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STAINLESS STEEL VACUUM CHAMBERS FOR THE EBS STORAGE RING

P. Van Vaerenbergh*, J.-C. Biasci, D. Einfeld, L. Goirand, J. Léonardon, H. P. Marques, J. Pasquaud, K. Scheidt,
ESRF, 38000 Grenoble, France

Abstract

The upgrade of the ESRF (ESRF-EBS) is a highly challenging project in many respects. One major challenge is to manufacture vacuum chambers within extremely tight tolerances. Indeed, the chamber envelope is constrained by the very limited space available between the beam stay clear and the magnets pole tips, requiring profile tolerances of just 500 µm over the full length of the chamber for a width of 55 mm. An additional challenge is guaranteeing the perpendicularity (up to 0.75 mrad) between the CF flanges and the chamber body. While a design using discrete removable absorbers was chosen, one family of chambers contains a distributed absorber required to protect the insertion devices from 600 W of upstream dipole X-rays. Two companies have been selected to produce a total of 296 stainless steel chambers. Given the unusual tolerance requirements, the manufacturers have been obliged to adapt and develop their production techniques to overcome the challenges. During manufacture, vacuum leaks were discovered on some of the BPM buttons. This paper will also present the two techniques that ESRF has developed in order to prevent the integration of potentially leaking buttons.

INTRODUCTION

After the successful delivery of the first phase of the upgrade programme in the period 2009-2015, the ESRF launched in May 2015 the ESRF – Extremely Brilliant Source (ESRF – EBS) project [1, 2]. This ambitious 150 M€ programme aimed, amongst other things, to construct and commission a brand new 844 m circumference ESRF-EBS storage ring. The goal is to increase by a factor of 100 the brilliance and coherence of the beam whilst reducing by 20 % the electrical cost of operating the storage ring.

In 2015, the Mechanical Engineering Group of ESRF initiated the design and calculations for the EBS project vacuum chambers. The design difficulties of these chambers included the narrow aperture constraint within the magnets, the density of equipment (free space between magnets within a cell is 3.4 m instead of 8 m previously), the overall ring impedance budget and synchrotron radiation handling.

GENERAL DESIGN OF A STANDARD CELL

Besides the exception of the injection cell, all 32 cells of the storage ring share an identical vacuum chamber shape (with minor variations in the diagnostic equipment installed on some chambers that replaces the generic CH12).

The design phase led to a set of 424 vacuum chambers of which 296 were designed in 316LN stainless steel and 128 in 2219 aluminium alloy. Aluminium vacuum chambers are equipped with bimetal Conflat flanges (custom made from the chamber supplier by explosion bonding) [3]. All BPM blocks are part of the stainless-steel vacuum chambers. Some of the stainless-steel chambers can also accommodate fast correctors operating at high frequencies that cannot be installed on aluminium chambers due to the Eddy current. Figure 1 presents the general layout of a cell as well as the associated vacuum assembly.

DESIGN OF THE CHAMBERS

Space constraints and tight tolerances were the major challenges in the chamber design and production. The chambers were made as large as possible within the magnets, using anti-chambers to improve conductance and discrete absorbers to collect the synchrotron radiation. The limited available space also restricts the locations where vacuum chamber hardware such as flanges, bellows, pumps and the diagnostic equipment can be installed. Typically, the stainless-steel chambers have an "elliptical shape" with variable dimension antechambers to provide the path for X-ray extraction. The wall thickness is 1.625 mm with reinforcement at the location of the antechambers. In order to fit inside the magnets, a strict geometrical tolerance of the profile was compulsory. Figure 2 shows that for 55 mm width, and over the full length of the chamber, we have limited the shape deviation to 500 µm. Such tolerances have been verified, during the Factory Acceptance Tests, by using customised "Go-No-Go" jigs [4] and CMM (portable of fix devices).

Electron beam welding has been widely used to limit the distortion of the 316LN sheets during the welding process.

The stainless-steel chambers family has been split in two categories, the "High Profile" and the "Low Profile" (see Fig. 2 and Table 1). The vacuum chambers pass through the inside of the lattice magnets (quadrupoles, sextupoles, octupoles) with a minimum clearance smaller than 1 mm. This limited space has to accommodate the bake-out environment, the manufacture tolerances and the alignment errors (see Fig. 3).

