LHC BEAM DUMP SYSTEM - CONSEQUENCES OF ABNORMAL OPERATION

T. Kramer, B. Goddard, J. Uythoven, CERN, Geneva, Switzerland

Abstract

The LHC beam dump system is one of the most critical systems concerning machine protection and safe operation. It is used to dispose of high intensity beams between 450 GeV and 7 TeV. Studies into the consequences of abnormal beam dump actions have been performed. Different error scenarios have been evaluated using particle tracking in MAD-X, including an asynchronous dump action, and the impact of different orbit and collimator settings. Losses at locations in the ring and the beam dump transfer lines have been quantified as a function of different settings of the dump system protection elements. The implications for the setting up and operation of these protection elements are discussed.

INTRODUCTION

The LHC Beam Dump System (LBDS) has been designed to extract all LHC beams with an energy range from 450 GeV to 7 TeV. For each beam it consists of 15 extraction kicker magnets (MKD), 15 septum magnets (MSD) and 10 diluter magnets (MKB), all installed in IR 6 [1] (Fig. 1). The extracted beam is horizontally kicked by the MKD, gets an additional kick from the Q4 and is so deflected into the aperture of the MSD where it is vertical extracted. The beam is then diluted by the horizontal and vertical MKB kickers so that it describes a spiral shape on the dump block (TDE). Two fixed 4 m long graphite blocks (TCDS) have been placed in front of the MSD and two single-jaw 4 m mobile graphite blocks (TCDQ) are installed further downstream in front of Q4 together with a double jaw 1 m collimator (TCSG) and a 2 m fixed iron mask (TCDQM). These protection devices are foreseen to intercept any miss-kicked beam. They should prevent a quench of Q4 and Q5 in the case of migrated particles within the abort gap and furthermore protect these elements as well as other aperture limits from destruction during asynchronous dump events.

For nominal operation the MKD rise time should always be accurately synchronised with the 3 μs abort gap. However some failure cases could happen where the beam abort is not synchronised with the abort gap or where the abort gap population is unacceptably large. In both cases particles are swept over the aperture. The so called "prefire" case takes place due to a spontaneous trigger event of one of the 15 MKD kickers. Consequently all other kickers will be fired immediately, without synchronisation to the abort gap [2].

TRACKING METHODOLOGY

A system of MAD-X tracking jobs was set up to study failure cases and losses for various asynchronous dump events. Particle distributions are created according to the used orbit which is set up in a separate job. These input parameters are then sent to each of the tracking jobs for the TD68 ring part, the rest of the long straight section in IR6 and finally the ring itself. Simulations with different collimator settings in IR 6 can be done in parallel. Already extracted beam was not further tracked down the dump line as this was already partly studied before [3]. Figure 2 shows an overview of the job architecture.

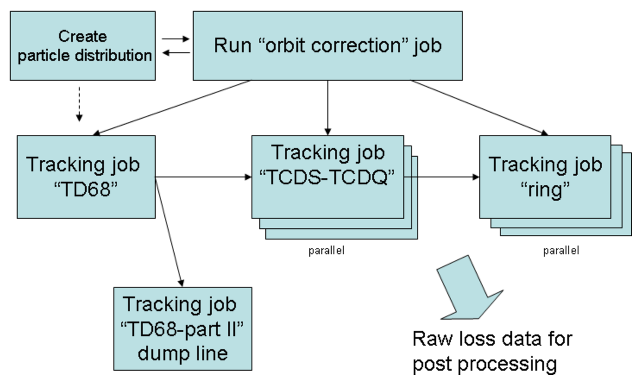

Figure 2: Architecture of the simulation programs.

The tracking itself is done in MAD-X-thintrack which is adapted to handle time dependent kicks as well as skew elements (collimators). All jobs are coordinated by shell scripts which also handle the dispatching to the LSF batch farm. Each of these jobs saves its results (raw loss data) in tables (tfs format) which are read into Matlab to be combined again and further processed. All results presented in this paper are done for LHC Beam 1 only and were performed with 1.5E4 particles for each step.

