STUDIES OF THERMAL LOADS ON COLLIMATORS FOR HL-LHC OPTICS IN CASE OF FAST LOSSES*

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Abstract

The new layouts for the HL-LHC pose new challenges in terms of proton loads on the collimators around the ring, in particular for the ones in experimental regions that become critical with squeezed optics. New layouts are under consideration, which foresee updated collimation schemes. Simulations of halo loads for the case of fast failures have been setup with SixTrack in order to determine beam loss distributions for realistic error scenarios. The particle tracking studies are used as starting conditions for FLUKA to evaluate the thermal loads on collimators in case of failures. In this paper, the preliminary studies performed for the baseline HL-LHC optics layouts are presented.

INTRODUCTION

The High luminosity LHC (HL-LHC) is an exciting project, extending the challenging LHC discovery potential [1]. Around 2020, the plan is to increase the LHC peak luminosity by reducing the beam spot size at the Interaction Point (IP), by introducing crab cavities to compensate for the otherwise large geometric loss due to the crossing angle, and by increasing the beam brightness. The IP spot size can be reduced by further squeezing the IP β^* from a nominal value of 0.55 m at 7 TeV down to 0.15 m (Table 1) by installing new final-focusing triplets and by accomplishing the associated chromatic correction and the matching to the arcs through a novel optics, called the Achromatic Telescopic Squeeze (ATS) [2,3].

Table 1: Major physics condition parameters for HL-LHC [2], in comparison to the nominal 7TeV scenario, as before the luminosity upgrade.

Main parameters		7 TeV ATS optics	7TeV nominal optics
Luminosity [$cm^{-2} s^{-1}$]		5e35	1e34
Bunches		2808	2808
Protons per bunch		2.2e11	1.15e11
Bunch spacing [ns]		25	25
β^* [m]	IP1/ATLAS	0.15	0.55
	IP2/ALICE	10	10
	IP5/CMS	0.15	0.55
	IP8/LHCb	10	10
Half Crossing Angle [μrad]	IP1/ATLAS	295	142.5
	IP2/ALICE	240	150
	IP5/CMS	295	142.5
	IP8/LHCb	305	200

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The luminosity increase requires the upgrade of several LHC systems, such as collimators [4]. One of the requirements of the collimation system upgrade includes improving its machine protection performance. In particular, in case of fast losses due to failures caused by asynchronous dump accidents in physics conditions with squeezed optics, the triplet magnets in the high luminosity experimental regions would be among the most exposed LHC elements, if the tungsten tertiary collimators (TCT) fail to protect them. Apart the triplets, the TCTs themselves could also be seriously damaged.

Since some asynchronous dump events per year are expected, the evaluations of the TCTs performance are shown in this paper. In this study, the nominal 7 TeV collimation settings are used (worst for TCT vs. Point 6 devices retraction) (see Table 2). Realistic collimator settings and orbit errors are considered.

Table 2: Reference LHC collimator settings for collimator families in the different Insertion Regions (IRs) for both Beam1 (clockwise) and Beam2 (counter clockwise).

LHC sector	Collimator type	Half gap 7 TeV ATS [beam σ]	Half gap 7TeV nominal [beam σ]
IR3 (Momentum cleaning)	TCP	12.0	15.0
	TCSG	15.6	18.0
	TCLA	17.6	20.0
IR7 (Betatron cleaning)	TCP	6.0	6.0
	TCSG	7.0	7.0
	TCLA	10.0	10.0
IR6 (Dump)	TCDQ	8.0	8.0
	TCSG	7.5	7.5
IR1, 2, 5, 8 (Experimental)	TCT (1, 5)	8.3	8.3
	TCT (2, 8)	30.0	30.0

