



IMPEDANCE OPTIMIZATION OF THE SIRIUS BPM BUTTON

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Design of several BPM Buttons is presented with detail impedance, heat transfer and mechanical analysis. Special attention is given to the application of ceramics as materials with low relative permittivity inside of the BPM Button and to the geometric shape of the BPM Button. The heat dissipation is evaluated based on the loss factor calculated for a 2.65 mm bunch length. The narrow-band impedance is discussed and its dependence on applied ceramic materials is compared.

INTRODUCTION

One of the main concerns in the BPM Button design, especially for the storage rings with short, high-current circulating bunches, is heating due to Higher Order Modes (HOM's) [1]. The BPM Button geometry and the materials choice need to be optimized from impedance and heat transfer points of view to avoid BPM Button overheating due to the resonance modes generated between the housing and the BPM Button itself by a passing bunch [2].

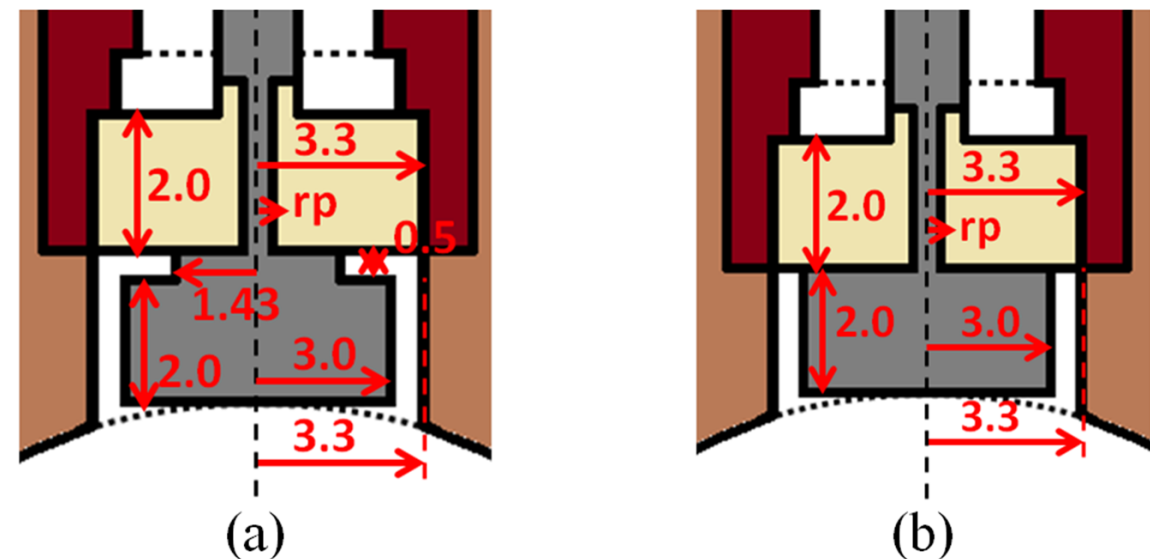
Here we discuss the results for three different BPM Button geometries. The main attention has been paid to:

- 1) The frequency spectrum of HOM's and their electrodynamic parameters;
- 2) The electrical conductivity of the BPM Button;
- 3) The thermal conductivity of ceramics materials;
- 4) The dielectric permittivity of ceramics;
- 5) Geometric dimensions of the BPM Button and the BPM housing;
- 6) Manufacturing process of the ceramics and BPM Buttons;
- 7) The magnitude of the signal out of feedthrough at RF frequency of 500 MHz.

The 3 GeV Sirius storage ring is the third-generation light source is under construction at LNLS, the Brazilian Synchrotron Light Laboratory.

Dielectric materials for vacuum insulation have been considered with high thermal conductivity to provide good heat transfer between the BPM Button and the BPM housing. Aluminum Nitride (AlN) and Boron Nitride (BN) composite materials have been chosen for analysis as shown in the Table below.

Properties of dielectric materials for simulations	
Considered Properties	Value (AlN – BN)
Permittivity, ϵ_r	9 – 4
Thermal Conductivity, σ_t	160 – 46 W/K.m
Loss Tangent, $\tan\delta_\epsilon$, @1MHz	0.003 – 0.0034



a) The inner profile of the standard BPM Button geometry.
 b) Modified BPM Button with dielectric material on top of it.
 All units are in mm.

