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DESIGN REVIEW OF BELLOWS RF-SHIELDING TYPES AND NEW CONCEPTS FOR SIRIUS

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Abstract

Large amounts of bellows in an accelerator justify the importance of simplifying the machining and assembling processes of their RF shield. Such quantity also makes this component one of the main contributors for a machine impedance budget. On the other hand, low impedance designs tend to complicate the mechanical aspects. Applied to Sirius round vacuum chamber of 24 mm inner diameter, the omega-strip and comb-type bellows concepts are compared with new proposed designs. In such comparison, the aforementioned aspects, wakefield losses and prototyping experiences are presented in this work.

INTRODUCTION

The small vacuum chamber aperture demanded by diffraction limited light sources has brought several engineering challenges to their storage ring design [1]. NEG coating technology can be considered a good approach for pumping chambers with reduced conductance and, in case of Sirius[1] storage ring chambers, an in-situ bake-out for NEG activation is employed. During this activation, attached bellows need to accommodate long thermal expansions of the beam pipes, requiring longer compression range which, in turn, may bring complexities to an effective bellows RF-shielding design. In addition, the reduced space between magnets available for BPM installation and the use of two bellows per BPM requires a compact dimension for the design.

Another consequence of low aperture pipes for a RF-shielded bellows design is the strong sensitivity of the geometric impedance with respect to radial changes on the chamber profile. Large amounts of bellows in a storage ring strongly contribute to the machine impedance budget and therefore to the beam collective instabilities on the ring [2].

The initial analysis for the Sirius storage ring bellows design have followed two development fronts guided by two identified concepts that will be called as:

- Gap-independent: designs that demands radial change in the chamber profile, whose longitudinal gap variation does not strongly affect the wakefield losses. The omega-strip RF-shielding design proposed at DAΦNE [3] was taken as starting point;
- Gap-dependent: designs that do not demand radial changes except in a high capacitance gap, whose longitudinal variation strongly affects the wakefield losses. The comb-type RF-shielding design proposed at KEKB [4, 5] was taken as starting point.

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[1] Sirius is the 4^{th} generation light source under construction in LNLS, Brazil.

DESIGN DEVELOPMENTS

Two designs for each front are presented (see Fig. 1) for Sirius 24 mm inner diameter beam pipes, taking prototyping experiences and wakefield analysis into account. GdfidL [6] was used prescribing resistive-wall boundary conditions and analysis were performed focusing on loss/kick factors at the single-bunch instabilities spectrum range and longitudinal higher order modes (HOMs). More specifically, the later comprises avoiding strong heat load from wake losses by either damping harmful HOMs or guaranteeing that the beam does not deposit energy at the HOM frequency [7].

Front 1: Gap-independent Designs

Developments started aiming at adapting the DAΦNE design concept to Sirius reduced transverse (chambers aperture) and longitudinal dimensions (installation space). In addition, great effort was put to simplify the machining and assembling processes. Tests with the resulting 8-strip modified omega bellows (see Fig. 1) have presented difficulties on keeping an evenly distributed contact with the octave-shaped cavity edges, mainly intensified when a lateral displacement was induced. In this way, it was identified the need of designing a precise movement limiter to minimize the contact issues when interacting with the beam. Furthermore, the strip thermal resistance to softening, when using standard beryllium- copper alloys, proved to be unsatisfactory for withstanding the bake-out cycles expected for the machine lifespan. Such problems, allied to the identified lack of lateral displacement requirements, have motivated the development of the telescopic bellows, where a silver-plated coil spring guarantees an axisymmetric electrical contact between the male and female parts (see Fig. 1, detail B). These machined pieces are shown in Figure 2.

