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

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Abstract

The CERN Super Proton Synchrotron (SPS) high-energy internal dump (TIDVG – Target Internal Vertical Graphite) is used to intercept beam dumps from 102.2 to 450 GeV. An inspection in 2013 revealed significant beam induced damage to the aluminium absorbing block, resulting in 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 operational limitations, i.e. a reduction of the beam intensity that could be dumped. In the winter stop of 2016-2017, a new version of the TIDVG (featuring several major design modifications) was installed.

This paper analyses the performance of the dump observed during the commissioning period and subsequent operation in 2017 of the most recent installed version of the TIDVG. The temperature measurements recorded during this time were used to benchmark numerical models that allow predicting the performance of the dump under different conditions. After several iterations, a good agreement between simulations and real measurements was obtained; resulting in numerical models that can produce reliable results for this and other devices with similar design.

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 developments (MD) and the residual beam for the fixed targets (FT) remaining after the slow-extraction process. The TIDVG is in charge of absorbing the primary SPS beam with energies from 102.2 to 450 GeV. In order to be dumped, the circulating beam is deflected by a set of vertical kicker magnets (MKDV) which direct the beam below the nominal closed orbit. In addition, the so-called "dilution horizontal kickers" (MKDH) are used to create a sinusoidal beam 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. The SPS dump system consists also of another beam absorber, the Target Internal Dump Horizontal (TIDH), where lower energy beams (14–29 GeV) are dumped [1].

Following a vacuum leak appeared in April 2016 in TIDVG#3, which limited beam operation [2], a new dump (TIDVG#4) has been prepared, in order to be able to provide more robust, reliable performance during operation. This device was assembled in March 2017 and installed in April 2017, before the machine closure. It will be requested to operate safely until the end of the run (December 2018).

This paper analyses the temperatures measured during beam operation and compares it with the numerical models of the device, so that the accuracy and reliability of the latter can be assessed.

DESIGN OF TIDVG#4

The design of the TIDVG#4 has been presented in detail in [2]. It consists of an inner core (Figures 1 and 2), enclosed in a seamless stainless-steel tube, which is responsible for the vacuum-tightness of the assembly.

The core consists of a CuCr1Zr jacket, directly cooled by means of stainless steel cooling pipes. Inside this jacket there are beam absorbing blocks made of graphite, CuCrZr and a tungsten alloy (Inermet IT180® [3]).

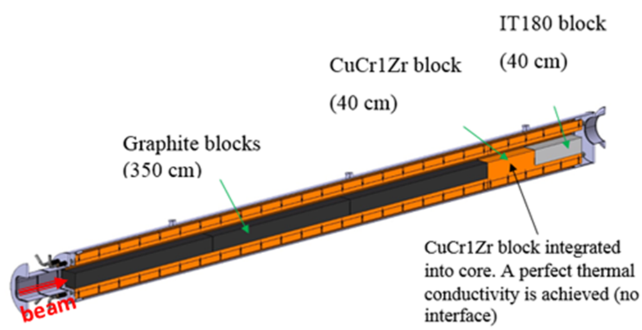

Figure 1: Longitudinal section of the TIDVG#4, showing the absorbing blocks configuration.

The dumped beam impacts directly on the upstream face of the graphite blocks (Figure 2) and deposits energy in all the materials of the core.

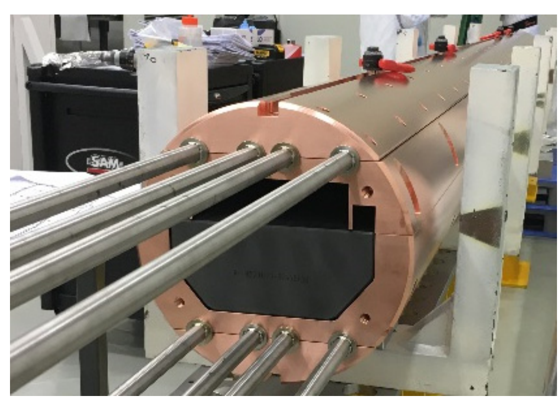

Figure 2: TIDVG#4 core assembly. Upstream face of graphite visible in the lower part.

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BEAM OPERATION MONITORING

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

There are 12 sensors located in the copper core: 5 on the graphite blocks, 2 in the CuCr1Zr block, 2 on the Inermet block and 3 in the copper jacket itself (Figure 3).