The standard BPM Button and the modified BPM Button are shown in Fig. a and in Fig. b above respectively. The difference between two geometries is in location of the vacuum insulator. In modified BPM geometry (Fig. b), the dielectric material lies on top of the button. It helps to improve the heat transfer efficiency. The pin diameter near the button is optimized based upon the dielectric material to match the characteristic impedance of the feedthrough: 0.54 mm with AlN and 1.24 mm with BN. The gap between the BPM housing and the BPM Button is 0.3 mm. The BPM Button is located on the round vacuum chamber with $R = 11.7$ mm radius.

Impedance Optimization – Cont.



The GdfidL code has been used for numerical simulations [3]. As can be seen from the results presented in the Figure, there are additional resonant modes, which are generated by a passing bunch inside the dielectric material. The electromagnetic fields, excited in dielectric materials, radiate back into the chamber through the tiny gap. The resonant modes in dielectric material and in the tiny button gap have been classified. The preliminary frequencies of those modes can be found using the equations below:

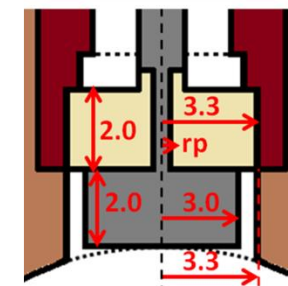
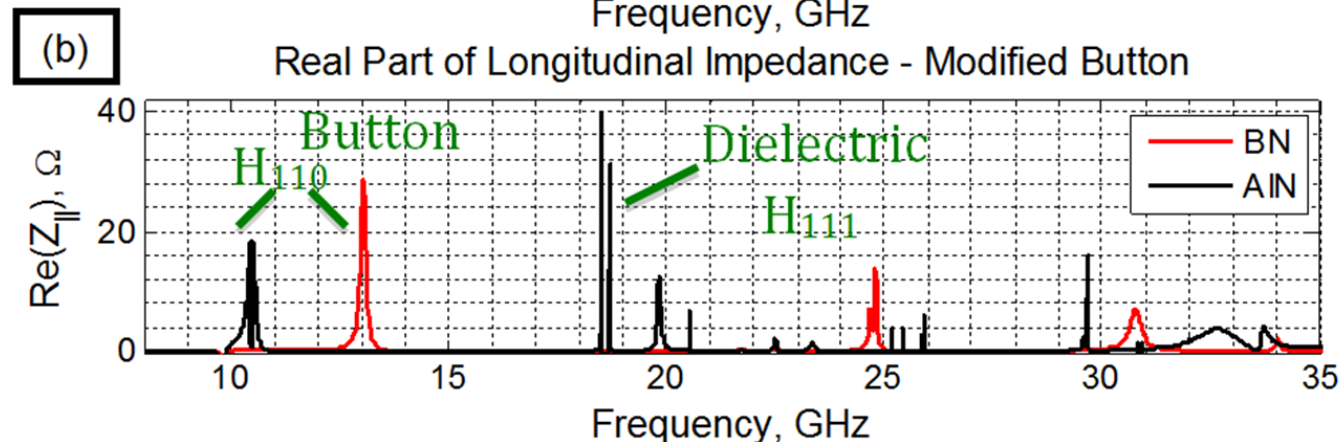
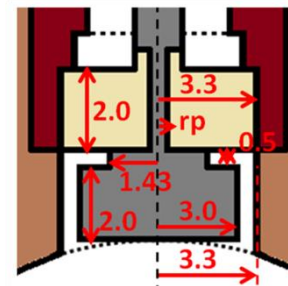
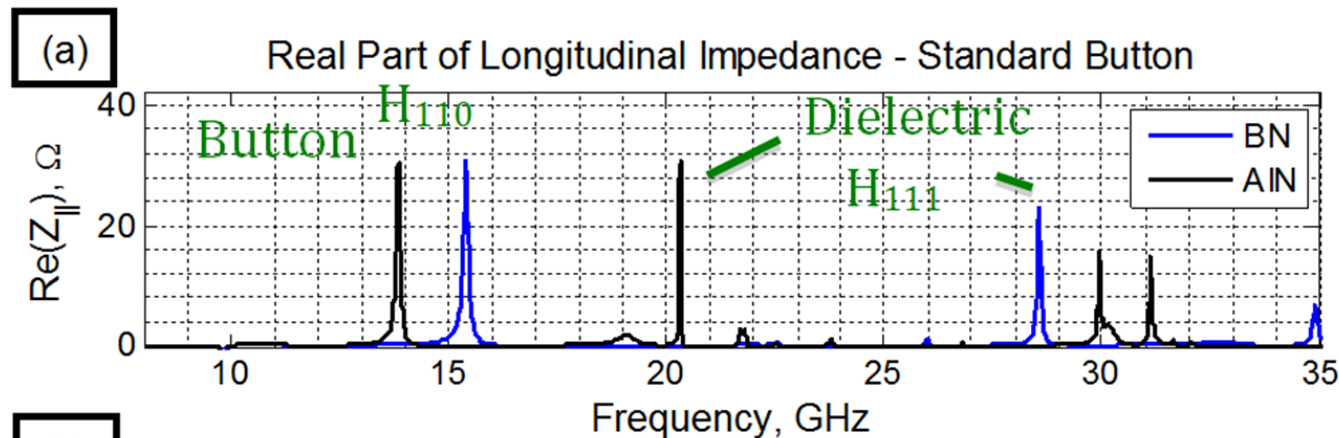
Insulator: H-modes in the coaxial dielectric-filled cavity (modes are not strongly trapped though!)

