LHC VACUUM UPGRADE DURING LS1

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Abstract

The last two years of LHC operation have highlighted concerns on the levels of the dynamic vacuum in the long straight sections in presence of high intensity beams. The analysis of the existing data has shown relationship between pressures spikes and beam screen temperature oscillations or micro-sparking in the RF fingers of the bellows on one side and coincidence of pressure bumps with stimulated desorption by electron cloud, beam losses and/or thermal out gassing stimulated by higher order modes (HOM) losses.

The electron cloud mitigation solutions will be adapted to the different configurations: cold/warm transitions, non-coated surfaces in direct view of beams, photoelectrons, etc. All scenarios will be presented together with their efficiencies. Additional pumping and reengineering of components will reduce the sensitivity of the vacuum system to beam losses or HOM inducing out gassing. The expected margin at nominal intensity and energy resulting from these consolidations will be summarized.

Finally, the challenges of the Experimental areas will be addressed, more specifically the status of the new Beryllium pipes (ATLAS and CMS) which are in the critical path and the consolidation of vacuum instrumentation, pumping and electron cloud mitigation. The risk corresponding to the proposed consolidations will be shown and the margins with respect to the schedule analysed.

WHAT HAS BEEN LEARNT SO FAR?

Beam Vacuum and Dynamic effects

No vacuum design issue has been identified. The pumping layout and instrumentation behaved as planed. The expected vacuum activity when circulating high bunch populated beams was enhanced by the fast increase of luminosity. Two configurations dominate the pressure rise:

- The Cold/Warm (C/W) transitions and the Beam Screens (BS). The cryogenic experts successfully optimised the BS cooling loop and the procedure to flash the gas from the BS to the Cold Bore (CB) was implemented. Indeed, the heavy gas coverage, which resulted from the fast increase of luminosity, was logically more sensitive to fast temperature variations of the BS. The C/W transitions were equipped with solenoids to mitigate the electron cloud (EC) build-up.
- The non-NEG (Non-Evaporable Getter) coated areas dominated by far the pressure rises resulting from the EC build-up. All equipment in view of beams is concerned and not only vacuum components.

The vacuum instrumentation appeared to be insufficient in few places of the long straight sections (LSS) where unexpected pressure rises were taking place resulting in difficulties to make accurate diagnostics.

As a matter of facts, the operation with 50 ns beams in 2012 should go smoothly for the beam vacuum even if the bunch population is slightly increased. The operation with ions is expected to stay “transparent” for the beam vacuum.

Insulation Vacuum and Leaks

In addition to helium leaks known to be detrimental to LHC performances, air leaks showed-up to become potentially harmful. Air leaks are not an intrinsic limitation due to the huge cryopumping by the cold surfaces and installed turbomolecular pumps that remove the helium, not cryosorbed. But air leaks could generate collateral damages since ice plugs can build-up on cold spots (insufficient thermal insulation) as observed in one bellows of the cryogenic transfer line (QRL) in Sector S45. Thus:

- Large leaks need to be fixed as part of the baseline and time has to be allocated.
- Preventive actions such as slower warm-up and additional pumping capacity adapted to the amount of gas released are required to avoid the thermal runaway.

The reliability of the elastomers gaskets installed in the LHC (22 km) is an important issue even if this type of leak is not a limitation during operation. So far, no degradation has been observed: no leak problems.

Helium (gas or liquid) leaks can only be partly mitigated by adding turbomolecular pumps. Indeed, additional pumping will provide a factor 2-4 maximum contingency. This solution is being applied for two critical leaks in a magnet cryostat in the Sector S34 and in the QRL in Sector S45. The problem is that leaks at cryogenic temperature tend to open and increase by orders of magnitude. By experience, the temperature cycles above 120 K have a detrimental effect and must be therefore avoided.

MAJOR CONSOLIDATIONS

Safety

The objective is to have all consolidations decided following the incident of Sector S34 [1] consolidated by end of the LS1. This includes in particular the installation of the pressure relief valves, flap valves (Fig.1) and half shells (Fig.1) and by-passes (Fig.2). These activities are in co-activities with the splice consolidation. As a consequence, the re-clamping of the quadrupole flanges (Fig.2) shall be made in collaboration with BE-BI group.

