatrix} x_0 \\ x_0' \\ y_0 \\ y_0' \end{pmatrix}, M = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{bmatrix}$$

where M is the total transfer matrix which can be calculated by [2]

$$R_{drift} = \begin{bmatrix} 1 & L & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R_{solenoid} = \begin{bmatrix} cos^2(kL) & \frac{1}{2k}sin(2kL) & \frac{1}{2}sin(2kL) & \frac{1}{k}sin^2(kL) \\ \frac{-k}{2}sin(2kL) & cos^2(kL) & -ksin^2(kL) & \frac{1}{2}sin(2kL) \\ -\frac{1}{2}sin(2kL) & -\frac{1}{k}sin^2(kL) & cos^2(kL) & \frac{1}{2k}sin(2kL) \\ ksin^2(kL) & -\frac{1}{2}sin(2kL) & -\frac{k}{2}sin(2kL) & cos^2(kL) \end{bmatrix}$$

Define x_{off} and y_{off} as offsets of the BPM next the solenoid, there are

$$\langle x_1 \rangle = m_{11}\langle x_0 \rangle + m_{12}\langle x_0' \rangle + m_{13}\langle y_0 \rangle + m_{14}\langle y_0' \rangle - x_{off}$$
$$\langle y_1 \rangle = m_{31}\langle x_0 \rangle + m_{32}\langle x_0' \rangle + m_{33}\langle y_0 \rangle + m_{34}\langle y_0' \rangle - y_{off}$$

Respectively, the following equations can be obtained:

$$\begin{pmatrix} \langle x_1 \rangle \\ \cdots \\ \langle x_N \rangle \\ \langle y_1 \rangle \\ \cdots \\ \langle y_N \rangle \end{pmatrix} = A \cdot \begin{pmatrix} x_0 \\ x_0' \\ y_0 \\ y_0' \\ x_{off} \\ y_{off} \end{pmatrix},$$

$$A = \begin{bmatrix} m_{11}^{(1)} & m_{12}^{(1)} & m_{13}^{(1)} & m_{14}^{(1)} & -1 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ m_{11}^{(N)} & m_{12}^{(N)} & m_{13}^{(N)} & m_{14}^{(N)} & -1 & 0 \\ m_{31}^{(1)} & m_{32}^{(1)} & m_{33}^{(1)} & m_{34}^{(1)} & 0 & -1 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ m_{31}^{(N)} & m_{32}^{(N)} & m_{33}^{(N)} & m_{34}^{(N)} & 0 & -1 \end{bmatrix}$$

With enough measured $\langle x_i \rangle$ and $\langle y_i \rangle$ values, the quantity of x_{off} and y_{off} can be fitted by using the least square method, which can be simplified as [3]

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$$\begin{pmatrix} x_0 \\ x'_0 \\ y_0 \\ y'_0 \\ x_{off} \\ y_{off} \end{pmatrix} = (A^T A)^{-1} A^T \begin{pmatrix} \langle x_1 \rangle \\ \cdots \\ \langle x_N \rangle \\ \langle y_1 \rangle \\ \cdots \\ \langle y_N \rangle \end{pmatrix}$$

EXPERIMENT AND RESULTS

The calibration was carried out on the Injector Scheme II Cryomodule 1. During the experiment, the beam was operated at a pulse width of 50 microseconds with the frequency of 1Hz and intensity of 2mA. By scanning the current of SOL1 from -100A to 100A, we acquired a series of values of beam positions.

Table 1: The First Experimental Data of SOL1

Current(A)	-100	-90	…	90	100
X(mm)	0.58	1.01	…	-0.17	-0.22
Y(mm)	3.20	2.84	…	-0.17	0.14

The raw data from BPM6 and the fitted curve are shown in Fig. 2.

