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ALUMINIUM AND BIMETALLIC VACUUM CHAMBERS FOR THE NEW ESRF STORAGE RING (EBS)

F. Cianciosi, P. Brumund, L. Goirand,
ESRF (European Synchrotron Radiation Facility), 38000 Grenoble, France

Abstract

The ESRF is proceeding with the design and procurement of its new, low emittance EBS storage ring (Extremely Brilliant Source project). This completely new storage ring requires a new vacuum system including UHV chambers with complex shape and strict geometrical and dimensional tolerances. Due to these complexities, it was decided to build some of the chambers in an aluminium alloy machined from bulk material; the only technology permitting to respect these challenging requirements. This project now consists of 128 chambers, 2.5m long, built in alloy 2219 with custom-built Conflat flanges made by explosion bonding. The production phase is nearly finished and the chambers that have been produced fully satisfy expectations. A second generation of experimental aluminium chambers was also designed as a substitute for some of the steel chambers in an attempt to resolve part of the geometrical difficulties. These chambers are highly complex as they contain steel-aluminium junctions in the body in order to accommodate bellows and beam position monitor buttons. The delivery of the first prototype of this type of chamber is planned for June 2018.

CHOICE OF THE TECHNOLOGY

The new storage ring requires a very complex vacuum chamber system [1]. The magnets lattice and its dimensions leave very little space for the chambers, resulting in a rather complex shape. Furthermore, the beam has a very curved path, due to the presence of 4 dipole arrays (each comprising 5 permanent magnet modules with 5 different bending radii), and 3 dipole-quadrupoles. For the chambers inside the dipoles, the only technology that can be used to produce such a difficult shape is machining from bulk material. For the other chambers, it is possible to use a construction of formed and welded sheet metal.

CHOICE OF MATERIALS

The material of the chambers shall have a very low magnetic permeability, sufficient strength at bake-out temperature (150°C), to be electrically conductive and, of course, UHV compatible (down to pressure levels of $10^{-10} mBar$). The only affordable choice for the dipole chambers that are made of bulk material was an aluminium alloy, while for the other chambers the best option was stainless steel AISI316LN ESR, which is more resistant in thin sheets and easily weldable [2]. The decision to make some of the chambers from steel meant that the EBS cell could be designed in such a way that all the bellows and the BPMs could be located on the chambers. These components are very difficult to integrate in aluminium chambers (see Fig. 1). A careful analysis of the available weldable aluminium alloys for the dipole chambers revealed that the best material used at high temperatures during bake-out is the 2219T851 (ultimate tensile strength at 150C for 1000h: $\sigma_{UTS} = 220\text{MPa}$ [3]).

MECHANICAL DESIGN

Flanges

Two types of flanges were investigated, both based on the CF standard. The first is the aluminium type produced by *Kurt J. Lesker*. It has the advantage of being made of the same alloy as the chambers (2219 T851). However, these flanges are only compatible with pure aluminium gaskets and are sensitive to damage. The second flange type was a bimetallic flange, which is compatible with copper gaskets and is more robust, although they do present a danger of galvanic corrosion and leaks in the joint between the two materials. After a profound analysis of tender offers for the production of these flanges, the ESRF accepted the tender from *CECOM*, Italy, whose proposal consisted of custom-made bimetallic flanges machined from bimetallic sheets carefully controlled in order to avoid the risk of leaks due to bad bonding. *CECOM* assumed full responsibility for the quality of the flanges even after their installation on the chamber, thus avoiding liability issues in the event of problems between the supplier of the bimetallic material and the manufacturer of the chambers.

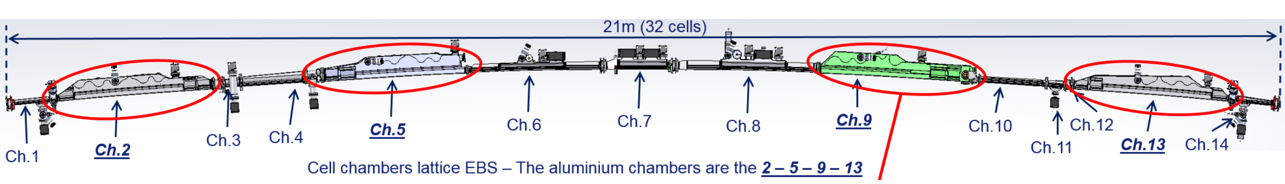

Figure 1: Vacuum chambers on one cell of EBS.

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Bodies and Welding

The bodies of the chambers are machined from bulk material Al2219 T851 plates. The drawback of this material is its weldability, which is slightly lower compared to 5XXX and 6YYY alloys. To investigate this aspect a welding test campaign and a prototype chamber were commissioned to *ALCA TECHNOLOGY* (Schio, Italy) (see Fig. 2). The welding is done on the exterior, on relatively thin lips. This is sufficient as the main efforts coming from the vacuum pressure are compensated by the body surfaces in contact near the joints and in some specific areas inside the chambers (see Fig. 3). As no cleaning is possible after welding, special attention is required to keep the chambers clean during the welding process.

