ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPME040

DEVELOPMENT OF ALUMINIUM VACUUM CHAMBERS FOR THE LHC EXPERIMENTS AT CERN

M. Gallilee, P Chiggiato, P Costa-Pinto, P Lepeule, J. Perez-Espinos
Leonel Marques Antunes Ferreira, Laurent Prever-Loiri, Antonios Sapountzis
CERN, Geneva, Switzerland

Abstract

Beam losses may cause activation of vacuum chamber walls, in particular those of the Large Hadron Collider (LHC) experiments. For the High Luminosity (HL-LHC), the activation of such vacuum chambers will increase. It is therefore necessary to use a vacuum chamber material which interacts less with the circulating beam. While beryllium is reserved for the collision point, a good compromise between cost, availability and transparency is obtained with aluminium alloys; such materials are a preferred choice with respect to austenitic stainless steel. Manufacturing a thin-wall aluminium vacuum chamber presents several challenges as the material grade needs to be machinable, weldable, leak-tight for small thicknesses, and able to withstand heating to 250°C for extended periods of time. This paper presents some of the technical challenges during the manufacture of these vacuum chambers and the methods for overcoming production difficulties, including surface treatments and Non-Evaporable Getter (NEG) thin-film coating.

INTRODUCTION

Beam losses and collision debris in the LHC induce activation of beampipes, in particular those integrated in the four LHC experiments [1], mostly made of stainless steel and copper. To reduce activation, more transparent materials are needed. This is why some aluminium vacuum chambers are now, during the LS1, replacing the existing beampipes. Experience with the manufacture of the first NEG-coated aluminium chambers for the ATLAS and LHCb experiments has yielded mixed results, and solutions for a better production procedure have been found.

Manufacturing a thin-walled vacuum chamber capable of operating in Ultra-High Vacuum (UHV) is difficult. Manufacturing such chambers in aluminium is even more difficult given that welding can result in porosity when compared with materials such as stainless steel. Also, the grain size of aluminium material is critical due to the fact that the LHC experimental vacuum chambers are generally machined from solid material for reliability reasons. As a rule, the vacuum chamber wall should have 10 grains through the thickness to prevent leaks appearing later. After an initial qualification of a manufacturing procedure for aluminium chambers, with successful first results, some further chambers manufactured for the ATLAS experiment exhibited peeling off of the internal NEG coating. A total of 16 vacuum chambers were manufactured in aluminium, namely the ATLAS VA, VAP, and VT chambers and the LHCb bellows UX85/1 and 2. A further 6 aluminium chambers would be manufactured later, more specifically three more ATLAS VA chambers and three newly designed ATLAS VJ chambers. It was observed that after baking the ATLAS VA chambers from the first set of 16 aluminium chambers to 250^{o}C, they exhibited deformation. It was necessary to qualify a new manufacturing method which was more reliable in terms of NEG coating and manufacturing tolerances after baking.

FIRST SERIES PRODUCTION CHALLENGES

During the production of the first 16 aluminium UHV chambers for the LHC experiments, an initial production method was established whereby the raw components for the assemblies were firstly tested for dimensional conformity, cut, cleaned for UHV and then welded in a clean environment by electron beam. This method was verified in conjunction with our coatings laboratory at CERN and worked for the first production of aluminium vacuum chambers. These chambers were 60 to 80 mm in diameter, between 1 and 1.5 mm wall thickness and up to 4.5 m in length. An unexpected non-conformity occurred for the ATLAS VA chambers. Firstly, they deformed with the bakeout process, post production [2]. This process was below the annealing temperature of the material; however it was understood that the heating had relieved stresses in the material, leading to the deformation. This deformation was mechanically removed to bring the chambers back to the required tolerance.

After the vacuum and metrology acceptance tests, each chamber was coated with a NEG thin film by DC cylindrical magnetron sputtering. (Additional information about the CERN coating the facility can be found in [3].) Prior to coating, the cambers were evacuated and baked at 180^{o}C for 20 hours. The discharge power density was 30 W per meter of cathode, the voltage about 450V, the pressure 2-1x10^{-3} mbar (Krypton) and the magnetic flux 0.015 T. During the deposition, the temperature was kept constant at 100^{o}C.

Small coupons, coated in each run, were used to monitor the thickness by x-ray fluorescence. Surface composition and activation, (2 hours at 250^{o}C), were checked by X-ray Photoelectron Spectroscopy (XPS). For all the chambers treated, thickness, stoichiometry and the activation performance, (reduction of zirconium oxide), matched the standard requirements.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPME040

Figure 1: Peel-off.

