LHC DUMP ASSEMBLY – OPERATIONAL FEEDBACK AND FUTURE PROSPECTIVE

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Abstract

The current LHC external beam dumps (TDE, Target Dump External) are operational since 2008. The dump cores are 7.6 m long and made up of different grades of graphite, enclosed in a duplex stainless steel vessel, welded together in different sections. The core itself is part of a longer assembly immersed in a nitrogen atmosphere, delimited by a thin stainless steel sheet upstream and a pure titanium disk downstream. Since end of 2015 a series of leaks of nitrogen have been observed. Leaks have occurred in all the gaskets upstream of the dumps (both UD62 and UD68) as well as in the downstream window for one of the two operational dumps (UD68). This presentation summarises the type of leaks observed and corrective measures taken during Run 2, together with the vibration and displacement measurements performed to analyse the behaviour of the device during beam dumping. Different upgrades are proposed to be implemented during LS2, aiming at increasing the reliability of the assembly and hence, reducing corrective interventions or eventual machine downtime. Additionally, numerical simulations are shown in order to analyse the risk of failure of the upstream and downstream windows under different beam dumping scenarios, including Run 2, Run 3 and HiLumi beams, under normal operation or in case of partial dilution failure. Considerations about the possibility to reach 1.8E11 during Run3 will be provided, together with upgrade proposals.

LHC DUMP LAYOUT

The TDE configuration is shown in Fig. 1 and Fig. 2. The complex is made up of a vacuum sector (extraction line connected to the LHC vacuum) and a nitrogen sector, which can reach a maximum pressure of 1.2 bar. The barrier between the above sectors is made by means of 0.05 mm thick, stainless steel 316LN foil. In order to withstand the forces resulting from the pressure difference between these to sectors, a carbon-fiber-carbon, 10 mm thick disk is installed on the vacuum side of the stainless steel foil. These two components make up the so called, upstream window (Fig. 2). The nitrogen sector, is made up of by a 10-m beam pipe and the actual dump core (8 m long), which is composed of an array of two different graphite grades, enclosed in a duplex stainless steel 318L tube. This sector is delimited on the downstream end by a 10 mm thick commercially pure grade 2 titanium disk. The dump core is surrounded by several shielding blocks (Fig. 1). All these components are connected together by means of helicoflex gaskets.

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MAIN OBSERVATIONS DURING LHC RUN 2

During the LHC Run 2, on several occasions, expert personnel from EN-STI, SMM and EA and well as TE-VSC have performed different operations involving mostly corrective measures related to leaks in the nitrogen sector. The main tasks performed during the interventions were leak detection, gasket replacements and flange tightening, refill of nitrogen sector and instrumentation installation. It should be noted that since the devices and the areas are radioactive, all these interventions combined have resulted in a cumulated dose to personnel of the order of 3 mSv during this period. One of the possible causes of leaks is believed to be linked to vibrations induced on the assembly after depositing such a high amount of energy (up to 314 MJ) when the beam is dumped. Details of some of these operations are mentioned in the following sub-sections.

Installation of Interferometers

In order to measure the vibrations generated on the dump, a set of interferometers were installed at different positions on the upstream window flange and the flange upstream of the dump core (just outside the shielding). The data obtained from this instruments gave information, for the first time, on the type of movements experienced by the device under such loads. For instance, one interesting observation was that the retroreflectors (glass prisms necessary to reflect the light beam used to measure the movement) broke during operation. This was caused by the high accelerations produced by the beam impacting the dump. In order to overcome this issue, metallic mirrors were installed during YETS 17-18. In general, high displacements were measured during when the beam was dumped. It was also observed that the device showed some permanent movements of the order of 5 mm longitudinally (towards downstream) combined with a clockwise rotation around the beam axis.

