ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMF090

UPGRADE OF THE CMS EXPERIMENTAL BEAM VACUUM DURING LS2

Josef Sestak, Chiara Di Paolo, Giuseppe Bregliozzi, Paolo Chiggiato,

CERN, Geneva, Switzerland

Abstract

Starting from December 2018, the Large Hadron Collider (LHC) is going to interrupt its physic operations for more than two years within the period called second long shutdown (LS2). The Compact Muon Solenoid (CMS) experiment will undergo the biggest upgrade of its experimental beam vacuum system since the first operations in 2008. The new experimental vacuum layout should comply with demanding structural, vacuum, integration and physics requirements. Moreover, the new layout should be compatible with foreseen engineering changes of the detector and the machine during the upgrade phase of High-Luminosity LHC in LS3. This paper gives an overview of the CMS LS2 experimental vacuum sectors upgrades. Both design and production phase of the new vacuum layout is discussed in detail.

INTRODUCTION

The CMS experiment is one of two general-purpose detectors installed in the LHC. His detector is located in point 5 in the vicinity of French village Cessy. Experimental cavern, located 90 meters under the surface level (UXC55), houses 21 meters long per 15 meters in diameter of 14 000 tonnes heavy detector. The CMS experiment has been designed to operate with nominal LHC parameters, meaning p-p collisions at energy 6.5 TeV, number of bunches 2808 and peak luminosity 10^{34} $cm^{-2}s^{-1}$ [1].

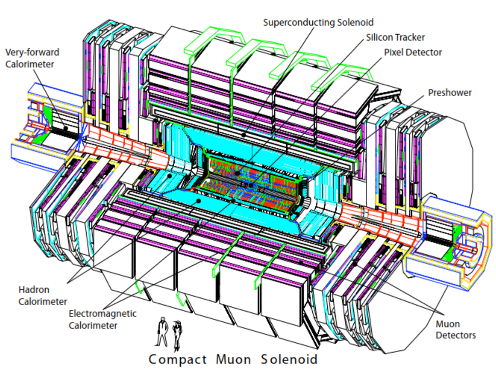

Figure 1: General layout of the CMS experiment [2].

EXPERIMENTAL VACUUM LAYOUT

Experimental vacuum layout of the detector is located between the first focusing inner triplet quadrupoles, Q1L5 and Q1R5. According to the LHC coordinate system, this area is located symmetrically at about ±22 meter around the IP5. It consists of three beam vacuum sectors (A1L5.X, IP5.X and A1R5.X) operating at room temperature.

Sectors A1L5.X and A1R5.X are about one meter long and accommodates beam instrumentation and vacuum assemblies used for injection and pump-down of the ultra-pure neon during maintenance phases of the detector. Vacuum chambers, belonging to the sector IP5.X, traverse from the LHC tunnel though front quadrupole absorber (TAS) into the UXC55. The schematic layout of CMS vacuum sectors, from the Q1L5 towards the IP is shown in figure 2.

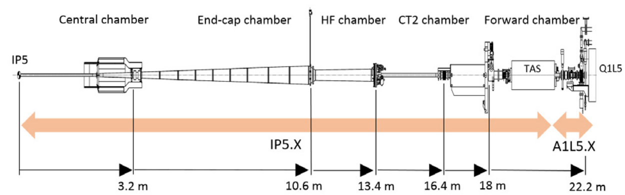

Figure 2: CMS experimental vacuum layout.

UPGRADE DURING THE LS2

The experimental beam vacuum layout will undergo a major upgrade in 2020 [2, 3]. Motivation for engineering changes included within this upgrade is:

- Reduction of radiation dose obtained by personnel during interventions;
- Extension of forward calorimetry range [2];
- Anticipate the HL-LHC aperture changes.

In order to minimize impact of LS3 changes on the new vacuum layout, it was decided to upgrade also the central beryllium chamber because the existing one will no longer be compatible with foreseen LS3 pixel detector.

Dose reduction by material change

Existing experimental vacuum chambers are mostly made of 316L stainless steel. As the level of induced radioactivity (neutron activation) is an important parameter for work dose planning, the experimental vacuum chambers for post LS2 era and HL-LHC should be manufactured using low Z materials.

Aluminium alloys EN AW-2219 (chamber segments) and EN AW-5083 (bellows) represents materials already proved by a successful period of machine operations. Aluminium alloys, compared to stainless steel, provide more than 5 times reduction of induced radioactivity [4].

