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CHARACTERIZATION STUDY OF A BUTTON BPM WITH AN APPROACH TO AUTOMATED MEASUREMENTS

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Abstract

Beam position monitors (BPMs) are one of the very important diagnostic components of any accelerator system giving information about beam position. It is a class of non-intercepting devices which use the coupling of the EM field around a charged particle bunch to some sort of conductor electrodes to recover beam position information from the beam-induced signals. In this paper, a characterization study of an in-house developed Button BPM including sensitivity measurement and transfer impedance studies is presented. Sensitivity measurement was done using the stretched wire method by passing current pulses through the wire of different diameters like 0.5 mm and 1 mm, thus mimicking the behavior of the actual beam. Sensitivity information was then used to reciprocate the 2-D position map of the device. Owning to the time taken for such huge measurements, an automated BPM test bench approach of the whole setup is developed by remote interfacing over LAN. A substantial decrease in measurement time was observed along with a reduction in measurement error.

INTRODUCTION

In particle accelerators, a beam position monitor (BPM) provides crucial information about the beam. A typical button BPM consists of four button-type electrodes mounted inside the surface of cylindrical pipe in vacuum. The main idea is to measure the charges induced by the time varying electric field of the beam particles on an insulated metal plate [1]. By measuring the electrode signal of various electrodes,the relative gains of the electrodes can be calculated. Studies have been performed in calculating the optimal dimension of BPM for maximum gain [2]. Button BPM have been used extensively and deployed at various accelerator systems [3, 4] ranging from ring systems [5] to developing test bench for proton LINAC [6] and with an approach to automation [7].

This paper presents a characterization study of a button BPM with transfer impedance studies and position sensitivity measurements with a development of an automated BPM test bench. Stretched wire method [8] with wire of different diameters 0.5 mm and 1 mm is implemented for sensitivity and mapping measurements to mimic the actual beam. Automated test bench for BPM have been considered an alternative to manual measurements (position mapping, sensitivity etc.) due to consumption of huge amount of time resource. In comparison to a Libera DAQ based automated test bench [7], the approach presented in this paper is cost effective due to usage of generally available lab equipment's. A comparison of manual measurements vs automated measurements is also been performed to evaluate the performance of automated measurements.

The paper is divided in various sections, first section provides a description of the test setup and device under test. The second section provides the transfer impedance study for both the wires and the third section presents the position sensitivity measurements. Paper is concluded with 2-D position mapping with development and implementation of automated test bench.

TEST BENCH SETUP

Figure 1 shows the automated BPM test bench setup which consists of a function generator, 2 sets of X-Y scanner motor assembly, motion controller, a DSO, Device Under Test (DUT) (BPM) and stretched wire with weights.

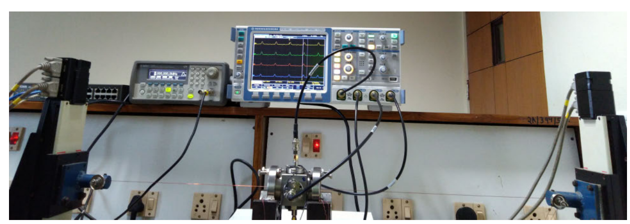

Figure 1: Automated Test bench Setup with Device Under Test (BPM).

Device Under Test

DUT in present case is a cylindrical SS pipe of length 88 mm with DN 63 flange having outer diameter of 63 mm and inner diameter of 35 mm with 4 electrodes (buttons) mounted using vacuum compatible 50 Ω SMA feed-through. Electrodes are of 6mm radius and made of Aluminium.

TRANSFER IMPEDANCE

Transfer impedance relates BPM output signal with the beam current. For measuring the Transfer Impedance of the Button BPM, the modified co-axial cable method [9] is used. In this method the total output voltage for the DUT is given as an infinite summation of the reflected and the transmitted signal converging to a definite value. Schematic setup is shown in Fig. 2. The port-1 node is fixed with the Vector Network Analyzer (VNA) and the port-2 node is varied to all the 4 electrodes to obtain respective transmission coefficients.

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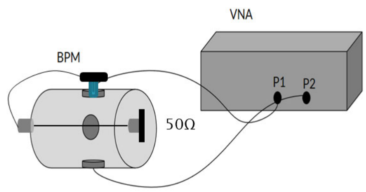

Figure 2: Setup for Transfer Impedance Measurement.

The variation of transfer impedance with frequency is shown in Fig. 3. The difference between electrodes impedance for a specific wire could be due to misalignment of geometric axis with sag in the wire. Another reason is the bad coupling between the input part and the button electrodes.

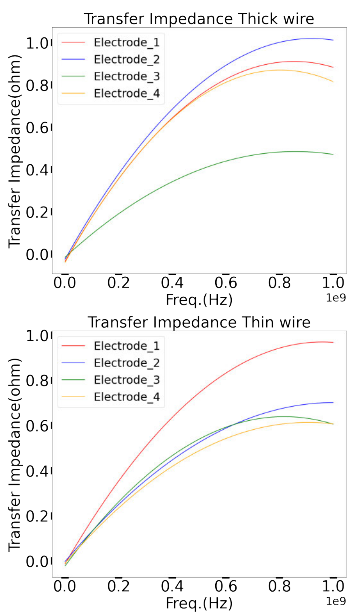

Figure 3: Transfer Impedance vs Freq. (Hz).