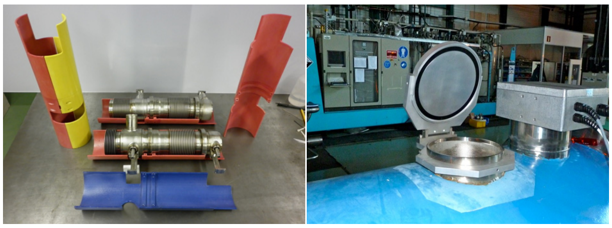

Figure 1: Picture of the half-shell (left) to protect the nested bellows and PIMs (Plug-In Module) at the cryomagnet interconnects and of a DN200 self closing over pressure valve (right) on a cryomagnet cryostat.

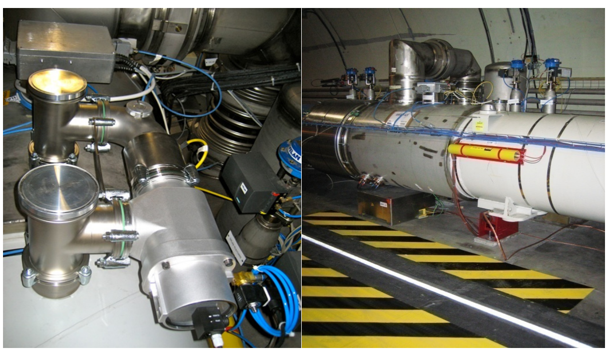

Figure 2: Picture of a by-pass (left) installed across vacuum barriers and of the places (right) where instrumentation ports have been unclamped.

To optimise the protection of the LSS from and incident taking place in the arcs, the pressure triggering will be installed at Q10 instead of Q7 and the sector valve's pneumatic will be modified for a faster closure: 1 sec instead of 2.5 sec. The valve's pneumatic will also be modified around critical equipment like kickers and superconducting RF cavities (SC-RF) and at Q1 to protect the Experimental Areas. Fast shutters will be installed upstream and downstream to the SC-RF cavities in LSS4. These installations will require cabling by EN-EL.

The consolidation of the splices will require an important support from the VSC group: beam screen installation in new magnets and leak testing in SMA18, extensive leak testing and pump down support in the tunnel (10'000 welds, 8'000 O-rings) and leaks to be found during critical path activities. These activities will be in a sequence mode and with a top priority limiting therefore the flexibility of vacuum experts and their availability for other tasks.

The Table 1 summarises the LS1 activities linked to Safety.

Performance

The pressure rises observed during the 2010 and 2011 Runs have been all understood and countermeasures integrated in the approved consolidations to allow performing at 7 TeV per beam and ultimate intensities. All equipment in view of beams are concerned, in addition to vacuum components, equipment from the following groups TE-ABT, BE-BI, BE-RF, EN-STI must be consolidated to mitigate the electron cloud effects and thermal induced desorption. The use of NEG or amorphous carbon (a-C) coatings or solenoids shall be considered. As an alternative, coated liners could be envisaged. Other consolidations are as well considered:

- Optimisation of C/W transitions of the standalone cryomagnets to push the condensed gasses to the beam screen where they are less sensitive to cryo-temperature variations;
- New beryllium beampipes for ATLAS, CMS and LHCb and new forward beampipes for ATLAS.

The Table 2 summarises the LS1 activities linked to LHC machine Performance.

Reliability

All known reliability problems will be addressed and fixed. These activities will start by an RF ball aperture tests right after the warm-up and the aperture test will be repeated before cool down. These activities are made in collaboration with the TE-CRG group.

Based on the conclusions of the PIM task force, it has been decided not to go for a systematic PIM replacement but rather to exchange the ones that are more exposed to temperature variations and therefore exposed to a potential buckling. Including the PIMs, which will be exchanged resulting from cryomagnet replacements, 114 PIMs (see Table 3) in total will be changed or consolidated.

Table 3: PIMs to be exchanges or consolidated.

Motivation	Quantity
Preventive actions (Q7/B, B/Q7)	18
Damage bellows	~10
Fingers buckled during warm-up	~14
Magnet replacement	72
Total	~114

The replacement of non-conforming RF inserts in bellow modules of the LSS will also be an important task. The type and quantity of inserts to be consolidated or replaced is not known yet. A task force has been assigned for the systematic evaluation of the installed designs and to make recommendations. As a new manufacturing shall be expected, these recommendations are expected by September 2012 at the latest to be on time for LS1 schedule.