End-cap angle reduction

Geometry of vacuum chambers installed within the IP5.X must comply with requirements set by physics, background to the detector and available mechanical envelope of the detector. Shape of vacuum chambers

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMF090

follows the same angle as followed by the particles relative to the beam axis. This angle is called pseudorapidity (η) and defines the envelope of vacuum chambers as shown in figure 3.

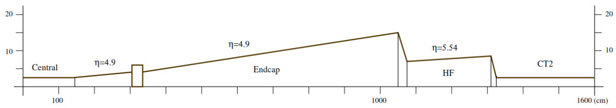

Figure 3: Pseudorapidity of existing layout [2].

One of the upper mentioned LS2 upgrade requirements is to improve capability of calorimetry in forward region of the detector. Increase of the pseudorapidity (η) of the end-cap vacuum chamber from 4.9 to 5.66 (as shown by figure 4) will provide more homogenous coverage of the region of interest for Higgs boson production processes [2].

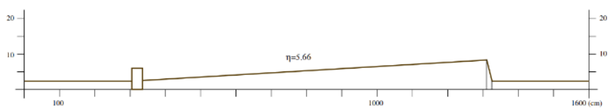

Figure 4: Pseudorapidity of end-cap for LS2 layout.

HL-LHC Aperture Changes

The baseline of the HL-LHC project is to upgrade the inner triplet assemblies. The aperture of the new Q1 will increase to 139 mm; this will require new front quadrupole absorber TAXS with aperture 54 mm (aperture of existing TAS is 30 mm) [5].

Another important aspect is that the Q1 magnet's length will be increased towards the IP. Existing vacuum sectors A1L5.X and A1R5.X will be suppressed and the VAX assemblies relocated inside the cavern.

Central Chamber for LS3 Pixel Detector

The new central chamber, compatible with LS3 pixel detector has straight cylindrical geometry (aperture 43.4 mm) with 3.8 m long beryllium section (thickness 0.8 mm). The length of the chamber remains the same, 6.2 m, including the position of the supporting points.

Design of the LS2 end-cap chamber is adapted to meet structural and vacuum requirements for the new central chamber: vacuum bellows and flanges.

Experimental Vacuum Layout After LS2

As shown in figure 5, a total of 8 aluminium chambers (4 per side) plus one beryllium chamber needs to be fabricated. In order to keep a certain degree of freedom for LS3 changes, it was decided to freeze LS2 layout on the ±18 m: future position of the LS3 VAX. The same layout will be kept from the ±18 m pumping station towards the Q1; this will be then upgraded during the LS3. Forward vacuum chamber will play a role of transition chamber between the LS2 and LS3 layout and will be therefore the only chamber from the new layout which will be re-fabricated after the LS3. Stainless steel edge-welded bellow module on 16 m will be reused due to its high stroke capacity.

Existing vacuum chambers will be conserved during the LS2 in order to be available as a spare solution.

VACUUM ASSESSMENT

Pressure in CMS experimental vacuum chambers relies mainly on the distributed pumping speed (for H_2, CO and CO_2) provided by in-situ activated NEG coating. Design of the LS2 vacuum layout was already studied in order to evaluate dynamic effect of beam current on the ion, photon and electron induced desorption [6]. Critical current (I_c) as a function of 16m ion pumps operation and NEG coating saturation is shown in Table 1. Within the experimental areas where two beams shares the same chamber following rule for critical current applies:

- In case of LHC: $I_c/2 > 2 \cdot 0.85$ A
- In case of HL-LHC: $I_c/2 > 2 \cdot 1.12$ A

Table 1: Critical Current – CMS LS2

Ion Pumps (16 m)	NEG Saturation [%]	Critical Current [A]	Dominant Gas
ON	0	75	CH_4
ON	99	30	H_2
OFF	100	5	CO

The expected static pressure in IP5.X will be in the order of $1 \cdot 10^{-11}$ mbar range dominated by H_2 and CH_4 species. Figure 6 shows expected simulated static pressure profile after the LS2.