METHODOLOGY

Simulations of fast losses in case of asynchronous dump were set up, using the latest version of the tracking code SixTrack, including a special collimation routine [5]. The new implementation allows the tracking of a proton beam with the full detailed LHC collimation system in place, in case of asynchronous dump accident scenarios. During such events, the misfiring of any or all of the 15 extraction kickers at Point 6 causes the beam to receive a potentially dangerous kick. Kicked protons are thus swept across the machine aperture, before being correctly dumped at Point 6 after one turn. The lost kicked protons at any TCT locations, output of SixTrack, are used as input for FLUKA [6,7] studies. A detailed TCT FLUKA model was used and set accordingly to the corresponding

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TCT half gap aperture (see Table 2 as reference), thanks to the LineBuilder tool [8]. The FLUKA study of particle showers allows the evaluation of energy load in collimator due to the beam interactions with each TCT jaw.

CASES STUDIED

In the simulations both Beam 1 and Beam 2 were considered. The idea was to identify the most exposed TCT locations and critical angles during the rise of the extraction kickers (MKD), which would cause high loads onto the TCT jaws. Perfect machine scenarios as well as pessimistic but still technically possible combined errors were considered. A retraction of 1.5 mm of the beam dump protection system at Point 6 was assumed for both beams. Moreover the TCTH.4L1.B1 at Point 1, identified on the basis of preliminary results as the most exposed TCT for Beam1, was set 1σ closer to the beam (from 8.3 to 7.3 σ). In addition the effects of 1 mm retraction of 4 Point 7 collimators was also taken into account. These are collimators that would be hit in case of non-ideal machine, so protecting TCTs (see [5] for more details). For what concerns Beam 2, two critical TCTs were considered. The first one (i.e. TCTH.4R5.B2) is installed at Point 5 downstream the Point 6 protection devices. The second one is located in Point 1 (i.e. TCTH.4R1.B2) and in principle could profit from shielding by upstream collimators. Both Beam 2 TCTs were moved in by 1σ more with respect to their nominal half gap to simulate a strong reduction of the misalignment margin.

COMPARISON OF LOSSES BETWEEN THE 2 OPTICS SCENARIOS

The local cleaning inefficiency is defined as the ratio of the number of protons lost locally per meter, in any given longitudinal bin, to the total of protons adsorbed by collimators [9]. Peaks of local cleaning inefficiency in loss maps, as resulting from SixTrack simulations, identify possible critical locations, where a high number of beam-machine interactions happened. The localization of such peaks, during normal operation as well as in failure conditions, allows foreseeing and efficiently dealing with machine protection issues and acting accordingly. Comparison of loss maps for nominal optics and ATS are shown in Fig. 1 and 2 for Beam 1 and Fig. 3 and 4 for Beam 2, in case of asynchronous dump accidents.

During an asynchronous dump in a perfect machine (see Fig. 1 and 3), the TCTs see negligible losses in both the nominal optics and ATS for all angles of the extraction kickers. However, in case of Beam 2, losses are observed on the Q5 quadrupole upstream the IR5 TCT. These particles are tertiary halo scattered out of the IR6 collimators. It is left as future work to study whether this loss could quench or damage the magnet.

When errors are introduced, the situation changes (see Fig. 2 and 4). The 1.5 mm orbit errors at Point 6 give a window of critical MKD kick angles (i.e. from 0.41 to 1.26 μrad) for which escaping bunches could become an issue for downstream collimators. In particular for HL-LHC, the TCTs in Point 5 and 1 are located at as unfavorable phase advance with respect to the MKDs (i.e. 99.5° for TCTH.4R5.B1 and 97.2° for TCTH.4L1.B1). Thus they will be exposed to the highest losses, if upstream protection fails. This is not the case for the 7TeV nominal, where a phase advance close to 180° was chosen by design.

