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STRIPLINE BEAM POSITION MONITOR MODELLING AND SIMULATIONS FOR CHARGE MEASUREMENTS

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Abstract

Strip line Beam Positions Monitors (BPMs) are the main devices used for non-intercepting position measurement for the electron LINAC of ELI-NP (Extreme Light Infrastructure - Nuclear Physics). All the 29 BPMs have the same design, with the exception of the one installed in one of the dump line, which has a much larger acceptance than the others. BPMs will also be used to measure the charge of the beam, by measuring the sum of the pickups signals and calibrating it with beam charge monitors installed along the LINAC. An analytical model has been developed for the proposed BPMs. This model has been checked by means of electromagnetic simulations, in order to obtain the pickups signals at the passage of the beam and to study the effects of BPMs non-linearities, particularly on charge measurements. Details of the analytical model, results of the numerical simulations and the correction algorithm proposed for charge measurements are described in this paper.

INTRODUCTION

An S-Band photo-injector and a C-band LINAC will be used at the Compton Gamma Source in construction at the ELI (Extreme Light Infrastructure) Nuclear Physics facility in Romania. They will operate with a repetition rate of 100 Hz with macro pulses of 32 electron bunches, separated by 16 ns and with 25–250 pC nominal charge range and a temporal duration of 0.91 ps [1].

Stripline BPMs will be installed along the beam path in order to measure the position of bunches. Each BPM has an approximate length of 235 mm and is composed by four steel electrodes with an angular width of 26 deg. The distance from the beam pipe is 2 mm and they have a width of 7.7 mm, see Fig. 1. The impedance of the transmission line created by the the electrode and the pipe chamber is roughly 50 Ω. The acceptance of the BPM is 34 mm. A further BPM with an acceptance diameter of 100 mm will be installed on the dump line after the low energy interaction point. [2]. The BPMs on the beam line have been calibrated on a test bench. On the contrary the dump line BPM cannot be calibrated with the test bench used for the other BPM because of its larger dimension.

These BPMs can be also employed to measure the macro pulse charge. By this way it is possible to have a non destructive estimation of the macro pulse charge along the beam line. Four Integrating Current Transfmorers (ICT) will be installed in the critical points of the machine: after

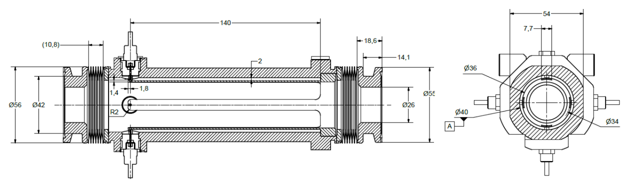

Figure 1: Main BPM CAD model for ELI-GBS. Units in mm.

the RF gun of the photo-injector, after the first six accelerating structures and before the interaction chambers. The measurement of the bunch charge is proportional to the sum of the four voltage signals from the output ports of the BPM. However, due to the non linear behaviour of the pick-up devices, a calibration curve should be applied to the readings. A full characterization of the voltage signals picked from the output port of the BPMs has been done by means of an analytical model and with full 3D simulations. Aim of this work is the development of a numerical calibration method for the charge measurement. The curve obtained with the simulation results has been compared with the experimental data and an estimation error is provided. This numerical method will be used for the calibration of the BPM for the dump line.

CHARACTERIZATION OF A STRIP LINE BPM AS A CHARGE MONITOR

The BPMs described in the previous paragraph have been characterized with an approximate analytical method and with the aid of 3D electromagnetic simulations. The results are summarized and compared with the measurements in Fig. 2. The curves in the three analysis cases (analytical model, simulations and measurements) have been evaluated over a grid of 841 points with 29 points for both horizontal and vertical axis. The points are in the span length of ±7 mm around the centre with a fixed step of 0.5 mm. The traces have been normalized to the central value of the grid.

The excitation signal used in the measurement setup is a 500 MHz sinewave. Therefore it is not a reproduction of the ELI_NP macro pulse charge and only a comparison of the normalized curves is possible. The normalization is based on the measurements in the central position, i.e. $y = x = 0$.