Regarding electromagnetic performance, modified-omega and telescopic bellows basically form cavities whose TM_{010} fundamental mode center frequencies are slightly below the ~9.56 GHz chamber cutoff. Considering the bunch length *versus* average current scenario for Sirius commissioning phases, this is the only mode to be concerned about and changes in geometry should have been made if its frequency coincided with an RF harmonic. It is worth mentioning that no coaxial effect is present between male and female telescopic parts, since at least one point of contact will exist between the edge of the former with the inner face of the later. For practical reasons, a longitudinally aligned linear contact was set in the simulations. On the opposite side with

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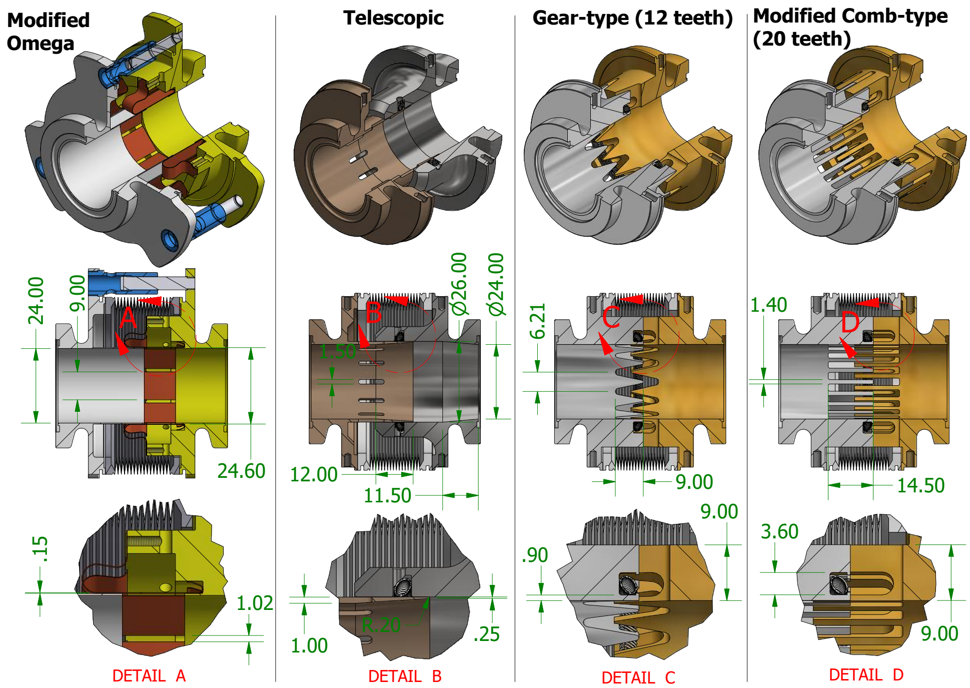

Figure 1: Mechanical designs for prototyping and wakefield simulations. Each column applies for one design: modified omega, telescopic, gear-type and modified comb-type, respectively. First row depicts perspective view (3/4 section, suppressed bellows); second row, center-cut longitudinal section; third row, electrical contact detail. Units in millimeters.

Figure 2: Telescopic bellows prototype: male (left) and female (right) parts, with the lodged coil spring.

respect to the beam axis, the transverse separation between the pieces reaches a maximum value of 100 μm.

Front 2: Gap-dependent Designs

For this approach, a specification of 0.5 mm lateral gap between neighbor teeth at the fully compressed position was employed. The initial efforts were spent at simplifying the electrical contact between the mating comb-type teeth. So as does the original contact through spring fingers [5], shielding ideas proved effective as they were closer to the inner chamber profile. Figure 3 highlights the importance of short-circuiting a bare 20-teeth shielding (blue curve) and other aspects. In this comparison, a 6 mm longidutinal gap was set for all geometries, that employs 9 mm long teeth – i.e. providing a 3 mm longitudinal overlap.

