

STANDARD BUTTON BPMs FOR PETRA IV

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Abstract

A new diffraction limited light source PETRA IV (DESY, Germany) with ultra-low emittance is currently being designed as an upgrade of the 3rd generation light source PETRA III. For transverse beam position measurements, beam position monitors (BPMs) will be used as an essential part of the beam diagnostic system. There will be a total of about 800 BPMs distributed along the 2.3 km storage ring. The inner diameter of the standard beam pipe, and therefore of most of the BPM chambers, will be 20 mm.

The primary purpose of the systems is to provide high-resolution measurements of the transverse position of the electron beam. By specification, the impact of the mechanical tolerances on the position readings should be below $150\ \mu\text{m}$ which is essential for the commissioning of the machine. To achieve this goal, the dependence of the accuracy of the beam position measurement on the tolerances of each manufactured part of the BPM was studied. This paper summarizes development and optimization of each part of the BPM by using EM simulations performed with CST Studio Suite.

INTRODUCTION

Similar to the PETRA III synchrotron ring, the standard button pickup electrodes BPMs will be used in PETRA IV. BPMs are the largest part of the PETRA IV diagnostic system. For the commissioning of the machine, an absolute beam position measurements accuracy of $\leq 500\ \mu\text{m}$ is required [1]. The following three main factors contributes to that number:

- manufacturing tolerances;
- tolerances from electronic part;
- tolerances from the BPMs alignment.

This article considers only the contribution of manufacturing tolerances to the accuracy of BPM measurement, which should not exceed the defined $150\ \mu\text{m}$.

DESIGN ASPECTS

During BPM development, the following goals were pursued:

- to have as few parts as possible to reduce the influence of the manufacturing tolerances on the beam position reading;
- compactness;
- ease of manufacture and assembly;
- reliability and ease of troubleshooting during operation.

Various shapes of the feedthroughs and buttons were considered, calculated, and simulated. The version of the BPM presented in this paper is currently being considered as the main candidate.

Assembly Overview

The final assembly of the BPM is shown in Fig. 1. Each BPM contains the main body and four feedthroughs with buttons. Before feedthroughs are inserted and welded to the main body, their electrical characteristics will thoroughly be measured to find pairs with equal characteristics. The overall dimensions of the BPM body are $72 \times 72 \times 31\ \text{mm}$. Additional cable holder will be attached to each BPM.

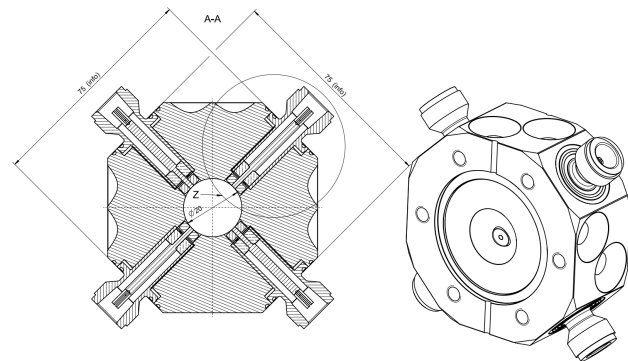


Figure 1: BPM assembly overview.

Feedthroughs with Buttons

Each feedthrough consists of the following parts:

- the body of the feedthrough with inner diameter of $7.5\ \text{mm}$ and attached to it N-type connector;
- the flat button without any skirt around it with a diameter of $7\ \text{mm}$ and a thickness of $3\ \text{mm}$ made of alloy C-22. The gap between the button and the insulator is $1\ \text{mm}$. When feedthrough is inserted into the main body, the gap between the button and the surrounding main body is $0.25\ \text{mm}$;
- the central pin with diameters of $3.04\ \text{mm}$ to match $50\ \text{Ohm}$ impedance. From one side it is connected to the button by laser welding and on the other, it forms a N-type female connector. The material is the same as that of the button - alloy C-22;
- the $5\ \text{mm}$ thick insulator;
- three channels on the outer surface of the assembled feedthrough to help vacuum pumping (see Fig. 2).