POSITION SENSITIVITY

Position Sensitivity is measured using stretched wire method [8] by passing current pulses through the copper wire of different diameters (0.5 mm and 1 mm). Best possible pulse characteristics out of function generator with 5 V pulses of 5 MHz rate with 20 ns pulse width are employed to the wire terminated in 50 Ω to mimick electron beam pulses. This is rough approximation of IUAC-FEL [10]. S_x and S_y can be calculated as slopes to normalized difference (Eqs. (1) and (2)) vs distance (mm) curves. The span of our distance (mm) in present case is from -8 mm to +8 mm for thin wire where as -4 mm to +4 mm for thick wire to consider only linear region as at large displacements, non-linearity arises due to the fact that position sensitivity is no longer a constant but start depending on position.

$$(\delta V/\sum V)_x = (V_R - VL)/(V_R + VL) \qquad (1)$$

$$(\delta V/\sum V)_y = (V_U - VD)/(V_U + VD) \qquad (2)$$

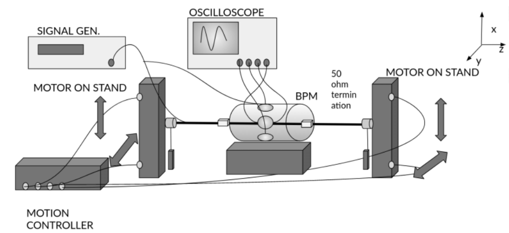

Figure 4: Setup for Position Sensitivity Measurement.

Signal is fed by signal generator and acquisition is done by DSO. The wire is moved using Motion controller which controls the stepper motor mounted on stands. The setup for position sensitivity measurement is shown in Fig. 4 and curves along X and Y axis for both wires are shown in Fig. 5. The normalized difference is not zero at the center indicating

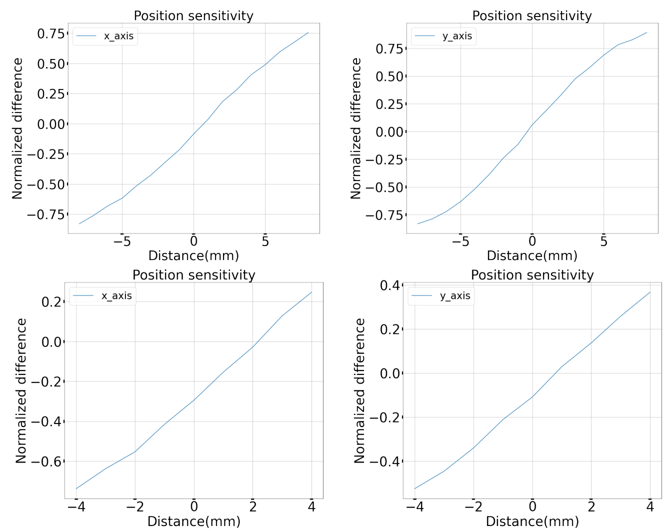

Figure 5: Sensitivity curves for X and Y axis for button BPM for thin wire (up) and thick wire (bottom).

there is a misalignment of buttons. The calculated values of S_x and S_y by calculating slope by fitting sensitivity curves with straight line are listed in Table 1.

Table 1: S_x and S_y Values (mm^{-1})

Wire	S_x	S_y
Thin	0.1176	0.1219
Thick	0.1211	0.1124

POSITION MAPPING

Position mapping is implemented using the same stretched wire method, by moving the wire in the span of -8 mm to +8 mm with various step size. Position Sensitivity values are used reciprocate the 2-D position map for the whole BPM by Eqs. (3) and (4) where S_x and S_y are sensitivity values calculated in previous section. But before making a position map, the wire is aligned to the geometrical center of the

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BPM. This is done using the cross-wire method.

$$x = (1/S_x)(\delta V/\sum V)_x \quad (3)$$

$$y = (1/S_y)(\delta V/\sum V)_y \quad (4)$$

Measurements time increases with reduction in resolution or step-size. For step size = 1mm, the total readings counted to be 289 which amount to 5hr to measurement time.

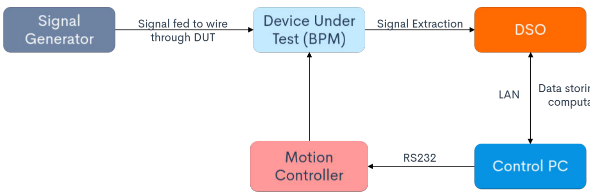

Figure 6: Block Diagram of Automated Test Setup.

Therefore, an approach to automated measurements is taken by developing a automated BPM test bench for 2-D position mapping. The setup of measurement is similar to Fig.4.

