ANALYSIS AND OPERATIONAL FEEDBACK ON THE NEW DESIGN OF THE HIGH ENERGY BEAM DUMP IN THE CERN SPS

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Abstract

The CERN's Super Proton Synchrotron (SPS) high energy internal dump (Target Internal Dump Vertical Graphite, known as -TIDVG) is required to intercept beam dumps from 102.2 to 450 GeV. The equipment installed in 2014 (TIDVG#3) featured an absorbing core composed of different materials surrounded by a water-cooled copper jacket, which hold the UHV of the machine. An inspection of a previous equipment (TIDVG#2) performed in 2013 revealed significant beam induced damage to the aluminium section of the dump, which required imposing operational limitations to minimise the risk of reproducing this phenomenon. Additionally, in 2016 a vacuum leak was detected in the dump assembly, which imposed further limitations, i.e. a reduction of the beam intensity that could be dumped per SPS supercycle.

This paper presents a new design (TIDVG#4), which focuses on improving the operational robustness of the device. Moreover, thanks to the added instrumentation, a careful analysis of its performance (both experimentally and during operation) will be possible. These studies will help validating technical solutions for the design of the future SPS dump to be installed during CERN's Long Shutdown 2 in 2020 (TIDVG#5).

INTRODUCTION

The TIDVG is one of the internal beam dumps of the CERN SPS. Its role is to absorb the beams circulating in the SPS in case of emergency, during LHC beam setup and LHC filling, machine development (MD) and the residual beam for the fixed targets (FT) remaining after the slow-extraction process. The TIDVG is deputed to absorb the primary SPS beam with energies from 102.2 to 450 GeV.

When dumping, the circulating beam is deflected by a set of vertical kicker magnets (MKDV) which direct the beam onto the dump by displacing it below the nominal closed orbit. Thanks to the so-called "dilution horizontal kickers" (MKDH), the impacting beam forms a sinusoidal pattern in the horizontal direction on the front of the dump, in order to decrease the density of energy deposition and reduce the peak temperature in the absorbing blocks. In addition, the SPS dump system consists also of another beam absorber, the Target Internal Dump Horizontal (TIDH), where the primary beams are dumped for energies from injection (14 GeV) up to 28.9 GeV.

Following a vacuum leak appeared in April 2016 in TIDVG#3, a new dump (TIDVG#4) has been prepared, in order to be able to produce a more robust device to be manufactured, assembled and installed during the Extended Year End Technical Stop (EYETS), lasting between December 2016 and April 2017.

DESIGN OF TIDVG#4

The TIDVG#4 (Fig. 1) has the same external dimensions (length, diameter, etc.) as the current TIDVG#3 to avoid the modification of any existing component surrounding the current device and ease integration aspects in a very radioactive area. The design of TIDVG#4 addresses some weakness observed in the TIDVG#3, namely:

- The new core consists of a CuCr1Zr jacket, directly cooled, and several contiguous blocks: 350 cm of Graphite R7550 P5D, 40 cm of CuCr1Zr and 40 cm of a tungsten alloy (IT180® – Plansee). The particles attenuation factor reached with this configuration is similar to that of its predecessors. Furthermore, the aluminium section of the dump was removed, as it was the limiting component of the previous TIDVG design [1].

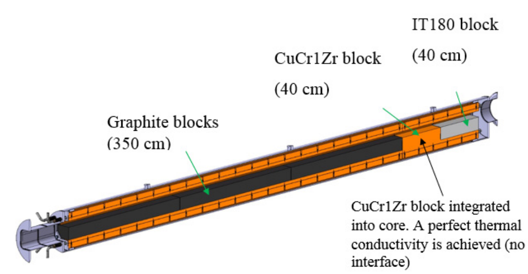

Figure 1: Longitudinal section of the TIDVG#4, showing the absorbing blocks configuration.

- In the TIDVG#4, CuCr1Zr part of the absorber is integrated into the cooled jacket as one unique part, ensuring a perfect thermal conductivity in this specific area.
  This copper core is cooled by means of water circulating in stainless steel tubes that are clamped into the copper mass.
  To achieve a good contact pressure (0.2 MPa) between the absorbing blocks (graphite and tungsten) and the jacket, compression springs

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were employed (Fig. 2).

- A vacuum chamber (SS316L seamless tube, grade 1.4435), added in order to improve the robustness in terms of vacuum tightness in comparison to TIDVG#3 (Fig. 3).
- A water-cooled shielding by embedded stainless steel tubes. This shielding is composed of two cast iron (EN-GJL-200) parts (Fig. 4), each of them weighting more than 11 tons.
  Between the cast iron blocks and the stainless steel vacuum chamber, copper shims were inserted to ensure a thermal contact between the vacuum chamber and this shielding.

