SLAC-PUB-14667

EVALUATION OF BEAM LOSSES AND ENERGY DEPOSITIONS FOR A POSSIBLE PHASE II DESIGN FOR LHC COLLIMATION

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Abstract

The LHC beams are designed to have high stability and to be stored for many hours. The nominal beam intensity lifetime is expected to be of the order of 20h. The Phase II collimation system has to be able to handle particle losses in stable physics conditions at 7 TeV in order to avoid beam aborts and to allow correction of parameters and restoration to nominal conditions.

Monte Carlo simulations are needed in order to evaluate the behavior of metallic high-Z collimators during operation scenarios using a realistic distribution of losses, which is a mix of the three limiting halo cases. Moreover, the consequences in the IR7 insertion of the worst (case) abnormal beam loss are evaluated. The case refers to a spontaneous trigger of the horizontal extraction kicker at top energy, when Phase II collimators are used.

These studies are an important input for engineering design of the collimation Phase II system and for the evaluation of their effect on adjacent components. The goal is to build collimators that can survive the expected conditions during LHC stable physics runs, in order to avoid quenches of the SC magnets and to protect other LHC equipments.

INTRODUCTION

The Large Hadron Collider (LHC) is a circular accelerator close to starting up at CERN based on Super Conducting (SC) technology. It will provide collisions of protons at a centre of mass energy of 14 TeV for high energy physics research. Already at normal operation conditions, tiny beam losses can quench any of the SC LHC magnets, which in turn would lead to a full beam loss and thus to an interruption of the beam operations and possible machine damage.

In order to attain the desired luminosity performance and to meet the LHC requirements in such a sensitive SC environment, the protons that diffuse into the so-called beam halo must be removed before they can touch accelerator components. This is achieved with a multi-stage cleaning system, made up of collimators, representing the limiting LHC aperture, located at adequate positions in the machine and installed for both circulating beams [1].

For the operational scenario, in order to improve the cleaning efficiency and to minimize the collimator-induced impedance, it is foreseen to complement the present 30 high robustness secondary collimators with low impedance Phase II collimators.

The Phase II collimators will be located in the two insertions regions IR3 for the momentum cleaning, and IR7 for the betatron cleaning, about 2-3 years after the first physics runs. These locations, where important beam losses are expected, are expected to be among the most radioactive areas of LHC.

PHASE II COLLIMATOR CALCULATIONS: METHODOLOGY

Before a decision can be taken about the installation of a generic accelerator component, important quantities such as the expected heat load have to be carefully investigated. Generally, a basic design of the component is firstly set up to support the future developments, giving indications about the major quantities coming into play. After several iterations among experts in different fields (e. g. radiation protection, beam optics, beam material interaction, impedance, stress analysis, etc), the generic calculations evolve to complex and detailed models.

In the case of Phase II collimators, the contribution of direct proton losses and of the particle showers from the upstream collimators has been extensively studied, using the interaction and transport code FLUKA [2, 3].

The complex layout of the collimation cleaning region IR7 (1.5 km) was modelled in FLUKA [4], including more than 250 beam line objects of about 25 different types, following a modular approach. This solution allows an accurate and manageable description of this complicated system. Objects were modelled and stored in a "parking" area for later mapping via the LATTICE option of FLUKA.

In this configuration, collimators and absorbers play a special role, since their aperture depends on the beta function which varies for different locations. The same prototype is thus adapted runtime through a customized routine which is also responsible for their orientation in the beam line.

Operation scenario

Since the largest fraction of particle losses takes place in the first three Phase I primary collimators, three scenarios have been studied separately: all losses concentrated in the first "vertical", in the second "horizontal", and in the third "skew" collimator. Their orientation refers to a cleaning plane, to which their jaws are perpendicular. The real distribution of losses will be a mix of the above three halo limit cases.

The coordinates and directions of the lost protons are given by a multi-turn beam optics code, called

Work supported in part by US Department of Energy contract DE-AC02-76SF00515.

