ANALYSIS OF FAILURES OF THE LHC COLLIMATORS DURING THE 2010-2013 OPERATION

Stefano Redaelli and Alessandro Masi, CERN, Geneva, Switzerland

Abstract

The LHC collimation system must be available in all phases of the machine operation in order to handle the high stored beam energies. The system availability is therefore crucial to achieve an efficient LHC operation. The collimation system has proved to work reliably in the first years of LHC operation, with total stored energies up to 140 MJ. The impact on the machine availability has been very limited. The analysis of collimation system faults affecting the 2010-2013 LHC operation is reviewed with the aim to identify possible further improvements for the future.

INTRODUCTION

The CERN Large Hadron Collider (LHC) has successfully completed its first 2010-2013 physics run that led to an exciting physics outcome [1]. The LHC performance is built on its outstanding performance of key parameters (stored beam energy, peak luminosity, β^* reach, etc.) as well as on the machine availability. The latter becomes obviously important during runs with stable machine configurations, when the time spent in physics determines to a large extend the yearly performance. It is therefore important that big and distributed systems – like the LHC collimation system with its 100 movable devices located in 7 out of 8 insertions – are well optimized in terms of reliability and that adequate support is provided to reduce to a minimum the impact of failures.

In this paper, the collimator faults occurred in the 2010-2013 run are reviewed and their impact on the machine efficiency is quantified. An analysis of the beam aborts caused by the collimators is carried out. Possible improvements for the future are considered. This work extends a previous analysis that addressed collimator controls performance and availability until mid-2011 [3].

LHC COLLIMATION SYSTEM

The LHC collimation system provides a multi-stage cleaning to protect the machine from regular and abnormal beam losses [2]. The complete collimation system deployed for the 2010 operation includes different types of collimators, as listed in Table 1, which fulfill different functionalities depending on their location, material and plane. The analysis carried out in this paper is focused on collimator types TCP, TCSG, TCLA, TCT, TCL, TCDI and TCLI that were built and commissioned within the scope of the LHC collimation project. The beam intercepting devices TDI and TCDQ for injection and dump protection are not considered in this analysis.

Table 1: LHC collimators for the 2010-2013 run.

Functional type	Name	Plane	Num.	Material
Primary IR3	TCP	H	2	CFC
Secondary IR3	TCSG	H	8	CFC
Absorbers IR3	TCLA	H,V	8	W
Primary IR7	TCP	H,V,S	6	CFC
Secondary IR7	TCSG	H,V,S	22	CFC
Absorbers IR7	TCLA	H,V	10	W
Tertiary IR1/2/5/8	TCT	H,V	16	W/Cu
Physics absor. IR1/5	TCL	H	4	Cu
Dump protection IR6	TCSG	H	2	CFC
	TCDQ	H	2	C
Inj. prot. (lines)	TCDI	H,V	13	CFC
Inj. prot. IR2/8	TDI	V	2	C
	TCLI	V	4	CFC
	TCDD	V	1	CFC

Collimation is needed at the LHC in all phases of the operational cycle: injection (“setup”, “probe” or “physics” depending on the types of beam), ramp preparation, energy ramp, flat top, squeeze, adjust (when collisions are established) and stable beams (data taking periods). Collimators follow complex functions of time (four per collimator, i.e. one per motor) during the ramp [6], squeeze and adjust modes. They sit idle at “discrete” settings in other modes. The number of setting parameters for the 2012 operational cycle are listed in Table 2. Correspondingly, the number on interlock setting functions can be calculated [4]. Three different types on interlocks (versus time, versus energy and versus β^* in the collision points) are active all the time and trigger a beam abort in case any of the collimator position or gap measurements exceed safe boundaries. The temperature of the collimators (5 sensors per device) is also interlocked. From the settings management point of view, this is one of the most complex LHC system.

The collimator low-level controls are based on the PXI technology [7]. Two PXI units control the motor driver controller (MDC) for the 4 stepping motors of each collimators and the position readout survey (PRS) monitoring system. Linear variable differential transformers (LVDTs) are used to measure collimator axis positions and gaps.

COLLIMATOR DRIVEN BEAM ABORTS

The number of beam dumps triggered by the collimation system for the different machine modes after the injection process are given in Fig. 1. These are more critical for the operational efficiency because they imply a time-consuming “pre-cycle” of all LHC magnets to recover the injection settings. The average dump-to-physics turn-

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Table 2: 2012 collimation parameters table.