Maintenance on Gaskets

As mentioned above, different interventions were necessary to either replace damaged gaskets (Fig. 3) or to re-tighten the flanges together (Fig. 4). Despite the fact that the collars closing the flanges were tightened to a high torque before operation, the bolts on some of them (namely the one upstream nearest to the dump as well as the flange on the upstream window) were loose after few months. Considering the position of these flanges and the time required to re-tighten them or to replace the gaskets, the dose to personnel involved in this operation was not negligible (hundreds of μSv per intervention).

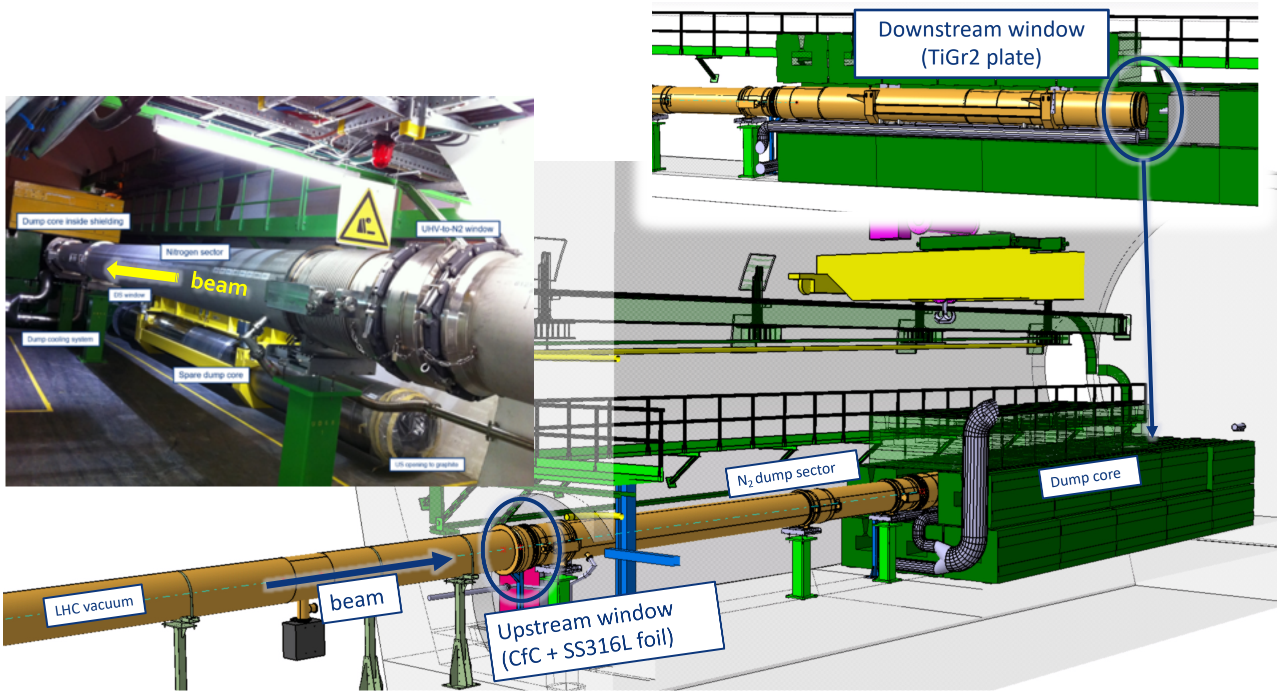

Figure 1: LHC Dump Layout.

