VACUUM – MUCH ADO ABOUT NOTHING

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Abstract

During the next long shutdown, the majority of the 557 LHC beam and insulation vacuum volumes must be vented and opened. The activities proposed by the Vacuum, Surfaces and Coatings Group will be elaborated, including their implications for other Groups, together will an estimation of the extensive VSC workload that is generated by other activities e.g. splice consolidation, new collimators and experimental area upgrades.

LHC INSULATION VACUUM

The work carried out for the insulation vacuum during the next shutdown will be done by mixed team of CERN staffs and industrial support. About 7 teams of two people each are required to perform the job. The total workload is estimated to be ~ 50 weeks. A better estimation will be given when a detailed planning will be done by EN-MEF.

VSC requests

Table 1 shows the list of insulation vacuum activities requested by VSC. For each activity is indicated the motivation of the work and the groups other than VSC with are affected. It is also said if the activity has a potential conflict with the splice consolidation.

The pressure relief system on the LHC cryostats [1] will be further consolidated by upgrading the un-sprung flanges, which open with flows up to 1 kg/s, with self-closing valves. In the event of a limited discharge, the insulation vacuum will then be protected from air ingress.

Figure 1: Self closing over pressure valve

Following the sector 3-4 incident, 5 of the 8 arcs were warmed to room temperature. So-called by-pass valves were installed at the SSS vacuum barriers which were not already equipped with by-pass pumping groups. The by-pass valve permits the linking of adjacent subsectors and creates redundancy and flexibility in pumping configurations. Three arcs, namely 2-3, 7-8 & 8-1 remain to be equipped. With the completion of the by-passes, all long subsectors of the LHC will have pumping redundancy except for the extremity subsectors A & I of each QRL. Hence 16 additional fixed turbo groups will be installed, requiring new cabling. On a similar theme, the 500 m cables from UJ33 to the 2 fixed turbos at 8R3, require replacement in order to achieve full functionality of the fixed pumping groups.

Preventive and corrective maintenance will be performed on the 170 fixed pumping groups of the QRL, arc and LSS magnet cryostats.

At a late stage in the installation of the LHC, a leaking beam screen capillary was identified on a fully installed magnet. The helium leak was localised 1.8 m inside the cold bore aperture of dipole #1060, cell 21L1, in sector 8-1. The capillary was subsequently isolated from the standard cooling circuit. The cause of this unique leak has not yet been understood. An endoscope has been procured that will allow an inspection of the capillary bore without removal of the bean screen or magnet from the tunnel.

A number of compact Penning gauges in the mid-arc continue to give erroneous reading despite several attempts to understand the issue. Further investigations will be made on the integrity of the cabling.

Table 1: VSC insulation vacuum activities

Activity	Motivation	Other Groups Affected	Potential conflict with splice consolidation
Install Flap Valves - arc, LSS, QRL	Self closing over pressure valves		no
Install by-pass valves - arcs 2-3, 7-8, 8-1	Create pumping redundancy		no
Install additional turbos (& cables) - QRL extr	Create pumping redundancy	EL	no
Install long cable for turbos IR3R - LSS3	Eliminate turbo restart problem	EL	no
Localise and repair known leaks - all arcs	Eliminate helium leaks	MSC,CRG	**yes**
Leak test envelopes (global) - arc, LSS, QRL	Check tightness integrity	CRG	**yes**
Maintain turbo pumping groups - arc,LSS	Maintenance - preventive & corrective		no
Inspect b.screen capillary in arc 8-1	Understand helium leak origin		no
Repair gauge cabling in mid arcs - all arcs	Eliminate faulty gauge reading		no

It is important to have the tightness status of all subsectors before the start of venting and modification works. This includes helium to insulation vacuum and air to insulation vacuum tightness. At temperatures above 80K, helium and air leaks are no longer pumped on the cryogenic surfaces. Leaking testing can therefore be performed if the pressures in the cryogenic headers are constant. With several teams working in parallel in an arc, all subsectors could be measured in 2 days.