Remote Interfacing was done over RS232 towards the NSC-G series motion controller by Newmark for controlling the motion of wire and over LAN for DSO for the acquisition of signal from electrodes. The motion controller is equipped with stepper motors having a resolution of 3.10559×10^{-5} mm per encoder count (1 mm = 32200 encoder counts) that move in x,y directions. Open source Gclib python library is used to control the motion controller and vxi11 is used to interface with DSO for signal extraction and storage. A block diagram of how the automation of system is carried out is given in Fig. 6 . Comparison between automated and manual measurement is shown in Fig. 7 and error comparison in Table 2. By comparison of the error, it can be observed that reduction in human error is done by following automated measurements using test bench. Due to less error using automation all further mapping is performed using automation.

Table 2: Absolute Average Measurement Error (mm) Calculated For Automated and Manual Measurements

Error	**X (mm)**	**Y (mm)**
Manual	0.81	0.64
Automated	0.73	0.43

2-D position maps for both wires with various step-size is shown in Figs. 8 and 9. The measured position corresponds accurately with the real position for small distances but at large distances deviation becomes large. This is due to the effect of non-linearity in S_x and S_y, which was assumed to be a constant and independent of the position. Moreover, due to the curvature of the BPM a curved map is obtained and misalignment of button, offset in wire along axis can also be the reason for distortion. Error for various step size and both the wires has been calculated and shown in Table 3.

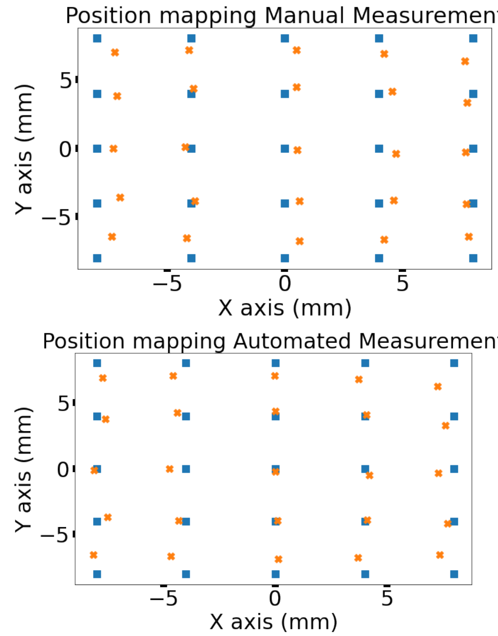

Figure 7: 2-D position mapping of manual (top) and automated (bottom) measurement with 4 mm step size where cross (orange) represents measured position and square (blue) is actual position.

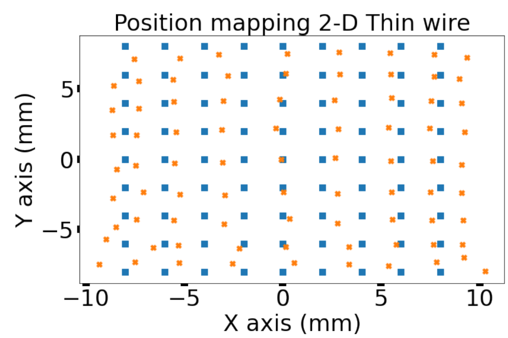

Figure 8: 2-D position map for Thin wire with step-size of 2 mm where cross(orange) represents measured position and square(blue) is actual position.

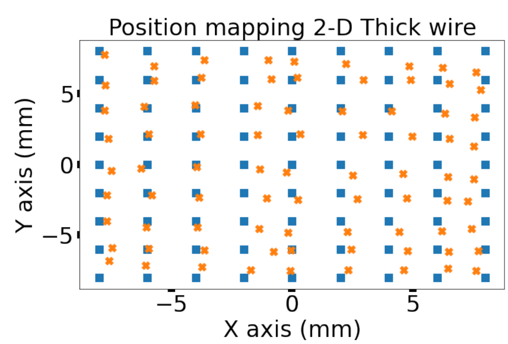

Figure 9: 2-D position map for Thick wire with step-size of 2 mm where cross (orange) represents measured position and square (blue) is actual position.

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Table 3: Absolute Average Measurement Error (mm) Calculated for 2-D Position Mapping of Thin and Thick Wires

Error	Thick (x,y)	Thin (x,y)
2mm	(0.45,0.62)	(0.38,0.69)

CONCLUSION

The aim of the paper is to present a characterization study of a button BPM, with the measurement of transfer impedance, position sensitivity and development of a cost-effective automated BPM test bench. Misalignment of button is observed in position sensitivity curves due to non-zero normalized difference at origin. Development and testing of automated test bench results in significant reduction in measurement error which led to adoption of test bench for further 2-D position mapping. Open source libraries and software is implemented to control the stepper motors and DSO. After an easy process of setting the measurement range, the developed BPM test bench carries out the necessary steps itself, provides and stores the results directly after processing them. Exemplary measurements of 2-D mapping of thick and thin wire with various step size have been performed with error measurements. Through automation, the results are obtained quickly and precisely. Further developments will focus on enhancing the user experience even more with building interactive GUI and more precise pulses for realistic beams.

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