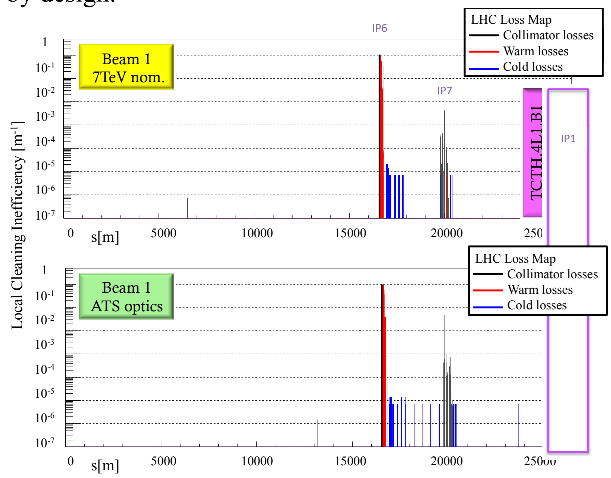

Figure 1: Local cleaning inefficiency loss maps for ATS and 7TeV nominal optics, for perfect machine. Results are normalized to the maximum of losses at the extraction protection TCDS.

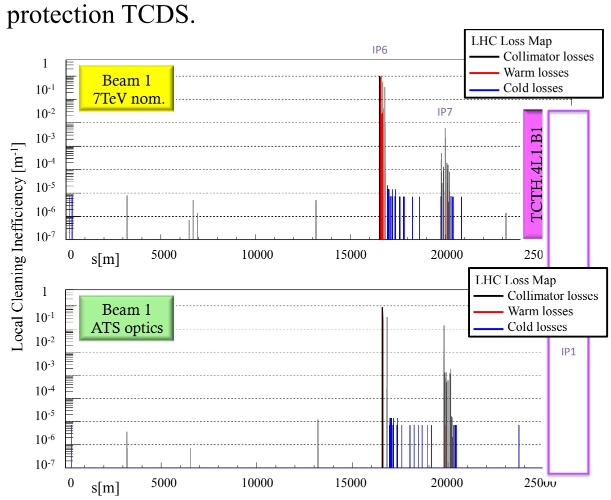

Figure 2: Simulated loss maps around the LHC ring, when errors are introduced. The highest contribution to the TCT peak at Point 1 is due to the retraction of the 4 critical collimators at Point 7. It has to be pointed out that in case of ATS optics a favorable phase advance between the kickers location and the horizontal primary collimator plays a major role to protect the TCT (i.e. TCP.C6L7.B1 at about 77° phase advance).

A range of dangerous kickers angles for TCTs has been identified, corresponding to a time window of about 220 ns for the fire of the spurious trigger. In this range of time a maximum of 8 or 9 bunches are involved, with 25 ns bunch spacing. However it has to be noted that the proton intensity per bunch involved changes in the different cases of asynchronous dumps under study with imperfections. For the TCTH.4L1.B1 at Point 1 about

9.2E10 protons are impacting in case of 7 TeV nominal, while 1.1E10 for ATS optics. For the TCTH.4R5.B2, a total proton intensity of 4.5E11 impacts for the ATS optics, while 8.36E8 are the protons on the TCT jaws for the 7 TeV nominal optics.

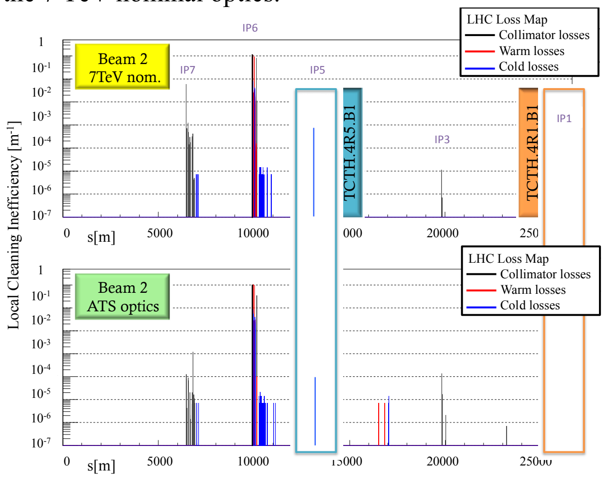

Figure 3: Local cleaning inefficiency loss maps comparison for Beam 2, perfect machine. The Point 5 peak (blue area) has to be noted. Located just downstream IP6 and with phase advance close to 90°, the TCT is already exposed in the case without imperfections.