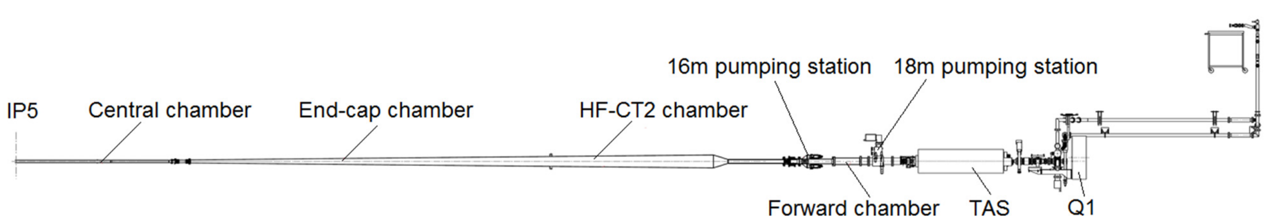

Figure 5: CMS experimental vacuum layout after the LS2.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMF090

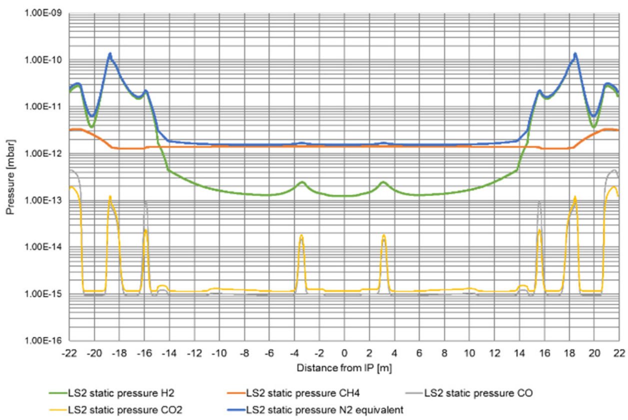

Figure 6: Expected static pressure profile after LS2.

STRUCTURAL ASSESMENT

Structural requirements for the experimental chambers within the LHC were discussed in [6, 7]. Detail design of each experimental chamber was crosschecked in order to evaluate critical buckling pressure (P_{cr}), acceptable sagging and maximum concentration of stress.

Finite element analysis shows that the critical buckling pressure of central beryllium chamber corresponds to value 10 bar (well within the limit; $P_{cr} \geq 3$ bar). Theoretical sag of the central chamber evaluated by simulation is 0.1 mm. Maximum of equivalent stress 11 MPa was observed in the vicinity of welds [8].

Thickness of the end-cap and HF-CT2 chambers was optimised in order to reach constant critical pressure 6 bars. Figure 7 shows theoretical operational sag 3 mm located on the end-cap chamber. Maximum of equivalent stress 25 MPa chamber ($R_{0.2RT}$ = 240 MPa) was observed at the 3.7 m fix point collar [9].

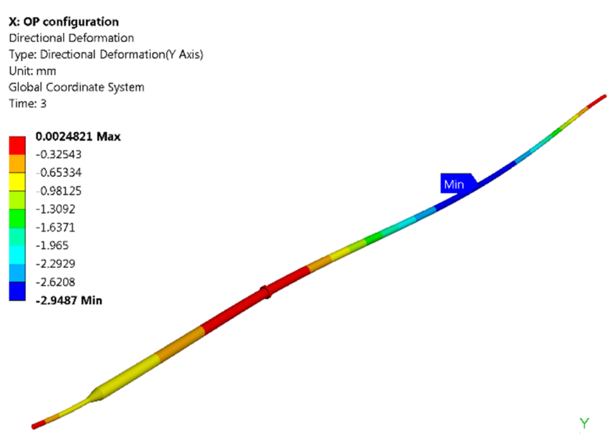

Figure 7: Operational sag of the End-cap and HF-CT2 [9].

PRODUCTION CHALLENGES

Raw Material

CERN material specification [10] states that raw material used for vacuum application must meet specific condition for grain size. Microstructure of the raw material must allow producing a chamber with at least 10 grains of material per wall-thickness (transversal direction). In case of experimental aluminium chambers is the grain size number of a raw material requested as G ≥ 4. This corresponds to average grain size about 90 µm thus for a chamber with wall thickness 1 mm is the number of grains per thickness about 11.

Grain size limit is applied due to high content of copper in aluminium series 2000. Suitable microstructure is an important parameter as the copper based secondary phases can causes potential corrosion issues [11].

Figure 8 shows microstructural differences in transversal and longitudinal plane after multi-directional forging. In order to find a supplier complying by upper mentioned specification intensive qualification was performed. Ring rolling technology offers acceptable grain size results together with preserving a reasonable length of bars.

