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DESIGN OF THE FUTURE HIGH ENERGY BEAM DUMP FOR THE CERN SPS

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Abstract

The future CERN Super Proton Synchrotron (SPS) internal dump (Target Internal Dump Vertical Graphite, known as TIDVG#5), has been designed within the framework of the LHC Injectors Upgrade (LIU) Project. It will be installed during CERN's Long Shutdown 2 (2019-2020) and will be built to intercept beam dumps from 14 to 450 GeV. The beam intensity and repetition rates to be absorbed by the dump will be significantly higher with respect to the present device (TIDVG#4, [1]), resulting in an increase in average beam power to 235 kW (currently, this value is limited to 60 kW). Considering such highly demanding specifications, in order to guarantee an efficient operation with little or no limitations produced by this device, new challenges in terms of design are encountered. This paper presents the proposed design, including material selection, manufacturing techniques and thermo-mechanical simulations taking into account the worst-case scenario for beam operation.

INTRODUCTION

At CERN, the forthcoming LIU & HL-LHC era [2] presents unprecedented challenges for the upgrade of several devices across the entire accelerator complex, including the internal SPS beam dumps. The present SPS beam dump system, installed in the long straight section 1 (LSS1), consists of two vertical and three horizontal kickers magnets (MKDV and MKDH respectively), which are responsible for deviating the beam onto two internal dumps (TIDH and TIDVG#4) [3]. This system is meant to dispose of the SPS circulating beam whenever necessary, i.e. in case of emergency, during LHC beam setup or LHC filling, machine developments (MD) and to dispose of the part of the beam for fixed targets (FT) remaining after the slow-extraction process. Beams with energy from 14 to 28.9 GeV are dumped on the TIDH, whereas the TIDVG is responsible of absorbing beams with energies between 102.2 and 450 GeV. Aiming at reducing the energy density deposited in the dump (and hence minimising the associated thermo-mechanical stresses), the beam is diluted by the kicker magnets, producing a sinusoidal pattern on the front of the first absorbing dump block (Fig.2).

The upgrade of the TIDVG is crucial to be able to cope with the increased intensity and brightness of the LIU beams. The future TIDVG will replace both of the present dumps (TIDH and TIDVG), and hence it will be required to absorb all beam energies in the SPS, i.e. between 14 and 450 GeV, including the current so-called today "forbidden" range, 28.9–102.2 GeV; hence, removing also this limitation for the future beam operation.

It was decided to install the future dump at a different location in the machine, as the current one (LSS1) imposes several limitations; namely, the vacuum pressure rise in the injection kicker magnets due to the outgassing originated in the TIDVG, MKDVs reliability issues, and the impossibility of completely shielding the dumps (which are the most radioactive equipment in the SPS) due to space constrains [4]. Extensive studies have converged towards relocating an improved and more reliable dump system to LSS5 [5]. The future dump, TIDVG#5, will be installed during the Long Shut-Down 2 (LS2). This paper describes the proposed design and its performance during operation based on simulations made for the most pessimistic beam dumping scenarios expected during operation.

TIDVG#5, DESIGN CHARACTERISTICS

The present high energy dump, TIDVG#4, is designed to cope with a maximum beam power of 60 kW; hence, it is not suited for LIU beam operation, which is expected to produce an average dumped beam power as high as 235 kW. Based on the experience gained with the previous dumps, and to overcome the TIDVG#4 limitations [1, 3, 4], several innovations have been implemented in the design of the TIDVG#5.

Core

In order to reduce the local energy deposition whilst keeping the total required beam absorption, the length of the TIDVG#5 has been increased by 70 cm with respect to the TIDVG#4, leading to a 5.0 m long dump. The blocks interacting directly with the beam are arranged inside the dump so that the density of the absorbing materials increases as the beam passes through the device (Fig. 1).

