LHC DETECTOR VACUUM SYSTEM CONSOLIDATION FOR LONG SHUTDOWN 1 (LS1) IN 2013-2014

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Abstract

The LHC has ventured into unchartered territory for Particle Physics accelerators. A dedicated consolidation program is required between 2013 and 2014 to ensure optimal physics performance. The experiments, ALICE, ATLAS, CMS, and LHCb, will utilise this shutdown, along with the gained experience of three years of physics running, to make optimisations to their detectors. New vacuum technologies have been developed for the experimental areas, to be integrated during this first phase shutdown. These technologies include bellows, vacuum chambers and ion pumps in aluminium, new beryllium vacuum chambers, and composite mechanical supports. An overview of this first phase consolidation program for the LHC experiments is presented.

INTRODUCTION

In the period 2007/2008, the LHC beam vacuum chambers were integrated into the four LHC experiments [1]. The LHC experiments started taking data in 2009. Since then, the LHC beam vacuum has performed extremely well. Knowledge has also been gained about the physics operation of the experiments with respect to beam vacuum chambers located in the heart of them. With this gained operational knowledge, certain changes have been identified to further improve the LHC running with respect to the experiments. A consolidation program has therefore been outlined in a series of three long shutdowns, the first of which (LS1), will take place between the period 2013 and 2014. This program of consolidations is broken down into agreed Work Packages between the LHC experiments and the CERN Vacuum Group (TE/VSC).

Changes to be implemented during LS1 include modifications of the ATLAS vacuum chambers from stainless steel to aluminium, implementation of an aluminium annular ion pump, aluminium bellows, more transparent beryllium vacuum chamber supports in LHCb. Finally, ATLAS and CMS will install smaller diameter beryllium chambers to accommodate an extra PIXEL layer [2].

REASONS FOR THE CHANGE

The LHC experimental vacuum chambers were designed in the period 1994-2003 [2]. Running of the LHC since 2009 has allowed experience to be gained with the beam vacuum system. With respect to the portion of the beam vacuum system running through the LHC experiments, certain changes have been identified. These identified changes will be implemented to improve detector background, material activation, and improve detector performance. Background and activation improvements will be implemented by changing vacuum chamber materials. ATLAS will change their forward chambers to aluminium; included in this change are aluminium bellows and a new aluminium ion pump. Detector performance will be improved by an additional PIXEL layer in the heart of ATLAS and CMS. These additional PIXEL layers will be added by reducing the diameter of the central beryllium chambers.

ALUMINIUM VACUUM CHAMBERS AND FLANGES

It was identified that the ATLAS forward chambers would benefit from a material change. This change will be from stainless steel to aluminium alloy AA2219, with the aim to reduce material activation and also background to the detector. The chambers were designed to be manufactured from sequentially welded tubular sections; machined from forged aluminium alloy AA2219.

The design challenge was with the chamber end sealing. Going from a fully stainless steel chamber to an aluminium version required reconsideration of the flange and seal design. The chosen seal was a Technetics HN190 with an aluminium skin and external centering ring, to allow for ease of installation when the chambers are in the horizontal position, as with the experimental caverns. Figure 1 shows an aluminium removable flange and HN190 seal. This flange was designed to be removable, allowing insertion of the central ATLAS vacuum chamber. The surface hardness of a chamber end flange sealing surface in AA2219 aluminium alloy was found to be greater than 65Hv, sufficient to seal against the aluminium skin of the HN190 seal [3].

