STUDIES FOR AN ALTERNATIVE LHC NON-LINEAR COLLIMATION SYSTEM*

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Abstract

A LHC non-linear betatron cleaning collimation system would allow larger gap for the mechanical jaws, reducing as a consequence the collimator-induced impedance, which may limit the LHC beam intensity.

In this paper, the performance of the proposed system is analyzed in terms of beam losses distribution around the LHC ring and cleaning efficiency in stable physics condition at 7TeV for Beam1.

Moreover, the energy deposition distribution on the machine elements is compared to the present LHC Betatron cleaning collimation system in the Point 7 Insertion Region (IR).

INTRODUCTION

The alternative LHC betatron cleaning collimation system evaluated in this paper is called 'non-linear' since it is based on the use of non-linear magnets, such as sextupoles and octupoles. As following previous studies [1,2], the proposed layout includes the installation of two strong skew resistive sextupoles (K_s~7m^{-2}), symmetrically located at about 191 m from the center of the Point 7 Straight Section (SS7). The purpose of the first non-linear element is to blow up beam size and particle amplitude, in order to place the collimator jaw further away from the beam and, as a consequence, to reduce the resistive collimator-induced impedance. On the other hand, the second sextupole, located at π phase advance downstream, is supposed to cancel the geometrical aberration induced by the first one.

The betatron collimation system at Point 7 has been adapted to catch the new beam halo profile developed by the introduction of these non-linear elements. New more relaxed collimator gaps have been proposed and the number of active collimators has been reduced with respect to the actual system from 19 to 14, accordingly to the new operation requirements.

Table 1 summarizes the proposed layout for the non-linear collimation system in comparison to the present one at Point 7 for Beam 1 (B1). In case of non-linear collimation, TCSG.A4L7.B1 and TCSG.A4R7.B1, which are secondary collimators in the present collimation system, play the role of primary collimators. Their orientation and aperture is set accordingly to their new function. The secondary collimators upstream the TCSG.A4L7.B1 are not taken into account for the non-linear collimation system and thus for the simulations they are considered totally opened, in order to reduce their effect at minimum. In addition, 3 new secondary collimators are introduced to improve the performance in absorbing the secondary halo, generated by the non-linear primaries, which, in this case, are located around the center and not at the beginning of SS7. No further modifications with respect to the present collimation layout have been introduced in the other LHC IRs.

Table 1: Collimator layout and setting in Point 7 for B1. The reference collimator apertures at 7TeV beam energy for the present LHC collimation layout [3] and the proposed ones for the alternative non-linear system are shown. In case of non-linear collimations, only the changed orientations in rad with respect to the present LHC system are specified as well as for the 3 additional collimators introduced (highlighted in red).

Collimator type	**LHC present collimation system (sigma units)**	**LHC non-linear collimation system (sigma units)**
TCP	All @ 6.0	All @ 10.0
TCSG	All @ 7.0	A6L7 - tot opened B5L7 - tot opened A5L7 - tot opened D4L7 - tot opened B4L7 - tot opened A4L7 - 16.0 [0 rad] A4R7 - 8.0[1.571rad] B4R7 - 9.0 [2.37rad] A5R7 - 9.0 [.651rad] B5R7 - 9.0 C5R7 - 9.0[1.571rad] D5R7 - 9.0 E5R7 - 9.0 6R7 - 9.0
TCLA	All @ 10.0	A6R7 - 9.0 B6R7 - 9.0 C6R7 - 7.0 D6R7 - 7.0 A7R7 - 7.0

The performance of the proposed system has been evaluated and compared to the present one, considering one beam line (i.e. B1) and protons at 7TeV. The reference optics in stable physics conditions (version V6.503 'as-built') has been modified to match the non-

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linear collimation specifications. The comparison in terms of Cleaning Efficiency and Energy Deposition is performed without considering any imperfection in the LHC machine.

CLEANING EFFICIENCY COMPARISON

In order to compare the two systems in Point 7 and their effect in the whole LHC ring, the same halo profile in the horizontal and vertical plane has been tracked starting from Point 1, using the SixTrack code [4]. It refers to a particle distribution with normalized amplitude of 6.003 and a smear of .0019 both in beam sigma units. A fractional energy spread of 1.129×10^{-4} was also taken into account.

Local Cleaning Inefficiency (= 1 - Local Cleaning Efficiency) results for the horizontal plane are shown in Fig. 1 and 2. The non-linear collimation results are worse than the present system ones, because of an higher contribution into the Dispersion Suppressor region at the entrance of Point 3 and the higher leakage close to the experimental regions in Point 2 (ALICE) and Point 8 (LHCb). Dotted green lines correspond to the beam dump threshold provided by the Beam Loss Monitor (BLM) in the LHC cold sections.