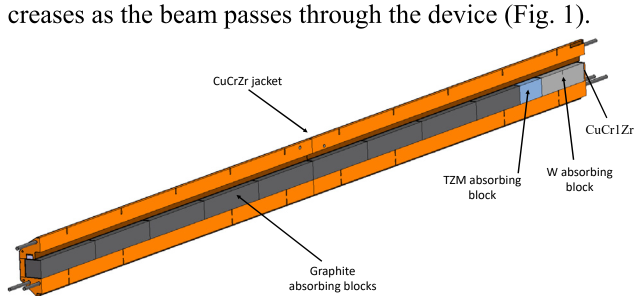

Figure 1. TIDVG#5 core, showing the internal absorbing blocks surrounded by the water cooled CuCr1Zr jacket.

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Such an array is necessary to minimise the energy density deposited by the beam and hence, to keep the stresses associated with the resulting thermal gradients within acceptable values. Table 1 lists the material sequence chosen for the TIDVG#5. With this configuration, the attenuation factor (ratio between primary particles escaping with respect to those impinging the dump) achieved is higher than the one produced by TIDVG#4.

Table 1: TIDVG#5 Core Materials

N.	Material	Total length
#1	Graphite R7550	440 cm
#2	TZM	20 cm
#3	Pure Tungsten	39 cm
#4	CuCr1Zr	1 cm

At the location where the dump will be installed (LSS5), the required beam aperture is smaller than in LSS1 (position of the present dump), due to the requirements in LSS1 to let the injected beam through. Hence, for the TIDVG#5, the beam will be more centred (horizontally) with respect to the mechanical assembly (Fig. 2 and Fig. 3).

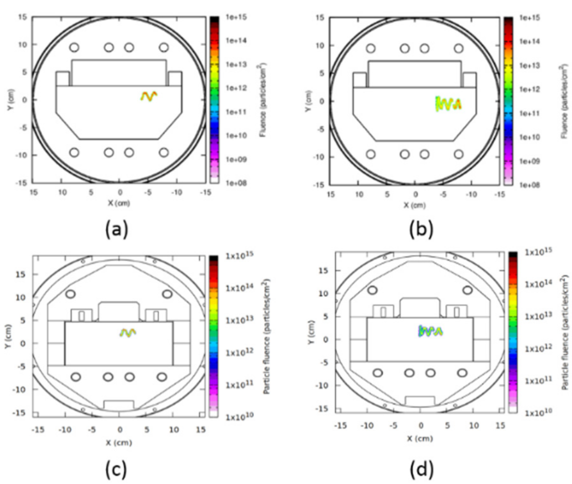

Figure 2: Beam sweep patterns. TIDVG#4: (a) LHC Standard, (b) SPS-FT SHiP. TIDVG#5: (c) LIU-SPS 80b, (d) FT.

CuCr1Zr Jacket

Since the core is the component of the dump assembly receiving the highest thermal load, it needs to be efficiently cooled. This cooling is done directly on the CuCr1Zr jacket surrounding the blocks, which can only release their heat through the contact with the jacket. In the TIDVG#5, the surface of the inner blocks at contact with the jacket is larger than in the TIDVG#4 (Fig. 3). In the worst-case scenario, a total power of 166 kW is deposited in the core. A total water flow of 15.3 m^3/h, distributed between 6 parallel circuits, is used to keep the temperature of the CuCrZr below 400 °C (maximum service temperature for this material). In order to maximise the thermal conductivity at the interfaces between the cooling pipes and the CuCr1Zr, these materials are diffusion-bonded together by means of Hot Isostatic Pressing (HIP) [6]. Due to the impossibility of applying this process on 5 m long parts, the cooling jacket has been divided into 4 plates, 2.5 m long each (Fig. 1).

