DESIGN OF THE BPM BUTTON FOR ALBA II

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Abstract

As many other light sources, ALBA is also going through an upgrade phase leading to ALBA II. In this context, new Beam Position Monitors (BPMs) have to be designed to fit the reduced vacuum chamber. The buttons and the block were designed to be as compact as possible minimizing the impedance to avoid overheat and maintaining a good signal level. Different shapes and materials were simulated and the best were selected to be produced as prototype. In this proceeding, we present the process and the simulations that lead to the ALBA II BPM button design.

INTRODUCTION

Beam Position Monitors (BPMs) are an essential part of the diagnostics of any particle accelerators. They measure the transverse position of the beam and and they provide the input for the Fast Orbit Feedback that guarantees the beam stability. This aspect is crucial in the arising fourth generation of light sources. Among these new machines, ALBA is also proposing an upgrade of the existing storage ring called ALBA II [1], and, in this framework, new BPMs buttons have to be designed to fit the new vacuum chamber.

The miniaturization of the vacuum chambers goes together with a miniaturization of the BPMs: the buttons are now very close to the beam and this demand for detailed study and simulation of the impedance and thermal response.

In this proceeding, we will outline the journey that brought us to the design of the new BPM buttons for ALBA II, starting from a theoretical approach and ending to CST simulation to optimize the material.

ALBA VS ALBA II

As a staring point for our consideration we take the Vacuum chamber and the BPM button designed for ALBA [2]. We know that with this buttons we are able to measure the beam with the required accuracy and precision.

Figure 1 shows a comparison in scale of ALBA and ALBA II vacuum chamber while the main characteristics of chambers and buttons are listed in Tab. 1 for both the machines. ALBA chamber is "flat", as in the majority of third generation light sources, while it will be round for ALBA II.

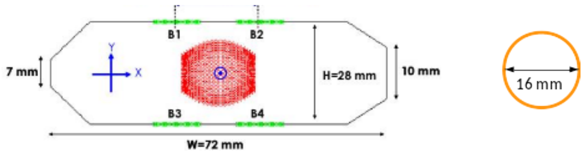

Figure 1: Comparison between ALBA and ALBA II vacuum chamber.

Table 1: Beam pipe and button characteristics for ALBA and ALBA II

	ALBA	ALBA II
Chamber radius a (mm)	14	8
BPM radius r_b (mm)	3.5	1-5
Gap g (μm)	300	100, 200, 300

Calculations and tests were performed for different radius and gaps for ALBA II BPMs button and the best combination have finally be selected.

THEORETICAL CONSIDERATION

To optimize BPM button performance, we aim to maximize transfer impedance, minimize coupling impedance, and avoid TE11 mode resonances. To do so we follow the approach presented in [3, 4].

Transfer impedance (Z_t) quantifies the button's ability to convert beam current into a measurable voltage. It is defined as:

$$Z_t = \frac{R}{1+i\omega RC}\frac{r_b^2}{2ac}i\omega, \tag{1}$$

where R is the detector resistance, C is the equivalent capacitance between the button and the block, ω is the angular frequency, and c is the speed of light.

A higher Z_t improves signal-to-noise ratio.

Coupling impedance (Z_l) represents power dissipation caused by the button's interaction with the beam and is defined as:

$$Re(Z_l) = \frac{1}{c^2}\left(\frac{r_b^2}{2a}\right)^2 R\omega_c^2 \frac{\left(\frac{\omega}{\omega_c}\right)^2}{1+\left(\frac{\omega}{\omega_c}\right)^2} \tag{2}$$

$$Im(Z_l) = \frac{1}{c^2}\left(\frac{r_b^2}{2a}\right)^2 R\omega_c^2 \frac{\left(\frac{\omega}{\omega_c}\right)}{1+\left(\frac{\omega}{\omega_c}\right)^2}, \tag{3}$$

where ω_c is the cutoff frequency of the equivalent RC circuit.

Minimizing Z_l reduces heat load and potential instabilities.

The TE11 mode is a resonant frequency that can affect button performance. It can be parameterized as:

$$f_1 = \frac{c}{\pi(r_h + r_b)}, \tag{4}$$

where r_h is $r_b + g$. Shifting this frequency away from the beam spectrum is crucial.