In some subsectors, helium leaks and or air leaks are already known to exist. Although the level of these leaks permits normal operation of the LHC, the leaks generate many difficulties for cryogenic operations team, as small temperature fluctuations can results in large pressure bumps and variation of heat loads. The localisation and elimination of the helium leaks requires a coordinated effort between TE/VSC, MSC and CRG. Longitudinal leak localisation in a subsector can be performed once the subsector temperature is above 20 K and the helium header pressures are constant. The measurements, taking 1 day per subsector, will give an indication of which magnet interconnection(s) to open. For some subsectors, variation of the header pressures will be required to confirm the leaking circuit (1 day). Once the measurements above are complete, and the system is at room temperature, the leaking subsectors can be vented and the identified interconnects opened (1 day). Leak localisation is then performed with helium pressure (5 bars) in the identified leaking circuit (2 days minimum). It is estimated that the above procedures to localise helium leaks will require a total of 5 days. Combining leak localisation of known leaks in an arc and systematic checks of all subsectors in an arc, having several VSC teams working in parallel and full availability of cryogenic hardware, software and operators, the minimum duration of leak localisation works is 5 days. The scheduling of these activities must be carefully prepared in collaboration with MSC, CRG and other tunnel activities, and will impact on the availability of magnet interconnections for splice consolidation.

VSC involved

VSC is also involved in several activities which are already planned or proposed. Table 2 shows the list of known activities where VSC will provide leak testing support.

Table 2: VSC involved insulation vacuum activities

Activity
Splice consolidation
Cryomagnet replacement
IR3 DS - bypass cryostat for collimators
Connnection cryostat consolidation
Y-Lines repair
New DN200 & Reclamping of instrumentation flanges
SAM helium gauge consolidation
Triplet braid

The details of these activities are provided in other reports from this Chamonix workshop. As all interconnect of the machine will be opened for modification or repair, the leak testing activities will be extensive and intensive. It is vital that the shutdown planning is made in such a way that VSC resources can be smoothed over the shutdown period, and contingency is added for the elimination of the leaks appearing during acceptance tests.

LHC BEAM VACUUM

The work carried out for the beam vacuum during the next shutdown will be done by mixed team of CERN staffs and industrial support. About 10-12 teams of two people each are required to perform the job. The total workload is estimated to be ~ 30 Wk. A better estimation will be given when a detailed planning will be done by EN-MEF.

VSC requests

Table 3 shows the list of cold beam vacuum activities requested by VSC. For each activity is indicated the area, the motivation of the work and the groups other than VSC with are affected. It is also said if the activity as a potential conflict with the splice consolidation.

The consolidation of the Plug-in-Module (PIM) is an important part of the work to be done during next shutdown in order to guarantee beam aperture or guarantee leak tightness with time of damaged bellows. Of course, ideally all the PIMs would have been exchanged but this could not be afforded for budget and time reasons. A detailed analysis has shown that the exchange of PIMs located at dispersion suppressors and at each vacuum barrier would give a satisfactory result with a low probability of RF finger’s buckling during warm up cycle. However, to shorten the shutdown activity, it has recently been decided to consolidate only the PIMs located at the arc extremity in the dispersion suppressor areas [2]. Beam vacuum protection shells will be installed at each interconnection to protect the bellows and minimise the amount of debris entering the beam tube in the event of an incident. Similarly, rupture disk will be installed at each Short Straight Section to avoid the overpressure in the beam pipe protecting the nested bellows in the event of an incident. During the interconnection activities and at the end of this job, leak detections and RF balls test are requested too. It is worth recalling that the RF ball test will be also done at the beginning of the shutdown in order to evidence PIMs which failed during warm up. After the sector 3-4 repair, a total of 12 dipoles and 2 quadrupoles have beam screens with reverse sawteeth. Their exchange is considered a low priority for vacuum performance issue, but the influence on the beam due to local enhanced electron cloud activity should be addressed. Installation of additional gauges in the arc is proposed to consolidate the vacuum instrumentation; this activity will require cable laying. Finally, mobile pumping groups and diagnostic benches will be installed at the start of the arc and stand alone warm up to check the helium tightness of the beam screen capillaries. These equipment will be used in a second stage before final cool down to evacuate gas in order to minimise the impact onto the beam performance of gas desorption stimulated by the electron cloud.

