NOVEL ELECTROSTATIC BEAM POSITION MONITORS WITH ENHANCED SENSITIVITY

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Abstract

Beam Position Monitors (BPM) measure the beam transverse position, the beam phase with respect to the radiofrequency voltage, and give an indication on beam transverse shape. Electrostatic BPMs are composed of four electrodes that transduce the associated electromagnetic field to the beam into electrical signal allowing the calculation of the beam parameters mentioned above. During commissioning and/or experiences phases that needs very low beam current; the precision of the BPM measurements is reduced due to the low sensitivity of electrostatic BPM to beam current. This paper addresses the design, the realization and the testing of a new set of electrostatic BPMs with large electrodes. It emphasizes the strong points of these BPMs in comparison with BPMs present in SPIRAL2 facility.

INTRODUCTION

The idea of developing a BPM with enhanced sensitivity arose at the qualification of SPIRAL2 BPM that shows weak received signals by the BPM electrodes at low beam currents (less than 150µA). Novel electrostatic BPM were designed taking into account mechanical constraints (space, stability) while offering better current sensitivity.

BEAM POSITION MONITORS

A BPM has four electrodes that couple to the beam through the image charge produced by the beam [1]. The BPM electrode is considered as capacitor C that is charged by the beam and discharged through a 50Ω resistor connected to ground. As for SPIRAL2 BPM [2], the electrode receives a multi-tone signal due to the beam bunched with an accelerating frequency 88.0525MHz. Only 1st and 2nd harmonic tones are taken into account in this study. A generic example of electrostatic BPM is sketched in Figure 1.

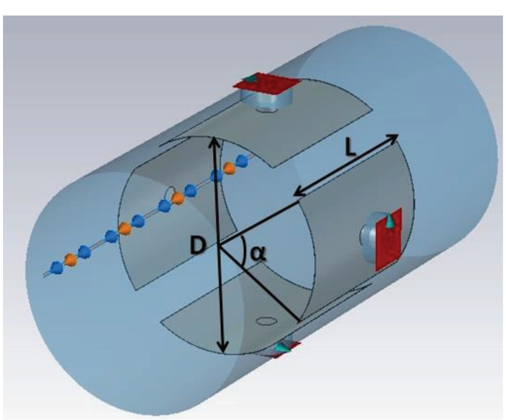

Figure 1 : Generic example of electrostatic BPM.

BPM diameter D, angular length α and length L have direct effects on BPM current and position sensitivities.

For instance, the formula for position sensitivity K_p for Gaussian beams at β=1 is:

$$K_p(dB/mm) = \frac{320}{\ln(10)} \frac{\sin(\alpha/2)}{D \cdot \alpha}$$

$$\alpha \text{ in radians and } D \text{ in mm}$$

Table 1 shows the type of proportional relation between these parameters, this guided the design of SPIRAL2 BPM and the new BPM.

Table 1: Proportional Relation Between BPM Sensitivities and Design Parameters

Parameter	Current sensitivity	Position Sensitivity
D	$1/D^2$	1/D
α	α	sin(α/2)/α
L	sin(πL.f/v)	No effect
C	1/C	No effect

v is the beam speed and f is the accelerating frequency.

As for SPIRAL2 BPM, the design of the new BPM took into account the fact that the BPM will be inserted in the vacuum pipe inside the quadrupoles which will be buried at their turn in the quadrupole magnet. Therefore, BPM diameter D was set to 40mm. the electrode angular length α was set to 63deg as it's a tradeoff between current sensitivity and position sensitivity. Change in BPM diameter should bring 1.5dB enhancement in BPM current sensitivity; it also raises BPM position sensitivity.

Main focus is pointed on the levels of the received signal tones at the first harmonic (176.105MHz) and the second harmonic (352.21MHz). Only BPM length L is modified in order to maximize sensitivity to beam current at the first and the second harmonic while maintaining sensitivity to beam position at these tones.

BPM ELECTRICAL SIMULATIONS

BPM simulations were run under Mathcad using the method described by Shafer [1]. BPM length L was swept over 180mm range and special focus was put over the level of signal received by BPM electrodes for centered low β (β= 0.08) beams.

