UPDATE OF THE COLLECTIVE EFFECTS STUDIES FOR SIRIUS

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Abstract

An updated impedance budget for Sirius, with contributions from 3D electromagnetic simulations and analytic calculations, is presented and the estimates for single and multi-bunch instability thresholds for the first operation phase are re-evaluated.

INTRODUCTION

Sirius is a 3 GeV fourth generation light source being built in Campinas Brazil by the Brazilian Synchrotron Light Laboratory (LNLS). The status of the construction as well as informations about the magnetic lattice and radiation sources can be found elsewhere [1–4]. The standard vacuum chamber of the ring will be round and made of copper, with a inner radius of 12 mm. The whole ring will be NEG coated, and two operation phases are predicted, in the first the nominal current for uniform filling will be 100 mA and 350 mA (with Landau cavity) in the second.

In previous works [5, 6] the impedance related collective effects in Sirius were reported using a very preliminary impedance budget, which took into account the resistive wall impedance and a broad band model for the geometric impedance. Since then several components of the storage ring had their impedance calculated with 3D electromagnetic codes (mostly with GdfidL [7]) such as the ones described in references [8, 9].

Some other components, which had not been designed in detail,and consequently did not have a 3D evaluation carried out, had their impedance estimation refined. Instead of broad band models, 2D codes such as ECHO2D [10, 11] were used to simulate approximate geometries, which preserved the main parameters of the structure under analysis. With this improved impedance budget the instabilities thresholds for Sirius were re-evaluated with the frequency and time domain algorithms employed in previous works [6].

All this work was split into two contributions for this conference, while reference [12] focus on the effort of 3D modeling the components to mitigate their impedance contribution to the whole budget, this contribution presents some 2D calculations results, the summary of the impedance budget and shows the estimates for instabilities for the first operation phase.

IMPEDANCE MODELING

While the methodology and codes used to model the resistive wall impedance are still the same as the one presented in reference [5], the geometric impedance has been improved, with new simplified models of important elements and detailed results from 3D simulation of several other components of the ring. Below we describe a few of these models.

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BC Chamber

In every arch of the Sirius lattice (20 sections) there will be a dipole magnet (BC) with longitudinal gradient and a thin section with very high field (3.2 T) for hard X-ray generation (ε_c =19.2 keV). The magnetic gap at the center will be of 11 mm, implying the vacuum chamber shall have a vertical transition from the nominal inner radius to 4 mm. The original proposal for this chamber kept the horizontal aperture constant along the transition, in such a way that at the region with minimal gap its cross section was an ellipse. However, the impedance of this geometry, simulated as a rectangular transition in ECHO2D, as shown in Fig. 1(a), had a much bigger impact on the beam than the axially symmetric model, shown in Fig. 1(b).

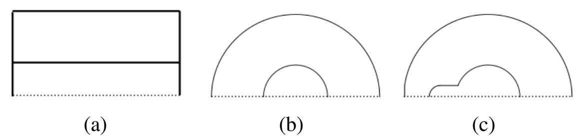

Figure 1: Longitudinal projection of the geometries studied for the BC vacuum chambers.

Figure 2 shows the comparison between the two types of transition and the beam spectrum for the first modes of oscillation from a 3 mm long electron beam. The integral of the imaginary part of the impedance weighted by the mode g_{00}^2 of the beam gives the tune-shift that brings modes 0 and −1 close to each other and the integral of the real part of the impedance weighted by the mode $g_{00} \cdot g_{01}$ is what causes the instability, coupling both modes once they are close. Simulations showed that even if the tune-shift caused by the round transition were artificially matched to the rectangular transition (by multiplying its impedance by 2.5), its real part is not sufficiently strong to couple the modes and generate the instability.

