ENERGY DEPOSITION STUDIES FOR POSSIBLE INNOVATIVE PHASE II COLLIMATOR DESIGNS

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Abstract

Due to the known limitations of Phase I LHC collimators in stable physics conditions, the LHC collimation system will be complemented by additional 30 Phase II collimators. The Phase II collimation system is designed to improve cleaning efficiency and to minimize the collimator-induced impedance with the main function of protecting the Super Conducting (SC) magnets from quenching due to beam particle losses.

To fulfil these requirements, different possible innovative collimation designs were taken in consideration. Advanced jaw materials, including new composite materials (e.g. Cu–Diamond), jaw SiC insertions, coating foil, in-jaw instrumentation (e.g. BPM) and improved mechanical robustness of the jaw are the main features of these new promising Phase II collimator designs developed at CERN.

The FLUKA Monte Carlo code is extensively used to evaluate the behavior of these collimators in the most radioactive areas of LHC, supporting the mechanical integration.

These studies aim to identify the possible critical points along the IR7 line.

INTRODUCTION

Based on Super Conducting (SC) technology, the LHC at CERN is characterized by its high density proton beams with a total stored energy about 200 times higher than in TEVATRON during nominal operational conditions at 7 TeV. In addition, the LHC quench limits are extremely severe: about 15 mW/cm^3 for quadrupole and about 10 mW/cm^3 for bending dipole SC magnets [1]. In such a sensitive SC environment, the protons which diffuse into the so-called beam halo must be removed before they touch the SC magnets and, in general, any other delicate accelerator component to avoid quenches and damages by radiation. The removal is up to the LHC Collimation System, performing a multi-stage cleaning [2], by means of collimators, located at adequate positions in the machine and installed for both circulating beams. The collimators represent the limiting LHC aperture and they are used to reduce the background in the experimental areas, too.

In order to meet the LHC requirements in stable physics conditions, the collimation performance must be carefully evaluated, since the collimators may limit the intensity of the beams and thus the luminosity. Indeed although the Phase I system, including primary and secondary carbon collimators, provide a maximum robustness solution, it cannot meet the required collimation efficiency specification. Moreover, carbon secondary collimators dominate the impedance budget of the LHC and ultimately prevent the machine luminosity from reaching its design value. For these reasons it is foreseen to complement the 30 high robustness secondary collimators with Phase II collimators to be used only towards the end of the low beta squeeze. The Phase II collimators will be located in the two insertions regions IR3 for momentum cleaning and IR7 for betatron cleaning. These locations, where important beam losses will take place, are expected to be among the most radioactive areas of the LHC. The installation of the Phase II collimators is foreseen about 2-3 years after the first physics runs (once the proposed new cryo-collimators will possibly be fully operational in the dispersion suppressor region) in order to reach the nominal and ultimate LHC beam intensity.

METHODOLOGY

The collimators must absorb a significant power in order to fulfil their main protection function. Thus the distribution of the energy deposited in the collimator areas has to be carefully investigated to support the final Phase II design choice. Different collimator designs are differently impacted according to their specific assembly and materials and imply different loads on the LHC components downstream, due to the shower propagation.

Extensive simulations with the Monte Carlo code FLUKA [3,4] were performed to assess the effect of beam impact on the different designs. Each collimator type has been integrated in the FLUKA model of IR7 (1.5 km long) [5] including more than 250 objects of about 30 different types. Objects are modelled and stored in a "parking" area for runtime mapping via the lattice capability of FLUKA. A customized routine allows to properly orientating collimators and absorbers and adapts their prototypes such as their aperture follows the actual value of the beta function.

To compare the behaviour of the different collimators on IR7 line, an accident scenario was considered. It refers to the abnormal beam losses due to a mis-firing of the horizontal extraction kicker at top energy. This kind of failure affects mainly the horizontal collimators, as the dump kick acts on the horizontal plane. The extreme cases of first and last kicker module were simulated and the worst case was considered. The bunch amplitudes versus time were calculated at the worst locations downstream of the kicker, i.e. at a $\pi/2$ phase advance downstream of the kicker. The scenarios studied were two. In the first scenarios, it is assumed that protons between 6 and 10

σ_x impact on a Phase I primary carbon (TCP.C6L7.B1). In the second scenario, since the aperture of the Phase II collimators is fixed at 7 σ, protons between 7 and 10 σ_x hit a Phase II collimator (TCSM.B4L7.B1). Local dump protection devices (TCDQ) are assumed to intercept all beam above 10 σ_x. These scenarios correspond to an impact of 5.6 nominal LHC bunches in 1.1 mm close to the edge of the TCP.C6L7.B1 collimator and of 4.2 bunches in 0.8 mm for the TCSM.B4L7.B1 one.

