ANALYSIS AND COUNTERMEASURES OF WAKEFIELD HEAT LOSSES FOR SIRIUS

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Abstract

Design evaluation and possible solutions for several in-vacuum components of Sirius are presented, having their impedance analysis focused on mitigating the wake heating impact. Thermal and/or structural simulation of the models are carried out by considering the heat load directly obtained from wakefield simulations with resistive wall boundary conditions.

INTRODUCTION

This work summarizes the impedance analysis, focusing on mitigating the wake heating impact on the in-vacuum components of Sirius, the 3 GeV fourth generation light source under construction in Brazil. The impedance analysis that regards of the reduction of its impact in the collective effects is presented in [1] and the authors recommend its previous reading since the following analysis complements the mentioned work. The detailed studies regarding Sirius collective effects, together with simulated 2D and analytical impedance evaluation are presented in [2]. The status of Sirius construction and informations about the magnetic lattice and radiation sources can be found in [3–6].

The components were simulated using GdfidL [7] and its recent feature of resistive-wall (RW) – or impedance – boundary conditions (BC) serves as basis for the referred results shown here. The presented multi-bunch (MB), RW loss factors were evaluated according to Eq. (1):

$$\kappa_l^{RW} = \frac{E_l}{q^2} = \frac{M\omega_0}{\pi} \sum_{p=0}^{\infty} \Re e Z_{\parallel}(pM\omega_0) e^{-\left(\frac{pM\omega_0}{c}\right)^2 \sigma_s^2} \quad (1)$$

where E_l is the energy lost by the bunch, q is the bunch charge, c is the speed of light, σ_s is the bunch length, $M = 864$ is the harmonic number, $\omega_0 = 3.634$ Mrad/s the revolution frequency of Sirius storage ring and $\Re e Z_{\parallel}(pM\omega_0)$ is the real part of the longitudinal impedance sampled at $pM\omega_0$ frequencies.

The power lost by the bunch P_l and the power dissipated into resistive materials P_d can be calculated since, for the later, GdfidL directly outputs the dissipated energy E_d for each resistive part of the model:

$$P_{l\,|\,d} = \frac{2\pi}{M\omega_0} \kappa_l^{RW} I_{av}^2 = \frac{2\pi}{M\omega_0} \frac{E_d}{q^2} I_{av}^2 \quad (2)$$

where I_{av} is the average beam current. It is important to note that an wakefield simulation has a continuum spectrum of excitation, so P_d from Eq. (2) is only 100% precise (with the exception of numerical errors) for single bunch case (M = 1). However, if κ_l^{RW} is approximately the same for several filling patterns – more precisely, M = 864, 432, 216 and 1 for the studies here presented – no strong higher order mode (HOM) is being excited and Eq. 2 is satisfactory reliable. This also explains one of the countermeasures in the components design: if a solution of damping a strong HOM is not found, then shifting its center frequency away from $(pM\omega_0)$ for the cited M values is an alternative.

Two configurations of bunch length *vs* average current scenario were chosen in order to conservatively – arround 25% shorter bunch length conditions – cover Sirius operation scenarios. Every studied component has therefore been simulated twice, one for each bunch length value:

- Case 1: I_{av} = 100 mA, σ_s = 2.5 mm (3.2 mm real case);
- Case 2: I_{av} = 500 mA, σ_s = 9.0 mm (12 mm real case).

EFFECT OF RW BOUNDARY CONDITION

Sirius fast corrector chambers are 100 mm long stainless steel wall. They have no geometric impedance and therefore are suitable for RW impedance evaluation. GdfidL's result (40 μm mesh step) was compared with theory [8] and ECHO2D [9], as shown by Fig. 1. Although the agreement considerably diverges for high frequency, wake heating analysis are performed below the 35 GHz limit. In case of models with larger mesh steps, we expect GdfidL to overestimate the power deposition, hence satisfying the analysis in a conservative way.

