ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-MOPRO040

COLLIMATION CLEANING FOR HL-LHC OPTICS SCENARIOS WITH ERROR MODELS *

A. Marsili†, R. Bruce, S. Redaelli, CERN, Geneva, Switzerland

Abstract

The upgrade of the LHC collimation system in view of the High-Luminosity upgrade of the Large Hadron Collider (LHC) foresees, amongst other scenarios, local collimation in the Dispersion Suppressors (DS) of IR7. Layouts have been worked out which rely on using stronger and short bending dipoles to free space for a collimator in the cold DS. In this paper, the effectiveness of the proposed layouts is studied with different imperfection models such as collimator alignment, jaw tilt and surface errors, gap errors and aperture imperfections. The effect of local DS collimation on the global losses around the ring is also addressed for different optics configurations.

INTRODUCTION

The High-Luminosity LHC (HL-LHC) upgrade project aims to increase the peak luminosity to $5 \cdot 10^{34}\,\mathrm{cm}^2\,\mathrm{s}^{-1}$ [1]. This can be done by decreasing the size of the beam at the Interaction Point (IP), with a baseline value of the beta function of $\beta^* = 15\,\mathrm{cm}$. It is achieve with the so-called Achromatic Telescopic Squeeze (ATS) scheme [2, 3].

SixTrack is a multi-turn thin-lens particle tracking code with a built-in Monte Carlo to model the particle-matter interactions in the collimators [4,5]. It was used to perform the first collimation cleaning simulations of the ATS optics with a perfect machine [6]. They showed that the cold locations with the highest losses in the ring are the same as during Run I of the LHC: the Dispersion Suppressor (DS) of IR7, but also other loss clusters appearing around the ring because of the modified optics in the arcs, possibly limiting the maximum intensity allowed. This issue could be addressed by replacing one 8.3 T dipole in cells 8 and 10 by two shorter 11 T dipoles, and installing a new collimator (TCLD) in the space gained [7, 8].

This paper presents more realistic simulations of collimation cleaning for the ATS optics, including several error models for the machine and the collimators. The effect of the TCLDs is discussed, demonstrating that they provide a robust solution to improve collimation cleaning around the LHC ring in presence of realistic imperfections.

Four simulation cases were considered: horizontal or vertical halo, each with or without TCLDs [7]. They were modeled as 1 m-long Copper jaws, set at 15 σ. This is a worst case scenario (the considered material is now Tungsten), with relaxed settings: cleaning could be improved further with tighter settings. The optics used is SLHC V3.1b. The settings of all collimator types is summed up in Table 1.

* Research supported by FP7 HiLumi LHC – Grant agreement 284404
† amarsili@cern.ch

CLEANING SIMULATION SETUP WITH COLLIMATOR ERROR MODELS

SixTrack allows to simulate different imperfections in the collimator system [9]. The ones considered here are:

- Gap: opening between the two jaws of a collimator;
- Offset: alignment error of the collimator jaws around the local beam orbit;
- Tilt: angle between jaw and beam;
- Flatness of the surface of the jaw.

All errors (except on flatness) follow a random Gaussian distribution (standard deviation given in Table 2) controlled by a seed. Simulations were performed with seven different seeds for each of the four cases, in order to study the overall effect of the errors and not only a specific case. The limiting factor in these simulation is the processing time: these simulations represent 800 years of CPU time.

