ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMF087

LHC INJECTORS UPGRADE PROJECT: OUTLOOK OF THE MODIFICATIONS TO THE SUPER PROTON SYNCHROTRON (SPS) VACUUM SYSTEM AND IMPACT ON THE OPERATION OF THE CARBON-COATED VACUUM CHAMBERS

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Abstract

Aiming at doubling the beam intensity and reducing the beam emittance [1], significant modifications of the LHC injector chain will take place during Long Shutdown 2 (LS2), starting from 2019. The LIU project (LHC Injector Upgrade) [2], in the specific, touches Linac4, the Proton Synchrotron Booster (PSB), the Proton Synchrotron (PS), the Super Proton Synchrotron (SPS). During LS2, important changes will take place mainly in the Long Straight Sections of the SPS to host a newly conceived dumping system, upgrade RF cavities and the extraction transfer lines. Additionally, the vacuum chambers of some main bending and focusing magnets, as well as vacuum drifts, will be coated with amorphous carbon coating (aC) in order to minimise the induced beam instabilities due to electron multipacting[3]. The guidelines followed to conceive and design the new vacuum sectors will be described hereafter and a first glance at the impact on the operation of aC coated chambers will be given.

INTRODUCTION

The SPS is the last stage of the injector chain before the LHC. It is composed of a 7 km ring and additional 10 km of vacuum transfer lines for injection from the PS and extraction to LHC, North Area target experiments (NA), AWAKE wakefield plasma acceleration experiment, and HIRADMAT target experiment.

Its injection energy is 25 GeV and it accelerates protons and ions up to 450 GeV, injection energy for LHC.

The ring is divided in sextants and each sextant is composed of two arcs and a Long Straight Section (LSS): in Table 1 are listed the basic functions of each of them in the machine as per today.

Table 1: SPS LSS and Transfer Lines

Name	Function
LSS1	Injection and dumping system
LSS2	Extraction to NA
LSS3	Acceleration
LSS4	Extraction to LHC (TI8)
LSS5	Collimation experiments
LSS6	Extraction to LHC (TI2)
TI2	Transfer line to LHC – Beam 1
TI8	Transfer line to LHC – Beam 2

The actual nominal intensity allowed in the SPS is $1.2*10^{11}$ ppb: as an example, the structure of the nominal intensity LHC beam is 4 batches of 72 bunches which are spaced at 25 ns. The LIU project aims at almost doubling the intensity up to $2.2*10^{11}$ ppb.

In order to manage such intensities in the SPS the following upgrades are taking place during the LS2:

- New dumping system in LSS5 [4,5];
- 200 MHz RF cavity upgrade in LSS3;
- Carbon coating campaign dislocated around the full machine;
- Impedance reduction campaign in synergy with the carbon coating campaign;
- Extraction Septa upgrade in LSS2;
- Machine protection upgrade for extraction in LSS4, LSS6, TI2 and TI8.

SPS VACUUM GUIDELINES

Aiming at guaranteeing the actual vacuum performances, minimising costs and limiting the impact on impedance, the new vacuum layouts have been conceived following these guidelines:

- The linear pumping speed should be 100 l/s/m in the LSS and 10 l/s/m in the arcs;
- The equipment installed should not exceed a maximum outgassing rate of $1*10^{-5}$ mbar l/s after 24 h of pumpdown;
- The sectorisation should be optimised to minimise the exposure of critical components, e.g. kickers, RF cavities, internal dumps;
- The vacuum apertures should be optimized to limit longitudinal and transverse impedance;
- The vacuum layout should be conceived maximising the use of existing standard SPS components in terms of vacuum flanges, vacuum chamber profiles, bellows, supports and sector valves.

The following paragraphs describe how the different aspects have been tackled to comply with the above-mentioned guidelines.

LS2 VACUUM LAYOUTS: TIME-DEPENDENT SIMULATIONS.

Being a non-baked machine, time-dependent simulations of the vacuum sectors are crucial to define if an eventual vacuum intervention can take place within 30 h, the usual allocated time for a short technical stop during beam operation.

