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CERN VACUUM-SYSTEM ACTIVITIES DURING THE LONG SHUTDOWN 1: THE LHC'S INJECTOR CHAIN

J.A. Ferreira, P. Chiggiato
European Organization for Nuclear Research, CERN, 1211 Geneva 23, Switzerland

Abstract

During the long shutdown 1 (LS1), several maintenance, consolidation and upgrade activities have been carried out in LHC's injector chain. Each machine has specific vacuum requirements and different history, which determine the present status of the vacuum components, their maintenance and consolidation needs. The present work presents the priorities agreed at the beginning of the LS1 period and their implementation. Of particular relevance are the interventions in radioactive controlled areas where several leaks due to stress corrosions stopped the operations in the past years. The strategy to reduce the collective dose is presented, in particular the use of remote controlled robots. An important part of the work performed during this period involves supporting other teams (acceptance tests, new equipment installation, etc.). Finally, as a result of the LS1 experience, a medium to long term strategy is depicted, focusing on the preparation of the next shutdown (LS2) and the integration of LINAC4 in the injector chain during the same period.

THE LHC'S INJECTOR CHAIN

The injector chain supplies proton and ion beams to the LHC. The protons are produced in the LINAC2 and are successively injected into PSB, PS, SPS, and finally to LHC. Lead or argon ions are produced in LINAC3 and then injected into LEIR, PS, SPS, and LHC [1,2].

The injectors supply also beams to different experimental areas. PSB provides beam to ISOLDE; PS to the East-Hall, n-TOF and AD; and SPS to the North Area and HiRadMat.

Figure 1 shows a simplified representation of the CERN accelerator complex

INJECTORS' VACUUM SYSTEM

Most of the accelerators that are part of the LHC injector chain were built more than 40 years ago.

The beam pipes of LINAC2, LINAC3, PSB, PS, SPS and transfer lines consist of unbaked vacuum chambers that are pumped using almost 2000 sputter ion pumps.

In PSB and PS, the use of titanium sublimation pumps helps keep a lower pressure during the ion run (pressure lower than 10^{-9} mbar are required).

Fixed and mobile turbomolecular pumping groups are used for pumping down from atmospheric pressure.

THE LS1 IN NUMBERS

The Long Shutdown 1 (LS1) started in February 2013 and will last about 2 years. During this period, the entire CERN accelerator complex is undergoing major consolidation and upgrade works to prepare the machines for LHC operation at 6.5 TeV/beam.

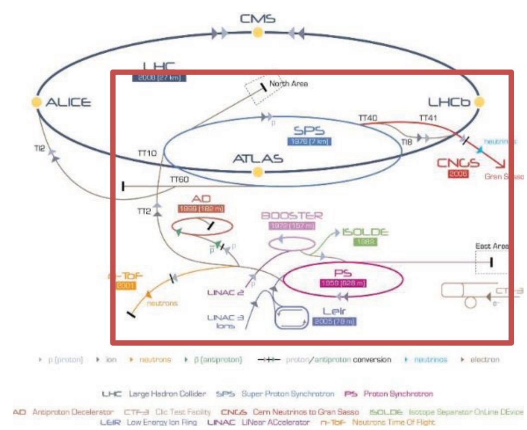

Figure 1: The LHC injector chain.

During the LS1, the LHC injectors are maintained and consolidated to face the next 3 to 4 years of operation. Table 1 summarizes the vacuum equipment that has being replaced during the shutdown.

Table 1: Summary of the Equipment Replaced during the LS1

Equipment	Num. of units
Sputter ion pumps	160
Sector valves	15
Roughing valves	100
Gauges	40
Ti sublimators	100
TMP pumping groups	5

Vacuum Support

On top of the vacuum system consolidation and maintenance, interventions related to other group activities (replacement of septa, kickers, instrumentation, etc.) are being carried out. More than 85% of the work developed by the vacuum group during the LS1 is related to support activities (more than 200 interventions). Figure 2 summarizes these works.

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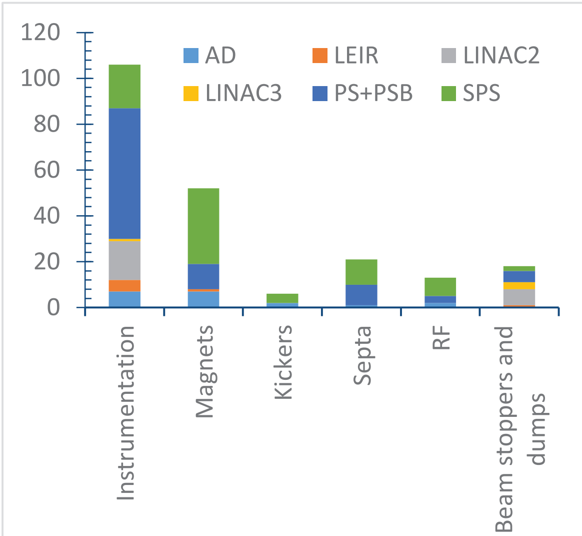

Figure 2: Vacuum support activities for other groups.

INTERVENTIONS IN CONTROLLED RADIOACTIVE AREAS

During the LS1, two major activities that involve work in controlled radioactive areas are carried out. Both activities consist in the dismantling of activated beam lines in the SPS to reduce the ambience dose. The beam line dismantling reduces the collective dose for the teams involved in the re-cabling of the area. The vacuum systems of the beam line are then consolidated during the reinstallation.