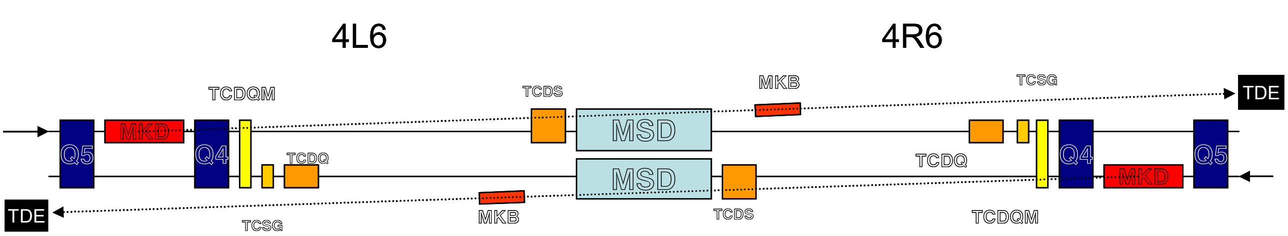

Figure 1: Schematic overview of the LHC extraction area in IR6.

BASIC SETTINGS

In order to create a model of a realistic machine several error types have been applied to the LHC sequence (Tab. 1). After running an orbit correction a machine with a peak-to-peak orbit of 8 mm and realistic corrector settings is used for further tracking. Fig. 3 shows the beta beating and Fig. 4 the phase advance difference between the model with and without the treatment described above. Note that the plots start at the position of the start of TD68 in IR6.

Table 1: Basic Error Settings

Type	Max value	Reference
MB field	Measured values (+/-1%)	LHC PR501
MQ field	Measured values (+/-1%)	LHC PR501
MQ misalignment	0.37 mm (trunc. Gauss)	LHC PN247
BPM reading	0.2 mm (truncated Gauss)	LHC PN347

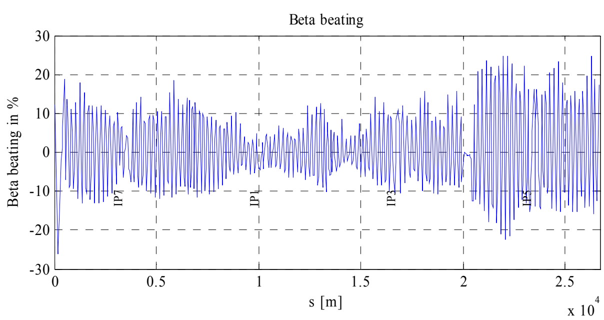

Figure 3: Beta beating for the 450 GeV model.

The tracking jobs use an improved aperture model of LSS6 and realistic collimator settings [4], Tab. 2, whilst for the rest of the ring the aperture model, offset and tolerances available in the database are used. All simulations are done with nominal LHC beam settings.

Table 2: Collimator Settings in σ

IR	Type	450 GeV [σ]	7 TeV [σ]
IR 1/IR 5	TCT	17	8.3
	TCL	10	10
IR 2/IR 8	TCLI	6.8	15
	TDI	6.8	17
	TCT	17	8.3
IR 3	TCP	8	15
	TCSG	9.3	18
	TCLA	10	20
IR 6	TCSG	7	7.5
	TCDQ	8	8
IR 7	TCP	5.7	6
	TCSG	6.7	7
	TCLA	10	10

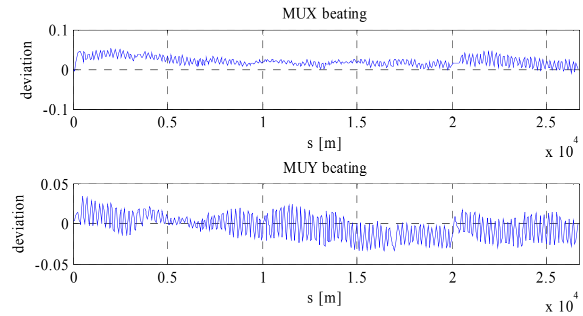

Figure 4: Phase advance error for the 450 GeV model.