The leak tests of the cryostat envelopes, localisation and repair of known leaks (21 known leaks) need to be synchronised with TE-CRG group and with the splice consolidation team. As the leak testing of cryomagnets is not always straightforward due to accessibility problems, the splice and TE-VSC teams and LS1 Coordination must be prepared to allocate more time or accept to leave with the leak.

The Table 4 summarises the LS1 Activities linked to the LHC vacuum Reliability.

Operation Margin

Several consolidations will be implemented to provide more operational margin in case problems occur during the operation with beams. These consolidations belongs to two categories:

- More pumping: Modification of the DN200 pressure relief flanges of the magnet cryostats in the arcs to adapt for DN100 pumping ports (2 per Sector) and additional pumping around injection kickers and collimators (LSS1, 2, 5 and 8).
- More instrumentation: pressure and temperature probes will be added around the collimators and the layout of the vacuum instrumentation installed in the sectorisation modules will be modified to avoid artefacts induced by electrons and photons. The later will limit wrong pressure reading.

The Table 5 summarises the LS1 activities linked to Operation Margin.

CHALLENGES

Impact of the Injectors' activities

The initial scenario for LS1 considered minimising the activities in the injectors to reallocate the specialised resources to the LHC activities. This can no longer be done since important activities are planed during LS1 in the injectors and most of them imply the venting and opening of the beam vacuum systems.

In the PS Complex, most of the activities are related to the maintenance of equipment except for the PS accelerator that needs a complete refurbishment of the vacuum instrumentation and control system. The activities linked to LINAC4 will also be important, acceptance tests when received from Industry, final tests prior to installation, installation and commissioning of the vacuum system.

In the SPS Complex, activities planed concern maintenance, upgrade and preparation work in the frame of the LIU-SPS project.

Activities in tunnel and support in Labs

At the exception of the NEG activation activities which have absolute priority since blocking a huge amount of material which availability is required to follow the LHC LS1 schedule, it appear difficult to allocate more resources from the Injectors in 2013. Even though, an impact on the Injectors' activities shall be expected.

To avoid creating a bottleneck during the period October'13 to March'14, TE-VSC group recommends starting as quickly as possible in 2013 on Injectors', at the exception of the activities, which are exposed to radiation issues. These one shall be pushed to the end of the shutdown to allow enough radiation cooling. Then, as from 2014 Injectors' Run, half of the vacuum Injectors' experts will be redeployed in LHC LS1 activities. The priority on LINAC 4 will be kept, other activities will suffer like AD consolidation studies, support to equipment owners and CTF3.

Despite the fact that the Industrial Support is expected to increase to up to 34 Vacuum Experts, activities not yet planed will have to go through the "priority" filtering since no longer compatible with available resources and material.

Risks & Schedule Issues

Some major risks have been identified like damaging the nested bellows during the splice's consolidation. An appropriate training of teams coupled with a strong supervision in-situ can solve this.

Difficulties to eliminate all leaks due to the tight schedule (cryomagnets and QRL) are also a concern as well as the possibility to have to redeploy compensatory measures if equipment from other groups cannot be optimised on time (HOM, Electron Cloud). The impact on TE-VSC resources could be important.

In term of schedule, again, the delay resulting from difficulties to localise and fix existing leaks and newly created leaks by the splice consolidation or magnet exchange is the major concern. Ensuring timely arrival of beryllium beampipes for CMS and ATLAS is essential and a close contract follow up to detect and mitigate schedule risks has been organized.

OPERATION AT NOMINAL LHC PERFORMANCES

During the operation with nominal beams (25 ns bunch spacing, 2808 bunches, 1.05 10^{11}ppb at 7 TeV), vacuum dynamic effects will be seen on all non-NEG coated components of arcs and LSS. Pressure rises will be seen in the LSS as only heat loads will be observed in the arcs since the arc gauges "should not see" pressure rises due to their limited sensitivity. As the electron desorption yield decreases also resulting from the electron bombardment, no pressure rise observed will not necessarily means no electron cloud.