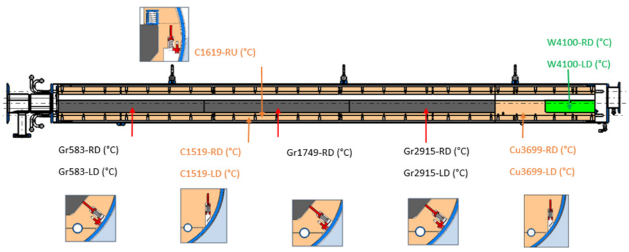

Figure 3. Location of the PT100 temperature gauges in the copper core.

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 external shielding (Figure 4) of cast iron.

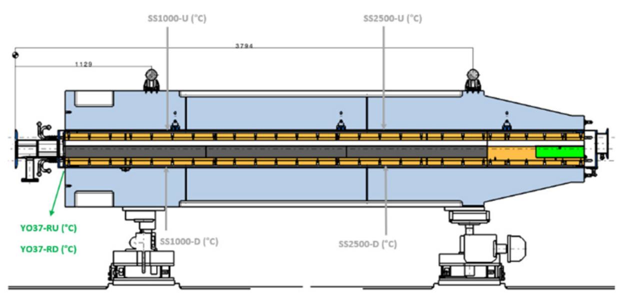

Figure 4. PT100 in the external shielding assembly.

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 (Figure 5).

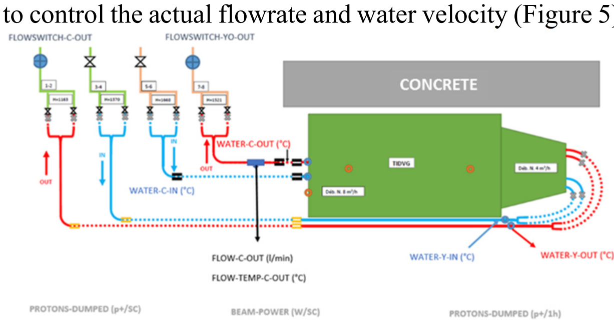

Figure 5. Sensors for the water cooling circuit.

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).

Readings from the PT100 are available online and logged for diagnostics, allowing to compare the temperatures measured during operation with values obtained from numerical simulations.

COMMISSIONING OPERATION

Different operation scenarios have been tested in the machine with the actual LHC beam, only with slightly lower energy, i.e. 440 GeV instead of the typical 450 GeV. The characteristics of the beam cycles tested are presented in Table 1.

Apart from few interruptions during the commissioning tests, the beam was dumped continuously (duration given in Table 1), with a time spacing of 40.8 s between pulses.

The beam was sent to the dump for a long time in order to observe the temperatures reached at the different positions in the device in steady state conditions. This situation emulates the operation scenarios in which a specific beam type is dumped without any limitation in terms of duration.

Table 1: SPS Beam Parameters

Bunch intensity [p^+/bunch]	Number of bunches	Total intensity [p^+/pulse]	Average beam power [kW]	Total duration [min]
$1.10 \cdot 10^{11}$	48	$5.3 \cdot 10^{12}$	9	150
$1.25 \cdot 10^{11}$	72	$9.0 \cdot 10^{12}$	16	240
$1.10 \cdot 10^{11}$	144	$1.6 \cdot 10^{13}$	27	180
$1.10 \cdot 10^{11}$	288	$3.2 \cdot 10^{13}$	55	90

Figures 6-9 display the evolution of the temperatures measured by the sensors shown in Figures 3-4.

For the low intensity pulses (48 and 72 bunches), steady state has been reached. This shows the maximum temperatures that can be observed under such loading. Since the dump has been designed to absorb an average beam power of 60 kW, as expected, the temperatures of the different components are well below their limits.

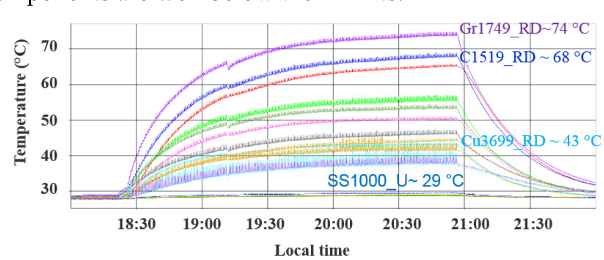

Figure 6: Temperature monitoring for commissioning with 48-bunch beam (steady state reached).

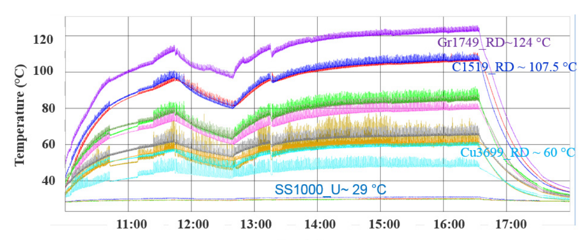

Figure 7: Temperature monitoring for commissioning with 72-bunch beam (steady state reached).

