STUDY OF THE ELECTRICAL CENTER OF A RESONANT CAVITY BEAM POSITION MONITOR (RF-BPM) AND ITS INTEGRATION WITH THE MAIN BEAM QUADRUPOLE FOR ALIGNMENT PURPOSES

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Abstract

To achieve the luminosity goals in a next generation linear collider, acceleration and preservation of ultra-low emittance particle beams is mission critical and requires a precise alignment between the main accelerator components. PACMAN is an innovative doctoral training program, hosted by CERN, with the goal of developing high accuracy metrology and alignment methods and tools to integrate those components in a standalone, automatic test bench. The method will be validated on CLIC components, a proposed Compact Linear Collider currently studied at CERN. The alignment between the electrical center of the Beam Position Monitor (BPM) and the magnetic center of the associated Main Beam Quadrupole (MBQ) is of particular importance to minimize the emittance blow-up, and therefore in the focus of the PACMAN project. On a first stage the two components have been independently characterized on separated test benches by stretched and vibrating wire techniques. Preliminary conclusions are presented in this paper, with emphasis on the characterization of the electrical center of the BPM.

THE PACMAN PROJECT AT CERN

The PACMAN [1] project is an Innovative Training Network (ITN), hosted by CERN and funded by the European Marie Skłodowska-Curie action. It is a multi-disciplinary network, including 10 Early Stage Researchers (ESRs), academic and industrial partners. The purpose is to develop innovative alignment strategies and technologies for the future generation of particle accelerators. The technical development is associated to the CLIC and therefore the tests are associated to its components.

ALIGNMENT STRATEGY

For CLIC, it is required that the main accelerator components, such as Beam Position Monitors (BPM), Accelerating Structures (AS) and Main Beam Quadrupoles (MBQ), are aligned with very tight tolerances, in the order of 14 µm for the main linac. It is foreseen that the modules are pre-aligned on a common girder of 2 m of length, with the final beam-based active alignment taking place in the CLIC tunnel to optimize the beam trajectory. In this scenario, PACMAN is proposing a wire-based pre-alignment methodology. In order to validate its feasibility, an assembly between the cavity BPM and MBQ was developed: the Final PACMAN Alignment Bench (FPAB - Fig. 1). It has the components mechanically centered on a common support. By means of a stretched-wire the electrical center of the BPM and the magnetic center of the MBQ are located. The wire is made out of copper-beryllium, with 0.1 mm diameter, it is tensioned by a stepper motor and, fixed on two specular end points, passes through the MBQ-BPM assembly. Two lateral 2-DOF stages are used to move the wire with respect to the devices [2].

A GENERAL OVERVIEW OF THE PACMAN MODULE

The following steps were taken to develop the MBQ-BPM pre-aligned system and fiducialize the electromagnetic offset.

1. The single components are separately characterized and calibrated: the MBQ by means of vibrating wire techniques [3], the BPM using stretched-wire methods;
2. The BPM and the MBQ are mechanically aligned on a common axis;
3. Initially, the assembly is studied in a laboratory environment and then moved on the platform of a Coordinate Measuring Machine (CMM) [1], in a temperature controlled and clean room;
4. The magnetic center of the MBQ and the electrical center of the BPM are located, each with the respective measurement method;
5. Through non-contact sensors the fiducialization process was performed. Two wire positions are recorded, one in point of the MBQ magnetic center, the other in the BPM electrical center.
6. Beyond the non-contact CMM probes, also micro-triangulation and Frequency Scanning Interferometry (FSI) technologies are employed for the fiducialization.

With the knowledge of the offset calibration constant between the magnetic center of the quadrupole and the electrical center of the position cavity BPM, the particle beam position measurements will be referenced to the quadrupole magnetic center and allow to detect beam misalignments with respect to this point. Moreover, as the beam drifts off-center, an active nanopositioning system will automatically operate, correcting the quadrupole position and recentering the beam to its magnetic center.

