

ORIGIN OF THE DAMAGE TO THE INTERNAL HIGH ENERGY BEAM DUMP IN THE CERN SPS

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Abstract

The high energy beam dump in the SPS has to deal with beams from 105 to 450 GeV/c and intensities of up to 4×10^{13} protons. An inspection during the last shutdown revealed significant damage to the Al section of the dump block. This paper summarizes the results of the analysis revealing the most likely cause of the damage to the beam dump. The implications for future SPS operation will also be briefly discussed, together with the short-term solution put in place.

INTRODUCTION

The SPS can provide a large variety of ion and proton beams in an energy range from 14 GeV to 450 GeV. The most demanding beams are the high intensity proton beams that are accelerated to 400 or 450 GeV with intensities of more than 4×10^{13} protons per shot. The characteristics of the high intensity proton beams relevant for the discussion in this paper are summarized in Table 1.

Table 1: Normalized emittance in horizontal and vertical plane, protons per bunch, number of bunches and cycle length of the achieved high intensity proton beams in the SPS: Fixed Target (FT) and CNGS beams are accelerated to 400 GeV and LHC beams to 450 GeV.

Beam	ϵ [μm]	ppb [10^{10}]	#bunches	T_{cycle} [s]
LHC 25 ns	2.6	12	288	21.6
LHC ultimate	3.5	17	288	21.6
FT	12/8	1.07	4200	14.4
CNGS	12/8	1.07	4200	6

The SPS Beam Dumping System

The beam dump system of the SPS is housed in the long straight section LSS1 along with the injection system. It is connected to the SPS interlocking system and has to be able to receive all types of SPS beam at all energies. The system consists of horizontal and vertical kicker magnets that are triggered together to move the beam down and then to sweep it across the beam dump block as indicated in Fig. 1. Due to limitations on the reachable minimum voltage for the kicker switches, two beam dump blocks are installed in long straight section LSS1. The low energy beam is dumped on the low energy beam dump TIDH. Beam above 102.2 GeV is dumped on the high energy beam dump, called TIDVG.

Whereas the concept of the SPS beam dump system is valid for all current and future beams in terms of aperture and

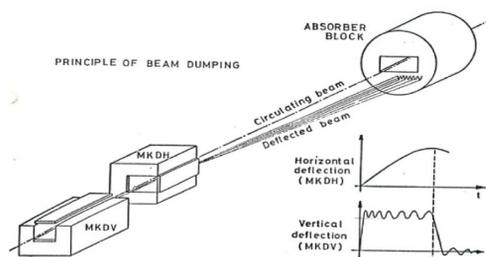


Figure 1: Principle of SPS beam dumping system.

technical feasibility for required kick strength, the radiation level in LSS1 due to the internal beam dump system and the robustness of the TIDVG dump block itself for high power loads have become a concern. In fact the TIDVG has suffered from beam induced damage during the years of the CNGS run.

TIDVG DAMAGE OBSERVATION

The absorber block of the high energy beam dump TIDVG is made of 2.5 m of Graphite, 1 m of Aluminum, 0.5 m of Copper and 0.3 m of Tungsten. The TIDVG Cu core is cooled with water and the absorber blocks are cooled through contact with the Cu core. Further information can be found in [1]. It was installed in 2006 before the CNGS run.

During the SPS shutdown from spring 2013 to September 2014 the equipment in LSS1 was dismantled and re-installed afterwards. When the TIDVG was ready to be re-connected, chunks of Aluminum close to its downstream end were detected. An endoscope inspection was carried out and the first Al block was found to have had melted and re-solidified, see Fig. 2. The damaged TIDVG was removed and the spare installed before the SPS start-up. The spare TIDVG absorber consists of the same materials as the original one, only that the graphite part is 2.7 m long and the Aluminum 0.8 m. As a consequence an analysis campaign was launched to understand the origin of the damage.

The TIDVG used between 1999 to 2005 was inspected as well. Also here the Al part of the absorber showed signs of damage.

