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COLLIMATOR FAST FAILURE LOSSES FOR VARIOUS HL-LHC CONFIGURATIONS*

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Abstract

The upgrade of the Large Hadron Collider (LHC), in terms of beam intensity and energy, implies an increasing risk of severe damage in particular in case of beam losses during fast failures. For this reason, efforts were put in developing simulation tools to allow studies of asynchronous dump accidents, including realistic additional failure scenarios. The scope of these studies is to understand realistic beam loads in different collimators, in order to improve the actual LHC collimation system design, to provide feedbacks on optics design and to elaborate different mitigation actions.

Simulations were set up with a modified SixTrack collimation routine able to simulate erroneous firing of a single dump kicker or the simultaneous malfunction of all the 15 kickers.

In such a context, results are evaluated from the whole LHC collimation system point of view.

INTRODUCTION

The upgrade of the LHC aims to increase the luminosity of the machine, in order to extend the LHC discovery potential.

Within the High Luminosity LHC (HL-LHC) project, this is done by increasing the intensity and decreasing β* at the Interaction Points (IPs).

The main parameters are given in Table 1.

Table 1: Baseline parameters for the HL-LHC at 7 TeV, compared to the nominal case. Note that the upgrade scenario refers to the Achromatic Telescopic Squeeze (ATS) optics [1].

Main parameters		7 TeV HL-LHC optics	7 TeV nominal optics
Luminosity [$cm^{-2} s^{-1}$]		5e34 levelled	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 new HL-LHC parameters require the up-grade of several LHC systems, including the collimation system. In particular, in case of a fast failure in nominal physics condition with squeezed optics, one of the main challenges of the multi-stage collimation system is to ensure the protection of the triplet magnets in the 4 Interaction Regions (IRs) while allowing the smallest β* to maximise the luminosity. Two different collimation settings are under study, as presented in Table 2.

Table 2: Reference 7 TeV LHC collimator settings in beam σ units for collimator families in the different IRs (3.5 micron emittance). Nominal and 2σ retraction settings have been studied for the HL-LHC. For the second case, the 2σ retraction refers to the primary (TCP) and secondary (TCSG) collimator in IR7.

LHC sector	Coll. type	Half gap HL-LHC ATS opt. nominal coll. set.	Half gap HL-LHC ATS opt. 2σ retr. coll. set.
IR3 *Momentum cleaning*	TCP	15.0	15.0
	TCSG	18.0	18.0
	TCLA	20.0	20.0
IR7 *Betatron cleaning*	TCP	6.0	5.7
	TCSG	7.0	7.7
	TCLA	10.0	10.7
IR6 *Dump*	TCDQ	8.0	9.0
	TCSG	7.5	8.5
IR1, 2, 5, 8 *Experiment*	TCT (1, 5)	8.3	10.5
	TCT (2, 8)	30.0	30.0

The scope of the study is to understand the beam loads in different collimators in case of fast losses due to a so-called asynchronous beam dump accident, in order to improve the LHC collimation system design by understanding realistic loss cases.

In such a context, particular attention was given to the evaluation of the tungsten tertiary collimator (TCT) response in their function of protecting the triplet magnets during a fast loss accident. Indeed the TCTs are not robust against large impacts, if the protection devices in Point 6 (i.e. TCDQs and TCSG in IR6) fail to intercept particles escaping. This could be the case when the simultaneous firing of all the 15 kicker magnets (MKD) occurs asynchronously with respect to the abort gap, or in case of spontaneous firing of a single kicker module (followed by a re-triggering of the other modules). This latter case is called single-module pre-fire. In both cases, one or several bunches see intermediate kicks and can potentially

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be deflected onto sensitive equipment, such as the TCTs. The worst case is actually the asynchronous firing of a single module followed by a re-triggering, as the rise time of the kicker field is the slowest.

