ACCELERATOR PHYSICS STUDIES ON THE EFFECTS FROM AN ASYNCHRONOUS BEAM DUMP ONTO THE LHC EXPERIMENTAL REGION COLLIMATORS*

L. Lari#, IFIC (CSIC-UV), Valencia, Spain and CERN, Geneva, Switzerland
R.W. Assmann, V. Boccone, R. Bruce, F. Cerutti, A. Rossi, V. Vlachoudis CERN
A. Mereghetti, CERN and UMAN, Manchester, UK
A. Faus-Golfe, IFIC (CSIC-UV), Valencia, Spain

Abstract

Asynchronous beam aborts at the LHC are estimated to occur on average once per year. Accelerator physics studies of asynchronous dumps have been performed at different beam energies and beta-stars. The loss patterns are analyzed in order to identify the losses in particular on the Phase 1 Tertiary Collimators (TCT), since their tungsten-based active jaw insert has a lower damage threshold than the carbon-based other LHC collimators.

Settings of the tilt angle of the TCTs are discussed with the aim of reducing the thermal loads on the TCT themselves.

INTRODUCTION

The Phase 1 Tertiary Collimators (i.e. TCTs) are installed upstream of the 4 LHC interaction regions to protect the triplet magnets. 8 tertiary collimators are horizontal and 8 are vertical, for a total of 16 devices installed in LHC ring [1]. While the vertical TCT in the Insertion Region (IR) at Point 8 (LHCb) has the 'two beams in one' tank design, the horizontal and the vertical TCTs installed in the IR1 (Point1 – Atlas), IR5 (Point5 – CMS) and IR2 (Point2 – Alice) have the classical 'one-beam' design.

The TCTs perform their cleaning action in the vertical and horizontal planes, through jaws perpendicular to the cleaning plane. In order to maximize their efficiency in absorbing potentially dangerous particles, the copper-based support of each TCT jaw hosts an insert made of 5 tungsten-based blocks, which are extremely sensitive to possible beam damage. During nominal operation, the damage risk is minimized since the TCTs are placed at large distances from the beam core. However, in case of abnormal operation, such as during an asynchronous dump event, the horizontal TCTs could experience insert melting. In the present study, only horizontal TCTs are considered, since the dump kickers act in the horizontal plane [2].

METHODOLOGY

State-of-the-art accelerator simulation programs (i.e. MADX [3], SixTrack [4] and FLUKA [5,6]) were set up in order to evaluate the effects of an asynchronous dump accident on the TCT jaws. The firing of one of the 15 extraction kickers at the wrong moment was evaluated. This kicks the beam onto a larger betatron oscillation, possibly causing large losses. This study follows a preliminary evaluation [7] and aims at giving indications in a more realist scenario.

MADX Simulations

The MADX code was used for a first screening in order to identify those cases for which a TCT is hit by an accidentally kicked bunch, in case of ideal machine. Scan studies over the pre-fire pulse shape for each of the 15 kickers (i.e. MKD) at Point 6, were performed separately, using as reference the V6.503 'as built' optics version and considering 1.5 mm as the maximum error in setting of the protection devices at Point 6 (i.e. the 2 diluter blocks TCDQs and the secondary collimator TCSG.4R6.B1).

SixTrack Simulations

The collimation tracking routine implemented in the SixTrack code was modified in order to add the miskick angle to protons at the failing kicker. The unmodified reference optics is used for the first turn, in order to correctly set the collimators centered around it (see Table 1). At the second turn, protons follow the accident trajectory, while the same collimator settings are used. After the second turn, it is supposed that the bunch or the residual part of it, in case of reaching again Point 6, is dumped. Maps of primary protons lost in the whole LHC ring are thus obtained.

FLUKA Simulations

The distribution of protons lost along the horizontal TCTs, as calculated by SixTrack at the second turn, is used as input for the FLUKA simulations.