Adhesion was also good for most of the chambers, being the VA type the only exception. For the three VA chambers treated, in independent runs, peel-off was observed at exactly the same place: after a weld between bellows and a short sleeve, around 2 cm in length, and on the flanges to a lesser extent. The outcome from an optical inspection with an endoscope (see Figure 1) has supported evidence for variation of the mechanical inner surface texture in the sleeve that coincides with the peel-off area. X-ray photoelectron spectroscopy was used to analyse the back of the coating that was in contact with the aluminium surface but no relevant contamination was found that could explain the poor adhesion. Since no wet chemical etching could be applied in order to remove the NEG in the whole chamber, due to the risk of trapping corrosion active elements in the bellow, the coating on the zones with peel-off was removed mechanically. The chamber was then bombarded with Krypton ions at approximately 400 eV at a dose of $2.8x10^{-3}$ C/mm^2, and then recoated with NEG without air exposure in between. The peel-off persisted, indicating the origin of the problem is not related with last layers of the aluminium surface. Since both the short sleeve and the flanges have the same turned mechanical surface finish, and the other parts are honed, except the bellow, we suspect this surface finish may be linked to the lack of adhesion.

To avoid the same problem in three subsequent VT type chambers, it was decided to etch the surface before coating. After an optimization study on coupons made of the same aluminium alloys present in the chambers, the treatment chosen was flush degreasing with P3-almeco® 18 (HENKEL) 20 g/l for 20 minutes at 50 °C and flush picking with CrO_3 and H_2SO_4 solution. About 80 nm of aluminium was removed. An important aspect of this treatment is its compatibility with the thin walled aluminium bellows. The chambers were then coated with the same parameters as the VA and no peel-off was observed after an endoscopic analysis and subsequent baking of the chambers.

NEW MECHANICAL ASSEMBLY METHOD AND NEG COATING

As some of the first set of chambers exhibited deformation after baking to 250°C for 24 hours to activate the NEG coating, a pre-annealing step was applied. Before manufacturing individual components from the raw material, the material was heated for a period of 48 hours at 250°C in a vacuum oven. This was to relieve any stresses in the raw material that would otherwise be relieved at this temperature. Although this will decrease the mechanical properties of the aluminium, it is the Young's Modulus that is important for the design factors of safety and this remains unchanged. Stresses are extremely low, with factors of safety decided by buckling modes of the chamber. It was found that with the introduction of the pre-annealing step, the newly assembled chambers yielded very good mechanical tolerances, mostly exceeding the straightness requirements with up to a maximum of 0.1 mm for individual tubes of 1 m in length, and 2.6 mm for the welded chambers of 4.5 m in length, compared with a maximum of 3 mm and 18 mm respectively from previous tubes and chambers [2,4].

In order to achieve a good surface condition for NEG deposition, several studies were made. After an optimization process, a new procedure was devised for individual components before welding, and an additional cleaning step added for chambers after welding assembly. Concerning the first step for the individual components, except for the bellows, the components were etched in a solution of H_3PO_4 and HNO_3, for 2 hours at room temperature [5]. The objectives were to modify the surface finish of the components, machined by turning, to overcome the lack of adhesion for NEG coating ensuring the vacuum compatibility of the surfaces of the honed components. Material removal of 7µm ± 1µm was expected in all the cases. Figure 2 shows a magnified image before and after etching. Where bellows formed part of a chamber, no change was made to the surface preparation procedure before integration.

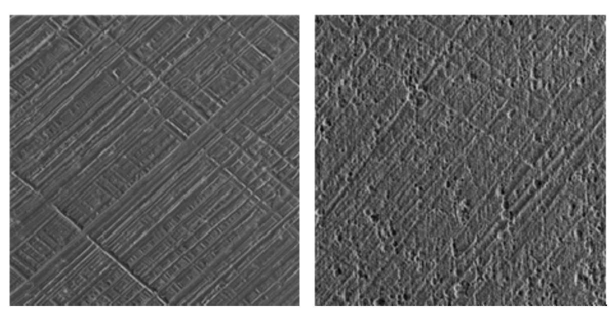

Figure 2: Image of honed surface finish before and after the etching process.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPME040

In addition to the work on mechanical integrity and surface analysis for NEG coating, during Electron Beam (EB) welding of the vacuum chamber components for the new chambers, unacceptable porosity was observed in some 2219 to 5083 aluminium welds between the chamber structure and aluminium bellows. After XPS analysis of a deposit on one of the support components for the chamber in the EB welder, it was found that this deposit was magnesium. It was therefore concluded that the magnesium alloying component in the 5083 grade of aluminium, due to a vapour pressure of 1 atm, was expanding in the vacuum environment and causing the porosity to occur in the melt pool of the weld under certain welding conditions. This conclusion was backed by a change in porosity levels depending on the weld rate. The dissimilar aluminium alloys were therefore welded by TIG, under an inert atmosphere. This prevented the rapid expansion of the magnesium vapour which led to the porosity.