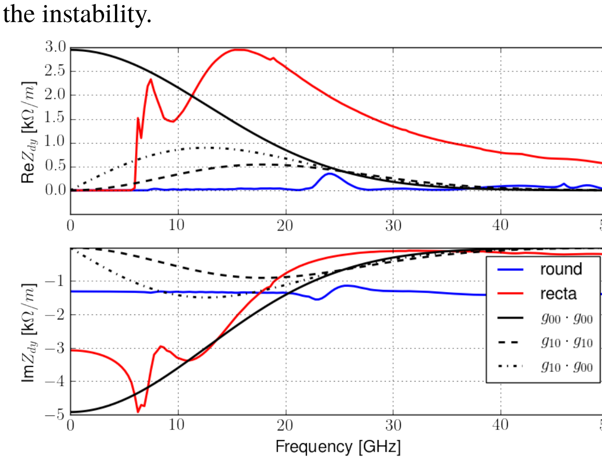

Figure 2: Vertical dipolar impedance comparison for round and rectangular transitions simulated in ECHO2D with same transition slope and vertical gap.

Based on the analysis presented above, the transition of the BC chamber was changed to the shape presented in Fig. 1(c). The axially symmetric version is not feasible due to heating caused by the synchrotron radiation generated in the upstream dipole, hence the *keyhole* profile. The impedance of this model was evaluated and is similar to the one of the round chamber.

Undulators Transitions

It was recently decided that for the initial operation phase of Sirius, seven undulators will be used (four with gaps of ≈5 mm and three with ≈10 mm). All of them are out of vacuum and their chamber will be NEG coated, being five Delta-type and two planar adjustable phase undulators (APU). The chamber of the Delta undulators has a close to round cross section, thus the impedance of its transitions were simulated as axially symmetric transitions in ECHO2D. On the other hand, due to the larger horizontal aperture of the APUs, its transitions were simulated as rectangular models in ECHO2D. All simulations considered a smooth transition slope of 1:20.

IMPEDANCE BUDGET

The impedance budget for Sirius was evaluated up to frequencies much higher then the mode 0 of oscillation cutoff of 30 GHz. In the longitudinal plane, impedances were calculated up to 150 GHz to provide a good characterization of the microwave instability threshold, and in the transverse plane, up to at least 85 GHz, to account for head tail damping due to chromaticity and the strong head tail instability.

In order to make the figures and their interpretation clearer, we grouped most of the components in several subcategories: *Ring RW* represents the resistive wall impedance from the standard pipe, from the BC chamber, injection components and fast correctors chamber; *Ring Geom* is the BC chamber transition, injection section and RF Cavity transition; *ID Geom* for the IDs transitions; *ID RW* for the IDs resistive wall; and *Vac. and Diag* for striplines, DCCTs and pumping slots. Other components, such as radiation masks, bellows and the blocks bellow-BPM-bellow and mask-valve-bellow-BPM-bellow (*Valve Block*) described in [12] and [13], respectively, were kept separate due to their big contribution to the budget.

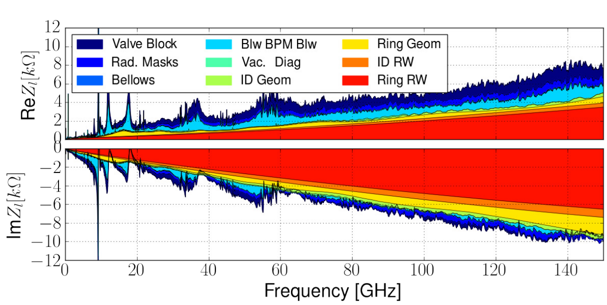

Figure 3: Longitudinal Impedance Budget for Sirius.

Figure 3 shows the longitudinal impedance budget for Sirius and Fig. 4 shows the loss factor and the effective Z/n. Notice that the *Valve Block* and the *Blw BPM Blw* dominate the loss factor, but for the Z/n and the high frequency spectrum the group *Ring RW* becomes the main contributor. It was verified that this property is due to the NEG coating on the chambers, which is mostly inductive for lower frequencies.

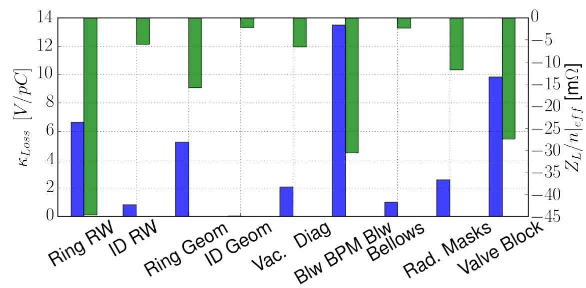

Figure 4: Single bunch loss factor κ (blue) and effective Z/n (green) calculated for a 3 mm bunch.