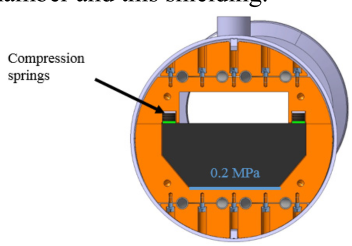

Figure 2: Compression springs.

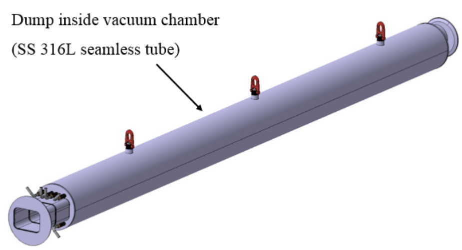

Figure 3: TIDVG#4 SS316L vacuum chamber.

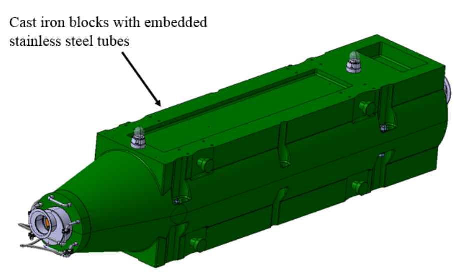

Figure 4: TIDVG#4 cast iron blocks shielding and overall assembly of the dump.

MONITORING DURING OPERATION

Eighteen PT100 temperature gauges were installed in order to monitor the temperature of the dump (Fig. 5) during operation.

There are 12 sensors located in the copper core: 5 on the graphite blocks, 2 in the CuCr1Zr block, 2 on the IT180® block and 3 in the copper jacket itself.

Furthermore, 6 sensors were installed in the shielding assembly: 4 to measure the temperature of the SS vacuum chamber and another 2 on the upstream surface of the shielding.

In the water circuit, 4 sensors were placed to measure the inlet and outlet temperature of the two main water circuits within the dump: the copper core and the shielding. Taking advantage of this new device, one water flow sensor was also mounted in the outlet of the copper core water circuit to control the actual flowrate and water velocity.

Two flow-switches are also present to be able to detect whether the water is flowing in the circuit (operation is stopped if no flow is detected by these sensors).

The main objective of the PT100 is to better understand the dump's behavior, comparing the temperatures measured during operation with the numerical simulations.

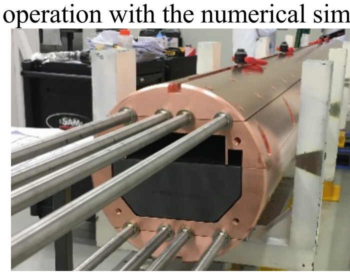

Figure 5: TIDVG#4 core assembly.

NUMERICAL SIMULATIONS

TIDVG#4 shall withstand all types of beams accelerated in the SPS supercycle. The main cases are reported in Table 1.

Table 1: SPS Beam Parameters [2]

Beams	Max E [GeV]	Bunch intensity [p^+/bunch]	# of bunches	Total intensity [p^+/pulse]
LHC (25 ns)	450	$1.5 \cdot 10^{11}$	288	$4.32 \cdot 10^{13}$
FT	400	$1.4 \cdot 10^{10}$	4200	$5.88 \cdot 10^{13}$
FT 10%	400	$1.4 \cdot 10^{9}$	4200	$5.88 \cdot 10^{12}$
LHC (BCMS)	450	$1.2 \cdot 10^{11}$	288	$3.45 \cdot 10^{13}$

A representative and typical supercycle has been defined for the simulations as indicated below:

- 1 pulse of LHC 25 ns beam ($4.32 \cdot 10^{13}$ p^+)
- 14.4 s of cooling
- 1 pulse constituted by 10 % of the fixed target beam (FT) original intensity ($5.88 \cdot 10^{13} p^+$) to represent the maximum residual beam after the slow-extraction.
- 26.4 s of cooling to the next cycle

The spatial distribution of the incident particles at the upstream surface face of the dump follows a sweep pattern, which is represented in Figure 6.

Beam Induced Energy Density

The maximum deposited energy density obtained with FLUKA [4, 5] simulations along the longitudinal axis is shown in Figure 7. The CuCr1Zr absorbing part is subjected to the highest energy density. As for the graphite blocks, the second one is the most exposed.