Four different advanced designs were developed at CERN [6]. They are been studied separately and compared with the Phase I secondary carbon collimators in terms of energy deposition.

Glidcop Collimator Design

An advanced Glidcop (1% Al and 99% Cu mass fraction) design (see Fig. 1 and Fig. 2) was developed with particular attention to the water cooling system and thermo-mechanical stability of the Molybdenum jaw support.

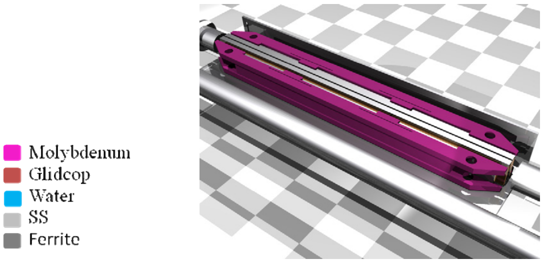

Figure 1: Glidcop collimator design – full assembly.

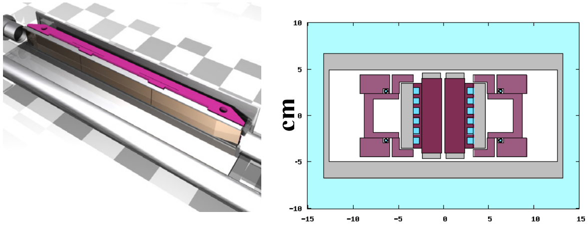

Figure 2: one jaw – cross section.

The 1 m Glidcop jaws have a favourable effect on the budgeting of LHC impedance, but they are subject to high localized temperature peak (at about 20 cm from the beginning of the collimator) which could bring to the destruction of the collimator in case of abnormal beam losses. Thus, the Molybdenum support, into which additional water cooling pipelines are dipped, has a C shape to guarantee geometrical stability.

Metallic Foil Collimator Design

This design features 1 m long Copper-Diamond (35 % Cu and 65% C mass fraction) jaws with 1 mm coating Cu foil onto the jaw surface seen by the beam. Behind the 2 cm thick jaws, the rectangular cooling water pipelines are brazed into a Cu matrix block, with a top of Stainless Steel. The supports of the jaws are in Molybdenum with their cooling water pipeline on the top and bottom. Ferrite jaw insertions for the RF connection are also implemented (see Fig. 3 and Fig. 4).

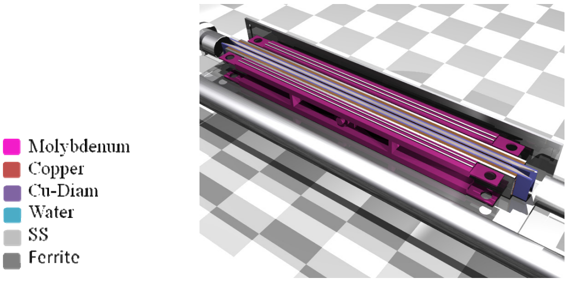

Figure 3: Metallic Foil design – full assembly.

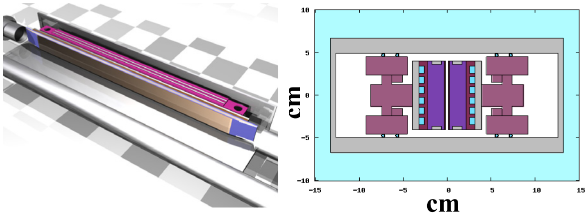

Figure 4: one jaw – cross section.

SiC Inserts Collimator Design

This collimator has 51 Silicon-Carbide tiles ($2\text{x}4\text{x}1\ \text{cm}^3$ each) located into each 1 m Copper-Diamond jaw (see Fig. 5). Water cooling circuits and Molybdenum supports are the same as for the Metallic Foil collimator design.

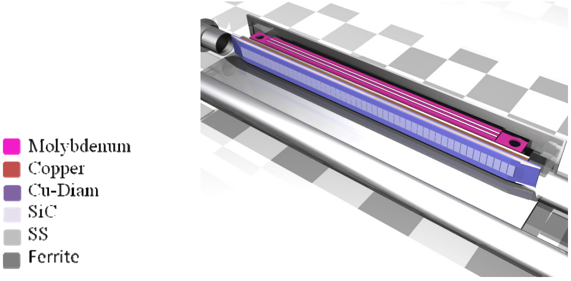

Figure 5: SiC inserts design – one jaw.

SiC Inserts & Ta Pipeline Collimator Design

This design refers to water cooling circuits different from the brazed one of the preview collimator. In this case, the cylindrical water pipelines in Tantalum are dipped in the 4.15 cm thick jaws, all made in Copper-Diamond (see Fig. 6). Peak of temperature and consequent increasing pressure in the water cooling pipelines are to be carefully evaluated in cases of abnormal bean losses, in order to avoid serious damage to the collimator.