The agreement between the analytical model, the simulation results and the measurements is quite good. The measurements have been carried out at ALBA with the wire stretching method [3]. The details of the analytical model and of the simulation analysis are described in the next sections.

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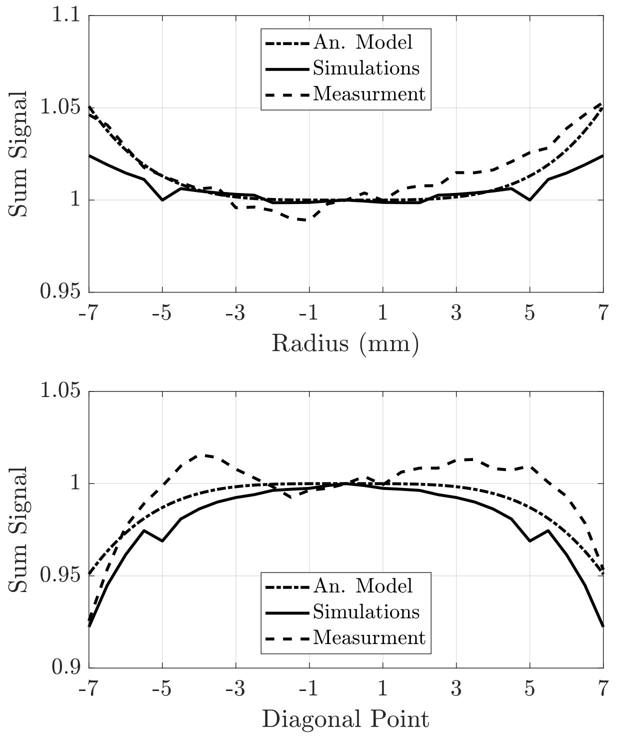

Figure 2: Sum of the voltage signals from the four ports versus the x axis (top plot) and the diagonal line, $y = x$ (bottom plot).

Analytical Model

The model is based on the assumption that an image current is induced on the stripline when the bunch (which is considered dimensionless in the transverse plane) pass though the BPM. The 2D profile of the BPM has been outlined like in Fig. 3. The external circle is the vacuum pipe. Four striplines with an azimuthal coverage of α are considered and the beam distance from the axis is given in polar coordinate, r for radius and θ for angle. The ϕ angle is the azimuthal coordinate.

The wall density current induced in the stripline is equal to [4]:

$$j_{im}(\phi) = \frac{I_{beam}}{2\pi a} \cdot \frac{a^2 - r^2}{a^2 + r^2 - 2ar\cos(\phi - \theta)} \tag{1}$$

where I_{beam} is the current of the beam and a is the distance of the stripline from the centre of beam line. The current delivered to the coaxial cable can be found with an integration over the coverage angle of the stripline:

$$I_{im} = \int_{-\alpha\backslash 2}^{\alpha\backslash 2} a \cdot j_{im}(\phi) d\phi \tag{2}$$

The voltage signal at the output port is proportional to the current therefore the calculation of the impedance of the coaxial cable is not necessary for the comparison of the normalized curves.

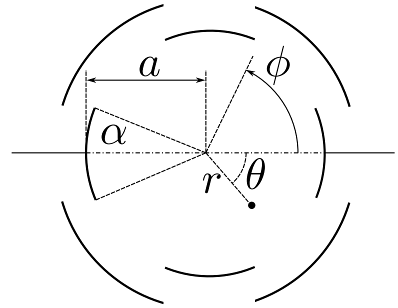

Figure 3: 2D electrostatic model for the analytical calculation of the voltage signal.

Simulations

The voltage signals at the output ports have been simulated by means of numerical simulation. The CST® particle studio code has been used, in particularly the wakefield module [5]. The beam has been simulated as a pencil beam without transverse dimension and only one packet of the macro-pulse has been considered. A perfect electric conductor (PEC) has been adopted for the striplines and the vacuum chamber. The striplines, as in the realized BPM, are terminated on a short circuit in one of the two sides and with a coaxial cable in the other one, see Fig. 4.

