OPERATIONAL EXPERIENCE AND PERFORMANCE OF THE LHC COLLIMATOR CONTROL SYSTEM

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Abstract

In order to handle stored beam energies up to 360 MJ, the LHC relies on a collimation system that consists of 100 movable collimators. Compared to other accelerators, the complexity of this system is unique: more than 400 motors and about 600 interlocked position sensors must be controlled in all the machine phases in order to ensure appropriate cleaning and machine protection. In this paper, the operational experience accumulated in the two first years of LHC operation is discussed, focusing in particular on failure and availability during the LHC operation and on the impact of failures on the machine downtime.

INTRODUCTION

The CERN Large Hadron Collider (LHC) will collide proton beams with an unprecedented stored energy above 350 MJ. In order to limit the effect of unavoidable beam losses in superconducting magnets and to protect the machine, a powerful collimation system is required. With 100 movable collimators located in 7 out of 8 insertions of the 27 km-long LHC tunnel, the LHC collimation advances by orders of magnitude the complexity and the cleaning performance of collimation systems built for other existing accelerators. The large and distributed LHC collimation system poses controls, operational and reliability concerns in view of steady en robust operation of the collider. The LHC operation relies on a continuous monitoring of about 600 interlocked position sensors with resolution below 5 μm. Note that the collimators and part of their controls electronics have to work properly in high-radiation environment.

In this paper, the operational experience of 2010 and 2011 is reviewed. After a brief description of the system design, the operational performance is discussed and statistics of collimator-induced beam dumps are discussed. The overall reliability of the system and the impact on the LHC operations are presented and some conclusions are drawn.

COLLIMATOR CONTROLS ASPECTS

Details of the collimator design, of the system layout and of the key controls aspects can be found in literature [1, 2, 3, 4, 5, 6]. Each collimator has two jaws that can move symmetrically into the beam, moved by 4 precise stepping motors with a 5 μm minimum step size. Typical operational gaps are down to less than 3 mm at 3.5 TeV, as needed to control losses with the high-energy LHC beams [2]. In order to ensure the required accuracy and reproducibility of jaw positions, an highly redundant positioning survey system is used [6]. Stepping motor drivers, resolvers and linear variable differential transformers (LVDTs) provide 14 position measurements of the 4 jaw corners and of the 2 collimator gaps. Appropriate controls solutions were developed to handle this system.

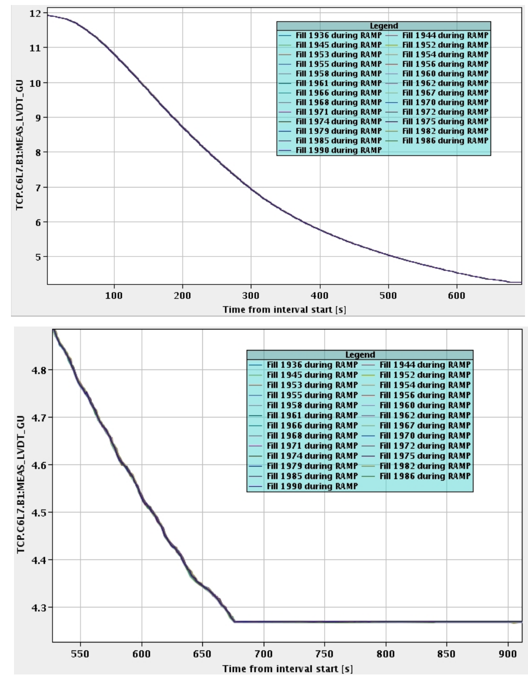

Figure 1: Gap of a primary collimator as a function of time during 19 recent physics fills.

Beam collimation at the LHC is needed in all operational phases, from injection to top energy, while the beams are being squeezed and during the long physics data taking periods [3]. In order to ensure optimum settings at all times, collimators are moved following pre-defined functions of time during each machine phase [3, 7]. The collimator jaw must follow the variation of local beam orbit and size. The ramp functions of a primary collimator gap is given in Fig. 1. In this case, the gap shrinks as the beam emittance. Tertiary collimators close to the experiments are affected by the optics changes during the betatron squeeze and follow functions like the one of Fig. 2 .

To comply its role in the machine protection, the collimators are redundantly interlocked to abort the beams in case dangerous situations are detected, About 3000 positions limits are defined around the set positions [4]. About 500 temperature sensors can also trigger a dump.