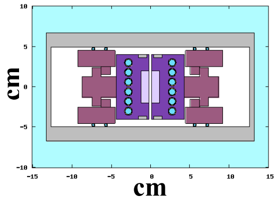

Figure 6: SiC inserts & Ta pipeline design – cross section.

HEAT DEPOSITION IN DELICATE WARM ELEMENTS

For the accident scenarios discussed above, the total instantaneous energy deposition in the IR7 line varies between the two limiting scenarios of Phase I secondary carbon collimators used as Phase II (lower limit) and Phase II Glidcop collimators (higher limit). For the TCP.C6L7.B1 directly impacted, the results are in 403 kJ and 425 kJ. For the TCSM.B4L7.B1 one, they are in 318 kJ and 412 kJ. The distribution of such an energy amount between the directly impacted collimator and the downstream components is dependent on the different Phase II designs considered.

Figure 7 shows the energy deposition distribution for the direct impact on the TCSM.B4L7.B1 (which is the first Phase II horizontal collimator in the IR7 line). The most loaded collimator is the directly impacted one for the Glidcop and Metallic Foil designs. In case of SiC designs the most loaded collimator is the TCSM.A4L7.B1. However, the energy density peak is always localised on the edge (within 0.1 mm from the surface) of the TCSM.B4L7.B1 jaw directly impacted. For Glidcop and Metallic Foil designs, the peak, at about 20 cm from the beginning of the jaw, exceeds 60000 J/cm^3 (instantaneous increase of temperature above the melting point). For SiC designs, it is found in the last 25 cm of the jaw and reaches 6000 J/cm^3 (instantaneous increase of temperature around the SiC melting point).

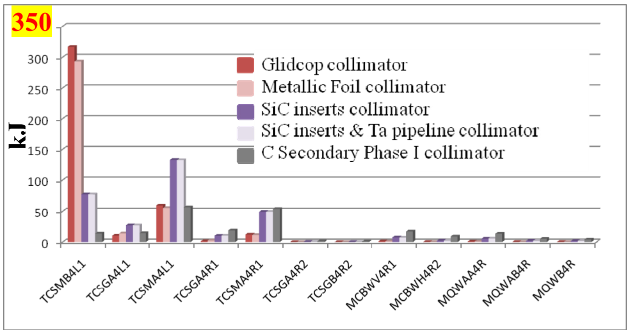

Figure 7: Energy deposition distribution along the IR7 line (TCSM.B4L7.B1 directly impacted).

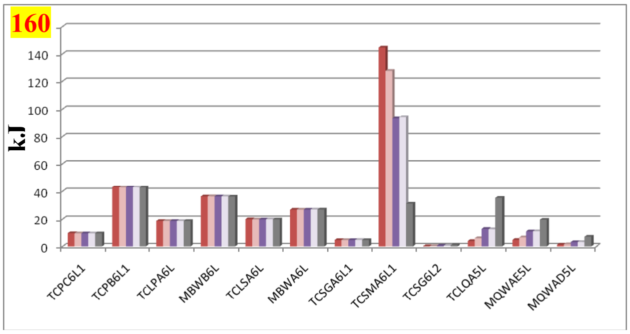

Figure 8: Energy deposition distribution along the IR7 line (TCP.C6L7.B1 directly impacted).

Figure 8 shows the energy deposition distribution in case of direct impact on one jaw of the Phase I primary collimator TCP.C6L7.B1. The most loaded collimator turns out to be the TCSM.A6L7.B1 for all the considered designs, unless it is assumed to be identical to a Phase I secondary carbon collimator. Instantaneous increases of temperature reach 200°C for Glidcop and Metallic Foil design and 40°Cfor the SiC collimators. The temperature peaks are localized in the same areas identified by the TCSM.B4L7.B1 directly impacted.

CONCLUSIONS

All design proposals, developed at CERN by the collimation design team, have been implemented in FLUKA. Energy deposition simulations are and will be used to provide input for FEM thermo-structural analyses to predict quasi-static, transient and dynamic thermal stresses on the collimator body and its supports. Particular attention was given to the accident scenario of horizontal extraction kicker mis-firing, even if it does not represent a project requirement. Results show that, when a Phase II collimator is directly impacted, it could be seriously damaged. SiC collimators, if used like horizontal Phase II collimators, could mitigate the expected sharply localized peak of temperature. Cleaning efficiency, collimator driven impedance, heat conducting and radiation protection constraints have to be further estimated, before any final decision could be taken.

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