Figure 5 shows the β_y weighted vertical impedance of the budget and Fig. 6 shows the vertical single bunch kick factor. At low frequencies the resistive wall dominates, reaching 100 MΩ at 100 kHz (the first coupled bunch sampling line for Sirius is ≈400 kHz) and for higher frequencies there is a strong contribution from the *Blw BPM Blw* and the *Valve Block*. It is also noticed from the figure the high order modes that comes from the striplines. As presented in reference [12], they were carefully designed so their shunt impedances and resonant frequencies did not induce coupled bunch motion.

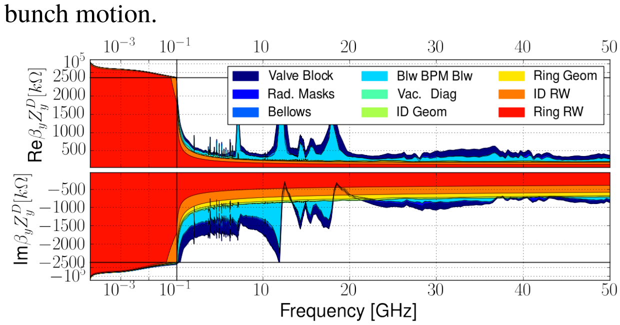

Figure 5: Vertical impedance budget weighted by the β_y.

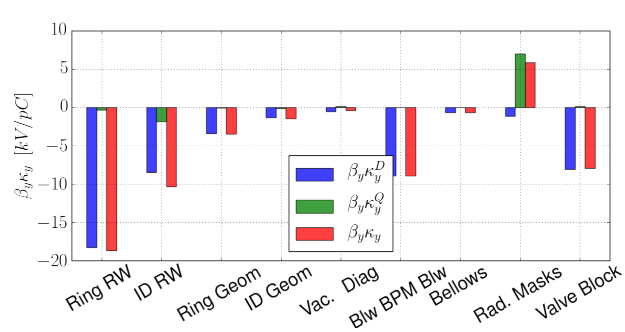

Figure 6: Single bunch vertical kick factor weighted by the β_y for a 3 mm bunch.

Figure 7 shows the β_x weighted horizontal impedance of the budget and Fig. 8 shows the horizontal single bunch kick factor. The same reasoning for the vertical plane also

ISBN 978-3-95450-182-3

applies for the horizontal, however in this plane there is also a big contribution from the *Radiation Masks*. These elements have a lateral iris in the outer horizontal side of the chamber for blocking the synchrotron radiation, which breaks the symmetry between the planes and generates this contribution in the horizontal impedance. The design of this component is discussed in details in reference [12].

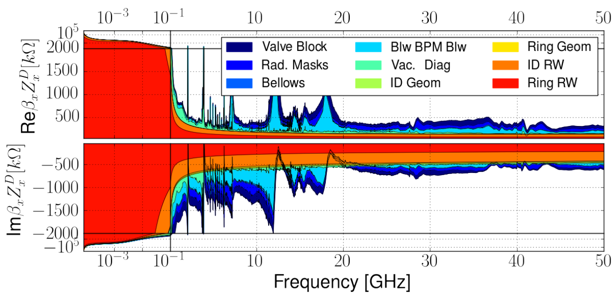

Figure 7: Vertical impedance budget weighted by the β_x.

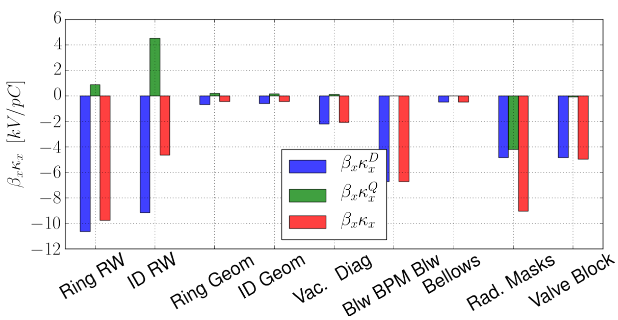

Figure 8: Single bunch horizontal kick factor weighted by the β_x for a 3 mm bunch.

