DESIGN OF THE NEW PS INTERNAL DUMPS, IN THE FRAMEWORK OF THE LHC INJECTOR UPGRADE (LIU) PROJECT

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Abstract

In the framework of the LHC Injectors Upgrade (LIU) at CERN, the two PS (Proton Synchrotron) internal beam dumps are being redesigned and upgraded for the new high intensity beams. The EN-STI group is in charge of the design and installation of the new dumps, foreseen for the next CERN Long Shutdown in 2019-2020 (LS2). The PS dumps have been installed in 1975 directly in the PS vacuum ring between two contiguous bending magnets, and they have been operating since then. The dump core is made of a 6 kg copper block which is moved into the beam line by a spring-based mechanism when requested by the PS machine operators. The current dumps are expected to not survive the impacts of the future high intensity beams foreseen within the LIU Project. A new design is presented for the dump cores based on FLUKA Monte Carlo and ANSYS® simulations. The dumps should be able to safely absorb any PS beam foreseen within LIU, be water cooled in ultra-high vacuum (UHV) medium, and enter the beam area in less than 150 ms. The dump should be used 200000 times per year, with a lifetime of 20 years, with minimum possible maintenance. The new challenging design is based on a thin dump shaving the circulating beams. Materials considered for the dump are Cu, Ti6Al4V or CuCr1Zr with embedded cooling channels.

INTRODUCTION

The LIU project is aiming at the upgrade and renewal of some equipment in the injector accelerators of the LHC [1]. In this context, the two PS internal dumps will be upgraded [2]. The PS internal dumps are installed inside the PS vacuum ring between the bending magnets in straight sections 47 and 48. The final purpose of these devices is to dilute the circulating beams in the accelerator to prevent beam extraction to the downstream machines or experiments. The dumps are mainly used during machine development programs to study new beams, but they are also triggered for machine protection purposes when a problem occurs that could damage the downstream machines. The dumps are movable devices, with a massive core part. The core moves in the beam area and interacts with the beam, when a dump is requested. The movement is realized by means of a mechanism that should guarantee a fast and repeatable beam dumping. Due to their design, the dumps are considered more as beam diluters, which reduce the beam intensity down to zero after several beam turns in the PS ring.

The design of the new dumps is challenging due to very intense and energetic post-LS2 beams and also due to the requirements from the PS machine operation. The dumps should perform the complete flipping movement in less than 300 ms in order to enter the beam area 150 ms after the triggering signal. The flipping movement can be repeated every 1.2 s for hours. This requires the dump core and the respective mechanism to be very reliable.

A prototyping phase has started in order to assess the compatibility of the considered materials, as well as of the bonding techniques, with the UHV requirements. Checking the mechanism performance and the fatigue strength will be also part of this prototyping phase.

CURRENT PS DUMPS

The current dump core is a vacuum melted copper block with a dimension of 40 × 130 × 140 mm^3 and a mass of around 6 kg, which is mounted on a 300 mm long hollow arm. The dump mechanism is based on a spring system with three arms rotating around a fixed fulcrum (Figure 1).

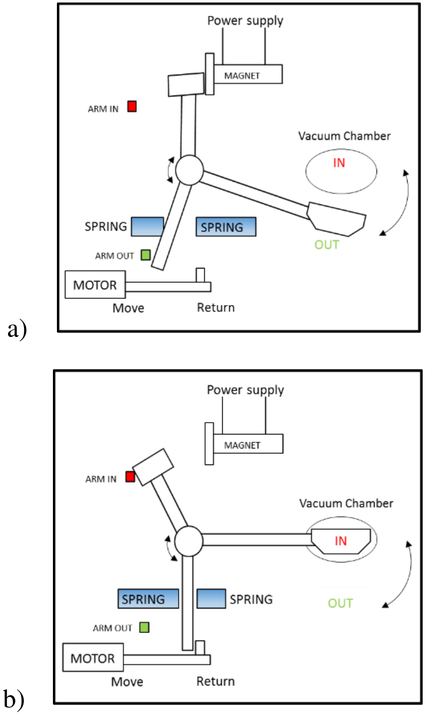

Figure 1: Dump mechanism: parking position (a) and in-beam position (b).

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The dump arm is doing a 14° rotation in UHV (pressure close to 10^{-9} mbar) from the parking position, outside the beam area, to the centre of the beam vacuum chamber. The mechanism uses an electro-magnet to keep the dump in the parking position (Figure 1-a). When the current in the magnet is cut, a pre-loaded spring pushes the dump core in the in-beam position (Figure 1-b). When the in-beam position is reached, the opposite spring pushes the dump back in the initial position. If a problem occurs with the magnet, a safety motor removes the dump from the beam chamber. Two water-cooling pipes are located inside the hollow arm to cool down the dump core, which is heated by consecutive beam impacts.

NEW DESIGN AND SIMULATIONS

Working Principle

The time needed by the dump to enter the beam area is around 70000 times longer than the revolution time of the beam in the PS ring, therefore a multi-turn dumping phenomenon occurs. In other words, the dump shaves the beam while moving into the beam chamber. Turn by turn the dump intercepts a small fraction of the beam protons.

