ANALYSIS AND CORRECTION OF GEOMETRICAL NON-LINEARITIES OF ELI-NP BPMS ON POSITION AND CURRENT MEASUREMENTS

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Abstract

The advanced source of Gamma ray photons is being built near Bucharest (Romania) by an European consortium (EurogammaS) led by INFN, as part of the ELI-NP (Extreme Light Infrastructure-Nuclear Physics). It will generate photons by Compton back-scattering in the collision between a multi-bunch electron beam, at a maximum energy of 720 MeV, and a high intensity recirculated laser pulse. An S-Band photo-injector and the following C-band Linac, which are under construction, will operate at 100Hz repetition rate with macro pulses of 32 electron bunches, separated by 16 ns and with 250 pC nominal charge. Stripline and cavity BPMs will be installed along the LINAC, in order to measure both the position and charge of the electron beam. Stripline BPM response can be considered linear within a limited area around the BPM origin. In order to use the full BPM acceptance area, without accuracy losses due to non-linearities, we plan to use correction algorithms, developed on the basis of simulations and measurements of BPMs response. In particular, suitable high-order surface polynomials will be used.

INTRODUCTION

The ELI-NP GBS (Extreme Light Infrastructure-Nuclear Physics Gamma Beam Source) is a high intensity and monochromatic gamma source under construction in Magurele (Bucharest, Romania). The photons (tunable between 1MeV and 20MeV) will be generated by Compton back-scattering at the interaction between a high quality electron beam and a high power recirculated laser. The accelerator layout is based on a S-band photo-injector followed by a C-band RF LINAC, with two interaction points at 280 MeV and 720 MeV electron energy. The LINAC will deliver a high phase space density electron beam, whose main parameters are listed in Table 1 [1].

Table 1: Main Characteristics of the GBS Electron Beam

Parameter	Value
Maximum Energy	720 MeV
Macro Pulse rep. rate	100 Hz
Number of bunches per Macro Pulse	up to 32
Bunch Spacing	16.1 ns
Bunch Length (σ_t)	0.91 ps
Bunch Charge	25 pC – 250 pC

Stripline Beam Position Monitors (BPMs) are the main devices used to measure the average transverse position of the macro pulse along the LINAC. Striplines monitors are common in conventional [2] and unconventional [3,4] high brightness LINACs. Twenty-eight stripline BPMs will be installed along the LINAC (see Fig. 1). Each BPM is composed of four stainless steel electrodes of length l=140 mm, width w=7.7 mm and thickness t=1 mm, mounted with a π/2 rotational symmetry at a distance d=2 mm from the vacuum chamber, to form a transmission line of characteristic impedance Zo=50 Ω with the beam pipe. Their angular width is ~26 degrees and the acceptance is (Ø)34 mm.

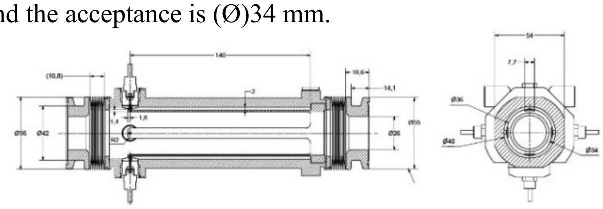

Figure 1: Main BPM model for ELI-GBS. Units in mm.

A 29th BPM with an acceptance of (Ø)100 mm will be produced and installed in the dump line, where the beam size and possible position misalignment require larger acceptance [5].

LIBERA single pass E modules, by Instrumentation Technologies, will be used as readout electronics [6].

Twenty of the 28 BPMs were produced and 16 of them were already characterized in ALBA with the stretched wire method [7]. With such characterization, we obtained the BPMs response map within ±7 mm from the center, from which the electromagnetic center and sensitivity were calculated for each BPM. From the response map we have been also capable to study non-linearities. As such, we applied correction algorithms, in order to get rid of them and to be capable to use a larger transverse area without losing position measurement accuracy.

BPM NON-LINEARITIES

In order to measure the transverse position of the beam with BPMs, we decided to use the difference over sum method. As such, it is possible to measure the horizontal (x) and vertical (y) position of the beam in the transverse plane as given by Eq. (1).

$$x_m = k_x \cdot \left(\frac{V_1 - V_3}{V_1 + V_3} - x_0\right) = k_x \cdot (x_{dos} - x_0) \qquad (1a)$$

$$y_m = k_y \cdot \left(\frac{V_2 - V_4}{V_2 + V_4} - y_0\right) = k_y \cdot (y_{dos} - y_0) \qquad (1b)$$

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In Eq. (1), V_1, V_3 are the voltages induced by the beam on the horizontal pickups (left and right in respect to the beam trajectory) and V_2, V_4 are the voltages of the vertical pickups (top and bottom). k_x and k_y (in mm) are the linear calibration constants. x_0, y_0 are the x_{dos}, y_{dos} measured at the central wire position (0,0). k_x and k_y were measured for each BPM, by using 3x3 measurements points within ±1 mm from the BPM center [7]. The average value of k_x and k_y for all the BPMs tested is 9.52 mm with a standard deviation of 0.03 mm for k_x and 0.02 mm for k_y. Such values agree with theoretical expectations in [8].