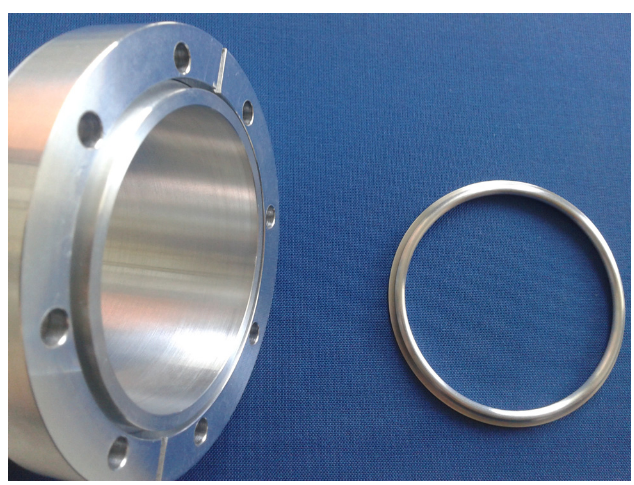

Figure 1: Aluminium removable flange and seal.

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ALUMINIUM ANNULAR ION PUMPS

For the ATLAS experiment, changes in vacuum chamber material from stainless steel to aluminium alloy AA2219 meant that the current integrated annular ion pumps had to be redesigned with an aluminium body. The ion pump construction is based on an annular triode cell encased in an aluminium body for a compact design and to allow the pumping noble gasses in the ATLAS experimental region. The construction of the first production models at CERN are shown in Fig.2.

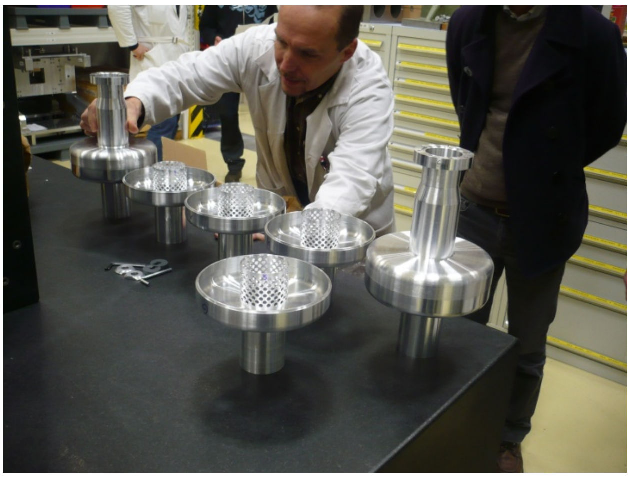

Figure 2: Production of ATLAS aluminium ion pumps at CERN.

A simulation of the ion pump design for pumping capacity showed no significant difference between the current pump and the aluminium version [4]. Ion pump cells procured from Agilent were integrated into an engineering model body and extensively vacuum tested at CERN. Testing validated no performance loss compared with the equivalent pump with a stainless steel body with a pumping speed for N_2 at $1x10^{-6}$ mbar of 11 l/s Compared with 12 l/s for stainless steel [5].

ALUMINIUM BELLOWS

Bellows are used as flexible elements to absorb the thermal expansion of vacuum chambers during bake-out and non-evaporable getter (NEG) activation, and also to compensate for mechanical tolerances. Aluminium bellows have been developed in order to increase transparency, and reduce material activation. Aluminium is a ductile material that can be used for thin walled corrugated shells; nevertheless the use for a vacuum bellows encompasses several technical issues. The material choice is crucial, it has to be weldable, corrosion resistant, and moreover keep good mechanical properties at high temperature for bake-out. The grade 5083 in the annealed state was chosen. The manufacturing technology is also important; a forming process was therefore used to take advantage of aluminium sheet metallurgical properties. For small diameter bellows, the ductility at room temperature is not sufficient to form the convolutions. High temperature forming was used in this case. The design of the bellows was done in two steps: a first set of bellow parameters was determined based on the Expansion Joint Manufacturers Association (EJMA) code, with an additional criterion related to the formability, i.e. the plastic strain occurring during the forming process with respect to the ductility. Then a Finite Element analysis was used to refine the bellows behaviour, including buckling analysis. The ATLAS bellows were manufactured in the CERN workshop and have been successfully validated for vacuum applications in terms of fatigue tests at room and high temperatures, and NEG coating. (see Fig.3). NEG coating is absolutely required to mitigate the electron cloud build-up resulting from the high secondary electron yield (SEY>2.7) of aluminium.

