COUPLED SIMULATIONS OF THE SYNCHROTRON RADIATION AND INDUCED DESORPTION PRESSURE PROFILES FOR THE HL-LHC TRIPLET AREA AND INTERACTION POINTS

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Abstract

The HiLumi-LHC machine upgrade has officially started as an approved LHC project (see dedicated presentations at this conference on the subject). One important feature of the upgrade is the installation of very high-gradient triplet magnets for focusing the beams at the collision points of the two high-luminosity detectors ATLAS and CMS. Other important topics are new superconducting D1 and D2 magnets, installation of crab cavities and new tertiary collimators, and re-shuffling of the dispersion suppression area. Based on the current magnetic lattice set-up and beam orbits, a detailed study of the emission of synchrotron radiation (SR) and related photon-induced desorption (PID) has been carried out. A significant amount of SR photons is generated by the two off-axis beams in the common vacuum chamber of the triplet area, about 57 m in length. The ray-tracing Montecarlo codes Synrad+ and Molflow+ have been employed in this study. The related PID pressure profiles are shown, together with simulations using the code VASCO for the analysis of beam losses and background in the detectors, including electron cloud effects.

THE TRIPLET AREA HL-LHC UPGRADE

One of the main areas of modification of the present LHC ring is the triplet area of the two large all-purpose detectors. Like done in all cryogenically-cooled areas of present-day LHC, the heat load on the 1.9K cold-bore is limited by introducing the so-called beam-screen (BS) inside of it [1, 4, 5].

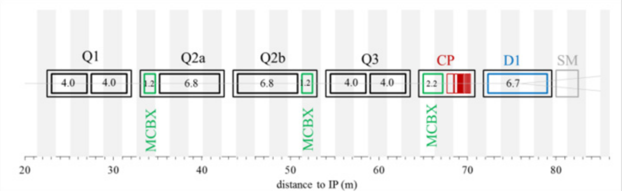

Figure 1: Layout of the HL-LHC Triplet Area, extending ~ 57 m on each side of IP1 and IP5. TAS is on the left of Q1.

3D MODELLING OF THE TRIPLET AREA

The montecarlo codes Molflow+ and Synrad+ [2] have been used to model and analyse the triplet area, from beginning of Q1 until the end of D1 (~57 m total axial length). The SR flux in this area is coming primarily from the incoming beam (i.e. moving towards the interaction point (IP) moving off-axis in the D2 and D1 dipoles, plus a minor contribution from the part of the orbit in the Q1-Q3 triplet magnets. The generated flux depends on the beam implemented orbits. Only SR in the far-field region and in the short dipole approximation, and no edge-effects or edge-radiation have been modelled at this stage of the analysis.

Figure 2 shows a screenshot of SYNRAD+ simulating the octagon-shaped BS placed inside the cold masses of all triplet magnets, connected by circular sections representing the part of the cold bore outside of the cold mass and/or the interconnects between different cryomodules.

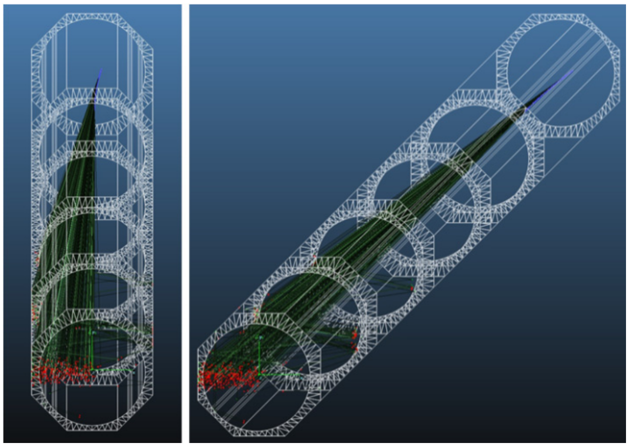

Figure 2: – Ray-tracing in Synrad+, incoming beam, with 50% reflectivity on walls. Few photons are scattered towards the opposite wall.

It is seen that most of the SR generated by the incoming beam falls on the external side of the BS and on the conical tapers/transitions between the BS and the round profile of the magnet interconnects. The exact geometry of these transitions has not been finalized yet, see [1] for further details, but by looking at the orbits, beam sizes, and after having carried out a sort of "sensitivity analysis" for angles and lateral orbit displacements, it can be seen (but is not reported here) that the SR cannot reasonably fall much outside of the area shown in Fig. 2, i.e. near the TAS and between Q1 and Q2. It will be ultimately the TAS and the pumping system (at room temperature) connected to it which will have to take most of any additional gas load generation, avoiding as much as possible its migration towards the NEG-coated areas of the experimental region, as discussed in the sections ahead.

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ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPME049

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Static Pressure, Pumping Speed and Conductance

Molflow+ has been used to first simulate the static pressure profile, i.e. the one when no beams are stored in the HL-LHC. Fig. 3 shows the 3D model created with Molflow+..