In order to simulate this process and understand the particle interactions within the dump core, a simplified model of the PS beam dynamics has been implemented. The PS rotation matrix is used to understand how the beam modify during a revolution inside the PS ring. The dump is simulated to be gradually moving into the beam area and the interaction of particles with the matter is studied with the FLUKA code, which evaluates the energy deposition of each particle on the dump core every turn. The combination of the dump movement and the beam dynamics results in a nonlinear beam intensity dumped over time (Figure 2), on a very thin layer of the dump core surface (tens of microns thick).

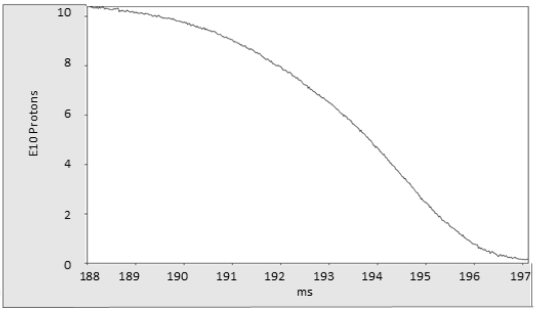

Figure 2: Beam intensity versus time, measured with a wall current monitor detector during dumping.

Beam Parameters and Simulation Strategy

To simulate the stress generated in the dump core, few representative beam scenarios have been selected among all the possible beam types circulating in the PS [3] (Table 1). The injection and extraction energy of these beams are always 2 GeV and 26 GeV respectively. The *Accidental* beam is the beam with highest intensity circulating in the PS after LS2 and the dumping of this beam is not supposed to happen regularly during operation. *BCMS* is the beam with the smallest emittance. *SFTPRO* could reach a high intensity (fixed target for the North Area operation) with quite small beam sizes. The *LHC25ns* beam instead has the highest peak energy density both at injection and extraction energy.

After performing a FLUKA simulation and checking the dump core survival with one pulse of these beam scenarios in a thermo-mechanical simulation, an average heat generation over one pulse period (1.2 s) is applied, until a critical temperature is reached. At this point another beam pulse is simulated to check the dump integrity. The average heat generation of all other PS beam cycles will be computed and, without performing any simulations, it will be compared with the known beams to check the thermal limits of the dump.

Table 1: Main Beam Scenarios Considered [3]

Beam	Intensity	Energy	Size ($\sigma_h \times \sigma_v$ mm)
Accidental	$5 \cdot 10^{13}$	26 GeV	4.67×1.84
LHC25ns	$8.7 \cdot 10^{12}$	2 GeV	5.46×3.31
LHC 25ns	$2.3\ 10^{13}$	26 GeV	1.74 × 0.87
SFTPRO	$4 \cdot 10^{13}$	26 GeV	3.68×1.99
BCMS	$5.8 \cdot 10^{12}$	26 GeV	1.55×0.65

Thermo-Mechanical Simulations

For the thermo-mechanical simulations, the dump model is a thin block with dimensions of 20 mm × 132 mm × 200 mm. The front edge of the dump shaving face is curved to prevent stress concentrations and to apply the energy deposited by the beam over a larger area in order to decrease the peak energy deposited. Pure copper, CuCr1Zr and Ti6Al4V are considered as a preliminary material choice; the two first ones being very good heat conductors allowing an efficient thermal management for regular beam impacts, whereas Ti6Al4V has excellent strength and fatigue properties.

To allow importing the FLUKA energy deposition into ANSYS, the finite elements in the shaving face need to have a thickness in the order of microns. Layered shell elements are used on the shaving surface to allow a heat generation import, while the number and aspect ratio of elements is kept reasonable. 3D elements would require a very large amount of very small elements to keep the aspect ratio acceptable, which would lead to unfeasible calculation times. The energy deposition process is divided into several time steps in FLUKA with an imposed time discretization of 150 µs. The load steps in ANSYS are the same. In steady-state simulations, the energy deposition is averaged over the whole pulse period.

In preliminary simulations, the new dump design in CuCr1Zr, reaches a local peak temperature of 993 °C in a single pulse of the SFTPRO beam (Figure 3). A similar result is obtained for pure copper. The temperature peak exceeds the maximum service temperature of CuCr1Zr (assumed to be around 450 °C), but the peak is very localised and time limited so the effect on the integrity of the material is being reviewed.

Despite its lower density, Ti6Al4V reaches a local peak temperature of 2500 °C which is beyond its melting point (assumed to be around 1650 °C). The peak energy deposition in Ti6AlV is lower, but due to its poor thermal conductivity, to the small region of heat application and to the relatively short dumping process, the resulting peak temperature is higher.