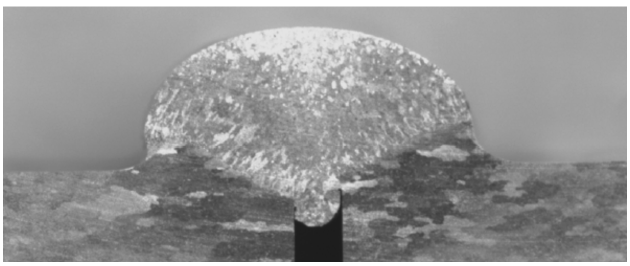

Figure 2: Welding test.

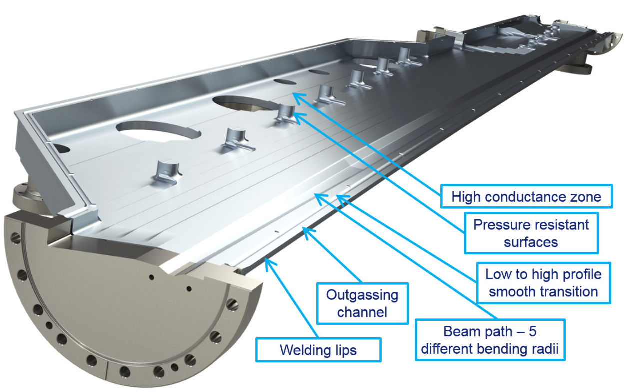

Figure 3: Bodies and welding (CH9).

Typical tolerance levels for the body are +/-0.05mm, whilst critical flange orientations of the final assembly are +/-0.06deg. Roughness levels are requested down to $Ra = 0.4$ in the beam zone.

CALCULATIONS

Static

The chambers have to resist the static loads resulting from the vacuum and gravity. A FEM analysis was performed to ensure sufficient resistance of the material with respect to these loads, especially in proximity to welding and even at the bake-out temperature (150°C). The maximum stress in the material, mainly due to the vacuum pressure, is below$\sigma_{vM} = 50MPa$, so the safety coefficient is 4. This relatively high value is necessary because of the possibility of imperfections in the welding. The maximum deformation of the chamber under its own weight including equipment (pumps and other vacuum equipment) is below 0.1 mm.

Thermal

The aim of the thermal calculation is to study the uniformity of the temperature field and the power needed during the bake-out. The heating is made with an electrical wire pressed into a groove in each of the two chamber halves and heating collars on the flanges. A strong thermal insulation of the chambers is impossible due to space constraints (especially in vicinity of the magnets), so even if each thermal source is closed-loop controlled with an independent thermocouple, significant temperature deviations can still occur. If the temperature is too low, the bake-out is not effective; if it is too high the chamber can be damaged. The calculations show that the maximum deviation from the target temperature $T = 150°C$ is around $\Delta T = 25K$, which is acceptable (see Fig. 5).

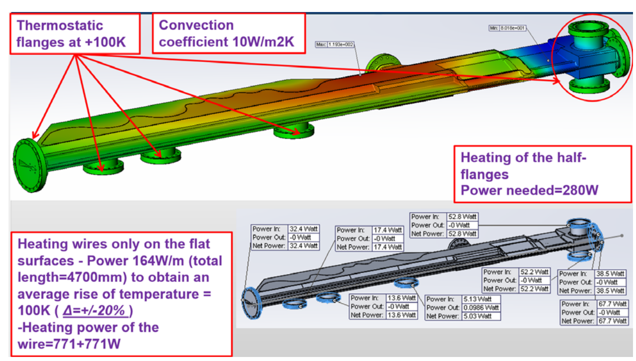

Figure 5: Thermal calculations

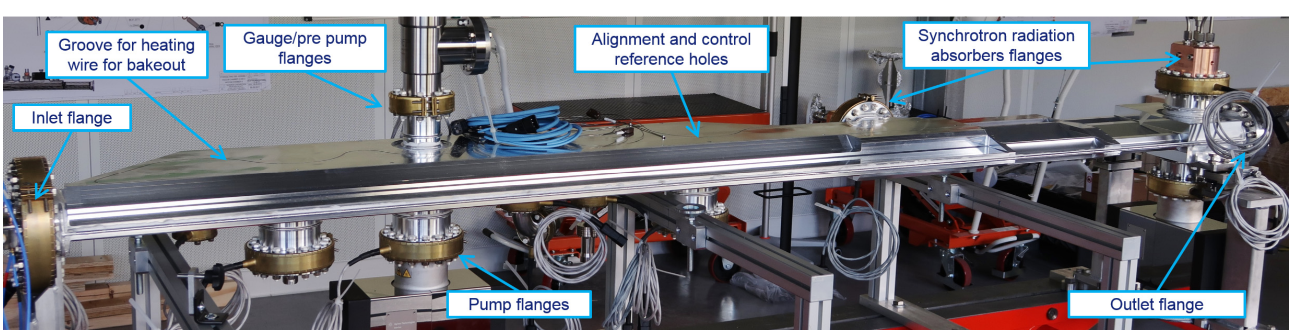

Figure 4: Series vacuum chamber (CH9) built by CECOM.