Table 3: cold beam vacuum activities

Activity	Area	Motivation	Other groups affected	conflict with splice
Exchange PIMS	Arc, LSS	Eliminate critical PIMs	MSC	YES
Install beam vac. Protection shells	Arc, LSS	Protection against electrical arcs	MSC	YES
Exchange beam screen with reverse sawteeh	Arc 3-4	Dynamic vacuum	MSC,EL, SU	YES
Install additional rupture disc	Arc SSS, LSS	Protection beam vacuum against overpressure	-	No
Install additional gauges in the arcs	Arc	Consolidate instrumentation	EL	no
Install/remove mobile pumping groups	Arcs, LSS	Remove desorbed gas/recondition	-	no
Leak test envelope-arc, LSS	Arcs, LSS	Check tightness integrity	-	Yes
RF ball test	Arcs	Aperture check	-	no

Table 4 shows the list of warm beam vacuum activities requested by VSC. With the LHC machine performances progressing towards nominal values, it is vital to ensure that the vacuum system keep its nominal performance. Particularly, the installation of NEG pilot sectors will help to estimate the NEG parameters in presence of beam around the experimental areas and will allow defining the time between two successive NEG activations. Figure 2 shows a NEG pilot sector to be installed in a vacuum sector. The injection of gas at one extremity with the monitoring at the other, allows estimating the pumping performance of the NEG coating [3]. Installation of electron clouds monitors will allow increasing the understanding of the electron cloud in the LHC and will allow diagnosing the scrubbing efficiency of each run.

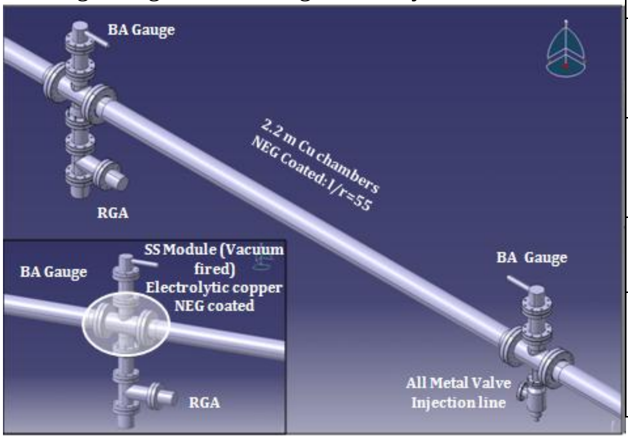

Figure 2: NEG pilot sector [3]

Inspections following the LHC installation have revealed that some RF fingers inside vacuum modules have bad contact due to a loose spring. A campaign of systematic inspections of vacuum bellows has just been launched with the support of EN-MME. A film and an X-ray source are used to do imaging and on-line analysis of each vacuum module. It is estimated that about 10 vacuum sectors around LHC could be re-opened to fix this issue. The 2 vacuum sectors around the MSD in LSS6 are ~ 155 m long. In case of intervention, the NEG reactivation of these sectors could last 4-6 weeks / sector due to their length and complexity. It is therefore of interest to perform an integration study and define a new layout around these components. Of course, the implementation should be done if necessary and therefore has low priority. However, a feasibility study with EN-MEF is required. Similarly, a minor layout change is required in LSS 2 and 8 to correct 4 vacuum modules which are out of their tolerance with a potential risk of RF buckling. The installation of thermocouples is foreseen in LSS3 and 7 to monitor the beam heating effect induced on the flanges by the collimators. Optimisation of the vacuum ion pump powering by laying new cables is proposed to consolidate the valve interlocking system and vacuum diagnostics around collimators. Finally, to protect sensitive LHC equipment, the modification of pneumatic valves and / or installation of fast shutters in the vicinity of RF cavities are foreseen [4].

