ELECTROMAGNETIC SIMULATIONS OF AN EMBEDDED BPM IN COLLIMATOR JAWS

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Abstract

Next generation LHC collimators will be equipped with button beam position monitors (BPMs) embedded into the collimator jaws. Such a solution will improve the accuracy of the jaw alignment with respect to the beam and reduce the beam time necessary for the collimator setup. This paper describes results of electromagnetic simulations of the jaw BPMs performed with the CST Particle Studio, aimed at characterization of the BPMs as well as the simulation software itself. The results are compared to the measurements obtained with beam on a prototype system installed in the CERN SPS.

INTRODUCTION

Photographs of the first LHC collimator prototype equipped with the embedded BPMs, so called "Demonstrator", are shown in Fig. 1 [1]. Currently, it exists as a unique unit and is installed in the SPS ring. More collimator types with BPMs are being designed, to be produced and installed in the LHC [2]. Various jaw inserts, such as Cu-diamond, Al-diamond, ceramics, metal tiles, are being considered to achieve the desired collimation performance with 362 MJ stored beam energy at 7 TeV and over 3×10^{14} protons per beam. Details on the BPM design, laboratory tests and first beam measurements can be found in [3].

The BPM pickups are positioned at both ends of each collimator jaw. Each jaw has independent upstream and downstream motors for positioning at an arbitrary angle with respect to the beam.

In the presented simulations the particle beam was modelled by a single bunch of 1.7×10^{-8} C, corresponding to the nominal LHC intensity of 1.1×10^{11} charges. The bunch has the speed of light and a longitudinal Gaussian charge distribution with the standard deviation σ used as a simulation parameter.

MODELING AND MESHING

The collimator "Demonstrator" model, shown in Fig. 2, was built and simulated in the CST Particle Studio v. 2010 environment. Each jaw consisted of a copper block (resistivity $\rho = 16.8$ nΩ·m), with height of 80 mm and length of 1194 mm. Additional 50 mm homogeneous extrusions were added at both ends to simulate a smooth transition to the beam pipe. Graphite ("electrographite R4550", $\rho = 13$ μΩ·m) was used as insert material on the jaw surfaces facing the beam. The four stainless steel (316L) pick-up buttons of 10.3 mm diameter, shown in Fig. 3, were placed at the jaw extremities at copper level, i.e. 10 mm below the jaw insert graphite surface [3].

A special meshing scheme was developed to optimize the simulation time and achieve good accuracy of the output port signals using a regular desktop PC. The BPM pick-ups, small with respect to the whole model, were manually meshed with locally increased mesh cell density, as shown in Fig. 3. Each collimator model required about 6 million mesh cells. The simulations were performed with 10 mesh lines per wavelength, a lower mesh limit of 15, a mesh line ratio of 15 and an equilibrium mesh ratio of 1.19.

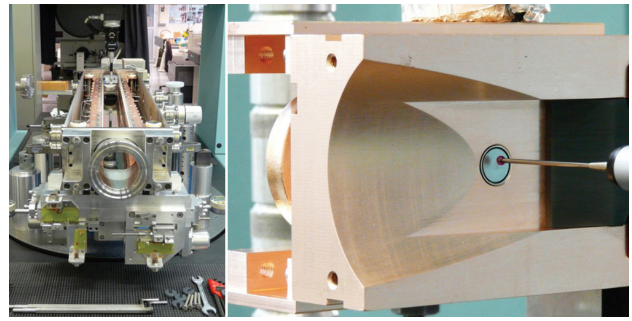

Figure 1: Collimator "Demonstrator" with its BPM.

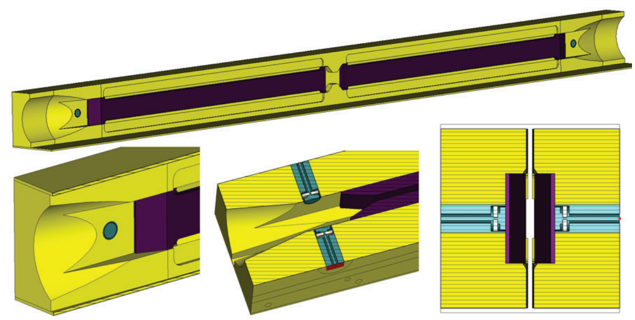

Figure 2: Cross-sections of the collimator "Demonstrator".