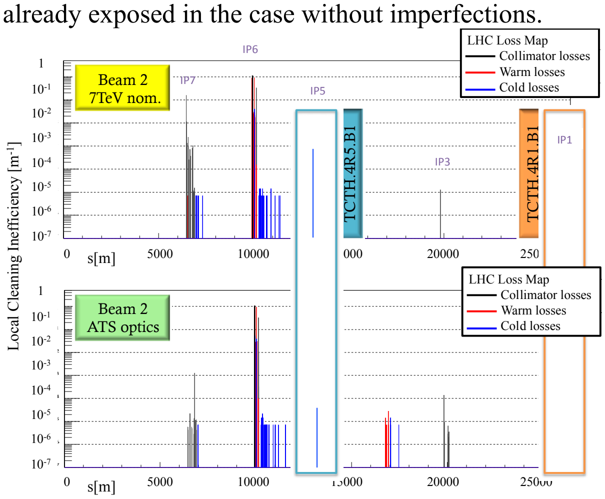

Figure 4: Local cleaning inefficiency loss maps for Beam 2 applying errors. It has to be noted that TCT at Point 5 set at 7.3 σ shields the Point 1 TCT.

THERMAL LOADS COMPARISON

The peak losses resulting from SixTrack on TCTs (e.g. TCTs in IR1 and IR5 for ATS and nominal optics with imperfections) have been evaluated with FLUKA in terms of energy deposited on the TCT jaw. Figure 5 shows the temperature peak calculated in adiabatic conditions for different population of the fraction of bunches intercepting the TCT jaws. It has to be kept in mind that these curves are only an approximation, since, once above the melting temperature, the material changes its state and the heat capacity at constant pressure cannot be considered constant. However these temperature profiles give indications of possible material damage during asynchronous dumps on the most exposed jaw and the position of the melted regions with respect to the beam entrance. Simulated energy distribution might be used for structural analysis (i.e. with Autodyn).

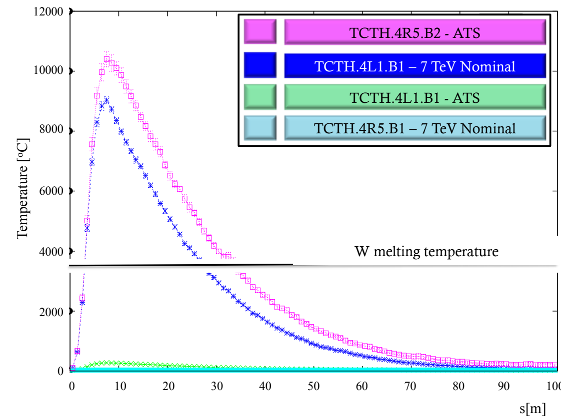

Figure 5: Temperature peaks in the tungsten TCT inserts. In the figure the most loaded jaw per TCT is shown. In case of errors, 2 critical TCT locations are put in evidence for the different optics. In particular for the LHC upgrade the Beam 2 TCT location at Point 5 is resulting the most exposed one.

CONCLUSIONS

The LHC upgrade in luminosity implies an undesired increasing risk to damage TCT collimators. In particular the unfavorable phase advance in the ATS optics, at TCT locations at the entrance of ATLAS and CMS experiments requires reliable upstream protection.

For Beam 1, reducing the misalignment errors at Point 7 is expected to solve the problem; this could be achieved just controlling better the orbit by reducing position interlock windows or by replacing the critical collimators with the already available Beam Position Monitors (BPM) buttons jaw integrated design [10].

For what concerns Beam 2, to protect the CMS TCT only the protection devices at Point 6 play a role. Fixing an upper limit in acceptable Point 6 errors, such as angular misalignment or implementation of additional collimators could help in overcoming overload issues.

Angular misalignment and optics errors could increment the load on the TCTs. These studies are left as future work.

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