Simulations, run with MathCad, show an enhanced output level at the first and second harmonic for L=65mm than the 39mm set for SPIRAL2 BPM (see Figure 2).

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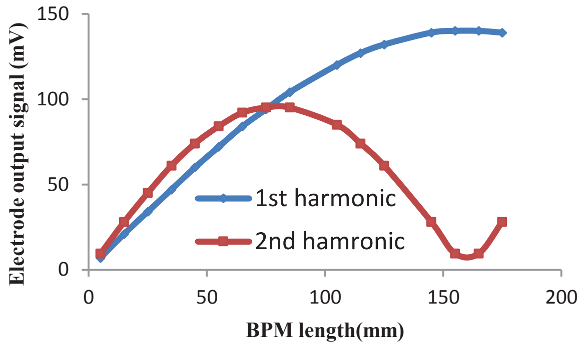

Figure 2: BPM simulations (beam current=5mA, centered beam, β=0.08).

BPM MECHANICAL DESIGN

Increasing BPM length to 65mm raises interrogations about mechanical realization: the electrode stability and cylindrical shape should be maintained with a good precision. The design adopted for SPIRAL2 BPM electrodes is based on a single contact between the electrode button and the electrodes, this design risked to show less stable and reproducible BPM with longer electrodes. Discussions with SOLCERA Advanced Materials lead to the inclusion of small anti-gazing ceramic plots on the corners of the electrode in order to offer a better stability and reproduction of the BPM. This solution should also reduce the difference between electrodes capacitances. The ceramic plots are 6mm large, 2mm deep and long.

The new solution is sketched in Figure 3.

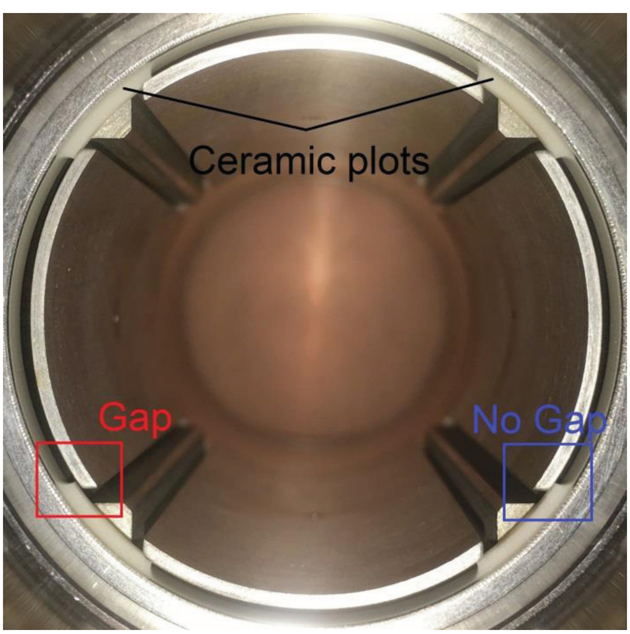

Figure 3: BPM with anti-gazing ceramic plots.

NEW BPM REALIZATION

As for SPIRAL2 BPMs, reverse polarity female SMA connectors are integrated. Few feed-throughs were made for the BPM realization; this led to a hard pairing of feed-throughs. Strong effort was put on pairing face to face electrodes as they directly influence the BPM electrical centre. Electrodes capacitances (see Table 2) and TDR response (see Figure) are depicted below.

Table 2: BPM Button and Electrode Capacitances

Position	Electrode	Button
Up (U)	13.66	1.31
Down (D)	13.61	1.36
Left (L)	13.96	1.34
Right (R)	13.62	1.37
U/D Difference	0.05	0.05
L/R Difference	0.34	0.03

The U/D difference is the same for buttons and electrodes whether it is worse for L/R difference.

Further investigations of the BPM realization shows a gap in the Left electrode between the ceramic barrettes and the plate (see red and blue boxes in Figure 3). This explains the raise in the left electrode capacitance.

For comparison, over the twenty SPIRAL2 BPMs, the U/D and L/R differences vary from 0.04pF to 0.4pF.

