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RF FINGERS FOR THE NEW ESRF-EBS STORAGE RING

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Abstract

In the new ESRF-EBS (Extremely Brilliant Source) storage ring vacuum chambers assembly, with a reduced aperture and the new omega shape, RF fingers are a key component to ensure good vacuum conditions and reach the best possible machine performance. As a result, dedicated efforts were put into producing a more compact more robust more reliable and easier to assemble RF finger design for the new machine. The work was done in parallel on the beam coupling impedance reduction, which have a direct impact on the electron beam lifetime, and on the mechanical aspect with FEA validation and geometry optimization. Many test have been made, in a mechanical laboratory, including high resolution 3D computed tomography images in order to measure the electrical contact, and also in the existing ESRF storage ring with the electron beam, to validate the final design before launching the series production.

INTRODUCTION

In order to absorb chamber-to-chamber misalignments, thermal expansion, for instance during bake-out, bellows are used to inter-connect a large number of chambers along the ring circumference. These bellows however are seen as resonant cavities by the beam hence breaking the geometrical continuity of the beam pipe and leading to degraded vacuum and stability performance. The continuity is restored by electrically shielding the bellows from the beam using so-called RF fingers which consist of conductors matching the vacuum chamber profile and connecting the beam pipes on either side of the bellow. The RF fingers are meant to absorb mechanical movements while providing the best possible mechanical and geometrical continuity: designing such a device is therefore far from trivial since many aspects have to be carefully optimized.

The new omega-shaped chamber profile is not compatible with the present RF finger design if geometrical continuity is to be enforced. A dedicated in-house design based on new concepts and principles was therefore devised for the ESRF-EBS ring. Figure 1 shows the final design. It is the result of several iterations and optimizations of beam coupling impedance and mechanical properties.

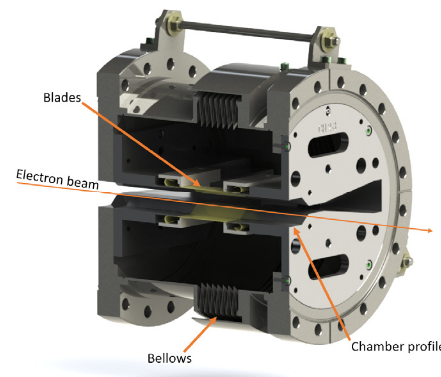

Figure 1: RF Finger placed in a bellows.

BEAM COUPLING IMPEDANCE REDUCTION

The first step was to ensure that the cavity formed by the bellow was properly shielded from the beam. This was achieved by 10 blades (5 top and 5 bottom) as seen in Fig. 2. Once the bellow is invisible to the beam, the beam coupling impedance is strictly given by geometrical discontinuities of the inner volume: in this case the steps and tapers angle at the entrance and exit of the RF fingers can be seen in Fig. 2. The step height was fixed to 0.3mm for mechanical criteria and the only parameter left for optimization was the taper angle, a good compromise was found with a reduction of the taper angle from 5° to 2° leading to a reduction of the beam coupling impedance by a factor 4. This result was found satisfactory as the resulting full contribution of the RF fingers to the total impedance of the machine became significantly smaller than the contribution of beam pipes themselves.

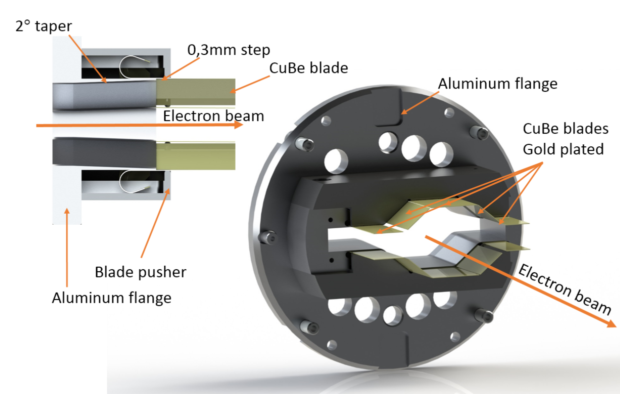

Figure 2: RF Finger cut view.