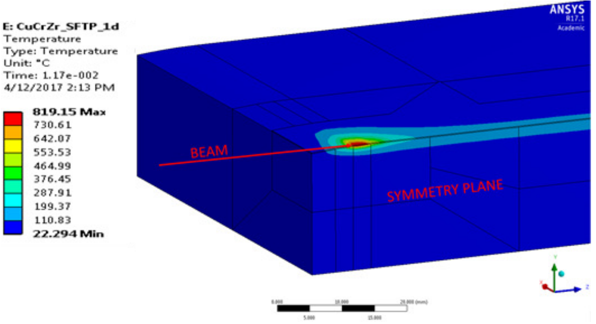

Figure 3: Maximum temperature in CuCr1Zr for a pulse of SFTPRO. Only temperature in the 3D elements is plotted. Maximum temperature in the surface shell is 993 °C.

Direct Impact at Beam Injection

When the dump is working with beams at injection energy, it could happen that, due to incorrect timing, the dump is present in the beam chamber, when the beam is injected in the ring. In this case, the beam will reach the full volume of the dump with a direct impact and not a shaving impact like in the previous case. In order to assure the dump survival also in this case, thermo-mechanical simulations have been done for the present dump geometry [4].

The simulations use bilinear kinematic hardening models with temperature-dependent data for each material and three consecutive beam impacts of the LHC25ns beam are simulated according to the specification document [3].

The simulations showed that pure copper is expected to deform plastically. For CuCr1Zr the material yield strength (260 MPa) is almost reached with 250 MPa equivalent v. Mises stress as simulation result. In Ti6Al4V instead a safety factor against permanent deformation of 6.3 is achieved, with an equivalent v. Mises stress of 105.5 MPa at a temperature of 90 °C, considering a yield strength of 670 MPa at 200 °C (Figure 4).

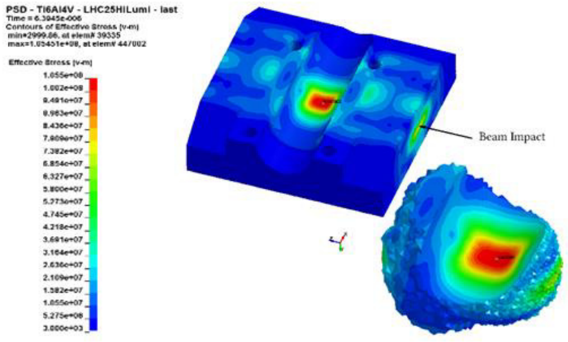

Figure 4: Equivalent v. Mises stresses after three consecutive impacts with a 2 GeV proton beam in Ti6Al4V.

Ti6Al4V is, from the thermo-mechanical point of view, the preferred material for three direct impacts, but CuCr1Zr could be a valid alternative, because the simulated scenario is rare and a small permanent deformation is considered acceptable.

New Dump Mechanism Design

Several actuating systems (e.g. motors or linear actuators) have been considered for the new dump, but due to the harsh working environment (radiation), the old dump mechanism concept has been chosen, since it has proven to be reliable and not sensitive to radiation. An analytical study has been conducted to understand the motion of the dump. The dump is simplified as a one degree of freedom mass-spring-damper system. The designed mechanism allows the required core movement (in vacuum chamber within 150 ms) (Figure 5).

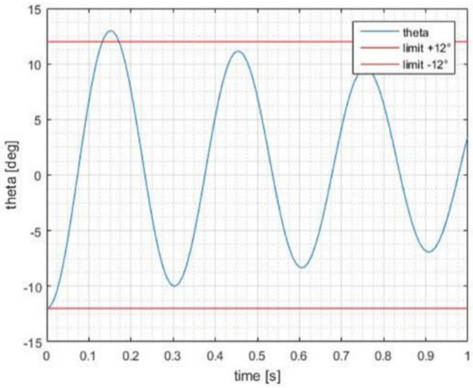

Figure 5: Dump core angular position versus time. Ideal movement foreseen between -12° and 12°.

CONCLUSION

The very demanding beam parameters, especially the high intensity and small spot size, are driving the temperature gradients in the dump core and therefore also the design of the core. The dump working conditions and a direct accidental impact have already been studied extensively. Thermo-mechanical simulations are on-going to simulate the regular operation and to determine the suitable material for the dump core. The PS beam shape evolution turn after turn and its effects on the beam energy deposition on the dump core are also considered. As an alternative material, Glidcop is being considered. For a direct impact, CuCr1Zr and Ti6Al4V are considered as possible materials for the dump head.

The dump mechanism was 3D modelled and its kinematics was simulated. After a fatigue analysis of its key components, a prototype will be produced at CERN to validate the design.

REFERENCES

[1] LHC Injectors Upgrade, Technical Design Report http://cds.cern.ch/record/1976692?ln=en

[2] W. Kozlowska, M. Brugger, PS Internal Dump in the Fluka Monte Carlo simulations, Reference, EDMS 1403161 V.1.

[3] PS Ring Internal Dumps Functional Specification, EDMS Document 1582110 V1.1.

[4] PS Ring Internal Dumps Thermomechanical Study for Direct Impact, EDMS Document 1803057.

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