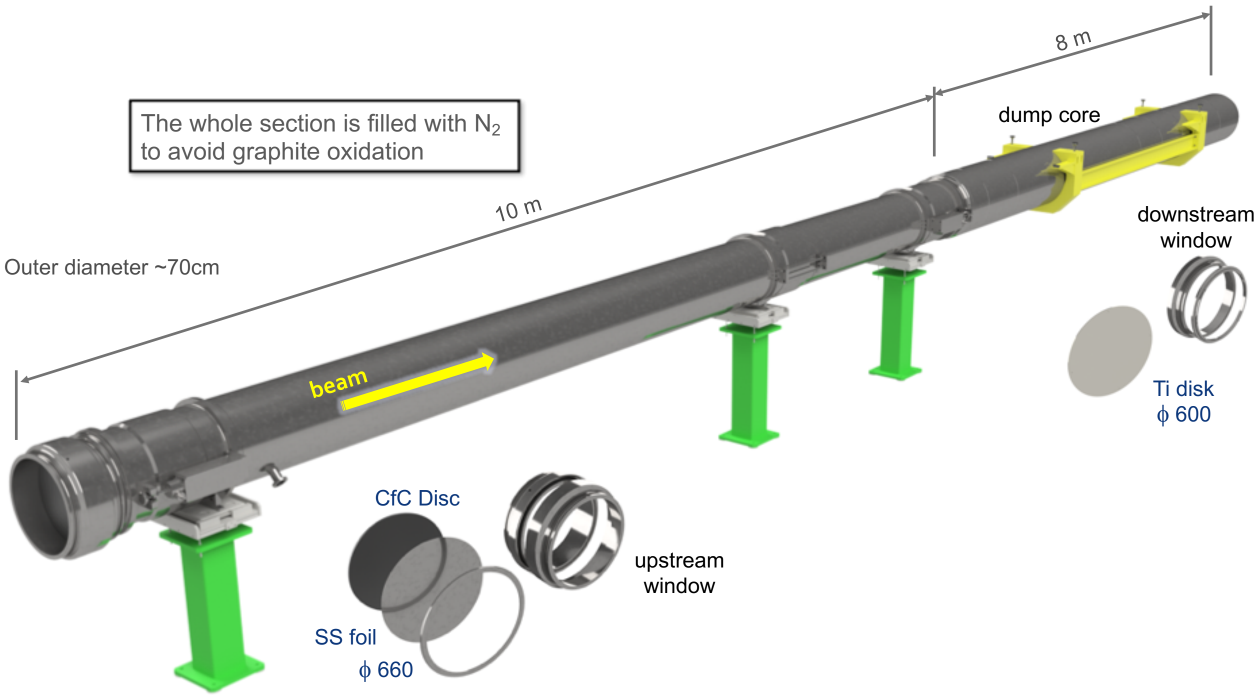

Figure 2: LHC Dump.

Upgrade of nitrogen gas supply system

Until 2015, any eventual leaks of nitrogen were automatically compensated by injecting new gas from a pressurised bottle located in the tunnel, next to each extraction line. As the leaks became more significant, the nitrogen bottled needed to be replaced more often. Nevertheless, this operation could not be performed quickly, as it requires a stop of the LHC machine so that personnel could access the area. In order to minimise the number of interventions related to this, the nitrogen bottle was replaced by a 6-bottle rack (mid 2016). However, this was meant to be just a temporary measure as it still required access of personnel (and dose). In February 2018, nitrogen gas lines were installed between

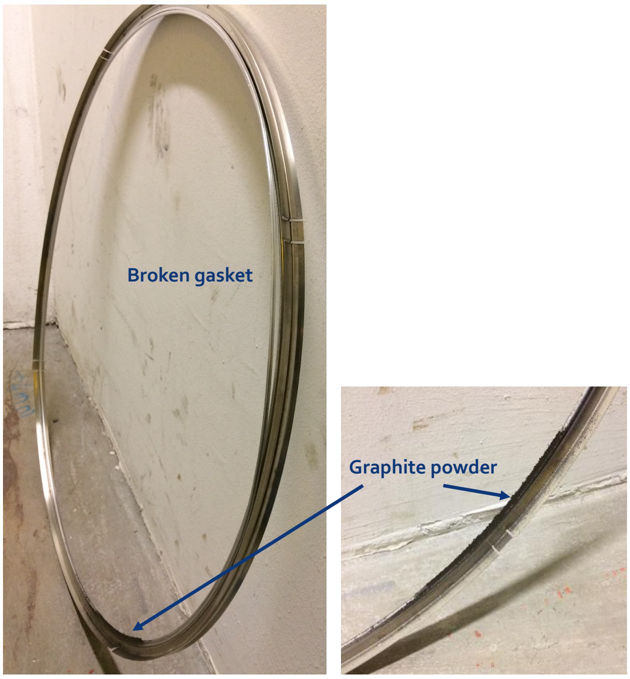

Figure 3: Example of damaged gaskets exchanged during YETS.