The concept of electrical contact was achieved (orange curve) by means of a spring coil tightly assembled in an axisymmetric holding groove machined at the tip of the teeth, just 0.9 mm away from the 12 mm chamber radius (see details C and D from Fig. 1). On the opposite mating teeth, a sliding groove is machined along almost their entire length. Later, smaller amounts of teeth were considered for machining simplification and was found that 12 teeth (red curve) provided a good compromise between mechanical and electromagnetic aspects. Finally, tapering the fingers in the gear-type shape in Fig. 1 have improved the high-frequency performance – to be discussed in the next subsection – without bringing any relevant HOM in the matter of wake heating, as can be seen by the green curve in Fig. 3. Figure 4 details the mating gear-type teeth and the spring grooves.

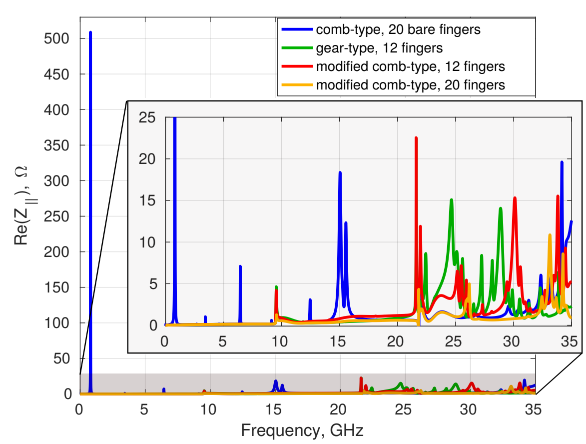

Figure 3: Real part of longitudinal impedance comparison between the studied gap-dependent designs with 9 mm long teeth and 6 mm longitudinal gap.

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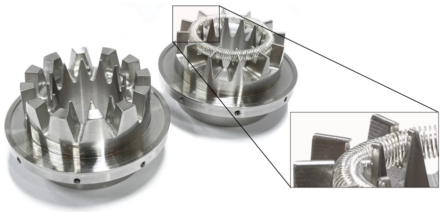

Figure 4: Gear-type bellows prototype: slider (left) and holder (right) parts, with the lodged coil spring in detail.

Unfortunately, the 12 teeth type designs are limited in compression range specification since the HOM trapped inside the sliding groove has its center frequency reduced and strength increased with the teeth lengthening. As a workaround, bringing the number of teeth up again reverses such effect, but a gear-shaped tooth is no longer feasible as can be easily observed in the 20-teeth modified comb-type design from Fig. 1, with 14.5 mm long fingers.

Final Motivations and Overall Comparison

Series production aspects and long range compression requirements of 9 mm have led the choice for telescopic bellows design to attend Sirius storage ring. Despite their easier assembling process, the tight fitting tolerances between their parts requires low machining tolerances and can lead to possible movement locking when not predominately subject to axial forces (bending moment). Thin longitudinal slots were machined on the edge of the male piece (see Fig. 2) as an attempt of softening it, but were unsuccessful and not applied to the final version. Locations where they experience such load distribution – after some bending dipole chambers – require only 6 mm bellows compression range, so the gear-type model is being considered as a possible substitute.

An extra demand has come from few places of the injection sector, where a 0.5 mm lateral displacement is needed to accommodate possible assembling offsets together with 9 mm longitudinal range for thermal expansion, therefore motivating the presented modified comb-type design.

An effective way to compare the electromagnetic performance of the four designs in Fig. 1 is through the loss and kick factors in the high frequency regime and their dependencies with the bunch length. This allows to observe how their contribution are distributed in spectrum. Among several aspects, the results presented in Fig. 5 show how the longitudinal gap variation impact behave differently on the gap-dependent designs and how better are their overall performance against the gap-independent ones. The 12-teeth modified comb-type was added to the comparison (red curves in Figs. 3 and 5) to give reference for the gear-type RF-shielding performance on the 9 mm long teeth basis.

CONCLUSION

Bellows RF-shielding solutions for Sirius storage ring have been presented. Table 1 qualitatively aids Fig. 5 to interpret the compromise between electromagnetic performance and mechanical aspects.