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[1] Maximum uncertainty: $0.3\mu m + L/1000$, where L is the length of the device under test expressed in [mm]

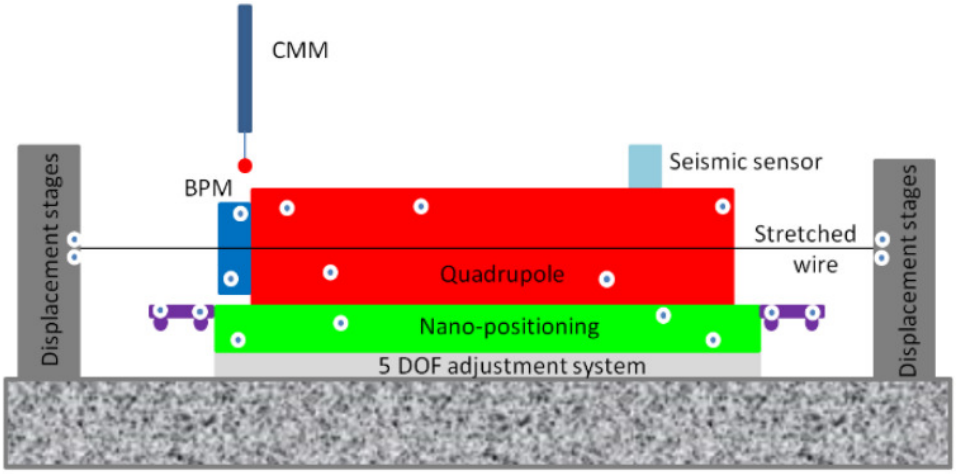


Figure 1: Technical assembly of the PACMAN bench (Source: H. Mainaud Durand et al. in *Proc. IPAC'16*, pp. 58–61).

THE CLIC/CTF3 CAVITY BPM

The cavity BPM used for CLIC and for the CLIC Test Facility (CTF3) is composed of both a dipole and a monopole mode cavity and resonating at 15 GHz (3D design in Fig. 2) [4]. As of the excellent resolution proprieties, anticipated to be 50 nm in space and 50 ns in time, this BPM meets the CLIC requirements, allowing the detection of sub-micrometetric beam drifts from the center of the focus quadrupole. It is therefore also in the focus of the PACMAN project in order to realize the first prototype alignment bench (FPAB). The position cavity is operating with the dipole mode, through monopole mode discrimination via the slot-coupled lateral waveguides. The picked-up signal is null when the beam is at the center of the cavity, and is proportional to its position when offset. This cavity was studied in a laboratory environment through stretched-wire technologies. Its mechanical ability to resolve nanometric wire displacements and resolution limit were demonstrated to be up to 3 nm in laboratory through a static measurement process [5].

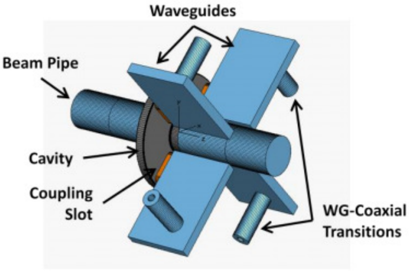


Figure 2: 3D view of the CLIC cavity BPM.

BPM Measurements Setup

The wire is used as a passive probe, coupling the electric field. The cavity is excited by the lateral slot coupled waveguides, the same are also used for picking up the signal resulting from the excitation induced and the wire perturbation. Scattering parameters measurements take place though a Vector Network Analyzer (VNA). A schematic view of the setup is shown in Fig. 3.

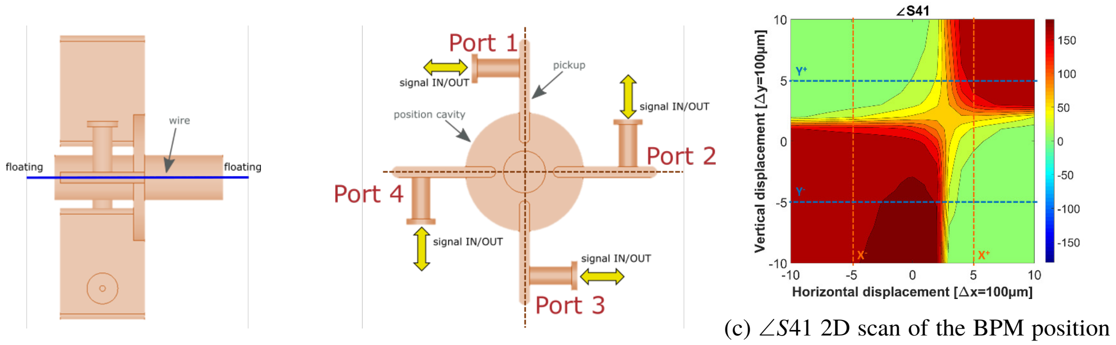
As the wire is stretched through the cavity and moves in the transverse plane, it couples the electric field. It was observed that the most sensitive scattering parameters to locate the electrical center are those between adjacent ports in phase argument, e.g. $\angle S41$, as it returns a linear behaviour around the electrical center, with an associated 180° phase transition (see Fig. 3c).