Table 1: Collimator Settings used in the Simulations

Type	[σ]	Type	[σ]
Primary IR7	6	Primary IR3	12
Secondary IR7	7	Secondary IR3	15.6
Absorber IR7	10	Absorber IR3	17.6
Debris Absorber	10	Secondary IR6	7.5
DS Absorber	15	Dump protection IR6	8
Tertiary IR1/5	8.3	Tertiary IR2/8	12

Table 2: Design Standard Deviation of the Errors, from [9]

Parameter	Value	Unit
Gap	0.1	σ_β
Offset	50	μm
Tilt	200	μrad

The flatness error of the jaw surface is modeled by a second order polynomial:

$$\pm 4 \cdot 10^{-4} (\frac{s^2}{l} - s) \quad [m] \qquad (1)$$

where s is the position along the jaw and l the length of the jaw in meter. The jaw flatness error is simulated by using four slices of length $l/4$ positioned along the parabolic shape of Eq. (1) (maximum deformation of $10^{-4} \times l$ [9]). The jaw can be bent inwards (towards the beam, negative factor) or outwards (positive); both are used in simulations. An example of the shape of the primary collimator jaw with all errors is given in Fig. 1.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-MOPRO040

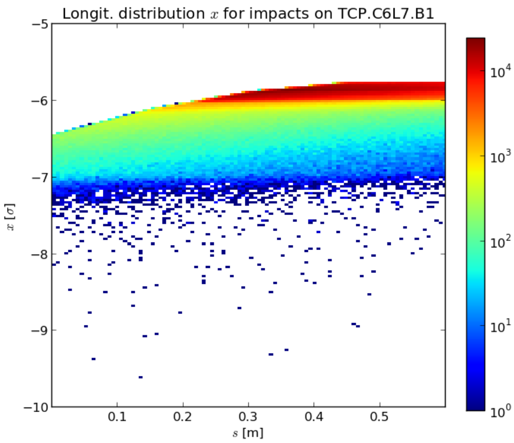

Figure 1: Distribution of losses in the volume of the jaw of the horizontal primary collimator in IR7. The inwards curvature (Eq. (1)) and the tilt of the jaw are visible. Due to the errors, the jaw is not at the theoretical opening of 6 σ any more.

SIMULATION RESULTS

Due to the error models, the distribution of losses in the collimator volume varies significantly. A particle situated at the theoretical setting of the collimator will encounter in average less material than in the case without errors. The distribution of losses on the TCP jaw for one case with errors is shown in Fig. 1). This decreases the cleaning efficiency of the whole collimation system, as shown in Table 3. The global inefficiency is expressed as the number of particles lost on aperture divided by the total number of particles lost. On average (over all seeds), the fraction of particles lost on aperture increases by a factor two with the addition of the error models.

An important fraction of the protons lost on aperture are lost in the DS of IR7 (Table 3). The TCLDs protect this area, but also alleviate losses further down the ring. Thus, they have a strong effect on the global inefficiency. Table 3 shows how the global inefficiency, averaged over all simulated seeds (first line), is drastically reduced by the addition of TCLDs in the DS: the proportion of particles lost on the aperture over the whole ring decreases by a factor 38.5 and 35.3 (H and V halo). The value for simulations without errors is also given.

Table 3: Global Inefficiency over all Seeds for each Simulated case and all Error Models, Expressed in [ppm]. Without error models, the global inefficiency for Horizontal halo, no TCLD, is 322.5. The error is calculated as $\sigma/\sqrt{n}$, where n is the number of seeds.

Case TCLD	H no	H yes	V no	V yes
Mean (μ)	675.6	17.53	508.6	14.41
Std. Dev. (σ)	165.9	11.44	106.5	4.50
Error on μ	62.7	4.33	40.2	1.70

The main features of the loss maps for the ideal machine were discussed in [6]. It was shown that all aperture losses downstream IR7 are dispersive, caused by particles that have lost energy after interacting with the IR7 collimators. They appear at local maxima of the (positive) dispersion, for negative offsets in the horizontal plane. In addition, the TCLDs in the dispersion suppressor protect from local losses in the DS itself, but also from loss clusters further downstream in arcs 7–8 and 8–1. The cut in dp/p created by the TCLD in cell 8 is not sufficient to protect the arcs; the TCLD in cell 10 is needed as well.