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MECHANICAL ASPECTS, FEA VALIDATION AND GEOMETRY OPTIMIZATION

The shielding blades (the RF fingers) are made with copper-beryllium (*CuBe2)* and the flange parts with an aluminium alloy. Copper-beryllium is a high resistance, highly conductive alloy perfectly fitting for the RF finger's function whereas an aluminium alloy is easier to machine to achieve the desired complex shape of the flange part.

A profound structural mechanical finite element analysis (FEA) was performed to validate the new RF finger design as regards occurring mechanical stress and the necessary electrical contact. At the same time the FEA served to study the design optimization possibilities considering the specific component requirements. A parameter study of three key geometrical dimensions was carried out to gain knowledge about their influence on the performance and mechanical safety. One of the parameters that varied in the course of this thorough analysis was the blade thickness of the fingers.

In the structural analysis the new component concept generally showed good compliance for the defined requirements as the electric contact quality is very high. The latter mainly depends on the contact force which is comparably high for all parameter variations and of at least 1.5N per blade. As generally the image current on the surrounding walls is rather a surface current, this contact should be sufficient. In all load cases and movements the blades are in good contact at the relevant contact position.

The required flexibility can be safely guaranteed. This counts for different promising configurations of different blade thicknesses. While thinner blades tend to be more flexible, their contact force drops but the safety margin of occurring mechanical stress is higher. The usage of thinner blades that lead to a lower contact force could be a solution to reduce friction-caused wear while maintaining a very good electric contact, as the analysis showed. The safety factor of occurring mechanical stress against the elastic limit is at least 1.2 for the analysed parameter variations during a relative flange movement of 2mm between both flanges which was considered as sufficiently flexible. Small plastic deformations in the flange part turned out to be tolerable and the component's functionality can also be maintained.

The new design, patented [1], will be used on all chamber profiles, high, low and straight section profiles. Table 1 shows the mechanical performance achieved.

Table 1: RF Finger Mechanical Performances

Axial stroke	+8 / -19 mm
Radial stroke (all directions)	+/- 1 mm
Angular stroke (flange / flange)	+/- 5 degrees
Mechanical safety *at 2mm flange radial movement*	>1.2

RF-FINGER VALIDATION

Computed Tomography (CT) Imaging

The electrical contact validation has been made using the computed tomography imaging technique at the ESRF BM5 beam line. RF Finger images were made with filtered white beam on a dedicated tomography setup. Data acquisition was made by a PCO Edge ccd camera mounted on an X-ray optic with a 13.4 µm pixel size resolution.

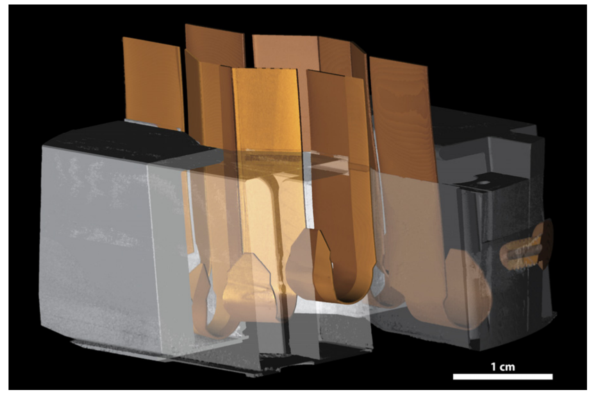

Figure 3: 3D generated volume view from CT images reconstructed.

After image reconstruction, as seen on Figure 3, it is possible to see the mechanical contact between blades and flanges at any position. The main point is the mechanical contact at the flange sleeve (Fig. 4 – Fig. 5).