Parameters	Number
Movable collimators in the ring	85
Transfer line collimators	13
Stepping motors	392
Resolvers	392
Position/gap measurements	584
Interlocked position sensors	584
Interlocked temperature sensors	584
Motor settings: functions / discrete	448/1180
Threshold settings versus time	9768
Threshold settings versus energy	196
Threshold settings versus β^*	384
Temperature thresholds	490

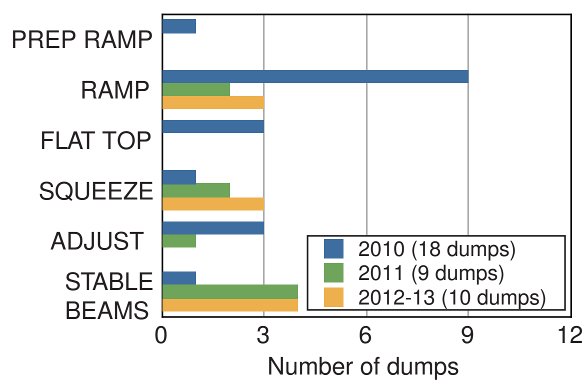

Figure 1: Number of dumps triggered by the collimation system above injection energy, listed per machine mode.

around time in 2012 was more than 4 h [8]. The first deployment of the ramp functions in 2010 explains the larger incidence of problems in this mode. The high-luminosity runs 2011-12 are mostly affected by single event upsets (SEUs) on the electronics that stopped the system during physics data taking periods. In 2012, the collimation system caused 1.5 % of the beam dumps in the modes of Fig. 1 (total of 686 dumps, 297 for physics).

In Fig. 2 the collimators dump caused by system faults are compared to the ones caused by human errors. The latter represent about 32 % of the dumps. Operational mistakes affect primarily the fills for machine studies, as in fills for physics the system operation is highly automated.

The collimator dumps in injection modes are summarized in Fig. 3. These cases are in general almost transparent for the operation (minimum recovery times). Indeed, the classification in Fig. 4 shows that they are primarily caused by operation mistakes, often occurring during the injection setup phases without beam. This situation shall be improved in the future for example by making the top-level controls less error prone.

The collimator dumps triggered by temperature interlocks were 1 in 2010, 3 in 2011 and 3 in 2012. Except for 1 case in 2012 triggered by a sensor fault, the other cases were triggered by real temperature increases above the predefine threshold.

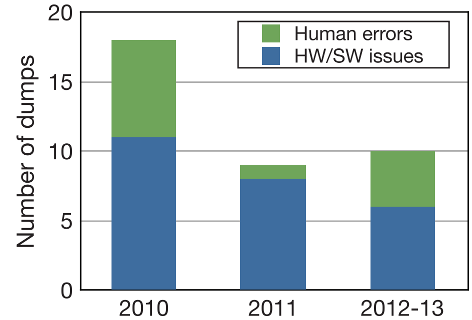

Figure 2: Dumps of Fig. 1 classified: real issues versus human operational mistakes.

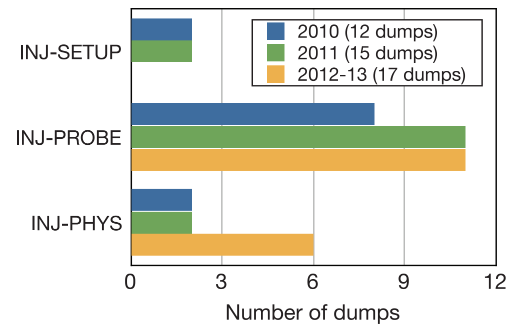

Figure 3: Collimator dumps at injection.

IMPACT OF COLLIMATOR FAULTS

The analysis of the previous section shows that 32 collimator dumps were caused by problem with the system (7 of which at injection). The summary of the collimator faults, also including the ones occurred outside the LHC beam operation (i.e., not listed in Fig. 1), is given in Table 3. The machine down-time associated to collimator faults is summarized in Fig. 5. Note, however, that this is calculated as the time when the machine was waiting for collimator interventions. Such analysis does not consider (1) problems recovered in the shadow of other system faults and (2) beam time required in some case to re-validate the collimation system (e.g., loss maps after setting changes). A typical example is given by the recovery from power glitches – see below – that is typically much faster for collimators than for other systems like cryogenics, power converters, etc.

