NEW GENERATION CERN LHC INJECTION DUMP - ASSEMBLY AND INSTALLATION (TDIS)*

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Abstract

During the Long Shutdown 2 (LS2) at CERN, several upgrades were performed to beam intercepting devices in the framework of the HL-LHC Project. Upgraded equipment included two internal injection beam dumps (TDIS) intended for LHC machine protection located at the injection points from the SPS to the LHC. These two units have been assembled, tested and then installed around LHC Point 2 and Point 8 and are currently ready to get commissioned with beam. They are 5.8 m-long, three-module-segmented vacuum tanks, with large aperture to accommodate the injected and circulating beams and equipped with absorbing materials. These comprise graphite and higher-Z alloys that are embedded in sub-assemblies reinforced with back-stiffeners made of molybdenum alloy containing Ti and Zr (TZM). The current contribution covers three main topics. First, it details the TDIS design and its key technical features. The second topic discussed is the outcome of a beam-imact experiment where a prototype module was tested under high-energy beam pulses at CERN's HiRadMat facility. To conclude, the return of experience from the pre-series construction, validation and installation in the LHC tunnel is presented.

INTRODUCTION

The CERN LHC TDIS is a device conceived to shield downstream elements from particle beams eventually missteered during the injection process [1]. Although rare, these events might occur at any time during the phase when SPS-accelerated particle bunches are transferred to the LHC rings. This new component replaces a version that was not suited to safely protect against the up-to-7.36x10^{13} 450-GeV proton beams that are to be transferred into the LHC in the High Luminosity LHC era [2]. The highlights of the main stages of the TDIS development, i.e. design, manufacturing, testing and installation, are covered in this contribution.

DESIGN

Among the various requirements, four aspects of the TDIS design were considered particularly critical:

1. high-accuracy positioning of the movable absorbing ensembles (a.k.a. jaws) with respect to the proton beam;
2. outstanding mechanical reliability and robustness to cope with accidental beam impacts and the resulting thermal shocks;
3. high vacuum performance to meet the required UHV level (< 10^{-8} mbar) for the LHC [3] and
4. fast exchangeability to minimize downtime in case one of the installed units becomes faulty or damaged and must be replaced with a spare.
5. impedance optimization and electron cloud effects

High-Accuracy Positioning of Jaws

To accomplish the first goal, instead of featuring full-length jaws as the previous generation [1], the TDIS is split into three segments, each of them accommodating shorter jaws, as represented in Fig. 1. Every jaw is supported by two shafts that can move independently from each other. The 940-mm span is small enough to keep bending at a reasonable level, which helps to achieve a low flatness defect (less than 0.2 mm) of the jaw's free-surface. Since particle beams passes through the small gap (~8-mm during injection phases) existing between upper and lower jaws' free surfaces, the flatness of these is key to minimize jaw-beam interaction.

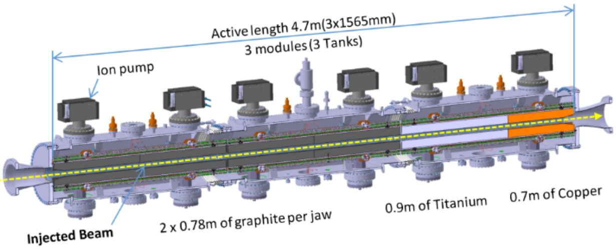

Figure 1: TDIS longitudinal cross section.

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The architecture of the jaw itself and the materials used also play a role when it comes to attain a low flatness defect of the free surface. In the case of the TDIS jaw, a back-stiffener (see Fig. 2) made of TZM ensures the straightness of the whole assembly.

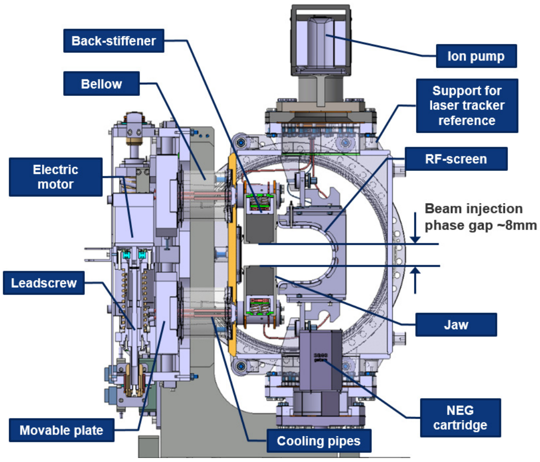

Figure 2: TDIS module transversal cross section.

As for the jaw positioning, the TDIS relies on six sub-assemblies (two per module) known as mechanical tables. These allow for the vertical movement of two integrated axes that are connected to support an upper and lower jaw, respectively. Each axis is powered by a 2.2 Nm-torque electric stepper motor whose rotational motion is converted into linear one via a roller-type leadscrew. The precision of this mechanism is such that the jaw position repeatability is in the order of +/-0.01 mm.