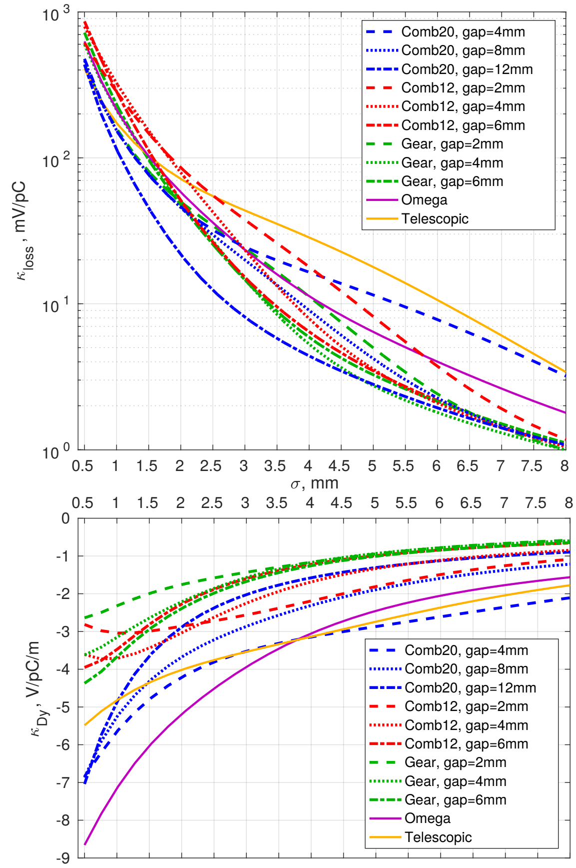

Figure 5: Single bunch loss/kick factor contribution of the 4 bellows geometries, with respect to the bunch length σ. A fifth design not prototyped at Sirius (12-teeth modified comb with 9 mm long teeth) was also added to the plot for comparison basis with the gear-type design.

Table 1: Qualitative Comparison between the Four considered Designs from Fig. 1 in Terms of Mechanical Aspects

Mechanical Aspect	**Modif. Omega**	**Telesc.**	**Gear**	**Modif. Comb**
Fabrication complexity	+++	+++	++++	+++++
Assembly difficulty	++++	+	++	++
Est. Cost	+++	++	+++	++++
Bake-out resilience	++	+++	+++	+++
Ext. limiter requirement	++++	+	+++	+++
Design complexity	+++	++	+++	+++
Manuf. tol.	+++	++++	+++	+++

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REFERENCES

[1] R. T. Neuenschwander, S. R. Marques, R. M. Seraphim, A. R. D. Rodrigues, and L. Liu, "Engineering Challenges of Future Light Sources," in *Proc. IPAC'15*, Richmond, VA, USA, May 2015, pp. 1308–1313.

[2] F. H. de Sá and L. Liu, "Collective Instability Studies for Sirius," in *Proc. IPAC'19*, Melbourne, Australia, May 2019, this conference.

[3] S. Tomassini, . Marcellini, P. Raimondi, and G. Sensolini, "A New RF Shielded Bellows for DAΦNE Upgrade," in *Proc. EPAC'08*, Genoa, Italy, Jun. 2008, pp. 1706–1708.

[4] Y. Suetsugu, K. Shibata, and K. Kanazawa, "Conceptual Design of Vacuum System for Super KEKB," in *Proc. PAC'03*, vol. 2, Portland, OR, USA, May 2003, pp. 806–808.

[5] Y. Suetsugu *et al.*, "Development of a Bellows Chamber with a Comb-type RF Shield for High-current Accelerators," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 531, no. 3, pp. 367–374, Oct. 2004.

[6] The GdfidL Electromagnetic Field simulator. http://www.gdfidl.de/

[7] H. O. C. D. Duarte, S. R. Marques, T. M. Rocha, F. H. de Sá, and L. Liu, "Analysis and Countermeasures of Wakefield Heat Losses for Sirius," in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 3052–3055.