Figure 3: ATLAS 5083 aluminium bellows.

BERYLLIUM VACUUM CHAMBER SUPPORTS

Currently, the LHCb vacuum chambers are supported by aluminium collars; stainless steel rods and ropes then secure these collars to an external support structure. The current supports are a source of background to the experiment. It was requested to redesign the support system with respect to the radiation transparency. This was achieved by minimising the volume of materials, and choosing materials with high radiation length [7]. After extensive analysis, the most optimised design was composed of the following: The collar was redesigned giving a subsequent volume reduction of more than 47 percent, and the choice of a high radiation length material; instrumental grade beryllium I220H [8]. A Celazole interface ring [8], more transparent than the current graphite reinforced Vespel version, connects the collar to the beryllium beampipe. The new wire system is manufactured from carbon fibre rods, and Technora ropes [8], leading to a transparency gain of 90 % relative to the current design while keeping mechanical performance. Figure 4 shows the current support collar (left) compared with an aluminium prototype of the new design (right).

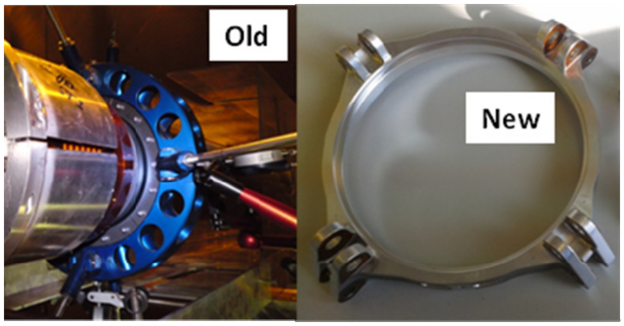

Figure 4: Current LHCb support collar design compared with the new design.

NEW BERYLLIUM CENTRAL CHAMBERS

The central beryllium chambers for ATLAS and CMS will be replaced between 2013 and 2014 to allow for an extra inner tracker PIXEL layer. The new chambers will be smaller in diameter to accommodate this new PIXEL layer. Information has been gathered since installation of these chambers in 2008. In the experimental areas, understanding has been gained with respect to the cavern stability, the size of the beam, and the mechanical and survey tolerances. Careful consideration of these parameters has allowed for the reduction in size of the new central vacuum chambers. The aperture reductions for these chambers have been analysed and agreed by CERN [2].

Both chambers were designed with ANSYS finite element; keeping a previously defined Factor of Safety of greater than 6 for the beryllium components [9]. The chambers are currently in production at Materion Electrofusion; the ATLAS chamber delivery is scheduled for August 2012, and the CMS chamber delivery planned for August 2013.

CONCLUSIONS AND FUTURE WORK

Knowledge has been gained during the running of the LHC Machine. Using this knowledge, a dedicated consolidation program was set up. LS1 is the first of a three-part consolidation program for the LHC experimental areas. It has been outlined that the work for LS1 will take place between 2013 and 2014; included in this work are changes to vacuum chambers, and their support materials to reduce background to the experiments. Many unique technologies have been developed at CERN around the concept of aluminium vacuum chambers. These technologies have been challenging to develop; however they will be of great benefit in terms of background and material activation.

A reduction of aperture for the central chambers will allow for an extra PIXEL layer; therefore improving detector performance for both ATLAS and CMS. Operational knowledge of the beam and detector has made this reduction in central chamber diameter possible.

In addition to LS1, future consolidation programs will extend up to 2022, with Long Shutdown 2 (LS2) planned for 2018, and Long Shutdown 3 (LS3) planned for 2022. In terms of technological challenges, LS2 and LS3 will be equally as demanding as LS1, with continual improvement of the detector beam vacuum, in line with CERN's mission to carry out fundamental Physics research whilst driving innovation.

ACKNOWLEDGMENT

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