ELECTROMAGNETIC SIMULATION

Extensive electromagnetic simulations have been performed by the CST Studio Suite [2] to study how the manufacturing tolerances affect the signal and therefore the beam position measurements. The model from the CST Studio Suite used for the tolerance study is shown in Fig. 3. The beam parameters of the PETRA IV timing mode specified in Table 1 were used for all the simulations.

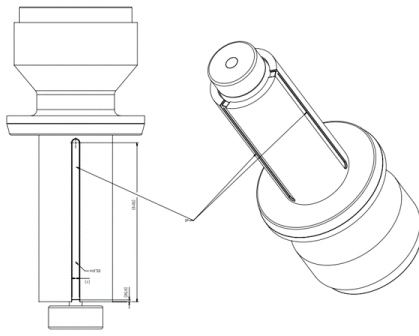


Figure 2: Three channels to help vacuum pumping.

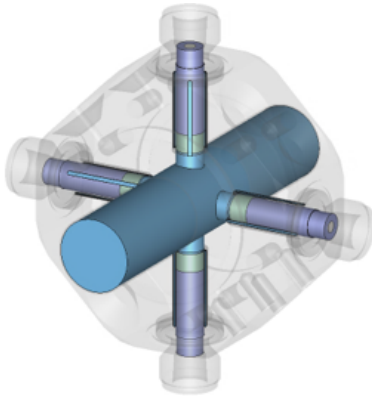


Figure 3: A BPM model from CST Studio Suite.

Table 1: PETRA IV Electron Beam Parameters [1] Used for Simulation and Analysis

Energy [GeV]	6
Bunch charge [nC]	7.68
Bunch length [mm]	13.2 (44 ps)
Bunch spacing [ns]	4

The simulations were performed for a single bunch with a Wakefield solver. Frequency range was set to the maximum of 20 GHz. At the end of each feedthrough, the voltage monitors were placed. Initial beam position was set to the center of the beam pipe.

To find out how tolerances affect the beam position reading, the dimensions and position of the one feedthrough were left variable (see Fig. 4) while the other three were fixed at nominal dimensions. Only one dimension of the variable feedthrough was changed at a time within the manufacturing tolerance of $\pm 50 \mu\text{m}$. The beam position was then calculated based on the difference of voltages obtained from the voltage monitors.

Output Signals; Beam Position Reading

A typical signal induced by a single bunch from a button pickup obtained from the voltage monitor in the time and frequency domains is shown in Fig. 5. Resonances at higher frequencies are not observed in simulation. This reflects good design decisions and results in a smooth and

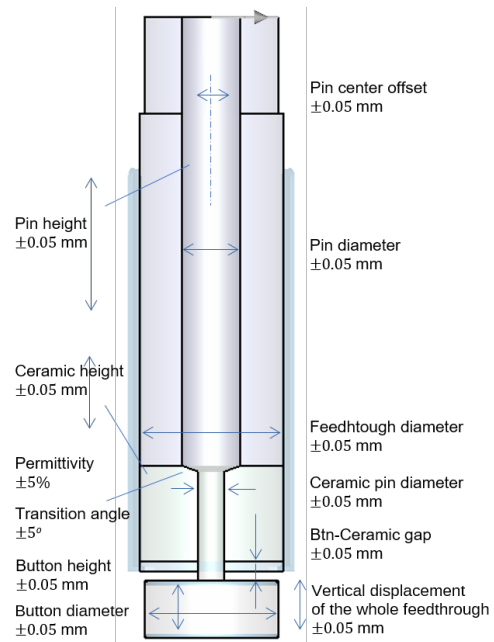


Figure 4: Feedthrough dimensions along with manufacturing tolerances that were used to set up the simulations for tolerance study.

fast (within $\approx 1.5 \text{ ns}$) decaying signal which will not interfere with the signal induced by the following bunch in 4 ns.