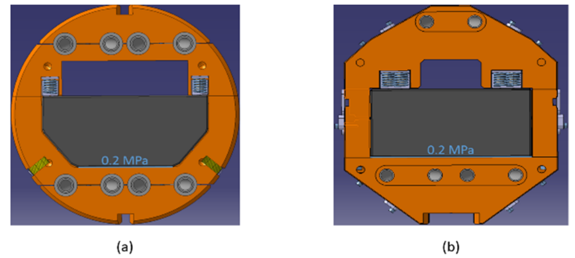

Figure 3: Cross section of TIDVG#4 (a) and TIDVG#5 (b) cores.

A prototype cooling plate has been manufactured and the results of thermal conductivity tests, performed on samples extracted from it, suggest that the bonding has been achieved fully. Figure 4 shows the thermal conductivity at the different interfaces.

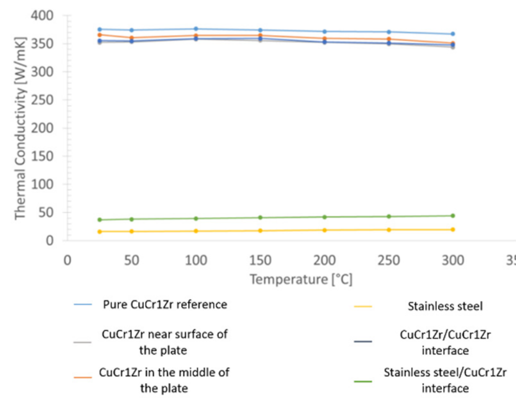

Figure 4: Thermal conductivity tests performed on samples extracted from the prototype cooling plate.

The absorbing blocks and CuCr1Zr jackets are enclosed in a stainless steel (316L), seamless vacuum tube, shown in Fig. 5.

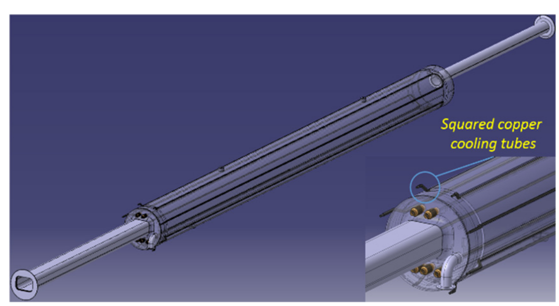

Figure 5: View of the vacuum tube surrounding the core. The tube is water cooled by means of Cu tubes clamped inside grooves machined on the outer surface.

Shielding

Due to the high activation of the dump expected after nominal operation, in addition to the first cast iron shielding (enclosing the CuCr1Zr core) the TIDVG#5 will be surrounded by a massive, multi-layered external shielding (fig. 6). The first shielding is made of two cast iron blocks, 8 tons each, and is water cooled by means of stainless steel pipes embedded in them. The external shielding consists of

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an inner layer of 50 cm of concrete, followed by 1 m of cast iron and an external layer 40-50 cm of concrete or marble. Marble is used on the three sides accessible by personnel, with the purpose of minimising the residual dose rate in the vicinity after short cool-down times. This would allow easy, fast access to the area in case of need.

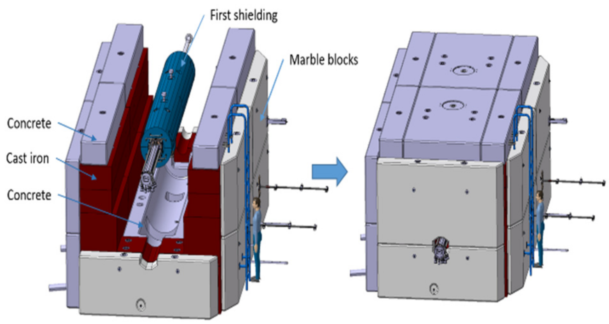

Figure 6: First and external shielding.

The different blocks are arranged so as to minimize the handling operations that need to be removed in case of replacement of the dump. Both the first and the external shielding are designed to be handled remotely. Service through-holes are foreseen in the shielding in order to allow for survey and alignment operations of the dump whilst inside the shielding.