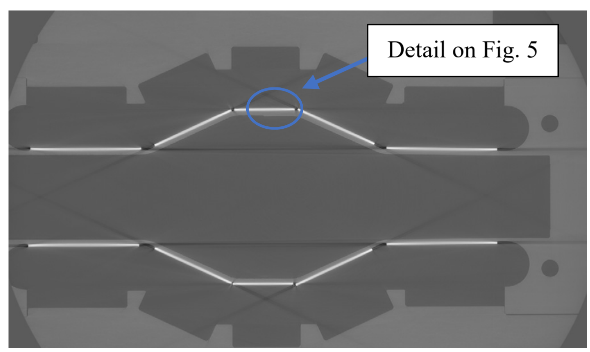

Figure 4 : 10 blades contact view on CT image.

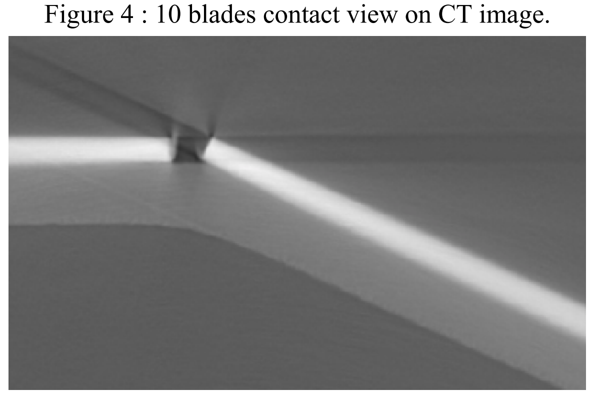

Figure 5: Detailed view of blade contact on CT image.

On Figure 6, at the 13. 4 µm pixel size resolution, the mechanical contact between the blade and the flange sleeve did not shows any gap.

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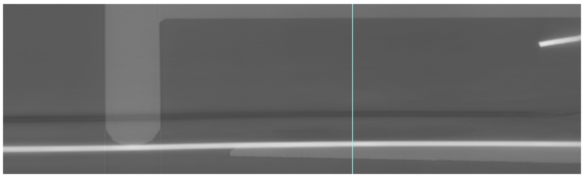

Figure 6: Longitudinal cut of upper central blade on CT image.

Synchrotron Beam Test

For RF performance validation, a test in the existing storage ring has been performed during a machine dedicated time (MDT).

Test bench description The test bench used (Fig. 7) was made with a dedicated vacuum chamber equipped on both ends with an edge welded bellows and RF-Fingers in the bellows. Thermocouples were welded on the middle of the external part of the upper and lower central blades, and connected to the data acquisition system. On the four thermocouples connected to the RF strips, only 2 were working during the test, Th3 and Th5. The central part of the chamber is mounted on a double remote controlled translation setup, one vertical (z) perpendicular to the beam and one horizontal (y) perpendicular to the beam. The x is the electron beam direction. Pressure gauges, penning type, were mounted on the upstream and downstream chambers.

The setup was placed in the European Synchrotron Radiation Facility (ESRF) storage ring, at a dedicated place.

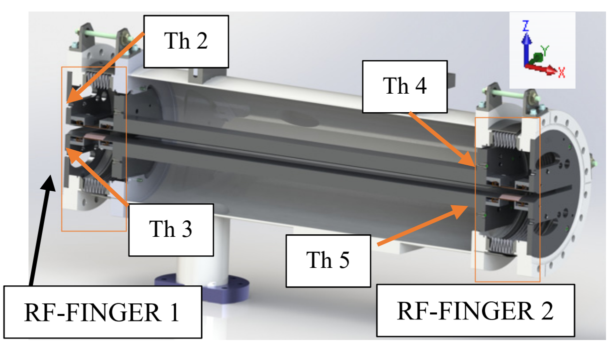

Figure 7: Cut view of the test chamber.

Test procedure The machine mode and ring current went up, step by step, in order to increase the current per bunch, as shown in Table 2. At each step, the chamber is moved by 0.1 mm from the central position to -1 mm and from the central position to +1 mm in Z. A Y translation is also performed using the same criteria but no variations, vacuum pressure and temperature, were observed during this scan.