While operating at higher beam energies, the vacuum system should "discover" the synchrotron radiation induced effects: heat loads and photoelectrons. Their effects on the electron cloud build-up will need some beam time to compare predictions with observations.

CONCLUSIONS

All consolidations related to Safety of personnel and of the accelerator will be completed. In terms of performances, the Vacuum system will be prepared for operation with 7 TeV beams with high bunch populations up to ultimate. The electron cloud will be mitigated whenever feasible (at reasonable cost: resources & budgets) keeping at the highest priority, the mitigation of the sources of background (HOM, RF inserts, ferrite heating) to the Experiments. The reliability of the vacuum systems and instrumentation will be improved, the target being 100%. Layout modifications are planed to add operation margin, which will give room for mitigation solutions if needed.

Several challenges exist but no showstopper has been identified. Issues are related to the final number of equipment to be removed from the tunnel to get optimized.

Finally, while resuming operation with beams, all benefits from 2010-2012 Runs will not be lost. The scrubbing of arcs is expected to be partly kept, measurements in the laboratory and in the SPS have shown that in case the SEY drifts up, the scrubbing will then goes faster (memory effect). The good understanding of the machine behaviors with beams by the OP Crew, Equipment Owners and Vacuum Experts will allow a faster understanding of the signals provided by the available instrumentation. The 2011 Run was the year of electron stimulated desorption in LSS, the 2014-15 Runs will be dominated by heat loads induced in the arcs and photon stimulated desorption and photo-electrons.

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REFERENCES

[1] New protection scheme and pressure relief-valve staging of the LHC insulation vacuum enclosure following the 19th September 2008 incident. P.Cruikshank, Vittorio Parma, Antonio Perin, Laurent Tavian, EDMS 1044895.

Table 1: LS1 activities linked to Safety.

Activity	Area	Motivation	VSC Coordinator	Groups Affected	Co-activities splice consolidation
Resume installation of DN200 Pressure Relief Valves	2-3, 7-8, 8-1 and half of 4-5	Self closing over pressure valves	PCr	MSC	Yes
Reclamping of Quadrupole DN100 flanges	2-3, 7-8, 8-1 and half of 4-5	No longer required after installation of DN200	PCr	BI	No
Install Flap Valves on DN200/DN160	arcs, LSS SAMs	Self closing over pressure valves	PCr		No
Install Pressure Relief Valves (2 per sector) - replaces unclamped configuration	QRL	Spring based closing over pressure valves	PCr		No
Install protective half shells in interconnections	arcs	Protect bellows (mechanical/arcs), increase buckling limit, limit contamination by MLI	CGa	MSC	Yes
Pressure triggering at Q10 instead of Q7 (present situation)	Arcs Q10	Provide Δt needed to trigger the closure of sector valves	VBa		No
Install additional rupture disc	Arcs SSS, LSS	Protect beam vac. against overpressure	VBa		No
Reconfiguration of permanent bake-out	IR3, IR7	Reduce the dose received by personnel	VBa		No
Install new cabling & instrumentation	LSS	Improve controls logic for sector valves – Impact of NEG coatings	VBa	EL	No
Install fast shutters	LSS 4 + MKIs	Protect sensitive LHC equipment (studies still ongoing)	VBa	EL, ABT, RF	No

Table 2: LS1 activities linked to Performance.