SIMULATION RESULTS FOR ROBUSTNESS LIMITS

In 2009 possible power load limitations of the TIDVG absorber were investigated in simulation [2]. The weakest material in the sandwich absorber block is Aluminum with a melting point of only 660°C. With the assumptions used in the study for the thermal contact conductance of the Aluminum part, the maximum allowed temperature in

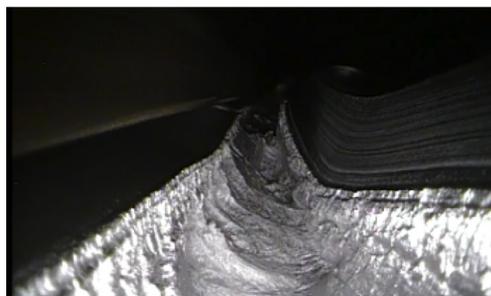


Figure 2: Melted and re-solidified Al block in the TIDVG that was removed from the SPS in August 2014.

the material was defined to be 450 °C. Simulations were carried out for LHC ultimate intensity and CNGS beams. In the simulations the maximum allowable number of repetitive shots ending up on the beam dump instead of being extracted was evaluated. For the relatively long LHC cycle no limitation was found. After 18 CNGS shots every 6 s however the Al part of the beam dump would reach 450 °C. A steady state can be obtained by allowing 18 shots on the beam dump followed by 5 minutes of waiting time. According to these simulations the TIDVG intensity rate limit should be $18 \times 4.8 \times 10^{13}$ protons in 18×6 s plus 5 minutes, corresponding to 8.6×10^{14} protons in 408 s.

No limitations have been found in simulation for the TIDH.

THE ORIGIN OF THE TIDVG DAMAGE

Every SPS cycle the intensity at specific points in the SPS cycle is logged. The intensity logged at the moment of extraction can be compared with the beam current transformer readings in the extraction lines to define whether the beam was extracted or dumped on the beam dump. The intensity dumped on the TIDVG for CNGS and LHC beams was extracted from the SPS logging system for the years 2012 and 2011 and compared to the above established limits. Before 2011 the logging data quality is unfortunately not sufficient. As it turns out the intensity dumped on the TIDVG with CNGS beams exceeded the limit at roughly 10 occasions per year in the years 2011/2012. An example is shown for the months October, November 2012. The limit is indicated in red. If too many high intensity shots are dumped consecutively on the TIDVG the Al part can be damaged and also the graphite part might become hot enough to start outgassing. Vacuum degradation affects the nearby equipment such as the sensitive MKP injection kickers. The evolution of the MKP vacuum is shown as the green curve in Fig. 3. The power load maxima on the TIDVG coincide with vacuum spikes in the MKP. One of the events during 2012 is shown in Fig. 4. It shows the result of 58 CNGS beams dumped on the TIDVG. Most of them one after the other with only 6 s cool down time in between. The first level vacuum interlock on the injection kickers is reached at 2×10^{-7} mbar. No more beam is then allowed in the SPS and the vacuum slowly recovers while the TIDVG is cooling down. The most

likely cause for the damage of the TIDVG are therefore extended periods with high intensity CNGS beam on the dump due to an extraction inhibit coming from an interlock in the CNGS line. The SPS surveillance to stop the production of the CNGS beam under such conditions did not cover all possible scenarios.

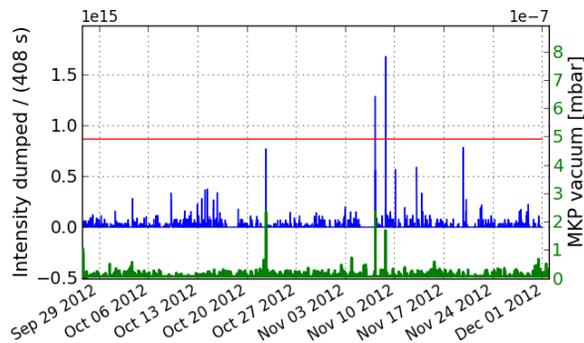


Figure 3: Intensity dumped in 408 s on the TIDVG and vacuum evolution in the injection kickers MKP downstream of the TIDVG. The red line indicates the intensity rate limit. The limit was exceeded twice in this period.

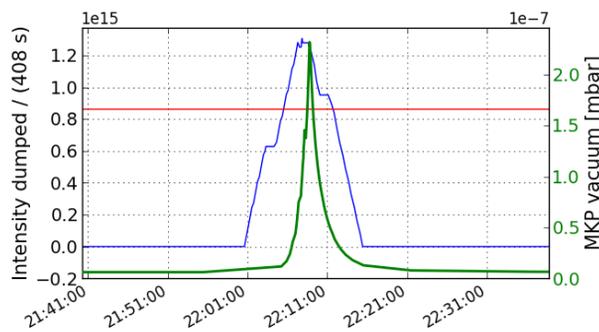


Figure 4: Intensity rate on the TIDVG on 3rd of July 2012 in blue and vacuum evolution in the MKP in green. The red line indicates the intensity rate limit.

SOLUTION

A more robust interlocking solution had to be put in place for the upcoming SPS run. A new TIDVG design was impossible in the short time available. An additional check in the software interlock system (SIS) [3] was proposed to survey the dumped intensity every cycle.