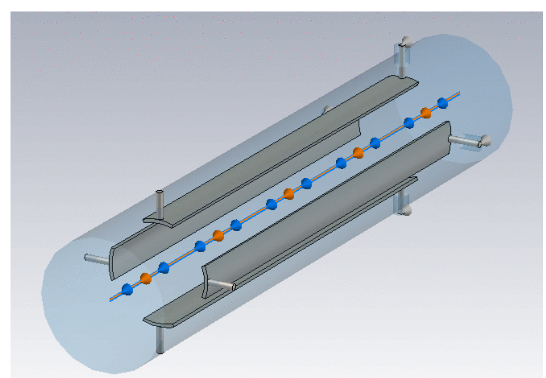

Figure 4: CAD draw for the 3D simulations.

The voltage signals are recorded during the simulation time: the maximum of the signals have been taken into account for the determination of the calibration curve. However other options, for example the integral of the curve, are possible. In order to save computational resources the simulation time is limited to 0.9 ns.

The simulation was performed with the beam in different position over an area of 7 mm × 7 mm with 0.5 mm step, for a total of 841 points. Thanks to the geometrical symmetry[1] of the device only an eight of these points should be simulated, i.e the points inside the region bounded by the curves $y = 0$, $y = x$ and $x = 7$ mm. The remaining points can be found with a simple post processing operation.

[1] In general, symmetry planes cannot be used in the simulations but for the points over the $y = 0$ line.

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POLYNOMIAL FITTING

In order to use the full BPM acceptance of ±7 mm area a correction algorithm based on a polynomial fit of the curve is here developed. The correction algorithm for the charge reading will be implemented as a high-level application within the control system. This algorithm has been enforced only for the simulation results (validated by the analytical model) and measurement readings.

A polynomial function of the x and y position of the fourth grade is adopted:

$$\begin{aligned} f(x,y) = {} & a_{00} + a_{10}x + a_{01}y + a_{20}x^2 + a_{11}xy + a_{02}xy^2 \\ & + a_{30}x^3 + a_{21}x^2y + a_{12}xy^2 + a_{03}y^3 + a_{40}x^4 \\ & + a_{31}x^3y + a_{22}x^2y^2 + a_{13}xy^3 + a_{04}y^4 \end{aligned} \tag{3}$$

therefore a total number of 15 coefficients, for both simulation and experimental case, are necessary in order to full characterize the fit equations. The obtained coefficients are listed in Table 1.

Table 1: Polynomial Fit Coefficients

Index	Coeff.	Sim.	Meas.
1	a_{00}	+1.00709	+9.88728e-01
2	a_{10}	+1.85821e-17	+1.52370e-03
3	a_{01}	+3.34763e-19	+1.29374e-03
4	a_{20}	-2.34095e-04	+5.84219e-04
5	a_{11}	-4.13974e-18	-5.49711e-04
6	a_{02}	-2.34095e-04	+7.27711e-04
7	a_{30}	-9.08888e-19	-3.05091e-05
8	a_{21}	-4.04803e-20	-1.23042e-05
9	a_{12}	+6.13145e-20	+5.54398e-05
10	a_{03}	-1.57277e-19	+1.20780e-05
11	a_{40}	+1.43842e-05	+1.03114e-05
12	a_{31}	+5.56406e-20	+2.17884e-06
13	a_{22}	-5.04218e-05	-7.80406e-05
14	a_{13}	+7.96769e-20	+4.19682e-06
15	a_{04}	+1.43842e-05	+1.18798e-05

Because of the parabolic behaviour of the non-linearities the most import coefficients are a_{20} and a_{02} which are in great agreement between simulations and experimental results. The linear terms, a_{10} and a_{01}, are not zero in the measurement fit because of the geometrical imperfection of the realized BPM and/or for the different gain level of the four channel of the electronic read-out. This dependency from the linear terms is not captured by the simulation already done. The mixed terms (a_{ij} for $i, j \neq 0$), with the exception of a_{22} coefficient, are nearly zero in the simulation results. Nevertheless, in the measurement fit, they are one or two order of magnitude lower of the a_{20} and a_{02} terms due to the linear dependence from x and y.