SIXTRACK SIMULATION FRAMEWORK

Simulations were performed with a modified version of the SixTrack [2,3] collimation routine that enables simulations of arbitrary kicks of any MKD [4]. The most recent improvements include the possibility to simulate either wrong firing of a single module of the MKD or the simultaneous malfunction of all the 15 MKD modules. In both cases, each bunch of the train sees a different kick, during the rising of the kicker field. The kick angles have been computed from the MKD pulse form. In case of firing a single module, a re-triggering delay of (650+50*p) [nano-seconds] was also applied, where p is the number of generators away from the one that pre-triggered. For the single module pre-fire, it takes more time for the total kick to increase to the value that ensures that all bunches are intercepted by the TCDQ. More bunches are thus affected by a potentially dangerous kick angle.

SIMULATION RESULTS

Simulations were performed for the different collimator settings and optics configurations as in Table 1 and 2. In the case of a perfect machine for HL-LHC v1.0 optics and for both collimation settings of Table 2, results show a safe condition in case of both asynchronous dump and single module pre-fire, with the dump protection devices in Point 6 intercepting all particles that do not enter the extraction line.

Results change when pessimistic but still technically possible combined error scenarios are applied to collimation position, beam orbit and machine optics. In particular, in this study the protection devices downstream of Point 6 are retracted from the beam orbit by 1.2 mm (this is the dump limit for orbit shifts at the TCDQ) and the most critical TCT collimator is set 1σ closer to the beam. In addition, we assumed an imperfect optics by taking the worst seed of 1000 randomly generated cases that respected the peak beta-beating errors measured during the LHC Run 1. In Fig. 1 and in Fig. 2 the worst cases for the two asynchronous dump accidents are shown using the HL-LHC v1.0 optics. They both refer to the LHC counterclockwise Beam 2, more critical for the HL-LHC optics than the clockwise Beam 1. Simulations were performed with the other ring collimators set at their nominal aperture.

Results show that the most critical collimator is the TCT.4R5.B2 in Point 5 (CMS). The limit for ejection of fragments for this collimator is reached in both accident scenarios. They refer to a phase advance between the MKDs and the TCT in Point 5 of about 100°, which means that kicked particles are close to their maximum amplitude at the TCT. There is not much margin for optimization due to optics constraints.

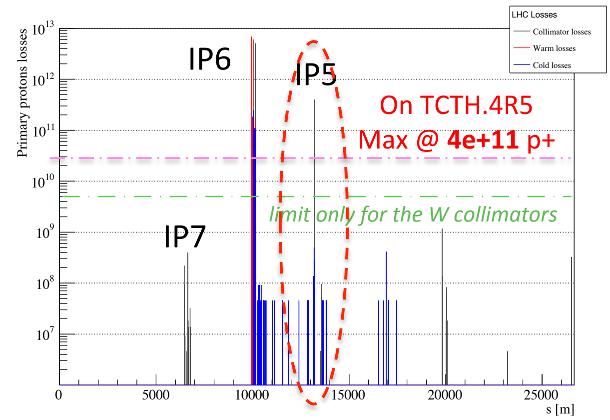

Figure 1: Simulated loss map, for the case of all the 15 MKD modules firing simultaneously, using HL-LHC optics v 1.0, nominal collimator settings, and full imperfections as described in the test. The green line is the limit for onset of plastic damage (i.e. 5e9 protons), while the pink one represents the limit for ejection of fragments (i.e. 2e10 protons). Both limits are only valid for tungsten collimators and are based on recent experimental results [5].

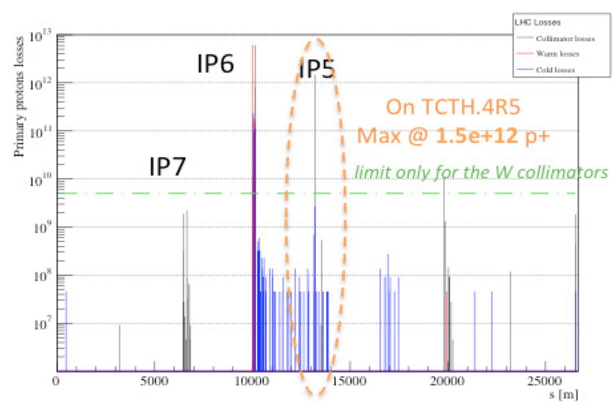

Figure 2: Simulated loss map for the case of single-module pre-fire, with the MKD closest to the TCDQ firing, using HL-LHC optics v.1.0, nominal collimator settings, and full imperfections as described in the text. Differences of the order of 25% in the TCT peak values are found when the MKD module farthest from the TCDQs is fired.