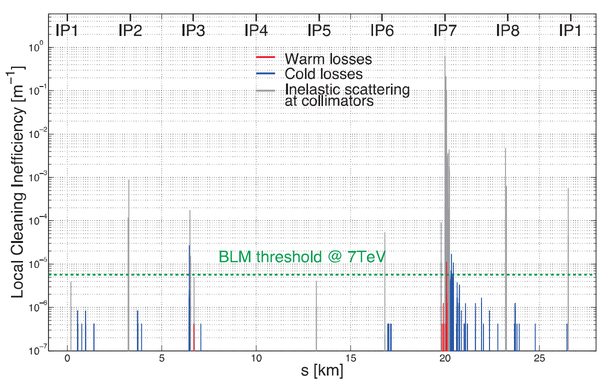

Figure 1: Collimation Inefficiency results for the proposed non-linear collimation system in Point 7 at 7TeV beam energy.

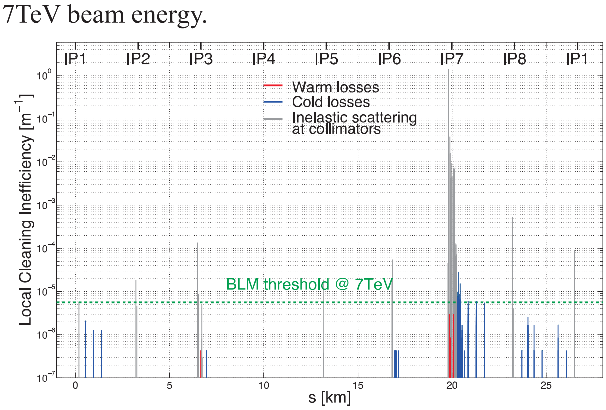

Figure 2: Collimation Inefficiency results for the present LHC collimation system at 7TeV beam energy.

Similar results are obtained studying the vertical halo separately. Note that the vertical and the horizontal halos are the two limit cases of a real distribution of losses: the latter is a mix of these two limit cases.

ENERGY DEPOSITION COMPARISON

Starting from the maps of primary proton non-elastic collisions in the collimators, calculated via SixTrack, a full particle shower study in Point 7 was performed. The FLUKA Monte Carlo code [5,6] was used to simulate the proton interactions with the collimator jaws and the resulting cascade along the SS7. The complex geometry of the 500m long SS7 line was modeled in detail in FLUKA by means of the LineBuilder and the FLUKA Element Database [7]. More than 100 beam elements have been taken into account such as dipole and warm quadrupole magnets, passive absorbers as well as the different collimators installed in the SS7 line.

Total power load distribution results in the SS7 collimators are compared in Fig.3 for the 4 cases studied separately. For the non-linear collimation, the power deposited on the first TCLA is 4 times higher in the tungsten part of the most exposed jaw than the present LHC system (from 0.17 to 0.8 kW). As consequence of the reduced tolerance, the LHC operation could become more delicate in case of the alternative non-linear collimation system.

The last 3 TCLAs installed at the end of the SS7 after the second sextupole, have not been considered in this comparison. Indeed, particle showers impacting these absorbers are heavily affected by the actual geometry of the upstream sextupole, not yet designed at moment.

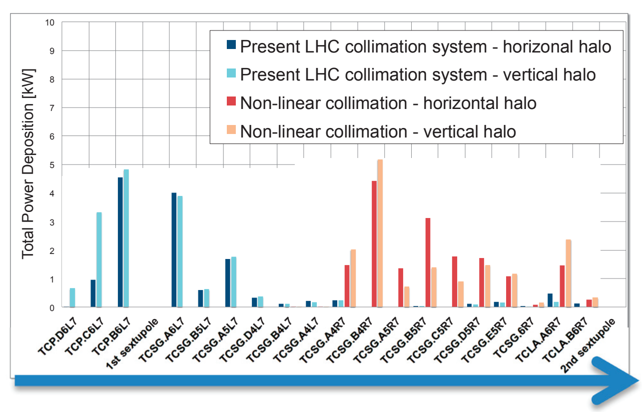

Figure 3: Total power deposition distribution on SS7 collimators, considering 1h beam lifetime at 7TeV and nominal intensity (i.e. 2808 bunches with 1.15E11 protons each). Statistic errors are below 1%. The blue arrow shows the B1 direction.

The peak power density on the jaw surface of the primary and first secondary collimators has been compared: indeed, for these collimators, the direct impact of protons or the absorption of particle showers play a major role with respect to other collimator locations. This study has followed the SixTrack impact parameter results on the primary collimators in which about one order of magnitude difference was found for the two systems (from few hundred µm to around 1 mm). The longitudinal profiles of the peak power for each of the two collimator jaws are shown in Fig. 4 and 5. It has to be noted that the

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spread of protons on the primary jaw surface is a direct consequence of using non-linear elements. Statistic errors are less than 10% for peak values.