The loss clusters representing potential limitations for collimation cleaning (Fig. 2) were studied independently. Fig. 3 shows the ratio between the number of particles lost in each cluster over the total number of particles lost, averaged

Table 4: Values of RMS Alignment Error in the two Planes, in mm, for each Type of Element, from Measurements [9]

Element type	Horizontal	Vertical
MB	2.40	1.56
MQ	2.00	1.20
MQX	1.00	1.00
MQW	2.00	1.20
MBW	1.50	1.50
BPM	0.50	0.50

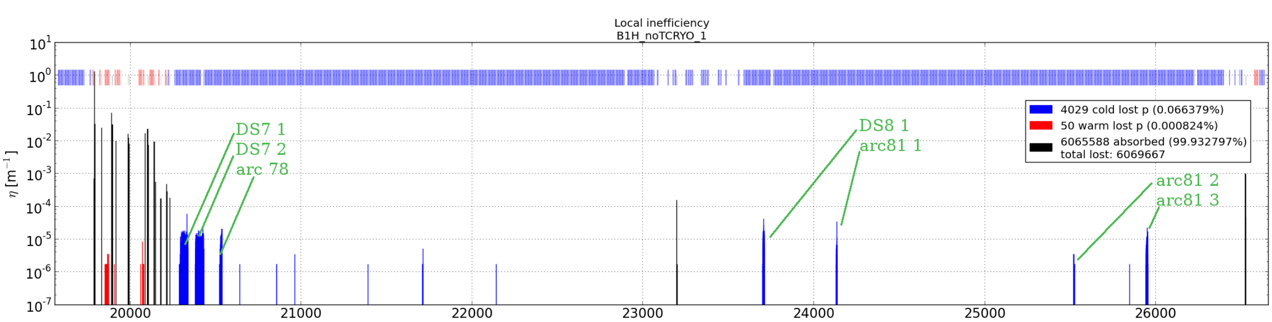

Figure 2: Horizontal loss map for arcs 7–8 and 8–1, for 6.4 million p, without TCLDs. The red and blue boxes at the top give the position of warm and cold magnets respectively. All the losses on the aperture of the two arcs are removed by the addition of TCLDs (not shown).

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-MOPRO040

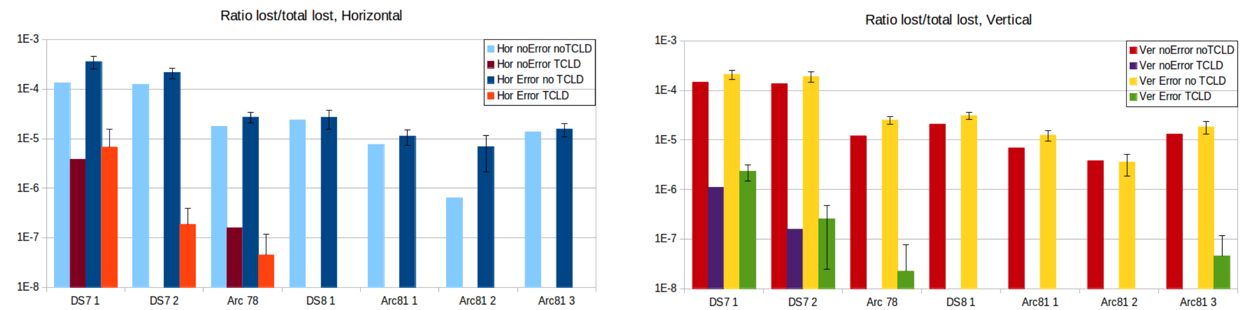

Figure 3: Ratios of particles lost in clusters over total number of lost particles, with or without errors, with and without TCLDs, for horizontal (left) and vertical (right) halos. See Fig. 2 for reference. In the cases simulated with errors, the average over all seeds and standard deviation are given.

over all seeds for the cases with errors. The value for the simulation without errors is also displayed for comparison.

