SIMULATIONS AND MEASUREMENTS OF BEAM LOSSES ON LHC COLLIMATORS DURING BEAM ABORT FAILURES*

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Abstract

One of the main purposes of tracking simulations for collimation studies is to produce loss maps along the LHC ring, in order to identify the level of local beam losses during nominal and abnormal operation scenarios. The SixTrack program is the standard tracking tool used at CERN to perform these studies.

Recently, it was expanded in order to evaluate the proton load on different collimators in case of fast beam failures. Simulations are compared with beam measurements at 4 TeV. Combined failures are assumed which provide worst-case scenarios of the load on tungsten tertiary collimators.

INTRODUCTION

A beam dump system fault could lead to severe damage on LHC machine components [1]. The worst case occurs when the beam dump is not synchronized with the abort gap. An abnormal horizontal deflection is thus applied to the beam and the triplet magnets could be among the most exposed elements in physics conditions with squeezed optics. One of the main function of the tungsten tertiary collimators (TCT) installed upstream the triplet magnets in each of the 4 LHC Interaction Points (IPs) is to protect the triplets in case of an asynchronous dump accident.

During the operation of LHC, a single asynchronous beam dump accident happened on November 19th 2010, without critical consequences. Afterward, the protection against fast beam failures has been improved [2]. However, it has to be pointed out that this kind of accident remains a concern for the future, because some asynchronous dumps per year are expected. Indeed, the risk of severe damage increases with the beam intensity and energy. For this reason, efforts are put in developing simulation tools to predict the loss distribution along the whole LHC ring and to evaluate the load on delicate tungsten tertiary collimators.

This paper shows the latest implementations in the SixTrack code and the benchmark with data from dedicated experimental tests.

METHODOLOGY

The SixTrack 6D collimation routine [3] has been modified to allow the tracking of kicked protons as resulting from an asynchronous dump accident. More precisely, a realistic dynamic kick can be now applied to the beam particles at any of the 15 extraction kickers (MKDs) at Point 6. The input kick angles are a function of the MKD rise time (the so called pulse curve). Simulations can be performed for any realistic combination of cases in which the voltage is still rising for one or more MKDs, when proton bunches arrive in the extraction region. Protons, swept across the machine aperture, are then tracked along the LHC ring, before being correctly dumped, when reaching again Point 6 after one more turn. The new SixTrack implementation allows thus studying both the consequences of the firing of all the dump kickers as well as the trigger of any subset of the 15 MKDs. The advantage is to simulate accidental scenarios where the full collimation system is in place for a detailed beam particles tracking with scattering.

CASES STUDIED AND PRELIMINARY RESULTS

The optics scenario considered refers to 4 TeV, i.e. the maximum beam energy reached in 2012 runs (Table 1).

Table 1: LHC β* and Half Crossing Angles @ the IPs

Beam Energy	Interaction Point	Half crossing angle [μrad]	β* [m]
4TeV	IP1	145	0.6
	IP2	90	3
	IP5	145	0.6
	IP8	230	3

Table 2: Reference LHC Collimator Settings for Collimator Families [4] in the Different Insertion Regions (IR)

LHC sector	Collimator type	Half gap [beam σ]
IR3 (Momentum cleaning)	TCP	12.0
	TCSG	15.6
	TCLA	17.6
IR7 (Betatron cleaning)	TCP	4.3
	TCSG	6.3
	TCLA	8.3
IR6 (Dump)	TCDQ	7.6
	TCSG	7.1
IR1, 2, 5, 8 (Experimental)	TCT (1, 5)	9.0
	TCT (2, 8)	12.0
	TCL (1, 5)	10.0

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Starting from the above reference machine configuration, a preliminary study identified the most critical TCT for Beam 1 and which upstream collimators played an important role in shielding it (using MAD-X [5]). The preliminary study took into account a pessimistic, but technically possible combined errors: the retraction of 1.5 mm for the Point 6 protection devices (i.e. both the TCDQs and the TCSG are retracted).

Results show that the most exposed location is the horizontal TCT at Point 1 (i.e. the TCTH.4L1.B1). To evaluate peak loads and setting margins, two conservative cases were studied separately. In both cases the TCTH.4L1.B1 is set 1σ closer to the beam i.e. its half gap is moved from 9 to 8 σ (see Table 2 as reference). Moreover, in the first case, an additional 1 mm retraction for 4 critical collimators in Point 7 are considered as well. It has to be noted that 1 mm misalignment is above the 2012 global orbit limit in LHC (i.e. 0.6 mm) excluding the 4 experimental Long Strain Section (LSS) regions close to the IPs. Above that limit the LHC interlocks act to dump the beam [6]. The 2 skew secondary collimators TCSG.B5L7.B1 and TCSG.A5L7.B1, 1 horizontal one TCSG.B4L7.B1 and 1 horizontal active absorber TCLA.A7R7.B1 are the 4 critical devices that have a strong impact on shielding the TCTH.4L1.B1.