A concern that came up in 2010 was the impact collimator setting reproducibility caused by power glitches and

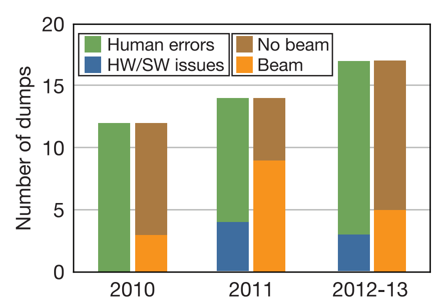

Figure 4: Source for injection dumps: real problem vs human errors and cases with or without beam in the machine.

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Table 3: Number of component and occurrence of faults.

Fault type	Total number	Number of faults 2010	2011	'12-'13
PXI power supply	120	1	6	3
PXI controller (MDC)	60	2	2	–
PXI controller (PRS)	60	–	1	–
LVDT sensors	750	–	–	–
LVDT electronics	108	4	7	2
Resolver sensors	392	–	–	1
Resolver electr.	108	–	1	1
Motor drivers	555	1	3	1
Gateways	8	–	–	–
Roller screws	392	–	–	3

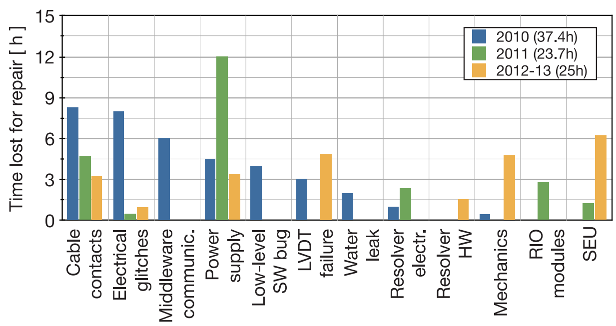

Figure 5: Machine down-time caused by collimator faults. Only failures that could not be recovered in the shadow of other systems faults are listed. Beam times required to re-validate the system after failures is not included.

site-wide perturbations of the electrical network that trigger a spring-based auto-retraction mechanism of the jaws [3]. The recovery procedure was fully automated with the result that, in spite of the large incidence of such events in 2012-13 (see Fig. 6), the impact on machine down-time was negligible.

The fractional incidence of difference failures in 2012-13, which can be considered as a stable operational year at high intensity, is summarized in the pie-chart of Fig. 7. The largest contributions come from replacement of power supplies (failure rate of 2.5 %, see Table 3), SEU in physics periods, of the the LVDT acquisition chain and from mechanics problem. A single occurrence of the latter in 2012 costed about 5 h out of a total yearly down-time of 25 h.

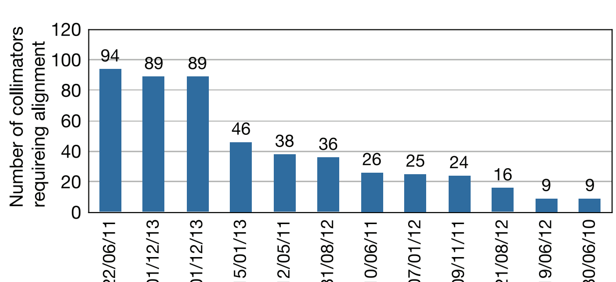

Figure 6: Number of collimators requiring the alignment recovery procedure after major power cuts in 2010-2013.

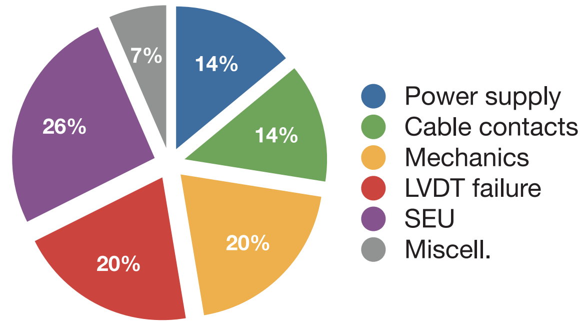

Figure 7: Percent incidence of different failures in 2012-13.

CONCLUSION

The statistics of beam dumps triggered between 2010 and 2013 by the LHC collimation system was reviewed. The system performed very well with a minimum impact on the LHC machine availability. So far, the performance with up to 140 MJ stored beam energy and peak luminosities of $7 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$ is satisfactory. The analysis of hardware failures indicates that, after the first commissioning phase when the complex collimator controls system was deployed, only hardware faults affect the system availability. The list of most critical cases was presented. There is also room for improving the incidence of human operational errors, in particular during the injection setup phase. The understanding of the machine down-time including beam time needed for system validation requires the development of appropriate tools that will be put in place for the 2015 LHC startup.

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