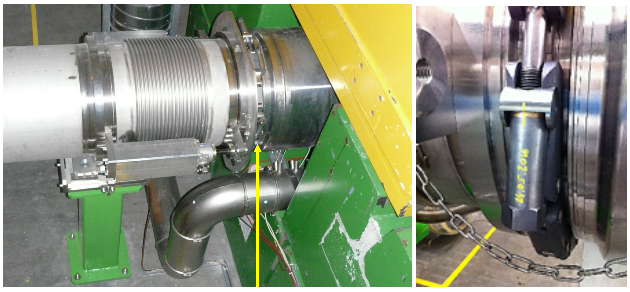

Figure 4: Tightening of flanges in the nitrogen sector, following observation of leaks.

the surface (SD6) and the nitrogen sectors of the two dumps. In this way, the nitrogen supplied is guaranteed by a set of racks on the surface, that can be replaced much more easily and quickly, with virtually no perturbations to operation (and no dose to personnel).

SUMMARY OF OPERATION DURING LHC RUN 2

Several factors have created limitations on operations or simply resulted in a reduced reliability of the dump block. Large displacements have been observed to be produced in the device after every dump. These displacements, which contain a significant dynamic component, probably have a a significant contribution in the nitrogen leaks experienced by the system. Vibrations and high accelerations of such a large and massive device could explain the loosening of collars compressing the gaskets. Due to all of the above issues, several interventions of different nature have been required during Run 2. Apart from suspending operation for hours each time, this has resulted in a non negligible dose taken by personnel taking part of these interventions (cummulated dose 3 mSv). The intensity of beams sent to the dump increased progressively over Run 2. This results in higher energy deposited in the different components of the device (and hence higher stresses). Specifically, the downstream windows is estimated to be submitted to stresses near the elastic limit of the material. Thus, the reliability of the device was reduced during as the intensity of the beam increased. For the first time, the displacement and dynamic response of the dump to the beam was measured. It was observed that the loads, displacements and vibrations involved are considerable. However, given the complexity of the device, a thorough analysis had not been done before. As a result, it could be concluded that the dynamic response of the device to high intensity beam dumps was unpredictable, which indirectly could represent a limit for operation.

PROPOSED UPGRADES FOR LS2

In order to address the main issues identified during Run 2, and considering the limited time and resources available until the end of LS2, different upgrades are proposed, as described in this section.

Downstream Window Upgrade

The current downstream window, responsible to enclose complete the enclosure of the nitrogen sector and exposed to the beam and showers exiting the dump (depositing still significant energy at each dump) is currently made of a disk of Ti-Gr2 (commercially pure titanium), clamped onto the stainless steel housing of the dump core by means of a helicoflex connection. This type of connection is not well adapted to such dynamic loads, as there is a risk that the bolts clamping the flanges and compressing the gaskets get loose after a certain number of dumps. Moreover, the material chosen for the window does not have sufficiently high mechanical properties as to withstand beams with the intensity expected in Run 3. Based on the above, a new Conflat flange will be welded onto the present one, and the window will be made of Ti6Al4V (titanium grade 5). This type of connection is well known at CERN and can guarantee a much stronger and reliable clamping of the gasket than the helicoflex one. Moreover, the use of Ti6Al4V instead of pure Ti for the window allows to increase the safety factor to failure by 3-4 times, as the loads will be virtually the same but the strength of this allow is significantly higher.

Connection line Upgrade

As explained above, the helicoflex gaskets have shown several issues during operation (resulting in nitrogen leaks), mainly because they are either not well compressed (inherent issue related to the design of the flanges) or get damaged during operation (probably due to vibrations). Hence, the gaskets will be replaced by EPDM O-rings, as this material can withstand the expected irradiation during Run 3, and it is much more elastic, being able to cope better with geometrical imperfections of the flanges and vibrations experienced during operation. This simple upgrade is expected to minimise significantly the risk of leaks in the nitrogen sector.