Button: H-modes in the coaxial waveguide

$$f_r^{Hm1p} = \frac{1}{\sqrt{\epsilon_r}} \frac{c}{2\pi} \sqrt{\left(\frac{2m}{r_p + r_h}\right)^2 + \left(\frac{\pi p}{t_c}\right)^2}$$

$$f_c^{Hm1} = \frac{c}{\pi} \frac{m}{r_b + r_h}$$

- ϵ_r : dielectric permittivity
- m : azimuthal index and
- p : longitudinal mode number
- r_p : insulator pin radius
- r_h : housing radius
- r_b : button radius
- t_c : ceramics thickness



The frequency spectrum of the modified BPM Button looks different than for the standard BPM Button, since the dielectric material is located right on top of the button and there is no additional gap between the dielectric material and the button surface

Candidate geometries



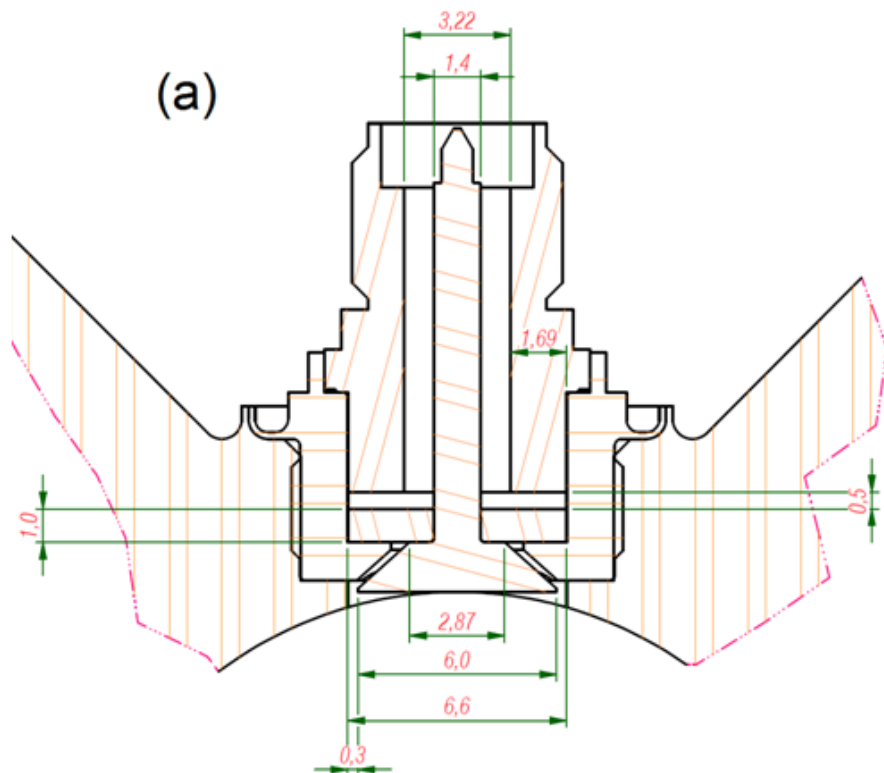
Among several BPM Button geometries analyzed, the process of choosing the three, was based on keeping the best two geometries (Bell-Shaped and Flat Geometry) from the electromagnetic point of view and having Step-Shaped one as a safe plan.