* email address: vanvaer@esrf.fr

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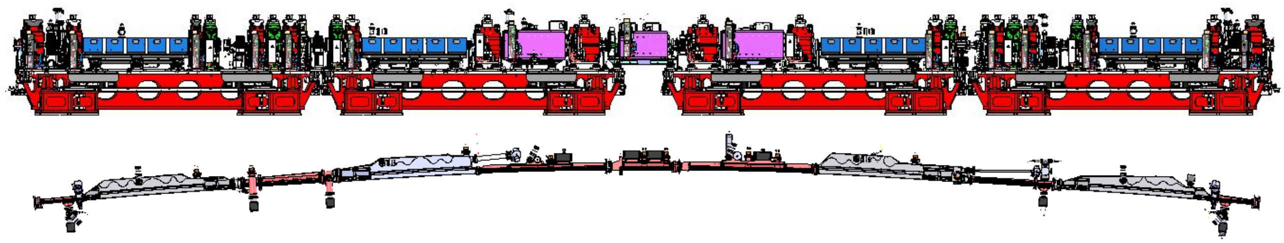

Figure 1: Front view of a cell (upper figure) and top view of the corresponding vacuum assembly (lower figure). Stainless steel chambers are highlighted in red in the lower figure.

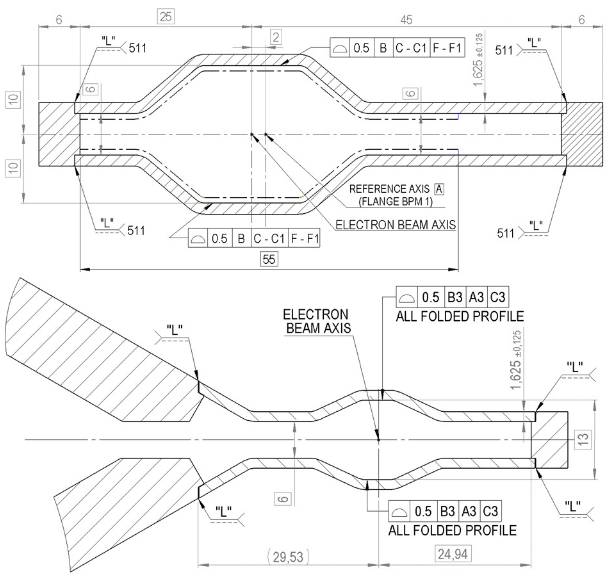

Figure 2: Side cut of a "*high profile*" chamber (upper figure) and of a "*low profile*" one (lower figure).

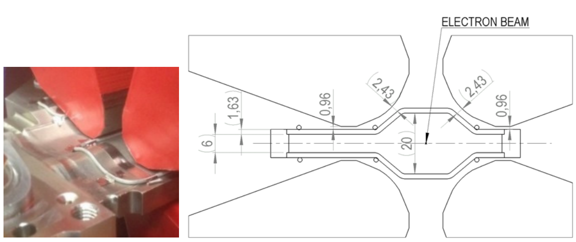

Figure 3: Picture and drawing showing the limited space available between the chamber and the pole tips. Heating wire elements are visible.

In the present design of a cell, the incorporation of the bellows has been made difficult due to lack of space. As a result, a good perpendicularity of the flanges (in the order of 0.75 mrad) was necessary to assemble the vacuum chambers and ensure their good positioning in the magnets. To do so, an extra thickness of material (typically 0.3 mm) was left on the side of the knife edge and the final machining of the fixed flange took place after its welding to the body. This ensured the best match between internal profiles of adjacent chambers (a step of just a few tenths of millimetres was allowed between two consecutive profiles). To avoid any internal gap between two flanges, soft aluminium RF gaskets have been designed and used.

Table 1: Stainless Steel Chambers Ordered

	Qty ordered	Qty delivered on 13/06/18	Profile type	Length [mm]
CH01	33	24	High	746
CH03	33	21	High	1386
CH04	37	1	High	269
CH06	34	10	Low	2290
CH07	34	1	Low	1202
CH08	34	7	Low	2366
CH11	35	19	High	1119
CH12	23	21	High	310
CH14	33	33	High	746

Out of a total of 296 chambers, 46 % have been successfully delivered, assembled in the girders and commissioned as of 13/06/2018.

CHAMBER WITH INTEGRATED ABSORBER

All along the length of a standard cell, discrete removable absorbers have been used. On the other hand on chamber CH14, to protect the beginning of the straight section chamber, a distributed absorber has been used due to lack of space. Impinging power (600 W) originating from the upstream dipoles, is stopped by a compound strip of OFHC copper and 316LN stainless steel (obtained by explosion bonding) welded in the chamber.