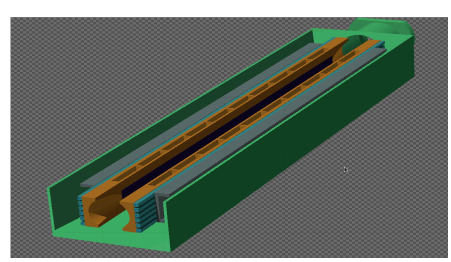

Figure 1: FLUKA model of the TCT. The tungsten-based insert can be seen on the internal jaw surface.

*Work supported by EUCARD
#llari@cern.ch

ISBN 978-3-95450-115-1

The detailed model of the TCT collimator as presently coded in the FLUKA Element Data Base [8] was used (see Fig. 1) and positioned by means of the LineBuilder [8]. The energy distribution in the jaws was scored, and the peak temperature was estimated in adiabatic condition (no heat flow taken into account).

STUDIED SCENARIOS

Two scenarios were considered: the first one refers to 4TeV for the 2012 run [9], while the second one to the nominal operation at 7TeV [1]. The transverse normalized emittance considered was 3.5 µm and a Gaussian transverse distribution was used as input for both cases. The two scenarios differ for collimator settings (see Table 1) and for values of β* and crossing angle at the interaction points (see Table 2). Even if the TCT in IR2 and IR8 will only be at the same tight settings of the other TCTs during the ion runs, in these conservative studies for protons, they are also assumed to have the same settings and not a relaxed half-gap of 12.0 sigmas.

Table 1: LHC Collimator Settings Used for 4TeV and 7TeV

LHC sector	Collimator type	4TeV Half gap (beam sigma)	7TeV Half gap (beam sigma)
IR3 (Momentum cleaning)	TCP	12.0	15.0
	TCSG	15.6	18.0
	TCLA	17.6	20.0
IR7 (Betatron cleaning)	TCP	4.3	6.0
	TCSG	6.3	7.0
	TCLA	8.3	10.0
IR6 (dump)	TCDQ	7.6	8.0
	TCSG	7.1	7.5
IR1, 2, 5, 8 (experimental)	TCT (1, 2, 5, 8)	9.0	8.3
	TCL (1, 5)	10.0	10.0

Table 2: LHC β* and Half Crossing Angles @ the Interaction Points (IP) for 4TeV and 7TeV Scenarios

Beam Energy	Interaction Point	Crossing angle [µrad]	β* [m]
4TeV	IP1	145	0.6
	IP2	90	3
	IP5	145	0.6
	IP8	230	3
7TeV	IP1	142.5	0.55
	IP2	150	10
	IP5	142.5	0.55
	IP8	200	1– 50

RESULTS

The results presented in this paper refer to Beam 1. Evaluations for Beam 2 are ongoing.

Starting from the MADX outputs, special scripts were developed in order to identify the cases leading to the highest proton losses on one of the four horizontal TCTs. In the case of the MKD.O5L6.B1 failure (i.e. the farthest kicker upstream of the TCDQs), the downstream TCTs result to be the most loaded for both 4TeV and 7TeV scenarios, than in case of one of the other 14 kickers failure. Figure 1 shows the results with reference to this case. The TCTH.4L1.B1 (@Point 1) is the most loaded collimator for the 4TeV scenario, while for 7TeV scenario the most exposed one is the TCTH.4L2.B1 (@Point 2). In this preliminary evaluation, in case of 1.5 mm TCDQs and TCSG errors at Point 6 and considering all the intermediate collimators opened, the TCTH.4L1.B1 will be reached by about 1% of the kicked bunch while TCTH.4L2.B1 intercepts about 40% of it.