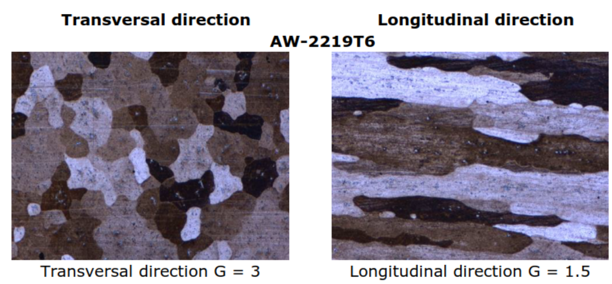

Figure 8: EN AW-2219 grain size measurement [12].

Welding of the Aluminum Segments

Assembling and welding of the aluminum segments are the most critical production steps. Intensive prototyping and qualification of the welding process is mandatory in order to meet required tolerances, achieve good process yield and minimize needs of spare segments. All aluminum welds are performed as butt welds with full penetration and conforming to ISO 13919-2 Level B.

Chambers for the CMS experimental vacuum layout will be welded using gas tungsten arc welding method (TIG). This decision was taken based on past production experience and is motivated mainly by dimensions and shape of the chambers: conical chambers with length up to 7.5 meters. Compared to the e-beam welding, the surface after the TIG welding is free from hard metallic residuals. This approach reduces possible peel-off problems during the NEG coating process and vacuum activation.

CONCLUSIONS

This paper gives an overview of the design and production of CMS experimental chambers for LS2 upgrade. The design of these vacuum chambers deals with challenging physics, vacuum and structural requirements which are then confronted with real production capabilities. Launching and follow-up of the production phase is now ongoing with foreseen installation in 2020.

REFERENCES

[1] O. Bruning *et al.*, "LHC Design Report Vol.1: The LHC Main Ring", CERN, Geneva, Switzerland, Rep. CERN-2004-003-V1, Jun. 2004.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMF090

[2] D. Contardo *et al.,* "Technical Proposal for the Phase-II Upgrade of the CMS Detector", CERN, Geneva, Switzerland, Rep. CERN-LHCC-2015-010, Jun. 2015.

[3] EDR CMS Phase 2 Beam Pipe, ***https://indico.cern.ch/event/649386/***.

[4] M. Gallilee *et al.,* "Development of Aluminium Vacuum Chambers for LHC Experiments at CERN", in *Proc. IPAC'14*, Dresden, Germany, Jun. 2014, paper WEPME040, pp. 2354-2356.

[5] G. Apollinari *et al*., "High-Luminosity Large Hadron Collider (HL-LHC): Preliminary Design Report", CERN, Geneva, Switzerland, Rep. CERN-2015-005, Dec. 2015, ***doi: 10.5170/CERN-2015-005***

[6] J. Sestak, G. Bregliozzi and P. Chiggiato, "Mechanical and vacuum stability studies for the LHC experiments upgrade", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, South Korea, Jun. 2016, pp. 3667-3669, ***doi: 10.18429/JACoW-IPAC2016-THPMY008***

[7] I. R. Collins, O. Grobner, P. Lepeule and R. Veness., "Mechanical and vacuum stability design criteria for the LHC experimental vacuum chambers", in *Proc. EPAC'98*, Stockholm, Sweden, Jun. 1998, paper C98-06-22, pp. 2202-2206.

[8] C. D. Paolo and J. Sestak, "Mechanical analysis of the new CMS central vacuum chamber", CERN, Geneva, Switzerland, Rep. EDMS 1907946, Feb. 2018.

[9] C. D. Paolo and J. Sestak, "Upgrade of the CMS vacuum chamber, structural analysis of the forward vacuum chambers EndCap, HF-CT2", CERN, Geneva, Switzerland, Rep. EDMS 1907976, Feb. 2018.

[10] F. Leaux, "EN AW-2219-T6 forged blanks for UHV applications", CERN, Geneva, Switzerland, Rep. EDMS 1429318, May 2014.

[11] J. G. Kaufman, "Corrosion of Aluminum and Aluminum Alloys", in ASM Handbook Volume 13B, Corrosion: Materials, S. D. Cramer, Ed. Novelty, OH, USA: ASM International, 2005, pp. 95-124.

[12] M. Meyer, "Aluminium AW-2219 Microstructural characterization", CERN, Geneva, Switzerland, Rep. EDMS 1752843, Feb. 2017.