MORE REALISTIC SIXTRACK RESULTS

The errors considered above are rather pessimistic. In order to evaluate more realistic error scenarios, a preliminary analysis of probabilities for orbit drifts was carried out based on 2012 data of Beam Position Monitors (BPM) located close to TCTs and in IR6. In addition, a 5% RMS beta-beating error was applied and converted to an error in mm, to estimate the cumulative distribution function of total drifts. Results show that for example a 0.2 mm drift at the TCT and 0.9 mm in IR6 or worse have approximately 1% of probability to occur. This was assumed as a more realistic error scenario.

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Figure 3 shows the loss map in this scenario for single module pre-fire using the 2σ retraction collimation settings. The primary proton losses on the TCT in Point 5 are just below the limit of plastic deformation. This could still be considered acceptable for operation if the TCT can be moved orthogonally to the beam to expose a fresh surface.

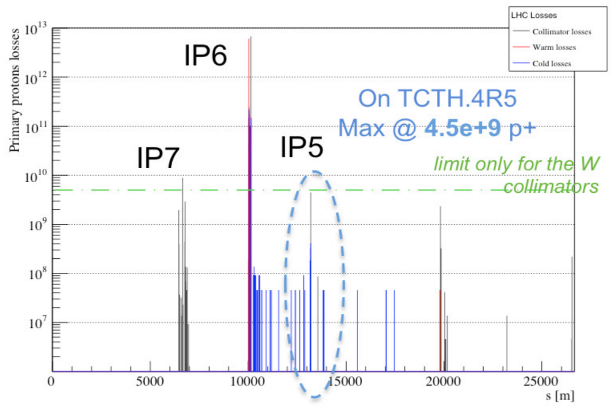

Figure 3: Simulated loss map for single module pre-fire, using HL-LHC optics v.1.0, 2 σ retraction collimator settings, and more realistic imperfections as described in the text.

CONCLUSIONS

In terms of protection from a beam dump accident (asynchronous dump or single module pre-fire), the 2σ collimation settings cause less losses than nominal settings on the TCTs in HL-LHC, thanks to the larger retraction from the dump protection devices.

This scenario can probably be considered as safe although further analysis should to be carried out to validate losses in other scenarios with finite probabilities.

However, the need to push the optics performance and other constraints, like the possibility to use TCT collimators to house wires for beam-beam compensation, call for a more robust solution in view of tighter collimation settings.

Possible improvements of the TCTs are already on-going, like a TCT design with integrated BPMs and others are under study, like jaw material of enhanced robustness, allow to reduce misalignment errors.

Experimental tests in the LHC are also foreseen to further benchmark simulation results (see for example previous tests [6]).

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REFERENCES

[1] S. Fartoukh, *Achromatic telescopic squeezing scheme and application to the LHC and its luminosity upgrade*, Phys. Rev. ST Accel. Beams 16, 111002 (2013) – Published 19 November 2013.

[2] F. Shimidt, *SixTrack – User reference Manual*, version 4.2.16, CERN/SL/94-56 (AP), Update January 2012.

[3] http://sixtrack.web.cern.ch/SixTrack/

[4] L. Lari et al., MOPWO047, Proc. IPAC13, Shanghai, China, p. 999.

[5] A. Bertarelli et al., *Updated robustness limits for collimator material*, LHC Machine Protection Workshop, Annecy, France (2013).

[6] L. Lari et al., MOPWO046, Proc. IPAC13, Shanghai, China, p. 996.