Finally, achieving high intrinsic resolution is crucial for accurate beam position measurements. This involves optimizing the signal-to-noise ratio (SNR), which is calculated as:

$$SNR = \frac{P(\omega)}{P_{Th}}, \tag{5}$$

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where P is the signal power and P_{Th} is the noise power. The position resolution can be then calculated as:

$$\sigma_x = k_x \frac{2}{\sqrt{2SNR}}, \tag{6}$$

where k_x is the BPM sensitivity.

Optimizing button design involves balancing these competing factors to achieve desired performance.

RESULTS FOR ALBA II

We fixed the thickness of the BPM to $T = 3$ mm and we study the variation of the transverse and coupling impedance, as defined in Eqs. 1, 2, and 3, as a function of the BPM radius and gap. Results are presented in Figs. 2 and 3.

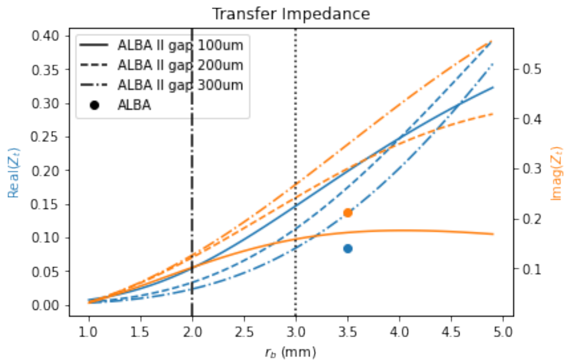

Figure 2: Transfer impedance as a function of button radius for different gaps (different line-style) fixing $T = 3$ mm (left). The dot represent current ALBA BPM button transfer impedance. Real (blue) and imaginary part (orange).

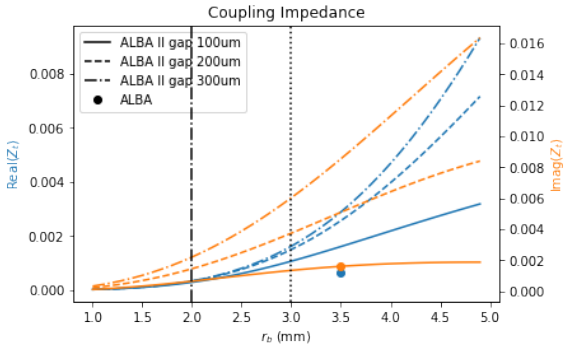

Figure 3: Coupling impedance as a function of button radius for different gaps (different line-style) fixing $T = 3$ mm. The dot represent current ALBA BPM coupling impedance. Real (blue) and imaginary part (orange).

We also calculated the frequency of TE11 mode as a function of the button radius (Eq. 4), as presented in Fig. 4. The TE11 mode will couple with the bunch spectrum and will contribute to the heat of the button.

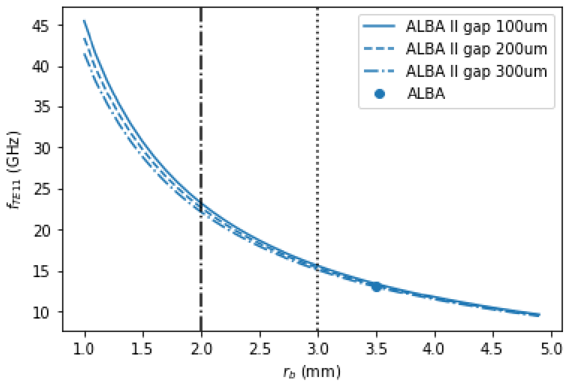

Figure 4: Frequency as a function of the button radius for different gaps.

When this calculations were performed, the ALBA II bunch was supposed to be 5.5 ps. To operate the machine, though, the use of a third harmonic cavity system is foreseen to enlarge the bunch roughly a factor 3. The spectrum of the bunch with an without harmonic cavity is presented in Fig. 5.