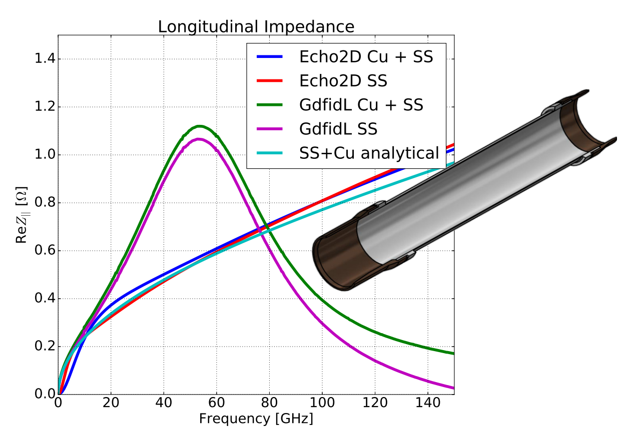

Figure 1: Real part of the longitudinal impedance of fast corrector chamber: comparison between ECHO2D, GdfidL – with and without copper pipe terminations – and theory.

Sirius BPM electromagnetic design was evaluated with perfect conducting BC [10]. By prescribing conductivities of Ti housing and Mo button, the confined mode has strong reduction on its quality factor as expected (see Fig. 2).

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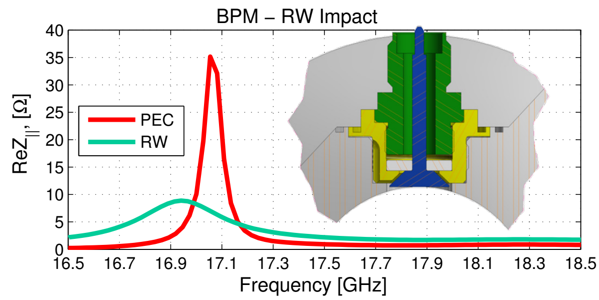

Figure 2: Effect of RW BC on BPM Button HOM.

GATE VALVES

The machine beam stay clear at the valve locations do not allow shadowing them with radiation masks. The only alternative was initially defining the inner radius of the valve 1 mm larger than the vacuum chamber one. The eigenmode study of the gate valves focused in evaluating the first 3 HOMs trapped in the structure formed by the RF-shield belly shape, flange gaps and tapers, as depicted by Figs. 3 and 4.

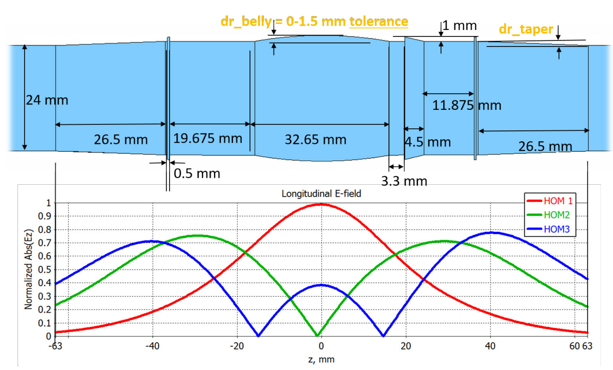

Figure 3: Longitudinal E-field distribution of the first 3 HOMs trapped in valve cavity profile.

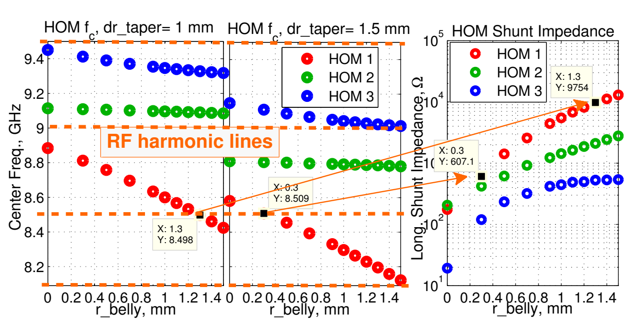

Figure 4: Valve HOMs shift and shunt impedance impact.