Instrumentation Upgrade

In order to build up knowledge on the real behaviour of the dump during operation, and to benchmark numerical models, the dump core will be instrumented with strain gauges, temperature sensors, interferometers and LVDTs. The details on the type of sensors, positions and data acquisition systems are to be defined with EN-SMM.

Upstream Window (YETS after LS2)

The upstream window is currently made of a thin foil of stainless steel 316 LN (0.05 mm thick), supported by a 10-mm thick disk of carbon-fiber composite (responsible to withstand the loads generated by the pressure difference between the nitrogen sector (up to 1.2 bar) and the extraction line (vacuum). The only loads experienced by the stainless steel foil are generated by the interaction with the beam sent to the dump. During Run 3, the combination of higher intensity and smaller emittance are expected to increase the loads on the window up to critical values, too close the the mechanical strength of the window. In order to address this issue, the window is proposed to be upgraded by replacing the stainless steel foil by Ti6Al4V. This modification would increase the safety factor by at approximately 6 times, thanks to a combination of higher strength, lower Young modulus and lower coefficient of thermal expansion. However, due to limited resources during LS2, this modification will be implemented during the YETS 20/21. It should be noted that until then, the current window will still be operating safely, as the nominal Run 3 intensity and emittance are not expected during 2020 (the beam will probably have the same characteristics as during Run 2).

LIMITATIONS DURING RUN3

With the proposed upgrades, most of the limitations observed during Run 2 should be either reduced or removed completely. The replacement and redesign of the downstream window increases significantly the safety factor in terms of stresses, resulting in a much more robust and reliable component. The upgrade of the connections should be able to cope better with the dynamic response of the dump to high intensity beams, resulting in a reduced risk of leaks. Thanks to the new instrumentation, the behaviour of the dump is expected to be understood better. The data collected during Run 3 will be of critical importance to define further upgrades and redesign of the dump assembly, aiming at addressing the issues generated by the significant vibrations generated by the beam. The upgrade of the upstream window will remove limitations for the HiLumi beams, as the safety factor will be increased by several times with respect to the current one (detail analysis to be carried out at a later stage).

CONCLUSION

The dump block is a complex assembly: issues of different nature observed during Run 2 (probably due to the increased intensity of the beam) has required a number of corrective measures, resulting in a high cumulated dose to personnel (approximately 3 mSv). In view of better understanding the behaviour of the dump, interferometers were installed to measure the displacement of some flanges upstream of the dump. The readings from these devices have revealed that the assembly experiences significant vibrations and large permanent displacements. Based on the above observations, different upgrades planned for LS2, including the replacement, re-design of some components (including downstream window and connections amongst others), are expected to increase the robustness and hence the reliability if the device. This should result in a considerable reduction of interventions (and hence personnel dose). Even though the upstream window is also to be upgraded, due to limited resources, this upgrade is foreseen to be implemented during the YETS 2020/2021. Once all upgrades are implemented, the dump block is expected to be compatible with reliable operation with the expected intensity and emittance planned during Run 3, i.e. & 1.8×10^{11} ppb and 1.8 µm respectively. It should be noted that there is still much uncertainty regarding the dump's dynamic behaviour. In order to fully address this issue a more in-depth study and thorough re-design of the entire assembly are recommended for LS3.

GENERAL REMARKS

It must be noted that this paper is based on the situation and analyses as of January 2019, when the EVIAN meeting took place. However, since then, there have been additional analyses and design iterations which have resulted in additional upgrades being proposed in December 2019, to be implemented by the end of LS2. Overall, all the issues mentioned in the paper are to be addressed and, in addition, other measures are being implemented to limit or remove the permanent displacements of the dump, as well as mechanically disconnecting the nitrogen sector from the extraction line.