EXPERIMENTAL TESTS

In June and November 2012, two experimental tests were executed to benchmark the SixTrack simulations for Beam 1. The tests were performed by switching the RF cavities off, so that the beam started de-bunching and populating the abort gap, and then by triggering a beam dump. This reproduces the loss distribution scenario of an asynchronous dump accident in which all the dump kickers firing at the same time. A local bump of 1.5 mm was applied at the place of the Point 6 protection devices retraction. Loss maps were measured, showing the distribution of losses along the LHC ring.

COMPARISON BETWEEN SIXTRACK SIMULATION RESULTS AND DATA

Several SixTrack simulations were performed each referring to a specific angle of the MKD pulse curve, and summed to reproduce the experimental conditions. More in detail, to simulate the de-bunched beam dump, the whole pulse form was mapped, selecting each 25 ns the corresponding angle and applying them to each of the 15 MKDs simultaneously.

Results show that, if the Point 6 protection devices are retracted, they are bypassed when the angles are in the range of 0.49 to 1.26 μrad, corresponding to the range of 0.6 to 0.75 μs for the fire of the spurious trigger. These angles could be critical for the downstream elements. The contribution of the farthest MKD from TCDQs (i.e. MKD.OL6.B1) on the TCTH.4L1.B1 load is the highest one, due to its unfavorable phase advance condition.

Figures 1, 2, 3 and 4 show the SixTrack results compared with the measured Beam Loss Monitors (BLM) signals.

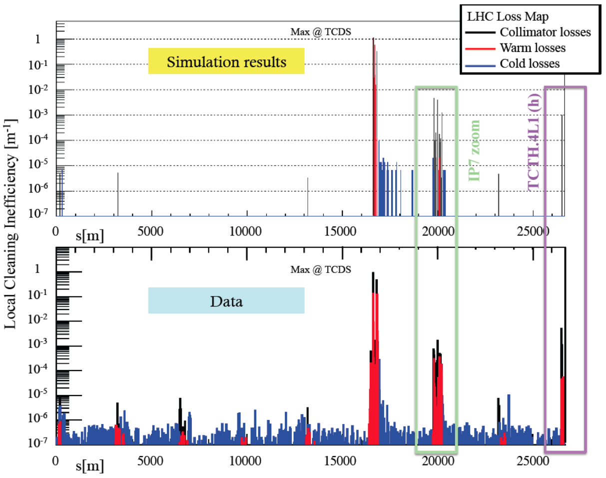

Figure 1: Local Cleaning Inefficiency [3] loss maps for the experimental test (BLM signals on bottom) and the SixTrack simulation results (on top) when the 4 critical collimators in Point 7 are retracted. In both cases the peaks are normalized to the maximum of losses concentrated at the extraction line protection location (i.e. the TCDS). Note that the high peak at the TCTH.4L1.B1 (violet area) is predictable via SixTrack calculations.

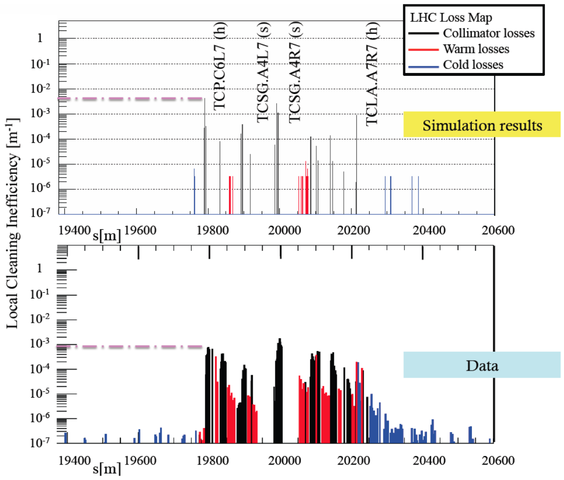

Figure 2: Zoom in the IR7 region (i.e. green area in Fig. 1). In the simulation results, the local Cleaning Inefficiency peak is slightly over estimated at the primary horizontal collimator and in the central TCSGs, where the shower contribution is not taken into account in SixTrack.

It has to be kept in mind that the simulation results give the distribution of the primary protons lost in the machine, while the BLM signals are due to the particles showers created into the collimator by beam-jaw interactions. Moreover, in the simulation a transverse normalized emittance of 3.5 μm was considered and a Gaussian transverse distribution was used as input and tracked from Point 1. A factor 7 in the BLM signal at the

TCT location versus the primary collimator one (i.e. TCP) per primary proton lost was also taken into account in the comparison of the simulation outputs with data [7].