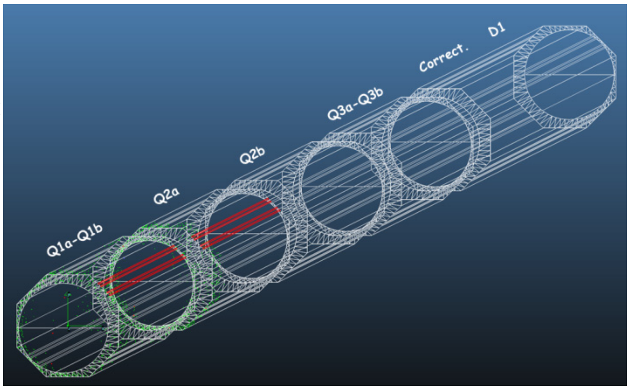

Figure 3: – 3D model of the BS, Q1-to-D1. Highlighted in red are the equivalent-conductance rectangular beam slots (4 of 16), on two BS sections.

The main pumping speed is given by the pumping slots machined along 4 of the 8 sides of the HL-LHC BS [1]. A pumping slot size and spacing equal to that of the present LHC has been initially assumed, i.e. rows of randomly spaced and sized racetrack-shaped slots of 1 mm width, averaging 62.5 slots/m. A total of 8x2x62.5 slots per axial meter of BS has been assumed. The transmission probability of the average slot (8 mm long) has been calculated to be 0.273, giving an average specific pumping speed of 0.99 l/s/slot for a 2 mm-thick BS and 0.8 l/s/slot for a 1 mm-thick BS. These values refer to N_2 at 20 C. Although N_2 is the usual reference gas in ultra-high vacuum (UHV) technology, the main gas desorption is constituted by H_2.

The temperature of the desorbed gas is also not going to be 20 C, but rather between 40 and 60 K [4], due to energy deposition considerations [see presentations by L. Esposito, F. Cerutti and N. Mokhov in ref.4]. Scaling to H_2 at 50 K one gets a multiplicative correction factor for the pumping speed of each slot of 1.545, i.e. 1.53 l/s/slot for the 1 mm-thick BS, and 1.24 l/s/slot for the 2 mm-thick one. As discussed in [1], preliminary finite-element analysis of the BS under triplet quench conditions show that the 1 mm-thick option for the BS is mandatory, in order to avoid permanent plastic deformation of the BS itself. This means that for H_2 gas at 50 K we can expect a specific pumping speed of 1530 l/s/m (838 l/s/m at 15 K), which should be sufficient to keep the gas density below the 100 hour gas scattering lifetime of 1.0E+15 H_2/m^3 [5], provided that no abnormal thermal outgassing rates are present in the system. Strict, clean UHV assembly conditions will be enforced towards attaining this goal.

Fig. 4 shows the static pressure profile for the geometry of Fig. 3. The pressure spikes are located in the interconnecting areas between cryostats, where no BS pumping slots are present. Note that this figure refers to an earlier case of 15 K BS temperature, but the overall shape is the same in the present case of 50 K average BS temperature.

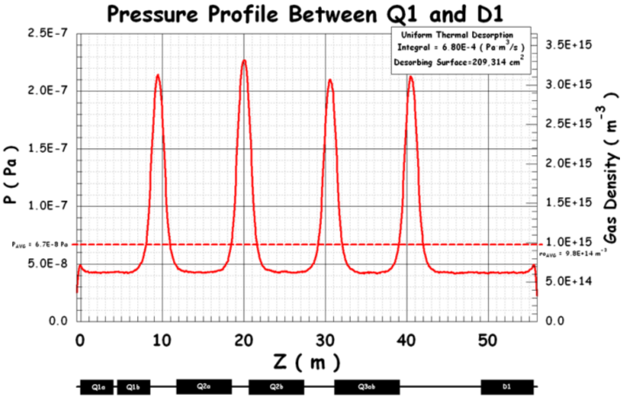

Figure 4: – Pressure profile normalized to an average of 1.0E+15 H_2/m^3.

Synrad+ Simulations

As already mentioned, the MC code Synrad+ has been employed [2]. The main source of SR is D1. At 5.2 T and 40 T·m integrated field (earlier version) the critical energy of its SR is 27.4 eV. A cut-off photon energy for PID has been set at 4 eV, i.e. only photons above this cut-off energy are considered (40% of total).

The integrated flux along the ~ 7700 mm-long orbit is therefore F=2.89E+17 ph/s, and the integrated power is P=0.98 W, for the nominal HL current of 860 mA.

The PID gas load is calculated using by $Q_{PID} = F{\cdot}\eta{\cdot}k$, where F is the photon flux, η is the PID yield in molecules/photon, and k is a conversion factor from molecules/s to mbar·l, k=4.047E-20 at 20 C. It is expected that the PID yield η will vary from an initial value to a “well conditioned machine” one in ways which will depend on a number of factors, not discussed in detail here.