Mechanical robustness

The mechanical reliability is ensured with the use of components and materials well known to be compatible with moderately radioactive environments (~1 Sv/hour prompt). The electric motors are suitable for exposure to up to 30 MGray [4] and all the bearings and leadscrews of the mechanical tables are lubricated with rad-hard grease Petamo® GHY 133N [5].

The components that are subjected to the highest level of energy deposition are located inside the vacuum chamber. Both their geometry and the materials they are made of were defined based on the results of FEM thermo-mechanical simulations, whose input is obtained by means of the FLUKA Monte Carlo code, which allowed estimating the amount of beam energy transferred to the. The high power density expected to be delivered by the SPS after the injectors upgrade (LIU project [6]) imposes the use of materials with exceptional mechanical and thermal properties including isostatic graphite, titanium alloy Ti-6Al-4V, CuCr1Zr and TZM. The first three form the absorbing bulk of the TDIS (Fig. 1) and are able to gradually dissipate the impacting beam without suffering any structural degradation.

TZM was selected for this demanding application thanks to its very high dimensional and mechanical stability at high temperatures combined with its exceptional response to effects induced by particle showers. Figure 3 shows its performances compared to other UHV-compatible alternatives in terms of critical mechanical and physical properties.

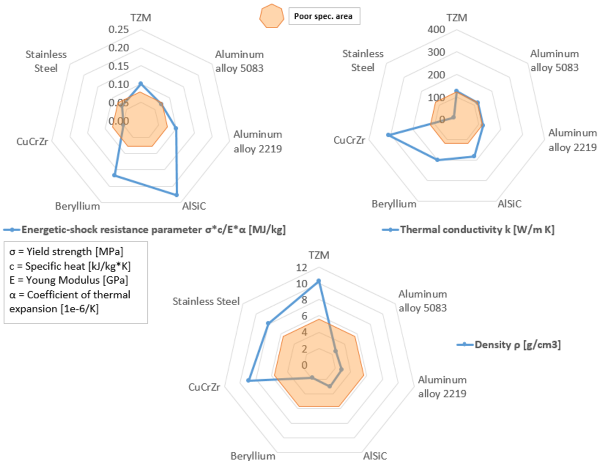

Figure 3: Comparison of back-stiffener candidate materials' key properties.

High Vacuum Performance

Besides its active vacuum hardware (six ion pumps Agilent VacIon® Plus 75 and six NEG – Non Evaporable Getters – pumps CapaciTorr® HV 2100) the TDIS also boasts a passive feature to enhance the vacuum performance that has to do with the coating of stainless steel surfaces directly exposed to traversing particle beams. The inner surfaces of transitions (Fig. 1) and RF-screens (Fig. 2) are ion-sputtering coated with Ti-Zr-V NEG and amorphous carbon, respectively, decreasing thus the SEY (secondary electron yield) factor and e-cloud build-up [7, 8].

Fast Exchangeability to Minimize Downtime

If any of the installed TDIS became faulty or got damaged it could limit the performance of the LHC or even prevent it from operating at all. In that scenario in situ fixing might not be possible so a swift replacement with the corresponding spare is required. Therefore, the TDIS has two pneumatic gate valves (Fig. 4) that allow keeping the system under UHV (after having undergone a lengthy bake-out process). In this way, the TDIS spares can be stored ready to be connected within the vacuum line of the accelerator with the valves closed. Without this design solution the equipment would have to be opened (by removing end closing flanges) prior to the linking to the adjacent flanges in the vacuum line, so a just-installed TDIS spare would have to be UHV-conditioned in the tunnel, which would take at least two weeks, whilst a complete TDIS exchange operation in less than 5 days is feasible with the current configuration.

PROTOTYPE TEST AT HIRADMAT

Due to the challenging operating conditions, it was decided to build up a prototype module of the TDIS for validation purposes. The HiRadMat facility at CERN [9] provided a very important part of the necessary set-up to subject the prototype to proton beam pulses that would reproduce HL-LHC conditions on the TDIS jaws. The focus of the experiment was the back-stiffener since pre-test numerical estimations revealed borderline thermomechanical stresses in this component induced by particle shower.

The module incorporated numerous pieces of instrumentation that enabled the monitoring of the absorber's thermomechanical response (and particularly of the back-stiffener) upon beam shots. Measurement data obtained out of temperature sensors proved to be in good agreement with simulations. The plot of Fig. 5 compares calculated values (orange dots) with values measured (blue dots) by the pyrometer right after a beam pulse.