SIXTRACK [5], which computes a map by tracking for more than 100 turns the 7 TeV beam particles at low beta settings. These tracking files form the basis of the here presented FLUKA studies, since each FLUKA simulation is initiated by a nuclear interaction undergone by a lost proton.

Asynchronous Dump scenario

The considered scenario for abnormal beam losses is due to a spontaneous trigger of the horizontal extraction kicker at top energy, when Phase II collimators are used. In this case the various bunches of the beam experience different deflections during the kicker field ramp and are spread downstream.

In principle, any collimator can be hit by miss-kicked particles but in practice the horizontal ones are those actually impacted. The amount of power absorbed in these collimators could be so high to destroy them.

In order to estimate the energy deposition, simulations have been run using a very pessimistic case, actually one of low probability. This refers to the largest bunch amplitude calculated at the worst location downstream from the kickers. It is assumed that particles with amplitude above 10 σ are efficiently absorbed by dedicated protection devices (TCDQ), whereas the particles with amplitude below 10 σ circulate in the ring for one full turn before they are extracted at the next passage by the kickers. Therefore, particles with amplitude between 6 and 10 σ might hit the Phase I horizontal collimator (TCP.C6L7.B1) or above 7 σ directly the Phase II horizontal collimators in the line (TCSM.B4L7.B1 or TCSM.6R7.B1).

It has to be pointed out that the Phase II collimator survival to the asynchronous dump does not represent a project requirement.

PHASE II: HEAT DEPOSITION IN CRITICAL WARM ELEMENTS

The results refer to the Phase II Rotatable Jaw design, proposed by SLAC in the framework of the LARP collaboration between CERN and several laboratories in the USA [6]. This design with 93 cm long Glidcop (0.15% Al and 99.85% Cu) rotating jaws is presently the most advanced one (see Fig. 1).

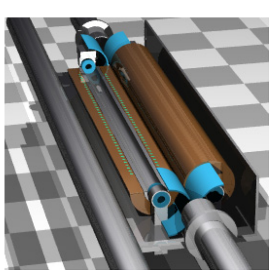

Figure 1: Rotatable Jaw design FLUKA Layout

To evaluate the consequences of beam impact on this type of collimator, 11 copies of the SLAC prototypes were implemented into the FLUKA IR7 model, with different orientations and adapting their gap to match the beta function evolution.

Operation scenario - results

The most loaded Phase II collimator is TCSM.A6L7.B1, which is the first downstream from Phase I primary collimators. The contributions of direct proton losses and of particles shower from the upstream collimators were considered. The fraction of energy deposited in the Copper jaws is about 70 % of the total amount in the collimator. In general, the FLUKA simulations show asymmetric energy depositions in the jaws for the horizontal and skew, whereas for the vertical one the load is almost symmetric. The energy density peak is sharply localized on the surface jaw, at about 20 cm longitudinal depth, for all the three scenarios. Table 1 summarizes these results, whereas Figure 2 shows the power deposition map at the depth of shower maximum and along the longitudinal plane.

Table 1: Summary of Energy deposition results on collimator TCSM.A6L7.B1 for the three halo scenarios

Halo	**Energy Deposition**	**1h [kW]**
Horizontal	Whole collimator	22
	One jaw	8.5
	Peak on the jaw surface	0.11/cm^3
Vertical	In total	22
	One jaw	8.5
	Peak on the jaw surface	0.12/cm^3
Skew	Whole collimator	8.5
	One jaw	3.5
	Peak on the jaw surface	0.05/cm^3