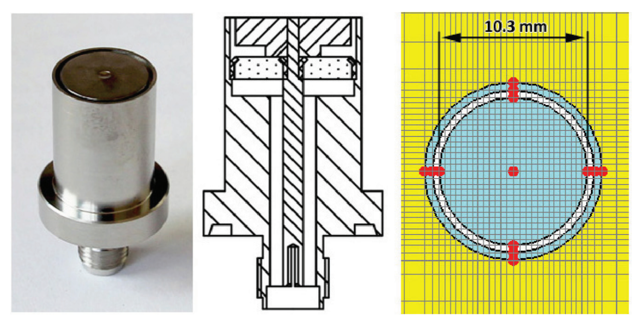

Figure 3: Photograph and a meshed model of the ∅ 10 mm stainless steel button BPM.

SIMULATION RESULTS

As depicted in Fig. 4, the four collimator pickup ports are denoted as A, B (upstream right and left) and C, D (downstream right and left). With the coordinate system origin on the symmetry axes of the collimator jaws (hereafter referred to as "center"), the beam position is denoted as x_{beam} and y_{beam}. Distances between the jaws and buttons are denoted as d and b respectively, with $b = d + 20$ mm.

Figure 5 shows the simulated transverse electrical (E) fields between ports A and B for centred (left) and offset (right) beams. Longitudinal E-fields for centred beams are shown in Fig. 6, for three bunch lengths. The presented results were obtained within 90 minutes per case with a desktop PC running Win7 x64 operating system, Intel 3.16 Core2 Duo CPU and 8GB of RAM memory.

The sensitivity of the embedded BPM signals for simulated beam position was studied by performing beam position sweeps in both horizontal and vertical planes. Such sweeps were performed for several jaw distances and bunch lengths. All simulated beam positions were normalized to the button distance b, rather than to the jaw distance d.

Figure 7 shows the simulation conditions for the beam displacement along the x axis ("horizontal sweep"). For each of 14 jaw distances a set of 5 beam locations on the x axis was simulated, namely x_{beam} = 0, 20, 40, 60, 80% of $d/2$, requiring 70 separate simulations. The "measured" beam position $x_{measured}$ was then calculated from the classic formula

$$x_{measured} = \frac{b}{2} \cdot \frac{V_A - V_B}{V_A + V_B}, \quad (1)$$

where V_A and V_B are signal amplitudes on ports A and B.

The linear conversion coefficient between measured and simulated beam position, referred to as "*slope*", is calculated as

$$slope = \frac{x_{measured}}{x_{beam}} = \frac{b}{2\, x_{beam}} \cdot \frac{V_A - V_B}{V_A + V_B} \quad (2)$$

This quantity defines the mapping between the actual beam position and the measured position obtained from the BPM signals. Its values, calculated from the results of the "horizontal sweep" simulation series according to (2), are plotted in Fig. 8. It can be seen that the "*slope*" coefficient value changes little with the beam position for small button distances b. For larger b, the "*slope*" increases for centred beam, while remaining fairly constant for beams close to the jaws.

For nominal operation the collimator BPMs will be used only to position the jaws symmetrically with respect to the beam, which will be indicated by equal signals from the opposing buttons. However, for measuring positions of offset beam with BPM signals the "*slope*" coefficient must be known. Its values can be obtained from a simple calibration procedure with beam. The procedure starts from positioning the jaws symmetrically with respect to the beam with a given jaw distance. Then the jaws should be moved with respect to the beam with fixed jaw distance to relate the BPM readings to the jaw displacement, precisely known from the jaw positioning system. The procedure can be repeated for different jaw distances to reproduce the plot in Fig. 8.