BPM MEASUREMENTS ON THE FPAB

The final PACMAN bench was assembled and shown in Fig. 4. The fiducialization process was performed on the CMM platform. The CMM is able to detect the wire position through a non-contact sensor (Leitz Precitec). Also the micro-triangulation system was in operation as cross-check fiducialization method [6].

BPM-MBQ Offset

To determine the two coordinates of the electrical center on the BPM transverse plane, 1-DOF was fixed and a position sweep was performed along the free direction. This was repeated on two specular and parallel lines separately along the horizontal and the vertical axis (refer to Fig. 3c). Preliminary BPM measurements are presented in Fig. 5, through the analysis of the phase argument between adjacent ports. The wire is moved by the lateral translation stages with an incremental step size of 50 µm. The plotted position is that one returned by feedback system of the translation stages. At each wire step, the VNA, which is plugged to the lateral BPM pickups, performs 4-port scattering parameters measurements.The cross-sections, between the two specular plots in phase, identify the transverse coordinate in which the electrical center changes its polarity, and therefore the electrical center location.



(a) Front view.

(b) Side view.

(c) ∠$S41$ 2D scan of the BPM position cavity

Figure 3: Measurement setup and scattering parameter scan.

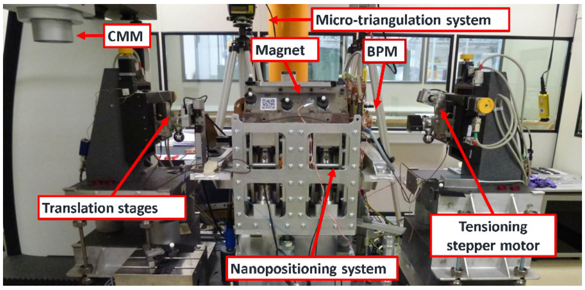
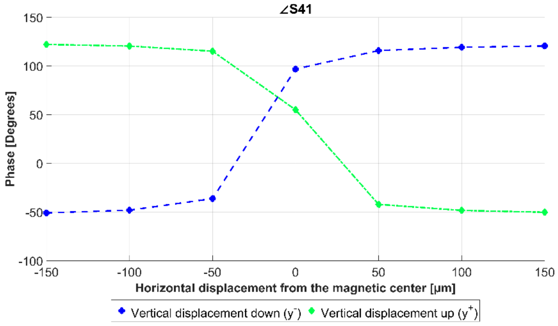
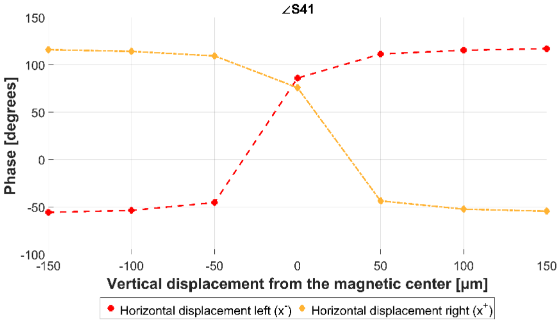


Figure 4: CMM assembly.



(a) Horizontal coordinate.



(b) Vertical coordinate.

Figure 5: Horizontal and vertical coordinates of the electrical center

CONCLUSIONS

The PACMAN study is at a final stage. First measurements of the electromagnetic offset between the quadrupole and BPM were performed and here presented, showing a misalignment better than 12.5 µm on the horizontal axis and 5 µm on the vertical one. Further measurements are on-going to fiducialize with a higher precision the electromagnetic offset. This study represents a milestone in the alignment strategy studies for the future generation of particle accelerators, allowing, through a precise micrometric mechanical alignment and the following fiducialization, a valuable increasing of performances and efficiency.

ACKNOWLEDGEMENTS

Special thanks are due to F. N. Morel, D. Glaude, C. Petrone, P. Naisson for the engagement they demonstrated on our project, and particularly for the design, the metrology support, the magnetic measurements and the FPAB assembly.

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