After welding of components, a second surface treatment procedure was applied. This followed three main steps: a first immersion degreasing with NGL 17.40 for 30 minutes at 50°C, a second degreasing with P3-almeco®, and finally a flush pickling with CrO_3 and H_2SO_4. This is the same treatment applied to the VT chambers in the first series to guarantee the local surface condition in the welding areas and UHV compatibility of the chamber.

Figure 3 shows the NEG coating on the second set of chambers after implementation of the new etching and cleaning methods as mentioned above. Peel-off is not observed, and a constant surface finish can be seen.

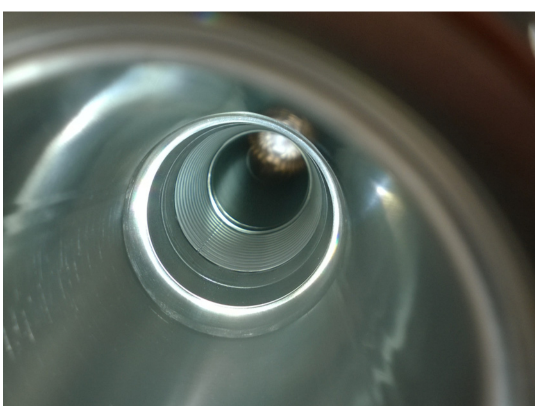

Figure 3: NEG coating of second series chamber with new surface treatments.

As a preventative measure for future production runs, during the second series, the production quality plan was updated with the CERN workshop and documented to integrate and record the changes. A physical traveller has been used to follow chamber manufacturing steps [6] and all relevant documentation has been added to the CERN manufacturing test file (MTF) to aid quality planning for future projects.

CONCLUSIONS AND FUTURE WORK

A previously qualified manufacturing method for aluminium UHV chambers was successful in trials and initial chamber production. In one set of chambers for ATLAS, NEG peel-off was observed in certain internal zones which were machined by turning. Etching modified the internal surface finish to resolve this issue. The new manufacturing method for these chambers has shown promise even on turned machined zones, and the pre-annealing has yielded vacuum chambers that adhere to, or exceed, the necessary mechanical tolerances. A further challenge was observed with porosity between aluminium grades 5083 used to manufacture aluminium bellows to 2219 used for the chamber bodies. This issue was resolved by using a TIG method of welding which doesn't allow the magnesium vapour in the 5083 aluminium to expand and create a void.

In future, vacuum chambers for experiments such as CMS and ALICE will be a further challenge when manufactured from aluminium. The quality records stored in MTF for the current chambers will help as a basis; however with larger diameter chambers, and thus reduced forging ratios for the aluminium raw material, achieving 10 grains through the wall thickness will be more difficult. Thinner walled chambers will also yield the same manufacturing difficulty, not only with the grain size, but also with development of new welding parameters. Discussion is ongoing with raw material suppliers to help find a solution.

Towards HL-LHC, even for aluminium chambers, activation will require remote handling in zones with high mass such as the chamber flanges. Reliability will be a key issue for such flanges so the aim will be to use highly reliable seals such as a ConFlat rather than the current helicoflex type in these zones.

ACKNOWLEDGMENTS

The authors would like to acknowledge the valuable inputs and discussions from colleagues, namely Gilles Favre, Stefano Sgobba and Ahmed Cherif.

REFERENCES

[1] R.Veness *et al.*, Installation and Commissioning of Vacuum Systems for the LHC Particle Detectors, PAC09.

[2] edms.cern.ch No 1240871 : VA ALUMINIUM CHAMBER ASSEMBLY LHCVC1AX0002.

[3] P. Chiggiato, P. Costa Pinto, Thin Solid Films 515 (2006) 382-388.

[4] edms.cern.ch No 1332006 : ATLAS chambre VA3 tubes LHCVC1TB0006 J3013803 après traitement.

[5] edms.cern.ch No. 1325441 Morphology comparison after different etching conditions of Al alloy samples (AW2219 and AW5083) from ATLAS VA Aluminium Chamber.

[6] edms.cern.ch No. 1308043 MASTER TEMPLATE Experimental Chambers Rev03 pdf.