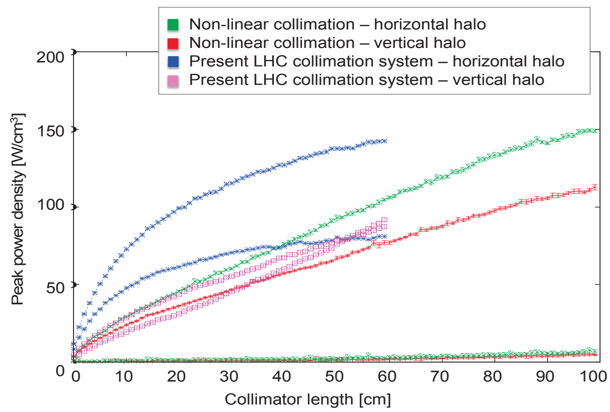

Figure 4: Peak power density profile at the primary collimators: @ TCP.C6L7.B1 for the horizontal and @ TCP.D6L7.B1 for the vertical present LHC collimation system scenarios, @ TCSG.A4R7.B1 for both vertical and horizontal non-linear collimation scenarios. A bin size of 0.01x0.01x1 cm^3 was used to score peak values.

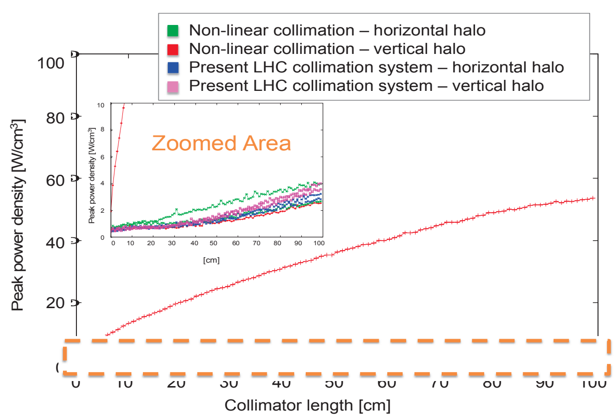

Figure 5: Peak power density profile at the first secondary collimators: @ TCSG.A6L7.B1 for both horizontal and vertical present LHC collimation system scenarios, @ TCSG.B4R7.B1 for both vertical and horizontal non-linear collimation scenarios. The bin size used in this case was 0.1x0.1x1 cm^3.

For what concerns the primary collimators, only one jaw is loaded in case of non-linear collimation system, since the first sextupole guides all the particles of the halo on the upper jaw of the vertically oriented TCSG.A4R7.B1, in both horizontal and vertical cases. Results show that peak values at the end of the jaw with respect to the beam entrance direction are both of the same order for the 1m (non-linear) and 0.6m (present system) long jaw.

On the other hand, in case of vertical halo with non-linear collimation, the peak on the first 1m long secondary collimator jaw is much higher than the one for the others. This is due to the fact that for the present LHC collimation system and for the horizontal non-linear case as well, more than 80% of the protons lost in the LHC interacts with the primary jaws, and few % in the secondary ones, while for the vertical non-linear scenario only 60% is directly lost on the primary collimator and more than 20% are lost on the first secondary collimator downstream.

CONCLUSIONS AND OUTLOOK

The LHC non-linear collimation system is a promising solution for high intensity beams at 7TeV. The non-linear elements allow to cut the number of collimators and to use relaxed gaps, reducing the resistive collimator-induced impedance. However the layout of this alternative system has to be optimized. In particular, locations, orientations and setting of the secondary collimators have to be revised on the basis of these new results through the scan of the beam halo profile along SS7, in order to reduce the direct losses on the SS7 TCLAs, on the tertiary collimators (i.e. TCTs) at Point 2 and 8 and in the Dispersion Suppressor (DS) region at the entrance of SS3. Moreover, the shift along Point 7 of the energy deposition distribution on the beam elements in case of non-linear collimation could also ask for the installation of additional passive absorbers to improve the lifetime of the resistive magnets, downstream of the more loaded collimators. The study of the layout has to take into account also this constraint. The performance of the non-linear collimation system could also be improved by the introduction of DS collimators. Preliminary studies for the upgrade of the present LHC collimation system are already evaluating the introduction of collimators in the DS regions [8]. Finally, since the non-linear elements guide the particles in a preferred direction, the insertion of crystals [9] could improve the efficiency of the system. Figure of merits can be helpful to classify and rank the different solutions.

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