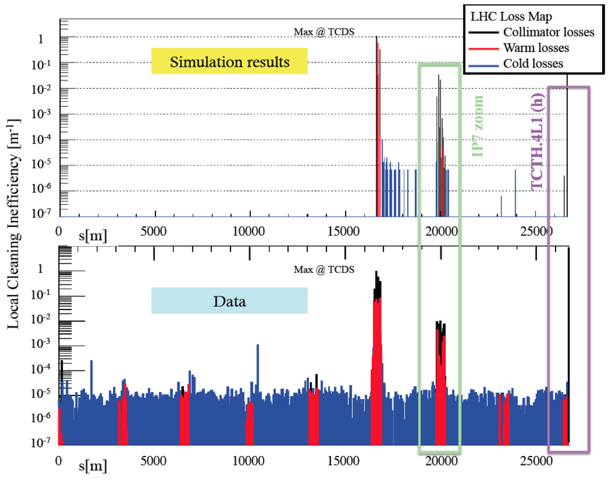

Figure 3: Local Cleaning Inefficiency loss maps for the second scenario (i.e. no Point 7 retractions). Note that even if the TCTH.4L1.B1 is set at 8 σ, the peak is of the order of BLM background as predicted by SixTrack.

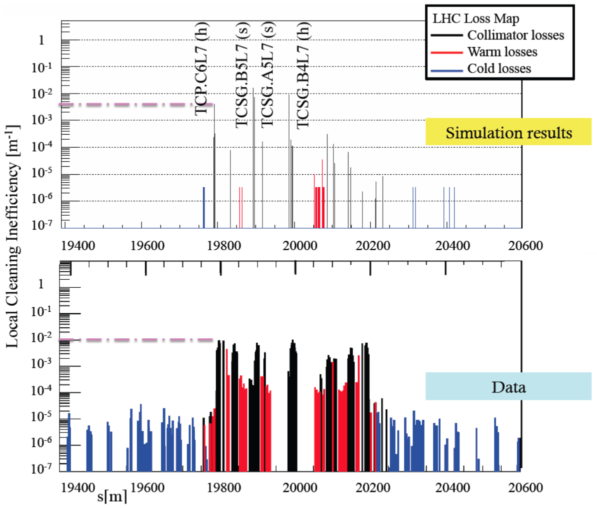

Figure 4: Zoom in the IR7 region (i.e. green area in Fig. 3). In this case the local Cleaning Inefficiency peak is slightly under estimated at the primary TCP horizontal collimator.

It has to be pointed out that the asynchronous dump tests were performed after the loss maps validations, during which the transverse damper (ADT) bunch-by-bunch excitation [8] was used. As a consequence the transverse emittance of the kicked beam in the abort gap has been affected by the previous excitations. Since it is not possible to measure it accurately when the beam is de-bunched, before the asynchronous dump test, a SixTrack study spanning over a range of normalized emittance from 2 to 4 μm was performed. The aim is to evaluate to effects of different beam emittance sizes (i.e. different tail population) on the cleaning inefficiency peaks. Results show a variation of the local cleaning inefficiency peak at the primary TCP location of approximately two orders of magnitude. This outcome could explain the oscillations of the TCP peaks as resulting from the two tests (see Fig. 2 and 4). To complete the study shower simulations, with code as FLUKA, could properly benchmark the peaks downstream the TCP. This is left as future work.

CONCLUSIONS

In this paper, the SixTrack results for asynchronous dump simulations and the experimental data are compared, showing a good agreement. The benchmark was performed considering asynchronous dump accidents in which all the MKD kickers fire simultaneously. However, it has to be noted that the latest version of the SixTrack collimation routine is able to investigate also different combinations of MKD failures, as when 1 of the 15 MKD spontaneously triggers.

Pessimistic studies involving the occurrence of several errors were performed to identify realistic critical scenarios in which the delicate TCT collimators are exposed to possible damage. Outcome of these studies is the identification of TCTH.4L1.B1 for Beam 1 as the most exposed one, in particular if the jaws of 4 upstream critical collimators are retracted 1 mm and the protection devices at Point 6 are out by 1.5 mm.

Additional benchmarking studies are on going for what concerns fast loss failures. Data considered coming from the distribution of losses during regular qualification of asynchronous dump tests [2] as well as during physics runs dump, but in such a case the effect of the superposition of the 2 beams has to be considered.

Finally, since the LHC upgrade in intensity and energy implies the increasing of possible damage risks, optics and misalignment errors have to be minimized. For this reason, replacing in the future the 4 collimators identified with the Beam Position Monitor (BPM) buttons integrated ones, is for sure an improvement (See also [9]).

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