Table 2: Machine Modes And Ring Current Used

Machine mode	Ring current [mA]	Current / bunch [mA]
uniform	20	0
16 bunches	16	1
16 bunches	32	2
16 bunched	64	4
16 bunches	92	6
4 bunches	31	8

Test results On the plot pressure versus Z position of the vacuum chamber (Fig. 8) the correct vertical alignment correspond to the minimum pressure observed. The pressure increase on miss alignment is linked to an increase of the temperature of all the system.

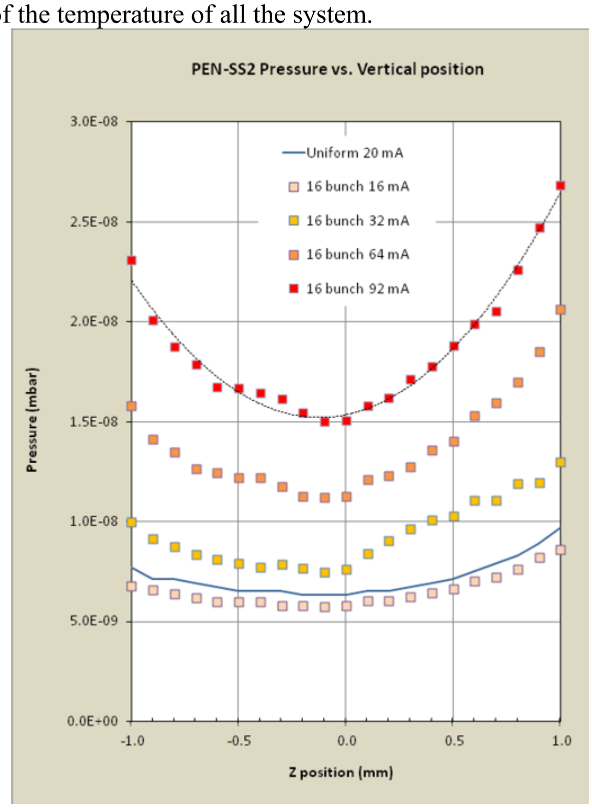

Figure 8: Pressure versus Z position.

No vacuum problem signature seen.

The temperature increase with the current per bunch in normal conditions with a maximum temperature measured at 130 °C (Fig. 9).

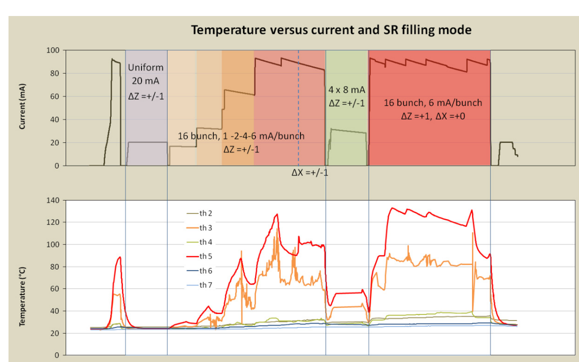

Figure 9: Temperature vs ring current and filling modes.

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The temperature and pressure observed during the test are acceptable considering that the test conditions are the more demanding modes. After dismounting, we did not observe any damage or marks on the two RF-Fingers devices

CONCLUSION

The new RF Finger design is flexible and compact. It can be adapted to any chamber profile. The full assembly is light, less than 1 kg, and made with machined pieces easy to assemble. No welding or brazing are used during the manufacturing process. It is easy to mount in any position, vertically or horizontally. The axial and radial strokes are large enough to compensate any chamber-to-chamber misalignments or chamber thermal expansion during the bake out. The reduction of the beam coupling impedance is archived with a very good electrical contact. The new ESRF-EBS storage ring will be equipped with this RF Finger design on all vacuum bellows and on all vacuum chambers where a RF Finger is needed.

REFERENCE

[1] Th. Brochard, L. Goirand, J. Pasquaud, “Dispositif de raccordement entre tronçons d'anneau de synchrotron”, B14959 EP, request number 17160419.2 -1211 / 3223591 claiming priority of patent FR 16/52454, March 22, 2016.