The BPM Button diameter is taken to be 6 mm for all geometries to provide about 100 nm position resolution at 100 mA. This resolution considers a 15 dB noise figure (cables + electronics) integrated in a 2 kHz bandwidth. The gap is 0.3 mm for each button. The instrumentation feedthroughs are designed for 50 Ω coaxial connectors: SMA, 3.5 or 2.4 mm types, to be defined.

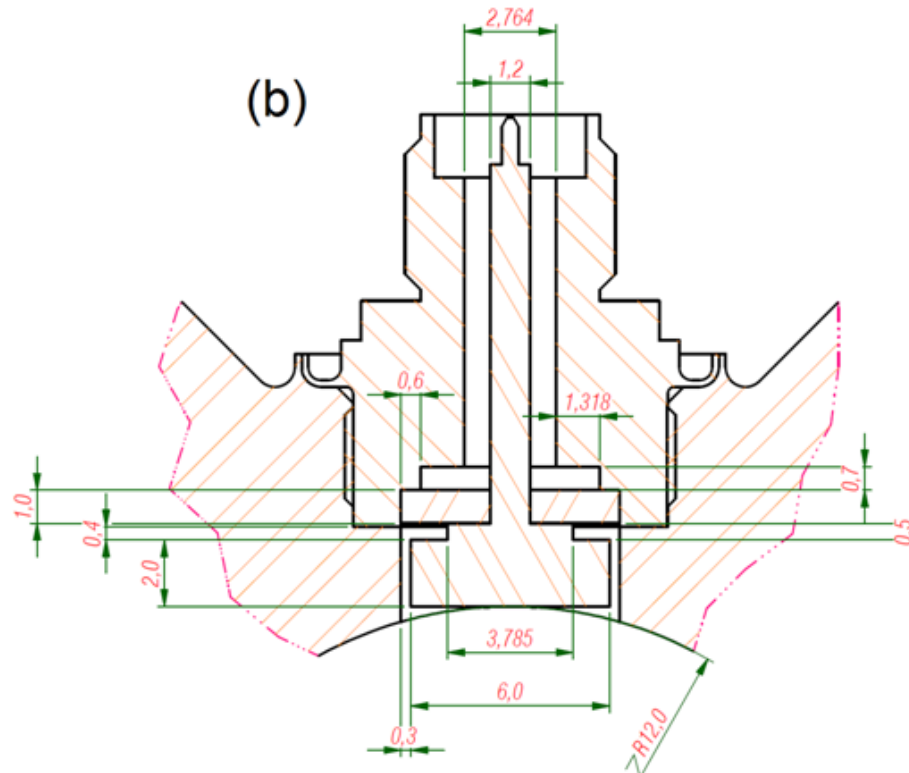
Designed with the objective of increasing the button cutoff frequency, without losing its sensitivity, since its bottom face area was kept the same as the other geometries.

Based on a well known button geometry style implemented at ALBA [5], just like the **standard button** analyzed previously.