All new vacuum sectors have been simulated using the Electrical Network Analogy, with the freeware software LT Spice. The outgassing data has been treated in the following way: for vacuum drift tubes, stainless steel water outgassing time-dependent behaviour as per literature has been used, as per Equation 1:

$$Q(t) = \frac{3*10^{-9}}{t\ (h)} mbar * l/s * cm^2 \qquad (1)$$

For the instrumentation, either existing experimental outgassing data, or, in case this information was missing, the maximum allowed outgassing rate as per acceptance limit have been used.

The time-dependent simulations reproduce the pump-down behaviour of the sector, starting from the use of mobile local turbomolecular pumping group system, up to the startup of the ion pumps at a set value of pressure of $5*10^{-}$ mbar. The simulations do not take into account the roughing time of the sector down to the molecular regime, as well as the conditioning of the ion pumps.

All new equipment will be tested in terms of outgassing rate and residual gas analysis: the experimental values will be used as new input to the electrical network aiming at evaluating the impact of eventual non-conformities on the pressure profiles.

Figure 1 shows an example of time-dependent pressure profile simulations on the future kickers MKDV sector.

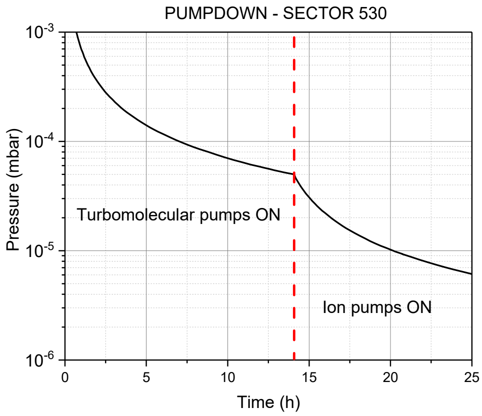

Figure 1: Example of time-dependent simulation showing the pump down curve of the vacuum sector 530.

LS2 VACUUM LAYOUTS: IMPEDANCE REDUCTION

In order to minimise the impact on the longitudinal and transverse impedance, the layout has been studied together with impedance experts: while maximizing the use of standard components, where needed conical smooth transitions at 15° have been implemented [Fig. 2]. In addition, the lateral pumping ports for ion pumps will be equipped with RF shields [Fig. 3].

The use of RF shielded sector valves would have a positive contribution to the reduction of the impedance budget of the machine: the installation of such components is postponed for the time being to a later stage.

Additionally, at the location of the short straight sections (SSS) of the focusing quadrupoles (QF), vacuum interconnections will be shielded in order to complete the implementation of a first impedance reduction campaign that took place in year 2000 [6].

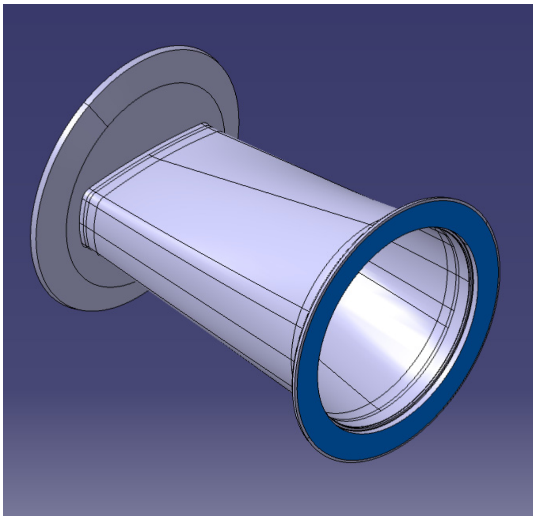

Figure 2: Proposed design for the ID156 to MBB profile conical transition.

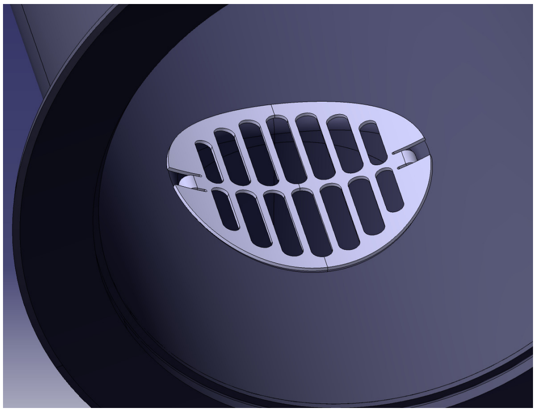

Figure 3: Proposed design for the DN70 pumping port RF shield.