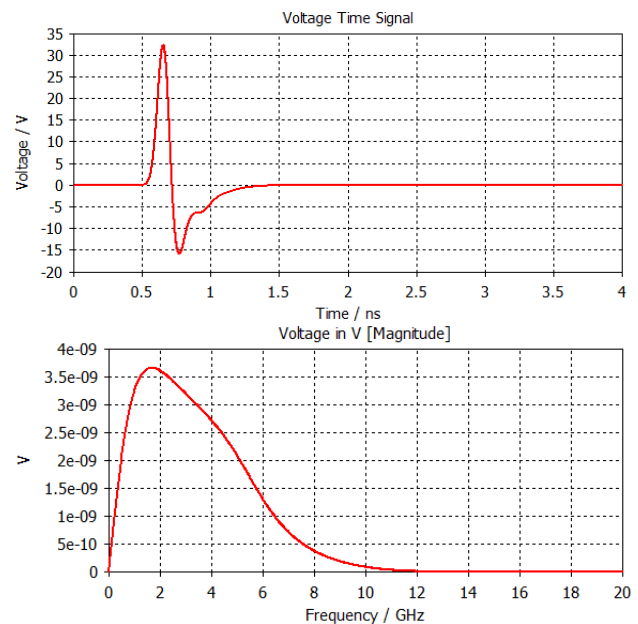


Figure 5: Signal from the feedthroughs in the time and frequency domains.

To determine beam position, the difference-over-sum (Δ/Σ) method was used

$$\begin{aligned} \text{Horizontal} &= K_x \frac{(V1 + V2) - (V3 + V4)}{V1 + V4 + V2 + V3} \\ \text{Vertical} &= K_y \frac{(V1 + V4) - (V2 + V3)}{V1 + V4 + V2 + V3}, \end{aligned} \quad (1)$$

where K_x and K_y are monitor constants, and V_N is the voltage amplitude obtained from the voltage monitor of the corresponding N_{th} feedthrough (see Fig. 6) at the frequency of 500 MHz which is the read-out frequency of the electronics for PETRA IV.

The monitor constants can be derived from the formula in Eq. (1) with a known small (on a μm scale) beam displacement from its central position.

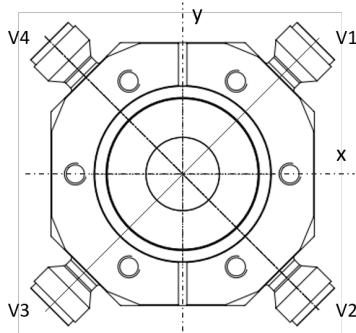


Figure 6: Alignment of BPM and voltage monitors to calculate the horizontal and vertical position of the beam by Eq. (1).

Tolerance Study Results

The beam position reading as a dependent value on the tolerances is shown in Fig. 7. The largest effects on the beam position reading are the vertical displacement of the feedthrough when the button goes inward/outward of the beam pipe and the deviation of the inner diameter of the feedthrough.

The effect of all tolerances on the beam position reading can be found as

$$S = \sqrt{\sum_{t=1}^n x_t^2} = 0.124 \text{ mm}, \quad (2)$$

where x_t is a beam position reading at each tolerance value t applied to the nominal dimensions.

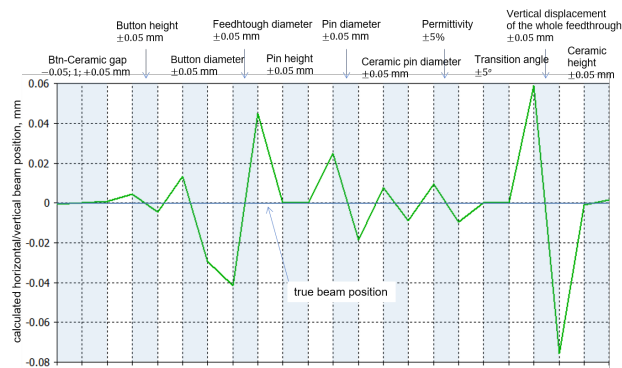


Figure 7: The dependence of the beam position reading on the manufacturing tolerances of the feedthrough with button.

SUMMARY

An extensive study on the influence of the manufacturing tolerances on beam position reading has been performed. It was found that the present manufacturing tolerances will theoretically reduce BPM resolution to $124 \mu\text{m}$ which satisfies the required $150 \mu\text{m}$.

Further tolerance study of the read-out electronics and alignment process of the BPM for PETRA IV is an ongoing task.

ACKNOWLEDGEMENTS

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- [2] Computer Simulation Technology, <http://www.cst.com>