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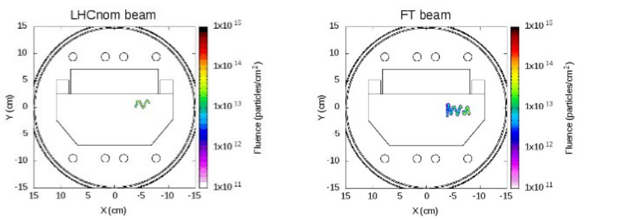

(a) (b)

Figure 6: TIDVG#4 sweep patterns for (a) LHC and (b) FT beams [3].

The energy deposition in the SS vacuum chamber is not uniform, i.e. the energy density is higher on the right upper side due to the asymmetry of the dumped beam with respect to the symmetry axis of the TIDVG#4. This also leads to a non-uniform temperature distribution in the core.

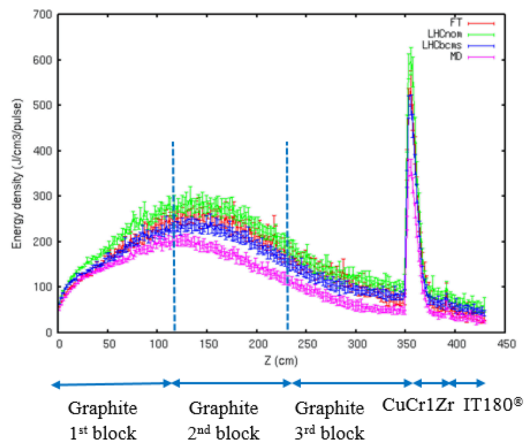

Figure 7: Maximum deposited energy density along the TIDVG#4 longitudinal axis for SPS beam types [3].

Thermo-Mechanical Simulations

In case of continuous operation of the most critical beam cases, the materials limit will be reached. Therefore, an interlock based on the dumped intensity has been implemented. The two limiting criteria for TIDVG#4 are:

- The temperature of the CuCr1Zr absorbing part must be below 300 °C to keep its mechanical properties [6].
- Plastic deformation of the SS vacuum chamber should be avoided in order to reduce the risk of vacuum leaks.

Interlocks In order to make sure that the TIDVG#4 runs in safe condition throughout the duration of the remaining part of RUN 2 (2017-2018), different interlocks have been studied [7].

A condition based on the integrated dumped intensity has been defined so that if more than $4.91 \cdot 10^{13}$ protons are dumped within a time window of 40 s, a cooling time of 70 s is imposed.

Another possible interlock will be based on the temperature measurements:

- In order to avoid permanent deformation of the vacuum chamber around the core, the maximum temperature allowed on the probe will be 100 °C. If this value is exceeded, injections in the SPS will be stopped until the temperature goes back to a value below 60 °C.
- With the purpose of double-checking that the measured temperature does not overcome the imposed limit, another interlock in the CuCr1Zr absorbing part at 125 °C is proposed, since the PT100 is not located in the area of the maximum temperature.

It is important to stress that these PT100-interlocks are not included in the operational safety system yet. After the TIDVG#4 commissioning period, the use of these PT100-interlocks will be assessed and, if deemed reliable, implemented.

Results The graphite block should withstand all the beam scenarios without failure based on the Christensen criterion [8]. For the most critical case (LHC 25 ns), the stresses are only 4 % of the limit defined by this failure criteria. The maximum expected temperature in graphite is 295 °C.

In the IT180® block, the maximum von Mises stress is 89 MPa, which is significantly lower than the yield strength of the material (500 MPa). The maximum expected temperature is 100 °C.

In the CuCr1Zr absorbing part, a localised plastic deformation of 0.07 % is foreseen after the first LHC (25 ns) pulse. The maximum expected temperature is 233 °C after unlimited dumping of the combined LHC (25 ns) and 10% of unextracted FT.

After steady state of the combined LHC (25 ns) and 10% of unextracted FT, the maximum temperature reached in the SS vacuum chamber is 253 °C. Around 6 hours of continuous beam are needed to achieve this condition. The maximum expected temperature is 253 °C, generating a maximum von Mises stress of 177 MPa and a plastic deformation of 0.14 %. This should be avoided and therefore, the interlock based on the temperature reading be assessed during the commissioning period.

CONCLUSION

TIDVG#4 has been installed during EYETS 2017 and it will be operating until the end of 2018. Its design has improved the robustness of the device in comparison to the TIDVG#3, allowing for safer and less limited operation with higher intensity beams.

The operation limits have been studied. During the commissioning period, a comparison between the experimental and operational temperatures with the added instrumentations will allow to better understand the dump's behaviour and determine the different interlocks.

These studies will also help validating technical solutions for the design of the future SPS dump to be installed during CERN's Long Shutdown 2 (TIDVG#5).

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