POSITIONING SYSTEM PERFORMANCE

The collimator positioning survey system is designed to achieve a measurement accuracy below 50 μm [6]. A key for the LHC performance is the good reproducibility the

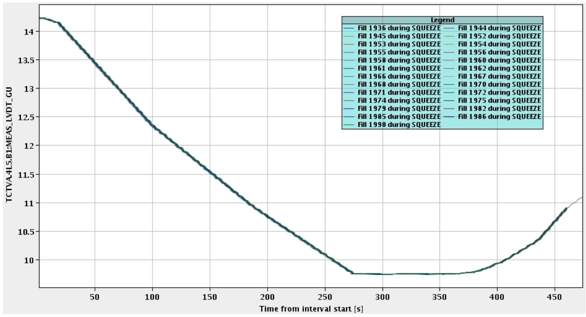

Figure 2: Gap of a tertiary collimator in the LHC experimental region as a function of time during the squeeze. Nineteen recent physics fills are given.

relevant beam parameters such as orbit and optics. It is thus essential that collimators settings are well reproducible fill after fill. Figures 1 and 2 illustrate that the over some 20 fill for physics at high intensities, the collimators follow the same setting functions to within better than 10 μm, This reproducibility is maintained over periods of weeks to months. The good reproducibility observed in the commissioning without beam [4] is confirmed in beam operation. The present setup strategy foresees infrequent collimator setups and regular verifications of cleaning performance every 4 weeks [8]. So far, one single alignment campaign per year has been required in each machine configuration.

Electronic drifts on position measurements are below ten microns over months however some readings are affected by magnetic interferences (shifts up to a few tens of microns). So far, these effects did not affect the operation. On the other hand, the setting stability can be jeopardized by power cuts. An spring-based auto-retraction mechanism was built into the system to pull the jaws out of the beam path in case of cuts of motor power [1]. The sudden jaw retraction is however uncontrolled and requires a dedicated recovery procedure to re-establish collimator settings, which takes 15-20 minutes per collimator. In 2011, such events occurred about 10 times, affecting a different number of collimators. Typically, the settings are recovered within less than 50 μm but occasionally errors well above 150–200 μm were observed (see Fig. 3)

So far, in case of power cuts the collimators were never the first source of beam dumps but only reacted after the dump triggers by other accelerator systems. An automated software tool was developed to recover the settings of all affected the collimators within less than 30 minutes. The recovery was always performed in the shadow or the recovery rimes of other systems. In one isolated case of a major power cut of July 2011, dedicated beam tests were performed to confirm with beam-based techniques that the system had fully recovered it's functionality. No beam time was required otherwise to re-validate the system.

STATISTICS OF COLLIMATOR DUMPS

The number of dumps triggered by the collimator system, grouped by beam mode, is given in the top graph

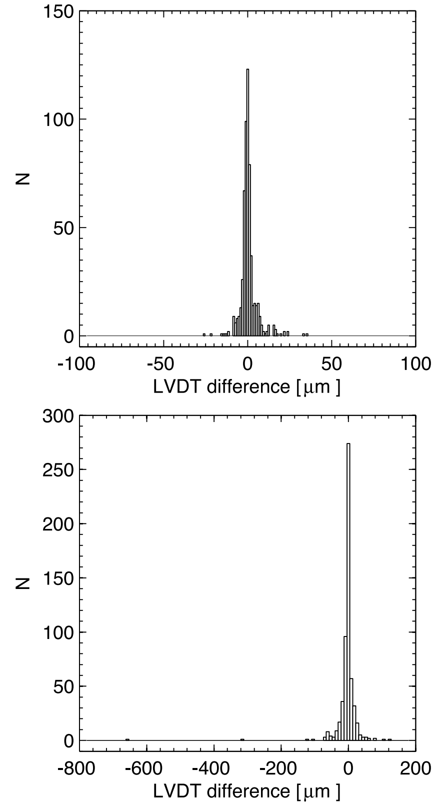

Figure 3: Distribution of LVDT differences measured for all collimators at physics settings before and after two power cuts in April 28$^{\mathrm{th}}$ (top) and July 10$^{\mathrm{th}}$ 2011 (bottom).

Fig. 4, for fills until the end of Aug. 2011. The percent fraction of the total number of dumps is also given (bottom graph). Overall, the collimation system has cause 45 beam dumps, 17 during fill for physics (green bars in Fig. 4). A total of 18 dumps occurred after the start of the ramp. These are typically longer to recover because they entails a full machine pre-cycle. Only the 2.4 % of the 212 dumps in "stable beams" mode were caused by collimators during physics data taking. The sources of collimator dumps are given in Fig. 5. About 30 % is caused by collimator hardware or software issues. Expert manipulations and operational mistakes occurred only during setup times and did not affect physics fills.