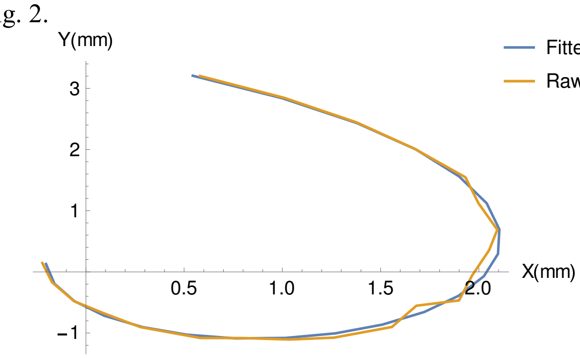

Figure 2: The first fitting result of SOL1.

After fitting, we acquired $x_{off} = 1.61mm$ and $y_{off} = -2.10$mm. Then change the beam position and direction before SOL1 and repeat the experiment to benchmark the result. The raw data and the fitted curve are shown in Fig. 3.

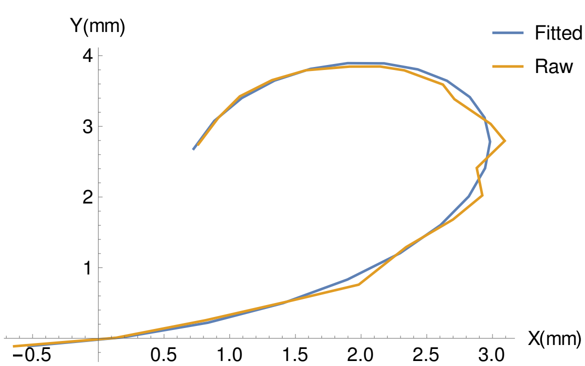

Figure 3: The second fitting result of SOL1.

We got $x_{off} = 1.52mm$ and $y_{off} = -2.01$mm, which was close to the first result.

Table 2: Fitting Results of BPM7 and BPM9

	BPM7	BPM9
x_{off}(mm)	-1.39	-2.20
y_{off}(mm)	-4.45	-3.70

At last we calibrated BPM7 and BPM9 respectively by using SOL2 and SOL4. The results are shown in Table 2. And the data with fitted curves are plotted in Fig. 4 and Fig. 5.

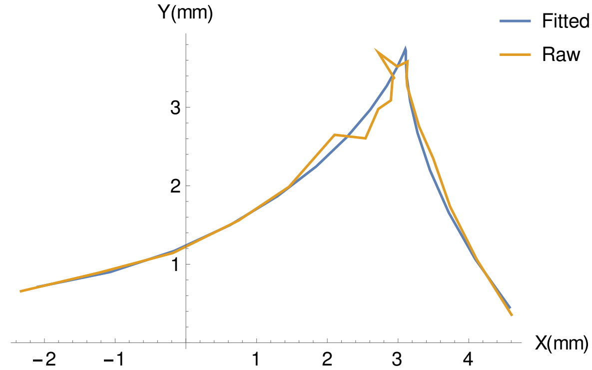

Figure 4: Fitting result of SOL2.

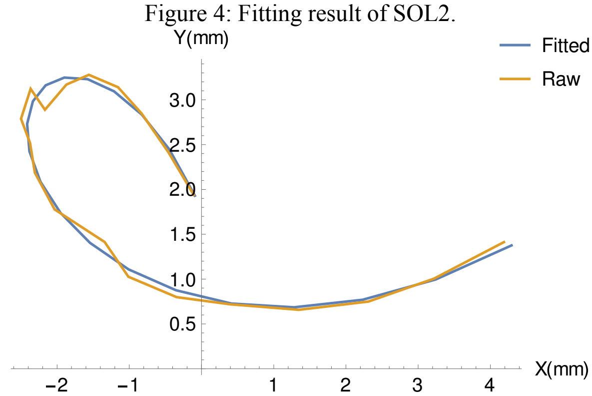

Figure 5: Fitting result of SOL4.

SUMMARY

In cryomodule, solenoid is likely an alternative to quadrupole to calibrate the BPM offset, which means the displacement between the magnetic axis of the solenoid and the electric center of the BPM. But the experiment is only at an early stage of feasibility study. As the step further, error analysis will be made. In addition, the availability of this method need to be verified in practice.

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