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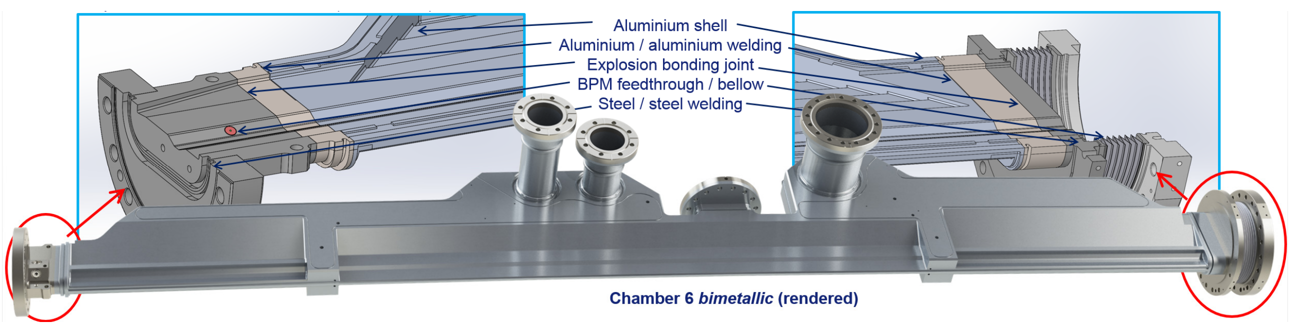

Figure 6: Vacuum chamber bimetallic (CH6).

BIMETALLIC CHAMBERS

Introduction

A new chamber series with bimetallic design was added most recently to the ESRF vacuum chambers for the EBS machine: the CH6-7-8 aluminum version. These chambers are highly complex in shape and technology as they contain both aluminum alloy and stainless-steel parts and have to guarantee very tight mechanical tolerances.

Origin of the Design Need

The chambers 6, 7 and 8 have a complex geometry, primarily due to their location within the quadrupole and dipole-quadrupole zones of the EBS cell. They contain both bellows and beam position monitor (BPM) blocks made of stainless steel as well as absorber ports. The initial design of the chambers was entirely of stainless steel due to this additional equipment installed on the chambers. The design involved welded sheet metal and plates, even though the complexity of the shape makes the dimensional and geometrical tolerances very hard to reach. Because of these technical difficulties, it was decided to create an alternative design in order to have spare chambers in case of problems.

Technical Details

The success of the aluminum chamber series CH2-5-9-13 through the collaboration with *CECOM* and the experience gained from this series paved the way for the design of a new generation CH6-7-8-series. This new design incorporates relevant parts in stainless steel AISI 316LN to hold the BPMs, the bellows and equipment ports. Nevertheless, a crucial difference from the initial series design is that the main section, the chamber body, is made of aluminum alloy 2219 bulk material. This alloy proved to be a very good choice regarding machinability and its welding capacity for the series CH2-5-9-13, as presented in the previous section.

The main difficulty in the new series lies in the junction between the two materials: Al2219 and AISI 316LN. Each chamber of the CH6-7-8-series contains a custom-designed bi-metallic part that serves as junction. These custom-built parts incorporate the material transition zone, the BPM blocks, as well as the corrector magnet and wiggler magnet zones. To avoid excessively high temperatures in the bi-metallic zones, sufficient material remains between the welding lips to the chamber and the bi-metallic section. The bi-metallic part is fed through the corresponding entry and exit flanges towards a welding from the chamber outside to the flange disks to keep raw material consumption low for the bi-metallic material (see Fig. 6).

The required geometrical and dimensional tolerances for the body and the bi-metallic areas are comparable to the chamber series CH2-5-9-13 - at some points slightly lower to leave an error margin due to difficulties with the bi-metallic junctions and additional welds.

The first prototype of the new design series is expected by the end of July 2018.

CONCLUSION

The aluminium vacuum chambers designed and produced for EBS conform to the specifications and have been successfully mounted inside the magnets on the girders ready for installation in the tunnel during 2019.

The preliminary results of the bimetallic chambers are very encouraging and demonstrate that this new technology can be used to produce affordable chambers with very complex shape and tight geometrical tolerances.

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