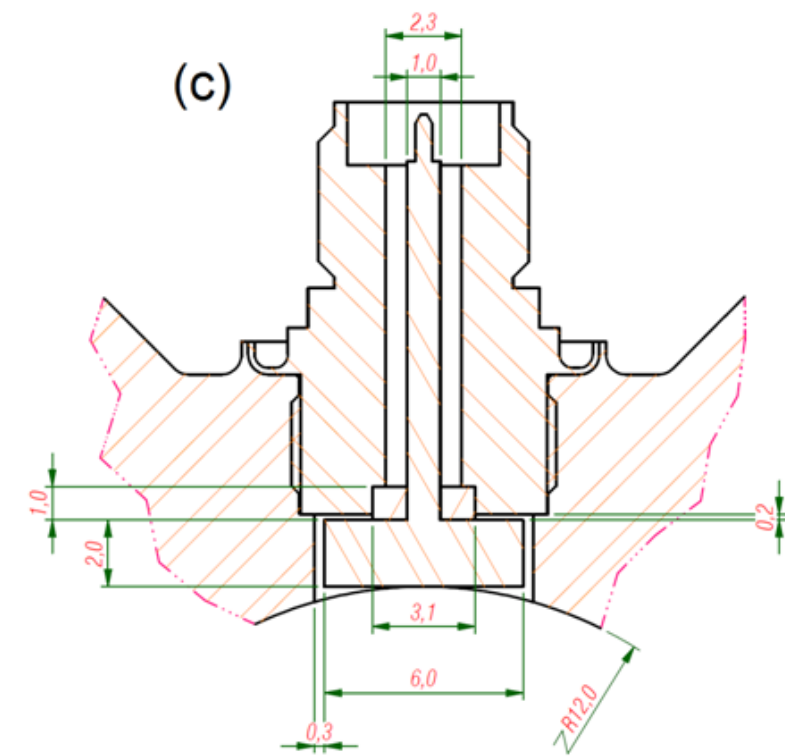
Derived from the previously analyzed **modified button**, with reduced vacuum insulator dimensions though to increase HOM's frequencies.



Bell-Shaped BPM Button.



Step-Shaped BPM Button.



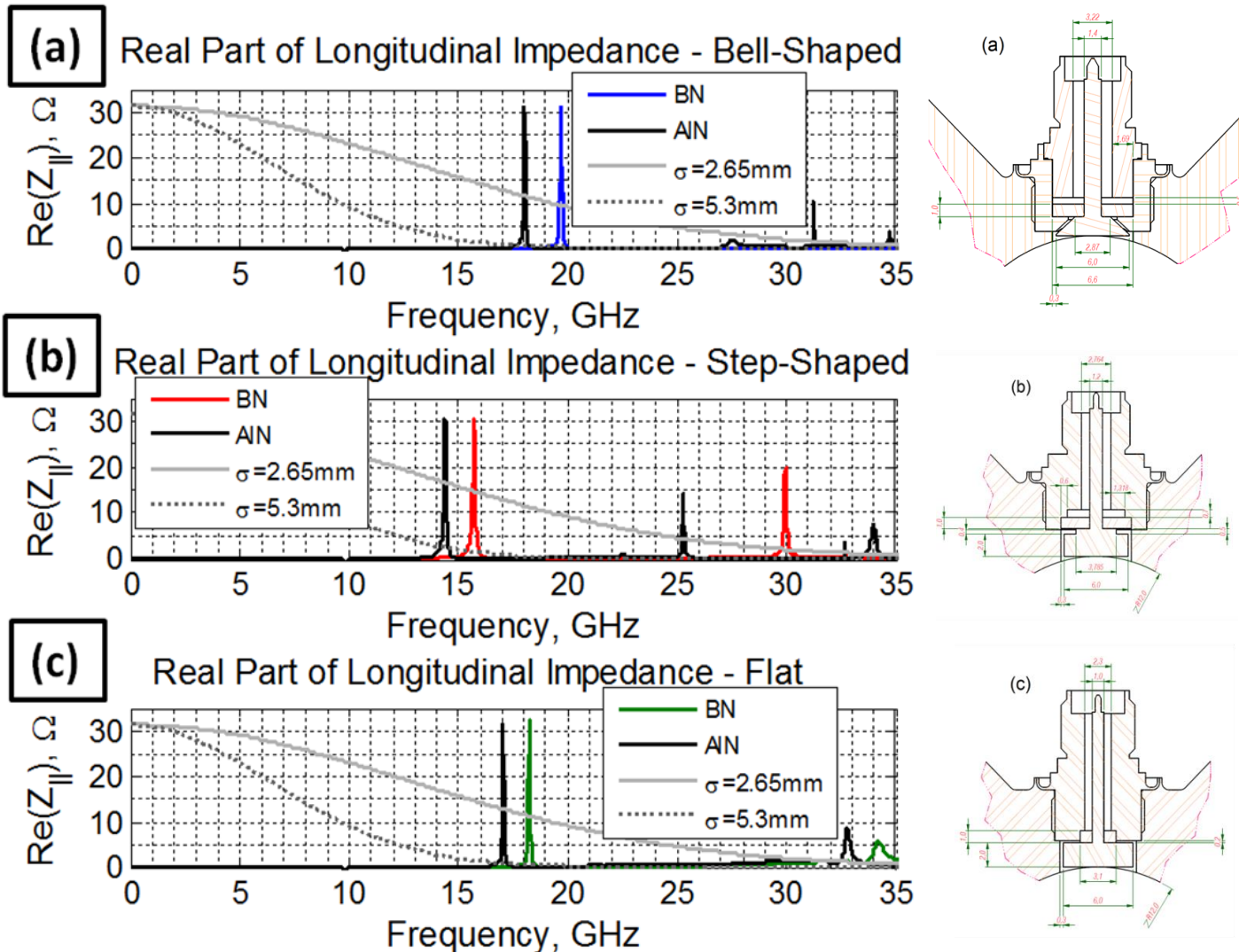
Flat BPM Button.