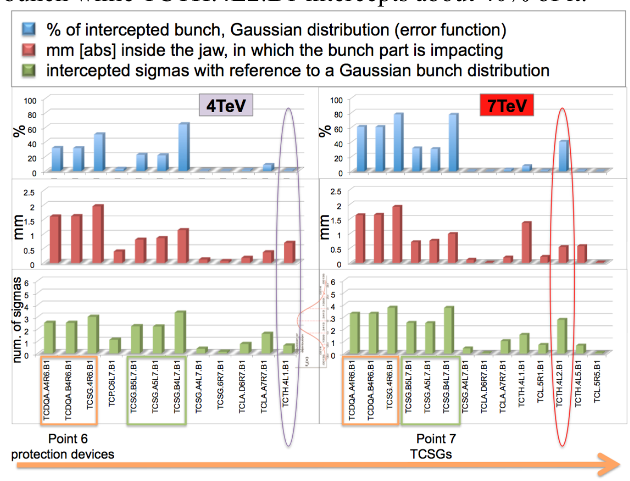

Figure 2: MADX based estimations of primary protons (in %) and impact parameters (in mm, red histograms, and in sigma units in case of a Gaussian distribution, green histograms). The collimators between the MKD and each of the shown collimator are considered as totally opened, so that each column represents a single case. Only the collimators affected by the deviated bunch in the range of +/- 3 sigmas are shown. For the 4TeV and the 7TeV scenarios, TCTH.4L1.B1 and TCTH.4L2.B2 are marked in the figure, respectively. These results refer to two different angles along the pre-fire pulse shape: about 8.8µrad (1.5µs) for the 4TeV and 8µrad (1.4µs) for the 7TeV scenario. The orange arrow shows the Beam 1 direction for both cases.

It has to be kept in mind that these preliminary evaluations aim at identifying the smallest angle for which the TCTs are exposed in case of MKD failure and of protection devices error settings at Point 6. It should be noted that an 8µrad kick (TCTH.4L2.B1 case) corresponds to a failure of the MKD re-triggering in about 1.4µs after the asynchronous dump event. On the basis of these preliminary evaluations, the 7TeV scenario has been selected for further studies.

SixTrack simulations were performed for the selected case in two different situations. The first one considers only the 1.5 mm retraction for the Point 6 protection devices, while the second one considers an additional 1mm misalignment for the three Point 7 TCSG collimators shielding the TCTH.4L2.B1 (see Fig.2 and 3).

More realistic simulations with SixTrack pointed out that the number of impacting protons is reduced from 40% of a full intensity bunch (primary evaluation based on MADX) to about 30%, in case of TCSGs at IR7 opened.

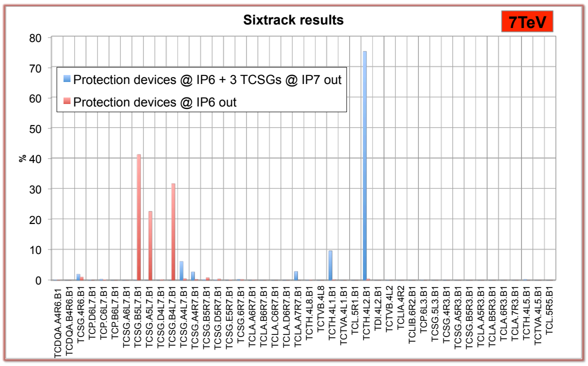

Figure 3: SixTrack results for the two cases under study. The lost protons distribution (in %) in the 45 LHC collimators is shown, starting from IP6. In case of 1 mm misalignment in IP7, the TCTH.4L2.B1 intercepts 75% of all the losses. This value corresponds to an interaction with 30% of a full intensity bunch. In case of the 3 TCSGs set properly in IP7, the interaction is reduced to 0.35% of a full intensity bunch at IP2. The SixTrack results agree with the preliminary MADX-based evaluations, giving more realistic estimations.

Two different maps of protons lost along the TCTH.4L2.B1 jaws produced by SixTrack were used as input for energy deposition and temperature peak profile evaluations with FLUKA for both cases. Values are scaled to a single bunch of 1.3E11 protons. Figure 4 compares the instantaneous increment of temperature along the jaw surface for the studied cases. The tungsten melting point is shown as well. The most loaded jaw is always the one on the side of the center of the LHC ring. Figure 5 shows 2D energy deposition maps in the insert along the longitudinal plane.