Activity	Area	Motivation	VSC Coordinator	Groups Affected	Co-activities splice consolidation
Install/remove mobile pumping groups	Arcs, LSS	Remove desorbed gas/recondition	VBa		No
NEG Coatings (use of liners?) on BPMs and other components (ADT, BPT, BGI) not NEG coated	LSS	Decrease the Electron Cloud induced pressure rise	VBa	BI, ABT, RF	No
Improvement of pumping performances	LSS	Decrease the pressure rise when Electron Cloud mitigation are not feasible	VBa		No
Install NEG and electron cloud pilot sectors	LSS (1,2,5,8)	Diagnostic instrumentation	VBa	EL	No
Install beam stoppers to protect Q4 in IR6 L&R	IR6	Protection of Q4	VBa	ABT, ATB	No
Exchange of Beryllium beampipes	ATLAS, CMS	New aperture	MGa		No
New aluminum based forward VI, VA, VT chambers	ATLAS	Improve transparency & activation, IBL detector	MGa	ATLAS coordination	No
New aluminum based ion pumps	ATLAS	Beampipe transparency and lower activation as compared to steel	MGa	ATLAS coordination	No
"Hambourg" experimental beampipes	IR1 L&R	ATLAS Experiment	MGa	ATLAS coordination	No
Change support UX85/2 & /3	LHC-b	Improve transparency of supports	MGa	LHCb coordination	No
Change supports in end cap/forward region	CMS	Improve access, reduce intervention risk	MGa	CMS coordination	No
Additional NEG cartridge pumps on ALL Inner Triplets and ALL SAMs with dipoles	SAMs	Decrease sensitivity to BS temperature oscillations	VBa		No
Heaters on Cold/Warm transitions to decrease the gas coverage	SAMs	Decrease sensitivity to BS temperature oscillations	VBa		No
NEG Coatings in sectorisation modules	SAMs	Mitigate Electron Cloud induced pressure rise	VBa		No

Table 4: LS1 Activities linked to Reliability.

Activity	Area	Motivation	VSC Coordinator	Groups Affected	Co-activities splice consolidation
RF ball test	Arcs	Aperture checks: after warm-up AND before cool down	VBa	CRG	No
Exchange PIMS	Arcs, LSS	Eliminate critical PIMs	CGa	MSC	Yes
Leak test envelopes (global)	arcs, LSS, QRL	Check tightness integrity	PCr	CRG	Yes
Localise and repair known leaks	all arcs	Eliminate helium leaks	PCr	MSC, CRG	Yes
Inspect beam screen capillary	arc 8-1	Understand helium leak origin	PCr		No
Install additional turbos (& cables)	QRL extremities	Create pumping redundancy	PCr	EL	No
Maintain turbo pumping groups	arcs, LSS	Maintenance - preventive and corrective	PCr		No
Repair gauge cabling in mid arcs	arcs	Eliminate faulty gauge reading	VBa		No
Install additional gauges in arcs	Arcs	Consolidate instrumentation	VBa	EL	No
Replace UX85/3 chamber	LHC-B	Eliminate NC chamber	MGa	LHC-B Coordination	No
Inspection X-ray VM modules	LSS	Identify RF finger problems	VBa	Access restriction	yes
Exchange VM modules as required	LSS	Reduce impedance	VBa		No
Review of the RF screen inserts in bellows	LSS, Experimental Areas	Improve HOM screening	VBa	ABP, MME	No
Modification of vacuum layout near cold D1 and Q3	IR1, IR2, IR5 and IR8 L&R	Decrease non-baked length	VBa		No

Table 5: LS1 activities linked to Operation Margin.

Activity	Area	Motivation	VSC Coordinator	Groups Affected	Co-activities splice consolidation
Install 2 DN200 flanges with DN100 pumping port/Sector	arcs	Provide more ports for additional turbo pumping	PCr	MME	No
Preparation of 10 mobile pumps with offset electronics	arcs	Be able to install quickly additional pumping	PCr	EL	No
Exchange S3-4 beam screens with reversed saw teeth	Arc 3-4	Dynamic vacuum effects	PCr	MSC,EL,SU	**Yes**
CMS carbon support to be replaced if not fulfilling the LS1.5 constraints	IP5	Be sure that existing support is compatible with future work	MGa	CMS Coordination	No
Additional vacuum instrumentation in ALICE at the centre (close to IP)	IP2	Provide local measurement of pressure	VBa	EL	No
Exchange of bellows between Q1 and VAX Requires new BPMs	All Q1/VAX	Allow more displacement margin for the ITs	VBa	BI	No
Vacuum performances of injection kickers intermodules	IR2L, IR8R	Improve the pumping and ultimate vacuum	VBa	ABT	No
Integration & Layout changes at MSD	LSS6	Reduce vacuum sector length	VBa	EL, ABT	No
Install thermocouples near collimators	LSS 3 and 7	Monitor effect of collimators	VBa	EL	No
Vacuum instrumentation modification to limit artifacts induced by electron cloud	LSS	Avoid the part of electron cloud is collected by gauges	VBa		No