The dose rate before the dismantling of the two beam lines was higher than 5 mSv/h. The ambience dose after the removal of all the activated components is reduced by approximately a factor of 5.

To prepare these interventions the ALARA (As Low As is Reasonably Achievable) principle was applied, focusing the collective dose optimization on the use of new survey techniques and tooling.

ALARA Principle

The implementation of the ALARA principle consists of five steps:

- Gather information related to the activity.
- Define precisely all steps to carry out the activity in the radioactive area.
- Preparation of tooling and training to reduce the exposure time.
- Execution of the activity.
- Study of the outcome to gather new information that will be used in future interventions.

All these steps should be linked and revisited when necessary.

The whole set of information gathered to study the activity (dismantling a beam line in our case) has a strong impact on the definition of the work and the minimization of in situ inspections.

Sources of Information

The first classical source of information is drawings and CAD files. Paper drawings don't need any support and can be available in the work area. CAD files have lower availability, but they provide a virtual view that can be studied in detail.

In addition to the drawings and CAD models, new 3D immersive techniques are being used to create a realistic virtual environment.

Two approaches are implemented:

- High-Definition Surveying [3].
- Immersive videos using 360º cameras.

The first technique uses a laser installed in one fixed position that makes 360º scans. The data are processed and exported to CAD formats. The advantage of this technique is the possibility of measuring distances between objects. The main drawbacks are the low resolution and the need to install the laser in different points of the radioactive area to obtain the information.

Figure 3: Robot with attached helium spray gun.

The second technique uses a 360º video camera that can be deployed using a remote controlled robot. The video is processed using specific software that allows the navigation through a recreated 3D world similar to "Google Street View". A demonstration of the capabilities of this technique can be tested in [4].

All these techniques are extremely useful to obtain a detailed knowledge of the work area minimizing the exposure to radiation. This knowledge allows us to prepare more accurate dose estimations.

Tooling

The use of specific tooling has a strong impact on the collective dose. For example, the use of a cordless impact wrench instead of a manual torque wrench to unfasten and install bolts reduces the exposure time by a factor of 6 (20 to 30 seconds to remove a clamp compared to 2 to 3 minutes).

The combination of dedicated tooling with a remote controlled robot allows intervention with minimized exposure.

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One multipurpose robot (TELEMAX® [5]) has been used at CERN to clean the area, install flanges, etc. The robot is equipped with different tools to extend its capabilities, in particular a cordless impact wrench and a portable helium spray gun (HeliJet+® [6]). These modifications are necessary to remove clamps and bolts, or to perform precise leak detections. Figure 3 shows the robot with an attached He spray gun and bottle during a training session in the field.

The use of the robot helps reduce the dose but has a strong impact on the planning. For example, to remove a clamp, the robot requires between 15 to 30 minutes. A compromise between the saved dose and the spent time has to be made. The robot is used only to avoid human work in high radioactive areas.

Implementation

The interventions are prepared using the information gathered from standard and innovative techniques (3D). For each intervention the different possible approaches are evaluated (tooling, remote operation) and then implemented. This strategy helps reduce the collective dose by 60% from previous estimations using standard methods.

STARTING OF LS2

The end of the LS1 represents the start of the preparation of the next shutdown (LS2) in 2018 – 2019. This shutdown will have as main objectives the upgrade and consolidation of the LHC's injection chain.

Several vacuum related activities are already defined:

- Connection of the new LINAC4 to PSB.
- Upgrade of the PSB for increased energy (2 GeV).
- Magnet renovation in PS.
- Improvement of the RF system in SPS.
- Installation of C coated beampipes in SPS magnets (under study, not yet approved).

The connection of LINAC4 will include the construction of a new transfer line and the refurbishment of the old transfer line from LINAC2 to PSB including the installation of a new septum; a new vacuum system (ion pumps, valves, etc.) will be installed and integrated in the vacuum control system.

Until now approx. 50% of the magnets in the PS has been fully refurbished. During the LS2 the rest will be refurbished. This activity involves the disconnection of 50 magnets, extraction of the vacuum chambers, reinstallation of new or reused chambers, tests and connection in the machine.

The RF system in SPS consists of 4 cavities (2 with 4 tanks and 2 with 5 tanks) that will be renovated and rearranged. The new layout will consist of 6 cavities of 3 or 4 tanks each. The seals between tanks are lip aluminium seals of big diameter (860 mm) that have to be closed following an established procedure in the tunnel avoiding any contamination of the cavity. A test bench will be prepared to test the reconnection and sealing between tanks. New tension survey systems (i.e. ultrasonic bolt measurement) will be implemented to allow the survey of the compression of the seals after installation.

Another activity, still under study, would be related to the low-SEY (Secondary Electron Yield) carbon coating of beampipes to mitigate electron cloud [7] instabilities. That activity would involve the disconnection of a big part of the dipoles and quadrupoles in the SPS ring, coating, testing and reinstallation.

During the LS2, upgrade and consolidation activities have to be carried out in parallel with the other consolidation and maintenance works. In particular, the consolidation of fixed turbomolecular pumping groups in PS and PSB, an improved sectorization of the SPS arcs, and the replacement of pumps in septum tanks in SPS.

CONCLUSIONS

The vacuum system of the LHC injectors has been consolidated and upgraded during the first long shutdown of LHC. A big amount of activities have been carried out in parallel during this period.

Some of main interventions during LS1 have been planned in controlled radioactive areas. New techniques have been implemented to reduce the received collective dose during the interventions.

The lessons learnt during the LS1 will be implemented in the preparation of the LS2. This phase is starting with the end of the LS1.

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