By increasing `dr_taper` to 1.5 mm, the consequent 303 MHz center frequency shift of the 3 HOMs could re-accommodate the required `r_belly` variation tolerance (from 0 to 1.5 mm) in such a way it crosses a RF harmonic with a HOM shunt impedance 16 times lower than with `dr_taper` to 1.5 mm. The 0.3 mm wide slots were added to the wakefield model (see Fig. 5) and the obtained HOM center frequency values successfully matched with the values in the datatips from Fig. 4.

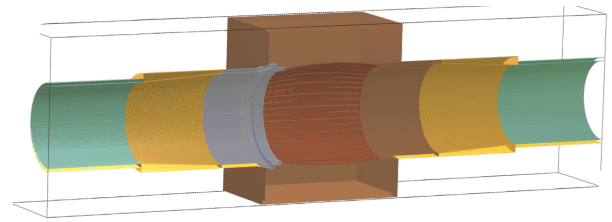

Figure 5: GdfidL model for the gate valve.

THERMOMECHANICAL ANALYSIS

The power depositions data retrieved directly from GdfidL was used as input for thermal and mechanical simulations of the components in ANSYS. For the thermal simulations, a conservative convection coefficient of 5 W/m^{2}K was considered. Below we present these results.

Stripline Kicker

Thermal load configuration for Sirius stripline kicker had larger temperatures for Case 2 parameters. Fig. 6 shows that the maximum achieved temperature was 48 ^{o}C and the BeCu pin has witnessed only 36 μm relative longitudinal displacement – value within mechanical machining tolerances. The strips material is copper and the body parts stainless steel.

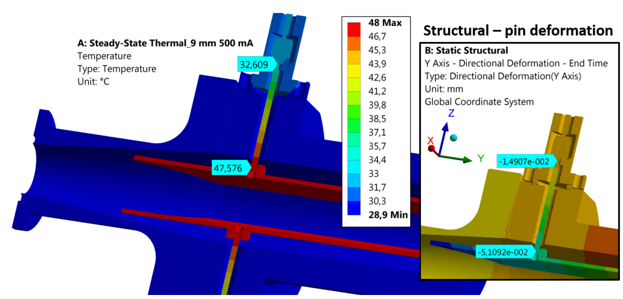

Figure 6: Analysis for the stripline kicker: thermal (left) and structural (floating right).

Stripline Tune Monitor

The Sirius tune monitor proves robust even witnessing extreme thermal load parameters: I_{av} = 500 mA and σ_s = 2.5 mm, as depicted by Fig. 7. It follows the same material configuration of the kicker. The 150 mm long strip has a approximately 6 mm height and width cross section. It is short circuited at the upstream end opposing a downstream longitudinal gap of 2 mm.

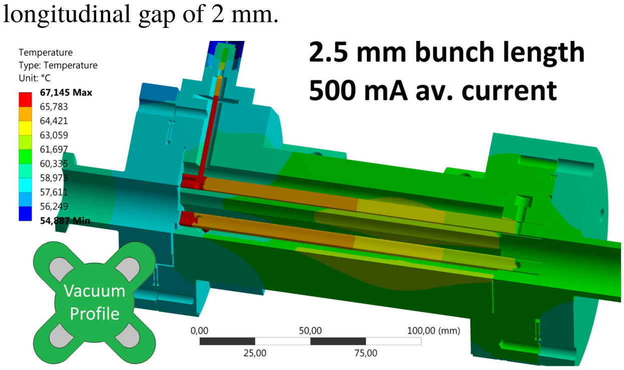

Figure 7: Thermal analysis of the stripline tune monitor.

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Bellows

After prototyping the omega-strip bellows design [11], the concept of the telescopic bellows (see Fig. 8) has been developed, since its gain in machining and assembly aspects justifies a worse electromagnetic performance (2x larger loss factor). The coaxial cavity formed by such concept was evaluated similarly to the valve cavity. Considering the mechanical tolerances, the predominant HOM center frequency was found equal 9.175±0.045 GHz, free from being excited by high-M filling patterns.