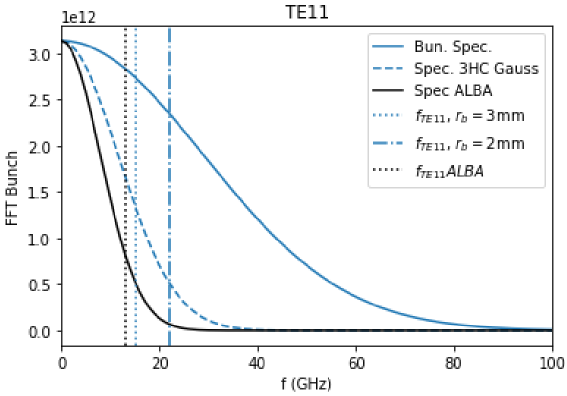

Figure 5: Bunch spectrum for different configuration without (blue) and with the harmonic cavity.

From Figs. 4 and 5, we evince that we must try to use the smaller radius possible to avoid to overlap with the central part of the bunch spectrum. Selecting a button radius of 2 mm we will have the TE11 mode around 23 GHz, the effect of the gap is not relevant in this choice. On the other hand, fixing $r_b = 2$ mm and looking at Fig. 3 it is clear that if we want to maximize the coupling impedance and minimize the transfer impedance we have to go to lower gap. 100 µm would be optimal but the manufacturing would be not possible, $g = 200$ µm has then be selected.

Finally, we verify that the SNR achievable with this BPM is comparable with the ALBA one. To do so the power of the signal produced by the beam, has to be compared with the thermal one ($P_{Th} = k_B T R = -133.8$ dBm) and the final resolution is obtained by using Eq. 6. Result for ALBA and ALBA II are presented in Fig. 6: the result for the resolution of the ALBA II BPMs is improved with respect to the ALBA one. This is due to the fact that the factor k_x is smaller in accord with the dimension of the vacuum pipe ($k_{x,ALBAII} = 5.53$ mm, $k_{x,ALBA} = 12.39$ mm).

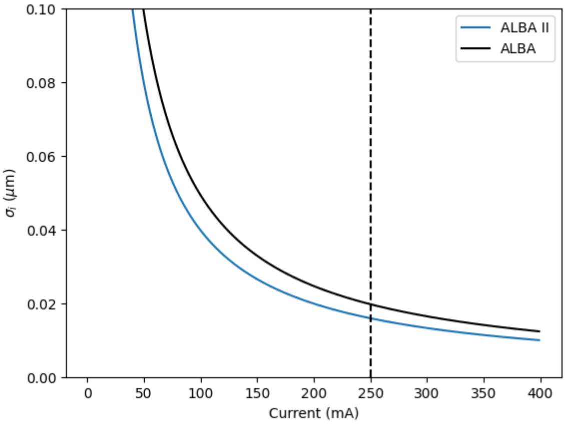

Figure 6: Comparison of resolution a function of current: in black real ALBA button, in blue the button chosen for ALBA II with a radius of 2 mm and a gap of 200 µm.

After these first calculation, we performed CST simulation to validate the theory and obtain quantitative thermal results.

CST SIMULATIONS

We fixed the radius at 2 mm and the gap at 200 µm and we modeled a BPM scaling the design of ALBA Booster BPM, which also have a round chamber. After some iteration, the final design is presented in Fig. 7.

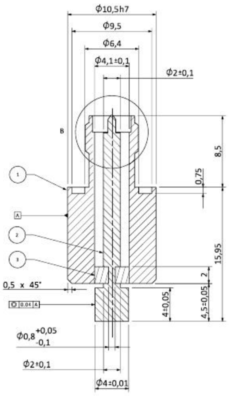

Figure 7: BPM button mechanical design.

Following other light sources [5], at the beginning we selected Molybdenum as material for the button, Alumina as material for the insulator, and Stainless Steel 306LN as material for the case. We inserted the model of the BPM block in CST [6] and we use the Wakefield solver to find the expected output signal and the longitudinal impedance of our model the output signal.

A comparison of output signal for ALBA and ALBA II BPMs block simulated in CST using a bunch of 1 nC of charge and 15 ps of bunch length is presented in Fig. 8. The results are comparable as expected: even if the button is much smaller we are much closer.