NUMERICAL STUDIES

The TIDVG#5 will have to operate under various beam types, which main parameters are shown in table 2. According to predefined super-cycle compositions (sequence of beam cycles for different users), the beam types are dumped in a certain sequence.

Table 2. Beam Parameters [7].

Beam Type	**E_{Max} [GeV]**	**Bunch Intensity [p^+/bunch]**	**# of bunches**
LIU-SPS 80b	450	$2.43 * 10^{11}$	320
HL-LHC Standard	450	$2.43 * 10^{11}$	288
Hl-LHC BCMS	450	$2.13 * 10^{11}$	288
SPS-FT North	400	$1.40 * 10^{10}$	4200
SPS-FT SHiP	400	$1.07 * 10^{10}$	4200

The most demanding super-cycle for the dump, in terms of average beam power (236 kW) will consist in the following sequence of beam pulses (which last micro-seconds) and time spacing:

1. 7.2 s, SPS-FT SHiP pulse period
2. 22.1 µs, SPS-FT SHiP beam dumping
3. 7.2 s, SPS-MD period (no beam dumped)
4. 21.6 s, LIU-SPS 80b pulse period
5. 8.6 µs, LIU-SPS 80b beam dumping

In other words, one SPS-FT SHiP beam pulse and one LIU-SPS 80b beam pulse will be dumped every 36 seconds.

Thermo-Mechanical Simulations

Even though the most demanding super-cycle (above) is possible, it is highly unlikely to happen more than a few times consecutively. Nevertheless, in order to avoid imposing limitations on beam operation, the TIDVG#5 has been designed with a conservative approach, assuming that beams with this super-cycle structure could be continuously dumped during long periods of time (hours).

The energy density distribution inside the dump was obtained by means of Monte Carlo Simulations using Fluka [8]. Figure 7 shows the variation of peak energy density along the beam axis inside the different absorbing blocks in the TIDVG#5, produced by dumping the LIU-SPS 80b beam.

Given that thermal contact conductance (TCC) at the TZM/CuCr1Zr interface is smaller than that between graphite and CuCr1Zr, the TZM blocks are not cooled as efficiently as the graphite ones. During the steady state configuration, even if the energy density in graphite is the highest, the temperature distribution in the TZM blocks is such that the stresses are expected to be greater. Preliminary results have shown that after approximately one hour of continuous dumping, the TZM blocks would reach a peak temperature of 448 °C and a maximum von Mises stress of 303 MPa.

Overall, simulations show that even during the most demanding beam dumping scenarios, thanks to the careful material selection and design features proposed for the TIDVG#5, the temperatures and stresses expected in all components are sufficiently low to guarantee a robust and long-term reliable operation of the device.

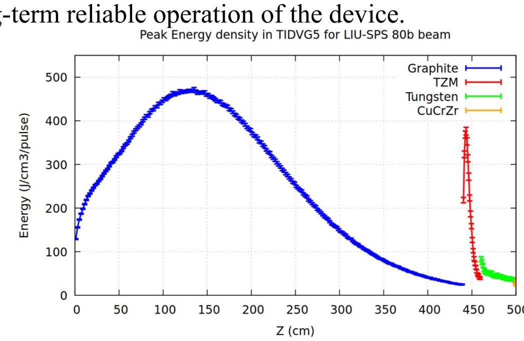

Figure 7: Peak energy density along z axis in the TIDVG#5 for LIU-SPS 80b beam.

CONCLUSIONS

An innovative and robust design for the future SPS dump has been produced. The change of the dump location inside the SPS enabled a comprehensive upgrade of the device by increasing its active length and adding a massive shielding that allows quick and safe access to the area. Moreover, all the complexity related to combining the dumping and injection systems in the same area are overcome by the change of position.

The proposed design for the TIDVG#5 makes it a more robust device capable of withstanding the highly demanding thermo-mechanical loads produced by the LIU beams.

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