Candidate geometries – EM Performance



The longitudinal narrow-band impedance is shown below. In the BPM Button geometries with BN insulator the lowest resonant modes exist at higher frequencies than in geometries with AlN, as expected. The frequency shift of the lowest mode is varied within 1-2 GHz for considered geometries.

As a conservative approach we can assume that the bunch length in the Sirius storage ring with passive third-harmonic Landau cavities will be extended at least by a factor of two, making all geometries as HOM's free ones. The calculated loss factors for different bunch lengths are also shown below.



Summary results of the loss factor for 2.65, 4.5, and 6 mm bunch lengths, for the BPM Button geometries including the ceramics materials, AlN and BN.

Geometry	$\kappa_{loss}, \text{ mV/pC}$		
	Bell-Shaped	Step-Shaped	Flat
$\sigma_s, \text{ mm}$	2.65–4.5–6.0	2.65–4.5–6.0	2.65–4.5–6.0
AlN	4.5–0.9–0.3	8.9–2.5–0.8	5.6–0.9–0.2
BN	3.6–0.8–0.4	8.3–2.3–0.7	4.6–0.7–0.2

Single-bunch power loss
$$P_{loss} = T_0 \frac{I_{av}^2}{M} \kappa_{loss}$$

goes from 1.9 to 4.4 W, for $\sigma_s = 2.65 \text{ mm}$, at $I_{av} = 500 \text{ mA}$ in $M = 864$ bunches and $1.73 \mu\text{s}$ revolution period T_0 .

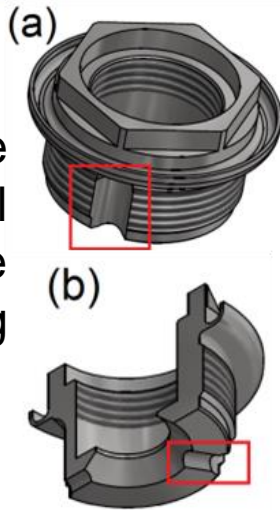
Bunch spectrum shapes are in gray color for $\sigma_s = 2.65 \text{ mm}$ (solid) and $\sigma_s = 5.3 \text{ mm}$ (dotted).