Table 4: warm beam vacuum activities

Activity	Area	Motivation	Other groups affected	conflict with splice
Install NEG and electron cloud pilot sectors	LSS	Diagnostic instrumentation	EL	no
Inspection with X-ray of vac modules	LSS	Identify RF finger issues	Access restriction	YES
Exchange vac. Modules as required	LSS	Reduce LHC impedance	-	no
Layout change at MSD	LSS 6	Reduce vac sector length	EL, MEF	No
Layout change at BPM/DFBX	LSS 2 and 8	Vac module over extended	EL, MEF	no
Install thermocouple near collimators	LSS 3, 7	Monitor effect of collimators	EL	no
Install new cabling and instrumentation	LSS	Improve logic for sector valves	EL, MPE	no
Install fast shutter and modify pneumatic valves	LSS 4 + other LSS	Protect sensitive LHC equipment	EL, MPE, MEF	no

VSC involved

VSC is also involved in several activities which are already planned or proposed. Table 5 shows the list of activities where the group is currently involved. The R2E project will require a systematic check of the electrical connections of each vacuum equipment. A 5th MKB should be installed in LSS 6 to complete the beam dump system as designed. Collimators should be installed in LSS 3 and LSS 6 according to the collimator project schedule. Four new collimators operating at room temperature but to be installed in the dispersion regions around LSS 3 with implications on the layout of LSS 3 are planned. The implementation of a new layout and installation of a TCT collimator in LSS 2 to optimise the physic of the ZDC is also planned. A proposal of the new layout is shown in Figure 3. The solution requires the construction of a new ID800 vacuum chamber and the design of new vacuum modules.

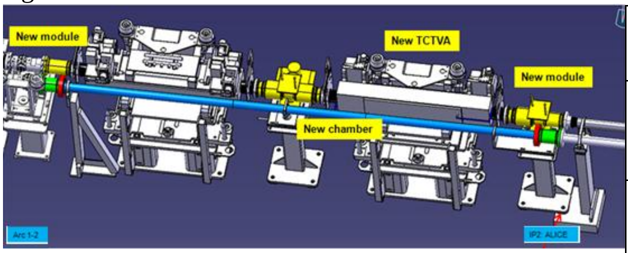

Figure 3: Proposed layout in the LSS 2 ZDC area

Repair of equipments are also required such as BQSH or other BI equipments. Finally, the neon venting and pumping of each LHC experiment will be required. It should be underlined that if a LHC experiment needs to be vented to air, a NEG re-activation of the experimental vacuum chamber will be required. The time to perform such an activity accounts to months.

Table 5: VSC involved beam vacuum activities

Activity	Area
R2E – move racks and cabling	UJ79 to TZ76
Connect 5th MKB	LSS 6
Connect collimators	LSS 3
Connect collimator W	LSS6
Connect collimator IR3 DS	DS LSS 3
Layout changes due to IR3 DS collimators	LSS 3
Layout change, TCT, ID800, ZDC in LSS2	LSS 2
Intervene on BQSH & BI equipment	LSS4
Vent and re-pump experimental chambers. NEG re-activation when vented to air.	Experiments

EXPERIMENTAL AREAS

The work carried out in the experimental caverns will be spread out over the full duration of the shutdown. Current schedules presented by the experiments show 15 months intervention time from beam to beam.

VSC consolidation

Table 6 shows the list of activities in the experimental caverns requested of VSC by the LHC experiments. Table 6 outlines the motivation and the affected groups for each task. None of the experimental activities will conflict with the splice consolidation in terms of access requirements.