The first observation is that without TCLDs, all loss clusters increase when collimator error models are added, showing how the cleaning inefficiency of the system gets worse. However, the addition of TCLDs drastically decreases or completely removes the loss clusters. The gain in cleaning inefficiency for the loss clusters is a factor 50 or higher. Even with collimator errors, the arcs are protected.

APERTURE ALIGNMENT ERROR

The aperture alignment errors are modeled during the post-processing of SixTrack simulations, by randomly offsetting the mechanical aperture. For one tracking simulation, a number of seeds for aperture alignment errors can be applied without repeating the halo particle tracking. The RMS errors applied to the main LHC lattice elements are are given in Table 4, and were taken from measurements [9]. The effect of TCLDs in presence of aperture alignments were addressed by considering the nominal machine. Simulations were performed with and without TCLDs, with 10 seeds for aperture alignment errors in each case.

The previous analysis on the higher loss locations cannot be performed in this case: shifting the aperture might result in a reduction of a local peak that would appear as an improvement. In reality, aperture errors induce more peaks in the cold magnets. However, the addition of TCLDs remove all loss clusters in the arc, as shown in Fig. 4 The number of particles in the only DS cluster still present is decreased by a factor 20. Even with aperture alignment errors, the arcs are protected.

CONCLUSION

The cleaning performance with and without DS collimation was studied for different collimator error models together, and for aperture alignment errors. Further work would include considering all errors at the same time. The error models deteriorate cleaning efficiency. The addition of local collimation in the DS of IR7 provides a robust solution that consistently reduces losses around the ring. This is an important result for the HL upgrade optics that features loss spikes around the rings and not only immediately downstream of IR7. The same solution based on TCLD collimators and 11T dipoles can be used to cure both the DS limitations next to IR7 and the specific loss patterns of the ATS optics. Catching off-momentum leakage with TCLDs close to IR7 make the overall losses around the ring less sensitive to machine imperfections.

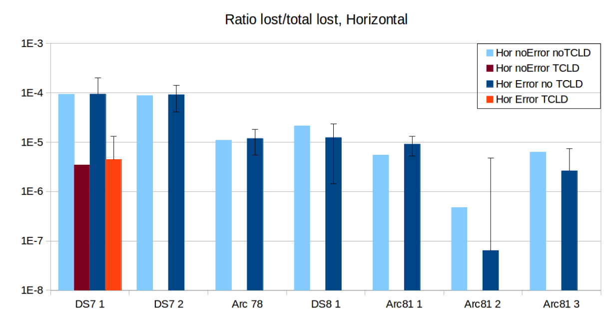

Figure 4: Ratio of particles lost in the cluster over total number of particles lost, without or with TCLD, without and with aperture alignment errors, for a horizontal halo.

REFERENCES

[1] L. Rossi, "LHC Upgrade Plans", IPAC 2011, TUYA02.

[2] S. Fartoukh, "An Achromatic Telescopic Squeezing (ATS) scheme for the LHC Upgrade", IPAC 2011, WEPC037.

[3] S. Fartoukh, "Achromatic telescopic squeezing scheme and application to the LHC and its luminosity upgrade", PhysRevSTAB.16.111002

[4] G. Demolaize et al., "A New Version of SixTrack with Collimation and and Aperture Interfaces", PAC 2005, FPAT081.

[5] F. Schmidt. CERN/SL/94-56-AP, 2012.

[6] A. Marsili et al., "Simulations of collimation cleaning performance with HL-LHC optics", MOPWO042, IPAC 2013.

[7] R. Bruce et al., "Cleaning performance with 11T dipoles and local DS collimation at the LHC", MOPRO042, IPAC 2014.

[8] A.V. Zlobin et al. IEEE Transaction on Applied Superconductivity, 10.1109/TASC.2011.2177619, 2012.

[9] C. Bracco, "Commissioning Scenarios and Tests for the LHC Collimation System", PhD thesis, CERN-THESIS-2009-031.