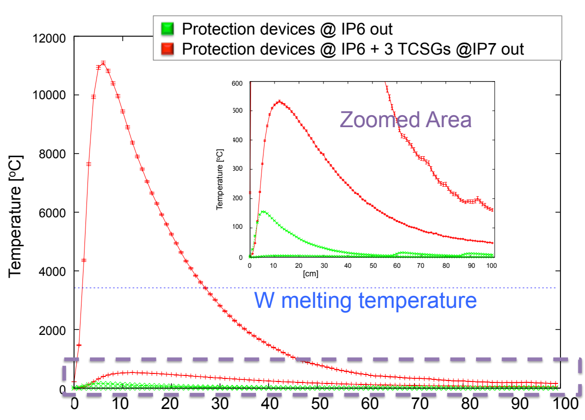

Figure 4: Temperature peak profiles of the two TCT jaws for each different accident layout at 7TeV. As can be seen, the jaws are asymmetrically loaded. Statistic errors are less than 5% for peak values.

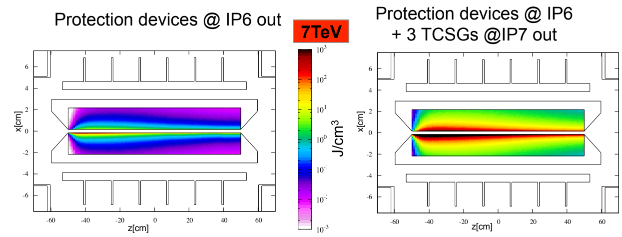

Figure 5: 2D energy deposition maps cut at the beam height due by 7TeV impacting protons. The two insert maps are superimposed to the jaw geometry cut. The binning used to score is 0.01x0.01x0.5 cm3. In the picture an average over 4 bins in the vertical direction is shown.

CONCLUSIONS AND OUTLOOK

State-of-the-art accelerator simulation programs were set up and/or modified in order to characterize asynchronous beam dump scenarios and assess their effects. Results presented in this paper refer to Beam 1, for which the TCTH.4L2.B1 has turned out to be in a high-level risk location if relaxed gaps are not used. The TCTH.4L2.B1 can be considered as a limit case for the all the other TCTs. In order to reduce the thermal load on the most exposed jaw, its tilting towards the beam exit position could be a promising solution [7], to be optimized with dedicated SixTrack simulations, for which code modifications are required. Jaw tilting can be effectively set by means of Beam Position Monitor (BPM) buttons (see Fig. 6) [10]. The integration of the BPM buttons in the TCT tapering part is foreseen for the next long shutdown (i.e. 2013 and half of the 2014). However, thermal loads in the super conducting coils of the inner triplet downstream each TCT, also considering machine imperfections, should be carefully evaluated before implementing any tilt angle.

Figure 6: BPM button integrated on the tapering part at the end of a collimator jaw.

REFERENCES

[1] R.W. Assmann et al., Proc. of PAC09, p.3205, 2009.
[2] B. Goddard et al., LHC Project Report 916, 2006.
[3] H. Grote, F. Smith, Proc. of PAC03.
[4] G. Robert-Demolaize et al., Proc. of PAC05.
[5] A. Fasso et al., CERN-2005-10(2005), INFN/TC_05/11, SLC-R-773.
[6] G. Battistoni et al., Proc. of Hadronic Shower Simulation Workshop 2006, Fermilab, USA, M.Albrow, R.Rajas eds., Proc. of AIP, p. 31, 2007.
[7] L. Lari et al., MOPPD080 this Proc., IPAC12.
[8] A. Mereghetti et al., WEPPD071 this Proc., IPAC12.
[9] R. Bruce et al. 'LHC β*-reach in 2012', Proc. of the LHC Beam Operation Workshop – Evian 2011.
[10] D. Wollmann et al., Proc. of IPAC11, p. 3747, 2011.

ISBN 978-3-95450-115-1