Figure 9 shows the comparison of the "*slope*" coefficients obtained from the simulations and beam measurements, performed during dedicated machine development time in the CERN SPS. The difference between the coefficients from the simulations and measurements is small for large jaw distances but increases when the jaws are closed. This can be explained by an error in centring the beam with Beam Loss Monitors (BLMs) during the beam measurements and other systematic errors, such as gain differences of the oscilloscope channels used for measuring beam pulse amplitudes. In addition simulation and measurement

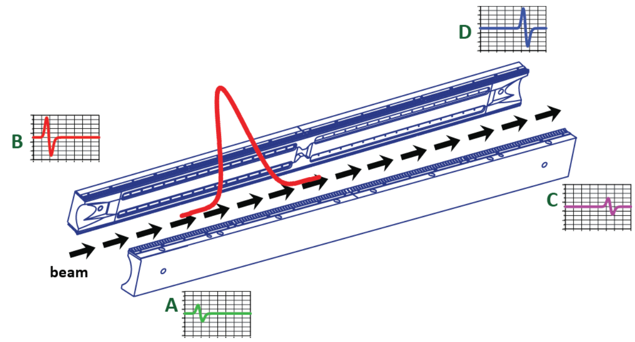

Figure 4: Collimator sketch with BPM port designation and example signals for an offset beam.

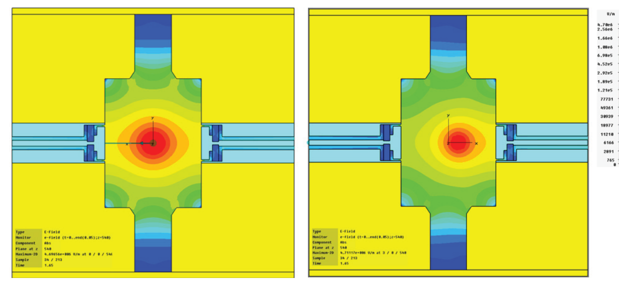
Figure 5: E-fields of a centred (left) and an offset (right) nominal bunch passing between the buttons A and B.

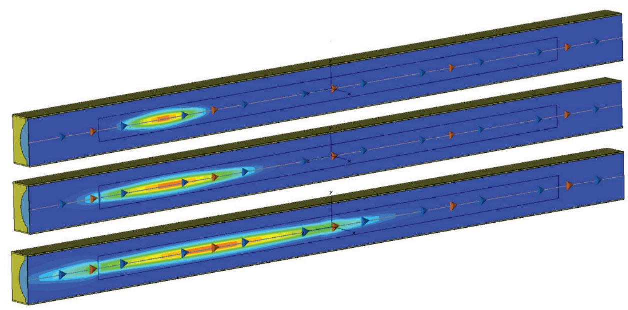
Figure 6: E-fields of a centred bunch with σ of 125, 250 and 500 ps.

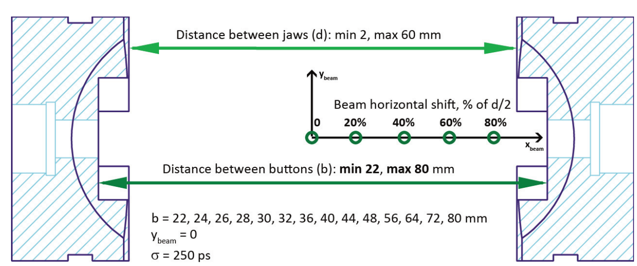

Figure 7: Schematic for the beam "horizontal sweep" simulations.

conditions were not exactly the same, for example the bunch σ in simulations was 250 ps, versus 900 ps during beam measurements.

Figure 10 shows the simulation conditions for the beam displacement along both horizontal and vertical axes (“area sweep”). For this simulation series a set of 12 beam locations was simulated for each jaw distance for a matrix of 3 horizontal and 4 vertical offsets.

Since the collimator is symmetric, only one quadrant of the “simulation coordinate system” was taken into account during simulations and beam measurements.

The green points in Fig. 10 indicate the simulated beam positions, while the red points show the corresponding values obtained from the BPM signals according to (1). The simulations were performed with b = 80 mm and the beam placed at x_{beam} = 0, 12, 24 mm and y_{beam} = 0, 2.5, 5, 7.5 mm. The corresponding changes in the “*slope*” coefficients are shown in Fig. 11. A significant dependence of the “slope” on y position is observed, which decreases with the increasing beam offset.

The observed dependence of the BPM signals on vertical beam offset can be used to position the jaws in the y direction, to have the beam on the button symmetry axis. Such position will be indicated by the signal maximum on the BPMs.