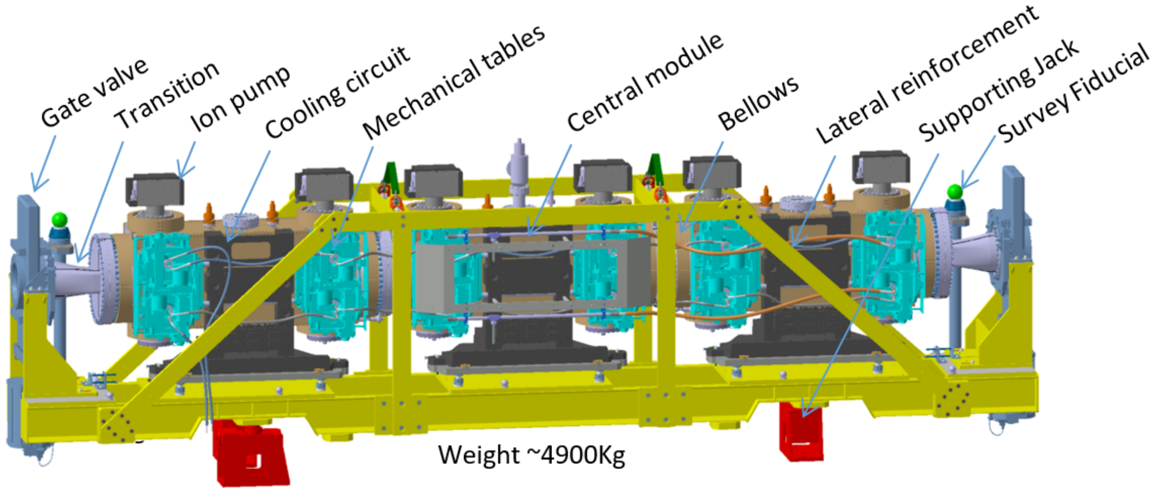

Figure 4: Isometric view of TDIS CAD model.

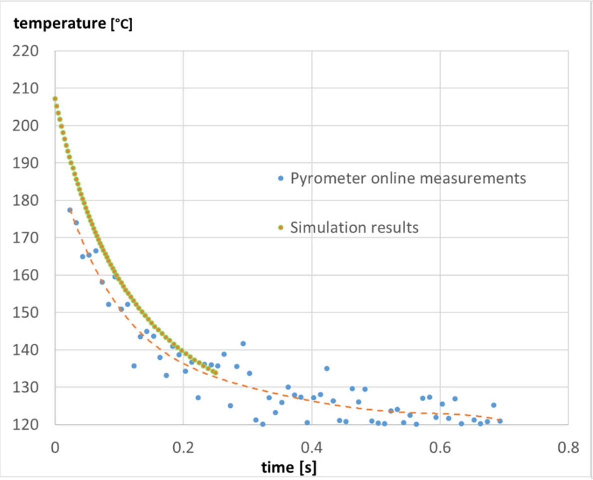

Figure 5: Chart of low sampling-rate reading vs numerical calculation of back-stiffener's temperature.

Recorded signals from strain gauges before and after the whole series of pulses did not suggest permanent deformation of the part, which was confirmed by collating pre- and post-irradiation metrological inspection results.

REX OF CONSTRUCTION, VALIDATION AND INSTALLATION IN LHC TUNNEL

During the construction, one of the most challenging activities was the inter-module alignment. While the main objective of this process is to achieve a high degree of coplanarity between the three jaw segments (upper and lower), this has to be done indirectly by aligning the whole modules instead (with the aid of a laser-tracker system whose references are placed on the allocated supports – see Fig. 2 –). In this step, the dimensional quality of all components with characteristics involved in the tolerance chain between jaw surface and module's flanges was key to enable the coupling of the latter. An equally important factor was the inherent flexibility of the shared supporting steel girder because the alignment procedure must compensate the slight displacements of the ensemble caused by the variation of the load state. The bridge-like structure formed by lateral bars as shown in Fig. 4 helped significantly in this regard and specially to maintain the alignment when the TDIS was set under vacuum: due to the absence of an axially-rigid connection between the central module and the end ones (with bellows – see Fig. 4 – designed to cope with axial thermal expansion), the girder has to bear an off-axis 1.4 ton compression force caused by the atmospheric pressure.

For the final installation of the two TDIS within the accelerator a permanent dedicated lifting system was fixed to the vault of the tunnel in order to simplify and speed up an eventual exchange of the absorbers in the future. The placement of both the lifting system and the TDIS itself required high accuracy and was based on a calculation accounting for the tunnel geometry and the coordinates of the reference beam axis. For that purpose it was crucial to consider, on one hand, the tunnel slope at that location (13.4 mrad) and, on the other, the correct beam axis as the orbits of the circulating beams inside the TDIS vary depending on the operation stage [10].

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