INSTABILITIES

The Sirius commissioning will be done with a PETRA7-Cell RF cavity, thus longitudinal coupled bunch motion is expected in this phase. However, before the start of user shifts it will be replaced by superconducting cavities. Besides, according to the current impedance budget there will be no coupled bunch motion in the longitudinal plane, so a longitudinal bunch by bunch feedback system is not planned.

The single bunch longitudinal instability was studied using the Haisinsky solver method described in reference [6]. Figure 9 shows the calculated bunch length and energy spread of the beam as function of the single bunch current. The energy spread is not constant at low currents because of the IBS effects, however, at ≈0.75 mA there is a change in the slope of the curve, which can be interpreted as the threshold of the microwave instability. This result was compared with a frequency domain code based on Suzuki's solution of the Fokker-Planck equation for the longitudinal plane assuming gaussian bunches [14] (neglects potential-well distortions), which provided a threshold of 1.2 mA. Further comparisons of this approach with self-consistent methods, such as tracking, are being carried out.

In the transverse planes the instabilities were estimated using Suzuki's theory based on the solution of the Fokker-

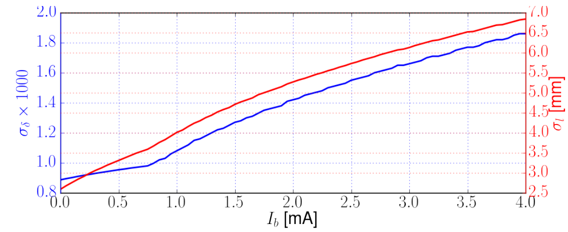

Figure 9: Bunch lengthening and energy spread predicted for Sirius as function of the single bunch current, considering IBS and longitudinal impedance.

Planck equation for the transverse plane for gaussian bunches [15]. Calculations were performed with and without the bunch lengthening predicted by the longitudinal instability calculation, presented in Fig. 9. For the latter case, only bunch lengthening due to IBS is considered, which is approximately half the bunch lengthening predicted with impedance.

Figure 10 shows the total beam current thresholds for the firsts head tail modes as function of chromaticity. At zero chromaticity the RW instability threshold is only 15 mA (25 mA) for the vertical (horizontal) plane, but at chromaticity 2.5 both planes become stable at nominal current. Even though simulation shows that chromaticity can suppress the coupled bunch instability, Sirius will have two transverse bunch by bunch feedback systems, one for each plane.

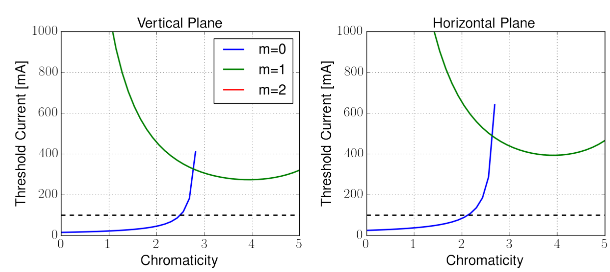

Figure 10: Uniform filling coupled bunch head-tail modes 0, 1 and 2 thresholds as function of chromaticity. The black dashed line is the nominal current of the ring.

The threshold for transverse mode-coupling instability (TMCI) for a single bunch without impedance bunch lengthening is 2.0 mA (2.5 mA) in the vertical (horizontal) plane. Considering the predicted effects of the longitudinal impedance, these thresholds increase to 2.5 mA and 3.6 mA, respectively. These estimations define a interval for the TMCI in both planes which is outside the single bunch current range that the storage ring is being built to operate.

CONCLUSIONS

Most components of the storage ring had their impedance calculated which allowed better estimations for the instabilities thresholds and beam parameters. The work must continue to finish the 3D simulations, include CSR contribution to the budget and improve the codes for beam dynamics simulation.

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