SIMULATION RESULTS

Simulations for asynchronous dump events at injection and extraction energies have been performed, both for the nominal and the prefire case.

450 GeV Nominal Case

Figure 5 shows the observed main losses in the ring during simulations where the TCDQ/TCSG were retracted step by step. The IR6 losses are not shown in this graph (max. 1.8E12 p+ at the TCDQ). All loss values are scaled to real beam losses and this case is averaged over 10 different orbit seeds. Losses on collimators are seen from the nominal 8 σ TCDQ position on, rising then dramatically as from around 9.5 σ.

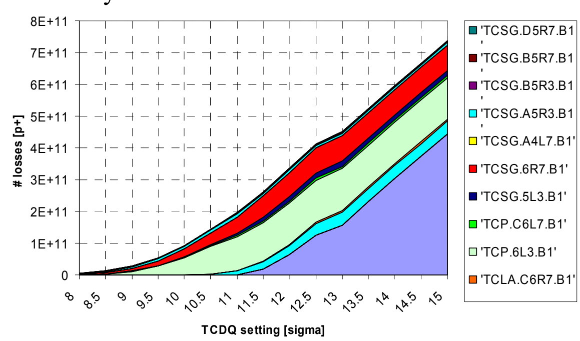

Figure 5: Asynchr. dump nominal conditions, 450 GeV.

7 TeV Nominal Case

The 7 TeV nominal case shows loss shapes similar to the 450 GeV ones, but they start rising later at around 10 σ with a stronger increase at 14 σ. (Fig. 6)

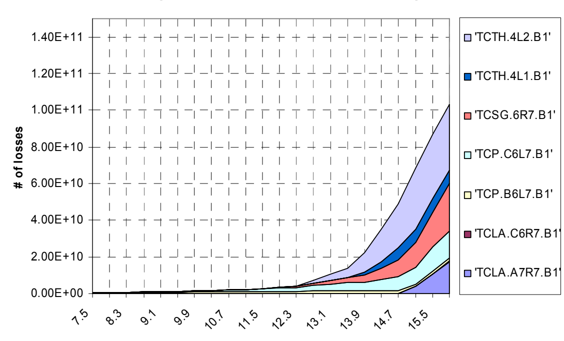

Figure 6: Asynchr. Dump, 7 TeV, nominal.

7 TeV Prefire Case

In this case (Fig.7) the pre-triggering of the first MKD was assumed. After 700 ns of delay for detecting and processing a trigger signal is sent to all other MKD with a cable delay of 25 ns/unit. Surprisingly the simulation only shows slightly higher losses than for the nominal case.

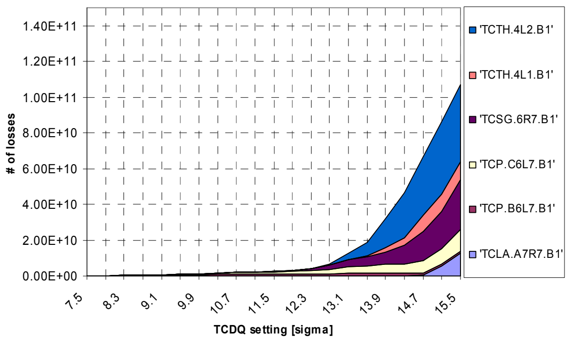

Figure 7: Asynchr. dump, 7 TeV, prefire case.

For all asynchronous dump cases the beam was always properly extracted in the subsequent turn and appeared well centered between the TCDS jaws.

MEASUREMENTS

During 2008 beam commissioning, some data were taken when debunched beam was dumped [5]. Figure 8 shows such a dump event seen by the BTVD in the dump line just before the dump block, nicely showing the MKB dilution. Figure 9 shows the IR6 BLM readings for such an event. The IR6 collimators (TCDQ and TCSG fully open at 30 mm) saw beam as predicted by the simulation.