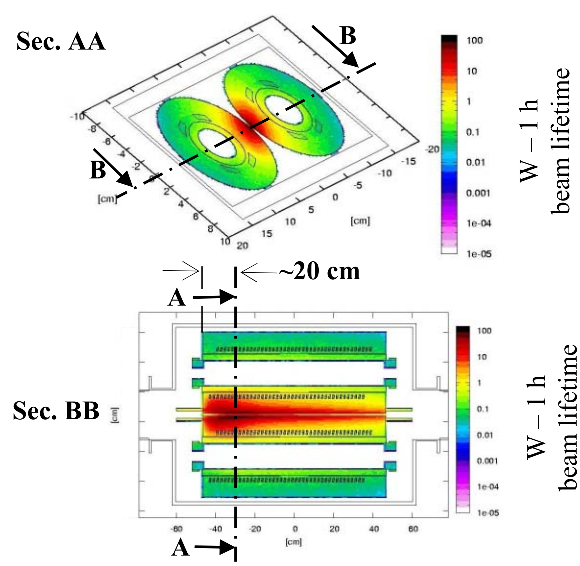

Figure 2: Power deposition map at 20 cm longitudinal depth for TCSM.A6L7.B1 jaws and along the jaws, for the horizontal loss scenario.

Based on these results, a more detailed technical layout has been developed and integrated into the simulations. To optimize design choices and to assure the proper functionality of the device, detailed analysis were performed for the heat load distributions respectively on the mandrels, the cooling pipelines, the motor supports, the flanges and the tank. Table 2 summarize these values for worst loss scenario.

Table 2: Summary of Energy deposition results on collimator TCSM.A6L7.B1 components for the horizontal loss scenario

Energy Deposition	**1h [kW]**
In the Molybdenum with Copper shaft	0.5 (x2 jaws)
In the Copper mandrel and Copper pipeline	0.8 (x2 jaws)
Only in the water	0.03 (x2 jaws)
In the Aluminium motor supports	0.04 (x2 jaws)
In the steel tank	1.5
In the steel flanges	0.07

Asynchronous Dump scenario - results

This abnormal beam loss scenario was studied for a direct impact on each of the three horizontal collimators, located in the IR7 line. Results show that the most loaded one is always a Phase II collimator type. The energy deposition was scored in a three dimensional grid. The total energy deposition, the peak energy density, and the resulting instantaneous increase of temperature (calculated under adiabatic assumptions) are summarized in Table 3.

Table 3: Summary of Energy deposition results on the most loaded collimator for the three impact cases

TCP.C6L7.B1 directly impacted TCSM.A6L7.B1 most loaded	
Total energy deposition	130 [kJ]
Energy density peak on the jaw	600 [J/cm^3]
Instantaneous increase of temperature	180^o
TCSM.B4L7.B1 directly impacted TCSM.B4L7.B1 most loaded	
Total energy deposition	300 [kJ]
Energy density peak on the jaw	50000 [J/cm^3]
Instantaneous increase of temperature	>>melting point
TCSM.6R7.B1 directly impacted TCSM.6R7.B1 most loaded	
Total energy deposition	300 [kJ]
Energy density peak on the jaw	50000 [J/cm^3]
Instantaneous increase of temperature	>>melting point

SIMULATION UNCERTAINTIES

The previous estimates carry uncertainties of various sources which are difficult to be precisely evaluated. While the statistical uncertainties are generally below 10 % for peak values and below 1 % for integral values, further systematic errors are a combination of several factors, e. g. due to the physics modelling of the inelastic interaction, to the approximations used in the description of the geometry and of the materials, to the neglecting of the collimator surface roughness, etc, which add up to at least a factor 2-3. Furthermore, because the tracking loss pattern forms the basis of the here presented FLUKA studies, errors due to the assumptions used to generate the loss maps have to be taken into account and added to the previous uncertainties.

CONCLUSIONS

The Rotatable Jaw design is actually in phase of prototyping at SLAC. The production of the jaws takes care of the results presented in this paper for the operational scenario. Following the production of the prototype, further optimization studies have to be carried out in the next future in order to optimize its performance or to support the mechanical integration. The resulting FLUKA simulations are and will be used as input in the engineering simulation (e.g. ANSYS) to predict static stresses on the collimator body and its supports.

Moreover, the simulations of the asynchronous dump scenario point out that the Phase II collimators are always the most loaded ones for this type of failure. Results show that, when a Phase II collimator is directly impacted, it is seriously damaged and most probably destroyed. Other possible design solutions could be investigated for these special locations.

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