The polynomial surface and the points for the fit are shown in Fig. 5. The R-squared coefficient for the simulation fit is 96.95% and for the experimental data is 98.10 %.

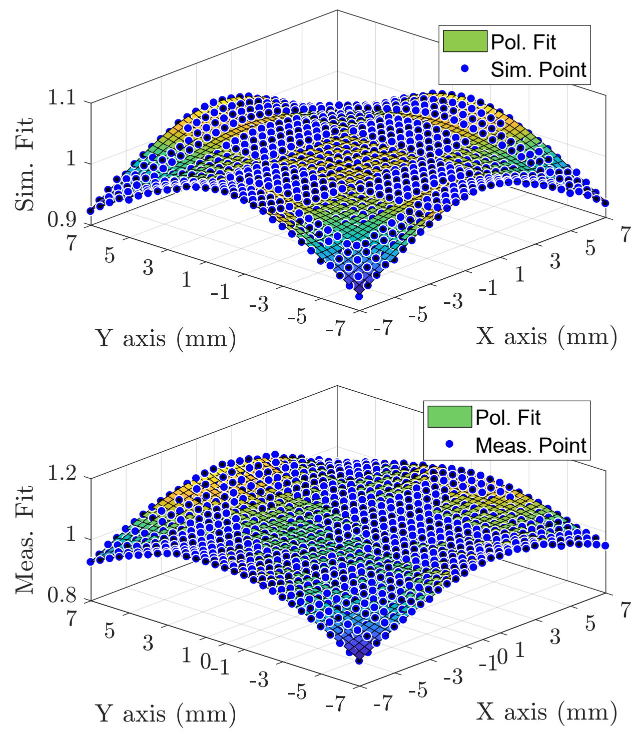

Figure 5: Polynomial fitting for the simulation results (top plot) and measurement data points (bottom plot).

The difference between the two fitted surface equations is shown in the Fig. 6. A very good agreement between the two fit equations is found. In the full acceptance area of 196 mm^2 the maximum error is equal to 5.4%.

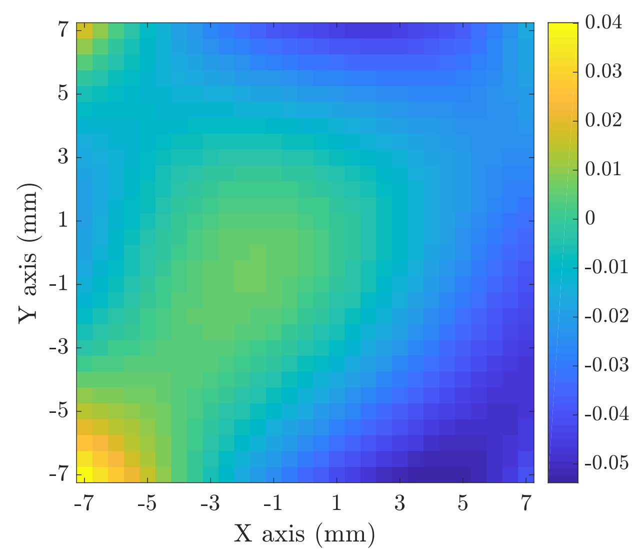

Figure 6: Difference between the two fitted surface equations.

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CONCLUSION

A correction algorithm for compensation of the non linearities in charge measurement by means of a stripline BPM has been developed. In addition to ICT measurements, it will be possible to have charge measurements along the beam line. The algorithm has been evaluated thanks to an analytical model and numerical simulations. The correction algorithm proposed here is based on a polynomial fit of the simulation results. The order of the polynomial equation is four for both the x and y coordinate. Therefore a total of 15 coefficients are necessary for the correction of the non linearities. In the full acceptance area of 196 mm^2 the maximum error between the correction algorithm based on the simulation results and the one based on the experimental data is equal to the 5.4%. This error is mainly due to the imperfect realization of the BPM and/or to the different gain level of the electronics channels. However the numerical correction method here discussed can be used for the BPM of the dump line with a reasonable error respect to the measurement characterization.

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