LS2 VACUUM LAYOUTS: CARBON COATING CAMPAIGN

Aiming at reducing the multipacting in SPS main magnet vacuum chambers, an internal review studying the impact of electron production on high intensity beam instabilities approved the deployment of aC coating on vacuum chambers, hereafter listed by priority: main bending magnet type B (MBB), ID156 mm drifts, focussing and defocussing quadrupoles (QF – QD).

The strategy and techniques used to deploy the carbon coating campaign are described here [3]: the vacuum chamber drifts and the QD will be coated ex situ, while MBB and QF will be coated in the tunnel with a dedicated set-up.

The campaign started during end of year technical stop (YETS) in 2016-17, continued in 2017-2018 and during LS2 will aim at coating 22 MBB pairs, 11 QD SSS, 11 QD and about 100 vacuum drifts ID156 mm.

The campaign has been focused on having a continuous coating of critical vacuum chambers profile in the arc 5-.

Figures 4 and 5 compare the vacuum activities of the first 3-4 batches with 72 bunches at 1.2*10^11 ppb, with 25 ns spacing at 25 GeV, SPS injection energy.

Figure 4 compares the carbon coated positions along the arcs with non-carbon coated arcs that have been exposed to air during the YETS. While Figure 5 compares the carbon coated positions with LSS and dispersion suppressors (DS) positions opened during the YETS, where the vacuum dynamics of components which are prone to multipacting (i.e. kickers, instrumentation) is highlighted: in both cases, a reduced dynamic pressure rise can be noted for partially coated sectors.

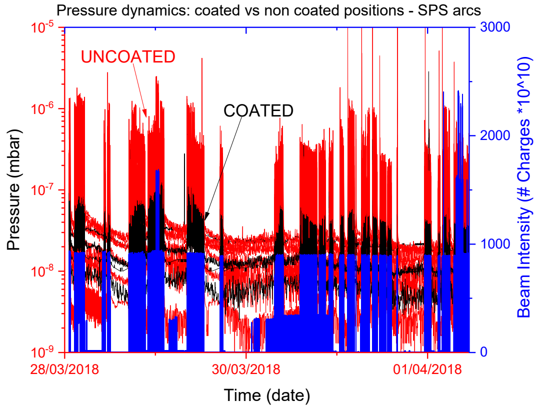

Figure 4: Dynamic pressure rise comparison of partially coated arcs and non-coated arcs with first nominal intensity beam.

CONCLUSION

During LS2 the vacuum layouts will be deeply modified within the framework of the LIU-SPS projects. Vacuum guidelines have been defined and followed for the conception and design of the new vacuum sectors, which have been optimised also from an impedance point of view.

The carbon coating campaign will be deployed on the most critical vacuum chamber profiles: the effect of beam instabilities on high-intensity beams will be studied during the first high intensity run after LS2.

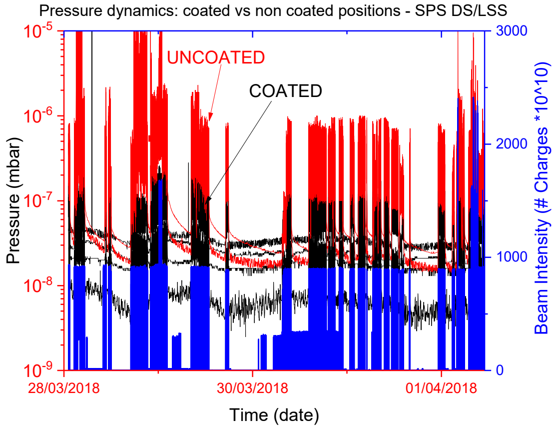

Figure 5: Dynamic pressure rise comparison of partially coated sectors and non-coated sectors with first nominal intensity beam.

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