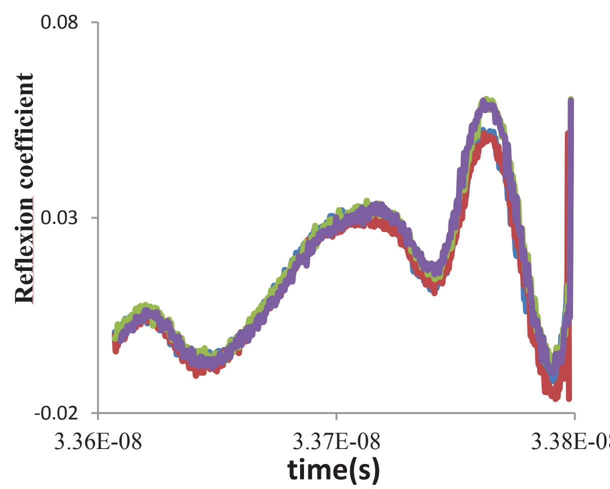

Figure: New BPM electrodes TDR responses.

Face to face electrodes have identical TDR response while there is a small difference between the four electrodes responses

NEW BPM CHARACTERIZATION

Current Sensitivity Measurement

The test setup, shown in Figure 4, is used. A cylindrical copper wire is inserted in the centre of the BPM. The calibrated VNA port1 sends a sinusoidal CW signal at 176.105MHz along the copper wire inside the BPM, the VNA port2 is connected to one of the four BPM electrodes while the others electrodes and the copper wire termination are loaded with 50Ω charge.

50Ω matching measurements show S11 and S22 levels way below -25dB.

S21 magnitude is measured for both New BPM and SPIRAL2 BPM and results shows 8 dB enhancement.

Table 3: S21 Magnitude Measurement Results

BPM	S21(dB)			
New	U	D	L	R
	-25.52	-25.48	-25.55	-25.5
SPIRAL2	U	D	L	R
	-33.5	-33.42	-33.56	-33.45

The symbols U, L, R and D refer to the upper, lower, left and right electrodes of the BPM (Shown in Table 3).

The measurement results are in a good agreement with simulations. The 2dB shortage is partially due to higher electrode capacitance for the new BPM.

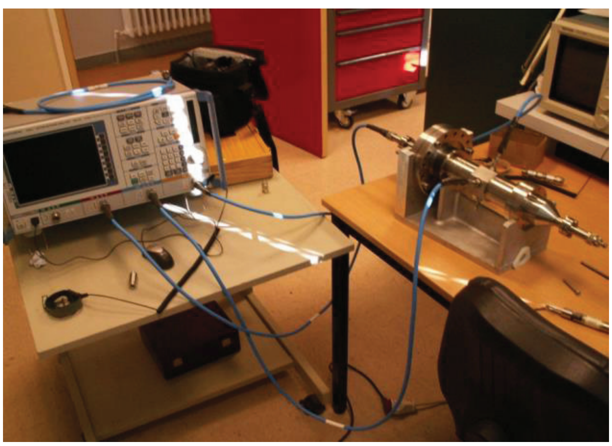

Figure 4: BPM current sensitivity measurement setup.

Position Sensitivity Measurement

The test setup used for SPIRAL2 BPMs [3] is repeated for the new BPM: the BPM electrical centre (relative to its mechanical centre) and position sensitivity are measured at 176.105MHz and compared to estimated values.

Results are depicted in Table 4, higher values of face to face differences between electrodes capacitance results in a further electrical centre coordinates for the New BPM. New BPM position sensitivity is in a good agreement with estimations.

Table 4: BPMs Electrical Centre and Position Sensitivity

BPM	New	
Electrical	X	Y
Centre	18µm	174µm
Sensitivity	Estimated	Measured
	1.68dB/mm	1.62dB/mm

For comparison, over the twenty SPIRAL2 BPMs, the electrical centres vary from 10µm to 300µm.

CONCLUSION

Novel electrostatic BPM design (optimized electrode length) offers a maximized current sensitivity while maintaining the position sensitivity intact. The mechanical arrangement is offering a stable and easily reproducible BPMs. The design and realization could be easily adapted to BPMs operating on other accelerator.

Although mechanical realization is not optimal, measurements show a strong gain in BPM current sensitivity.

The next step is to eliminate gaps between electrode corners and anti-gazing ceramics, re-characterize the BPM and ultimately test it with beam either on IPHI [4] or SPIRAL2 facilities.

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