Mechanical Aspects / Heat Transfer



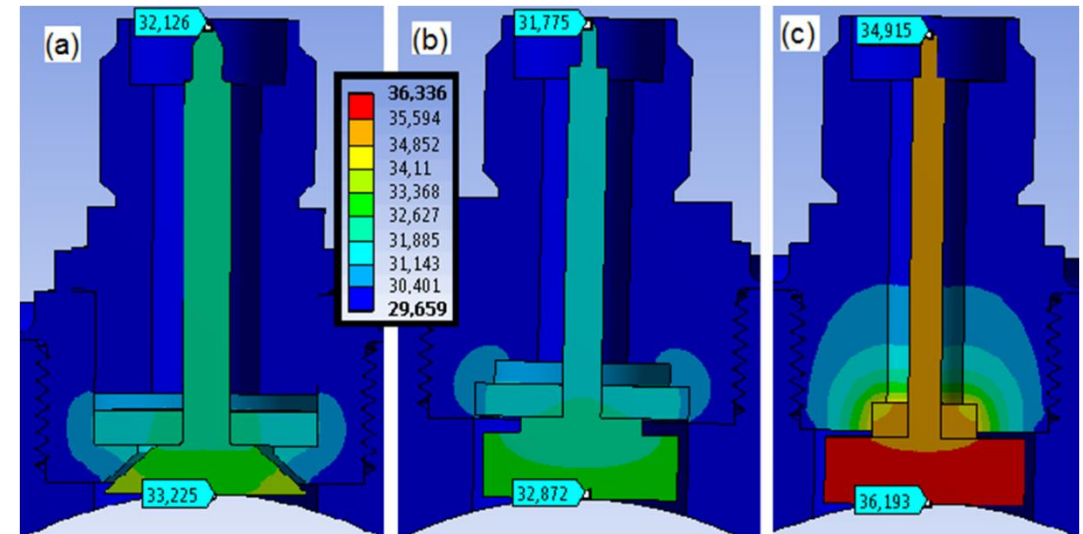
Mechanical aspects are briefly discussed:

- Housing to body coaxial cavity effect: the use of threads, brings RF shielding, thermal contact. In order to reduce virtual leaks, some valleys were designed to work as gassing channels, highlighted in the figure on the right.
- Reverse polarity connectors;
- Constant pin diameter: brings improvements in mechanical resistance and in the thermal contact area between the pin and the ceramics. Also allows to have the button and the pin as a single piece;
- Tiny dimensions require very small tolerances and precise alignment. It makes the brazing process harder (small filler sites, short circuit risks, etc.);
- Materials choice: The higher the button electrical conductivity, the lower the button power dissipation [6]. Brazing and welding process play also a big role on materials choice;
- Vacuum insulation between BPM body and housing: only tests with prototypes will show the success of the welding. An alternative is using flanges.

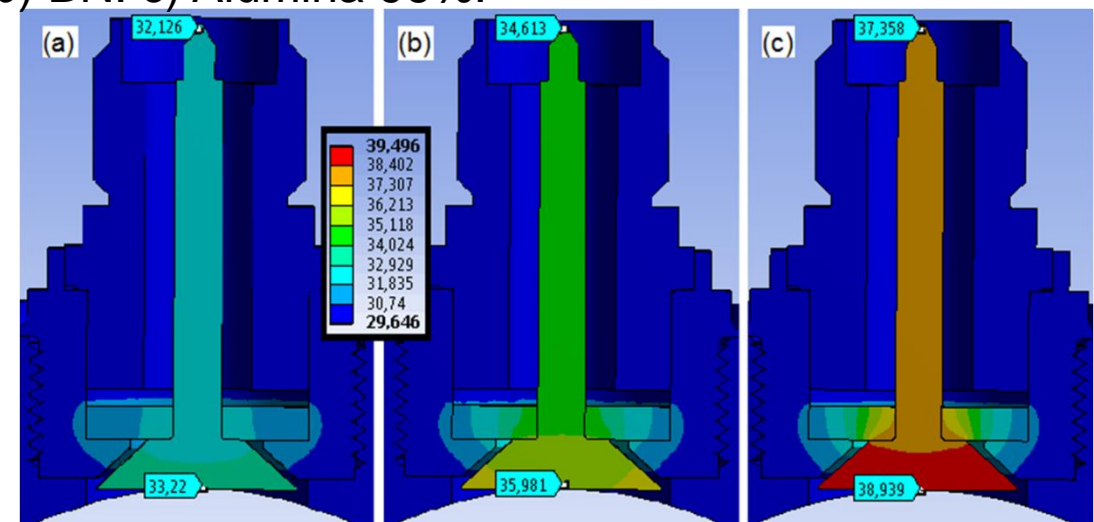


Heat Transfer analysis performed:

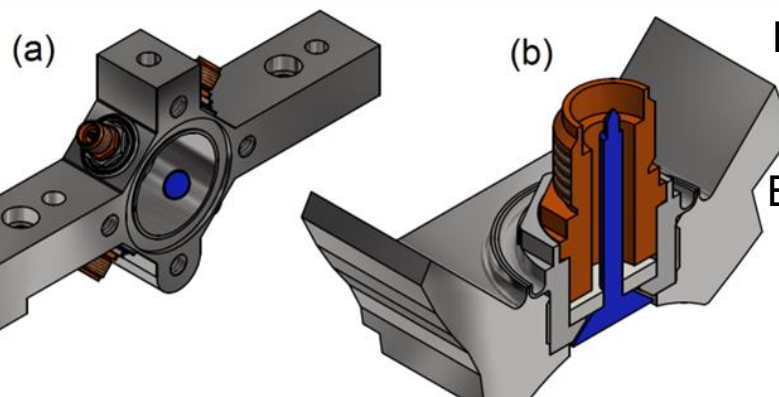
Thermostatic results for: a) Bell-Shaped BPM Button. b) Step-Shaped BPM Button. c) Flat BPM Button. AlN ceramics was considered as vacuum insulator.



Temperature profile of Bell-Shaped Button with: a) AlN. b) BN. c) Alumina 96%.



Considerations: Stainless Steel ($\sigma_t = 15.1 \text{ W/K.m}$) for BPM Body, Kovar ($\sigma_t = 17.3 \text{ W/K.m}$) for Housing and Molybdenum ($\sigma_t = 138 \text{ W/K.m}$) for the Button. Alumina 96% ($\epsilon_r = 9.4$, $\sigma_t = 24 \text{ W/K.m}$). Air convection, radiation ignored, 1W per button.



Mechanical Project of the Sirius BPM Prototype with the Bell-Shaped Button: a) BPM Assembly in the perspective view. b) One-half of the Button

CONCLUSIONS

Three different presented geometries of the BPM Button are good candidates for the Sirius storage ring. Their design, electromagnetic analysis and thermal analysis have been discussed as well as the mechanical aspects. The kind of design we choose one will be determined mainly by the entire construction process: machining, assembling, brazing and welding. The Bell-Shaped BPM Button and the Flat BPM Button have shown promising electromagnetic performance. However, these geometries require more effort in production than the standard design. The entire project is very challenging; many techniques still need to be improved. The first prototypes are underway.

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REFERENCES

- [1] N. Kurita, D. Martin, C.-K. Ng, S. Smith, T. Weiland, “Numerical Simulations of PEP-II Beam Position Monitor”, SLAC-PUB-95-7006, September, 1995.
- [2] A. Blednykh, M.J. Ferreira, S. Krinsky “Impedance Calculations for the NSLS-II Storage Ring”, Proceedings of PAC09, Vancouver, BC, Canada (2009).
- [3] W. Bruns, GdfidL code; <http://www.gdfidl.de>
- [4] A. Blednykh, “Wake Loss Simulations at NSLS-II”, Mini-Workshop, Oxford University, England (2012); http://www.diamond.ac.uk/Home/Events/Past_events/Simulation-of-Power-Dissipation---Heating-from-Wake-Losses.html
- [5] ALBA website, Storage Ring Blocks and Buttons; http://www.cells.es/Divisions/Accelerators/RF_Diagnostics/Diagnostics/OrbitPosition/BlocksAndButtons/SR/
- [6] A. Olmos, T. Günzel, F. Pérez, “BPM Design for the ALBA Synchrotron”, Proceedings of EPAC 2006, Edinburgh, Scotland (2006).
- [7] R. Nagaoka, J.-C. Denard, M.-P. Level, “Recent Studies of Geometric and Resistive-Wall Impedance at SOLEIL”, Proceedings of EPAC 2006, Edinburgh, Scotland (2006).
- [8] I. Pinayev, A. Blednykh “Evaluation of Heat Dissipation in the BPM Buttons”, Proceedings of PAC09, Vancouver, BC, Canada (2009).