The response map of one of the BPM characterized is presented in Fig. 2, where the non-linear response of the BPM is clearly visible. This is caused by the application of the difference over sum method (linear) to the geometrical design of the BPM, which is inherently non-linear [9].

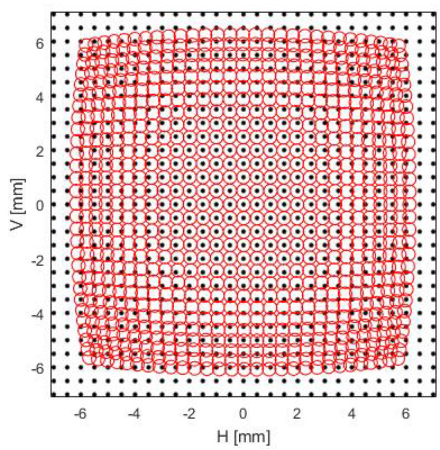

Figure 2: Maps of wire positions (black point) and measured positions (red circle) for BPM10 (see Eq. (1)).

In order to assess the difference between the reference position of the wire and the position obtained by the BPM, the definition of the absolute error is given in Eq. (2):

$$E = \sqrt{(x_w - x_m)^2 + (y_w - y_m)^2} \tag{2}$$

where x_w, y_w are the horizontal and vertical wire positions and x_m, y_m are the measured horizontal and vertical positions, respectively. The absolute error map for each wire position is shown in Fig. 3. The horizontal and vertical errors are very similar to each other, over all the area scanned (x_w- $x_m \simeq y_w$- y_m). This is typical for circular geometry BPMs. The absolute error is higher for longer distances from the BPM center and reach values up to 1.8 mm within the ±7 mm region from the center.

POLYNOMIAL CORRECTION

In order to use the full BPM acceptance area without having high accuracy errors, we decided to use correction algorithms for position and charge measurements. The correction algorithm for the position readings will be implemented in the DSP of the LIBERA modules.

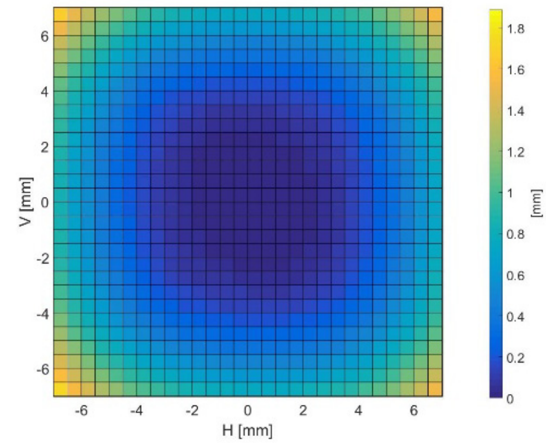

Figure 3: Absolute error between wire positions and measured positions for BPM10 (see Eq. (1)).

The function is based on bi-dimensional polynomial up to the 6th order:

$$x_{mc} = \sum_{i,j=0}^{3} K_{x_{i,j}} (x_{dos} - x_0)^i (y_{dos} - y_0)^j \tag{3a}$$

$$y_{mc} = \sum_{i,j=0}^{3} K_{y_{i,j}} (x_{dos} - x_0)^i (y_{dos} - y_0)^j \tag{3b}$$

with $K_{x0,0} = K_{y0,0} = 0$; x_{mc}, y_{mc} are the horizontal and vertical position measurements after the correction. $K_{xi,j}$ and $K_{yi,j}$ are the algorithm coefficients. They were calculated by the least squares method applied to (x_w – x_{mc}) and (y_w – y_{mc}) respectively, over the entire area.