Simulations with the bunch length σ as a parameter were also performed. They showed that the “*slope*” coefficient changes no more than 2.5% for σ varying from 125 to 500 ps.

CONCLUSIONS

The CST Particle Studio package has been successfully used to simulate a beam position monitor embedded into collimator jaws. The simulation results were confirmed with corresponding beam measurements. The accuracy of this comparison should be improved in the near future, when dedicated BPM electronics becomes available.

The Particle Studio package proves to be a valuable tool for simulating beam sensors. Its use allows a significant speed up in the development process, taking into account details which would otherwise be very difficult to address in classical prototyping. Further simulations are now planned to investigate the effect of different materials on the jaw surface to the beam position measurements.

ACKNOWLEDGEMENTS

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[2] LHC design report, Collimation chapter, CERN, 2001.

[3] C. Boccard et al., "Embedded collimator beam position monitors", this conference.

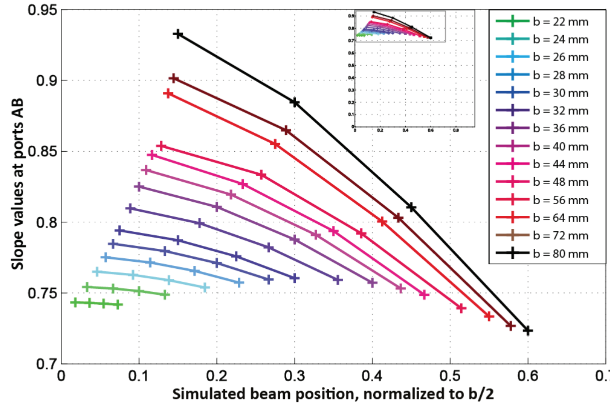

Figure 8: “*Slope*” vs. normalized beam position for the “horizontal sweep” simulation series.

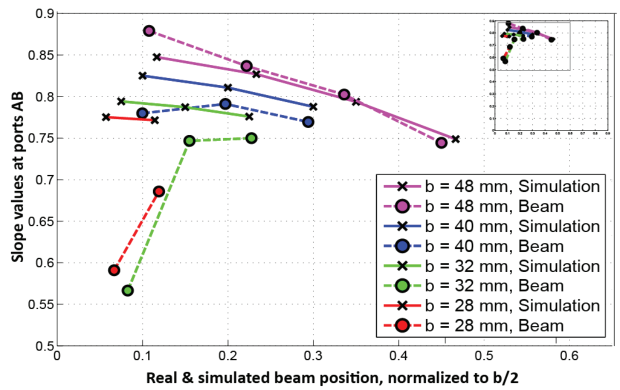

Figure 9: “*Slope*” vs. normalized beam position from simulations and beam data.

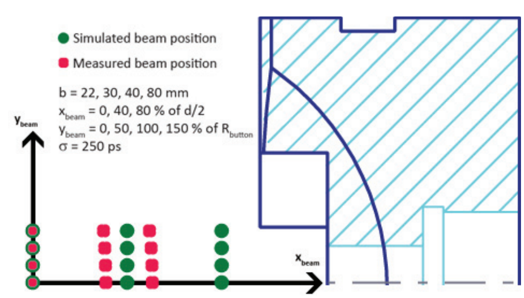

Figure 10: Schematic for the beam “area sweep” simulations.

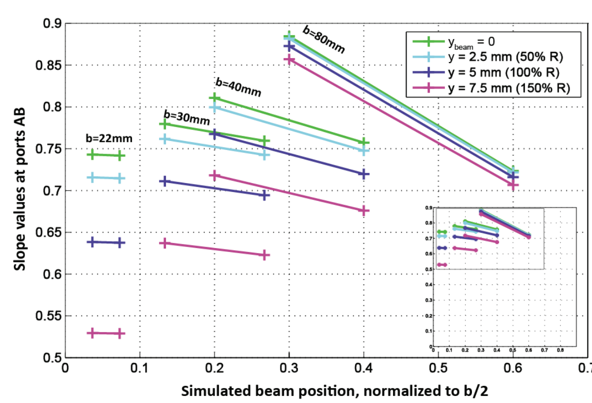

Figure 11: “*Slope*” vs. normalized beam position for beam “area sweep”.