All of these activities represent an important part of the consolidation and upgrade of the experimental areas. Installation of the IBL detector (Figure 3) is of particular importance for ATLAS in order to maintain the integrity of their inner detector. LHCb require an important intervention to change a piece of central vacuum chamber which had non-conformities during installation and was temporarily repaired in order to allow the program to continue. CMS plan modifications to the vacuum chamber support in the forward parts of the detector.

Table 6: Experimental Vacuum Activities

Activity	Area	Motivation	Other groups affected	conflict with splice
Replace UX85/3 Chamber	LHCb	Eliminate non-conforming chamber	LHCb coordination & survey	no
Change supports UX85/2 and UX85/3	LHCb	Improve transparency of supports	LHCb coordination & survey	no
Change supports in HF and forward regions	CMS	Improve access and reduce intervention risk	CMS coordination & survey	no
Replace ATLAS VI, VA, and VT chambers	ATLAS	Improve transparency, reduce activation and install IBL detector	ATLAS coordination & survey	no

As the current work packages stand, it is estimated that the interventions within the experiments will require 1.2 FTE of category 2 staff and 2.9 FTE of category 3 staff, plus industrial support. Work will be spread out over a 15 month period. Table 7 contains a breakdown of the estimated duration the resources within VSC for cavern activities related to installation and re-commissioning of the vacuum sectors for each activity. Resource estimates are taken from work packages agreed with each experiment [5]. Possible replacement of the central CMS beryllium chamber, which was proposed at the workshop is not included in Table 7. NEG activation will take approximately 2 months per experiment, with resources included in table 7.

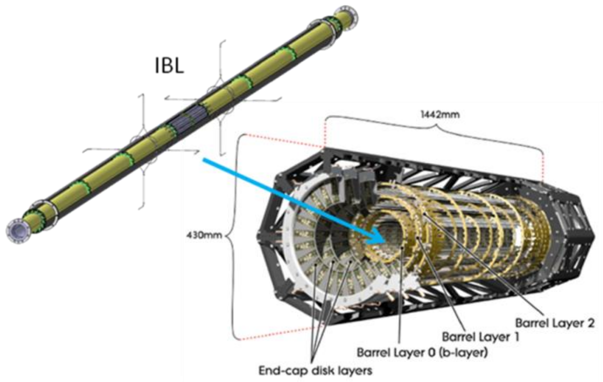

Figure 4: ATLAS IBL Detector

Survey will be required during most of the VSC/EIV activities. This activity will be undertaken by members of BE/APB Group who are dedicated to the experimental caverns.

Table 7: Estimated Time for VSC Integration Activities

Activity	Estimated staff resources (FTE)	
	Cat.2	Cat.3
Replace UX85/3 Chamber	0.3	0.8
Change supports UX85/2 and UX85/3	0.1	0.5
Change supports in HF and forward regions	0.2	0.6
Replace ATLAS VI, VA, and VT chambers	0.6	1.0

CONCLUSIONS

Elimination of known leaks in the insulation vacuum is a primary objective for VSC. The insulation vacuum system will be extensively modified during the splice consolidation and other machine modifications. As its reassembly will be made in a much reduced time compared to its initial installation, ensuring that a more leak tight system exists after the long shutdown than before will require considerable effort, coordination and flexibility from the multiple teams involved.

The intervention required to be made by VSC on the beam vacuum system are divided into 2 categories: requested and involved activities. Consolidation of the PIMs in the arcs and installation of the NEG pilot sectors and electron cloud detectors are the most important activities for the LHC beam vacuum system. However, activities linked to collimators or experimental projects are time and resource demanding. A total workload of 30 Wk for 10-12 teams is estimated.

The work to be performed for the experimental vacuum systems extends to 15 months. The described activities are to be done for ATLAS, CMS and LHC-B experiments.

ACKNOWLEDGEMENTS

The authors would like to acknowledge colleagues of the VSC group for their inputs for this report.

REFERENCES

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