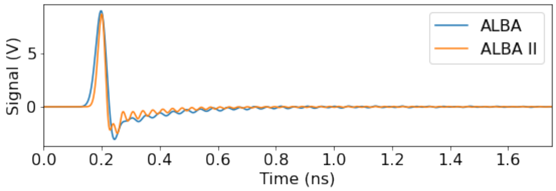

Figure 8: Output signal for ALBA and ALBA II BPM button.

The longitudinal impedance of the BPM block using a 1 nC particle beam with a bunch length of 1.5 mm is presented in Fig. 9 top. The main frequency, corresponding to the TE11 mode is found to be around 23 GHz, in agree with the theoretical expectation.

In order to improve the power dissipation, and to better match the 50 Ohm, , following the design of other light sources [7], we changed the material of the insulator to be Borosilicate Glass and we re-perform the simulations. It looks like the change of material improve the power dissipation in the TE01 peak by reducing it of 50 %, as presented in Fig. 9 bottom.

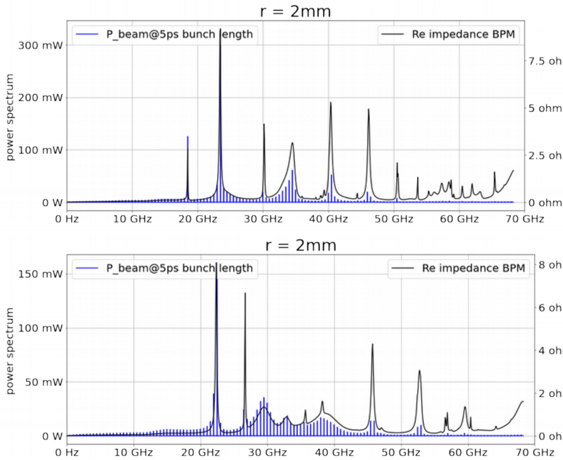

Figure 9: Wake impedance for ALBA II BPM with Alumina (top) and Borosilicate Glass (bottom) as an insulator.

Frequency spectrums presented in Fig. 9 are obtained using the code MBTrack2 [8]. This code compute the convolution of the wake impedance obtained with CST and the bunch spectrum. The code also compute the dissipate power and provide the input that can be fed to CST to perform thermal simulations.

The power dissipated for a very short bunch of 1.5 mm (5.5 ps) in the BPM block using Alumina as an insulator is 2.5 W, while when using Borosilicate Glass we obtain 2 W.

The 0.5 W difference comes mainly from the difference in the TE11 peak reduction.

Using these results we were able to simulate the thermal behavior of the BPM block. The result is shown in Fig. 10 left. The maximum temperature is expected to be on the button and to be around 65° when starting from 25° ambient temperature, which is acceptable.

All these calculations have been performed for a very short bunch length. After some lattice updates, the new shortest bunch length is expected to be around 9 ps and in present of third harmonic cavity, a factor 3 of elongation is expected. The wake impedance is drastically reduced in this case since the bunch spectrum is much narrower. In this situation, we expect to see maximum temperature lower than 28° as shown in Fig. 10, right.

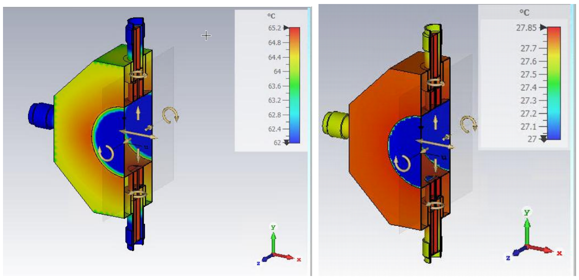

Figure 10: CST Thermal simulation for short (left) and long (right) bunches.

CONCLUSION

The geometry of the ALBA-II BPM buttons has been optimized using simulations and analytical studies. The button will have a radius of 4 mm and a gap of 200 µm. After some iteration, we are going to prototype two batches of 20 button BPM each from two different manufacturer. Both of the batches will have borosilicate glass as an insulator, but one of the manufacturer proposed to change the material of the button from Molybdenum to Hastelloy. CST simulations were re-run and comparable results were obtained. Both batches will be at ALBA before the end of 2024 and test in the laboratory and probably with beam will be performed to select the best candidate for ALBA II.

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