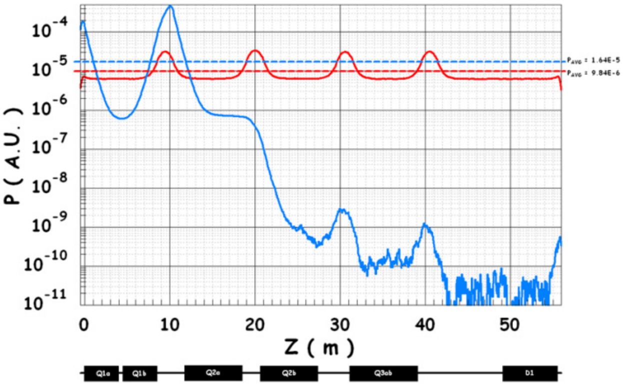

Figure 5: – Pressure rise for static (red) and PID (blue) unitary outgassing rates, arbitrary units. Note the quasi-exponential decrease of the PID pressure profile moving away from the area where the D1 photons hit (tapered sections between Q1 and Q2 and TAS taper before Q1).

VASCO CODE SIMULATION

The VASCO code simulation is another tool widely used in the Vacuum Surfaces and Coatings group at CERN to study gas density distributions in any newly proposed layout and in order to define the possible pressure increase in case of electron multipacting effects and SR impinging onto the beam vacuum chambers walls [3,4]; its advantage over other codes is that it allows a calculation of the critical current for vacuum stability as defined in [3].

A preliminary pressure profile for the new suggested layout of the Long Straight Section 1 for the HL-LHC project is calculated. A copper beam screen cooled at a temperature of 15 K is taken into account for all the simulations. All along the beam screen length, distributed pumping holes, as already installed in the LHC, are taken into consideration. The diameter of the new inner triplets beam screen is 103 mm [1]. The total length, considering the triplet Q1, Q2 and Q3, the dipole D1 and the corrector package area is of about 56 m. The layout of the interaction point of ATLAS and the recombination chambers are kept the same as will be installed in the LHC after the Long Shutdown 1: all room-temperature surfaces facing the beam are NEG coated, the presence of ion-pumps is maintained, and the average diameter of the beam vacuum chambers is 80 mm. VASCO is a 1D simulation code which employs "equivalent diameters" for any non-circular vacuum component cross-section.

Figure 6 shows an example of three distinctive pressure profiles for the case of no circulating beam, with circulating beam producing an electron flux of 10^{15} e^-/m/s uniformly distributed all along the beam pipe walls at the start up and after a scrubbing period of the beam pipe wall.

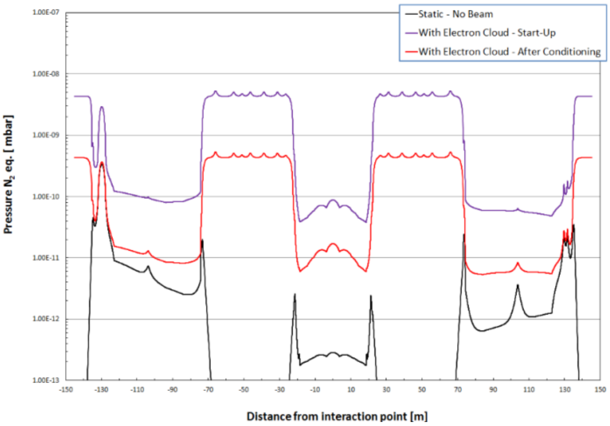

Figure 6: – Example of static and dynamic pressure increase in VASCO ~ 145 m on each side of IR1.

As already seen in the past and in the LHC operation [3], a scrubbing run is an effective way of reducing the secondary electron yield of the inner surface of the beam screen. A reduction of the electron induced desorption yield of the beam screen surface from $\approx 1\cdot 10^{-2}$ to $\approx 1\cdot 10^{-3}$ molecule/e^- will produce a decrease of the pressure of about 1 order of magnitude.

After an effective scrubbing run an average pressure of $\sim 4\cdot 10^{-10}$ mbar is expected in the inner triplets. The gas density in molecules/m^3 is given by $\sim 8.5\cdot 10^{12}$ H_2, $\sim 2.3\cdot 10^{11}$ CH_4, $\sim 1.5\cdot 10^{12}$ CO and $\sim 4\cdot 10^{12}$ CO_2.

Further analysis of the vacuum behaviour of this area of HL-LHC using VASCO is given in the companion paper [6].

CONCLUSIONS

An analysis of the HL-LHC triplet area pressure profile has been carried out, taking into account the proposed new size and shape of its beam screen. It is found that the pumping speed and pressure profiles should be compatible with a low-background in the detectors, and also with the global 100-hour gas scattering lifetime of the LHC. Montecarlo as well as finite-elements codes have been used for this task, namely the MC suite Molflow+/Synrad+ and VASCO. All these codes have been extensively benchmarked in the past at CERN and elsewhere, and therefore we believe that the results obtained here can be safely assumed to be realistic.

Future refinements of the models and a re-calculation of all contributions to the pressure profiles will be carried out as soon as prototyping and validation of different components will be carried out, most notably the one for the beam screen [1].

ACKNOWLEDGEMENTS

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

RK acknowledges the critical support of Marton Ady (CERN, TE-VSC) for the development of the MC codes Molflow+ and Synrad+.

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