The design (Fig. 4) included cooling of this strip as well as cooling of the opposite side of the chamber (in order to cope with the reflected power).

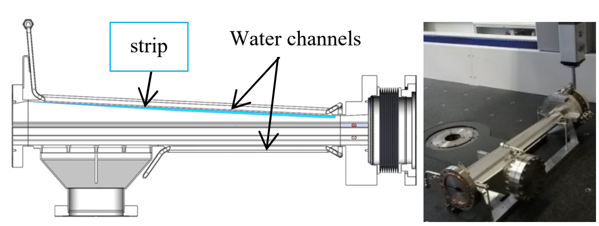

Figure 4: Cut view of the CH14 design (left) and measurement of this chamber on a CMM (right).

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VACUUM CONSIDERATIONS

CH01 and CH14 are integral parts of the straight section vacuum sector. These chambers are connected to the ID chambers: in-vacuum undulators or aluminium, 8 mm internal gap, ID chambers. ID chambers are required to be coated with NEG (Non-Evaporable Getter) to achieve the necessary vacuum performance.

NEG coating was applied on CH14 to better pump photodesorbed gases from the distributed absorber on the narrow cross section. This avoids higher pressure at the entrance of the ID chamber.

Although in terms of vacuum the storage ring could be operated with an uncoated CH01, it was decided to also coat CH01 so that the complete straight section is NEG coated (the coating is produced in-house [5]). This will maintain low pressure all along the straight section and the ID chambers will be better pumped from both extremities.

BPM BUTTONS AND ASSOCIATED DEFECTS

With the exception of CH04 and CH12, all the stainless-steel chambers have up to 8 BPM buttons each. Two analysis techniques have been used in order to detect mechanical defects within the buttons, as well as to prevent the welding of vacuum-leaking buttons to the chamber body.

A 3D X-ray tomography technique was used to identify defects within the bulk of a sample. In the present case, we have identified numerous "straw"-like defects within the 316L material (which serves as the BPM body). Some of these "straws" (see Fig 5, left picture, the black line crossing the button is the defect) have been identified as through holes and therefore lead to a vacuum leak. Their diameters are in the range of the micrometer. This problem has been solved by selecting a 316L raw material manufactured specifically according to the ESR (Electro-Slag Remelting) process.

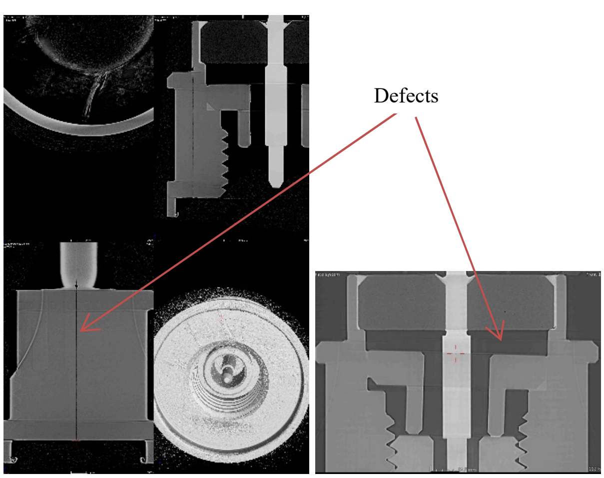

Figure 5: Tomographies of BPM buttons. Presence of a "straw"-like defect crossing the whole button (left picture) and wrong mechanical assembly (right picture). Courtesy: P. Tafforeau (BM05/ID19 – ESRF).

A second technique has been used to confirm the vacuum tightness of the buttons: a special attachment was fitted to a leak detector, the BPM button rim was put in direct contact with a customised *Viton* gasket and a cap was fitted on top (Fig. 6). By spraying helium through the cap, it was possible to identify leaks in the range of 10^{-10} mbar.l/s. [6]

Figure 6: Leak detection device for an individual BPM button.

CONCLUSION

The building of an ultra-bright synchrotron source, with performances 100 times superior to present day synchrotrons, is well underway and shall deliver its first beam to users in August 2020. The production of the associated chambers is ongoing and as of 13/06/2018, 57 girders of a total 129 have been successfully equipped with their chambers. To do so it has required the development of specific machining techniques to cope with the requirement of flange perpendicularities and other tight tolerances.

ACKNOWLEDGEMENTS

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