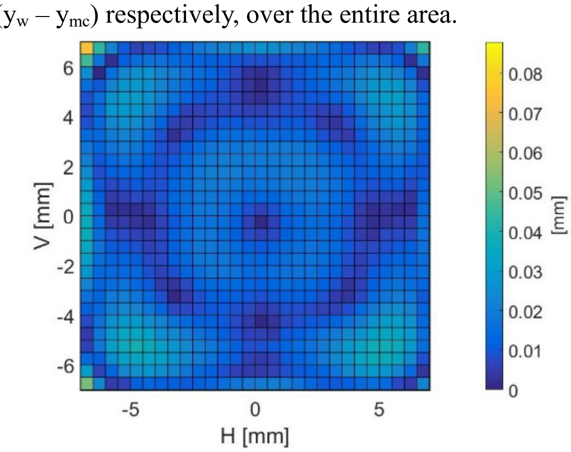

Figure 4: Absolute error between reference (wire) and measured positions after the polynomial correction for BPM10. See Eq. (3).

By applying the polynomial correction, the absolute error between the reference and measured positions is reduced, with a maximum of 0.09 mm near the top-left corner (see Fig. 4). This was verified for all the BPMs tested, for which different sets of polynomial coefficients were calculated. Figure 5 shows the mean error for each wire position for all the BPMs tested. The error map is well reproduced for each BPM, with a standard deviation below 10 µm for each wire position and with the highest mean value of 86µm.

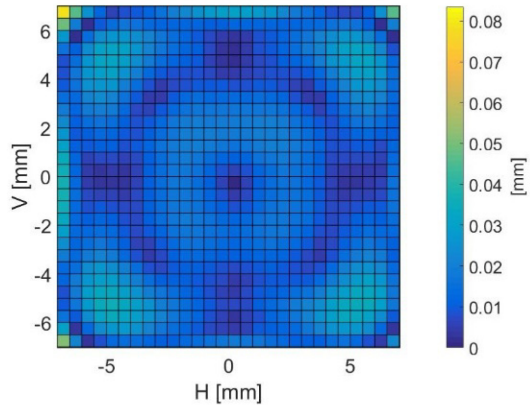

Figure 5: Mean error of all the 16 BPMs between reference (wire) and measured positions after the polynomial correction. See Eq. (3).

CHARGE MEASUREMENTS

In order to measure the charge of the macro bunches passing though the BPMs, it is possible to measure the sum of the signals coming from the four striplines. The latter will be then calibrated by using the Beam Charge monitors which will be installed along the LINAC.

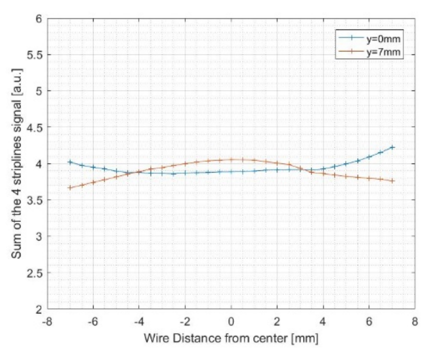

Figure 6: Sum of the 4 striplines signal against the wire horizontal position, for two vertical offsets (BPM10).

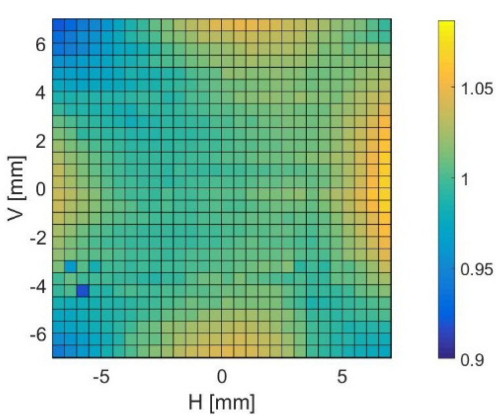

Figure 7: Maps of the sum of the 4 striplines voltages normalized to the value of the sum at the central wire position of BPM10.

For the measurements performed in ALBA, a sinewave signal of 0 dBm (with 50Ω termination) and frequency of f=499,65 MHz was used. Non-linear response of BPMs is clearly visible on the sum of the signals (see Fig. 6 and Fig. 7 for BPM10). It gives a relative accuracy error up to ±10% on charge measurements. Thus, a correction algorithm similar to the one used for the position measurements is under study and will be implemented with a high-level application within the control system.

CONCLUSIONS

BPMs non-linearities heavily affects the accuracy of the position and the charge measurements, especially for off-position beams. For ELI-NP BPMs, a beam misalignment of 7 mm from the center produces an error on the position up to 1.8 mm, while on charge measurements the relative error can be up to 10%.

Thanks to the characterization of the BPMs performed in ALBA, we developed a correction algorithm for each BPMs, based on surface polynomials up to the 6st order, which can compensate the non-linearity errors. Simulations performed with the algorithm on the position measurements shows a maximum error of 90 µm within ±7 mm from the center. A similar algorithm for charge measurements is under study and it will be developed.

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