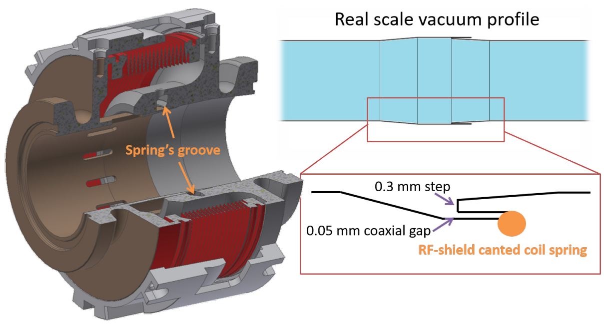

Figure 8: Telescopic bellows project and sketch.

Figure 9 depicts the thermal simulation for both wake heat load Cases.

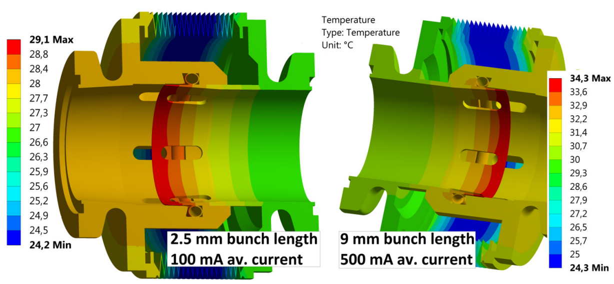

Figure 9: Thermal simulation for telescopic bellows: Case 1 (left) and Case 2 (right).

BPM Block

Every BPM is going to have bellows flanged to both ends. The thermal simulation of the BPM block is presented by Fig. 10 for Case 2. Although the BPM is HOM free for σ_s = 9 mm [10], the bellows drains higher load in such configuration than in Case 1.

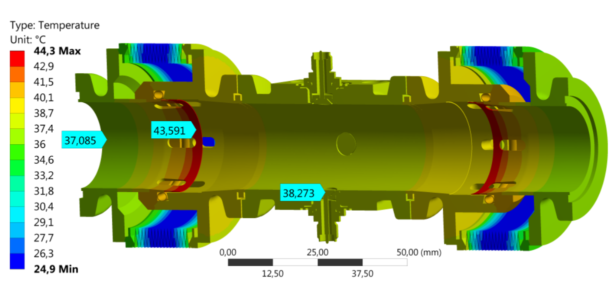

Figure 10: Case 2 thermal simulation for the BPM block.

BPM Deformation

BPM block simulations were performed changing the button electrical gap. Thermal load for 100 μm gap was applied in the two bottom buttons and housings, as the same for the top, but for a 200 μm gap. Case 1 was more critical than Case 2, and only the BPM was considered in the thermomechanical analysis, depicted by Fig. 11.

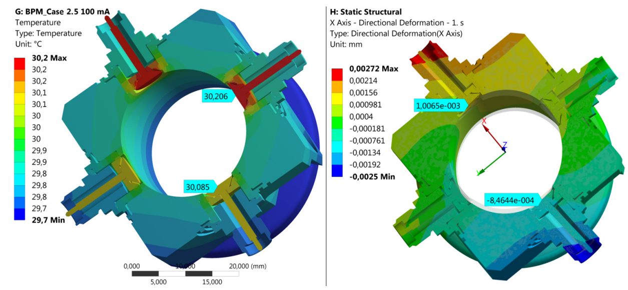

Figure 11: Thermal (left) and structural (right) analysis for the uneven worst-case load.

From the structural analysis presented, opposite buttons displace about 150 nm from each other, which represents 300 nm of deviation in measurements of the BPM electrical center. This value is above the Sirius sub-hundred nanometers requirement. Therefore, for Sirius BPM, sorting the buttons with similar gap sizes (or, close capacitance values) proves to be a necessary task.

FINAL REMARKS

All the components for which thermomechanical analysis were performed will not need cooling solutions, even though a conservative convection coefficient was considered in the simulations. However, this analysis must be completed with evaluation for the gate valves and other elements not discussed in this contribution, such as the DCCTs.

Some components of the Sirius storage ring will have thermocouples attached as close as possible to the hot spots in order to perform crosschecks with the simulation results.

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