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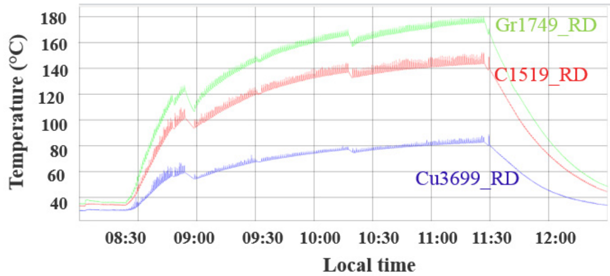

Figure 8: Temperature monitoring for commissioning with 144-bunch beam.

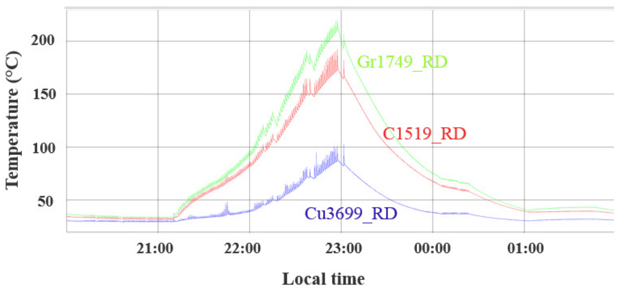

Figure 9: Temperature monitoring for commissioning with 288-bunch beam.

For the 144-bunch beam, the dumping duration was also relatively long (3 hours), allowing to achieve temperatures near steady state operation.

Finally, the 288-bunch beam, which is the nominal one for LHC filling, could not be left long enough to reach the maximum temperatures expected for this device. However, information was obtained to cross-check the numerical models also for this beam type. In any case, the good performance of the cooling has been confirmed as the temperature of the device is kept under control, even for such high beam power (55 kW). It is to be noted that the power deposited in the dump (including its shielding) is essentially 90% of the average beam power.

In Figures 6-10, some discontinuities in the rate of temperature rise can be observed. This effect is due to the fact that during this time the beam was either not sent to the dump or dumped at a slower rate (e.g. once every 2 or 3 cycles).

BENCHAMARKING OF NUMERICAL MODELS

A complex finite element model of the device was produced in order to assess the performance of the dump under different operational scenarios. Since there is significant uncertainty in some of the assumptions (mainly related to the thermal contact conductance at the interface between different pairs of materials), a cross-check of this model with the real measurements described in the previous section are of paramount importance to be able to rely on the results from the numerical simulations.

The energy density distribution inside the dump for the different beam scenarios were obtained from simulations made with Fluka [4, 5].

Figure 10 shows a comparison between simulations and measurements of the highest temperature in graphite. This graph correspond to pulses of 72 bunches (Table 1).

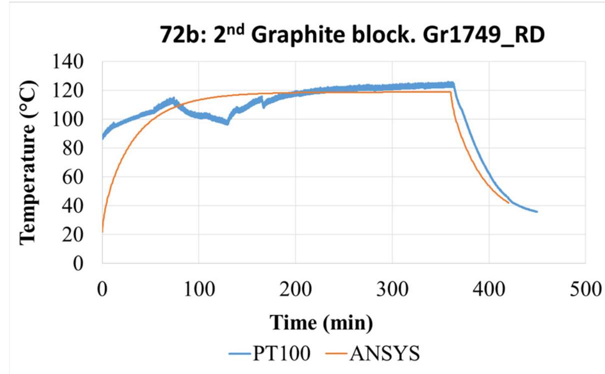

Figure 10: Comparison between simulated and measured temperatures 2nd graphite block at steady state for 72-bunch beam.

As observed in the graphs, the results from the simulations match closely the measurements performed during operation.

This comparison was performed on all the points with temperature sensors and overall, the difference between simulations and measurements is within 20%. This level of accuracy produces enough level of confidence in the numerical models to predict the performance of the device under any other beam operation scenario.

CONCLUSION

TIDVG#4 has been installed in April 2017 and it will be operating until the end of 2018. Its design has improved the robustness of the device in comparison to its predecessors, allowing for safer operation with higher intensity beams, combined with virtually no limitations imposed by the device in nominal beam operation.

The operation limits have been studied. During the commissioning period, a comparison between the experimental and operational temperatures with the added instrumentations has allowed to better understand the dump's behaviour and determine with good reliability the beam interlocks that need to be imposed in order to guarantee a safe and efficient operation of the accelerator.

These studies have made a significant contribution in view of validating some of the technical solutions that are to be implemented in the design of the future SPS dump to be installed during CERN's Long Shutdown 2 (TIDVG#5).

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