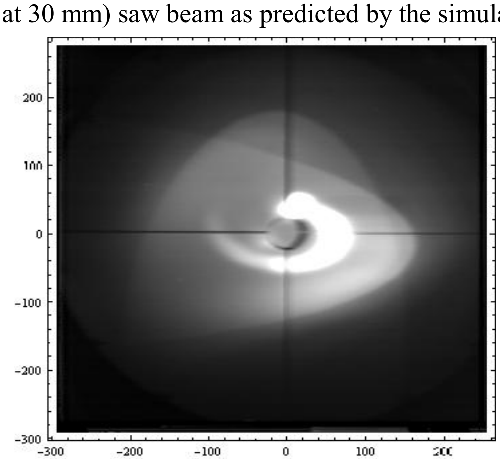

Figure 8: BTV-image of beam 2 dumped with debunched beam during RF commissioning, 11th Sept 2008, 21h14.

Readings on the MSDA magnets can be interpreted as shower coming from the TCDS and possibly also from beam sweeping over the edge of the first septa on the extraction channel side, as seen in simulations before [3]. Showers might as well be the explanation for the small MQY.4L6 reading which should come from hits on the TCDQM.

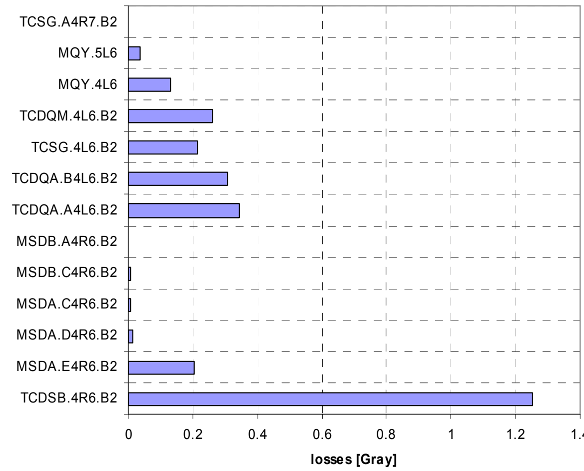

Figure 9: BLM readings of an asynchr. dump during 2008 beam commissioning, 12th Sept.2008, 02h34.

CONCLUSIONS

Extensive MAD-X studies have been made to simulate the consequences of abnormal beam abort. For all cases the nominal TCDQ/TCSG settings seem to properly protect the arc magnets. For injection energy the arc is also protected by the fixed TCDQM aperture. The prefire cases have so far not shown any sign of particular danger. At 7 TeV some higher losses at the TCT and TCLA collimators were seen for TCDQ positions of 10 σ and above. For the IR6 circulating beam part no losses are seen on the kickers and in front of the TCDS and all losses around the second Q4 are on protection elements. Beta-beating and a local difference in phase advance at collimator positions are still issues which have to be followed up in more detail, as well as the possibility of local bumps in the arcs and large orbit errors.

Data from the LHC commissioning 2008 validates the simulation results in LSS6. However dedicated measurements are required to fully confirm the results.

REFERENCES

[1] O. Brüning et al., “LHC Design Report Volume 1”, ISBN 92-9083-244-0, Geneva 2004, Chapter 17.

[2] R. Assmann, B. Goddard, “The Consequences of Abnormal Beam Dump Actions on the LHC Collimation System”, LHC Project Note 293, Geneva, May 2002, p4.

[3] T. Kramer et al., “Apertures in the LHC beam dump system and beam losses during beam abort”, EPAC08, Genoa, 2008.

[4] C. Bracco et al., “Scenarios for Beam Commissioning of the LHC Collimatiom System”, PAC07, Albuquerque, 2007.

[5] B. Goddard et al., “Initial Comissioning of the LHC Beam Dump”, PAC09, Vancouver, 2009.