TIDVG Dumped Intensity Interlock

Instead of reading out the intensity at a pre-defined moment in the cycle as done for the current implementation of the logging system, the intensity curve through the entire cycle is used in the new software interlock together with the timestamp of the dump kicker firing and energy of the moment of dump. The information is combined to evaluate whether any intensity was dumped and whether it ended up

on the low or high energy dump. Configurable input parameters are: maximum total intensity $\sum_{max} I_n$ over a certain time interval ΔT_0 and waiting time T_w that is required after the limit has been exceeded. Every SPS cycle the dumped intensity is written into a rolling buffer and the sum of the intensity in the last ΔT_0 is calculated and compared to $\sum_{max} I_n$. If the limit is exceeded the interlock stays active for T_w and resets itself afterwards.

The beam absorber experts carried out new simulations to verify the 2009 results [4]. With the latest results Al should not go beyond 250° C to avoid plastic deformation and reduction of the thermal contact with the surrounding Copper. The contact of the Al with the surroundings of the currently installed TIDVG is however unknown and a reasonable assumption had to be made [1]. The results of this study were used to configure the above described interlock:

- $\sum_{max} I_n = 3.656 \times 10^{13}$ protons corresponding to a full LHC 25 ns beam shot followed by an FT cycle where 5 % of the intensity is dumped at the end of the cycle
- $\Delta T_0 = 36$ s
- $T_w = 70$ s

Other improvements had been put in place for the long term storage of data in the logging system. Issues were found when analyzing the logged cycle intensity data and associated statistics. Now the intensity evolution through the entire cycle is logged every cycle as well as the timestamps of the beam dump trigger, main bend currents and a few other new parameters such as the energy at the moment of the dump. In this way the dumped intensity at a given energy is easily reconstructable.

The current beam dump design will not suffice for the LHC beams that have to be produced by the LHC injectors including the SPS for the LHC High Luminosity (HL-LHC) era after the LHC injector upgrade (LIU) [5]. The Al part of the TIDVG would be able to take a single shot only. With the second shot the Al would already be above the allowable temperature of 250°, see Fig. 5. Before each LHC fill, the SPS needs about 30 minutes of continuously dumping the LHC beams on the TIDVG for setting-up. This mode of operation would not be compatible with the current TIDVG for LIU beams. A new design of the high energy SPS internal beam dump will therefore be needed. The most promising solution for the time being is to remove the beam dump system from SPS LSS1 and move it to SPS LSS5 where space for a longer beam dump could be available with a longer graphite section to remove the necessity of Aluminum [6].

CONCLUSION

The Aluminum part of the high energy internal beam dump was damaged with high intensity proton beams. It had been installed in 2006/7 and was removed during the 2013-2014 shutdown as the damage was noticed. The damage had

no impact on operation. Data analysis strongly indicates that

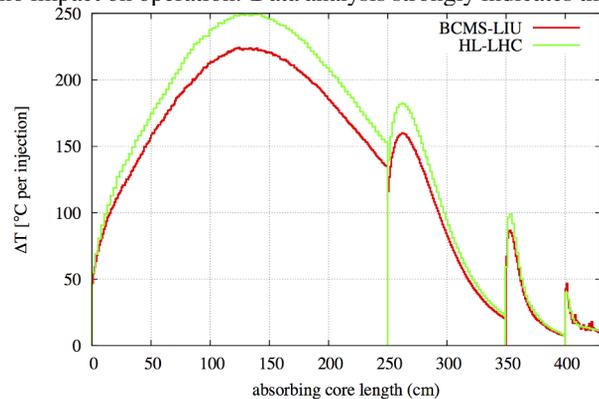


Figure 5: Maximum temperature along the TIDVG absorber block for the HL-LHC beam and the high brightness BCMS-LIU beam also for the HL-LHC era [7].

the damage had been provoked by continuously dumping CNGS beams over extended periods instead of extracting it towards the CNGS target. The dumped intensity rate was found to be above a limit established in 2009 at about 10 occasions per year in the last years before the end of the CNGS run. High intensity LHC beams were below this limit due to the low repetition rate. Also the core of the currently installed high energy beam dump contains Aluminum. A software interlock had been put in place to avoid damage of the SPS beam dump in the future. The interlock evaluates the dumped intensity each cycle and compares the sum of the dumped intensity over a pre-defined time interval with a limit established by the experts. LHC beam preparation for LHC run 2 should not be impacted. A new beam dump design without Al will however have to be found for LHC run 3 and beyond to deal with the increased LHC beam intensities. Moving the beam dumping system from its current location in the SPS accelerator to another location with more space for a longer beam dump and hence avoiding the need of Aluminum is being discussed.

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