The comparatively larger incidence dumps during the energy ramp is caused by the complexity of the collimator ramp functions that required some tuning and debugging in the first beam commissioning. Only 4 dumps during ramps were caused by collimators in 2011.

IMPACT ON MACHINE EFFICIENCY

The list of faults for the various collimator controls components is given in Tab. 1. Estimating the impact of faults on the machine availability is not straightforward. Even a serious problem can be irrelevant if it occurs in the shadow of other faults but a small issue can cause several hour without physics if it kills a good fill. The time losses caused by issues with collimator hardware and software are cal-

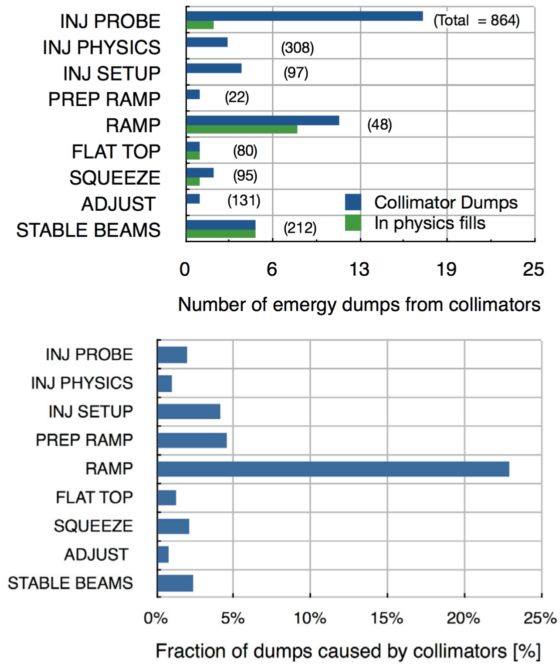

Figure 4: Collimator dumps occurrences per machine modes. Top: absolute, bottom: fraction of the total dump number (number in brackets on top graph).

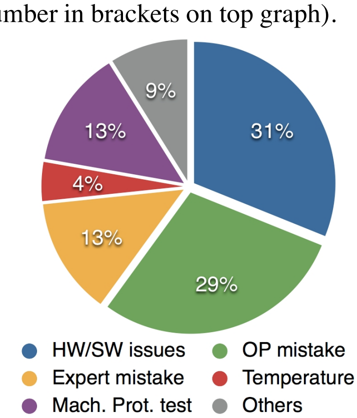

Figure 5: Causes of collimator-induced beam dumps.

culated considering only the times spent for the resolution of the problem itself. The 2010 data are summarized by the chart of Fig. 6. One of the largest contributions comes from the recovery after power cuts. Failures of power supplies are also lengthy since machine accesses are required. Note that not all faults imply a beam dump: middle-ware problems can be transparent for the beam and are typically carried out in periods without beam. Overall, in 2010 the system availability was 99.94 %.

CONCLUSION

The LHC collimation system has proved to work very reliably in the LHC accelerator environment. So far, the experience with high intensity beams up to about 100 MJ stored energy and peak luminosities up to $2.4 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ was very good. The impact of collimator faults on machine efficiency is limited and the controls

Table 1: Number of component and occurrence of faults.

Fault type	Num. of components	Num. of faults
PXI power supply	120	6
PXI controller	120	2
LVDT sensors	750	9
LVDT electronics	108	0
Resolver sensors	392	4
Resolver electronics	108	1
Motor drivers	555	4
Middle-ware gateways	8	0

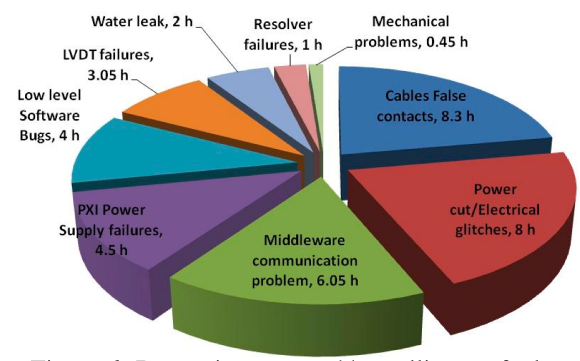

Figure 6: Down times caused by collimator faults.

choice have been confirmed by the good operational performance. The effects of power cuts on the position settings is now under good control as appropriate recovery procedures has been developed. The radiation on the electronics is at small levels (2 % of physics fill dumps) but is under constant monitoring in view of pushing the LHC performance.

The authors would like to kindly acknowledge R. Assmann, R. Losito and M. Donze from the collimation team and M. Zerlauth for the help with the *post-mortem* analysis.

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